SPOT AND ARC WELDING

BY

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ILLUSTRATIONS

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To My Wife

MARIE MORSE HORNOR

WITHOUT WHOSE AFFECTIONATE AND UNTIRING AID THIS BOOK WOULD NOT HAVE BEEN WRITTEN

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PREFACE

Although electric welding has been used for many years for repair work, there exists to-day a hesitancy in applying it to new construction, especially to the joining of heavy steel parts. It is the purpose of this book to endeavor to dispel this apprehension. The data of tests made in the spot welding of heavy steel plates by the Emergency Fleet Corporation is furnished in full with the expectation that in making this information available to shipbuilders and others, they will be able to adopt this process to their own manufacturing advantage. In like manner the underlying question of arc-welding processes is fully discussed with the intent of reassuring any one who may doubt the ability of these methods to supersede the rivet.

The author wishes to acknowledge the courtesies extended to him both by those who have contributed to the text and those who have permitted the reprinting of valuable published material.

Minerva, N. Y.
March, 1920.

H. A. Hornor.

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SPOT AND ARC WELDING

CHAPTER I

Materials

The essential consideration for those who practice the art of electric welding is the character of the materials to be joined. As a matter of fact, this principle has been the basis of all successful engineering achievement and a lack of it the cause for many vital failures. The wide range of processes combined with ingenious designs permits the broad statement of probability that all the metals and their alloys may in varying degrees be held together by electric methods. This provides a varied and interesting field for the engineer although, like untilled ground, there will be found many obstacles in the way of cultivation. The success of the harvest will be in direct proportion to the thought bestowed upon the actions of the metals when under the treatment required for their jointure.

It is not proposed to consider here the welding of the soft metals such as gold, silver, copper, tin, zinc, aluminum, etc. It is sufficient to affirm that in small articles processes of electric welding have been devised that satisfactorily accomplish such joints as are needed for special industries. The processes employed are fully described in many published articles.[1] As metal is added to the objects joined the method is referred to as soldering rather than welding. On the other hand, nickel, copper,

[1] "Electric Welding," by D. T. Hamilton and Erik Oberg, 1918.

and aluminum wires of small diameter are joined by means of a condenser spark, the process being called percussion welding. Interesting as these applications are, only this brief mention can be made in order to allow a full opportunity for the discussion of the welding of heavy steel pieces.

Definition.—Doctor Howe gives this definition of steel in its specific sense: "A compound of iron possessing, or capable of possessing, decided hardness simultaneously with a valuable degree of toughness when hot or when cold, or both. It includes primarily compounds of iron combined with from, say, 0.30 to 2 per cent. of carbon, which can be rendered decidedly soft and tough or intensely hard by slow and rapid cooling respectively, and secondarily, compounds of iron with chromium, tungsten, manganese, titanium, and other elements, compounds which like carbon possess intense hardness with decided toughness.[2]" The reasons underlying the behavior of this material when subjected to temperature changes must be sought for in the researches made by eminent metallurgists. This is the broad subject of the heat treatment of steel with which the practical welding engineer should have some knowledge in order to escape the error of applying electric welding to the detriment of the original materials.

Production of Iron.—Iron ore when taken from the earth may contain many and various minerals. The ore is treated in a blast furnace for the purpose of removing the oxygen which had a persistent affinity for the pure iron. The product of the blast furnace is not chemically

[2] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. i, p. 1, 2nd Ed., 1891.

pure, consisting usually of iron, carbon, silicon, manganese, sulphur, phosphorus, and oxygen. Pure iron may be obtained by careful preparation in the laboratory but not for commercial purposes. This molten metal from the furnace is cast into a form called " pig iron." When pig iron is remelted in a crucible and cast into some commercial form it is called " cast iron."

Cast iron takes two forms, depending upon its treatment when poured. If the molten metal is cast in sand it is a grey iron casting, if it is cast in metal moulds (chilled) it is a white iron casting. The point to observe here is the difference caused by the slow and rapid cooling of the molten metal. The names given to these castings are taken from the appearance of the fracture caused by the large amount of free carbon in a case of grey cast iron and the small amount of free carbon in the case of white cast iron.

Annealing is effected by slow cooling from a high temperature. If then white iron castings, which are brittle as compared to grey iron castings, are annealed so as to free the carbon which is in a combined state, malleable castings will result. Malleable iron is free iron with which is mixed carbon in a free state in the form of graphite. The effect of annealing does not penetrate the mass of metal and annealed castings seldom show any effect much further than an inch below the surface.

When pig iron is melted in a puddling furnace at a point where the pure iron appears to separate from the mass of impurities it is removed and the slag that it tenaciously carries with it is squeezed out by means of rolls. The rolls naturally form the mass of metal into the shape of bars. This mechanical treatment of the iron tends to produce purity and its efficiency is in direct ratio to the quality of the resultant wrought iron. From the mechanical treatment it receives it derives the name of wrought iron. The purity also bears a direct relation to the ore, and for this reason imported iron (Norway and Swedish) is well known for this quality. Wrought iron because of its purity is used in the manufacture of high-grade crucible steel.

Steel Processes.—The essential difference between the manufacture of steel by the open-hearth or crucible processes is disclosed by their names. In the latter case, iron of like or unlike carbon percentage is melted in crucibles usually totally enclosed, the molten mass is held in these crucibles (either graphite or clay), so that it may absorb silicon from the crucible walls, and then the liquid metal poured into castings or ingot forms. The open-hearth process melts the pig iron in a cupola, transfers it to an apparatus whereby the impurities are removed after which desired elements may be added to obtain various properties in the finished steel. The process is referred to by steel makers as basic or acid in accord with the chemical nature of the lining of the vessel used for removing the impurities. Crucible steel is of high grade, more expensive of manufacture and more costly. It is used for cutting tools, springs, fire-arms, etc. The added elements in the open-hearth process may be varied in many ways, thus producing many steel alloys useful to the industries. For ordinary plates and shapes the controlling elements are carbon and manganese. Both these elements hold high favor due to their ability to add greatly to the tensile strength and ductility of steel.

From the steel furnace by either process the metal is cast either into moulds for steel castings or ingot moulds for rolling into plates or shapes or into billets for forging. It should be carefully noted that plates, with which the electric-welding engineer is much concerned, are really steel castings which have received additional temperature and mechanical treatment in proceeding through the rolling mill. In applying the processes of spot and arc welding to new steel construction it will be such material that will require successful joining. As heat is the prerequisite for the welding of the metals in any case it becomes necessary to give close attention to the theories of the heat treatment of steel, the metallurgy of steel. This subject will be taken up in a later chapter.

Chemical Constituents of Steel.—Without proceeding into a maze of theoretical argument it may be well to consider briefly a few opinions regarding the effects of the various elements added to steel and following that their composite action on the weldability of steel.

"As the carbon increases, the tensile strength, elastic limit, elastic ratio, and compressive strength increase within limits; the fusibility, hardness, and hardening power increase perhaps without limit; while the malleableness and ductility, both hot and cold, and the welding power diminish apparently without limit. The modulus of elasticity appears nearly independent of the percentage of carbon, at least within the limits of carbon zero to carbon two per cent." [3]

Silicon is considered by some authorities to cause brittleness and redshortness, and by others to be in many

[3] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. ii, p. 13, 2nd Ed., 1891.

cases harmless, sometimes even increasing the ductility and in the presence of manganese "to counteract its tendency to cause redshortness."[4]

Phosphorus is an undesirable element. It is well known to cause "coldshort" or brittleness. The steel manufacturer takes every care to remove as much of this element as possible so that only a small percentage is found in good commercial grades of steel. It is negligible as far as welding problems are concerned.

The same remarks apply to sulphur. Howe states: "Sulphur has the specific effect of making iron exceedingly brittle at a red heat and of destroying its welding power."[5]

The effect of manganese on steel is still in the regions of dispute. One of the best authorities states: "The net effects of manganese on tensile strength and ductility are slight." Manganese seems to promote continuity and in this manner aids the ductility of steel. This is an important characteristic of this element which may throw light upon its use in the composition of electrodes for arc welding.

Chromium gives hardness to hardened steel probably increasing the tensile strength and elastic limit. The weldability of steel is reduced by chromium.

The addition of tungsten tends to produce great hardness in the steel alloy. This characteristic which it retains at high temperature makes it useful for the manufacture of high-speed cutting tools. Tungsten

[4] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. iii, p. 40, 2nd Ed., 1891.

[5] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. iii, p. 52, 2nd Ed., 1891.

steel is brittle and is difficult to forge even at relatively high temperatures. Doctor Howe doubts if it can be truly welded by ordinary methods.

Nickel steel surpasses the best carbon steel in its superior tensile strength combined with elongation. Upon its first introduction it was found difficult to machine, but this disadvantage has been overcome by improvements in machine tools. This alloy is also less liable to corrosion than steel.

Vanadium influences steel in much the same manner as nickel. Its first introduction was heralded by claims which soon disappeared in the presence of tungsten steel.

Copper and iron act curiously in combination. A little copper with iron or a little iron with copper are said to unite into a homogeneous mass, but if the proportions approach equality they seem to split up into alloys. The effect of copper is like that of sulphur, causing red-shortness, brittleness, and an opposition to welding. This tendency of the metals must be carefully held in mind by those who seek to improve the non-corrodibility of an arc-welded seam by the introduction of copper into the composition of the electrode material.

Many other metals, such as zinc, tin, lead, titanium, arsenic, cobalt, aluminum, may occur in iron but disappear in the manufacture of steel. Those that have been treated in brief detail above are to be found in commercial steel and must be investigated by those who are desirous of making a successful application of the practical processes of electric welding. For those who wish to investigate and experiment with steel compositions for the betterment of any special welding process there remains the action of the alkaline earths and the combination of iron with the noble metals. This latter field attracted the attention of some of the older and illustrious scientists without material success, but the sign of their failures may by modern methods be turned to a mark of attainment.

Weldability of Steel.—The important consideration for the welding engineer is the degree of weldability of the metals placed before him to join. Not only is this knowledge of great concern prior to the performance of the work, but also is necessary for the investigation of immediate and subsequent failures. Commercial steel castings upon analysis show a general chemical composition as follows:

Carbon	0.35 per cent.
Silicon	0.40 per cent.
Manganese	0.80 per cent.
Phosphorus	0.05 per cent.
Sulphur	0.05 per cent.

Of these five chemical elements the proportion of phosphorus and sulphur are so slight as to make them negligible. Among technicians there is argument regarding sulphur. The extreme is that 0.02 per cent. sulphur opposes welding, the other extreme that successful welds can be made with sulphur as high as 0.07 per cent. Sulphur as high as 0.15 per cent. is considered "quite unweldable." There remains the three principal constituents, carbon, silicon, and manganese, of which many scholars give carbon the leading place in lessening the weldability of the alloy. This opinion is largely borne out in practice. The whole subject resolves itself into one needing at the present time much earnest study and careful research, especially when considered with the complications introduced by the arc-welding process.

As regards manganese and silicon so little of their reactions are known that no trustworthy statements can be made other than those quoted and referred to above. Doctor Howe says of silicon: " The good welding power of crucible steel, usually rich in silicon, goes to show that silicon is not especially injurious in this respect." [6] For the benefit of the practitioner and the art as a whole it would be well for some of our colleges to engage in this industrially useful field of research.

The carbon content has received more careful and substantial investigation with the result that more harmony of opinion exists. The same authority states: " It was formerly thought that the presence of a little carbon was indispensable or at least very favorable to welding; but this, I think, is no longer believed. Certain it is that in general the difficulty of welding increases with the proportion of carbon, and the welding power probably practically disappears when the carbon rises above 1.3 per cent. The larger the proportion of other elements present, probably the lower, in general, is the welding power for given percentage of carbon. Thus the welding of apparently common Bessemer steel is said to be hardly possible with 0.20 to 0.35 per cent. of carbon, and impracticable with 0.35 to 0.50 per cent.; while to the practiced worker the welding of the relatively pure crucible steel is said to be easy with 0.87 per cent., and possible, using the greatest care, with 1.25 per cent. of carbon. Though the difference is probably much less

[6] " Metallurgy of Steel," by H. M. Howe, vol. i, chap. xiv, p. 252, 2nd Ed., 1891.

than this rather loose wording implies, and though there are welds and welds, it appears to be very marked.

"A reason why rising carbon lowers the welding power is that it lowers the point to which we can heat the metal without danger of burning, but does not lower correspondingly the temperature at which plasticity sets in; indeed, it seems to diminish the plasticity and adhesiveness for given temperatures."[7]

Doctor Howe is here treating purely of the weldability of steel in general and his statements, although in a large degree apply, must not be construed as referring to the electric weldability of steel. To indicate his agreement with others and subjecting the question to a specific reference to electric welding the following opinion is also quoted: "Little is known at the present time regarding the effect of the weldability produced by the presence of most of the impurities given above, where the electric arc-welding process is used. No data has been published on the subject. It is known, however, that steel containing 0.5 per cent. or more carbon is subject to "burning" at much lower temperatures than low-carbon steels. This fact can readily be observed in arc-welding practice, *i.e.,* the tendency being towards "burnt" metal in the weld. The observations which have been made up to the present time seem to indicate that the tendency toward "burning" shown in steel of comparative high-carbon content, is the only considerable effect which is produced on the weldability by the presence of any of the impurities in their usual amounts."

Physical Characteristics.—The foregoing opinions

[7] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. xiv, p. 251, 2nd Ed., 1891.

deal with the chemical nature of steel and are given concretely with the hope that the practitioner may find them convenient in his daily application of electric welding. Of an equal degree of importance are the physical changes that take place in steel when subjected to high and low temperature, sudden and slow changes of temperature. Here is to be considered not the composition nor the changes of composition of the material, but simply its physical properties.

Steel is hardened by rapid cooling from a high temperature. This is practically attained by quickly immersing the heated steel in a bath of water or oil. The kind of liquid used to quench the steel develops a greater degree of tensile strength and different methods must be pursued for difference in carbon content. Thus it is stated that to give the highest tensile strength to low carbon steel it should be quenched in water from a high temperature; for mild carbon steel (0.40 per cent.) it should be quenched in oil with a "rather high quenching temperature;"[8] and for steel with large percentage of carbon (1.25 per cent.) it should cool slowly from a low temperature and immersed in oil. In general the hardening of steel brings about the desirable physical characteristics of better elastic limit, greater firmness, and better tensile strength. The ductility tends to diminish as well as the specific gravity. Steel may be quenched in other media such as tallow, coal tar, and even lead, but tensile strength is not bettered by these methods over the use of oil.

The tempering of steel is employed to modify to some extent the previous effects of hardening. This re-

[8] "Metallurgy of Steel," by H. M. Howe, vol. i, chap. ii, p. 19, 2nd Ed., 1891.

quires the reheating but to a lower temperature and then in general cooling quickly and in some cases slowly. As hardened steel is brittle tempering increases its ductility and makes it much tougher. It does this without decreasing the tensile strength and, in fact, it has been stated to increase the tensile strength. Though the ductility is bettered by tempering over that of the hardening process it is still not as ductile as annealed steel. The advantage of tempering which apparently is an unnecessary second operation lies in the better control of temperature with the result that hardness and tensile strength are not impaired but to them is restored the ductility lost in the hardening operation.

The annealing of steel is to completely undo the effects of hardening and bring the steel to a very soft and tough state. " It increases the ductility and specific gravity and it generally lowers the elastic limits." [9] Besides restoring the tensile strength of violently hardened steel annealing also restores the tensile strength caused by cold working and internal stresses in steel castings. Much of the advantage gained by annealing resides in the cooling temperature and the medium used for the cooling process. It may be stated broadly that slow cooling brings about the softer and tougher qualities desired, but for many purposes both cold-worked low-carbon steel and steel castings the cooling may be interrupted at a certain point and the material quenched. This procedure will not give results equal to full slow cooling, but often will serve the purposes required.

It is thus seen that iron and steel in many shapes and with a great variety of physical properties will be laid

[9] " Metallurgy of Steel," by H. M. Howe, vol. i, chap. ii, p. 24, 2nd Ed., 1891.

before the electric-welding engineer, and it will depend more or less upon his familiarity with this wide range of conditions how he will meet and solve the problems. This brief résumé from the mining of the iron ore to its fabrication for use in the mechanic arts is a necessary preliminary to the study and practice of the joining of steel by electric power. To materials that have already been subjected to modifications in their chemical constituents, to changes in their physical properties by the application of different temperatures, and to internal mutations of their own making—to these materials are applied chemical reactions, and physical effects of like nature to obtain a connection which will either approach or exceed the advantageous characteristics of the original metal. It is mainly upon this point that objectors to electric welding rest their argument: that no joint can be equal to the original material. It is upon the same point that those who are favorable toward and well acquainted with electric welding uphold their belief in the process because the evidence has accumulated to a degree which permits the statement: that electric-welded joints can be made which will be stronger than the metals joined.

Summary.—This plainly places before the engineer a new problem, namely, whether he wishes his jointures to be more or less lasting than the materials which he is using for a given purpose. On the other hand, with this new ability to secure a more favorable joint will he not economically and safely reduce the amount of materials to secure the same result? These engineering problems are closely knit with a study of the metallurgy of steel and the modern applications of electricity to the welding of steel.

CHAPTER II

Electric-welding Systems

Fundamental principles separate electric-welding processes into two distinct groups: resistance methods and arc methods. As its name implies, resistance welding is accomplished by the phenomenon of the transformation of electric energy into heat energy by opposition to the flow of current. The arc method follows the behavior of the electric circuit whenever it is suddenly opened, namely, the production of a spark which if the distance between the terminals is maintained will preserve an arc. It was this characteristic of electricity that produced the first electric-lighting unit, the arc lamp; and the former, or resistance characteristic, that furnished the incandescent lamp.

Many processes of welding have been devised from these two primary groups but, as will be seen, the differences rest entirely on details generally associated with special applications. The following diagram gives the sub-divisions of each group:

Resistance Processes

1. Butt welding
2. Spot welding
3. Seam welding

Arc Processes

1. Carbon arc welding
2. Metallic arc welding
   - *a.* Bare electrode
   - *b.* Covered electrode
     1. Gas flux
     2. Liquid flux

Butt Welding.—This process consists of bringing two pieces of metal into contact end on end and then clamping these ends between two jaws of high conductive material supplied with high current at low voltage from the secondary of a transformer. With pressure applied forcing the two pieces together and the current turned on, a localized welding temperature is provided which, as the operation is visible at all times, may be held on until proper fusion results. It is usual practice to maintain the pressure for a short time after the current is turned off. Due to the end pressure a burr will form at the juncture of the pieces aiding the observer to make a satisfactory weld. As the outer surface of the metals tends to conduct heat away from the point of contact of the clamping jaws so advantageously, the interior metal offering the greater resistance will arrive at a welding heat before the exterior. This feature protects the process from any doubt as to the soundness of the finished weld. In blacksmith welding the reverse is true and the finished weld exteriorly may look sound but in reality cover poor fusion. There is a large field in the industries for the application of butt welding, especially for the welding of tool shanks, rods, etc.

Spot Welding.—This process is so called because the materials are not joined together continuously, but spaced as in riveting. Plates are lapped and then brought to a machine and placed as in butt welding between two high conducting points. Spot welding for this reason is frequently referred to as "point" welding. Pressure is brought to bear upon these points, current of high value is turned on, the materials at the points are thus raised to a welding temperature, current is then removed, the pressure released, and the weld completed. The intensity of the current produces a very rapid rise of temperature which with the pressure tend to prevent the ill effects of entrapping oxygen in the weld. This characteristic assists in practice to blow out the slag which may form on the surfaces of the plates. It is natural to see an analogy between smith welding and resistance welding, for just as the smith heats his materials in a forge and then applies pressure with his hammer, so the spot-welding machine raises the material to welding heat and then applies pressure. It would be reasonable to believe that the differences in the application of pressure would have a marked effect upon the results in a relative degree to the time difference in the raising of the temperature, but this particular interesting side of spot welding has never been fully investigated or at least reported. Spot welding of light materials, steel up to ¼ inch, has had a remarkable development in this country for some years. Heavy spot welding, steel up to 1 inch, was experimented with in the last few years. In the manufacture of automobile bodies, metal furniture, and bicycle parts, it has established itself firmly. It is especially fitted for shop work, and for new construction, but has not been developed nor used for repair work. The decided advantages of resistance welding over arc welding rest upon the fact that a weld can be made independently of the operator, that the work can be done rapidly and in the open, and that it permits of practical inspection. As will be seen later these points of advantage give a confidence in results not accorded to any of the practical processes of arc welding. It is for this reason that those who are responsible for new construction work are less conservative to the introduction of spot welding on a large scale.

Seam Welding.—A minor application of resistance welding is employed on very thin sheets for making a continuous seam. Instead of clamping jaws, or points, the current is led to the work on rollers under pressure. It is possible that this method may be capable of extension to heavier materials but it has not been shown by any large commercial use. The seam welded successfully in this way would undoubtedly provide a ready means for obtaining fluid-tight work and its point of economy would then rest upon the speed with which good welding could be accomplished. When considering fluid-tight work one point of vital difference must be borne in mind, namely, the simple retaining of the liquid in the vessel as against the liquid under pressure.[1] It may be stated as a general precaution that all electric-welding processes should be carefully investigated before applying them to work involving danger to human life. Doubtless future research will permit this work to be done, but the applications not involving such risks are plentiful.

Carbon Arc Welding.—In this process an arc is held between the metals to be joined and a pencil or rod of carbon. In all arc welding the rod used for maintaining the arc and manipulated by the operator is called the electrode. The carbon electrode is connected to the negative side of a low potential circuit (60 to 75 volts) and the work to the positive side. A very intense heat is produced by the carbon arc which draws from the electric supply 300 to 600 ampères. Flanged or butted edges of thin tank steel (1/16 inch and 3/32 inch thick) are satisfactorily fused together by the carbon electrode

[1] This refers also to gases under pressure.

without added metal,[2] but steel of greater thickness requires a melt rod of proper composition to supply the filling. The process under these conditions bears a similarity to soldering. Where there is a great quantity of shop repetition work with thin materials, automatic machines equipped with carbon electrodes are feasible and economical. The process is specially valuable in the heating of large areas and the filling of large holes. It is a good tool for heavy repair work. It is also possible to cut metals with the carbon arc, but few operators are able to follow a sharp line and thus the uncontrolled arc leaves a very poor working edge. It is stated that the carbon arc is economical for the rough cutting of scrap materials and the demolition of steel buildings. Undoubtedly there is a future for this process not only in special lines, but for extensive application to new construction when methods have been devised for the better control of the arc and ease in manipulation.

Metallic Arc Welding.—By far the greater proportion of electric welding is performed to-day with the metallic electrode. The arc is held in the same manner and by the same means as in carbon welding, but the connections are usually reversed as the metallic electrode supplies the filler for the weld and a larger percentage of the thermal energy is conducted to the metals being joined. The process is far more comfortable for the operator as the heat is less intense and more localized. It is a cold process. One hand is free in which to hold a screen for eye and face protection. A low voltage is required as in the carbon process but the current is

[2] "Electric Arc Welding in Tank Construction," R. E. Wagner, *General Electric Review*, December, 1918.

much reduced (50 to 175 ampères). The process is very simple. It makes a very handy tool for any shop engaged in metal work either for repairs or new construction. The apparatus for metallic arc welding has its reason in the field of commercial economics and as an aid to the operator. An experienced operator should be able to make as good a weld with an electric circuit controlled through a water resistance as with the most expensive apparatus obtainable. This is not intended to discredit the work done in providing tools for the advancement of arc welding, but it is stated to protect those who may interest themselves in the practical applications of this process from the assertion that the apparatus irrespective of the operator will produce good and satisfactory work. This process of welding has had extensive use in the railway repair-shops in this country for many years, and its expansion in this line is evidence of both its reliability for serious repairs as well as its economic value. In like manner it has been used for repairs to marine boilers and other applications which will be considered later. The process has not been extensively employed on new construction work, but its adherents have recently given it great impetus in this direction in connection with the hastening of the shipbuilding program during the war. This application required not only its extension to heavy materials, but also its investigation by specialists to convince conservative engineers of the shipbuilding industry.

Bare and Covered Electrodes.—Arc welding has its modifications like any other process. Those who strive to securely advance a beneficial art are certain to fall upon some weakness which may be improved or, for special requirements, some strong point which may be intensified. Students of the metallic-arc method while watching the successes and failures under varying conditions hit upon the theory that the bare metal electrode brought oxygen from the air and carried it into the weld. Practical tests showed that the bare metal electrode produced a brittle weld, strong as far as tensile strength was concerned, but lacking in ductility and resistance to shock. Invention soon provided a cover for the electrode and this practice has become general in England. In this country the practice has been entirely with the bare electrode; apparatus has been developed solely on these lines and opinion is biased for that reason.

In England two methods are employed, one the use of a non-conducting fireproof sleeve which leads the molten metal from the end of the electrode and protects it from contact with the surrounding air. The other method consists of an asbestos yarn impregnated with fluxing compound wound upon the metallic electrode. This sleeve melts with the arc and furnishes a slag which, while it prevents the access of oxygen to the weld, must also be brought by the welding operator to the surface of the weld. If additional layers of metal are necessary to finish the joint the slag formed on each layer must be carefully chipped off before depositing the succeeding one. Many variations are permitted with this system as combinations may be made with different chemical constituents in the electrode as well as in the flux covering. The differences of opinion existing as they do between the two countries (America and England) naturally creates an interesting discussion among welding engineers. It is not proposed here to enter into this disputed field. Certain engineers in this country claim to have produced welds with bare electrodes superior to or equal in ductility to covered electrode welds. In England they are apparently unable to approach with the bare metal electrode any of the work done by the covered electrode process. Attracted by the claims of the advocates of covered electrodes many American engineers are experimenting with coated electrodes, *i.e.*, simply immersing the metal electrode in a solution and permitting it to dry before using. In this regard it is well known that a solution of ordinary whitewash will often improve the welding quality of an otherwise poor welding electrode. This experimental attitude of the American engineer at least leads to the belief that the use of a covering on the metal electrode is of some advantage despite its cost.

Other Processes.—There are two processes of electric welding which will receive only brief mention because they have been developed for special purposes and were not found applicable for the joining of heavy steel parts such as are usual in steel ship construction. They are called the electric blow-pipe method and the " water-pail forge." The latter is not strictly a welding process in that electricity is used merely to heat the metal which is afterwards forged in the customary manner. As its name implies one side of an electric circuit is connected to a solution held in a wooden pail and the other side of the circuit is connected to the metal to be heated. In the former process the electric blow-pipe is essentially a horizontal-flame arc lamp using two carbons mounted like the letter V. Between these two carbons is placed a powerful magnet which creates a sufficient magnetic field to blow the arc in the direction desired. This method eliminates the passage of the electric current through the work and is said to be successful in the welding of small pieces of steel and brass. The voltex process is a modification of the blow-pipe method in which the carbon electrodes are impregnated with metallic oxide which is vaporized in the flame of the arc.[3]

Besides these processes there are many modifications of details and apparatus connected with arc welding. The simplicity of the electric circuit for arc welding has already been mentioned, and it will be seen later how apparatus has been devised to aid the operator and decrease the cost of operation. Arc welding may be performed with either direct or alternating current. The advantage advanced for using the latter is the simplicity and inexpensiveness of the apparatus.

Variations in the chemical composition of the electrode material and variations in current for the welding of different thicknesses and compositions of steel go to make up a catalogue of modifications which give great latitude to the designer of welding apparatus. The use of arc welding in the shop for repetition work allows ingenuity of arrangement and connection of apparatus. For instance, several single arc-welding units may be connected in series if the work will permit their simultaneous use instead of each unit being separately connected as for general field work. These are a very few of the many possible modifications which the process of arc welding encourages.

Summary.—From these different methods the specialist called to advise the government upon the applica-

[3] "Electric Welding," Hamilton and Oberg, p. 5, 1918.

tion of electric welding to ship construction selected spot welding and metallic arc welding because they were recognized for the joining of light materials and logically could be quickly advanced to the state of joining heavy steel plates and shapes. They proved that electric-welding processes, particularly spot and metallic arc, could be utilized for the joining of steel plates of ½ inch in thickness. Further, that spot welding could be employed for the joining of greater thicknesses and also a number of heavy pieces. This cleared the way for the practical applications of electric welding to ship construction.

CHAPTER III

Spot Welding

There are four important points to be considered in either light or heavy spot welding: (1) The electric current requisite for producing the welding temperature; (2) the time in which this current is utilized for making the weld; (3) the mechanical pressure necessary for the electrical contact as well as for squeezing the materials during the application of heat; (4) the condition of both surfaces of the two pieces of material that are to be joined. In the spot welding of thin (or light) sheet steel apparently the wearing away of the electrode points is not of prime importance, but in heavy spot welding this feature becomes a serious matter when viewed from a shop-production standpoint. This point of difference as well as others will be set forth when the results of the demonstration of heavy spot welding are discussed. In general a heavier current must be employed for the welding of greater thicknesses of steel plates, more time must be consumed, the pressure must be increased, although to what degree is questionable, and the contact surfaces, *i.e.,* those next to the electrode as well as those impinging upon each other, must receive the attention of the engineer responsible for the results.

Apparatus for Light Spot Welding.—For this class of work the design of machine may take various forms in conformity with the special nature of the product. For the process alternating electric current is employed because a high current at a low voltage is needed to produce the welding heat. The usual voltage supplied to shops in this country for power purposes is 220, and this requires a transformer usually integral with the machine. In smaller-sized machines the pressure may be secured by levers operated by hand or foot; in larger machines the practice is to employ either water or air

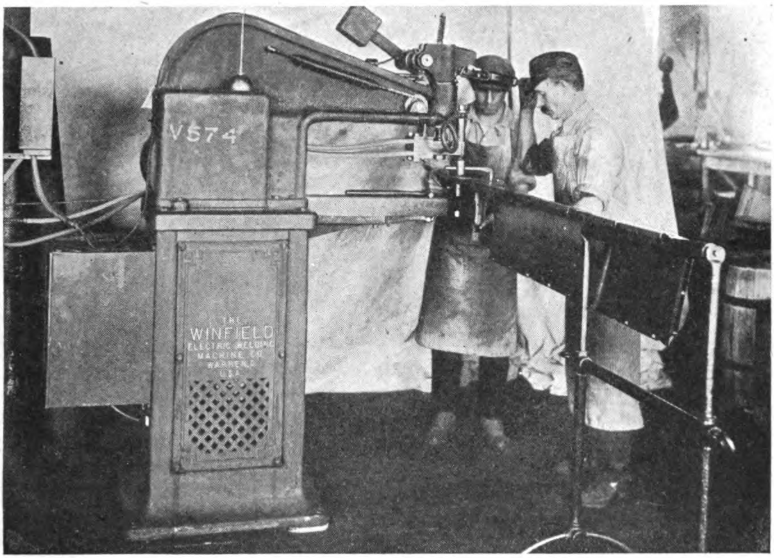

Fig. 1.—Small spot-welding machine.

pressure. In like manner small apparatus may require no water-cooling arrangement for the copper electrodes, but in larger machines this is essential. The lighter machines may also permit of the offsetting of the electrode for performing in close quarters or accomplishing some special object, but in the heavier designs the pressure must come directly in line with the electrodes. As will be seen in Fig. 1, the secondary of the transformer,

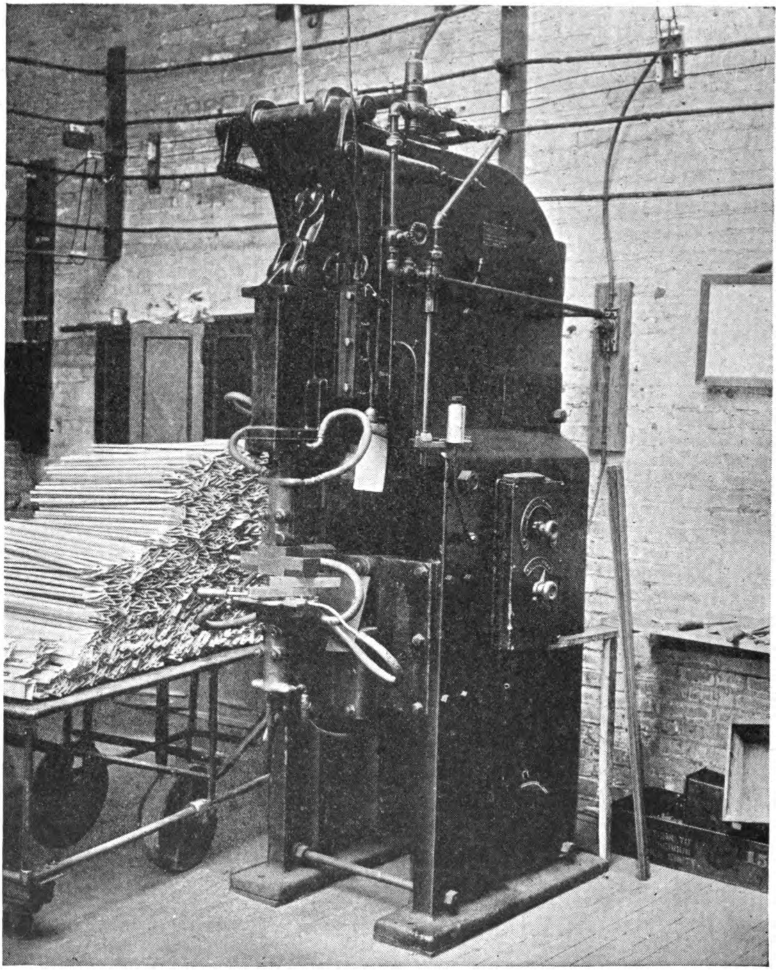

FIG. 2.—25-kw. light spot-welding machine.

which in this case is composed of thin copper strips, conducts the induced current from the transformer to the electrodes. This machine is used for plate work and is designed with the necessary gap. The electrical connections are arranged so that adjustments for current may be made for varying conditions of work. Automatic features may be included in the design, so that repetition work can be done with great rapidity and with uniform results. Fig. 2 illustrates another type of spot-welding machine having a capacity of 25 to 30 kw. and capable of doing fairly heavy spot welding. This machine has a small gap and could not be used for extending over wide plates. It is to be noted that the pressure operates in a direct line through the electrodes.

Applications of Light Spot Welding.—As the pressure required for light sheet steel (say 1/16 inch thick) is approximately very low, about 200 to 300 pounds, the application of this method to the fabrication of small articles is very large. As noted, the electrodes may be placed in various positions and offset in the electrode holder in any manner required by the special job. Thus kitchen utensils, like coffee pots, saucepans, etc., are made by spot welding the spout on to the body, thus facilitating the finishing operation by leaving a smooth surface. House fittings, such as doorknobs, sash pulleys, etc., are made by the thousand in a very short time. Small chains for various purposes are made on special and very interesting machines, and the use of this process in the bicycle and automobile industries has been responsible for decreased cost. Many special applications are of interest, such as the welding of the two magnet bars in a telephone receiver. The difficulty of doing this by other methods of welding is that the temper of the magnet steel would be drawn and so destroy the purpose for which it was intended.[1]

[1] "Electric Welding," Hamilton and Oberg, p. 121.

Possibilities of Light Spot Welding.—Many operations not strictly spot welding may be performed on a light spot-welding machine (see Fig. 3). By preparing the materials in a special way, by the use of a button placed on the materials, by means of special electrode, many small articles can be easily and quickly welded. Sheets may be welded to studs, bolt heads to body in a spot-welding machine, although the operation bears a strong likeness to butt welding. In the same manner

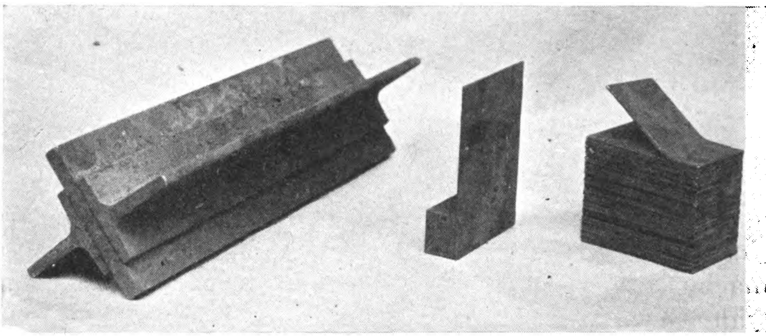

FIG. 3.—Special jobs done by light spot-welding machine. Thick piece to thin piece. Many pieces of thin sheets welded together.

screws may be welded to sheet tubing. The spot-welding machine may be utilized to heat rivets in place and squeeze them " home," thus performing as an automatic riveting machine. A wrongly punched hole may be corrected by introducing a proper-sized stud and then spot welding it in place. This also may be done with heavy spot-welding machines.[2] By arranging the edge of thin sheets with projections which act to localize the heat, and with special electrodes or multiple electrodes, a number

[2] " Spot Welding and Some of Its Applications to Ship Construction," H. A. Winne, *General Electric Review,* December, 1918.

of spot welds may be made in one operation. It is stated that there are machines made with a solid electrode of copper against which a single electrode is made to move at designed intervals. This apparatus is capable of making thousands of spots a minute and connecting thin sheets. It only requires a fraction of time to make a spot in such materials.[3] It is not believed that all the possibilities for light spot welding are by any means exhausted and undoubtedly the introduction of heavy spot welding will result in the further extension of spot welding in general.

Possibilities of Spot Welding in Ship Construction.—Although spot welding was applied in the industries only for steel plates not exceeding 1/8 inch in thickness, the results had led many engineers to a belief in its extension to greater thicknesses. So in 1911 the American Car & Foundry Company built a portable spot-welding machine with a gap of 66 inches, so as to extend across wide plates and with which they constructed a gondola freight car. The welding machine was equipped with a transformer of 85-kw. capacity "having a primary voltage of 400 and a secondary open-circuit voltage of 25. . . . Pressure was applied by means of a hand wheel, but subsequent machines were equipped with air cylinders for applying the pressure. Copper electrodes 3 inches in diameter were used at jaw, the welding points having a diameter of 3/4 of an inch. It was found that perfect welds could be made with this machine through 3 sheets each 3/4 inch thick, or 2 1/4 inches total thickness."[4] The results of the completed car were satisfac-

[3] "Electric Welding," Hamilton and Oberg, p. 108.

[4] "An Electrically-Welded Freight Car," J. A. Osborne, *General Electric Review*, December, 1918.

tory in every way and reports while in service show that no abuse has occasioned serious embarrassment to the spot-welding process. The engineer of this work states his opinion: " I believe that this severe test of the process has demonstrated the fact that spot welding for heavy structures is absolutely practical and reliable. It has demonstrated that riveting can be replaced in almost all instances. The ease of manipulation, as well as the great saving, will no doubt cause this process to be universally adopted." [5]

For this particular application a portable welding machine of large dimensions was necessary, and the makers of spot-welding apparatus were evidently not inclined to develop such. They had built stationary machines of 100-kw. capacity and pressure of 50 tons on the electrodes, but had not considered designs of this size for portable use. The upper electrode of the 100-kw. machine was 2½ inches in diameter and the lower 3 inches in diameter, the pressure coming directly on them. This apparatus was capable of welding " two strips 1¼ inches thick." [6]

A long series of tests were undertaken in 1917 at the plant of the New York Shipbuilding Corporation at Camden, N. J. These tests were never published in detail, although an account of them is available. For certain small operations a 25-kw. spot-welding machine was purchased in 1916. This apparatus was the only means for carrying on the investigations, and therefore the tests could not be extended beyond the welding of two thicknesses of ⅜-inch steel plate. The results all

[5] *Idem.*

[6] " Electric Welding," Hamilton and Oberg, p. 118.

assured the use of the process in the fabricating shops with machines of proper size and design. There are many pieces of the ship's structure, such as deck houses, doors, skylights, hatch frames, masts, stacks, etc., which are put together and form quite a separate part from the hull of the ship. These various sub-structures go to make up a long list of what is generally called ship's fittings. Such fittings rarely demand thick sections, as they are not required to resist heavy strains nor undergo excessive stresses. Even in the heavier class of vessels such fittings will be made of 1/4-inch steel, in some cases less.

In view of this wide variety of work that could be done by spot welding and the large saving to be secured by its use led those who were making this investigation to extend their trials to the building of a water-tight bulkhead door. Fig. 4 shows the spot welding of the 3-in. × 3-in. × 5/16-in. angle frame to the door plate. In the endeavor to secure water-tightness with a great number of spots and the use of flux about 141 spots were made. It was noted that a smaller number of spots and the edges of the angle arc welded would give more satisfactory results. After the door was completed it was placed with the edges of the angle upon a steel plate, securely clamped and made water-tight by the customary methods used on shipboard. A water connection was then made and pressure gradually applied. A slight deflection in the plate at the top and middle of the door was noticeable when the pressure reached ten pounds per square inch, but there were no leaks. The pressure was increased up to a maximum of 22 1/2 pounds per square inch without leakage, but upon examination showed that some of the spot welds on the stiffeners had given away. The structure had withstood pressures far beyond those required for this service and the tests were conclusive as far as the adoption of the process was concerned.

As has been intimated there are two distinct condi-

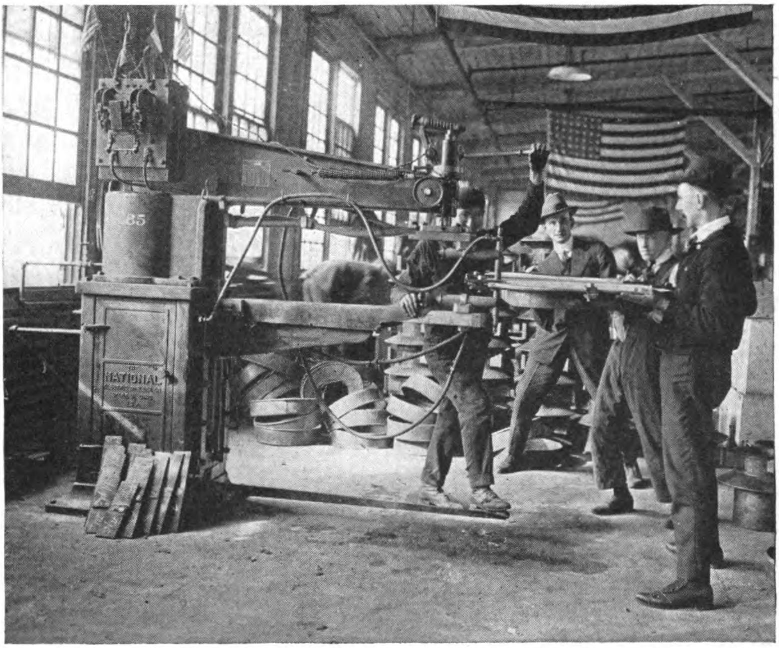

FIG. 4.—Spot welding.

tions under which riveting is done in shipbuilding: that which secures the principal members of the hull structure called "field riveting," and accomplished in this country by a group of men in which one man uses an air-driven rivet hammer, and that which is done in the shops by semi-portable machines. These latter machines are of large size, usually suspended from jib-cranes, and are portable in the sense that they may be brought to the work and moved from rivet to rivet by the operator. These portable riveting machines are equipped with air cylinders and connected by flexible hose to a common source of supply. They are as in field riveting dependent upon the forge fire for the heating of the rivet, and on the rivet boy for supplying the rivets at a correct temperature and at the proper time. This practice in shipbuilding shops differs from that in bridge shops where the machines are stationary, usually mounted with their jaws in a vertical position and to which the overhead crane brings the material and moves it for the continuous performance of riveting. The rapidity with which such work is accomplished in this latter case is astonishing. A close study of this problem is like the run of spot-welded work, merely requiring as much time and attention devoted by those who understand the process as has been given by those who understand riveting. In short, it is a question of shop production which in the case of riveting has been developed to a high state of efficiency.

All these points and many more suggested that spot-welding machines similar to a pneumatic riveting machine could be employed with advantage in shipbuilding and would hasten the construction of steel ships. The idea was proposed to convert the pneumatic riveting machine as now used into spot-welding machines by adding a transformer and the proper flexible connections. This was the inception of the design of two machines for spot welding which were built for the Emergency Fleet Corporation of the U. S. Shipping Board and with which a practical demonstration was made the early part of last year. The builders of this apparatus had previously experimented with a stationary apparatus of large size to determine if there were any obstructions to the welding of thick steel plates, and as their researches showed no hindrance to the process up to the spot welding of three thicknesses of 1-inch boiler plate, they accepted an order for two portable spot welders and one stationary spot welder for the purpose of fabricating the steel parts for the hull structure of ships.[7] This apparatus will be fully described in connection with the discussion in the next chapter.

There were men who desired to put the welding methods to test in shipbuilding, for the emergency was pressing, and yet they did not follow the English example in going so far as the building of small water craft. The English Admiralty built in the early part of this year (1918) a cross-channel barge entirely arc welded, and the results of this craft were and are well known in this country. It was decided to make a demonstration of a large portion of the middle body of one of the standard steel ships building for the Emergency Fleet Corporation. The scaffolding for this work was erected, the raw material delivered, and a five-foot-gap portable spot welder was ordered and delivered. The demonstration as planned was abandoned after the signing of the Armistice. The portable spot welder was sent to the same shop as the other spot-welding machines and was tested as a part of the demonstration of spot welding.

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[7] "Research in Spot Welding of Heavy Plates," W. L. Merrill, *General Electric Review*, December, 1918.

Summary.—The spot welding of light materials has been practiced in this country for the last fifteen years and its performance not only has guaranteed a successful product, but also has increased production and

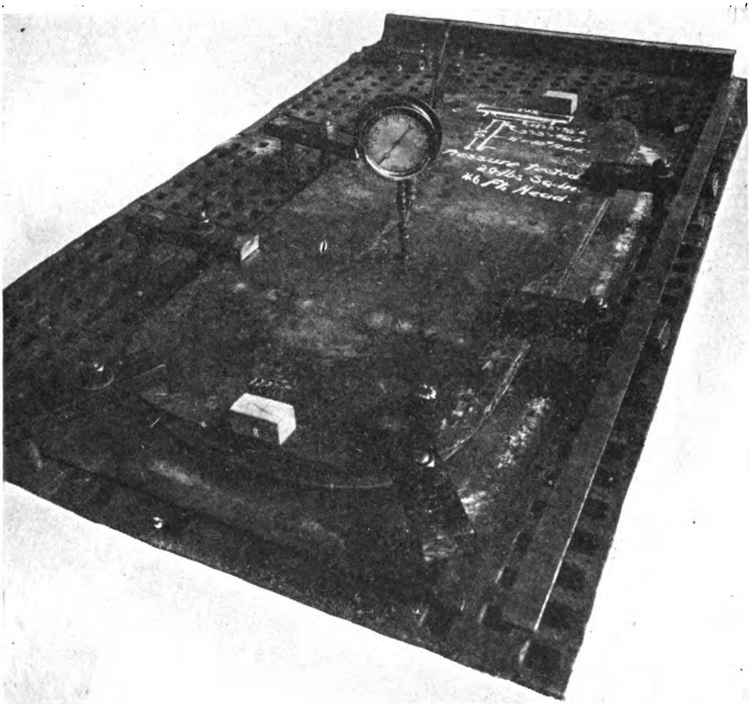


FIG. 5.—Spot-welded W. T. door under test 20 lbs. per square inch.

profits. It is safe to state that its extended service in those industries that find a use for it assure its future. For the joining of light sheet steel it has no competitor, but for the softer metals the process has not been successfully developed. There are certain alloys that may be welded by the preparation of the materials or by changes in the apparatus. The whole subject is one requiring investigation, and where the results may be serious attempts should not be made without thorough tests.[8] As stated, copper has been the only available metal found for electrodes and any metals which approximate the current carrying capacity of copper would offer no resistance to current flow, and upon this principle depends the welding heat.

With the satisfactory results of the spot welding of thin steel sheets placed before him the engineer surmised that the process was capable of extension to heavier steel structures. The industry that it was most important to aid happened to be that of shipbuilding, but the principles of the application are suitable to all manufacturing concerns employing heavy steel plates and shapes which are now joined by rivets.

In shipbuilding the shop rivets are used to connect and assemble small parts of the structure and for the manufacturing of sub-structures. The field riveting is employed to put the assembled materials together and form the completed hull of the ship. The shop rivets are driven by machines brought to the work and between the jaws of which the rivet is squeezed. The field rivet is put in place through holes punched in the assembled parts of the ship structure and is driven by a hammer on one side of the work, actuating against a pressure applied to the other side of the work. The main question of applying spot welding to the entire process of shipbuilding resolves itself into two possibilities. There can be no doubt as to the use of spot welding in shop work,

[8] "Electric Welding," Hamilton and Oberg, p. 95.

but the question rises whether it can be applied in the field. Either great developments must be made in the spot-welding tool whereby it may act on both sides of the structure without interruption to other work, or there must be prepared special designs of ship and shipyard whereby the spot-welding tools may be used. That is to say, that the welding machines would not be required to assume shapes and sizes that militate against the convenient working of the tool. As in other matters, this last possibility is one for coöperation between three important factors in shipbuilding: the owner, the naval architect, and the shipbuilder. There is always an experiment going on in any shipyard, as the experienced shipbuilder recognizes that every ship he is building is an experiment. Perhaps it is this every-day affair that makes the shipbuilder hesitate to accept new methods for connecting his steel ship. The shipbuilder is accustomed to experimenting and when he discovers the benefits to be derived by the adoption of spot welding he will be its firmest advocate.

CHAPTER IV

Demonstration of Heavy Spot Welding
(by the Emergency Fleet Corporation)

The first principle laid down for this investigation was that it should be practical so that the limitations of practice would be shown in high relief. That these limitations were a hindrance to a full report of the ability of the apparatus to perform in a certain way must not be interpreted as a detriment to the process nor a lack of skill upon the part of the designer. On the contrary, such practical handicaps as were encountered only go to prove the field of usefulness and the profits yet to be made by those who desire to invest their capital in a process as certain as the results of this demonstration showed. No theories were acted upon in the conductance of the test and only minor modifications were made in the nature of developments after the initial trial of the first machine. The results of the tests speak well enough to assure the most skeptical of the safe joining of heavy steel members by the spot-welding process.

Description of Apparatus.—Considering the adaptability of the machines for shipbuilding service it was decided to build three machines, two semi-portable of moderate size and one stationary machine of large size. The semi-portable welders took an external form similar to the pneumatic riveter and were provided with bails for attachment to cranes for facility of handling. After a careful survey of the usual run of materials in the plate and angle shops of shipyards, it was agreed to build two sizes of portable machines to cover all conditions now met with in practice. The smallest machine has a gap, or throat, capacity for reaching over a width of 12 inches and the other a gap of 27 inches. This difference in throat not only increases the weight due to the additional frame size, but also adds bulk by reason of the transformer capacity which must be greater in order to overcome the reactance caused by the enclosing of a large body of magnetic material in the electric circuit. Although much care was given to the lightening of the frame and, as will be seen, the transformers were made remarkably small for their rated capacity, still these machines are much heavier than the ordinary pneumatic riveter.

The frames of these portable machines were cast out of gun metal to provide against any chance of a reactance sufficient to counteract their welding qualities. In what may be termed the body of the machine a recess was left for the transformer. On the top arm was located the air cylinder for providing the necessary pressure on the electrodes. The under body portion of the frame was arranged with ample projections on both sides so that the machine could be bolted down in place and used as a stationary tool. As will be seen from Figs. 6 and 7, the copper electrodes are mounted in a holder insulated from the frame, but in direct line with the pressure. The lower electrode holder is bolted directly to one arm of the secondary of the transformer, the upper electrode holder is connected by flexible leads of laminated copper in order to permit the necessary movement for squeezing the two pieces of work together.

The maximum air pressure provided was the same for both machines. The air cylinder was 8 inches in

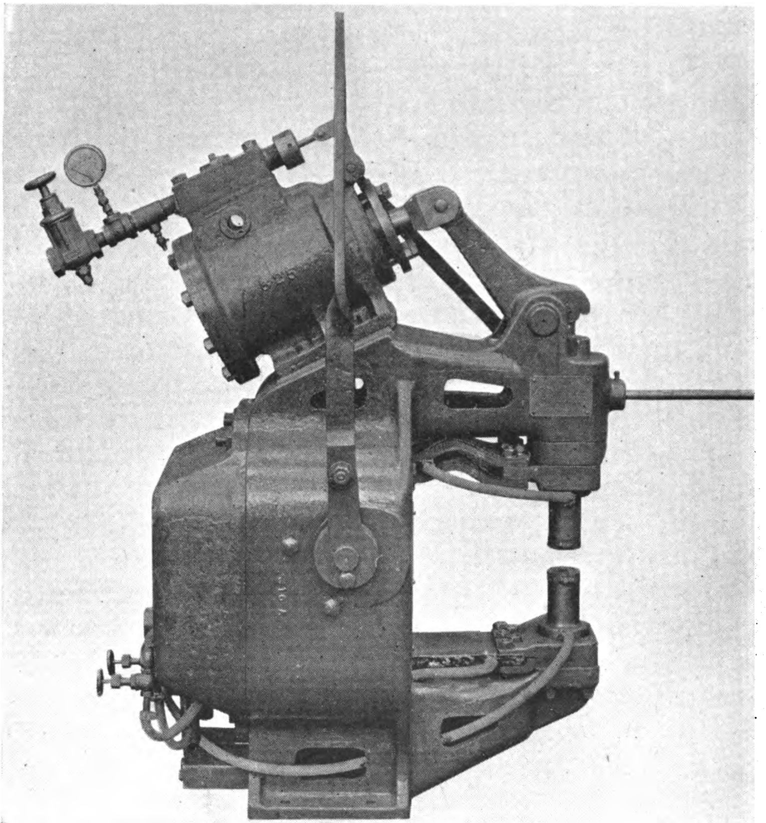


FIG. 6.—Electric welder—12″ reach—60–265–440–8.45. Capable of welding together two steel plates ⅝″ thick in spots 1″ in diameter.

diameter and attached to it was a lever arm with a ratio of 5 to 1, so that with a gauge pressure of 100 pounds per square inch, 25,000 pounds per square inch could be exerted on the work. During all the tests this was never

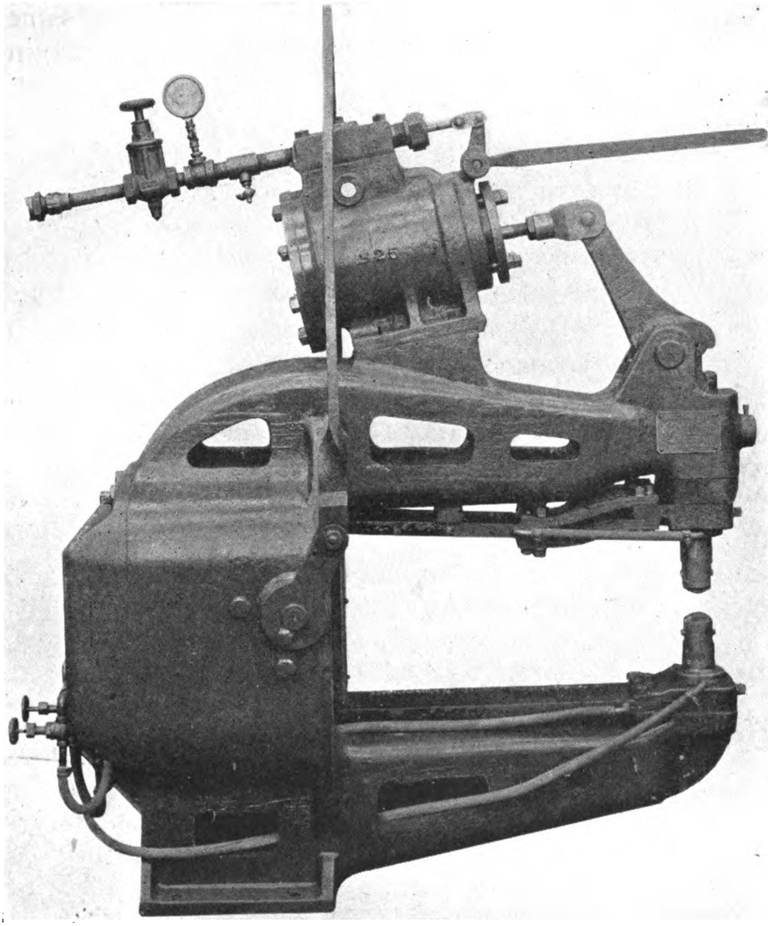


FIG. 7.—Electric welder, 27" reach—60-350-440 = 11.25. Capable of welding together two steel plates ⅝" thick in spots 1" in diameter.

obtained, but good welding was accomplished at 70- and 75-pound gauge, representing 17,500 and 18,750 pounds per square inch on the work. A gauge was installed on the air line for the purpose of checking the pressures at all times. A reducing valve was also provided, so that the test conditions could be changed and variations allowed for thinner material.

There are many interesting points of design in connection with these two machines which can receive only brief mention. One of them is the transformer. Perhaps no transformers were ever designed or built within so small a space and with so great a capacity. The designer for this alone, to say nothing of the successful operation of the machine, should feel proud. The capacity of the transformer for the 12-inch machine at 440 volts 60 cycles is 265 kv-a, and for the 27-inch machine at the same voltage and cycles 350 kv-a. In the large stationary machine there are two transformers of 450 kv-a each at 500 volts 60 cycles, and the over-all dimensions are 11 inches by 16 inches by 18 inches. The nature of the work done as well as a resort to water-cooling enables this reduction in transformer size. The making of a spot weld takes a few seconds. The current is used almost instantaneously. The primary windings are made of copper tubing specially prepared for this purpose, and the single-turn secondary was built of copper plates bent to shape and fitted over each other in such a way that a passage was left for the circulation of cooling water.

Another interesting point of design is that connected with the electrodes. As stated before, copper seems to be the best available material for this purpose, and its use has astonished those acquainted with metals, for it is so much softer than the steel which it welds. "The severity of the conditions to which the tips of the electrodes are subjected will be understood when it is considered that the current density in the electrode material at this point is approximately 60,000 ampères per square inch, and that this material is in contact with the steel plates which are brought to the welding temperature, under pressures of 15,000 to 20,000 pounds per square inch. It must be remembered, also, that copper, which is the best material for this purpose, softens at a temperature considerably lower than the welding temperature of steel. The difficulty of making the electrode tips stand up under the conditions to which they are subjected has, in fact, constituted the most serious problem which has been met in the development of these machines."[1] This question has been practically dealt with by providing caps and separable tips for the electrodes as well as by maintaining a free circulation of water through the electrode. This matter will be further discussed when considering the results of tests.

Although these machines could be properly operated directly from a 440-volt 60-cycle alternating-current source, they are provided with auxiliary transformers and panels for regulating the voltage and current. This allows for a wide range of work and permits great freedom for experimentation. The regulating transformer panel also contains a contactor for the ease of operation at the spot welder where it is only necessary to work a hand lever for the mechanical pressure and a tripping switch to actuate the contactor on the transformer panel. The contactor functioning as a throwing-in switch for completing the electrical circuit whereby the high current passes through the electrodes producing the local-

[1] "Recent Developments in Machines for Electric Spot Welding," J. M. Weed, *General Electric Review*, December, 1918.

ized welding temperature. This arrangement of connections permits the selector panel to be placed remotely from the spot-welding machine, thus allowing freedom for movement from spot to spot.

The large stationary machine was built with a 6-foot throat, so that it could reach the width of the usual run of plates used in shipbuilding, and as was thought at the time of designing, would be able to fabricate complete deck houses as well as join two steel plates of ¾-inch thickness. In order to reduce the great capacity that would be required to overcome the effects of reactance in this case, the designer did two skilful things. He provided two transformers, two pairs of electrodes, thus doubling the number of spots per operation, and then disposed the transformers one on each side of the work, thus reducing the reactance to a minimum. Incidentally this allowed the use of steel for the frame which was constructed of two steel plates each two inches thick. Gun metal was used for the heads carrying the copper electrodes.

Fig. 8 illustrates this machine, showing that the same arrangement of connecting the upper and lower electrode holder to the secondaries of the transformers was employed. The same general features of design are carried out on a larger scale. The air pressure is increased to a maximum of 30,000 pounds per square inch on each cylinder. There are two cylinders provided, so that each pair of electrodes may be separately operated and also to obtain successful spots when making two welds simultaneously. The air cylinders are located in the body of the machine and operate through 7-foot levers to the electrodes.

The electrodes are arranged to be easily removed and may be shifted on their bases to positions of 90 degrees, so that the spots may be made in line with the axis of the machine or transversely. The electrodes are

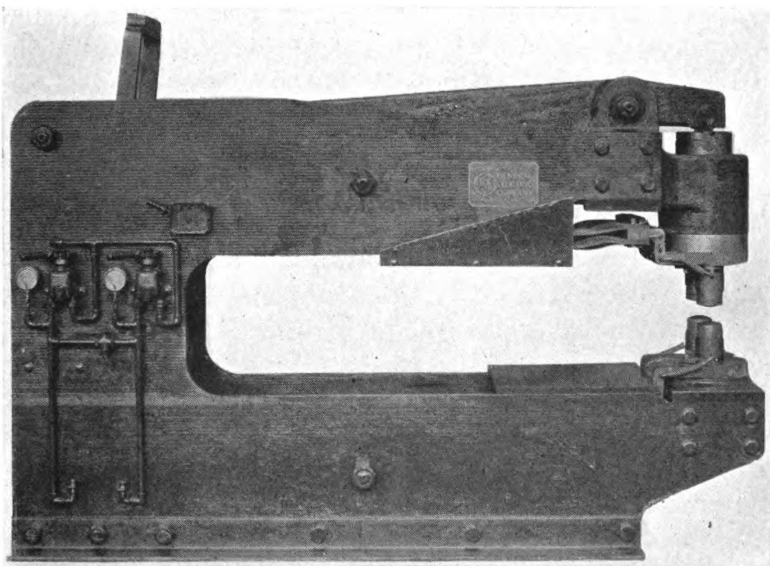


FIG. 8.—Duplex electric welder—6 ft. reach. 2 (60–400–220–7.86). Capable of welding together two steel plates ¾" thick in two spots 1¼" in diameter.

spaced 8 inches centre to centre, but may be disposed from 10 to 6 inches centre to centre.

The cooling of the electrodes as well as the cooling of the transformer winding is similar to that of the smaller machines. Hydrant water has been found practical for this purpose. The water traverses the apparatus in two parallel paths, "one being through the primary winding and the other through the secondary and the electrodes in series."[2] Separate valves are provided for independent control of flow in the two paths.

This duplex spot welder, as it is called, is capable of producing 50,000 ampères with 500 volts 60 cycles. With this much current in the secondaries the current in the primaries is 1800 ampères. The kv-a under these conditions is 450 for each transformer, and at 440 volts and the same cycles kv-a will be approximately 350.

As with the smaller machines the 6-foot duplex machine may be operated on a 440-volt 60-cycle alternating-current source of supply, but a regulating transformer was provided for the purpose of connecting these machines to a higher voltage supply as well as to regulate the voltage and current for different thicknesses of material for experimental purposes. The capacity of the transformer supplied was 350 kv-a, and as was just stated, this machine required at least 350 kv-a at 440 volts on each welding transformer—a total of 700 kv-a. The apparent discrepancy is removed when it is remembered that the operation is in seconds, a period of overload too short to injure the transformer. More interesting is the physical difference in size between this 350 kv-a regulating transformer and one of the transformers of the duplex spot welder.

On the regulating panel is mounted the contactor for connecting the electrical supply to the two transformers and, as will be seen in Fig. 8, the remote control switch for actuating the contactor is mounted in a group with the air levers and air gauges. The entire mechanism is controlled from this point and with a nicety that

[2] "Recent Developments in Machines for Electric Spot Welding," J. M. Weed, *General Electric Review*, December, 1918.

reflects much credit to its builders. From this position both electrodes may be raised or lowered independently or together, and by placing a spacing block of copper between one of the pairs of electrodes the other electrode may be used to make a single spot. This is often of advantage in working along a seam, as the multiple of two may not meet the requirements of the adopted spacing, so that it may be necessary to make a single spot to complete the job.

These machines are equipped with all the best and latest features of good design. The workmanship is excellent and the materials well calculated to endure the heavy duty that should come to this machine in regular production work. Intrinsically the machine is of high value and is self-contained; extrinsically this machine for commercial production will probably require an auxiliary that will change the frequency of the electric supply, distribute the power as now supplied over the three phases, and reduce the sudden rushes of current required by the process. As has been described of this apparatus, it all operates on a single-phase current and at 60 cycles. Under these conditions there is a large unbalance to be expected in the supply as well as in the low-power factor. By means of proper auxiliary apparatus the power consumed as well as the other desirable features mentioned may be obtained, and this apparatus will then function well within the bounds of commercial economics.

Specified Requirements.—When the orders were issued for this apparatus this previous consideration was probably never entertained because it was not estimated that these three machines would be in simultaneous use.

If such had been the case some form of apparatus to correct the electrical-supply conditions would have been required. It was thought that the work of these machines was so rapid that even our largest shipyard, Hog Island, for which these machines were ordered, would fail to supply them with as much work as they could perform. And this would have been true unless great changes in the methods of building ships had come to pass. These machines were never completely delivered or operated at Hog Island, but were diverted for demonstration purposes to one of the many bridge shops which were fabricating material for the shipyard. This work being in line with strict production output these machines were more suitable, and their introduction was interrupted solely because of the Armistice.

Some of the detail requirements of this apparatus had to conform to the electrical-supply conditions of Hog Island, so that the regulating transformers were all furnished for a primary voltage of 2200, single-phase, 60-cycle alternating current. As the electrical current at the Island was also distributed on a low-voltage (440) system at 60 cycles the transformers integral with the welding machines were so specified. These points were common to all the machines.

The 6-foot-throat, duplex, spot-welding machine was required as a maximum of capacity to weld two spots at once through two thicknesses of ¾-inch steel plate, *i.e.,* it was to be capable of welding continuously two thicknesses of ¾-inch steel and two welds at each operation. No particular ship work was specified nor any requirements conditioned upon the efficiency of the spot-welded joint as compared to the customary methods of riveting.

In the same way the 12- and 27-inch welding machines were required as the maximum of work to weld two thicknesses of ⅝-inch steel plate without further stipulation as to performance. Other requirements referred to the special features described above and appurtenances, such as flexible leads for the portable machines, transformers, panels, remote-control switches, water-cooling arrangements, etc.

The point to be noted is that in all fairness to the builders this specification was their responsible guide and legal guarantee. No more could be sought in an acceptance test, which was the real purpose of this demonstration, than that these machines would securely weld two thicknesses of ⅝-inch steel plate in the case of the two semi-portable and two thicknesses of the ¾-inch steel plate in the case of the duplex welder. It is estimated roughly that 80 to 90 per cent. of riveted ship joints are three thicknesses, and approximately 15 to 20 per cent. four thicknesses of steel plate. The question then arises, Are these machines suitable for ship construction? It is not altogether possible to carry the demonstration to an unequivocal answer in the affirmative, but it is believed that the many tests made, remembering the limitations under which they were conducted, show that these machines would give a satisfactory performance for ship fabrication under favorable shop-production management. It should be borne in mind in looking critically at the results that the responsibility of those interested in this demonstration ceased when the requirements of the specifications were fully met.

Arrangements for Tests.—The bridge-construction company, which was one fabricating ship material for

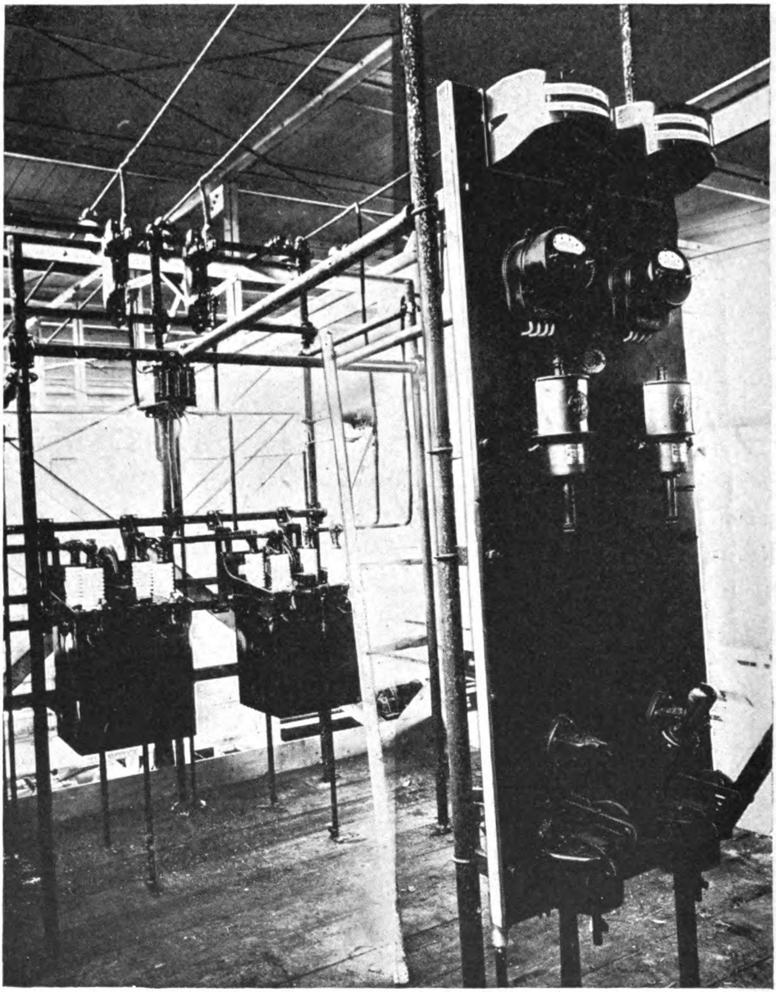


FIG. 9.—Oil switches and high potential in-coming-line panel for spot-welding demonstration.

the Hog Island shipyard, selected for the demonstration was the McClintic-Marshall Construction Co., located at Pottstown, Pa. At the time of preparation for the tests the new Liberty Shop, devoted entirely to ship fabrication, was just nearing completion. It was decided to erect the apparatus in this shop in one of the bays designed for a group of riveting machines with the intention of retaining them in this production position if all went well. This location gave easy access to air and water supply and avoided interference with other sections of work in the shop.

At a high point near the roof a temporary platform was built with head-room for the incoming-line panels, oil switches, and the regulating transformers for the 12- and 27-inch semi-portable machines. Fig. 9 shows the arrangement of this apparatus which secured safety by keeping the high potential away from the working spaces. Fig. 10 illustrates the mounting of the regulating transformers for the semi-portable machines. The electric conductors were carried down in a vertical line from these transformers to a second, or lower, temporary platform upon which were placed the selector panels. Upon these panels were placed the remotely controlled contactors. This is clearly seen in Fig. 11.

This same illustration shows the electrical connections from the selector panels to the two machines. On the left-hand side is the 27-inch welder and on the right is the 12-inch. The leads which look like hose in the photograph are electric wires which close the contactors which in turn energize the machine transformers from which the secondary or induced current is obtained for producing the welding current. The large dark leads are the wires which carry the main primary current from the taps on the selector panels. It will be seen from the photograph that the taps on the panels are numbered starting on the left-hand upper row and by means of

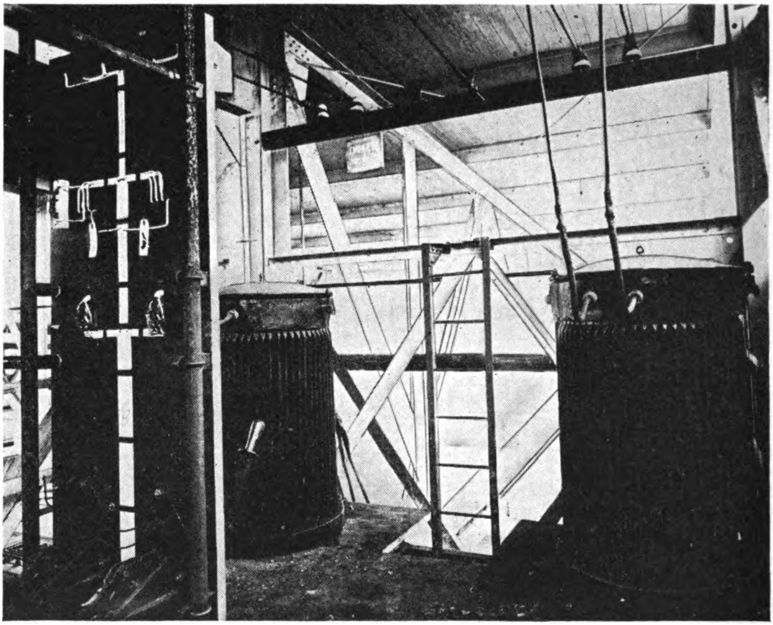


FIG. 10.—Regulating transformers for 12"x 27" semi-portable spot-welding machines.

two removable sliding contacts a varied combination of connections may be made.

In this same Fig. 11 on the right-hand side will be seen the water supply and exhaust for the cooling system for the 12-inch machine. These connections are made at the lower back end of the frame just inside of which is the transformer. Almost in a direct vertical line will be seen the air connections, reducing valve, and air gauge. The photograph incidentally shows the 12-inch machine spot welding a part of one of the samples used in the demonstration and to be described later.

This particular photograph was taken very shortly after the apparatus was installed, and at that time it was

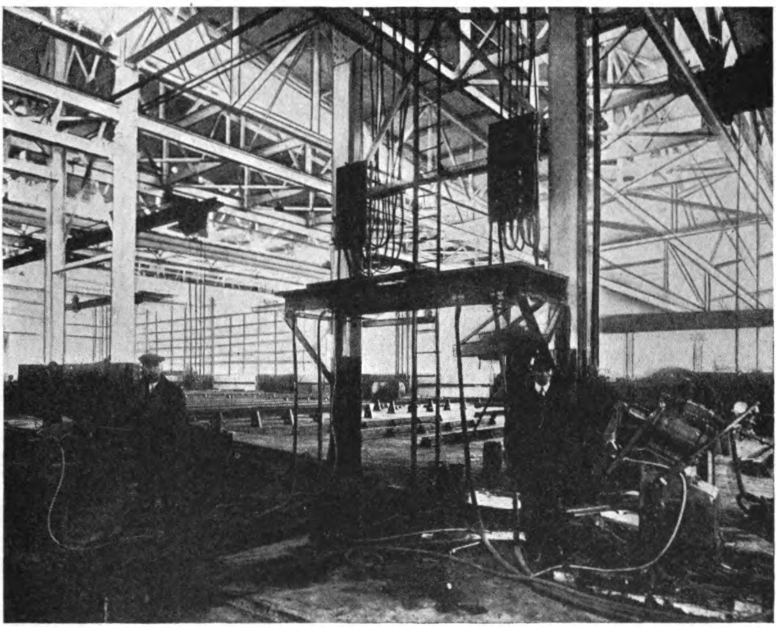


FIG. 11.—Selector panels for 12"x 27" semi-portable spot-welding machines.

anticipated that the machine would be operated as portable tools. A sufficient attempt was made to do this, but it was quickly discovered that the shop did not have the requisite crane facilities for permitting this arrangement as a regular method. These machines were then transferred to the other side of the steel columns and made stationary on steel horses. This gave permanency to the machines and served the purpose of the tests, although it required very awkward and detrimental handling of large bulky pieces to the machines. This latter arrangement of the small machines can in part be seen in Fig. 12 to the left of the large 6-foot duplex spot welder.

This same illustration indicates the size of the 6-foot

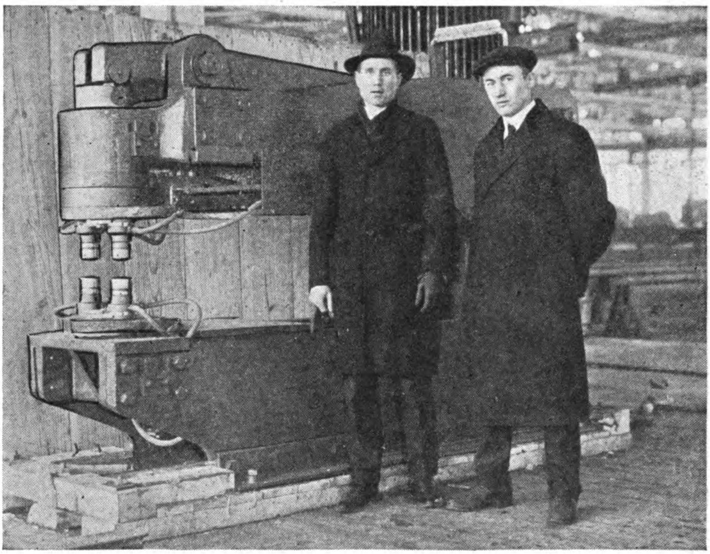


Fig. 12.—Six-foot duplex spot-welding machine in place for tests.

duplex spot welder, and shows distinctly the electrodes with cooling-water connections and the arrangement for replacing the electrode tips. As the regulating transformer (Fig. 13) for this machine was too great in height and weight for the temporary platform already supporting the two regulating transformers for the small machines, it was placed as shown on the main shop floor just back of the spot welder. To one side of it was located the selector panel (Fig. 14) containing also the

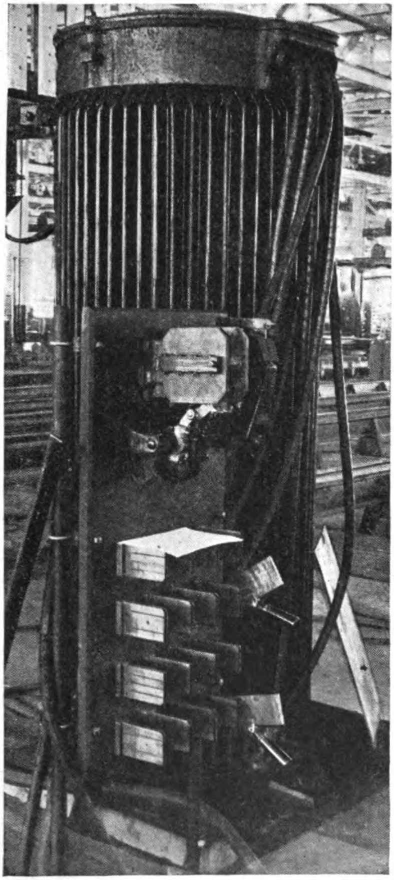


FIG. 13.—Regulating transformer for six-foot spot-welding machine, in place for testing.

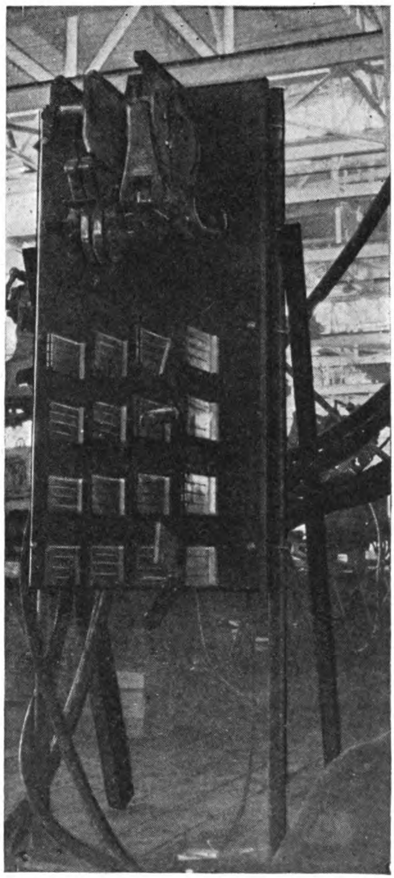


FIG. 14.—Selector panel for six-foot spot-welding machine in place for testing.

main switch contactor. This arrangement, although necessitating a continuation of the high-potential leads to the floor of the shop, permitted short connecting leads between the transformer, panel and machine. The high-potential leads were carefully protected. The whole layout was of a temporary nature, due to delay in the delivery of this machine and the fact that the time allotted for this demonstration was drawing to a close.

In the same space, but a little farther down the shop,

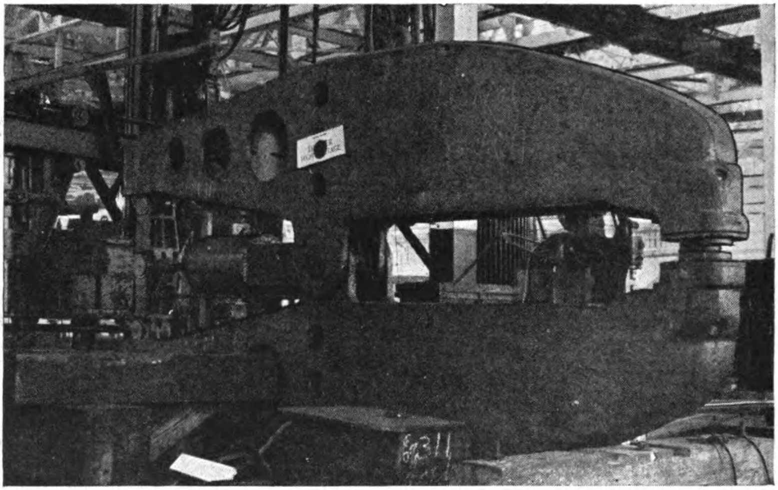


FIG. 15.—Five-foot portable spot welder in place for tests.

was placed the 5-foot portable spot welder (Fig. 15) which was intended for use in building the demonstration section of a middle body portion of a standard ship. Through the large gap may be seen the 27-inch semi-portable spot welder, and to the extreme right the rear or control end of the 6-foot duplex spot welder. This photograph gives the appearance of great bulk and weight to the machine, but the castings were lightened in great measure and with a sufficiently powerful crane and proper rigging this 5-foot spot welder could probably be handled. The head, as will be seen, was fitted with a pair of short-circuiting electrodes and a pair for making the weld. These copper electrodes were about three inches in diameter and the intention was to use a copper button on each side of the joint to be welded. There were no mechanical arrangements for holding these buttons in place in case the machine had to be tipped to make the weld, but presumably it was intended that the buttons would be held in place by the operator or one of his assistants. Back of the hinge can be seen the air cylinder and piston which provided the mechanical pressure on the electrodes. Just above this cylinder and enclosed in the upper arm was a small electric motor for close adjustment of the jaws. The welding transformers were enclosed in the casing just back of the head near which on the opposite side from that shown was placed the operating switch. This control switch combined the movements of the jaws and the operation of the main-line switch through the remote contactor which as in the other designs was placed on a panel at some distance from the machine. This spot welder was not provided with means for changing the supply voltage, but operated on a 220-volt 60-cycle single-phase alternating current. This supply voltage was taken from a suitable tap from one of the regulating transformers of the other machines.

The high-potential line was brought from the main power-house of the plant which in turn was served by the local central station. Every precaution was taken as regards the effects that might be occasioned on these lines. The central-station company was fully informed as to the experiments to be made and the amount of energy that would be suddenly demanded. Additional central-station transformers were at hand in case they should be needed. No difficulties as to power supply were encountered during the trials of the small machines, and the voltage drop at this period of the demonstration was not excessive. It was not necessary to operate both these machines together, and so this was never done. When the 6-foot duplex machine was first tried the voltage drop was very great and additional copper conductors were installed with available material. This reduced the voltage drop an appreciable amount, but not to a point which would give the maximum capacity of this machine. The time for correcting this limitation would greatly exceed that permitted for these tests and it was considered inexpedient to expend further time and money in view of the fact that this machine had shown itself fully capable of meeting the specification requirements, and undoubtedly with a full voltage supply would have greatly exceeded them. The results in the opinion of those most concerned testified to the reasonableness of the action taken.

Methods and Procedure of Tests.—In view of the broad interest taken by Lloyd's Register of Shipping in the application of electric welding to steel ship construction and the recent investigations of this classification society into the processes of arc welding which were conducted in England, it was deemed appropriate to parallel some of the smaller practical tests for the sake of comparison. One of these tests was designed to compare the bearing value of a short attachment lug riveted as against arc welded. This same design was used but the attachment lug was spot welded with the same number of spots as rivets. The test pieces consisted of ⅜-inch flat plate 6 inches wide by 18 inches long upon which was riveted an angle lug 2½ by 2½ by ⅜ inches. The lug was secured to the plate by four ½-inch rivets spaced 2½ inches centre to centre. The attachment lug was 12 inches in length. In the spot-welded test piece four spots, located as nearly as possible to the same spacing, secured the same-sized angle lug. This sample represents a very frequent job in the fitting-up of the hull of a ship and the practical value of the comparison cannot be questioned.

The second test piece was intended in the Lloyd's investigations to compare " the relative value of welding and caulking under tension." [3] In the case of the spot-welding comparison this was at first not considered, although a sample of spot- and arc-welded joint was later made with results that were easily foretold. This test piece took the shape of a cross and simulated the boundary of a water-tight compartment. It consisted of a 20-pound flat plate 24 inches long and about 15½ inches wide. At the centre of this plate and perpendicular to it were, attached by 3½ × 3½ × ¾-inch angles, two flat plates 24 inches long and 7½ inches wide. The ¾-inch angles were first secured to the two small pieces of 20-pound plate by ten ¾-inch rivets, and then the two angles joined by the same number and size of rivets to the large flat plate. This required the joining of three thicknesses of material amounting to a total thickness of two inches. The spot-welded test

[3] " Lloyd's Experiments on Electrically-Welded Joints," H. J. Cox, *General Electric Review*, December, 1918.

pieces were made up in the same manner and secured the members with ten evenly spaced spot welds. As much difficulty was encountered not only with modifications of the then-available spot-welding machine, but also with the testing machine, and, as the ¾-inch angles of this piece were in excess of practice for such a connection, the spot-welded test pieces were afterwards changed to 3½ × 3½ × ½-inch angles. During the trials certain other test pieces were prepared and tested in order to determine the proper proportion of current, time, etc., needed for spot welding three thicknesses of ½-inch steel plate. These test pieces consisted of two strips of size convenient for the testing machine placed end to end and the joints covered by a small strip top and bottom. This allowed two spots through three thicknesses of ½-inch steel, a total thickness of 1½ inches.

This practice of spot welding three thicknesses was of value in the next undertaking which was the spot welding of a ship's floor. Fig. 16 shows the floor in process of spot welding. This job is in line with regular production work. In order to make comparison, material was prepared for three sets of floors. One of these was to be riveted in the usual manner, the next was to be arranged with a few holes punched for assembling and then to be spot welded, and the third was simply the materials cut ready to be spot welded. In the latter case the materials were assembled by arc-weld tacking. When these floors were ready for test only one spot-welding machine was available, the small 12-inch machine. An accident had happened to the 27-inch welder and the 6-foot duplex machine was not ready for shipment. In addition, modifications to the electrodes of this machine were necessary both in order to weld through three and four thicknesses of 20-pound plating, and also in order to manipulate the apparatus so as to locate the spots in the proper position with respect to the heel of the bounding angle. These floors were spot welded with only two points in mind,

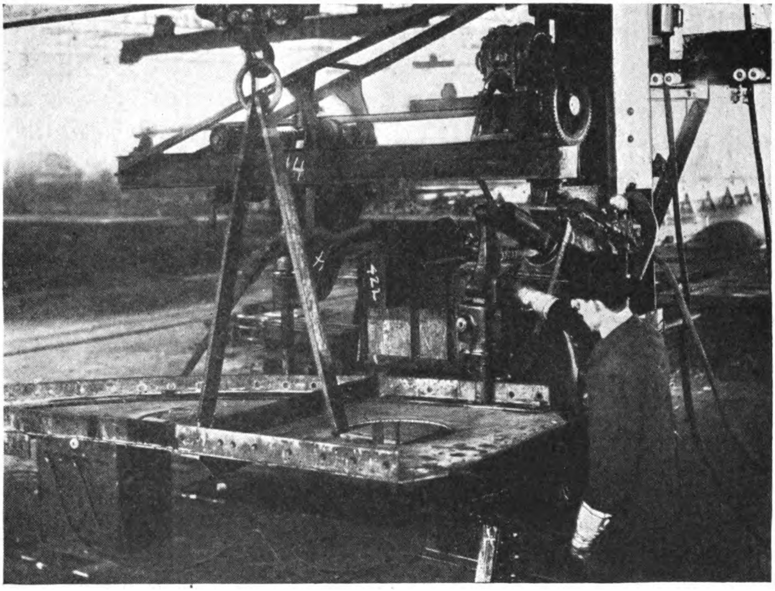


FIG. 16.—Spot-welded ship floor.

both of which were clearly demonstrated: (1) That spot welding along a certain circumscribed seam would neither distort nor elongate the material, *i.e.,* cause a creeping effect; (2) that the edge of the angle resting on the flat plate would not be scored nor distorted to the detriment of the mechanical caulking, *i.e.,* that a caulking edge would be preserved. That the spot welding of these floors also showed other features that were fair must be considered without the intent or purpose of the test; that the floors did not meet with a full success when subjected to later tests was to be expected.

Historically considered the demonstration had now reached a point where more practical data was desired. The 27-inch semi-portable machine had been repaired and was now set up with modifications principally in the protection of the electrodes. This machine as mounted and modified was found more convenient for the next series of tests, although the 12-inch machine with similar modifications would have produced like results. The test pieces now prepared were varying thicknesses of steel plate from 1/4 inch to 3/4 inch, *i.e.*, 1/4, 3/8, 1/2, 5/8, and 3/4 inch. The pieces were ten feet long and of a width suitable for easy handling in the tensile-testing machine. These strips of plating were lapped and tacked together by means of the electric arc. Continuous spots were made at a spacing which would permit of the cut samples entering the jaws of the testing machine. The spots were made in various ways to detect any gain or loss by the order in which the spots were made. After the plates were spot welded, each spot—about thirty for each 10-foot plate—was cut by means of the oxy-acetylene flame, then pulled in an Olsen tensile-testing machine. These tests were made to demonstrate the uniformity of work that might be expected in regular practice and to determine to what extent the operator or the machine entered into the problem. As will be seen, the results are very clear on these points.

To convince those who might feel that spot welding would not be able to withstand the shocks which threaten the destruction of a ship when she strikes a submerged rock, a sample of 20-pound plate 6 feet long and 24 inches wide with a bounding angle 3½ by 3½ by 7/16 inches was spot welded. This was subjected to a rough test under a 30-ton steam hammer. The highest static pressure that the hammer could exert did not affect this sample while placed on edge. The hammer was then raised, the sample braced on the angle and a blow delivered. After several blows, the sample being returned to the same relative position after each pounding, the angle on the top edge showed fatigue. The sample was then turned and blows repeated at different positions in the length. A careful examination showed that where the angle had broken away from the plate the welded joint had torn the original metal with it. This sample showed distortion and it was noted how tenaciously the spot-welded angle clung to the plating.

As a sequel to the uniformity test a number of shorter test pieces were made up of 20-pound plating and lapped to varying widths, spot welded with two, three, and four rows of spots. These tests were made as a comparsion with double-, triple-, and quadruple-riveted joints.

These latter tests with the uniformity tests on ¾-inch steel plate brought the demonstration to an end. The ¾-inch uniformity tests could be made only on the duplex spot-welding machine, which was not available until near the conclusion of the allotted time. It was fortunate that this series of tests could be completed, as it furnishes data of value to those who may wish to go forward with this process.

Results of Tests.—Before spot welding the first test pieces of 20-pound plating it was essential that a determination of the time for welding this thickness of material be obtained. It was also necessary for the operator to know the effects of the different voltage taps. Thirteen samples were spot welded with a single spot and with varying time and current. These samples were all made on the 12-inch spot welder and pulled for ultimate tensile.

TABLE I.

SAMPLES FOR ADJUSTMENT OF MACHINE.

Sample No.	Open-circuit Voltage	Welding Time	Ultimate Load	Remarks
1	560	13	40,600	
2	560	8	30,600	
3	360	22	20,100	
4	410	15	20,800	
5	455	7	36,700	
6	455	9	36,600	
7	455	9	35,600	
8	407	11	43,000	
9	460	11	45,300	
10	510	13	45,100	
11	510	10	43,600	
12	510	10	40,400	
13	510	15	73,100	

sile. Table I gives the results as taken. The second column is the voltage reading of the taps on the selector panels with the main contactor switch open; that is, no work being done. The drop in voltage is not taken into account. The last sample differed from the others in that it consisted of three thicknesses of 20-pound plating. This was to determine the conditions for welding three thicknesses. Fig. 17 gives an idea of the appearance of a spot weld after undergoing shear in the tensile-testing machine. Fig. 18 illustrates the torsional strains suffered by the sample while under tensile pulling. This is caused by the overlap of the two pieces, throwing the action of the testing jaws off centre.

An independent set of electrical readings were taken as a preliminary step, so that afterwards results might be interpreted from them, but it was determined that the electrical conditions did not vary to a point detrimental to the welding requirements. Consequently, electrical readings were not taken in every instance. During the uniformity tests electrical readings were taken as a check and proved the correctness of this decision. Table II gives the open-voltage readings across the primary winding of the 12-inch spot-welded transformer when the connections on the selector panel were made as indicated by the numerals on the panel. These readings at once established the practice for the selection of the taps, and so by trial of the various thicknesses of stock material or the number of the thicknesses required to be welded, the open-circuit voltage was approximately known. With this information those familiar with the electrical design could estimate the amount of current passing through the electrodes.

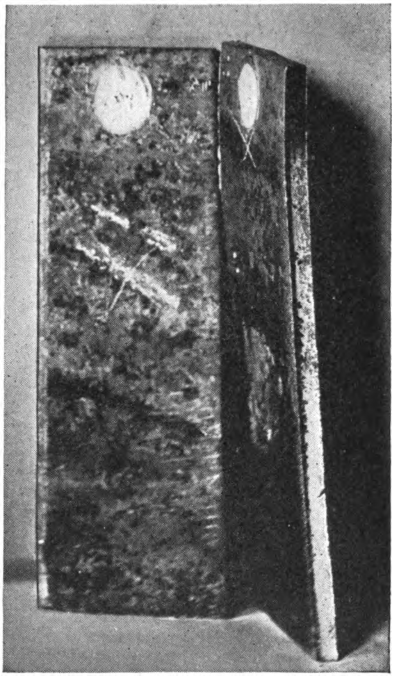


FIG. 17.—Single spot weld in two thicknesses of 20-lb. plate.

For a full investigation into the electrical conditions

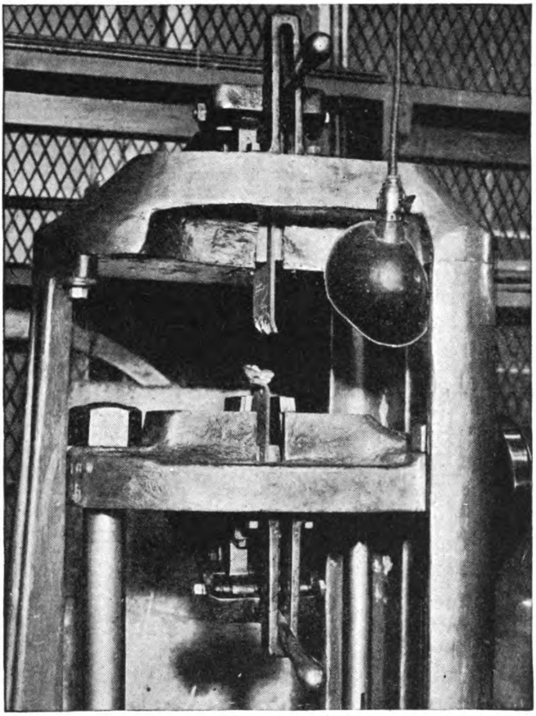


FIG. 18.—Shows sample weld after shearing in the testing machine. Note the effect of torsional strains.

TABLE II.
VOLTAGE TAP READINGS.

Connections Upper and Lower	Voltage	Connections Upper and Lower	Voltage
1 and 5	277	3 and 5	375
1 and 6	308	3 and 6	407
1 and 7	363	3 and 7	455
1 and 8	410	3 and 8	505
2 and 5	353	4 and 5	427
2 and 6	360	4 and 6	460
2 and 7	410	4 and 7	510
2 and 8	463	4 and 8	560

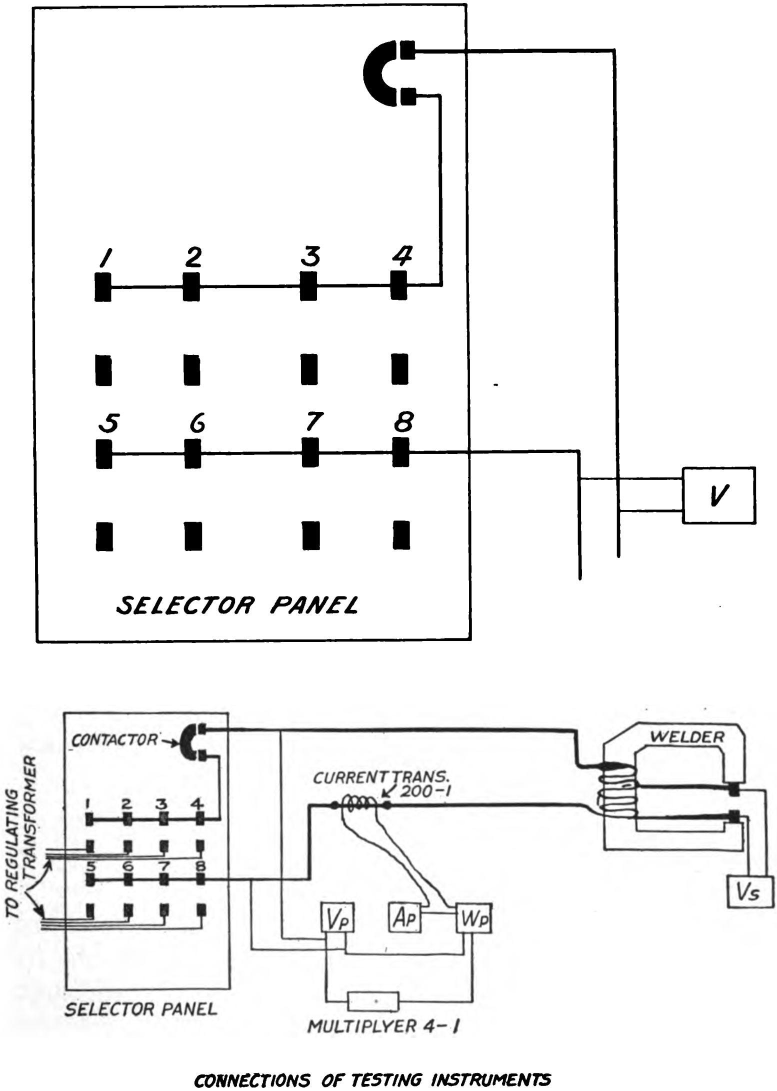


FIG. 19.—Connections of testing instruments.

it was decided to take a complete set of readings. Instruments were introduced into the circuit as shown in Fig. 19 and the mean of four readings is recorded in Table III. These readings were taken under load. The

TABLE III.
ELECTRICAL READINGS OF 12-INCH MACHINE.

V_p Direct	A_p x 200		W_p 200 x 4		P.F.	V_s Direct	Connections	A_s (A_p x 52)
				K.W.				
260	1.75	350	50	40.	.44	2.	1 and 5	18 200
282	1.95	390	60	48.	.435	2.	1 and 6	20 280
340	2.15	430	80	64.	.436	3.	1 and 7	22 360
385	2.4	280	95	76.	.703	3.2	1 and 8	14 560
310	1.9	380	70	56.	.475	2.4	2 and 5	19 760
330	2.2	440	80	64.	.44	2.4	2 and 6	22 880
375	2.45	490	90	72.	.392	3.	2 and 7	25 480
415	2.7	540	112	89.5	.40	3.1	2 and 8	28 080
350	2.2	440	80	64.	.415	2.	3 and 5	22 880
375	2.5	500	90	72.	.384	2.	3 and 6	27 000
415	2.9	580	105	84.	.35	1.5	3 and 7	30 160
440	3.2	640	122	97.5	.346	1.5	3 and 8	33 280
360	2.7	540	95	76.	.391	2.7	4 and 5	28 080
410	2.8	560	110	88.	.384	2.6	4 and 6	29 224
440	3.2	640	130	104.	.37	1.6	4 and 7	33 280
475	3.4	680	142	114.	.354	2.2	4 and 8	35 360
*485	3.05	610	147	118.	.40	3.	4 and 8	31 720

* This set of readings taken with the plates set full width of gap 12 inches.

varying connections refer to the same numerals (Fig. 11) as marked on the selector panels. The last column, secondary amperes, is calculated by multiplying the primary amperes by the number of primary turns in the 12-inch spot-welded transformer, which is 52. The last set of readings was taken with the steel-plate test piece shoved back in the machine in order to introduce the full reactance and to ascertain the effect this would have upon the power factor.

While taking these readings it was noted that the secondary volts across the electrodes gradually lowered as the welding time continued. No noticeable change was seen in the primary readings during this short period. Table IV shows readings taken on two different sets of

TABLE IV.

SHOWING DROP IN SECONDARY VOLTS.

Connections	V_p	A_p		W_p		P.F.	V_s (Direct)						
					K.W.		0 sec.	5 sec.	10 sec.	15 sec.	20 sec.	25 sec.	30 sec.
3 and 6	370	2.4	480	100	80	.45	2.5	2.3	2.0	1.5	1.3	1.3	
3 and 6	370	2.4	480	100	80	.45	3.3	2.5	2.2	2.0	1.5	1.3	1.25
3 and 7	410	2.75	550	115	92	.407	3.0	2.7	2.0	1.7	1.5	1.5	
3 and 7	415	2.70	540	115	92	.41	3.0	2.7	2.0	1.7	1.5	1.4	

connections with the secondary voltage read every five seconds.

Electrical readings were taken during the spot welding of the lug attachment on the 20-pound-plate test piece. These readings are given in Table V and by ref-

TABLE V.

ELECTRICAL READINGS TAKEN WHILE WELDING SAMPLE LUG ATTACHMENT.

Connections	V_p	A_p		W_p		P.F.	V_s	A_s
					K.W.			
4 and 7	425	3.2	640	120	96	.353	2.3	33280
4 and 7	425	3.5	700	125	100	.336	2.5	36400
4 and 7	430	3.1	620	130	104	.39	3.0	32240
4 and 7	425	3.2	640	120	96	.353	2.5	33280
3 and 7	415	2.8	560	110	88	.379	2.5	29120
3 and 7	410	2.9	580	110	88	.407	2.4	30160
3 and 7	420	2.9	580	104	83	.340	3.0	30160
3 and 7	420	2.95	590	110	88	.355	3.2	30680

erence to the same connections shown in Table III the constancy of the electrical conditions may be judged. Ten samples of this type were spot welded and tested for tensile in the Olsen testing machine. Table VI gives the results of this test and Table VII gives the comparable results for the riveted sample. Fig. 20 illustrates this comparison and shows compositely the general re-

TABLE VI.
TENSILE TEST OF LUG ATTACHMENT.
SPOT WELDED.
(Electrode pressure 15,000. Time on spots 10 seconds.)

Sample No.	Open-circuit Voltage	Ultimate Load Pounds	Remarks
1–1	455	98,000	Sample forced out of machine
1–2	455	105,700	Angle bent away from plate .176″
1–3	455	92,000	4 spots broke
1–4	455	89,000	Sample forced from machine
1–5	407	89,000	All spots sheared
1–6	407	99,300	Sample forced from machine
1–7	407	67,000	Spots 1 and 2 tore away
1–8	407	63,700	Sample forced from machine
1–9	455	68,500	
1–10	455	73,900	

sults of the tests. On the left is the riveted sample which invariably sheared three or all of its rivets under an ultimate tensile of 45,000 to 48,000 pounds. In the middle

TABLE VII.
TENSILE TEST OF LUG ATTACHMENT.
RIVETED.

Sample No.	Ultimate Load	Remarks
2–1	48,000	Sheared all 4 rivets
2–2	47,400	Sheared all 4 rivets
2–3	46,700	Sheared 3 rivets
2–4	47,200	
2–5	49,700	Sheared 3 rivets
2–6	44,000	Sheared 3 rivets

is the spot-welded sample which would spring from under the jaws of the testing machine after an ultimate load of 89,000 to 100,000 pounds. To the left an attempt was made photographically to show the twisting of the

20-pound plate which caused the sample to spring from the jaws of the testing machine. It will be noticed in Table VI that the last four samples tested at an ulti-

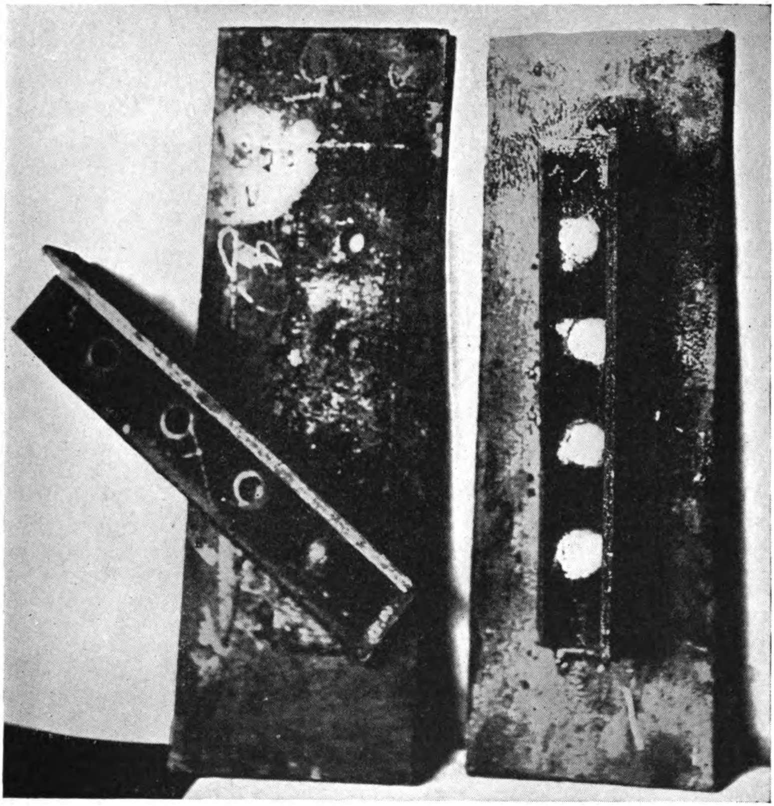


Fig. 20.—Comparison of riveted and spot-welded test piece.

mate load of 63,700 to 73,900 pounds. It will also be seen in Table V that the connections were changed for these four samples. This was done after the first samples were pulled in order that tests might be made that would shear the lug attachments in order to enable a view of the spot weld. The results showed that a good weld could be made at reduced amperage.

The riveted test pieces of the cross-connection sample were next prepared for tensile test. Before this could be done small pads of ½-inch plate were arc welded to the small sides of the sample (see Fig. 21). These pads

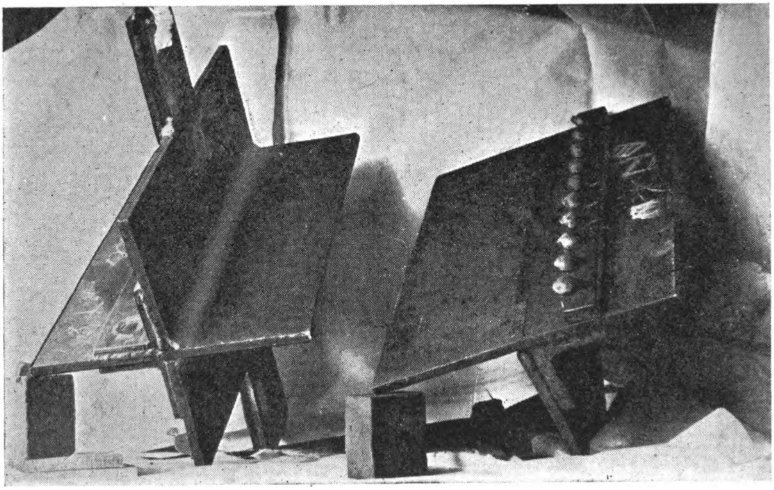


FIG. 21.—Comparison of riveted and combination arc- and spot-welded sample.

were about 3¾ inches wide and were found necessary in order to obtain a satisfactory pull in the testing machine. These test pieces were too heavy for the testing machine, which though originally rated at 150,000 pounds capacity, was only safe to operate up to 124,000 pounds. At this ultimate load the ten ¾-inch rivets were either sheared entirely, or the angle broke, or the rivets stretched. The spot-welded samples were in excess of the capacity of the 12-inch spot welder for welding three thicknesses. A number of samples were made and pulled with interesting results as far as examination of the condition of the spot welds after shearing strains. Later the angles were reduced to ½-inch thickness, but when this change was made the uniformity tests were in progress and it was not considered of value to continue this comparison. In view of the original intention which was the relative value of mechanical caulking versus electric welding, a sample was made both spot welded and arc welded. That is, the edges of the angles were arc welded. This test piece was set up in the testing machine and resulted in breaking the head of the machine. The strain on the sample in both a static and dynamic sense must have been very great. This special sample is shown on the left in Fig. 21 after the test had been made. There were no signs of distress in any of the joints. It has been sent to the Commercial Museum, Philadelphia, Pa., where it may be seen by any one interested. On the right in this same illustration is one of the riveted samples in which the ¾-inch angle broke in line of the rivets at an ultimate load of 118,900 pounds.

The results of the first trial for uniform strength of spot welds in one long seam was not successful. It brought to light the necessity of two important points in the preparation of the steel plates and focussed attention on the serious problem of the electrode tips. During the first test no care was given as to the condition of the material. It was spot welded as received. If it happened to be clean on the surfaces next to the electrode tips these tips were still used; if, on the other hand, much scale and rust rested on these surfaces the tips were badly burned with the result that they had to be renewed.

This was one of the reasons why the 27-inch machine was now used. The builders had changed the method of renewing the tips which reduced the time and inconvenience very considerably. In like manner in the early

TABLE VIII.

GLASGOW IRON WORKS, POTTSTOWN.

FEB. 24, 1919.

No.	Load Lbs.	Time Sec.	Remarks	Electrode Changed
1	49,700	15		
2	41,600	12		
3	40,600	12		No. 3 (b)
4	41,100	12		
5	41,300	12		
6	43,700	12		
7	46,100	12		No. 2 (b)
8	45,200	12		
9	51,200	12		No. 1 (c)
10	35,900	12		
11	41,700	12		
12	40,700	12		
13	44,200	12		No. 2 (a)
14	43,800	12		
15	44,500	12		
16	41,200	12		
17	31,300	12		No. 1 (b)
18	43,700	12		
19	39,400	12		
20	40,800	12		No. 1 (a)
21	43,400	12		
22	41,900	12		
23	40,300	12		
24	46,800	12		No. 2 (c)
25	42,600	12	* Re-Spotted	
*26	43,700	12	Full time after 26	
27	42,100	12		
28	41,600	12	Fore plate	No. 3 (a)
29	44,000	12		
30	48,800	15	Pulled spot out	

10′—10″ Plate 20 lbs.—$\frac{11}{32}$″—2½″ lap—Green operator—27″ G. E. Spot Welder.
Present at test: Green, Schrader and Hornor.
Average break, 42,750 lbs.
Shearing stress (single shear) steel rivets and steel plates:
Half-inch, 12,250 lbs.
Three-quarter inch, 25,600 lbs.
Seven-eighths, 34,100 lbs.
One inch, 43,700 lbs.
Rusted, scale.

tests no attention was paid to the surfaces of the materials between the lapped portions. A few tests indicated clearly that the reverse condition was more desirable for welding, namely, that the surfaces between the plates to be joined be dirty, *i.e.*, have some mill scale or rust. This does not mean that clean surfaces cannot be welded, but that more successful and uniform welds are made in shorter time, with less current, and less pressure. This fact must be observed by those who wish to repeat the results here shown.

The results of the second set of spots made for the uniformity tests are given in Table VIII. These spots were not made consecutively, as it was thought at the time that the sequence of welds might bear some relation to the results. This consideration was not borne out by subsequent tests. So that the following samples were all made consecutively. The test pieces were all of the same nature: Two 10-foot lengths of a desired thickness of plate; these two pieces lapped about 2½ inches to 2¾ inches, arc welded at intervals along the edge, and then spot welded from one end to the other. The first sample was unfortunately cut in a shearing press which so deformed the samples that they were awkward to place in the testing machine. The surfaces next to the electrode tips for all samples were cleaned by a portable grinder in way of the spots before welding. Although no particular insistence was needed, the plates were placed so that the surfaces between had the ordinary mill scale and rust usual in practice. It could be easily noted when pulling the samples which were the relatively clean portions of the plates.

A series of tests were now made using ¼-, ⅜-, ½-, and ⅝-inch steel plates, including electrical readings for each spot made. The results are given in Tables IX, X, XI, and XII. It will be seen with what constancy the electrical conditions were maintained and how little they affected the results. After these particular tests no elec-

TABLE IX.

UNIFORMITY TEST ¼-INCH STEEL.

Test: 10-foot ¼" S. Plate
27" G. E. Spot Welder
Pressure: 18,750 lbs. at electrodes
Voltage: 325. Amperes: 22,230
Time of each spot: 12 seconds

No. of Spot	Ultimate Load	Amperes	Remarks
1	29,700	23,400	Spot in line with tack weld
2	19,000	22,620	
3	20,500	22,620	
4	20,200	22,230	
5	19,300	22,230	
6	18,900	22,230	
7	20,100	22,230	
8	20,100	22,230	
9	20,300	22,230	
10	19,400	22,230	
11	26,400	22,230	Spot in line with tack weld
12	19,100	22,230	
13	19,700	22,620	
14	19,000	22,230	
15	17,600	22,230	
16	19,200	22,230	
17	18,900	22,230	
18	20,200	22,230	
19	18,600	22,230	
20	17,100	22,230	
21	30,300	22,230	Spot in line with tack weld
22	19,900	22,230	
23	20,600	22,230	
24	20,900	22,230	
25	19,800	22,620	
26	22,700	22,230	
27	19,100	22,620	
28	19,000	22,620	
29	20,000	22,620	
30	26,000	23,400	Spot in line with tack weld

NOTES.—Present at welding test: Same as on ⅜" S. P.
Pulling tests made March 18, 1919, at Glasgow Iron Works.

trical readings were taken. As the ¼-, ⅜-, and ½-inch plates were below the designed rating of the machine the results given are arbitrary, as the current taps may be selected to give more or less current and successful weld-

TABLE X.

UNIFORMITY TEST ⅜-INCH STEEL.

MARCH 13, 1919.

Test: 10-foot ⅜″ S. Plate
27″ G. E. Spot Welder
Pressure: 18,750 lbs. at electrodes
Voltage: 395. Amperes: 27,900
Time of each spot: 12 seconds

No. of Spot	Ultimate Load	Amperes	Remarks
1	42,100	28,470	
2	27,800	27,690	
3	27,300	28,080	
4	30,900	27,690	
5	29,100	27,690	
6	30,100	27,690	
7	32,000	27,300	
8	30,500	26,910	
9	32,600	27,300	
10	33,000	26,910	
11	39,900	27,300	Spot in line with tack weld
12	27,600	27,456	
13	30,000	27,456	
14	30,400	27,534	
15	30,100	27,300	
16	32,200	27,300	
17	36,100	27,300	
18	31,600	27,690	
19	30,300	27,690	
20	34,100	27,690	Spot in line with tack weld
21	31,000	27,690	
22	25,700	27,300	
23	26,500	27,690	
24	29,100	27,300	
25	29,200	27,300	
26	29,300	26,910	
27	31,100	27,300	Spot pulled out
28	30,800	27,300	Spot pulled out
29	30,900	27,610	
30	28,000	28,470	Spot pulled out

NOTES.—Present at welding test: Seltzer and Newell (Steamboat Inspection Service), Martin (American Bureau of Shipping), Stewart and Hornor.
Pulling tests made March 18, 1919, Glasgow Iron Works.

ing accomplished by a relative adjustment of the time of making the weld. This brought these sizes into the realm of shop-production questions with which this demonstration had nothing to do.

TABLE XI.

UNIFORMITY TEST ½-INCH STEEL.

MARCH 12, 1919.

Test: 10-foot ½″ S. Plate
27″ G. E. Spot Welder

Pressure: 18,750 lbs. at electrode
Taps set constant 4–8
Voltage: 440. Amperes: 31,200
Time of each spot: 13 seconds

No. of Spot	Ultimate Load	Amperes	Remarks
1	44,100	32,370	Spot in line with tack weld
2	42,000	31,200	
3	38,000	31,200	
4	33,500	31,200	
5	28,900	31,200	
6	34,000	31,200	
7	35,000	30,810	
8	44,000	31,200	
9	38,500	31,200	
10	34,100	30,810	
11	29,000	30,810	
12	30,700	31,590	
13	35,300	31,200	
14	38,000	30,810	
15	32,600	30,810	
16	28,800	31,590	
17	27,600	31,590	
18	49,200	30,810	Spot in line with tack weld
19	36,500	31,200	
20	40,700	31,200	
21	38,000	31,590	
22	33,800	31,200	
23	31,600	31,200	
24	23,900	31,200	
25	30,200	31,590	
26	30,400	30,810	
27	30,200	31,590	
28	51,200	32,370	Spot in line with tack weld

NOTES.—Present at test: J. B. Stewart, H. A. Hornor.
Clean steel.
Pulling tests made March 18, 1919, Glasgow Iron Works.

It will be seen that the time given the ½-inch samples was 13 seconds (Table XI). It was expected that better results would be attained by increasing the time, so a smaller sample (5 feet in length) was run through

TABLE XII.

UNIFORMITY TEST ⅝-INCH STEEL.

MARCH 13, 1919.

Test: 10-foot ⅝″ S. Plate
27″ G. E. Spot Welder

Pressure: 18,750 lbs. at electrodes
Voltage: 440. Amperes: 31,200
Time of each spot constant: 18 seconds

No. of Spot	Ultimate Load	Amperes	Remarks
1	51,200	32,370	
2	......	31,590	Sample held for other tests
3	29,500	31,980	
4	19,700	32,370	
5	......	32,370	Sample held for other tests
6	28,600	31,980	
7	26,700	31,980	
8	22,200	32,370	
9	15,000	32,370	
10	18,600	31,980	Spot in line with tack weld
11	23,200	32,370	
12	38,300	32,370	
13	24,600	32,214	
14	26,600	32,370	
15	31,100	32,370	
16	33,400	32,214	
17	31,000	32,136	
18	29,100	32,370	
19	20,900	32,370	
20	44,100	31,590	Spot in line with tack weld
21	35,700	31,590	
22	32,800	31,200	
23	27,900	31,590	
24	30,000	31,200	
25	35,800	31,200	
26	31,300	31,200	
27	29,600	31,590	
28	21,200	31,200	
29	35,700	31,595	
30	49,900	32,370	

NOTES.—Present at welding tests: J. B. Stewart, Seltzer (Steamboat Inspection Service), Newell (same), H. A. Hornor.
Pulling tests made March 18, 1919, Glasgow Iron Works.

test without electrical readings at 15 seconds with results as shown in Table XIII. The ⅝-inch sample (Table XII) was welded with a constant time of 18 seconds for each spot, and as this was the maximum capacity of this machine better results could only be obtained by increasing the time. Table XIV gives the results on a 5-foot sample with spot welds made in 25 seconds, all the other conditions remaining the same.

These results were laid before the technicians of Lloyd's Register of Shipping, the American Bureau of Shipping, and the U. S. Steamboat Inspection Service of the Bureau of Commerce. It was then suggested that a similar series of tests be made as a check upon what had been done and with variations in the time of making the spots in each sample. Electrical readings were not required for each spot, but readings of the circuit were taken from time to time to assure that they were holding to a constancy that would not disturb the results. The records of these tests are given in Tables XV, XVI, XVII, and XVIII. The first ten spots of the ¼-inch sample were given 16 seconds each, the next ten spots were given 12 seconds each, and the last ten spots 8 seconds each. The average ultimate load in pounds for the first ten spots was 16,720 pounds, for the next ten spots it was 17,540 pounds, and for the last series 17,560 pounds. The first ten spots of the ⅜-inch sample were given each 16 seconds, with an average ultimate load of 34,720 pounds, the next ten spots were given 12 seconds each, with an average ultimate load of 32,790 pounds, and the last ten spots were given 8 seconds each, with an average ultimate load of 27,770 pounds. The first ten spots of the ½-inch sample were

TABLE XIII.

UNIFORMITY TEST ⅝-INCH STEEL.

Test: 5-foot ½″ S. Plate
Pressure: 18,750 lbs. at electrodes
Voltage: 440. Amperes: 31,200
Time of each spot: 15 seconds

No. Spot	Ultimate Load	Remarks
1	50,000	Spot pulled out
2	......	Sample held for other tests
3	40,000	
4	41,800	
5	41,900	
6	43,000	
7	......	Sample held for other tests
8	38,100	
9	35,000	
10	38,600	
11	......	Sample held for other tests
12	35,100	
13	37,700	
14	......	Sample held for other tests
15	45,400	

Welding done March 19, 1919.
Pulling tests, March 20, 1919, Pottstown, Pa.

TABLE XIV.

UNIFORMITY TEST ⅝-INCH STEEL.

Test: 5-foot ⅝″ S. Plate
Pressure: 18,750 lbs. at electrode
Voltage: 440. Amperes: 31,200
Time of each spot: 25 seconds

No. Spot	Ultimate Load	Remarks
1	......	Sample held for other tests
2	52,100	Spot in line with tack weld
3	47,500	
4	......	Sample held for other tests
5	49,200	
6	49,400	
7	64,700	
8	......	Sample held for other tests
9	52,600	
10	54,200	
11	......	Sample held for other tests
12	53,700	
13	52,900	
14	50,900	
15	60,300	

Average, 53,409 lbs.

TABLE XV.

Lloyd's Tests:

10'—¼" S. P. Tensile Test.

March 27, 1919.

Glasgow Iron Works, Pottstown, Pa.

Pressure at electrode constant: 18,750 lbs.
Amperes: 22,230. Volts: 325

No. Spot	Time Sec.	Diameter Spot, Inches	Ultimate Load, Lbs.	Remarks
1	16	¾"	20,600	
2	16	¾"	19,000	Pulled out spot
3	16	¾"	19,800	Gas hole
4	16	¾"	18,700	
5	16	13/16"	16,700	Two small gas holes
6	16	¾"	15,500	
7	16	11/16"	15,100	Small gas hole
8	16	11/16"	13,400	Small gas hole
9	16	11/16"	12,200	Small gas hole
10	16	11/16"	16,200	
11	12	11/16"	17,900	Small gas hole (Plate cold—welding resumed)
12	12	11/16"	16,000	
13	12	11/16"	18,500	Small gas hole
14	12	11/16"	16,700	Small gas hole
15	12	11/16"	16,700	Small gas hole
16	12	11/16"	18,000	Small gas hole
17	12	11/16"	18,000	
18	12	11/16"	16,900	Small gas hole
19	12	11/16"	18,100	Small gas hole
20	12	11/16"	18,600	Small gas hole
21	8	9/16"	17,200	
22	8	⅝"	16,700	
23	8	⅝"	17,300	Small gas hole
24	8	⅝"	16,600	Small gas hole
25	8	9/16"	16,100	Small gas hole
26	8	⅝"	15,200	Small gas hole
27	8	9/16"	16,800	Small gas hole
28	8	⅝"	18,200	Small gas hole
29	8	¾"	21,800	Small gas hole. Rusted specimen; slag between plates
30	8	11/16"	19,700	

Present at test: Same as ⅝" test.
Tests show a torsional strain on samples while in machine.
Average load first ten at sixteen seconds, 16,720.
Average load second ten at twelve seconds, 17,540.
Average load third ten at eight seconds, 17,560.

TABLE XVI.

Lloyd's Tests.

10′—⅝″ S. P. Tensile Test.

March 27, 1919.

Glasgow Iron Works, Pottstown, Pa.

Pressure at electrodes constant: 18,750 lbs.
Amperes: 27,700. Volts: 395

No. Spot	Time Seconds	Diameter Spot, Inches	Ultimate Load, Lbs.	Remarks
1	16	. .	34,700	Spot pulled out
2	16	⅞″	31,100	Small gas hole
3	16	1 1/16″	34,900	Small gas hole
4	16	1 1/16″	36,900	Small gas hole
5	16	1″	34,500	Small gas hole. Spot started to pull out
6	16	1⅛″	35,600	Small gas hole
7	16	1″	34,300	Small gas hole
8	16	1″	34,100	Small gas hole
9	16	1 1/16″	34,800	Spot pulled out
10	16	1 1/16″	37,300	Highly rusty material
11	12	1 1/16″	31,700	Small gas hole
12	12	15/16″	28,800	Small gas hole
13	12	1″	32,200	Small gas hole
14	12	1″	34,400	Small gas hole
15	12	1″	36,200	Small gas hole. Fracture around edge of spot
16	12	1″	33,800	Small gas hole
17	12	15/16″	30,500	Small gas hole
18	12	15/16″	32,300	Small gas hole
19	12	1″	34,800	Small gas hole
20	12	15/16″	33,200	Small gas hole
21	8	⅞″	25,400	Small gas hole
22	8	15/16″	28,700	Small gas hole
23	8	15/16″	25,500	Small gas hole
24	8	15/16″	28,600	Small gas hole
25	8	⅞″	26,600	Small gas hole
26	8	11/16″	24,600	Small gas hole
27	8	¾″	22,000	Small gas hole
28	8	15/16″	29,900	Small gas hole
29	8	⅞″	29,800	Small gas hole
30	8	1″	36,600	Small gas hole (Very slight)

Present at test: Same as ⅝″ test.
Tests show a torsional strain on samples while in machine.
Plate bent before spot pulled.
Average load first ten at sixteen seconds, 34,720.
Average load second ten at twelve seconds, 32,790.
Average load third ten at eight seconds, 27,770.

TABLE XVII.
LLOYD'S TESTS.
10′—½″ S. P. TENSILE TEST.
MARCH 27, 1919.
GLASGOW IRON WORKS, POTTSTOWN, PA.
Pressure at electrodes constant: 18,750 lbs.
Amperes: 31,200. Volts: 440.

No. Spot	Time Seconds	Diameter Spot, Inches	Ultimate Load, Lbs.	Remarks
1	20	..	41,000	End spot. 3¾″ wide plate. Plate fractured
2	20	1″	41,900	Started to tear around rim of spot
3	20	1 1/16″	42,800	
4	20	1⅛″	41,100	Spot pulled out 1″ diameter
5	20	1 1/16″	39,100	Plate fracturing in direction of grain. Spot pulling out
6	20	1 1/16″	43,100	Spot pulled out
7	20	1 1/16″	41,400	Plate fracturing in direction (1⅜″) of grain. Spot pulling out
8	20	1″	40,700	Plate fracturing in direction (1⅜″) of grain. Spot pulling out
9	20	1⅛″	41,600	Plate fracturing in direction (1⅜″) of grain. Spot pulling out
10	20	1⅛″	38,100	Plate fracturing in direction (1⅜″) of grain. Spot pulling out
11	15	1″	39,000	Slight plate fracture 1″ around edge of spot.
12	15	1 1/16″	39,900	Plate fractured. Spot pulled out
13	15	1″	36,300	Fractured around edge of spot
14	15	1⅛″	43,000	Heavy fracture around edge of spot
15	15	1″	39,300	Slight fracture around edge of spot
16	15	1″	43,900	Slight fracture around edge of spot
17	15	1″	43,700	Heavy fracture around edge of spot. Spot pulling out
18	15	1 1/16″	41,600	Slight fracture around edge of spot
19	15	1″	41,800	Slight fracture around edge of spot
20	15	1¼″	50,200	Heavy fracture around edge of spot. Spot pulling out
21	10	⅞″	33,500	
22	10	13/16″	31,200	
23	10	11/16″	24,300	
24	10	⅞″	34,000	
25	10	13/16″	33,100	
26	10	⅞″	33,900	
27	10	⅞″	33,000	
28	10	15/16″	35,500	
29	10	15/16″	35,400	
30	10	1⅛″	44,900*	Fractured around edge of spot

* Plate bent before spot pulled.
Tests show a torsional strain on samples while in machine.
Average load first ten at twenty seconds, 41,080.
Average load second ten at fifteen seconds, 41,780.
Average load third ten at ten seconds, 34,180.

TABLE XVIII.

LLOYD'S TESTS.

10′—5/8″ S. P. TENSILE TEST.

MARCH 27, 1919.

GLASGOW IRON WORKS, POTTSTOWN, PA.

Pressure at electrodes constant: 18,750 lbs.
Amperes: 31,200. Volts: 440

No. Spot	Time Seconds	Diameter Spot, Inches	Ultimate Load, Lbs.	Remarks
1	25	..	59,500	
2	25	1 3/16″	53,600	
3	25	1 1/4″	53,700	
4	25	1 3/16″	54,700	
5	25	1″	44,900	
6	25	1″	42,100	
7	25	1″	45,800	
8	25	1″	44,100	
9	25	1 1/16″	45,500	
10	25	1″	43,600	
11	20	15/16″	36,900	
12	20	1 1/16	49,200	
13	20	15/16″	38,300	
14	20	1″	34,300	
15	20	1″	33,900	
16	20	1″	33,200	
17	20	1″	41,100	
18	20	15/16″	32,600	
19	20	7/8″	26,700	
20	20	7/8″	26,900	
21	15	15/16″	32,300	
22	15	15/16″	29,900	
23	15	13/16″	24,000	Gas hole in spot
24	15	13/16″	28,700	
25	15	3/4″	21,200	
26	15	3/4″	29,900	
27	15	11/16″	18,000	
28	15	15/16″	33,500	
29	15	7/8″	30,700	Regular spot adjacent to arc-weld tack
30	15	1 3/8″	29,400	

Present at test: Messrs. Aspinall, Frickey (A.I.S.C.), J. B. Stewart, M. I. Eshbock, H. A. Hornor.
The tests show a torsional strain on samples while in machine.
Average load first ten at twenty-five seconds, 48,740.
Average load second ten at twenty seconds, 36,310.
Average load third ten at fifteen seconds, 27,760.

given 20 seconds each, with an average ultimate load of 41,080 pounds, the next ten spots were given 15 seconds each, with an average ultimate load of 41,780 pounds, and the last ten spots were given ten seconds each of an average ultimate load of 34,180 pounds. The first ten spots of the 5/8-inch sample were given 25 seconds each, with an average ultimate load of 48,740 pounds, the next ten spots were given 20 seconds each, with an average ultimate load of 36,310 pounds, and the last ten spots were given 15 seconds each with an average ultimate load of 27,760 pounds.

Table XIX gives the results of pulling tests of a 5-foot sample of 3/4-inch plate spot welded with the duplex machine. All the spots were made in pairs except

TABLE XIX.
TENSILE TEST 3/4" S. P.
APRIL 11, 1919.
GLASGOW IRON WORKS, POTTSTOWN, PA.
Welding done on 6-ft. Duplex Machine

No. Spot	Ultimate Load	Remarks
16	66,700	
17	81,100	Single spot
18	66,800	
19	61,900	Broke plate
20	54,400	
21	72,300	Broke plate
22	61,000	
23	64,100	Broke plate
24	43,300	
25	70,300	
26	47,800	
27	64,500	
28	45,400	
29	61,400	

Average, 61,500.
Sheer 1" rivet, 43,700.
Present at welding: Stewart and Hornor, April 9, 1919.
Present at pulling: Stewart and Eshbock, April 11, 1919.

Number 17, which, as indicated, was made with a single pair of electrodes in 40 seconds. It required eight operations to complete this sample and the spots were made under a pressure at each electrode of approximately 22,500 pounds in the following time intervals: 30 and 28 in fifty seconds; 26 and 24 in fifty-three seconds; 22 and 20 in fifty-five seconds; 18 and 16 in fifty-five seconds; 29 and 27 in fifty-four seconds; 25 and 23 in sixty-five seconds; 21 and 19 in sixty-five seconds. This sample was very bulky, difficult with rigging at hand to hold in the spot welder, and, in addition, the arc-weld tacking repeatedly failed to hold the plates together. For these reasons spot No. 30 being the end spot did not give good results. The other spots upon examination were excellent, and there was no doubt that this performance could be repeated indefinitely with as good or better results. Electrical readings were taken for each of the eight operations; the calculated secondary current averaged 35,520 amperes, the open voltage averaged 481, and the closed voltage averaged 369. The average voltage drop was 112 volts. This was an excessive amount, but all the available materials had been exhausted for reducing this drop which initially was over 150 volts. The results under this limitation proved that the apparatus when supplied with the correct voltage and current would more than meet the specified requirements. Also that the element of time in making the spots under given conditions is a relative question involving other elements than the electrical characteristics and appertain to shop-production methods.

The results of the final tests made are given in Table XX and show the tensile strength of two and three spots in a row. Samples were made up of ½-inch steel plate and spot welded in the same manner as the other samples. After spot welding they were cut in strips and pulled for ultimate tensile. The entire series is not shown. The purpose of this test was to investigate and compare the lapping of the plates as in a single-, double-, treble-, and quadruple-riveted joint. The single-spot samples were lapped 3 inches and the results were similar to those already given. The double-spot sample was lapped 6 inches with results as shown in Table XX. The treble-spot sample was lapped 9 inches

TABLE XX.
TENSILE TEST.
APRIL 10 AND 11, 1919.
GLASGOW IRON WORKS, POTTSTOWN, PA.
2 SPOTS IN ½″ S. P.

No. Spot	Ultimate Load	Remarks
1	85,800	Pulled April 10, 1919
2	66,200	Pulled April 10, 1919
3	77,700	Pulled April 11, 1919
4	74,100	Pulled April 11, 1919
5	85,100	Pulled April 11, 1919
6	83,400	Pulled April 10, 1919

TENSILE TEST.
3 SPOTS IN ½″ S. P.

No. Spot	Ultimate Load	Remarks
1	115,800	Pulled April 10, 1919
2	92,200	Pulled April 10, 1919
3	89,900	Pulled April 11, 1919
4	85,200	Pulled April 11, 1919
5	97,000	Pulled April 11, 1919
6	124,500	Pulled April 10, 1919 Limit of testing machine (sample not affected)

Present at welding: Stewart and Hornor.
Present at pulling April 10, 1919: Messrs. Higgins, Stewart, Eshbock, Hornor, Smith, Ker.
Present at pulling April 11, 1919: Eshbock and Stewart.

with results as given in the same table. The quadruple-spot sample was lapped 12 inches. This is the standard "lapping" in each case for a ship's riveted joints. The quadruple-spot sample either exceeded the pulling capacity of the testing machine, so that no results were possible, or the original plate material would break some distance from the welded joint, usually about 4 to 6 inches from the last spot. These investigations lead to the conclusion that much material can be saved in steel ship construction when designs are based on the spot-welding method.

What do these results mean in a broad view of the joining of heavy steel members? The answer is clear. Those who are familiar with ship designs know the conservative requirements placed upon the strength of joints and strength of materials for the vital parts of the hull structure. It would seem logical that any method of joining that would meet or exceed the specifications of Lloyd's Register could be employed in other applications. Compare Lloyd's Requirements with the results given above. For thicknesses of steel plate 0.22 and under, ½-inch steel rivets are required; for thicknesses of 0.22 and not exceeding 0.34, ⅝-inch rivets; for thicknesses of 0.34 and not exceeding 0.48, ¾-inch rivets; for thicknesses of 0.48 and not exceeding 0.66, ⅞-inch rivets; for thicknesses of 0.66 to 0.88, 1-inch rivets. The single-shearing stress of rivets of the sizes mentioned are:

½ inch steel rivet	12,250 pounds
⅝ inch steel rivet	18,300 pounds
¾ inch steel rivet	25,600 pounds
⅞ inch steel rivet	34,100 pounds
1 inch steel rivet	43,700 pounds

According to these rules, ½-inch rivets would be required for ¼-inch steel plates. Referring to Table XV it will be noted that the average ultimate tensile of the spots made was approximately 17,000 pounds. For ⅜-inch steel plates ⅝-inch rivets are required. Table XVI shows an average ultimate tensile of 31,760 pounds for a spot in ⅜-inch steel plate. For ½-inch steel plates ¾-inch rivets are required. Table XVII gives an average ultimate tensile of 39,010 pounds for a spot in ½-inch steel plate. For ⅝-inch steel plates ⅞-inch rivets are required. Table XVIII gives an average ultimate tensile of 37,603 pounds for a spot in ⅝-inch steel plate. These averages are over the whole test, including the short and medium time given two-thirds of the spots. The averages would be excessive as compared to the single shear of the appropriate rivet if only the best spot welds were taken. For ¾-inch steel plates 1-inch rivets are required. Table XIX gives an average ultimate of 61,500 pounds for a spot in ¾-inch steel plate. If this data were composed of isolated tests then questions might be raised as to the process, but these tabulations are repetitions with no special considerations other than that of assuring uniformity.

Take the average of spots in Table XX, representing double shear: in the case of steel rivets a double shear is not twice the single shear, but for argument agree that it is. This would mean that the shearing stress of two ¾-inch steel rivets was 51,200 pounds. The average of two spots in ½-inch steel plate is a little more than double the single spots, 78,683 pounds. The tensile strength of two spots in ½-inch steel plate is more than the tensile strength of three ¾-inch rivets based on multiplying the single shear of a ¾-inch rivet by 3. It is not known whether the shear of three ¾-inch rivets has ever been definitely established, but comparative tests made during this demonstration would lead to the opinion that the ultimate tensile would be much less. It seems unnecessary to note in the same table that the average ultimate tensile of three spots in ½-inch steel plate was 100,433, although the last set of spots (No. 6) was not pulled to its ultimate.

An interesting set of tests with three and four thicknesses of various size plates was contemplated when the demonstration was brought to a close. It is reasonable to assume that if the rated voltage had been supplied to the duplex spot welder, this machine would have welded three and four thicknesses of ⅝-inch plate. Undoubtedly the same uniformity of spot welding would have followed the results as shown. It is needless to speculate on what this apparatus could do, it is sufficient to record here its performance.

One of the best practical results was the discovery of a fairly simple and non-destructive method of inspecting spot-welded work after completion. During the tests it was suggested that this might be accomplished by punching a hole, or holes, on the line of demarkation of the spot weld. A number of experiments was made which gave confidence in the method. In finished work these test samples could be taken of a reasonable number of spots and with sufficient variation to assure that the work was uniform and well done. To further emphasize this method of inspection the ship's floors previously mentioned were sent to the shipyard and a request made for an inspection of this nature of independent parties.

It was known by those who had followed the work of spot welding that there were good, bad, and indifferent spot welds made, and the intention was to observe how closely this method of inspection could be relied upon. The results more than exceeded expectation. The punchings showed all degrees of welds. The finished article is not greatly injured by this method as the punched hole can be refilled by either spot welding a stud, refilling by means of the metallic electrode, or by riveting.

General Comment.—There are two primary and serious considerations to be given the process of heavy spot welding. They are briefly, electrode-tip protection and the preparation of materials to be welded. These two points are closely interlocked and greatly circumscribed by our lack of proper metals or knowledge of known metals. There are two secondary considerations which may be easily improved upon and which may be stated briefly: (1) The separation of the electrodes, and (2) the shape of the head of the spot welder. These secondary matters are mixed with questions of the applicability to shipbuilding and shop-production methods.

Fig. 22 illustrates roughly the type of electrode-tip protection used on the 12-inch welder with which the early tests, including the ship's floors, were made. It consisted of a strip of soft copper which covered and conformed to the top of the electrode. When this strip was worn down it could be renewed by slipping out the steel through-bolt. The difficulties that were met with in practice were the "freezing" of the copper strip to the electrode, thus requiring it to be chiseled off, and the deformation of the electrode itself when under severe working strains as well as a result of the method of breaking away the strip from it. This latter necessitated either the removal of the electrode and the machining of same or the filing or truing of the electrode tip before replacing the copper strip. This design was modified and much improved upon for the 27-inch and the duplex machines. A steel collar was fitted to the electrode by a

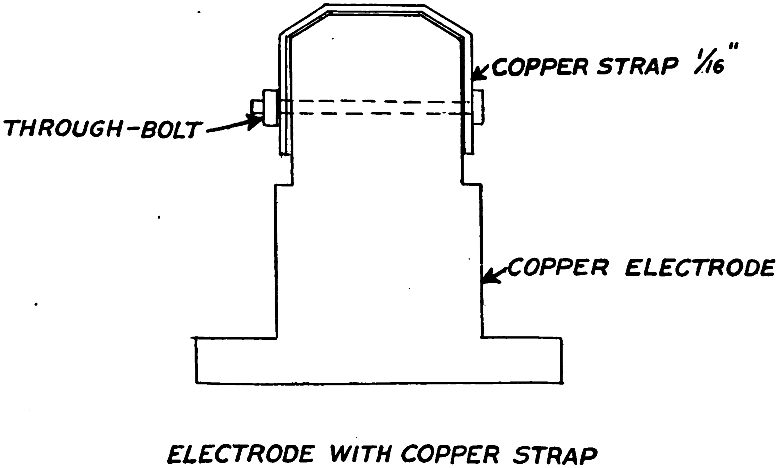


FIG. 22.—Electrode with copper strap.

coarse thread and was removable by means of a spanner wrench. This steel collar securely held separable tips in close contact. As these tips were pyramidal in form the crushing pressure deformed the tip, but did not affect the electrode proper. The tips may be re-machined, and as they go through an annealing process in the act of spot welding they should do duty several times before final scrapping. Their cost is insignificant as compared to the electrode cost or the work which they are instrumental in performing. It was found essential in the uniformity tests of the heavy materials to replace these tips quite frequently, and if this is found necessary in regular production work it raises a serious problem as to the quick action of the process. Further developments will be needed to solve this problem, although suggestions having in view automatic attachments for renovating the tips have been made.

Naturally a great reduction in the number of tip renewals is accomplished by the proper preparation of the surfaces of the materials coming in contact with them. The tests at Pottstown proved this and justified the opinion of the designer of these machines. The subject raises a large question. The suggestion in practical steel shops of cleaning the surfaces of steel plates and shapes brings down upon the spot-welding process a cloud-burst of opposition. Three methods for cleaning steel have been brought forward, but none are looked upon as solving the difficulty. By pickling, that is, dipping the steel in acid, the mill scale and rust may be removed. The surfaces may be cleaned by sand-blast, or they may be prepared as in these tests by the use of a portable air grinder. The first proposal necessitates a large installation expense and causes delay. The second is a dangerous operation to perform on a large scale in an open shop, as the flying sand or dust particles enter the small parts of adjacent machinery as well as affect neighboring workmen. The last proposal is feasible, could be done while other material is going through the spot-welding process and would not be excessive in cost. The opponents of the spot-welding process cannot but believe that this is an awkward makeshift. There is a probable solution in a suggestion made to equip the spot-welding machine with an automatic grinder under the control of the operator. This method would permit the operator to be the judge as to the fitness of the material and give him the option of saving time either by cleaning the materials or by more frequent renewals of the electrode tips. Besides this utilitarian advantage of clean steel for welding there is a humanitarian reason. When there is an accumulation of rust or mill scale next to the electrodes a higher resistance is provided at the point of contact. The desired place for this high resistance is between the plates being welded. Accompanying the high resistance at the electrodes the instantaneous production of intense heat causes the slag to be thrown out with great violence. This condition is dangerous for the operator, not only for his eyes, which may in time be affected by the radiant energy, but also to his body into which may enter the fine slivers of molten slag.

Though secondary because they appertain to mechanical features, yet important in that they are necessary, the distance between the electrode tips in machines designed for all-around work should be readily adjustable. In the apparatus just described this distance was fixed and provision was made to fit the electrodes so that they could be removed from their holders, thus allowing for the placement of the machine over obstructions, and the replacement of the electrodes when the work and machines were properly set. Undoubtedly such an arrangement would be awkward in any steel fabricating shop. Time is an essential element in all production work. The correction of this mechanical difficulty in new designs is too simple not to be insisted upon. The shape of the head, or more descriptively the nose, of the machine should be such as to permit the electrodes to function in very close quarters. The attachment of angles to plates, angles to angles, two angles on opposite sides of the same plate, are common connections in steel construction. It is particularly necessary for this application that the electrodes be quickly adjustable and that they be easy to manipulate in corners and along bounding angles. Although the electrodes of the 12-inch welder had to be changed in order to bring them in the proper position for welding the boundary angles of the ship's floors, it proved what was one of the greatest previous objections to the process, namely, that a good caulking edge could be left on the angle after spot welding. As a matter of fact, a good weld cannot be made on edges without danger to the operator due to the throwing of melted slag. This mechanical difficulty can be overcome in as simple a manner as the adjustability of the electrodes, and should be called for in new designs of apparatus.

CHAPTER V

General Applications of Arc Welding

Those who began an investigation into the application of arc welding in 1917–18 were naturally surprised at the wide use of the process in repair work and certain manufactures. Indeed, for both land and marine repairs the success of many of the applications had warranted its approval by conservative inspection bureaus and frequently insisted upon by the owners in preference to older and more tried methods. It was for this reason that the United States Navy Department adopted the process for the quick repairs made to the damaged machinery of the interned German ships, and the success accruing from this work lent impetus to the proposals for its extension to shop construction. Although these applications [1] are now fairly well known and recently have received a greater publicity, it may be well to briefly review them.

Repair Work.—There are three interesting points connected with this subject: (1) Ease of application, (2) the vital nature of the repairs, and (3) the cost. The first and third items caused the introduction of the process, the second item was the effect of its continued success. Engineers associated with business men will readily put into effect an innovation that carries with it the dual saving of time and money without involving great danger, but a similar group will refuse to establish as a regular industrial practice a method that will hazard

[1] "Electric Arc Welding," Lincoln Electric Company, Cleveland, Ohio.

the lives of those who as a general rule are innocent of the means employed.

The majority of repairs are usually required for component parts of large pieces of machinery. The older methods of repair made it necessary to disassemble the machinery to obtain either the broken or worn part, or to expose it for access. In turn, indirect expense was caused not only by the damage done by the taking apart of the machine, but also by the reassembling of those parts which were in no sense injured. This indirect charge has been the most frequent factor of dispute in the comparison of costs, not only in the case of arc-welding applications, but in many other lines of engineering. It is not an uncommon occurrence to discover that the work of demolition has cost as much as, or more, than the cost of the new construction. No wonder, then, that the electric arc, which is easily brought to the work and there produces a localized welding temperature, was eagerly accepted. In the metallic-arc process the actual tools required for the operator are a screen, a wire brush, a hammer and chisel, and the electrode holder with its flexible lead. A bundle of electrodes near at hand complete the outfit needed at the work. Back of these local tools provision must be made for the proper electrical conditions. In American practice this takes the form of a motor generator for direct current and a transformer for alternating current. This machinery end of the tool for a single operator is not so large nor heavy that it cannot be made semi-portable and thus provide flexibility.

In very large installations the machinery end of the arc-welding tool may be of a size to supply many welders, in which case the equipment may be made stationary and the electrical circuit distributed to plug boards for the individual operators. So in any desired manner the tool may be brought easily to the work and the broken or used parts of the complicated machinery may be repaired rapidly and safely in place.

Many of the large railroad systems of this country have employed arc welding in the vital repairs to locomotives, which is being extended rapidly to freight and passenger cars. This means that millions of people are being carried across country often at high speed, around curves, and up and down grades with the strains and stresses of such work resisted by a jointure carefully made by the electric arc. The boilers and stern posts of ocean-going vessels are repaired by the same method. In addition to this, street railways are employing the process for the maintenance of tracks and cars, and machine-shops for the repair of machine tools. If these instances were chance experiments there would be cause for questioning the further use of this process, but what is referred to here is now established practice and has been an accepted method for many years. In the case of locomotive-boiler repairs the records indicate that electric-arc repairs exceed the allowed use of the original boiler material.

As to the cost of arc-welding repairs and a comparison with the older methods, the preceding remarks give an indication which is quite true, namely, that they are very much less. In round figures it is roughly estimated to save between 50 and 60 per cent. The Chicago, Rock Island and Pacific Railroad kept excellent detail accounts when introducing electric welding.[2]

[2] "Railway Electrical Engineer," E. Wanamaker, 1918.

As an illustration, it cost this railroad by the old method to repair wheel spokes $1276.80, and by electric welding $35.08, a saving of $1241.72; for repair cracks in tanks by the old method $372.69, by the electric arc $36.16, a saving of $337.53; for filling worn spots by the old method $2677.80, by the electric arc $329.60, a saving of $2348.20. These are a few items of a large list. In a summary for the year it is shown that the cost by other methods would have amounted to $171,279 as against arc welding $24,912.36, a saving for the year of $146,366.64. There may be, and probably are, other as significant figures, but these alone are considered proof enough not only of the cost but of the other two factors which are just as important, the ease of the application and the seriousness of the work performed.

Examples.—The following applications of arc welding for repairs may give an idea of the extended use of the process. In steel foundries it is found difficult to avoid sand spots, blow holes, and shrinkage cracks in the finished steel castings. It is an expensive process and not only would cause a higher cost if defective work were scrapped and recast, but also would involve a delay. Such defects are readily and satisfactorily repaired with the electric arc, either carbon or metallic. By means of the carbon arc utilized for pre-heating, it is also possible to employ the process for the same conditions in the manufacture of grey iron and malleable castings. Reference has already been made to railroad-shop repairs where established use is made of this process for the repair of engine side rods, brake fulcrum, eccentric crank, side frames, flues of boilers, fire box, mud ring, engine cross head, bumper beams, brake-shoe heads, piston cross heads, motion frames, yokes and spokes of wheels, building-up flanges on wheels, etc. A list three or four times this size could be cited. Marine repairs are usually those connected with the boilers, the rudder post and in some exceptional cases to small portions of the hull plating. In street-railway work much work is done in building up the rails and worn parts of cross-overs. Worn down armature shafts, side frames of trucks, and gear cases are also repaired by this process. In forge shops the metallic arc is being used not for improving the strength of the forging, but to give it a good appearance. Small defects are apt to result from the forging operation, especially in forgings for automobiles. These can be neatly corrected by this process. In the large or small machine-shop the large machine tools as well as the small hand tools may be quickly put back in service and often result in a much longer effective life when skillfully arc welded. Bolt holes become worn, shafting in motors (particularly alternating-current motors of the induction type with small air gap) wear down in the bearings to the point of injury to the armature windings, bearing surfaces on slides and cams wear away in the same manner. These and many more cases are conveniently corrected by building up the surfaces with the metallic arc and then turning the pieces in a lathe to the original dimension. " Steel mills have found it economical to install arc welders for the purpose of repairing wobblers in the rolling mill. Work is also being done successfully in the working surfaces of the roll."

Manufacturing.—Three characteristics of this process brought it to the attention of manufacturers: (1) Its secrecy, (2) its adaptability, and (3) its low cost.

As the rivet was for many years the best-known method of joining metals either very thin or of moderate thickness where a medium-strength joint was required, this became the established practice. As commercial competition grew the manufacturer sought means to reduce his costs so that his selling price would reward him with the contract. More than this, he desired that this be brought about through some process that for a time would remain hidden to his competitors. The electric arc allowed this because the manufacturer could develop all the apparatus and tools in his own shop and design them for his own special production. It was not necessary for him to divulge his needs to the makers of electrical machinery nor the builders of standard arc-welding apparatus. In this manner his special method of manufacture was concealed and his secret safeguarded. Manufacturers of arc-welding apparatus will admit that of these applications they have little knowledge.

More than this, the manufacturer found that the electric-arc process was adaptable. Whatever his methods had been the first cost of the apparatus was of no concern in the benefits both of reduced costs and the elimination of competition. Besides this, the arc-welding tool, like any new tool, gave promise of greater possibilities. It could be safely handled for repetition work by ordinary operators, and the future promised some form of automatic machine. Other methods such as gas welding were tried and found both expensive and dangerous. By experimentation with different compositions of electrodes, by varying the electric current, by the use of coating on the electrodes, and by suitable selection of electrode size for different thicknesses and kinds of material, the manufacturer had a tool which needed only ingenuity to uphold his production on a paying basis.

The savings in cost of this application are impossible to obtain. The characteristic mentioned above precludes anything more than assumption. The fact that this process is employed must be the best evidence that it is the cheapest process now available. To those acquainted with the riveting process there is no question that adding the cost of drawing to the finished product there is no competition with electric-welding processes. In the case of gas welding it is to be remembered that the arc can weld where the gas flame cannot, and *vice versa.* This last expression should probably be restricted to welding only, as it is possible to cut steel with either the carbon or metallic arc. From this it will be seen that to compare gas welding with arc welding it is requisite that the work be common to the two processes. When this is done the consensus of opinion is that the electric arc is cheaper. Direct comparison of costs between oxy-acetylene and metallic arc welding have been made, but such costs are not of great value in that the conditions are changing. After all, in general manufacturing other elements often take precedence in the introduction of a new process, not solely because they have the elements of money saving so much as money making.

Examples.—The electric arc is much used in general boiler shops. Here are built tanks, vats, tumbling barrels, wagon tanks, oil stills, and several more specialties of a similar kind. Other shops have used the arc for manufacturing gear cases, automobile frames, street-car entrances, garage heaters, steel bed plates for supporting machinery, and a long list of minor parts of apparatus for oil and sugar-making machinery. The construction of transformer tanks with the arc has for many years superseded other methods and the combination of hand and automatic arc welding constitutes an advance over all other methods tried. This method was found superior because of its reliability in service and its economy in production.[3]

[3] "Electric Arc Welding in Tank Construction," R. E. Wagner, *General Electric Review*, December, 1918.

CHAPTER VI

Discussions on Arc Welding

Aroused by the interest in the rapid extension of arc welding in the industries as well as impelled by patriotic feelings, a group of men gathered to discuss the fundamentals of the art. Although this group was engaged in widely-separated occupations and was sincere in wishing to coöperate for such a good purpose, it was discerned that the differences of opinion generally ran in parallel lines, indicating that great latitude was permitted for volitional selection. Under such conditions group action of a determining character was not to be expected. It was not an established body. That is to say, each meeting constituted itself into a new meeting to discuss the different phases of some subject and, although a few members were in regular attendance, new members were admitted, which reacted not only to reopen previous discussions, but also to stay the pursuit of investigation by new suggestions. This explanation is made so that proper values may be placed upon the following outline of discussions which took place in 1918.

Extension to Thick Steel Plates.—Doubt existed in the minds of conservative experts whether uniform results could be expected in the welding of ½-inch steel plates of the composition used in shipbuilding in this country. Certain members of the group reported that compositions of steel had been experimented with and they had found it practically impossible to successfully weld. Other more radical supporters of the process made light of this with the remark " that you can electrically weld anything." The need was clear for a determination of the fact that ship's steel of a thickness of ½ inch could be successfully welded. With this fundamental question was coördinated the query whether firms, who performed welding, could turn out equal results despite the different methods pursued. A sub-committee was appointed to follow the practical details which consisted in obtaining ship's steel plates ½ inch thick, have them prepared for arc welding (double V, butt joint), and make observations of the welding. These firms were given entire freedom in the methods, materials, operators, electrodes, current, etc. In some cases two samples were made, one with a reinforced weld and the other with the reinforcement machined down. This collection of samples was sent to the Bureau of Standards for physical test—tensile, torsion, vibration, and bending. The results confirmed the opinion that successful welds could be made in this material. Many of the samples exceeded the yield point of the original material as well as ultimate strength. In a number of cases the elongation in two inches expressed in per cent. approached fifty per cent. of the original material, and one test piece was made with alternating current at 25 cycles bent in the weld to an angle of 78 degrees. The reinforced welds all showed a higher ultimate tensile than the machined-down test pieces. The yield point in pounds per square inch of the original plate was 38,400. Some of the reinforced samples gave yield points of 42,460, 40,280, 40,480, 42,200, 39,000, 46,440, and 44,700 pounds. Five machined-down samples showed a yield point of 39,000, 39,000, 38,400, 42,400, and 41,800 pounds. The original plate tested to an ultimate tensile of 64,700 pounds per square inch. Reinforced welds showed results as follows: 65,470, 65,400, 66,480, 66,400. None of the machined samples equalled nor exceeded the ultimate tensile of the original plate, but three samples reached 62,600, 62,800, 62,700. These tests

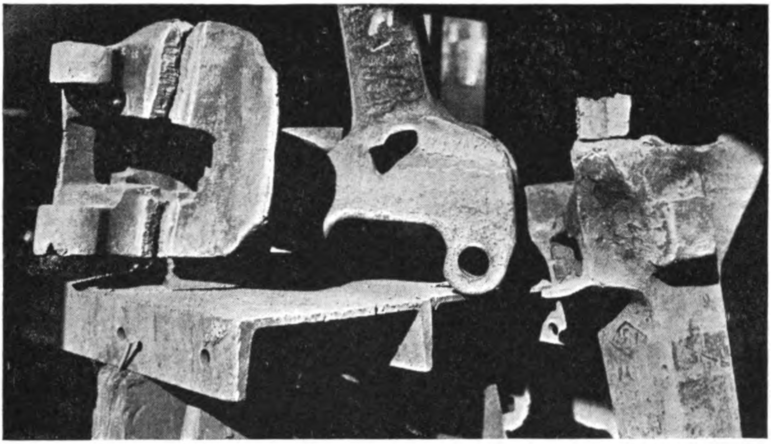


FIG. 23.—Car coupler used in railway work before arc welding.

were looked upon as practical, formed the base line for further argument, and suggestions were made both for improvement in testing and for extension of results. The outcome was the preparation of a more elaborate program of tests with like materials, but with more uniform welding conditions and the elimination of some of the many variables. It had been difficult to carry out the foregoing tests without delay. The more elaborate tests were by their nature subject to greater postponement, and as a consequence were halted before their entire completion. Broadly viewed it is questionable whether such investigations are of great value in that the arc-welding operator is a serious link in the chain. All the tests of manual welding made by others would prove little to the man who wished to use the process.

Composition of Electrode.—The material used for electrode wire had long been the subject of investigation by users of this process. Not only chemical analyses of the electrode wire but also similar analyses of the deposited metal in the weld were made. Side by side with the chemical inquiry ran the metallurgical. It was true that certain alloyed steels gave better results with certain compositions of steel plate. In fact, it was suggested that for the best interests of shipbuilding a different composition of steel might be required on the basis of its weldability. This suggestion would be difficult in view of the commercial conditions which likewise dictated the composition of the electrode materials. Doubtless an increased demand for electrode wire for special applications might ease the situation, but under the conditions the user must accept what was on the market. That certain desirable results in welding could not be attained with the electrode composition as furnished is true, and one manufacturer was unable during this period to duplicate results made elsewhere. There resulted from this discussion a practical specification for electrode wire. This instrument was issued as a guide to shipbuilders who wished to purchase such material. The chemical composition was such as to include all of the manufacturers, and the test requirements were made to invite the manufacturers' attention to the need of a demonstration of his product before the completion of the sale. The chemical composition is as follows:

Carbon	Not over 0.18
Manganese	Not over 0.55
Phosphorus	Not over .05
Sulphur	Not over .05
Silicon	Not over .08

Design of Weld.—This was the subject of special debate because of its bearing upon the design of an all-welded ship. The type of joint, the design of weld, the position of weld, kind and type of weld, all required investigation before the naval architect could make drawings for the ship. Early in the proceedings the strap joint was considered to be 100 per cent. efficient and remained so until word was received from England that the butt joint was better. The strap joint was then questioned as to the order in which the three seams of welding should be performed which led the discussions into metallurgical theories. Not quite the same fate was reserved for the angle of bevel. This was a subject upon which many differed. Evidently no practical action was taken to settle this argument, so finally it was left to the choice of the designer. As the amount of deposited metal from the electrode is relative to the size of the bevel, and as the goodness of the weld depends on the ease given the operator to fuse the original metal with the deposited metal, the biting-in effect, this point bears no small ratio to the final results. In the use of covered electrodes practice might permit a different angle of bevel or with special electrode, where the cost was excessive, a reduction of the needed deposit of electrode wire would greatly affect the final cost.

Associated with this question was the number of layers of deposited metal. Though the generally accepted position was that for ½-inch steel plates, one layer was not the proper method for securing the best tensile strength of weld, yet the tests showed welds made in one run which gave results as high as 62,600 pounds

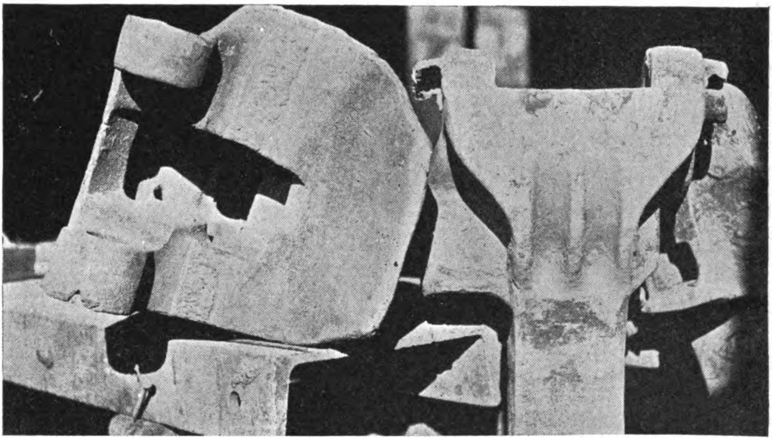


FIG. 24.—Car coupler used in railway work after arc welding with coated electrode.

per square inch ultimate tensile. There were very few welds made in two layers which exceeded this figure. This was an important point, because it directly affected the speed of welding, one of the main factors of its economy. Before a second layer of deposited metal can be run in, it is necessary to clean thoroughly the top surface of the first layer. If much slag has been brought up to the top of the weld, which must be done by the welder, it requires a chisel and hammer to fully clean this surface. In the case of slag-producing electrodes, this deposit must also be scrupulously removed before beginning the second run of metal. It is claimed, and the claim has elements of justification, that the second layer in its act of deposition partly anneals the first layer; but curiously it is found, except with special processes, that annealing does not greatly improve the qualities of the weld. If there is no virtue in adding layer upon layer of deposited metal, and if one layer will produce a reliable and satisfactory weld, time and labor would be wasted. This question has been left to the designer.

In a like category were the discussions on the positions of the weld, *i.e.,* flat, horizontal, vertical, and overhead. The extremists held that overhead welding should be done only by specially trained men. More than this, that the ordinary man should not be trained to do overhead welding. The intention of the extremists was that in order to train operatives quickly it was a waste of time to expect them with a brief training to make successful welds in the overhead position. Experience in the training schools for welders showed advantages for overhead welding as a method of practice in that the student was more confident in all the other positions after having mastered the difficult overhead conditions. At the other extreme were those who, having experience with handling the electrode, asserted that the position was not as distressing to the operator nor as detrimental to a good weld as generally considered. The other positions, though not receiving the same prominence in the argument, were not as easy for the operator as supposed. The flat position is the most comfortable and convenient, although welders may be found who prefer the vertical position. The horizontal position is most awkward and in difficult places requires the operator to be ambidextrous.

From the tests above cited attention was called to the difference in ultimate tensile strength in the reinforced weld and one that had been machined. No comparisons were made with a flush weld, *i.e.*, one made flush by the operator. The tests show quite convincingly the opinion held that the reinforcement of the weld added strength to the joint. With this point established it is

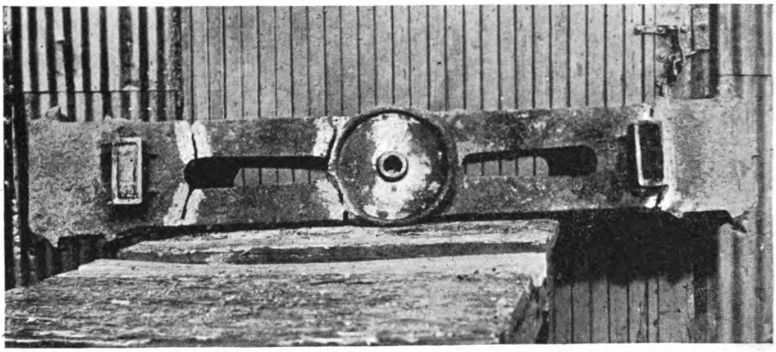


FIG. 25.—Bolster used in railway work before arc welding.

necessary to go one step farther and determine the amount of reinforcement requisite for a certain strength of joint or for a particular application. In this case the particular application was shipbuilding, and some limit either maximum or minimum of reinforcement was essential. In this as in the case of the angle of bevel, the question is of importance in that it means consumption of the electrode and the time of making the weld.

Covered Versus Bare Electrodes.—The bare-metal electrode process was introduced about 1895 by a Russian named Slavianoff. The covered-electrode process bears the trade name of Quasi-Arc and is the invention of Mr. Arthur Strohmenger, of London. Both systems have been already described. The Slavianoff system has been used in this country for many years and it is stated by one authority " that he is not aware of any user " in England.[1] The Quasi-Arc, or covered-electrode system, was only recently introduced to American practice. It was natural that those who were familiar with the working capabilities of the bare electrode should insist upon its equal performance to the covered electrode. When a physical test of a covered-electrode weld showed superior qualities, naturally advocates of bare-electrode systems hastened to exhibit welds that would equal or surpass the new competitor. To the full appreciation of the discussion must be brought the commercial attitude because this affects directly one of the principal technical points. The customary practice for direct current was to provide a " striking voltage " of 60 to 75 volts. Upon this practice, standard apparatus in this country was designed and built. This " striking voltage " corresponds approximately to an arc voltage ranging from 15 to 25 volts. The covered electrodes required a " striking voltage " of at least 100 volts, and preferably a little over, giving an approximate arc voltage of 35. Very few manufacturers of arc-welding apparatus allowed for any possible adjustment of the voltage of the welding generator. This condition reacted severely on the rapid introduction of the covered electrode. Despite this condition test results both from England and in this country indicated very clearly that for alternat-

[1] " Electric Welding," Thomas T. Heaton, *The Journal of the Inst. of Mechanical Engineers*, London, February, 1919.

ing stresses and ductility there was a superiority in the use of a covered electrode. The experiments of British Lloyd's in electric welding were all made with this type of electrode, and the process was approved by this classification society. The characteristics of resistance to shock, a reasonable ability to withstand fatigue, an increased bending angle are important considerations in the applicability of a welding process to ship construction. The claims for the covered electrode were based on the fact that the covering provided a slag which protected both the electrode and the deposited metal from oxidation. The result was that in the hands of a skilled operator there was less porosity and a more ductile weld, retaining at the same time good tensile strength.

The reported results soon turned the attention of investigators to the advantage of some form of protection to the electrode. Experiments easily performed showed that electrode wire that was not smooth running or would not produce good welds, if heat treated, dipped in acid or alkaline solution, would become better or worse, depending upon the methods used. These trials were in line with Kjellberg's invention which provided an electrode coated with a fusible silica. This coating formed a flux which was converted into a gas by the heat of the arc and therefore left no slag as is the case with the Quasi-Arc covered electrode. Coating of the electrode now came into style and the results of tested welds above referred to showed one sample in which half the electrode was coated with a special solution giving unusual bending characteristics. The covered-electrode sample, though not giving results as high as this particular sample, were next to it and exceeded all the others. The decision of British Lloyd's in approving this process of covered electrodes, although it threw great weight in its favor, has not caused the adherents of the bare-metal electrode to relinquish their position.

Although it may be possible to successfully weld mild steel for ordinary purposes with the bare-steel electrode and thus avoid the expense of covered electrode, where toughness is a desirable or necessary characteristic of the weld, or for the welding of steel alloys, a special coat-

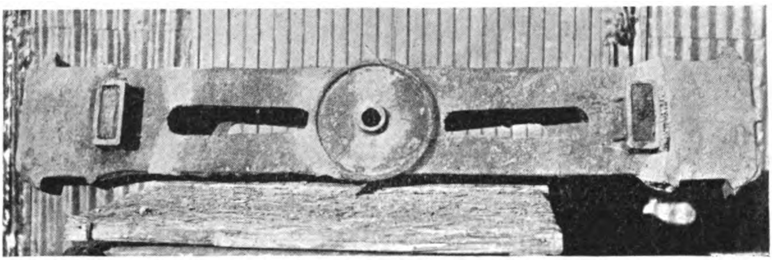


FIG. 26.—Bolster used in railway work after arc welding with coated electrode.

ing will give better and in many cases the only successful results. One of the foremost electric-welding engineers in this country has lately experimented with and has now achieved much success with coated electrodes. He states: " Regarding the chrome steel would advise that we have received and successfully welded with chrome steel, nickel, vanadium, manganese, and carbon. Have also welded with bronze when using our electrode coating. We have received patents on this process but have not as yet placed any coated electrodes on the market, largely due to the fact that it was difficult to obtain alloy electrodes during the war (Fig. 26).

"Recently we ran some tests on four bare mild steel electrodes, each made by a different manufacturer. When used bare it is impossible to secure the weld, but with our coating the weld is very successful. Outside of the possibility of using alloyed steel, and all results attendant with the use of same, our chief aim has been to make a weld in which the added metal would be comparatively free from oxidation. This would give us a weld possessing much greater toughness than that possessed by the bare-steel electrodes. It is needless to say that this toughness imparts a quality very much to be desired, and has a very important bearing on the success of electric welds to withstand fatigue." [2]

Direct Current Versus Alternating Current.—Apart from the fact that many engineers believed that arc welds could not be made with alternating current, their arguments attacked the application of alternating current from three sides: (1) Its newness, (2) its wasted energy, (3) its difficulty of operation. Direct current had long held the field and hence the apparatus and tools were familiar to both engineers and operators. The design of transformer, unlike power transformers, required a large leakage reactance in order to stabilize the arc. Due to the character of alternating current it was impossible to weld without holding a short arc. This is a requisite for successful welds with direct current, but in this latter case the apparatus gave a certain tolerance to the operator, whereas with alternating current the arc position was dependent and must be held by the operator. This required more practice, greater skill, and more fatigue

[2] Communicated to the Author by Mr. E. Wanamaker, E. E., Chicago, Rock Island & Pacific Railway, September, 1919.

for the operator. If the operator repeatedly lost his arc, the weld would be porous and filled with blow holes, and the opponents of alternating-current welding claimed that by the nature of things this would be true.

Of this latter point the advocates of alternating-current welding made much. They insisted that with it you could only weld and never " not weld," as in the case of direct current. They held that the process showed distinctly a " biting-in " effect, *i.e.,* better fusion of the original metal with the deposited metal. As to the operator, it was not a difficult matter to train those who handled the direct-current arc and that a number of old operators claimed a preference for alternating current. As to the second point of the argument, they believed that upon development the low-power factor, or poor efficiency, would be greatly improved and in some instances claimed that the power factor was not so low as to put the process out of the running as compared with other systems. To this end they made tests to prove that good welds could be made with any frequency and at the lower frequencies the power factor would be better. In answer to point three, while admitting the " newness," they claimed equality as far as the application to new construction work was concerned, and then endeavored to show the advantages from the standpoint of economy in first cost, continuous operation, and upkeep. As it was only necessary to have a transformer connected to the electrical-supply leads this obviated the necessity for rotating machinery and gave the apparatus a more practical portability.

As in the case of the other discussions these interesting points were never clearly determined. No comparative data is at hand to indicate whether direct-current welding is faster or slower than alternating current; whether this practical advantage is benefited in either case by flux-covered or coated electrodes; whether it is more difficult, or impossible, for the ordinary operator to weld in all positions, including overhead, in the one system than the other; whether the practical losses in motor generator and resistance in the direct-current system, other things being equal, compares favorably or unfavorably with the alternating-current system and whether there are physical obstructions to the training of operators that would make the alternating-current system improbable of industrial acceptance without assurance that the system gave promise of being capable of improvements which would overcome such impediments. Individual investigators may have settled all of these questions to their own satisfaction, but the general practitioner looks in vain for independent authority. Many more claims than are cited here are made by both parties to this controversy, but they lead into the field of theories.

Testing of Welds.—Perhaps no subject received as much consideration both by suggestion and experimentation than the discovery of some practical method of testing a welded joint. Though the question was emphasized by practical men who wished a practical method, all the exertions were toward theoretical or laboratory methods. Exhaustive tests were made with delicate apparatus upon samples containing purposely poor and good welding and by maintaining certain characteristics constant. Methods were suggested, such as measuring the magnetic permeability, the change in hysteresis, drop in voltage, resistance, X-ray photographs, etc. The practical methods were by hammering the welds or chipping out small portions for examination or by wetting a cleaned portion with kerosene. This latter test, due to the penetrating qualities of kerosene, would indicate porosity. The theoretical desire was to determine positively the physical characteristics of the weld: the practical desire was to convince or assure those who inspected the work that the weld was sound. A little more was needed. The men who serve as inspectors are responsible to those above them in authority, and it is necessary that a practical method be established so that individual responsibility, or opinion as to workmanship, is not relied upon for serious applications. No practical method of testing long seams, such as those that would be encountered in ship construction, have as far as is known been devised. To fill all the compartments of a merchant vessel for the purpose of testing joints would be out of the question, although for bulk-oil vessels this is now done. The only practical suggestion advanced is that the inspectors should be trained just as they were trained to inspect riveting work. If a man knows how to hold an electrode and can make a sound weld, no other man could deceive him either as to his ability as a welder, or the quality of work that he was performing. Much can be said of the comparative merits of the practical methods of testing rivets. But it is not necessary to extend the argument because there will be a method forthcoming as soon as electric welding is established practice.

Current and Electrode.—Although the manufacturers of apparatus give tables showing the current and electrode diameter for varying thicknesses of mild steel, they accompany such information with words of precaution to the operator that such figures are only approximations. The electrode size is related to the amount of current and the class of work. The amount of current is not necessarily relative to the thickness of the plate, although this is a good practical guide for mild-steel plates under ¾ inch. The design of joint has some bearing upon the current requirements, as, for example, the lap-joint, which undoubtedly will be better made with a greatly increased current over that necessary for the simple double-bevel butt-joints.

In the tests of sample welds it was noticed that some of the best results were secured with increased current, and this observation aroused much interest. Investigations by individuals showed that increased current, through a range of 80 to 275 amperes with all other conditions constant, improved the tensile strength and ductility. The next question was where the effects of increased current terminated. It is not known whether succeeding experiments have determined this point.

The largest-size electrode suggested in practice is 3/16 inch in diameter. A 5/32-inch electrode being a popular size for currents ranging from approximately 100 volts to 190 volts, and used for mild-steel plates of from ⅜ inch to ⅝ inch in thickness. In heavy welding the metal is deposited in layers, sometimes two or three, left to the option of the designer. It is claimed that each succeeding layer anneals the one beneath it and if a reinforced layer is placed on top it will complete the annealing process and may without affecting the joint be machined down. This method appealed to many engineers as a long and tedious process, and the question arose whether a weld could not be made with larger-diameter electrodes and accomplish the work in one run. In addition to the explanation of the annealing effects of the layer method it is believed that with an electrode, say of 3/8-inch diameter, that the increased current would be so great that it becomes a cutting current, and control of the arc not within the skill of the operator. That is to say, that the arc characteristic would be such that smooth movement at short-arc length would not be possible, and smooth running of the electrode is an essential of good welding.

Rigid Versus Non-rigid Assembly.—The question of the best method of preparing long plates for seam welding fell into two groups: those whose practice warranted the belief that welded seams could be made when the two plates were rigidly connected either mechanically or by means of widely-spaced tack welds, and those whose practice, though not denying the possibility of rigid assembly, warranted the belief that, by giving the plates room for expansion and contraction, the cooling stresses (locked-in) would be greatly reduced and that more uniform success would result. The non-rigid system provides for a tapered separation between the plates, the welding beginning at the small end. Clamps are inserted between the plates and hold the proper distance. The operator upon releasing them observes the rapidity or slowness of the expansion and acts in accordance therewith, *i.e.,* if the opening closes quickly he hastens his welding, or if it is slow in closing he waits. The effects of expansion and contraction are observed and cared for in the rigid system in much the same way with this difference, that usually the seam is not made continuously but in sections which permit of a distribution and equalization of the cooling stresses. The marked effect of the discussion was its relation to ship construction, for it is not conceivable how the non-rigid system could be applied.

Both for practical evidence of the ability of arc-welded seams in ½-inch steel plate to withstand shock and fatigue comparable to those met in ship design, as well as to put the non-rigid system to test, a 12-foot tank[3] of ½-inch tank steel was built and tested. Incidentally complete records were kept of the cost, time, metal deposited, quality of electrode, etc. The designs of joints were patterned after those already suggested for an all-welded ship and included individual designs of which there was doubt. After the tank was finished it was filled with water and alternately subjected to 15-pounds pressure and 22-inches vacuum. The designer and builder reports that "after the first 12 cycles had been completed, a break occurred at one end of the box; the break was confined principally to the solid-end and bottom plate. . . . After 42 cycles the end patch began to leak and had to be welded along one edge. . . . After repairs had been made the breathing test was continued and has now been carried to 200 cycles. There is now a slight break on the patch and one in the centre of the bottom seam."

It was suggested that a riveted tank similar to this 12-foot box be built and tested in the same way, but shipbuilders advised that their experience with riveted tanks showed that such an undertaking was a waste of time and money in that no riveted tank could be kept water-

[3] "Electric Arc Welding in Tank Construction," R. E. Wagner, *General Electric Review*, December, 1918.

tight nor stand the abuse given the all-welded tank. A tank of the same dimensions and materials has been assembled and built on the rigid system. This tank has not yet been tested.

Ductility Versus Strength.—Closely connected with the discussion on covered and bare electrodes was that of the results from these instrumentalities. A good strength weld was possible in mild steel with the bare electrode, but the flux-covered or even thinly-coated electrodes could produce a weld with very much greater ductility. It was claimed broadly that strength welds were not all that was desired in a ship joint. The ship subject at all time to the forces of waves and wind, affected by continual vibration of her own propelling power and fatigued by the creeping action of many complicated moments of forces—all these must be insured by joints that would bend and not break; that would strain and not leak; that would creep and not snap away; and, in short, would act in all respects like rubber. Upon question it was admitted that riveted ships hardly approached this desideratum and that in practice the riveted joint was comparatively a rigid joint. The suggestion then followed that as ductile welds were expensive for electrodes, time, etc., and not always to be assured, strength welds of 85 to 90 per cent. of the plate, or greater than the plate strength, be designed and employed. To the practitioner this was reasonable and permitted the work of shipbuilding to proceed; but to the theorists such an argument was alarming, and they advised that the whole subject of the application be returned to the laboratory for further investigation.

Cast Iron.—From time to time claims are made that cast iron can be welded to cast iron, or cast iron to cast steel. Like many arguments, deductions were made from misleading, if not entirely wrong, premises and often the parties to the controversy were both right. In a large way it was heralded that the engine cylinders of the interned German ships which were of cast iron had been electrically welded. The correct statement was that they had been admirably repaired by the instrumentality of the metallic arc in combination with mechanical skill. There is no doubt that the method employed was superior both in point of economy and excellence of result. Briefly, the method was to make a cast-steel patch to fit the broken part. A series of studs were tapped into the cast-iron cylinder. From these studs metal was deposited from the electrode which was carefully played about the seam locally so as not to cause dangerous over-heating. When the V of the seam was filled the deposited metal was continued until it covered a broad band. The finished weld was then hammered with the intention of improving the quality of the weld as well as stopping leaks. Samples of this work were examined both for physical tests and for fusion of the metals. The weld, as expected, was always stronger than the cast iron and invariably the samples broke at the joint. A small piece of deposited metal on the cast iron could be easily broken off. This carried with it some of the cast iron, but also indicated a brittle structure at the jointure. It would seem that the cast iron was weakened by the reactions which take place in the heat of the arc and the chemical changes caused by the constituents of the electrode material. From such large work as engine cylinders and the method used for their repair, no reasonable deduction can be made that small pieces of cast iron can be arc welded. Fundamentally, cast iron is a cheap material with a rating in this country of approximately 17,000 to 18,000 pounds per square inch tensile strength. Though some engineers state that cast iron may be welded as well by the arc as by any other method, they are quick to restrict this statement by the clause, " but the results are always uncertain."

Automatic Arc Welding.—In line with the prophecies that manual arc welding would be superseded by some form of machine, one of this group of specialists devoted himself to the practical solution of this problem. The methods he pursued and the present results which he has attained not only tell a story of achievement but also reflect much light of importance to arc-welding operators. Here is his own description of his first assumptions and how they developed:

" Early in his investigations, the writer [4] concluded that a substantial equilibrium must be maintained between the fusing energy of the arc and the feeding rate of the welding strip; and it soon became evident that if the welding strip is mechanically fed forward at a uniform rate equal to the average rate of consumption with the selected arc energy, this equilibrium is actually maintained by the arc itself, which seems to have, within certain circumscribed limits, a compensatory action as follows: When the arc shortens, the resistance decreases and the current rises. This rise in current causes the welding strip to fuse more rapidly than it is fed, thereby causing the arc to lengthen. Conversely, when the arc lengthens, the resistance increases, the current falls, the

[4] Harry D. Morton, Secretary-Treasurer, Automatic Arc Welding Co.

welding strip is fused more slowly than it is fed, and the moving strip restores the arc to its normal length. . . . While this compensatory action of the arc will maintain the necessary equilibrium between the fusing energy and the feeding rate under very carefully-adjusted conditions, this takes place only within relatively narrow limits. It was very apparent that, due to variations in the contour of the work, and perhaps, to differences in the fusibility or conductivity of the welding strips or of the work, the range of this self-compensatory action of the arc was frequently insufficient to prevent either contacting of the welding strip with the work or a rupture of the arc due to its becoming too long. The problem that arose was to devise means whereby the natural self-compensatory action of the arc could be so greatly accentuated as to preclude, within wide limits, the occurrence of marked arc abnormalities. There was ultimately evolved, by experiment, such a relation between the fusing energy of the arc and the feeding rate of the welding strip as to give the desired arc length under normal conditions; and tendencies towards abnormalities in arc conditions, no matter how produced, were caused to bring into operation compensatory means for automatically, progressively, and correctively varying this relation between fusing energy and feeding rate, such compensatory means being under the control of a dominant characteristic of the arc. In their ultimate forms, the devices for affecting the control of the arc are simple and entirely positive in action, making discrepancies between fusing energy and feeding rate self-compensatory throughout widely-varying welding conditions." [5]

[5] *Journal of Amer. Inst. Mining Engineers,* p. 818, 1919. Discussion by Harry D. Morton.

The inventor of these machines has made many experiments to illustrate the " compensatory action of the control," by using varying compositions of electrode material and work material as well as varying the volt-

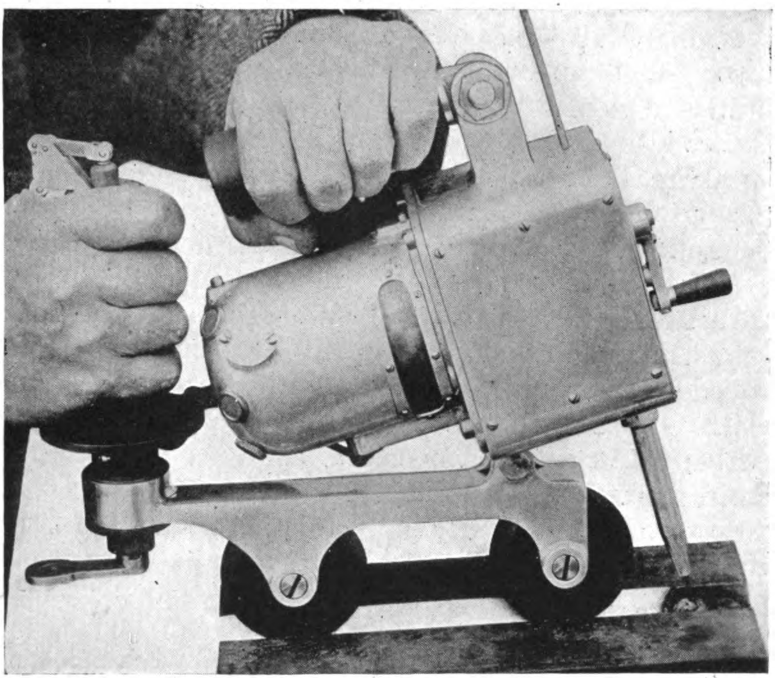


FIG. 27.—Morton semi-automatic metallic-electrode arc-welding machine.

age supply and changing the contour of the work. He has developed two types of machines which he designates automatic and semi-automatic. The latter appears to be a practical shipyard tool, resembling a portable drill (Fig. 27).

Many interesting points have been observed in the operation of these tools. Those of a practical nature are:

(1) The importance of the angle of inclination of the electrode to the work. "An annular variation of 5 degrees will sometimes determine the difference between success and failure. . . . About 15 degrees from the perpendicular works well in many cases. In welding some materials the electrode should drag, that is, point toward the part already welded rather than toward the unwelded parts of the seam." (2) The affinity between electrode materials and work materials. "Generally speaking, the Swedish and Norway iron wires seem to produce more quiet arcs and, possibly, a more uniform deposition of electrode material than do other wires. . . . To date, no steel has been tested on which apparently satisfactory welds could not be made. High-speed tungsten steel has been successfully welded to cold-rolled shafting, using Bessemer wire as electrode material. Ordinary steels varying in carbon content from perhaps 0.10 to 0.55 per cent. have been welded with entire success." (3) The electrical-supply variations. "So far, electrode wires 1/8 inch in diameter have been chiefly used in the machines. Successful welds have been made with current values ranging from below 90 to above 200 amperes at impressed voltages of 40, 45, 50, 55, 60, 65, and 80. Under these varying conditions, the voltage across the arc has been roughly from 16 to 22. The machines have thus far been run only on direct current." (4) The short arc. "While undoubtedly it is difficult, if not impossible, to maintain in manual welding an arc shorter than this (0.1 inch), the writer has frequently, with the automatic machines, made continuous and strikingly good welds with arcs of much less length." (5) Rate of doing work. "With the auto-

matic machine, black drawing steel 0.109 inches thick has been welded at the rate of 22 inches per minute. A Detroit manufacturer welded manually with oxy-acetylene at the rate of four per hour a large number of mine floats 10 inches in diameter, made of this material. The auto-

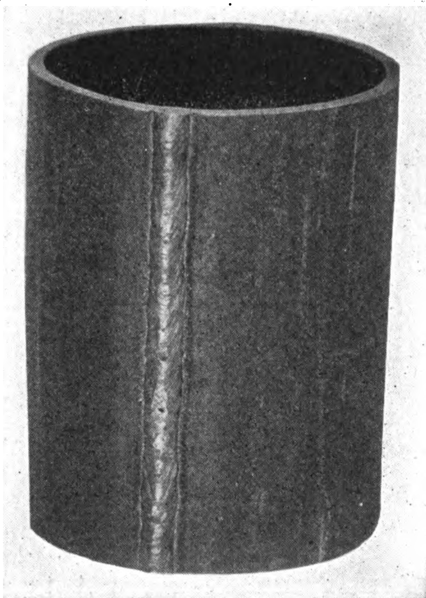


FIG. 28.—Gauge steel tubing automatically arc welded at the rate of 1 ft. per minute.

matic machines made the welds at the rate of forty per hour. . . . The productive capacity of the machines so far made has been from three to ten times that of manual welding methods." (6) Type of electrode. "Bare wire only has been used in the automatic machines. and the results obtained seemed to indicate that the covering of the electrodes is an expensive superfluity." (7) Cleanliness of materials. "The writer has repeatedly welded with wire showing evidence of pipes and seams, as well as with rusty wire and with wire covered with dirt and grease. In this connection it may be said that no pains are ever taken to remove rust, scale or slag from the work material—even where welds are superimposed. Apparently under uniform conditions of work traverse, arc length and electrode angle of inclination, such as are possible in the automatic machine,

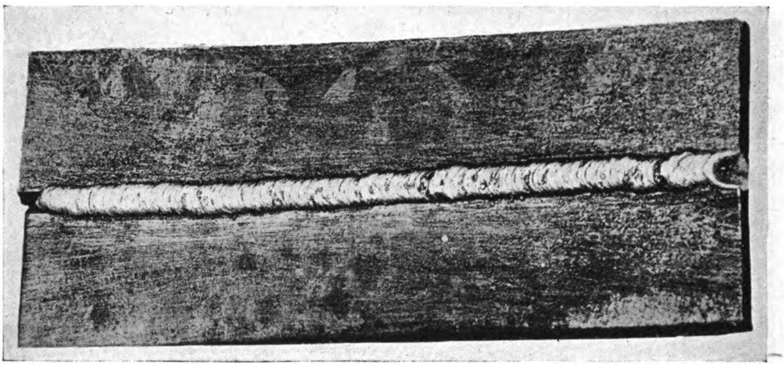


Fig. 29.—Two ½" ship plates automatically arc welded.

impurities vanish before the portion of the work on which they occur reaches the welding area of the arc."

Many of these practical observations of automatic arc welding will change former opinion, but their greatest good will result in the attention given them by manual arc welders. In experimenting with such machines it has been discovered that great differences in the welding results come about from the location of the ground connection in relation to the location of the arc. Doubtless this is a phenomenon of magnetism or conductivity. It is well that the arc-welding operator be acquainted with such an observation, although in large work, long seams, or heavy materials this phenomenon may not seriously affect the goodness of the weld. Besides these practical observations the inventor of automatic arc-welding machines takes note of the theoretical side of the " controlled " arc which will be considered in connection with the theories of electric welding.

The Training of Operators.—Unanimity of opinion places the arc-welding operator as the chief factor of the making of a sound and perfect weld. His participation in the process has been estimated at 80 to 90 per cent. Early in the debate the statement was made that the apparatus, the electrode, or the work materials had little to do with a successful weld when compared with the man who makes it. The operator who could not make a weld despite the opposition of these elements was, at least, not a skilled welder. This does not mean that there were not combinations that could for a time baffle his skill, but it does mean that the skilled welder if not interfered with could produce excellent work without specialized apparatus or with elaborately prepared electrodes.

This was not the essential question. The timidity of conservative advocates of arc welding was occasioned by this very high percentage of operator and the inconsistent results of his work. In other words, the conservatives were not willing to risk their reputation because of the non-uniformity and instability of this personal equation. It is nonsense to say that the operator could not hide poor work, for this he could do and more—he could place good and bad work side by side. For this reason the first requirement claimed for the operator was that he be conscientious.

On the other hand, the radicals adhered to their practical view that men who had some knowledge of steel jointure either in blacksmith shops or boiler shops could be made good welders. The work of such had been in use for many years for much serious work, and this was a sufficient guarantee of the results. They pointed to other long-tried methods and asked why demands were not made to destroy such work, as it too only received exterior inspection. For example, the large varied use of cast iron for many purposes connected with danger to life, so steel castings and forgings: who knew what was inside of these finished articles? It was not that they did not agree with the conservatives that for special work a competent man should be employed, but that there was too much stress laid on the importance of the operator for a large run of work.

In the eagerness of the desired application it was natural that the time of training welders should be given most attention. There were engineers who did not hesitate to state that arc welders could be trained in a few days. A little experience on the part of any one with the handling of the electrode would assure that this time was too short. Any one with a steady hand and a comfortable adjustment of the electrical supply may make the first time a deposit of metal from the electrode; but he makes a great error if he leads himself to believe that this is all that is required to produce uniformly good welds. As previously noted there is a great difference in the training of a man for one single operation and making the same man capable of applying his knowledge and training to a large variety of work.

Further details of the training of operators will be treated in the next chapter.

Summary.—The endeavor of this chapter has been to rehearse briefly the salient discussions on arc welding and its bearing on the application to the industries. Questions here alluded to have been selected for their interest to the general practitioner and to illustrate the many-sided nature of the opinions. The following list gives an idea of the investigations suggested:

The supply and distribution of electric power.

Vanadium coating on electrodes.

Titanium coating on electrodes.

Boron sub-oxide coating on electrodes.

Magnesium coating on electrodes.

Titanium-core electrodes.

Boron-core electrodes.

Charcoal-core electrodes.

Aluminum-core electrodes.

The effect of the height of deposited metal in weld.

The value of extending the projection of the deposited metal in the weld.

Determination of the separation distance between the metals to be joined.

The proper size of lap in a lap-joint.

The proper width of strap in a butt-strap design.

The proper thickness of strap for varying thicknesses of plate.

The advantages of change of current for different layers of deposited metal.

The effects of increased current on different sizes of electrode.

The limits of layers, *i.e.*, how many for varying thicknesses of steel plating.

Effects of the elements, *i.e.*, rain, wind, snow, etc.

Eye protection for the operator.

CHAPTER VII

The Arc Welder

If successful arc welds are dependent upon the man behind the electrode it is fair to assert that those who wish the best of this process should consider him carefully. Experience in the training of miscellaneous men has shown that no amount of training will make a man a welder. Some men are so constituted, or have been so molded by other occupations, that they cannot hope to acquire skill in the handling of the electrode. Electric welding is in this respect no different from any of the other vocations and has its degrees expressed by the competency of the man. This comparative scale does not mean exclusion, but for special applications it signifies the importance of selection. To the employer undoubtedly all degrees of proficiency will have their field of usefulness and the lower degrees will work upward through the fostering of ambition. This is the keynote of selection. An experience with metals, a practical knowledge of the effects of heat treatment, even a few years' use of the electrode in repair work—all these may aid the arc welder in seeking a job, but they will not assure the employer that, even with months of training, the man will be a welder upon whom he may rest the responsibility of a new application. On the other hand, a man who knows nothing of these things but who displays a spirit of conquest and a willingness to accept failure that he may gain success, this fellow will make not "just a welder," but a skilled craftsman.

Training.—Forced methods are not conducive to the best results. Some men can right themselves under the confusion of haste, but others cannot get their bearings. The object of the Emergency Fleet Corporation was to aid the shipbuilders in hastening the construction of ships. The procedure adopted was a notification to the shipbuilders that training would be furnished to such men as they cared to select with the option of welding instruction, and in addition, an intensive course in practical methods of imparting knowledge. This latter gave the shipbuilder the opportunity of setting up his own training school after a few men were equipped. Upon the introduction of this system a restricted bonus was offered to those who immediately accepted the proposal. This arrangement reacted advantageously to the training, as it permitted the retention of the men in the schools until they were proficient with the electrode. By making the training exclusively for the shipbuilding industry another constant was established, namely, the work material. In this respect the training of arc welders was a specialty. Although a broad view was taken of the benefits of a liberal education, this feeling was held in check by the demand for men who could be trusted to weld certain parts of the ship without endangering the structure or discounting the advantages of the process.

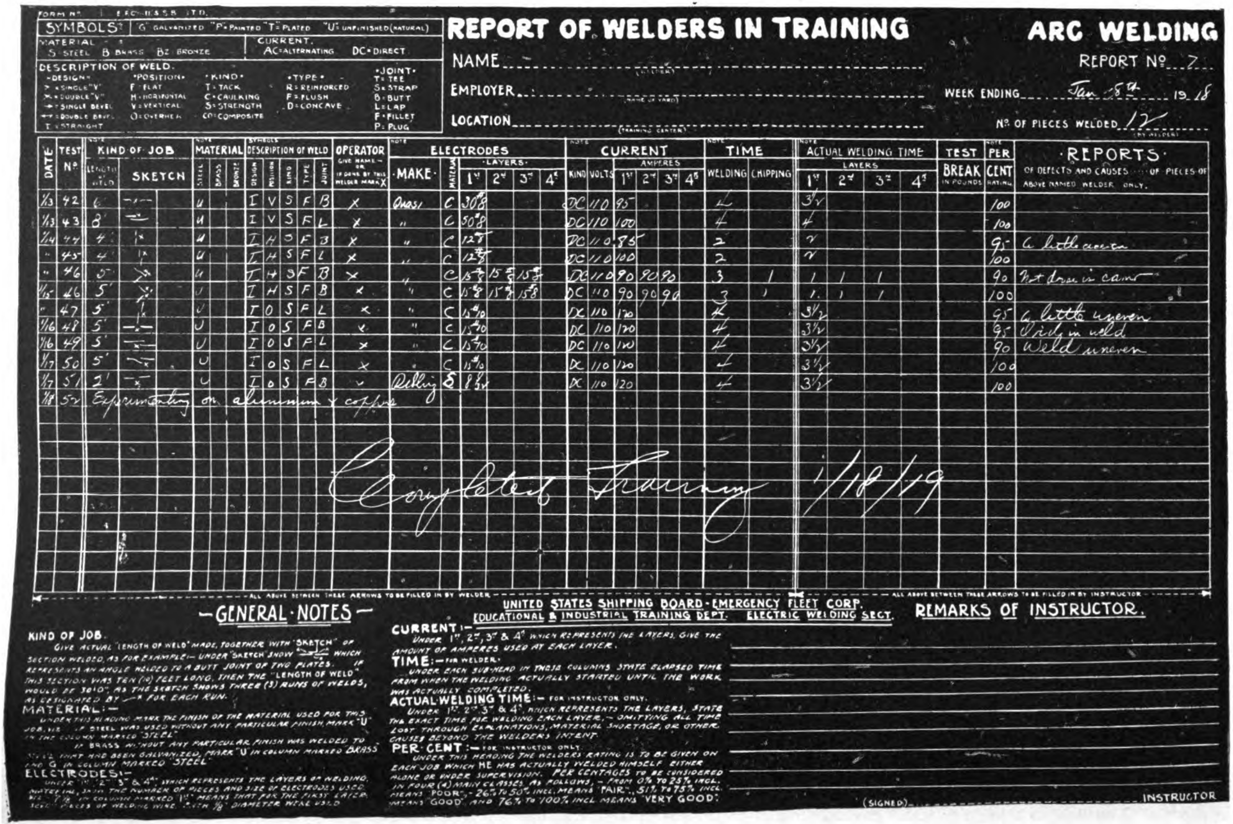
Another constant could have been instituted but opinions pointed to the necessity of future development. This refers to the question of the kind of electrode. Guided by American practice the bare mild steel electrode could have been made the standard and the men trained only with this type; but persuaded by argument and the examples of what had been done in England the men were also trained with the covered electrode. That in practice this policy did not warrant the exertions made, nothing can be said, as the application has not yet been put to the full test of shipbuilding in this country. It cannot be known whether the first welded ship will be built with either one or the other type of electrodes, but very likely both would be used.

Endeavors were made to provide at every school various types of apparatus so that the student would be familiar with the special features and characteristics of operation of different machines. This was done for two reasons: (1) That no question of commercial preference could be raised, and (2) that the men would be prepared to operate any apparatus in the event that their company wished to experiment with a number of types. Although it has been stated that arc welders did not need to know anything about electricity, the intention being the science of electricity, it is of importance for him to be able not only to start his motor generator and adjust the current for welding, but also to understand enough of the workings of the machinery to exercise discrimination in the case of derangement of the apparatus. In some of the schools the equipment was not so diversified as it should have been, with the result that a number of men, although well equipped as welders, did not obtain a proportionate knowledge of arc-welding machinery. This is a handicap for good welding, as many of the manufacturers do not agree in their fundamentals of design with this result to the welding operator that frequently he will make adjustments on a machine that will not produce the desired results because of his lack of familiarity with this particular apparatus. The Emergency Fleet Corporation was able to give this additional training on many different machines through the courtesy of various manufacturers throughout the country.

For the purposes of standardization a list of symbols was proposed and approved. This list has been adopted as a standard by all users of the process throughout this country. It led, as will be seen from the last page, to the important economic point of the simplification of detail drawings. Those familiar with riveted structures appreciate the necessity of calculations, allowances of spacing of rivets, and dimensioning of such drawings. Here was a uniform set of standard symbols which, when understood by the arc welder, were placed on an outline drawing and then sent to the yard. These symbols were purposely made elaborate so that the entire ground would be covered, but it was intended to simplify them as the application settled into established practice. The men under training were all drilled in the symbols as here given, as will be noted on the sample record of the student (Fig. 30).

In view of the fact that this training was special, a detail of each practice lesson would be of little value. A good general course of lessons for commercial welding will be found in the Appendix. As a matter of fact, time did not permit the establishment of standard methods of instruction throughout the schools. The procedure of the training may be of interest.

First, the student was provided with such necessaries as gloves, screens, electrode holder, etc., and then assigned to a welding booth. He was then shown by the instructors how to hold his electrode, both at the proper



FORM Nº ... E.F.C.–U.S.S.B. LTD.

SYMBOLS: G = GALVANIZED "P" = PAINTED "T" = PLATED "U" = UNFINISHED (NATURAL)

MATERIAL – S = STEEL B = BRASS BZ = BRONZE

CURRENT. AC = ALTERNATING DC = DIRECT

DESCRIPTION OF WELD.

•DESIGN• ⋎ = SINGLE "V" ⋎⋏ = DOUBLE "V" → = SINGLE BEVEL ↔ = DOUBLE BEVEL I = STRAIGHT

•POSITION• F = FLAT H = HORIZONTAL V = VERTICAL O = OVERHEAD

•KIND• T = TACK C = CAULKING S = STRENGTH CO = COMPOSITE

•TYPE• R = REINFORCED F = FLUSH D = CONCAVE

•JOINT• T = TEE S = STRAP B = BUTT L = LAP F = FILLET P = PLUG

REPORT OF WELDERS IN TRAINING

ARC WELDING

NAME .... (WELDER)

REPORT Nº 7

EMPLOYER .... (NAME OF YARD)

WEEK ENDING Jan 18th 19 18

LOCATION .... (TRAINING CENTER)

Nº OF PIECES WELDED 12 (BY WELDER)

DATE	TEST Nº	KIND OF JOB: LENGTH OF WELD	SKETCH	MATERIAL: STEEL	BRASS	BRONZE	DESCRIPTION OF WELD: DESIGN	POSITION	KIND	TYPE	JOINT	OPERATOR (GIVE NAME – OR IF DONE BY THIS WELDER MARK X)	ELECTRODES: MAKE	MATERIAL	LAYERS 1st	2d	3d	4th	CURRENT: KIND	VOLTS	AMPERES 1st	2d	3d	4th	TIME: WELDING	CHIPPING	ACTUAL WELDING TIME: LAYERS 1st	2d	3d	4th	TEST BREAK IN POUNDS	PER CENT RATING	REPORTS OF DEFECTS AND CAUSES OF PIECES OF ABOVE NAMED WELDER ONLY
1/3	42	6'		U			I	V	S	F	B	X	Quasi	C	30 #/8				DC	110	95				4		3½					100	
1/3	43	8'		U			I	V	S	F	L	X	"	C	50 #/8				DC	110	100				4		4					100	
1/4	44	4'		U			I	H	S	F	B	X	"	C	12 #/8				DC	110	85				2		½					95	A little uneven
"	45	4'		U			I	H	S	F	L	X	"	C	12 #/8				DC	110	100				2		½					100	
"	46	5'		U			I	H	S	F	B	X	"	C	15 #/8	15 #/8	15 #/8		DC	110	90	90	90		3	1	1	1	1			90	Not drawn in center
1/15	46	5'		U			I	H	S	F	B	X	"	C	15 #/8	15 #/8	15 #/8		DC	110	90	90	90		3	1	1	1	1			100	
"	47	5'		U			I	O	S	F	L	X	"	C	15 #/10				DC	110	120				4		3½					95	A little uneven
1/16	48	5'		U			I	O	S	F	B	X	"	C	15 #/10				DC	110	120				4		3½					95	Void in weld
1/16	49	5'		U			I	O	S	F	L	X	"	C	15 #/10				DC	110	120				4		3½					90	Weld uneven
1/17	50	5'		U			I	O	S	F	L	X	"	C	15 #/10				DC	110	120				4		3½					100	
1/17	51	2'		U			I	O	S	F	B	✓	Rolling	S	8 [illegible]				DC	110	120				4		3½					100	
1/18	52	Experimenting on aluminum & copper																															

Completed Training 1/18/19

ALL ABOVE BETWEEN THESE ARROWS TO BE FILLED IN BY WELDER — ALL ABOVE BETWEEN THESE ARROWS TO BE FILLED IN BY INSTRUCTOR

UNITED STATES SHIPPING BOARD · EMERGENCY FLEET CORP.
EDUCATIONAL & INDUSTRIAL TRAINING DEPT. ELECTRIC WELDING SECT.

— GENERAL · NOTES —

KIND OF JOB. GIVE ACTUAL "LENGTH OF WELD" MADE, TOGETHER WITH "SKETCH" OF SECTION WELDED, AS FOR EXAMPLE – UNDER "SKETCH" SHOW ... WHICH REPRESENTS AN ANGLE WELDED TO A BUTT JOINT OF TWO PLATES. IF THIS SECTION WAS TEN (10) FEET LONG, THEN THE "LENGTH OF WELD" WOULD BE 30'0", AS THE SKETCH SHOWS THREE (3) RUNS OF WELDS, AS DESIGNATED BY ... FOR EACH RUN.

MATERIAL: – UNDER THIS HEADING MARK THE FINISH OF THE MATERIAL USED FOR THIS JOB, VIZ. IF STEEL WAS USED WITHOUT ANY PARTICULAR FINISH, MARK "U" IN THE COLUMN MARKED "STEEL". IF BRASS WITHOUT ANY PARTICULAR FINISH WAS WELDED TO STEEL THAT HAD BEEN GALVANIZED, MARK "U" IN COLUMN MARKED "BRASS" AND G IN COLUMN MARKED "STEEL".

ELECTRODES: – UNDER 1st, 2d, 3d & 4th, WHICH REPRESENTS THE LAYERS OF WELDING MATERIAL, GIVE THE NUMBER OF PIECES AND SIZE OF ELECTRODES USED. ... IN COLUMN MARKED 1st MEANS THAT FOR THE FIRST LAYER ... PIECES OF WELDING WIRE ... DIAMETER WERE USED.

CURRENT: – UNDER 1st, 2d, 3d & 4th WHICH REPRESENTS THE LAYERS, GIVE THE AMOUNT OF AMPERES USED AT EACH LAYER.

TIME: – FOR WELDER. UNDER EACH SUB-HEAD IN THESE COLUMNS STATE ELAPSED TIME FROM WHEN THE WELDING ACTUALLY STARTED UNTIL THE WORK WAS ACTUALLY COMPLETED.

ACTUAL WELDING TIME: – FOR INSTRUCTOR ONLY. UNDER 1st, 2d, 3d & 4th, WHICH REPRESENTS THE LAYERS, STATE THE EXACT TIME FOR WELDING EACH LAYER, – OMITTING ALL TIME LOST THROUGH EXPLANATIONS, MATERIAL SHORTAGE, OR OTHER CAUSES BEYOND THE WELDER'S INTENT.

PER CENT: – FOR INSTRUCTOR ONLY. UNDER THIS HEADING THE WELDER'S RATING IS TO BE GIVEN ON EACH JOB WHICH HE HAS ACTUALLY WELDED HIMSELF EITHER ALONE OR UNDER SUPERVISION. PER CENTAGES TO BE CONSIDERED IN FOUR (4) MAIN CLASSES AS FOLLOWS, – FROM 0% TO 25% INCL. MEANS "POOR", – 26% TO 50% INCL. MEANS "FAIR", 51% TO 75% INCL. MEANS "GOOD" AND 76% TO 100% INCL. MEANS "VERY GOOD".

REMARKS OF INSTRUCTOR.

(SIGNED) .... INSTRUCTOR

Fig. 30.—Report of welders in training.

angle and the correct distance from the work. He was then allowed to practice on depositing one layer of metal in rows on a flat plate. Following this he placed a second layer, then a single layer between the first row and then completing the sample by a second layer. The sample was then to be retained by the instructor as a record and inspected for the determination of rating. This same exercise was repeated with the work material set up at an angle of 45 degrees from the welding table. Following this practice the same exercises were carried out in the vertical, horizontal, and overhead positions. The first course was done entirely with the bare mild steel electrode. They were repeated with the slag-covered electrode.

It was expected by the time the student had performed these exercises he would gain sufficient confidence in his ability to undertake the more difficult joining of plates. If in the judgment of the instructor his deposited samples did not give evidence of such confidence he would repeat such of the exercises as he considered adequate. The student was then given a graded course in joining small samples of ¼-inch steel plate with different types of joints in all positions. These exercises were repeated with ½-inch plate. In the same way as with the deposited metal sample, first the sample joints were made with the bare electrode and then with the covered. Coupled with these exercises and in some cases interrupting the regular course, production jobs were given the more proficient student. Although in a way these exercises were laid out as routine lessons the exigencies of the training were such that it was considered beneficial not to make the instruction too monotonous.

The time of the student in the schools was never limited. If the man were conscientious, speed was not a consideration, but the quality of his work permitted his discharge that much sooner. As a matter of general interest the average time of the average student in becoming proficient in the handling of the electrode was approximately eight weeks. That is to say, that by consistent attention the average student could go through the course laid down in this time. There were some men in attendance for three months. There were others who finished the course in five or six weeks.

Home-office records were kept of the available arc welders in order to supply information of this kind to the shipbuilders. The form for this purpose is shown in Fig. 31. From this accumulated data a list was compiled filing additional information that would both aid in the proper selection of men and would assist the instructor in case any of the men were sent to one of the training schools. Following this system a card was filed (Fig. 32) for each student. On this card the designations of the different schools (called training centres) are given and space is provided for showing transfers from one school to another. The shifting of the student was not the usual procedure, although in some cases it was deemed advisable. At times better instruction was given in certain details in one school than at another, physical opportunities sometimes decided the transfer, and rarely the transfer was requested by the employer. Although this filing card shows seven welding schools, the work never proceeded to more than five schools, as follows: One in Schenectady, N. Y.; one in Cleveland, Ohio; one in Brooklyn, N. Y.; one in San Francisco, Name .... Date of entry ....

Name of employer ....

Address .... Are they on E. F. C. work? ....

Name of your superior .... Title ....

Address of your superior ....

What is your trade? ....

What welding equipment have you been using? ....

Will you use A.C. or D.C. at your works? ....

What class of work will you be required to do? ....

DO NOT FILL IN BELOW THIS LINE

Course .... Training centre No. .... Completed. Withdrawn ....

FIG. 31.—Record of arc welder.

Cal.; and one in Philadelphia, Pa. The two latter schools were only just opened when the electric-welding activities of the Emergency Fleet Corporation ceased. In conjunction with the home-office record of the students, a weekly report was forwarded from each head instructor of the schools (Fig. 30). As will be seen, this report was filled in by the student up to the column headed " actual welding time," from this column it was filled in by the instructor. It will be noted that the standard list of symbols is used with slight modifications due to the fact that the students were not working from drawings, so that drawing symbols would only confuse them. These weekly reports gave a check on the instructor as well as the student, and also formed a reference in determining the results of the examinations for certification.

It was determined to certificate those men who after several months' actual work in the shipyards showed themselves capable of performing successfully with the electrode. This required a further examination of the student. The system, though exacting fairly rigid requirements, was based on broad, practical lines following the course of instruction given. As a guide for determining whether the man was entitled to certification these points of observation were required of the examining instructor: (1) Ability to weld in all positions, flat, horizontal, vertical, and overhead. (2) Ability to weld in all positions with both alternating and direct current. (3) Ability to weld in all positions with both bare and covered electrodes. (4) Ability to maintain an arc not over $\frac{1}{8}$ inch long, without more than three breaks in a 12-inch run of the electrode. (5) Welding by observation must be smooth and even. (6) A sample weld when

Name..........	Employer..........	Instructor { No / Yes
	Address..........	Welding
		Centre No.
	Time to..........	1W
		2W
Date of entry..........		3W
Date of completion..........	Transferred to..........	4W
Date of entry..........		5W
Date of completion..........	Transferred to..........	6W
Date of entry..........		7W
Date of completion..........	Transferred to..........	
Instructor's course at..........		
Date of entry..........	Five days' teaching at..........	
Date of completion..........		
Date of welding examination..........	By..........	At..........
Type of machine used..........		
Date and number of welder certificate..........	Remarks..........	
Date and number of instructor certificate..........	....	
	....	
	....	

FIG. 32.—Student's record.

cut by hack saw must show perfect penetration with work materials. (7) The weld must be free from slag and blow holes. (8) The operator must display a knowledge of the effects of too high or too low open voltage. (9) The operator must display a knowledge of the correct current adjustment for the electrode size and work material. (10) The operator must display a knowledge of the proper polarity for various welding conditions. (11) The operator must not be examined unless he has had at least four months' experience in production work.

Differing slightly from these requirements for certification the following points were laid down as a guide to the examining instructor for a refusal to recommend certification: (1) Unsteady habits of the operator. (2) Inability to hold an arc 1/8 inch or less. (3) Slag or blow holes found in the welded sample. (4) A rough or uneven weld. (5) Lack of penetration when the welded sample is cut with hack saw. (6) When the sectional area of the weld is equal to the sectional area of the work material, the ultimate tensile strength of the weld must not be less than 75 per cent. of the work material. (7) Lack of knowledge of current adjustment, size of electrode, kind of electrode, and voltage conditions. (8) Lack of knowledge as to the proper polarity for the type of weld. (9) Less than four months' experience in production work.

With these instructions the examiner was sent to the plant employing the student and made his notations on a record card (Fig. 33). These cards were kept on file as a reference when viewing the sample welds. These latter were brought to headquarters for final examination and tests. The system was planned to avoid inter-

Name .... Age ...... Married .... Instructor ....

Location .... Employer ....

Machine used .... A.C. or D.C. ....

No.	Position		Arc	Runs	Rough	Even	Holes	Slag	Volts	Amperes	Electrodes
1	Flat	B									
2	Flat	C									
3	Horizontal	B									
4	Horizontal	C									
5	Vertical	B									
6	Vertical	C									
7	Overhead	B									
8	Overhead	C									

How Many Times Arc Broke		Time Consumed Per Lesson		
No. 1	No. 2	No. 1	No. 2	Where trained ....
No. 3	No. 4	No. 3	No. 4	E. F. C. centre ....
No. 5	No. 6	No. 5	No. 6	Instructor ....
No. 7	No. 8	No. 7	No. 8	Date of completion ....

Date of examination .... Examiner

FIG. 38.—Record for examining instructor.

ference with the operator and, in addition, to furnish him with further instruction if he so desired. Fig. 34 illustrates the form of certificate.

Needs of the Operator.—The process is not dangerous. Low voltages are employed so that there is no fear of serious electric shock. The temperature of the arc is

United States Shipping Board
Emergency Fleet Corporation

Certificate No. ______

Education and Training Section
Electric Welding Branch

This Certifies that H. C. Horner employed by The Emergency Fleet Corporation has satisfactorily completed the Course of Training as an Electric Arc Welding Operator, at Training Center No. 2 Located at Schenectady N.Y. on the 1st day of August A.D. 1918

Head of Education and Training Section

E. E. MacNary
Superintendent of Training

Head of Electric Welding Branch

Fig. 34.—Form of certificate for arc welder, Emergency Fleet Corporation Schools.

high and the metal in the vicinity of the weld becomes and remains hot for some time after the weld is made and should be handled either with some form of tongs or with non-inflammable gloves. The arc is usually accompanied with sputterings and sparking which requires that the operator wear gauntlets so that the spark will not burn his arms. It is not the general custom to wear a leather apron, though in some positions and classes of work this should be insisted upon. Usually the arc welder wears a pair of overalls, but if a piece of slag accidentally falls or is blown from his weld his overalls will not protect him. Accidents have been caused by molten metal falling into the shoe-top, and it is wise to provide shoes with special tongues.

The most necessary protection is that for the eyes. Many investigations[1] have been undertaken in order to supply the operator not only with correct lenses in the sense of preventing the harmful invisible rays, but also with proper lenses that will not reduce the light intensity so low that vision is difficult. The arc welder must see as much as possible what is going on while the electrode is depositing metal in the weld. Protective lenses may be mounted in three ways. For inspection work a pair of close-fitting goggles is all that is necessary. They must be screened at the sides, because the invisible ultra-violet and infra-red rays are reflected in the same way as visible rays. Goggles do not protect the operator as well as a hand screen. He can quickly lay this down when he has broken his arc and it gives him a ready means for viewing quickly his cooling metal. The screen covers his face and chest, giving him protection on all sides. Some operators claim a liking for the screen on the basis of its steadying quality; that is, by holding the left arm tightly pressed to the body gives added confidence to the movements of the right arm. Metallic arc welders rarely use a helmet, but in carbon arc welding this is necessary both for the added protection to the

[1] "Eye Protection in Iron-Welding Operations," W. S. Andrews, *General Electric Review*, December, 1918; Bulletin 93, Technologic Papers, Bureau of Standards, Washington, D. C.

neck and shoulders from the intense heat, and also for the freedom of the left hand, in which the melt rod must be manipulated. There are many designs of helmets and screens which are subject to the personal preference of the welder. In some welding shops combination of glasses for making up lenses are left to the selection of the operator. Only glasses are provided whose combinations will guarantee safety. Other employers are more rigid and require only one type of glass to be used. A clear glass is placed outside of the colored lenses to protect them against pitting. The cheap clear glass saves the expensive colored glass.

Three Important Lessons.—Too much stress cannot be laid upon the primary points in the instruction of an electric welder. All training practice must begin with the laying-on of metal from the electrode. The three following lessons explain clearly how the beginner should practice in (1) making beads, (2) spreading the deposited metal, and (3) padding.

" LESSON I

" BEADS

" As shown in Fig. 35, Lesson I, Running Beads.

" The electrode must be held close to the work, *i.e.*, a close arc for successful welding. The natural tendency is to draw a long arc, but in this case too much of the heat is lost by air radiation and there is too great an area for oxidation of the metal in passing from the electrode to the work and there is too great an area provided for the air to get in and form oxide and nitride, both of which are very undesirable impurities in the weld. There is a further chance with a long arc that the electrode material will not be deposited in the parent metal made fluid by the arc, but spattered outside or overlapping, in which case no weld results.

" As shown, the electrode material must pass into the crater or fluid bowl of the work made so by the arc, and the electrode must be held in such a position that the metal can pass nowhere but into this fluid bowl.

" The fluid bowl only appears at the point the arc strikes, and the arc must be kept striking just ahead of the deposited metal partially in the parent metal or, to say it in another way, the arc must be kept at the advancing edge of the puddle. If the arc is allowed to draw back on the bead simply a bridge of metal welded from the weld to the point where the arc next strikes the parent metal will result. This exercise should be made with both flux-coated wire and bare wire. It will be noted that with flux-coated wire with the bare side advancing as it is designed, the flux coating will follow along, covering the molten puddle and preventing the arc backing up on the weld providing a close arc is held.

" To get the correct rate of heat for any given condition of electrodes or work the following test should be applied, and it is the best, in fact, the only test yet devised. Run a bead and note whether the edges are undercut as at Fig. 35*b*, overlapped as at Fig. 35*c*, or perfect as at Fig. 35*d*. If they are slightly undercut it can be told by looking at the bead, but the perfect weld and the overlapped weld can only be told by chipping off the beads. Different electrodes melt at different rates of heat, and different kinds of parent metal show small and large fluid bowls or craters, depending on their make-up, so that even with the correct length of arc this test should be applied for each new condition. The

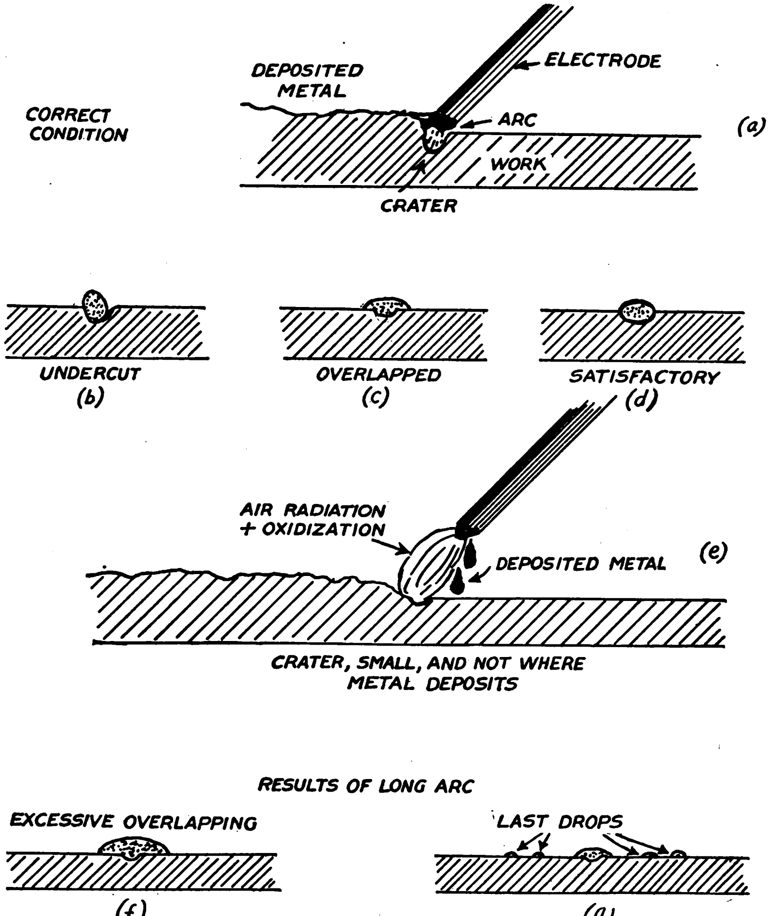


Fig. 35.—Running beads.

undercut in general results from a larger bowl than the electrode deposited to fill it, and the overlapped bead may result from this or from a long arc. Where the bowl is made smaller with an arc over $\frac{1}{2}$ inch long with certain current densities the bowl may disappear entirely, showing results as at Fig. 35*f*, *g*, and *e*, which also show how the results shown may be had.

" The bead should be run until proficient with the three main different styles of electrodes, that is, the completely coated electrode in which the arc exists inside of a viscous tube deposited at the same rate as the electrode, the idea being to keep the oxygen and nitrogen of the air from combining with the steel when molten and when it has its greatest chemical affinity. With this electrode a slag is left around and on top of the weld which must be chipped off for a clean start if the arc should happen to get out or in restarting to continue the bead.

" With the flux-covered electrode, bare side advancing, it will be noted that there is no danger of slag inclusion and that the slag can be crushed off and that in restarting there is no need for chipping the weld clean. The best way of cleaning the weld is by the same action which brings the slag and dross to the surface of the weld with this electrode. With bare wire there is naturally no danger of slag inclusion, but a continuous amount of the oxide and nitride of iron are included as the time for bringing them to the surface, *i.e.*, while the metal is too short to allow them to disentangle and come to the surface.

" After proficiency in running beads horizontally is attained the beads should be run on a vertical surface from the bottom up. Here it will be noted a close arc must be held or metal will run away. The next step is to run the beads horizontally on the vertical surface, and lastly, from the top down. By this time a close arc will be so natural that overhead welding can be attempted, but if not successful no worry need result, as it will come naturally in time. The most important things to be learned in running beads are: (1) Close arc, *i.e.,* not so close as to sputter, but close enough to crackle. (2) Keep the arc at the advancing edge of the puddle. Beads are used commercially to seal cracks, caulking edges, and as the first layer in butt and fillet welding for ductility.

" LESSON II

" SPREADING

" Here the electrode method is applied by moving the electrode from side to side at the same time advancing, *i.e.,* back and forth in a zig-zag manner as shown in Fig. 36*a*. The electrode must *not* be moved rapidly, *i.e.,* must not be moved faster than the arc can make the liquid bowl or crater and must be moved at an even rate, so that this crater becomes a trough into which the electrode material is deposited at an even rate. The rate of speed back and forth of the electrode must be the same rate as that used for the advance in running beads, and, in fact, each successive layer in spreading is simply crosswise beading done continuously and shortly, the welded metal becomes heated to such a point where a greater speed is attainable than at first. It will be noted that the completely-covered slag-coated electrode lends itself admirably to this method. It is much easier to apply this electrode by spreading than by any other method, as the successive movements from side to side keep the puddle of deposited metal in the centre as a river of metal with banks of slag, and as advance is made the banks of slag close over the metal a short distance behind the arc. This electrode in starting or restarting the cold slag must be chipped away, and it should be noted that the slag must be cold, *i.e.,* black before it can be chipped away. In merging the spreaded beads in these electrodes the edge to be merged must be chipped clean, else there is almost a certainty of slag inclusion in the weld. In spreading with a flux-coated electrode the bare side should be kept pointed towards the parent metal, and it will be noted that the flux coating forms an insulating slag, so that with a close arc it is a natural tendency to advance at the edge of the previous layer or bead, and not to back up on the already deposited metal. With bare wire there is no such aid and special care must be taken to not bridge over or leave voids in this method of spreading, *i.e.,* bare wire is least applicable to this method and completely-coated wire is most applicable, while the half-coated flux-covered lends itself to either spreading or padding by beads. Correct spreading is shown at Fig. 36*b* with the welded metal sunk in, or, as the experienced welder terms it, bit into, the parent metal. Spreading with too long an arc results in the deposited metal simply lying on the parent metal as at Fig. 36*c*, with no biting-in effect. Fig. 36*e* shows how padding can be accomplished by spreading, care being taken, of course, to merge the spread layers into each other, and it will be noted that this method is more applicable to a small amount of beading whereas beads are more applicable wherever the surface has to be raised higher. In general more heat and hence with the same length of arc more current can be used in spreading than by any other method, and with speed or rate of deposition of the metal with the arc at constant length

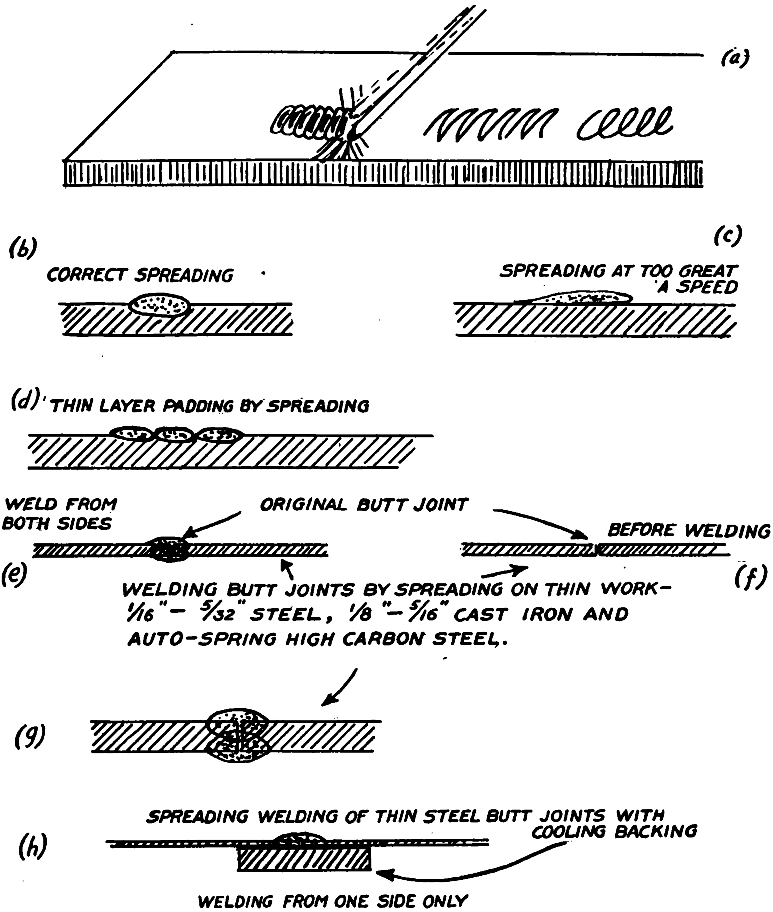


Fig. 36.—Spreading.

depends on the current; greater speed can be made by spreading than by any other method. This is because the parent metal is advanced over at a more rapid rate and hence a greater rate of heat in the arc can be taken care of by the weld conducting the heat of the arc into the parent metal. It is this action of heat conduction by welding that allows of the high temperature of the arc to be the correct results from mass temperature for molten iron and other metals. The fact that a weld is made conducting the heat away, and if a weld was not made as would be the case in depositing steel on a copper plate, the deposited metal would be burned beyond recognition at a rate of heat, and hence current adjustment with the right length of arc would be perfectly correct when welding into steel. Figs. 36*g* and *f* show an application of spreading to a butt-joint on thin work. By thin work is meant from 1/16-inch to 5/32-inch steel and ⅛-inch to 5/16-inch cast iron, or high-carbon steel, such as an automobile spring. Work thinner than 1/16 inch should be backed up as in Fig. 36*h*, with a cold mass such as another piece of steel or a water pad, so that the metal when molten for welding will not fall through. If the piece is of such thickness as in *e* and *f* that the spreading will not melt the edges so as to fall through, a spread can be put on both sides which will merge in the centre as shown, and weld without any preparation of the joints. Automobile springs being about 3/16 inch to ¼ inch thick can be welded successfully in this manner, and the excess metal of the spread ground off. The reason spreading is used for this comparatively thin work is the phenomenon that in proceeding with a bead the edges become too hot and fall through, whereas in lacing back and forth, as in spreading, more of the heat is carried into the parent metal.

"LESSON III

"PADDING

"Padding in general is a succession of beads run parallel to each other and offers a great field for usefulness in building up worn parts or parts machined down too far for subsequent machining to correct size. In laying these pads parallel the electrode must be held so that the arc bites into the preceding pad and the parent metal at the same time, as shown in Fig. 37*a*. If the arc is held as in Fig. 37*b* a good joint will be had to the parent metal, but little or no joint to the first bead, and in machining these welds voids will be found as black slag spots, as can be imagined from Fig. 37*f*. Fig. 37*c* shows these beads correctly merged, and Fig. 37*d* shows the beads perfectly welded to the plate but no merging, and hence no good for subsequent machining. In commercial padding the choice of running the beads lengthwise or crosswise of the work is to be had, and in general lengthwise is the more desirable, as the piece has more time to absorb the excess heat of the arc before returning to supply more heat. In either case the outer edge should be gone around with the bead for each layer, so that a sort of trough can be formed while the metal is cool and shows the least disposition to run away. For quick rough work this trough could then be filled in by spreading, but in general successive lines of beads is the more reliable method. After the method of a reasonably smooth pad on a horizontal flat surface, if attained, making a pad on a vertical surface is next in order, running a bead horizontally with successive beads directly over it and later making the pad both from the bottom up in vertical layers horizontally and from the top down. In making these pads overhead it will be noted that the only hard bead to put up there is the first one, and when

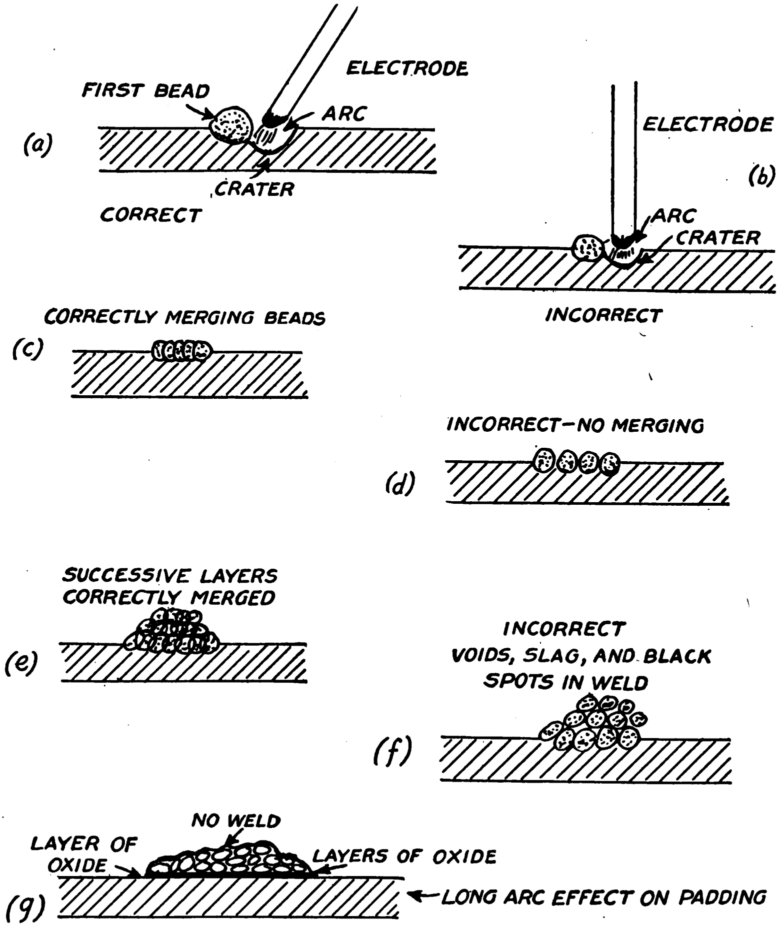


FIG. 37.—Padding.

welding against this first bead and the parent metal the student will be able to notice correct conditions for drawing the arc equally from both, as in that case the metal shows the least disposition to fall. The overhead welding has no function of negative or positive polarity, but simply the fact that one liquid drop will remain on the ceiling, excess over one drop falls, leaving one there, is the secret of overhead welding. It has probably been noted before this that in welding no drops should appear at the end of the electrode, *i.e.*, when the arc is held the right length and the metal flows evenly, the metal of the electrode passes through the fluid bowl as a gas or vapor and condenses on the parent metal as a liquid, rapidly changing into a viscous and then a solid mass. The rippling appearance of the finished weld being successively frozen ripples of the liquid pool due to the magnetizing effect of the current in the arc when just at the point of freezing. In general; overhead welding requires more current for the same conditions, as the arc must be held closer, which means slightly less voltage, and hence to make up the same heat the current must be raised. As stated before the one trick in overhead welding is in getting started and holding an absolutely unbroken close arc. A great aid in holding this close arc is for the student to rest his body and left elbow, if he is right-handed, against the piece to be welded, steadying his right hand holding the electrode holder.

" Another way is to put the right elbow up against the overhead surface and to use the elbow as a centre and guide for bringing the hand and electrode up at an even rate. In overhead welding the student will best see how the electrode must be fed into the weld at the exact rate the electrode is being melted. Another method still, in order to feed the electrode at an even rate, is to use the elbow of the welding hand resting on the knee and raising the toe at the rate desired. Another permissible method for welding and especially useful in overhead or vertical welding is to use a stick similar to an artist's maul-stick. Overhead welding even when unsuccessfully tried shows what is required for first and successful pads more quickly than any amount of verbal or written instructions. Padding by beads should only be done with bare-wire or flux-coated electrodes, as coated electrodes are only successfully applied by spreading, as shown in the second lesson. The one thought necessary in successful padding is the merging of the pads with the parent metal and with each other." [2]

[2] These lessons are published in full by the Electric Arc Cutting & Welding Co., Newark, N. J. They were communicated to the Author by Mr. C. J. Holslag, chief engineer of the company.

CHAPTER VIII

THE ALL-WELDED SHIP

THE first and last resolution of the group of experts gathered to advise the Emergency Fleet Corporation on the use of electric welding in the ship program urged the building of an all-welded ship. The last resolution carried with it the request for the organization to be formed and the money to be appropriated for this purpose. Such requests were never followed by authorization, and the all-welded ship, like other innovations, was for one reason or another never started. The advocates of the process never halted in their endeavors to suggest means of obtaining permission to build such a vessel and many progressive shipbuilders offered to undertake the construction if formally approved.

In the early deliberations it was not felt that the proposal to build a welded ship would be immediately acceded to, but when certain practical tests and demonstrations were completed there would result no hesitancy on the part of those in authority. This view was consistent with the times as greater innovations were readily sanctioned. So that no time might be wasted, the investigational work, both practical and theoretical, was pushed with all haste, data in great quantities gathered, and the educational work was laid down in some systematic form. Without a great deal of effort, it was found that the shipbuilders were using the process very sparingly and efforts were made to find the reason why the non-essential parts of the riveted ship were not arc welded. Some shipbuilders were doing a little of this work but wished to do more, and the question of permission rested with the classification societies. This excuse, if it were such, was soon expunged by a joint approval by Lloyd's Register and the American Bureau of Shipping of a list of ship's fittings which could be arc welded (see Appendix). It was objected that this list referred only to jobs with which ordinarily classification societies did not concern themselves. These societies had gone further by a clear statement that upon submittal with full information they would consider for approval proposals for arc welding "other parts of the vessel." It was this last expression that gave rise to the probable extension of arc welding to a standard riveted ship with the result that a special committee was appointed to give views on this subject.

Welding a Standard Riveted Ship.—Realizing fully the greater benefits that would accrue in a welded ship designed from the point of view of this process, still it was believed that the standard riveted construction could be more expeditiously put together with the electrode than by riveting, riveting work being at that time the reason claimed by shipbuilders for the delay in ship deliveries. The steel shapes and plates were being delivered by the mills in ample time; and quantities of material unfabricated could be assembled in the way selected. This naturally would not show the saving in cost nor the reduction in materials and weight that was inherent in the electric-welding process when used to the full; but still there would be a small percentage of saving. The main assumption was not commercial economy but saving of time, the serious problem then facing the country. The report of this sub-committee showed that speedy construction would follow the omission of water-tight stapling required in riveted ships, the omission of all cementing of decks to the shell, as the electrode could guarantee water-tightness, the omission of all laps, liners, jogglings, straps, etc., in the shell plating above the bilge by employing butt-welded seams—the same thing was recommended for decks. Riveting of shell plates to frames was suggested as a conservative measure. Spot welding of the brackets to frames or beams and the spot welding of floor plates to frames, reverse frames and clips, was considered feasible if done in the shop and these assembled parts arc welded to the other members in the ship. Spot welding was also recommended for the attachment of cargo battens and other fittings. Additional suggestions included all non-strength members, all deck erections, smoke pipes, up-take, ventilators, ducts, combings for hatches, and man-holes, door frames, separately-built tanks, lockers, and racks. The masts, booms, shaft and pipe tunnels, and similar cylindrical work usually riveted in two pieces were to be welded throughout, omitting the straps. Cast-steel fittings were to be welded to plates. Oil tanks were to be welded "even in conjunction with riveting." Swash plates could be tack welded to decks and bulkheads omitting the flanges in order that these plates might be washed away without endangering the hull proper. The recommendations also include the welding of all stanchions both head and heel, pipe railing, and all flanges on steel pipe and tubing.

It is easy to see that this detail list covers the welding of approximately 90 to 95 per cent. of the ship. In fact, it only reserves for riveting the main strength members of the hull. This suggestion was never put into effect. It occasioned a full discussion on the merits of combining arc welding with riveting and established the opinion that an arc-welded and riveted joint was not satisfactory.

For emergency repairs certain riveted joints had been arc welded along the edge instead of caulking. The damaged part had destroyed the caulking edge. These jobs were carefully watched. The riveted joint, if not reinforced by a strength weld, *i.e.*, if the edges were simply made water-tight with a fillet weld, due to the creeping action, would throw the strain upon the welding. The water-tightness of the joint would then be impaired. If a strength weld were made on the edge, all strains would be taken off the rivets and they would serve no good purpose. In repair work it was found desirable to weld on a thin-flanged piece over the entire riveted joint. This flanged piece allowed sufficient play to the riveted joint and yet would not tend to open the welded joint. In this manner a good water-tight job could be obtained.

Welded Craft.—As far as is known the first water craft to be partially electrically welded is the *Dorothea M. Geary,*[1] a motor boat built of steel and 42 feet in length. She was launched about the end of November, 1915, and is used for ship repairs in Ashtabula Harbor, Ohio. Although the small size of this boat and the thin plating (about 3/16 inches thick) used for shell and

[1] "The First Electrically-Welded Boat," John Liston, *General Electric Review,* December, 1918.

decks may not assure the conservatives that 10,000-ton ocean-going cargo vessels may be built likewise, yet the record of the boat in service is remarkable from the standpoint of the strength and fatigue-resisting qualities of electric welds. "On December 17, 1915, shortly after the launching, a call for repair work was received from Fairport Harbor, distant about 30 miles, and although Lake Erie shipping was practically suspended at that time owing to weather conditions, the welded boat was at once headed into the lake which was covered with floe ice and made the run to Fairport in about three and one-half hours. When the harbor was reached it was found to be covered with four inches of solid ice, and into this the welded boat was rammed, breaking her way through, at reduced speed but without a stop, to the pier where the ship she was to work on was laid up. After the return to Ashtabula careful inspection of the boat failed to show that any injury had been sustained." [2]

And again: "In the following year an accident occurred which threatened to destroy the welded boat. Work was being performed aboard the freighter *Alexis Thompson* in the Superior Slip at Ashtabula, the welded boat lying alongside, when the freighter *C. Russell Hubbard,* which, moored at the opposite side of the slip, broke adrift, swung across the slip, literally squeezing the small craft between the two large freighters. . . . The sides of the welded boat being crushed into a maximum distance of 18 inches amidships. . . . This damage was repaired by means of jacks which were used to force the sides back into normal position. . . . Leaks were

[2] "The Electrically-Welded Boat," John Liston, *General Electric Review,* December, 1918.

started, but investigations showed that they were again due to loosened rivets and not to any failure of the weld."

The edges of the plates were V'd for butt welding and a metallic electrode was used of approximately the following constituents: Carbon, 0.10 per cent.; manganese, 1.87 per cent.; and a trace of silicon. The keel was electrically welded, but the hull plating was riveted to the frames and keel, and " the structure above the deck line was riveted and strengthened with angle iron." The welded seams were left reinforced, and after welding were " pneumatically hammered."

In 1917, a 60-foot section of a 1200-ton bulk-oil barge[3] was electrically welded in this country. The remainder of the barge was the usual riveted construction. This craft was for service in Mexico. She was 165 feet long, 38-foot beam, and about 8 feet 6 inches in depth. She was constructed of $\frac{1}{4}$-inch plates for decks and shell, and the transverse members were of 5/16-inch plating. It is stated that this barge carried nearly a full cargo from New York to Tampico, a distance of 2500 miles on the ocean, without harm to hull or cargo. " No repairs have thus far been required, notwithstanding the barge has been in service about twelve months as a bulk-oil carrier on the Panuco River, where the rapid currents, wind, and tide, combine to make navigation difficult."

Reference has already been made to welding activities in England. In the early part of 1918 there was built an all-welded cross-channel barge.[4] This craft had a deadweight carrying capacity of 275 tons. The frames were $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$-inch steel angles, the floors were

[3] Report of Capt. James Caldwell to the U. S. Shipping Board, 1918.
[4] Report of Capt. James Caldwell to the U. S. Shipping Board, 1918.

$7 \times 3\frac{1}{2} \times 7/20$-inch angles, and the shell and deck plating $\frac{6=5}{20}$ inches. The edges of the shell plating were joggled in order to provide flat welding and to reduce overhead welding to a minimum. Holes were punched for assembling the vessel in the regular manner. These holes were spaced about $10\frac{1}{2}$ inches to receive the service bolts for erection purposes. After the welding was completed, the holes were closed by the electrode. The shell seams were full welded on the exterior, but tack welded on the interior. She was divided by three water-tight bulkheads. The hull was flat and there were four strakes of plating to each side.

Though minor leaks were discovered on the first loading, the barge has been in successful use across the channel and has shown no signs, according to last reports, of anything detrimental to the process.

Careful records of time and cost were kept for comparison with riveted barges of the same size and type. It is interesting to note that the total cost of electric welding was $1500. Of this item $310 represented cost of labor, $300 the cost of current, and $890 the cost of electrodes. This latter item is high, due to the use of the slag-covered electrodes, which is the approved practice in England.

Next of interest is the time of welding. At the commencement of the work, the average was about 4 feet an hour, but towards the completion this increased to about 7 feet an hour. During the work a maximum of 14 feet an hour was attained.

In 1918, arrangements were completed for the electric welding of a battle-towing-target keel, to be built at the Norfolk Navy Yard. This structure is built of steel shapes and plates, and functions under water to support the wooden target which is destroyed by gun fire. Although not rightly classed as a water craft, still the shock, strains, and stresses that are so much the concern of those who design and build steel vessels will be suffered by this keel. It is unnecessary to detail the con-

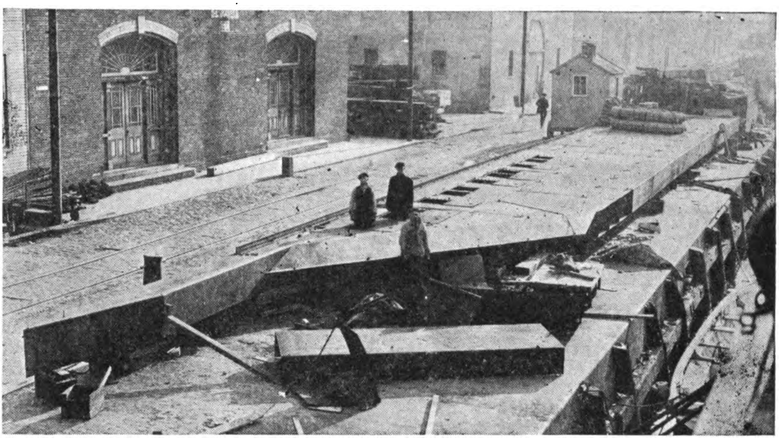


FIG. 38.—Battle-towing-target keel.

struction elements. A very good idea of the keel is given in Fig. 38. This structure is now completed and awaiting the wooden super-structure. When this latter is built and their combination effected, the entire target will be tested at sea. Full reports of the trial of this keel in service will probably be available after the navy has completed its investigations.

Patented Designs.—During the war, two American-patented designs for welded ship constructions were patriotically offered for the use of the Emergency Fleet

Corporation. As will be seen, these designs were not accepted, and drawings were prepared for a proposed welded ship by a special sub-committee. Without entering into a mass of patent claims, one of these American designs [5] was characterized by omitting many of the small connection pieces used in regular riveting construction and thus reducing weight and cost. By tack welding of clips and lever fulcrums temporarily, the usual run of badly twisted shapes and plates could be straightened preparatory to welding. By this same method it was claimed that an entire ship could be easily assembled without the use of assembly bolts, thus avoiding the expense and damage to the work material by punching holes. As the fulcrum clips and handling attachments were only lightly welded, they could be readily knocked off the original metal with little loss of time and no damage.

The other American design [5] was based fundamentally upon the conception that angle bars, which are necessary to a riveted connection, were unnecessary for the welded connection. With this in view, the construction of a vessel was reduced to the use of plating throughout. The design carried the requirement that one edge of the plate be flanged. Thus in the case of the shell plating the flange served as a continuous longitudinal member. The design embodies the best strength qualities with reduction of weight of both the transversely- and longitudinally-framed vessels. By cutting notches in the straight edge of the plates at desired intervals, bolts could be used to draw up and secure the work for

[5] Capt. James Caldwell's Report to the U. S. Shipping Board, pp. 109 and 93, 1918.

welding. This method of assembly was not essentially different from present practice. The main objection to this design was the fact that the plates must be flanged at the mill, as the run of ship structural steel would not permit of cold flanging. As the larger percentage of material was required to be flanged, it would seem from the standpoint of standardization that the design merits consideration.

An English patent shown in this country differs from the last American design in that it clung to the angle-bar connection. Instead of employing continuous welds along the edges of the angle, it preferred to notch out the angle flanges with desired spacing and then arc weld at the notching, if the bounding bars were simply for holding together non-water-tight members. If the compartment was to be water-tight, then one edge and the notching of the angle bars were welded. Straps were prepared with elliptical holes, so that they would be welded as well as the edges. The whole design was considered from the point of view of the fusion of all the parts requiring to be joined. In such places as the inner bottom of the ship, where lengths of moderately-thin plating would affect the jointure by panting or fatigue stresses, brackets formed by angle bars were welded as required. Evidently this design had in mind the reduction of welding, but seemingly the preparatory work on the original materials would exceed the saving in arc-welding labor and materials. In view of the American design discarding the angle bar, and the results of tests of both butt-welded joints in flat plates and cross connections, apparently there is little merit in this patented construction.

Emergency Fleet Corporation Design.[6]—This design was made under pressure due to the exigency of the time. No more than three weeks were given for the preparation of complete drawings of both the ship and a proposed yard in which to build her. At that particular time, no shipbuilder would consider the proposition of building any more ships. There was a growing shortage of labor, and riveters were scarce and costly. The objects sought in this design were a ship that could be quickly manufactured, not built, a method of shop procedure that would not make further demands on a depleted labor market, and yet a restriction of design that would not exceed the possible workings of the economic law.

For general outlines, accommodations, propulsive machinery, etc., a standard ship was taken as a guide. The majority advice of welding experts was taken in the adoption of, and the approximation of, percentage strength of the electrically-welded joints. At that time, the consensus of opinion was that the strap-joint with three full-strength welds was the strongest joint. This design of joint was used in all connections of principal members. Where plates met at right angles in cruciform, full-strength welds were provided. At the time of design, it was considered conservative to provide a bearing strip to distribute the thrust where a plate was connected at right angles to another unsupported plate. After discussion on this point, other methods were suggested for overcoming this difficulty without resort to the bearing strip which in the minds of some experts was a detriment to the connection.

Perhaps the most radical departure from a ship-

[6] Supplement of *Nauticus,* June 1, 1918, N. Y.

design viewpoint was the use of transverse plating instead of the customary longitudinal plating. When the design was first discussed the question was asked: What is the function of the shell plating of a ship? The reasonable answer is contained in the familiar name " the skin of the ship," *i.e.,* it keeps the water from coming in and prevents the cargo from going out. In short, the shell of the ship has but a small share in the strength of the ship. In this design, the strength of the hull was more than conservatively designed. The keel, the centre keelson, rider, bilge plate, shear strake, and upper-deck stringer, were planned in long lengths and with few joints. These joints were carefully distributed. The calculations of the naval architect showed that a section through the cargo hatch as designed was stronger by 10 per cent. than the riveted vessel. The practical purpose served by the transverse plating was that it gave a method for manufacturing ships.

Adopting a 6-foot-wide plate, the design provided for putting the ship together in sections the width of the transverse plate. Each plate was fitted in the shop with two frames and their connections. There were two of these pieces, one for each side of the vessel. Two sections of the floor were likewise built in the shop and two 6-foot deck sections with two beams attached, one for each deck, completed the pieces, making up one 6-foot section. The plan of operation was to build these pieces under shop-production methods and so arrange the work that each day one 6-foot section of the vessel would be completed. Thus plans could be made ahead of time to follow a strict schedule. As these details would become standard procedure, more time on the part of executives, superintendents, etc., could be devoted to the delays usually connected with the fitting up of the vessel.

To meet this manufacturing scheme, a yard plan was devised. This consisted in the establishment of one, and only one, way to build the ship, from stern to stem. A crane was designed to move up the ways, handling the pieces from the shop, until they were securely welded, and then moving on for the next section. This was more than a crane, it was a moving shelter for the men and shops with the addition of flexible scaffolding. The estimates showed that a 6-foot section could be erected and completely welded in one working day of eight hours; which meant that when such a shipyard was working under its best efficiency that a standard ship of 410 feet could be completed in seventy-five working days. This estimate is on the basis of a single shift of operators.

The designs as submitted were widely criticised, and, curiously, on one point, namely, that it was not a rivetless ship. The frame brackets were riveted to the beams. This was considered a conservative measure by the design committee. Opinions were pronounced for an all-welded ship, based, no doubt, on the sentiment that an innovation must stand on its own feet. Then, as time went on, shipbuilders claimed that their works were progressing so rapidly that shortly they would have vacant ways. There would be no necessity for a special yard in which to build the first welded ship. At once with this argument, all the fundamental reasons for its being deprived this welded-ship design of further consideration. No longer did there exist a shortage in the labor market, no longer were people at large aroused at the shortage of ships, no longer did the foreign cables cause sensations, and no longer did the shipbuilder worry over the delivery of completed tonnage. And soon to follow this were the straws of the Armistice.

Isherwood Welded Ship.—Just before the news of the cessation of hostilities, Mr. J. W. Isherwood brought to this country from England a design of a 3900-ton deadweight ship which could be electrically welded. The application of welding was made to his well-known patented longitudinally-framed ship. The main objects sought were: (1) Adaptation to existing shipyards, *i.e.*, all the pieces fabricated in the shops could be easily handled on the ways by the crane service provided for riveted ships; (2) a careful reduction of overhead welding, especially in the field work; (3) the use of service bolts as customary for the assembling of the hull materials; and (4) the small amount of welding necessary in the field. Full details of this interesting design will be found in the Appendix. Mr. Isherwood stated that: "This design was prepared by me in London with the coöperation of Mr. W. S. Abell, Chief Ship Surveyor of Lloyd's Register of Shipping." This gives added weight to the design, if indeed it were needed, as the inference is that the rules of Lloyd's for electrically-welded ships have been fully considered. The designer has provided broadly for any play of conservatism that might question the electrically-welded process, and he believes as a matter of economy that, where many service holes would be required for proper fairing, the punching of a few additional holes and riveting that particular connection might result in an increased speed of construction and a reduction of cost. In general, he has taken the very best and safest points of the welding process and combined them with the best and most customary shipbuilding practice. As a careful study of his design will show, every eventuality in electric welding has been considered and as well an inclusion of the possible developments of the art.

With this design as a basis, it was not difficult to increase the size of the vessel to 5000 tons deadweight. And as by that time the majority opinion was favorable to the larger-sized vessel, negotiations for the commencement of work on a design of this type were about to be effected through the formation of a proper organization when the activities in electric welding were postponed, due to the close of the war.

Lloyd's Rules.[7]—Before the issuance of requirements for the use of electric welding in ship construction, Lloyd's Register made specific investigations of a technical and practical nature. That is, the tests were made on fairly-large samples and careful measurements with delicate instruments were taken. Realizing that many tests of the ultimate tensile strength of electric welds had been made but that other and more important characteristics of the joint had not been considered—these being essential to the construction of ships—experiments were performed to determine if there were any differences in the modulus of elasticity of the weld and adjacent plate; or at least a difference that would prohibit the use of the process. Experts in the testing of steel were not surprised at the results which showed that " the difference in elasticity between the weld and the plain

[7] See Appendix.

plate is negligible."[8] This deduction was made upon the completion of the welded sample, but the same authority states: "To obtain further information regarding the properties of this deposited material, small test pieces were prepared entirely composed of it, and the modulus of elasticity thus determined was found to be 11,700 tons per square inch as compared with about 13,500 tons for mild steel and 12,500 for wrought iron."

Although ultimate strength tests were made for a comparison between treble-riveted lap-joints and lap-welded and butt-welded joints, the most important tests from a structural viewpoint were those subjecting the joint to alternating stresses. The results indicated that, whereas the welded joint would break down under repeated stresses (5,000,000) with 6 tons per square inch, the unwelded test pieces would not break down until they had reached 10 tons per square inch. Alternating-stress measurements were taken on various types of joints, all of which led to the following conclusion: "These tests showed generally that welded material will not withstand a very large number, say several millions of alternations, if the applied stress is greater than about plus or minus 6 tons per square inch. The capability to resist alternating stresses is, of course, of the very greatest importance in shipbuilding materials, and would appear for the present, at least, to limit the application of welding to vessels in which the stress is not exceeded. The calculated stresses in ship structures are in the case of large vessels rather in excess of this figure, although, from such information as is available on the subject, it

[8] "Electric Welding for Shipbuilding Purposes," W. S. Abell, *Journal of East Coast Institute of Engineers and Shipbuilders*, 1918.

would appear that the stress actually experienced by the material in a ship is considerably less than that calculated under the usually-assumed conditions. It is well, however, to proceed cautiously in the application of a novel method of construction like electric welding, and it would probably be wise to limit its application meantime to vessels whose length is not greater than about 300 feet."[9]

Specialists in electric welding, though interested in all these investigations, were disappointed for one reason, namely, that the welded samples were all made by one process. In a practical sense this may be looked upon as unfortunate, but in a technical sense the maintenance of a constant electrode material, current adjustment, and skill of operator was more important. One of the difficulties to the introduction of electric welding has been the claims of those who prefer some special system or appliance. And confusion must result where all the different modifications to the simple practice are intermingled in elaborate tests. Let it be squarely said that Lloyd's Register has announced rules which require a certain process to be employed. They have also announced that they will undertake to approve any process of electric welding which meets their rules and which in the judgement of their technical staff qualifies it for the joining of ship's steel.

Summary.—From the preceding outline of the development of the all-welded ship, it will be seen that in this country the proposals did not advance beyond the point of design. In England it proceeded to the actual laying down of a coasting vessel 150 feet in length. The

[9] "Electric Welding for Ships," W. S. Abell, *Journal of East Coast Institute of Engineers and Shipbuilders*, 1918.

latest advice concerning the building of this vessel indicates that the work is proceeding at a slow rate. The underlying causes are concerned with commercial matters which cannot be discussed here. With the removal of the impedimenta surrounding the technical ability of the welding processes to joint heavy structural pieces, there can exist but optimistic feelings that practical obstacles will vanish in the future.

CHAPTER IX

Theories of Electric Welding

It is proper to state that unfortunately the nomenclature of electric welding is not clear. This makes doubly difficult an exploration into the field of theories. In the matters already treated the terms used have been those customary to practice. It may be better for what is to follow to explain the general conception of welding and what is meant by "autogenous soldering" or "autogenous welding."

The word "weld" in accordance with the dictionary is of Anglo-Saxon origin, probably related to the verb "well," to gush. "Welding," as a term for the modern processes of joining metals, is in dispute. Some experts hold that it is not fully descriptive of what takes place in the process; others claim that used as a general term it creates confusion; and still others in order to conserve time immediately divide "welding" into two parts, calling one "pressure welding" and the other "autogenous welding," and proceed to define these branches. Historically, welding as performed by the blacksmith was the union of two pieces of metal with or without an external source of heat or without fusion. That is to say, that metals in a cold state can be united by pressure derived by striking with a hammer, although the force of the blows or friction might impart some heat to the union. This is an approach to a generic definition of "welding."

Much confusion has grown around the use of the words " soldering " and " autogenous." It is generally accepted that when a metallic joint is affected by means of some external unionizing medium which adheres to the pieces to be joined and closes up the gap between them, this is " soldering." The unionizing medium is usually a softer metal or alloy melting at a lower temperature than the parts to be joined. " Brazing " does not complicate matters because the term is used restrictively for a hard " solder," one that melts at a relatively high temperature. But the word " autogenous," said to have been introduced by the French, gives much trouble. The word is from the Greek, and means self-generated. Evidently considered applicable to the carbon-arc process and oxy-acetylene process when joining thin sheet metal, as the soldering rod was not requisite. If the term " autogenous " gives the conception of furnishing or generating its own heat, then those who claim that arc welding with the metallic electrode should be called " autogenous soldering " are not without justification. On the other hand, if the conception of metallic arc welding resides in the electrical view that the heat is produced by the arc and that this metallic vapor is furnished by an external source of energy, there can be nothing " autogenous " about it. In the same sense this word is held by the advocates of the oxy-acetylene process.

Forgetting terms for the moment, there is marked distinction between the joining of metals by the two electric methods. In the former, called " welding," pressure is used and the heat is localized by the resistance to the flow of electric current; in the latter no pressure is applied and the heat is localized through the action of the electric arc. These characteristics are fully differentiated by the accepted nomenclature, the former termed generically resistance welding, and the latter arc welding. Of these genera, two species have been selected for special investigation, respectively, " spot welding " and " metallic arc welding."

Spot Welding.—There are very few theories to be found for the effects produced by spot welding. This is specially the case with the spot welding of heavy materials as the development in this line is of very recent date. It is a fertile field of investigation and should be undertaken while the process is on the threshold of industrial acceptance. Some work was done in the related process of butt welding,[1] though the investigations were cut short at an important point. The heat treatment of steel has received careful study because the employment of this metal is of necessity to the industries. It is well known that the grain structure of steel can be materially changed after being strained by annealing. It is an every-day affair in manufacturing lines to thus remove the harmful effects of cold-worked steel or to soften, strengthen, or harden, rolled or forged steel in order to adapt its physical properties to specific uses. But little is known of the effects produced by strains at the immediate moment of heating and this is the crucial question connected with spot welding. Those who have watched the practical operation of making spot welds question the need of high pressures except for making good contact at the electrodes, and for holding the lapped pieces firmly together. A poor contact between the pieces is a

[1] " A Study of the Joining of Metals," J. A. Capp, *General Electric Review*, December, 1918.

desirable condition because a high resistance at that point localizes the heat. If an excessively high pressure is not required, or is a disadvantage to the grain structure for the right quality of weld, then the designer of spot-welding apparatus would welcome the news, because the pressures now employed for heavy steel sections work a hardship on the electrodes.

There are two theories of spot welding that have recently come to notice, though it should be remembered while considering them that it has not been possible for either of the investigators to enter into a consideration of all the questions involved. The first investigation was made with rather medium material, about 3/8-inch mild-steel plates, and the deductions made were all of a metallurgical character. The second was made upon the hurried request of the author who submitted two samples of spot welds in 5/8-inch mild-steel plate. The second investigation reduced the matter, at least for the present, to the ordinary behavior of the structure of steel under the effects of heat. The former theory for the sake of exposition will be called the metallurgical theory and the latter the heat theory.

Metallurgical Theory.—This theory was advanced by its author Mr. E. E. Thum,[2] in an article entitled "Electric Welds" which appeared in the September 15th issue of *Chemical and Metallurgical Engineering,* 1918. It is interesting not only as a metallurgical observation but also as one of the first contributions to a study of the changes in the structures of mild steel when submitted simultaneously to high temperatures and great pressure.

[2] Assoc. Ed., *Chemical and Metallurgical Engineering,* N. Y.

Mr. Thum describes a comparative test of the strength of a rivet as compared with that of a spot weld. "Four 3 × 8-inch bars were cut from 3/8-inch stock structural steel plate. Two of these were riveted together with two 3/4-inch rivets, one driven 1 1/4 inches from either end; while the other pair were spot welded at corresponding points with a machine designed to give a weld 7/8 inch in diameter. The bars were then laid flat on end supports, bent through about 45 degrees by a concentrated central load and sawed lengthwise throughout, cutting through the centre of the connection. . . . The bars riveted together slipped past one another, shearing the rivets, while the bars welded together showed absolutely no movements at the ends nor did a microscopic examination of the weld show any indication of plastic yielding."

It is to be noted that small blow holes were observed in the weld which is explained on the basis that "the sheets were taken from a stock pile and no attempt made to clean them of rust or scale before welding. At the time of welding little chance was given for any extrusion of hot metal, owing to the continuous lateral support of the heated area; in this manner any impurities which originally existed on the surfaces of the plate would be trapped and retained."

Although Mr. Thum observed a peculiar structure "to a greater or less extent in all the spot-welded low-carbon-steel plates," which was not noticeable in the butt welds examined, he found this peculiar structure best developed "near the outer edge of the spot-welded structural plates" used in the above experiment. The structure referred to lies next to "spheroidal mass at the centre of the welds " and " grades into the unaffected original stock less abruptly." The micrograph illustrating his article shows " parallel striations " and foliations which he believes suggests pearlite " which it evidently cannot be, since the original metal is ordinary structural steel, whose micro-section gives the typical hypo-eutectoid appearance." He next suggests the resemblance to martensite, but puts this aside on the basis that " low-carbon steel would not be expected to develop such large quantities of martensite nor would martensite be expected in separating zones of sorbite and pearlite." He then considers a possible explanation on the assumption of annealing twins, mechanical twins, X-bands or slip bands, but these conditions under which the structure forms eliminates all of these suggestions. This leads to the question of the " suppression of the carbonaceous areas so prominent in the centre of the weld and in the original stock."

After tracing in detail the temperature in the various ellipsoidal zones forming the spot weld and clearly delineating the growth and subsequent contraction of the heated areas, he then forms his opinion which follows: " The austenitic spheroid, being directly between the dies of the welding machine, is under considerable compressive stress, but is unable to flow any measurable distance owing to its uniform side supports by relatively rigid metal. Extrusion of a fin as in a flash weld is evidently impossible, but the highly-stressed crystals of austenite develop their characteristic octahedral cleavage planes exactly similar to those accompanying the surface slip bands appearing in a polished surface after its underlying metal has been severely strained. On cooling through the transformation range, the austenite tends to precipitate its excess ferrite—each crystal rejects the sorbite to its boundaries, hence the ferrite tends to gather along the cleavage planes. Thus the central position of the weld is largely of dark-etching troostite or sorbite, but close examination shows a well-defined hair-like precipitation of the excess ferrite fringing many of the allotriomorphic crystalline boundaries, and numerous very fine, white, parallel striations crossing at 60 degrees appear in one of the dark areas near the centre of the original micrograph. Very definite ' fringes ' of larger parallel ferrite needles extending inward from the grain boundary are seen near the edge of the sorbitic zone.

" Just outside the darker-etching zone (in the region of eutectiform structure) a peculiar conjunction of pressure and temperature occurred. During welding the temperature passed the transformation range, and the pearlitic areas passed into austensite. Migration of carbide, to equalize the carbon contents of these original austenitic crystals, must have been extraordinarily rapid. The austenitic crystals were at the same time fractured along their octahedral cleavage by the compressive stress of the welding dies, exactly as indicated in the discussion of the underlying dark-etching areas, and on cooling, after the electric current had been interrupted, each little lamina bounded by the parallel cleavage planes acted as an independent crystal in expelling ferrite to its surfaces. Hence the ferrite marks the sub-microscopic cleavage planes; or rather, the thinnest plate of eutectoid remains at the nucleus of each crystalline lamina. After polishing and etching, the eutectoid films etched dark as a series of straight lines crossing from boundary to boundary of the original crystalline entity. Evidently the process of extruding the ferrite from the original austenite laminæ was just completed when the cooling of the zone in question prevented the further molecular mobility necessary for the agglomeration of the thin plates into balls of less superficial areas, which is the normal appearance of low-carbon steel."

He completes his interesting paper with a comparison of this " peculiar structure " to the appearance not of the Widmanstättian structure as ordinarily illustrated, " but the close-packed W-bands . . . on a lower magnification," and then states that, " Howe and Levy observe the same general appearance in over-strained and heated austenitic manganese steel, caused by the same train of events, that is to say, first fracturing the original austenitic crystals of the quenched metal along their cleavage planes and thus forming a multitude of new crystalline entities."

Heat Theory.—Reference to Table XII, Chapter IV, giving the results of tensile tests on thirty spots made in one 10-foot length of lapped 5/8-inch structural-steel plates will show that " spot No. 5 " was held for other tests. The same will be noted for " spot No. 8 " in Table XIV, Chapter IV. These samples were called respectively " bad weld " and " good weld." They were sent to Mr. S. W. Miller, proprietor of the Rochester Welding Works, who kindly examined them and prepared the micrographs (Figs. 1, 2, and 3).

The " bad weld," No. 5, in Table XII, lay between spots 4 and 6 which show an ultimate tensile of 19,700 and 28,600, respectively, hence the name given the sample. The " good weld," No. 8, in Table XIV, lay between spots 7 and 9, which show an ultimate tensile of 64,700 and 52,600, respectively. This was considered practically " a good weld," because these tests were to convince those interested that uniform spots could be made that would exceed the strength of a single rivet shear of the size required for the stock material by ship classification societies. Lloyd's for ⅝-inch steel plate would require a ⅞-inch rivet which is calculated to shear at 34,100 pounds per square inch. So the " bad weld " was only about half as good as the required rivet and the " good weld " was about half again as good as the specified rivet. The mechanical pressure, the current, and voltage, were held approximately constant; thus maintaining only two variables, time and condition of materials. As to the latter, the slag and mill scale was undisturbed on the lapped surfaces of the plates, but the surfaces next to the electrodes were ground down with a portable hand grinder. As the tables show, the " bad weld " was given 18 seconds of both mechanical pressure and current, and the " good weld " was given 25 seconds of the same treatment. Although no chemical tests were made to insure the exact composition of the ⅝-inch steel plate, this material was taken from stock which was purchased under the specification requirements of the American Society for the Testing of Materials, which usually conforms to the following analysis:

Sulphur	0.04 per cent.
Carbon	0.22 per cent.
Phosphorus	0.01 per cent.
Manganese	0.41 per cent.

Figs. 1 and 2 show a section cut through the spot welds and magnified to double the size. Mr. Miller's notes on Fig. 39 showing the " bad weld " are as follows: " Small defects in centre probably due to shrinkage. Grain at 'A' is very coarse, at 'B' very fine, and at 'C' coarser than original, but not bad. 'A' and 'B' are shown on continuous micrograph (Fig. 41), but 'C' is not shown. 'D' shows columnar grains due to high

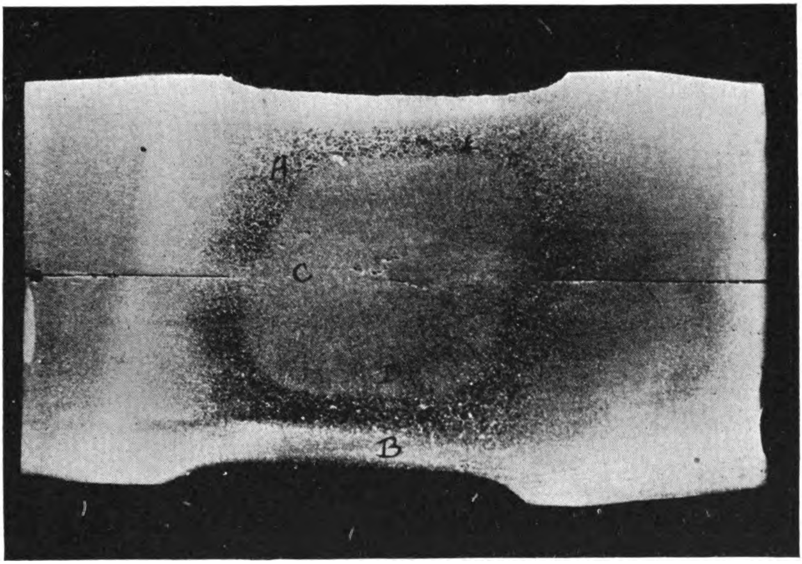


FIG. 39.—Bad weld magnified about twice. Small defects in centre probably due to shrinkage. Grain at A very coarse; at B, very fine; at C, coarser than original, but not bad. A and B shown in Fig. 41. D shows columnar grains due to high temperature and rapid cooling. Grain at C equiaxed due to slower cooling.

temperature and rapid cooling. Grains at 'C' equiaxed due to slower cooling. Referring to Fig. 40 showing 'good weld,' the notations are the same as in Fig. 39. 'E' crack at end of weld probably due to shrinkage. In course of time these might be dangerous. 'F' spot of oxide in plate not caused by welding, original defect. Columnar grains 'D' very clear in this specimen. Referring to Fig. 41 this is a continuous micrograph at 100 diameters taken from the edge of ' bad weld ' (Fig. 39) towards the centre. The ' good weld ' is the same except in degree. The union in both welds is perfect."

Mr. Miller explains the development of the steel structure as shown by these particular samples as fol-

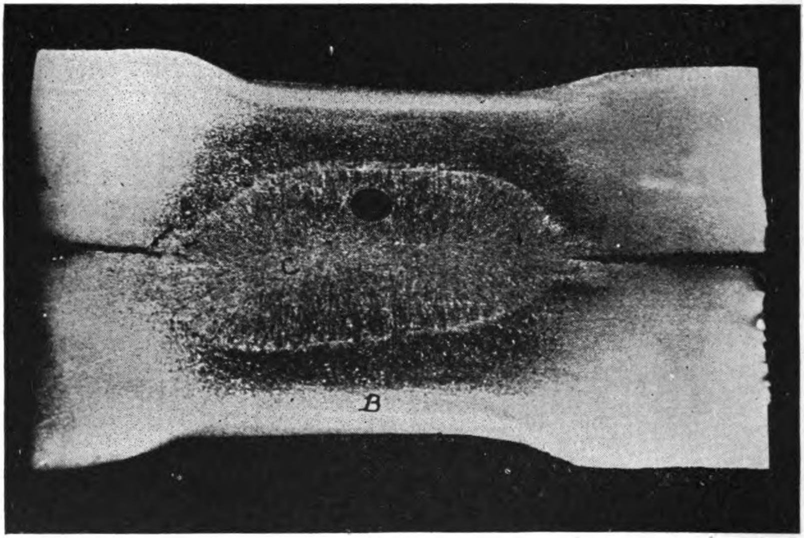


FIG. 40.—Good weld magnified twice. Grain at A very coarse; at B, very fine; at C, coarser than original, but not bad. E, crack at end of weld probably due to shrinkage. In course of time these might be dangerous.

lows: " I have spent considerable time in examining the structure of these welds under high power. I was very much interested in examining them in view of a letter which I received from Mr. Thum, western editor [3] of *Chemical and Metallurgical Engineering,* in which he claimed to have found in spot welds (made, I think, in lighter material) a very peculiar structure which he

[3] Now Associate Editor.

accounted for in a very peculiar way. I have been unable to find any evidence whatever of the structure to which he refers, or anything resembling it.

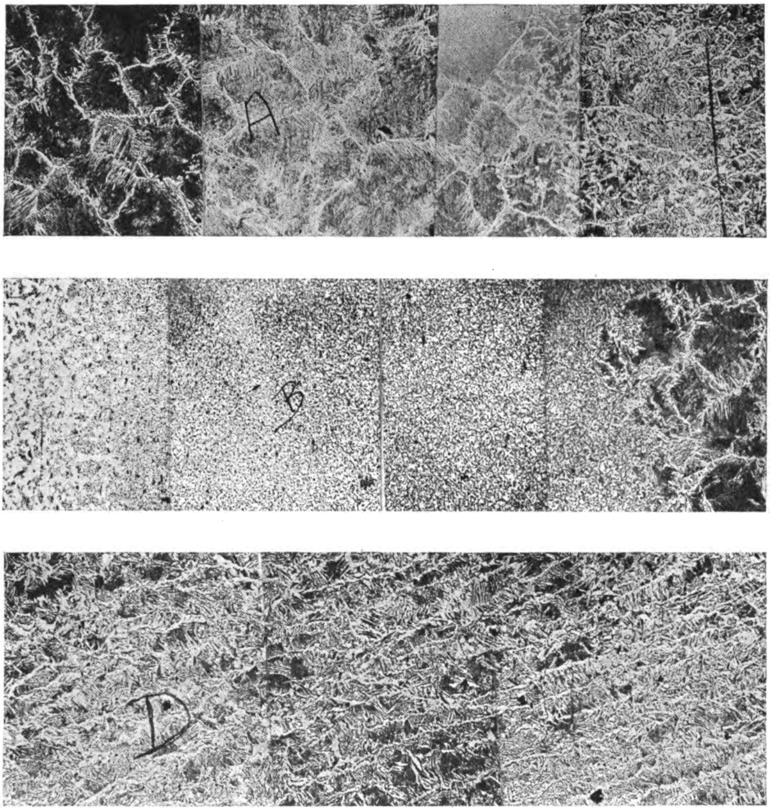


FIG. 41.—Continuous photograph of structure at 100 diameters from edge toward centre, taken from bad weld. The good weld is the same except in degree. The union in both welds is perfect.

"The changes in structure which occur in spot welds, using the two you sent me as a basis for my statements, are only such as would be expected from the heat conditions under which the work is done. When the plates are just touching, the heavy current heats up the spots that are in contact, and the temperature becomes very high locally, due to the resistance. The amount and extent of this heat will vary, of course, between different welds, but not seriously. The heat becomes less as the outside of the plate is approached because of the conductivity of the plate and the cooling effect of the cooler outside layers. There are certain well-defined temperatures of steel of any given carbon content at which changes in structure take place when heated, these resultant structures depending on both the amount and time of application of the heat.

" In the centre of a spot weld the temperature is very high, probably near the fusing point. The cooling is rapid and the result is a structure in the centre of the spot weld inside of the ellipse in which the grains are columnar and perpendicular to the outline of the ellipse. This is just what occurs in electric arc welds and in the cooling of steel castings in molds. In the case of a weld, the long axes of the columnar grains are perpendicular to the sides of the V's. In a casting, they are perpendicular to the sides of the mold. Further inside of the ellipse the grains are coarse, due to the very high temperature. Just outside of the ellipse the temperature has not been high enough to permit of the formation of columnar grains, but the grains are coarse; and due to the comparatively high temperature and rapid cooling, pearlite has not had time to form, so that the structure is confused and the ferrite and cementite are rather indiscriminately mixed.

" Still further out in the dark zone the heat has been high enough and the cooling rapid enough to produce sorbite in the grains, surrounded by a film of ferrite. This is also a typical structure in electric and oxy-acetylene welds, and is simply another degree in the transition stage from melted metal to normal steel. The temperature in this sorbitic zone has been so high that the grains have had time to grow. They are, therefore, very large, although equiaxed and not columnar.

" Just beyond this zone is one in which the temperature has been just above the upper critical point, the Ac_3 point. This temperature was sufficient to refine the grain as much as can be done by heat treatment alone. This also is characteristic of electric and oxy-acetylene welds. Outside of this last zone the material gradually changes to that of the original metal unaltered by the heat. As stated before, I can see no difference between the structures in and around spot welds and those in oxy-acetylene and electric welds except in degree.

" It seems to me that these statements are entirely in accordance with the theory of heating, and I cannot find any evidence so far that the pressure has anything to do with the structure, although it is possible, as stated in my former letter, that it may have some effect. This, however, would require considerable investigation before drawing conclusions. I think it can be safely said that there is no reason to be apprehensive of the strength of spot welds; and the two that you sent me appear to be of excellent quality, although probably the second one is somewhat better than the first." [4]

It is to be expected that these two theories of spot welding will lead to further inquiry into the nature of

[4] Personal letter from S. M. Miller, dated May 7, 1919.

the reaction which takes place in the steel structure. The important practical deduction is clear that the process is a sound one for joining heavy structural members.

Practical Aspects.—In this connection there were a few points observed during the demonstration at Pottstown that may aid in dispelling certain preconceived notions. On the other hand, they may lead to more interesting doubt which often ends in greater benefit to such a process.

The first point had to do with the size of spot indicated after tensile pulling. It was generally held that the size of spot had a great deal to do with its physical strength. In the earliest tests attempts were made to compute the diameter of the spot and reduce the ultimate tensile strength to pounds per square inch of the observed spot. This was reasonable in view of the method pursued in the case of a riveted joint, but the punching of the holes for riveting had removed good metal usually replaced by one of poorer quality. In spot welding the original metals are there, but changed in structure, and logically the union of the metals could be made continuous by the proximity of the spot or to the overlapping of same. It was conceded during these tests that the diameter of the spot was merely an estimation depending upon the observer. Allowing liberally for this inaccuracy it will be seen from the tabulations in Chapter IV that the diameters of spots so recorded do not consistently indicate the strength characteristics of the union. The data of Lloyd's tests (Tables XV, XVI, XVII, and XVIII) in this respect gives composite estimates made by several observers. The difficulty of judgment of the spot size is complicated by the change in form of the spot. As will be seen by comparing Figs. 1 and 2 the impression is at times of a circle and then of an ellipse. Further, the effect of the cooling process makes for more confusion in determining the ring or boundary of the adhesion. It is possible, also, that these lines of demarkation may be attributed to the surface strains occasioned by tensile pulling. A good example of the range of ultimate tensile for constant observed size of spot is seen in Table XV, Chapter IV. From spot No. 7 to spot No. 20 the data gives the spot diameter as 11/16 inch. The first four of these spots were made in 16 seconds, the next ten were made in 12 seconds. The ultimate tensile ranged from 18,600 pounds to 12,200 pounds.

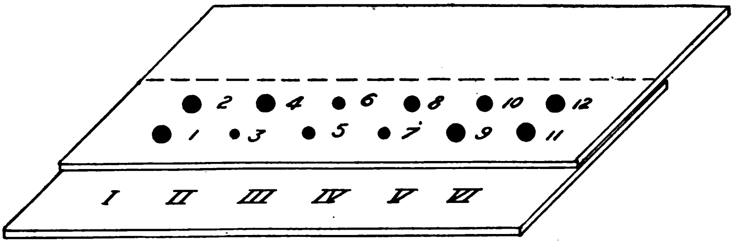
The next point of interest, and often of surprise to those who had not seen it, was the fracturing of the stock material and the complete adherence of the union at the spot. This is remarkable in the ½-inch plate samples as shown by the results in Table XVII, Chapter IV. The samples were visibly twisted in the Olsen testing machine and in the majority of cases the yielding of the material surrounding the spot was clearly observable, taking many seconds before complete rupture. In some instances it was necessary to wait quite a time, and in others to subject the test piece to further loading. The implication is not unwarranted that the ultimate rupture is more than safely removed from the initial yield point. This statement should not be confused with the impression so often concluded that, because the stock material fractures without the region of the weld, that the weld is better than the stock material. As a matter of investigation this may be a serious defect of the process. The important consideration is how far the application of heat and pressure may be employed so as to preserve the integrity of the original structure and yet obtain a tensile strength sufficient for practical purposes. Table XVII, Chapter IV, shows a much higher uniform tensile strength of spot welds than is required to compete with the rivets required for a similar jointure.

The third and last point observed has to do with the heat conductivity of the plate material and its relation to electric conductivity. Unfortunately, this observation was most clearly noticed in the last series of tests which could not be extended with sufficient fulness to make definite conclusions. In the earlier tests it was noticed that the end spots in a continuous seam, if given an equal time with the intermediate spots, would show an increased ultimate tensile. If the end spot were given slightly more time, the ultimate tensile was very much increased; and in many cases, if the time were less on the end spots, the ultimate tensile was as good or better. This action can be noted by reference to the tabulations in Chapter IV. The first samples made with the object of adjusting the machine were two narrow strips of steel with a single spot. Undoubtedly, the results from this test which fixed the adjustments and constants used in welding the ship's floors gave a wrong assumption which the uniformity tests afterward corrected. There can be no doubt that in making successive spot welds, either in single, double, or triple rows, the temperature variations in the stock material bear a close relation to the resultant tensile strength of any given spot. It is suggested that, in line with the heat cycle of each individual spot, the residual or recuperating structure of the stock material may interfere with its natural changes. Conversely, the heat cycle of an individual spot may, through the action of conductivity, or convectivity, affect the spots already made. During the tests it often happened that work was interrupted and seams were left to cool all night in a rather cold shop, but continuation of the work did not indicate that such interruptions were detrimental to uniformity.

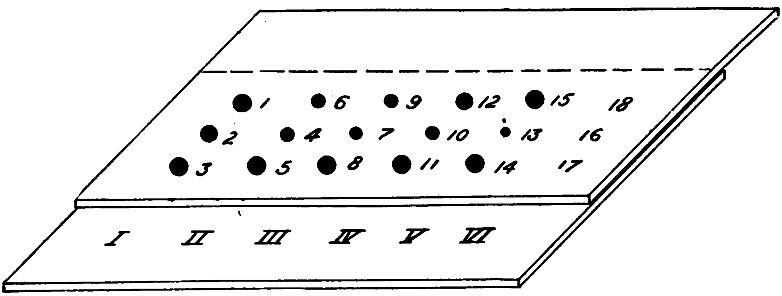
In the last practical tests two and three rows of spots were made in ½-inch steel plates. The first samples were made by continuous spots first on one row and then on the next row, and the time was held constant for all spots. As the uniformity tests for this thickness of material indicated good results at 15 seconds, this time interval was adopted. The tensile pulling of all these samples were far below expectations and a second attempt was immediately made.

Fig. 42 shows the order in which the spots were now made. It is to be noted that this order of spot put them in line with the tensile pulling. The time intervals were varied, *i.e.*, in the two-row sample the end spots were given 15 seconds and the intermediate spots 20 to 30 seconds; in the three-row sample the end spots were given 20 seconds and the intermediate 25 to 30 seconds. Fig. 42 attempts roughly to show the relative size of spots as observed on the samples after tensile pulling. The Roman numerals are the strips as cut for the pulling tests. Nos. I and VI of the two-row and Nos. I and VI of the three-row samples, though given reduced time, exceeded, except No. V of the two-row sample, all the intermediate spots.

As speculation is only possible, it is assumed that, as the metal is locally heated by the electric resistance which increases with the temperature, the surrounding metal tends to conduct away the heat. The end spots would have the advantage of no plate material or,



COMPARATIVE SIZE OF SPOTS-2 SPOTS 6" LAP



COMPARATIVE SIZE OF SPOTS-3 SPOTS-9" LAP

FIG. 42.—Comparative size of spots—3 spots = 9" lap.

at least, a very small area of conductance on one side and a large area on the other side. The intermediate spots would be in varying degrees circumscribed in this respect. It will be noticed in Fig. 42 that the No. II strip, which is a combination of spots 3 and 4, is not comparable in tensile strength to strip No. V which is a combination of spots Nos. 9 and 10. These latter spots being made after the entire piece of material was well heated. It is observed in continuous spot welding that the spot adjacent to the one being made glows to cherry-red heat. Further, though not so common, a number of spots in the vicinity of the weld being made glow at varying degrees. This observation would indicate that the metal of the plate is conducting some of the electrical energy from the electrode and doubtless aids in the results of decreasing ultimate tensile as shown by these tests.

Arc Welding.—Whereas the theories of spot welding are scant, those for metallic arc welding are very numerous. It is not to be inferred that numbers in this case give finality to conclusions; on the contrary, the light is very dim in the region of the weld, and besides the phenomenon of the arc leads to various aspects of the problem.

Metallurgical Views.—The deposit from the metallic-arc electrode is defined and treated as an unannealed steel casting. In the making of this casting the stock materials joined play an important rôle, because the arc must fuse the adjacent metal and mix with a portion of it to form the weld. Accepted as a casting, the efforts of the metallographists have been to discover why the structure displays brittleness with good tensile strength and what means may be taken to make this casting more ductile. These are questions which when fully answered will standardize materials and apparatus, and also relieve the operator from much responsibility.

With the aid of the microscope, investigators have found, upon the examination of the weld, whether by fracture or by cutting, a structure which contains a large number of lines or plates. The determination of the composition of these plates has brought with it differences of opinion and modification of views which make conclusions impossible. One specialist finds these plates at the grain boundaries as well as in the grains, and further observations have caused him to believe that the grains are bounded by thin films which are sufficiently tenacious to preserve a high tensile strength in the weld, yet will rupture under shock or alternating stress. His observations affirm that crystallization cannot take place through these films, but he is not ready to state what the composition of the films may be. He suggests the improbability of their being cementite in the case of metallic-electrode welds, "as the carbon is almost entirely burnt out,"[5] but he allows the possibility of iron oxide, or nitride of iron.

Another expert concludes that the plates or lines "are not cementite, or martensite, or any similar carbide product, but most probably nitride of iron."[6] This conclusion was arrived at after careful investigation of a specimen in which the deposited metal was analyzed and showed a carbon content of 0.04 per cent. carbon.

Still another specialist calls these plates "Nitrogen lines," showing "the presence of a considerable percentage of nitrogen, but their absence does not always mean that nitrogen is not present."[7] He states further:

[5] "Path of Rupture in Steel Fusion Welds," S. W. Miller, *Trans. Amer. Inst. Mining Engineers*, February, 1919.

[6] "Micro-structure of Iron Deposited by Electric Arc Welding," G. F. Comstock, *Amer. Inst. Mining Engrs.*, Feb., 1919.

[7] "The Metallurgy of the Arc Weld," W. E. Rudder, *General Electric Review*, December, 1918.

"Nitrogen is one of the most effective elements for making steel brittle. As little as 0.06 per cent. will reduce the elongation on a 0.2-per-cent. carbon steel from 28 per cent. to 5 per cent. It is contained in regular steel only in very small amounts, varying from 0.02 per cent. in Bessemer steel to 0.005 per cent. in open-hearth. Under ordinary conditions of fusion, nitrogen has little effect upon iron, but under the conditions of the electric arc the nitrogen becomes more active. This is probably due to the formation and decomposition of nitrogen-oxygen compounds with a consequent liberation of active atomic nitrogen. The fact that these lines do appear in welds made in nitrogen gas alone suggest that the oxygen need not be present, the nitrogen molecule being split up by the arc stream, or perhaps the iron vapor combines directly with the nitrogen. There is some evidence that it does."

This opinion leads to the subject of occluded gases, *i.e.,* gases that are absorbed by steel. Theoretically, these occluded gases would play some part in the reactions that take place under the intense heat of the arc vapor, the temperature changes following the passage of the arc, and the cooling effects produced by the conductivity of the mass of steel acted upon. For this reason the arc operator learns to localize his arc and thus prevent the stock materials from attaining a high degree of heat. Such a condition, if permitted, causes too slow cooling which results in a coarse grain and probably traps gases which react to cause brittleness in the finished weld. The field of research for the comprehension of the nature and action of occluded gases is as important as any of the other investigations tending to a solution of the questions which now cloud a complete knowledge of this process.

An interesting set of experiments with the object of analyzing and measuring the occluded gases in iron alloys was performed by Gellert Alleman, professor of chemistry, Swarthmore College, Pa.[8] The results of this investigation are so closely akin to the theories of arc welding that it is recommended that those desiring further information on this subject carefully consider them. It is not possible to quote the whole article, but the conclusions that have a bearing upon the metallurgy of arc welds are as follows: " (3) It appears that the gases are evolved in the following order: Hydrogen is most readily set free, carbon monoxide comes next, and nitrogen seems to be held most tenaciously.

"(4) Whether oxygen is the result of the decomposition of various oxides of iron or the disassociation of carbon monoxide or carbon dioxide has not been determined.

"(5) We have shown that ferrous alloys may occlude relatively large volumes of gases—in some cases equal to about two hundred times the volume of the metal.

"(6) We suggest that in addition to the ordinary functions of metals like aluminum, tungsten, chromium, manganese, titanium, silicon, etc., when placed in ferrous alloys, these elements may act as a catalytic agent; and either prevent the occlusion of large quantities of gases or aid in the elimination of such gases at lower temperatures than would ordinarily take place.

"(7) We have shown that the removal of gases from ferrous alloys markedly changes the microstructure and increases the density of the alloy."

[8] "Occluded Gases in Ferrous Alloys," Gellert Alleman and C. J. Darlington, *Journal of The Franklin Institute,* 1918.

Arc Characteristics.—"The arc is the welder's essential tool. It functions to transform electrical into highly concentrated thermal energy. At the terminals this energy serves to melt the parent and filling metals: in the stream it stabilizes the arc and surrounds the fluid pencil metal with a protecting mantle of hot inert gases, usually oxide. A short arc length obviously assures greater protection to the transferred metal than a long arc, as the path traversed by the incandescent metal is shorter and the liability of convection currents disturbing the protecting envelope less.

"The mechanism producing crater formation and transference of metal from the pencil electrode to the parent metal has not been definitely isolated. However, it appears reasonable to assume that the propulsive force projecting the filling metal across the arc is largely obtained from the rapid expansion of occluded gases and vaporized metal, the impact of the conveyed gas, vapor, and liquid on the molten surface of the parent metal producing the familiar crater.

"It is well known that all metals absorb gas, and that the quantity of gas occluded varies with the characteristics, preparation, and exposure of the metals. Iron has been analyzed containing, at atmospheric temperature, as much as 50 volumes of gas. Upon forming an arc the extreme end of the pencil electrode is partly liquefied and partly vaporized and then conveyed across the arc stream. The concentration of energy at this terminal, approximating 1500 watts for a 150-ampere welding current, produces a rapid increase in temperature, and therefore a corresponding increase in the expansion of the metallic liquid and vapor and absorbed gas. This expansion would tend to follow the path of least resistance which extends through the arc terminal and into the arc stream. Its effect would be to produce a metallic blast. The force of this stream has been observed to vary with change in electrode analyses, character of occluded gas, current density, arc length, and the use of direct or alternating current. An additional expansive force is probably secured by the union of electrode materials with occluded and atmospheric gases. However, as the temperatures in the arc stream are too high to permit the existence of such compounds their formation must occur in the surrounding envelope with the result that the force developed is partly absorbed in scattering hot metal.

"The metallic blast is of particular interest because it appears to be the basis for overhead welding. However, to properly utilize this phenomena it is necessary for the welder to maintain obviously a short arc and to adjust welding conditions so that the electrode end immediately below the arc terminal remains comparatively cool. If a globule of molten solder is dropped on the inclined surface of a cold plate, it will run off at a slower rate than if it strikes an inclined hot surface, due to the difference in strength of the film produced by both surface tension and the congealing of the metal. Similarly, if the electrode end is maintained at a high temperature, the molten metal will run down the side of the electrode, thereby greatly increasing the difficulty of utilizing the vapor blast. Such heating of the electrode also causes leakage of occluded gas through the hot wall with consequent diminution of the force produced by gas expansion at the arc terminal.

" Excessive electrode temperatures are usually obtained as a result of repeated attempts to start the arc. When a number of false starts are made increased heating results, due to the greater current flowing with the arc short-circuited. If the operator develops the necessary skill to deposit metal after but a single start, the pencil electrode end will remain quite cool, facilitating thereby the continued transference of metals to an overhead weld. Other aids to the maintenance of the proper electrode temperature are:

" 1. Use of a lower current density than that employed for flat or downward deposition.

" 2. Use of an electrode having a melting point higher than that of the parent metal.

" 3. Use of a direct-current supply circuit having such characteristics that the arc short-circuit current does not exceed greatly the operating current.

" 4. Use of a thin coating on electrode to facilitate starting the arc." [9]

Physical Views.—In general the theory is accepted that after the metallic arc is struck a vaporous stream of metal from the electrode is formed. Surrounding this vaporous stream is a clearly-visible flame indicative of ordinary combustion and hence considered " a flame of oxides." An observer working upon the problems of automatic arc welding holds this theory: " As the result of thousands of observations of welds produced automatically (wherein the personal equation is entirely eliminated), the writer [10] inclines towards the theory that

[9] Communicated to the Author by O. H. Escholz, Oct. 4, 1919. See *Electrical World,* Sept. 27, 1919, *et seq.*

[10] " Discussion on Welding Mild Steel," Harry D. Morton, *Transactions American Soc. Mining Engineers,* 1919.

the molten electrode material passes through the arc in the form of globules, and that where 1/8-inch electrode material is employed with a current of about 150 amperes these globules are deposited at the rate of approximately two per second. The passage through the arc of each globule apparently constitutes a specific cause of instability in addition to those existent with slowly-consumed electrodes. This hypothesis seems to be borne out by ammeter records, together with the fact that the electrode fuses at the rate of about 0.2 inch per second. Moreover, the globules appear to be approximately equal in volume to a piece of wire 0.125 inch in diameter and 0.1 inch long."

In the same article this last observer gives this vivid picture of the arc at work: "What seems to occur is that the molten metal in the crater is in a state of violent surging, suggestive of a small lake lashed by a terrific storm. The waves are dashed against the sides of the crater, where the molten metal of which they are composed quickly solidifies. The surgings do not seem to synchronize with, nor to be caused by, the falling of the globules of molten metal into the crater, but seem rather to be continuous. They give the impression that the molten metal is subjected to an action arising from the disturbance of some powerful force associated with the arc—such, for instance, as might result from the violent distortion of a strong magnetic field. Altogether, the crater phenomena are very impressive; and the writer hopes ere long to be able to have motion pictures made which, when enlarged, should not only afford material for the most fascinating study, but also throw light upon some of the mysterious happenings in the arc."

Other opinions have to do with a study of the spectrum of the metallic arc in which department of research apparently little work has been done. Such investigations would require special apparatus whereby the arc would be not only observed under varying electrical conditions, but also recorded in small increments of time. Following one set of electrodes and stock materials many combinations would need examination before a complete spectroscopic theory could be approached.

Electrical Views.—Much of the electrical theory is concerned with voltage drop. It has been well stated that "up to the present no satisfactory proof of any theory has been put forward. It is by some ascribed to a back e.m.f. produced at the point of volatilization of the carbon and by others to the energy absorption required by this volatilization." In view of this opinion, it is interesting to note the experience of a careful observer as to the action of the welding voltage. The results of his investigations are given in full:

"After careful compilation of about five-hundred readings of voltage across the arc and current through it, I was forced to the conclusion that the current does not affect the voltage enough for an ordinary meter to notice it. With an oscillograph the rapid variations in voltage due to changes in the current can be traced; but the voltage as shown by an ordinary meter, no matter how delicate, is constant for any set of given conditions. The conditions which do change the volts across the arc are: First, length of arc; second, type of electrode; third, gases in the arc such as would appear from coating on the electrode or flux used on the job.

"There is a voltage below which an arc cannot be held. And without starting an argument, as to whether this is a counter e.m.f., a C. R. drop, or a combination of the two, we are calling it a minimum arc voltage. This lies between 10 and 11 volts. There is added to that always a constant drop, depending on one of the three conditions named above, and this drop varies from one to two volts in bare wire at ordinary welding currents to 15 to 20 volts for heavily-coated wires. There is the added resultant due to the average value of the superimposed guardian, or puncture voltages, the peaks of which are shown only on the oscillograph, but the average value, of course, adds to the other two, making the voltage across the arc as we have found it to be as follows: For bare wire from 11 or 12 volts to 22 volts, the lower value being an inhumanly steady operator holding the closest arc possible with a wire that has no carbon content nor any covering or flux. The other end of the scale is the carbon arc, about which much has been published, which voltage varies from 40 to 55. The highest metallic-arc voltage is that of a very heavily-coated electrode, such as the English Quasi-Arc. The voltage across this varies from 27 to 40. The voltage across a completely-coated gaseous-flux electrode is from 22 to 35. The voltage across a half-coated electrode varies from 15 to 30, the variations being as aforestated, the sum of the variable-length voltage to the constant ordinary resistance drop and the necessary voltage. The only voltage that is variable is that due to the man's hand in holding different lengths of arc.

"I think it is admitted by now that the short arc is desirable; in fact, a short arc is absolutely necessary for good work. With a short arc there is less chance of the metal being oxidized, less chance that it will fall on cold work, less chance that nitrogen will be raised to such a temperature that it will combine with carbon and steel to form harmful compounds, and less chance of oxidation. And, a point that has probably not been mentioned before, the total heat is kept within reasonable control; namely, every welder knows that with a short arc he has the metal under control, but with a long arc the heat is raised by the voltage having risen across it. If there is any decrease in the current and the temperature, it rises until the steel is 'wild.' And, whereas the transition from a short arc to a long arc is easy, the transition backwards is very hard, and the tendency is, once having started the long arc, to hold it at least until the end of the electrode. Unfortunately, when no check is made on the quality of the metal deposited, the long arc being easier held—depositing the metal faster—is used; and in some rare cases, such as filling in castings, where the mass of metal is great enough to satisfactorily dispose of the increased rate of heat, it can be used to advantage.

"There has been much promotion of constant-current apparatus, and equal promotion of constant voltage, but it can hardly be denied that a constant rate of heat is what is desired. For a necessary change in length of arc due to various physical imperfections in the circuit or the electrode, this change being within the working range between too long an arc and too short an arc, there is considerable variation allowable—we would say 1/8 inch to 3/16 inch; whereas anything over 3/16 inch begins to be too long an arc, and rapidly tends to become 3/8 or 1/2 inch long, in which case no welding can be done, the metal of the electrode melting so much more rapidly than the work that there is not crater enough in the work to receive the electrode metal; and, unless the crater in the work is as large or larger than the deposited electrode metal, no welding can result. For instance, steel cannot be welded by pouring molten steel on it at any temperature except molten.

" The conditions, then, for good welding are: First, control of the arc length; second, constant rate of heat; third, a good operator; because, with the first two conditions ideally realized, we are still at the mercy of the man that he guide the arc to weave the desired joint together.

" In limiting the voltage across the arc some apparatus has been equipped with relays which cut the arc out, or cut resistance in, or give other notifications that the arc is too long. Other efforts to limit the voltage of the arc have been made by reducing the open-circuit voltage or guardian voltage until only a certain length arc could be held. It is interesting to note here that an arc cannot be held with a supply at the voltage across it; in fact, the values begin to be twice the voltage of the arc before any arc at all can be held. This is true of alternating current or direct current. The minimum voltage at which an arc can be held is around 31 or 32 volts and this is obtained with bare wire and with no flux or coating. While the gases of coated wires help to hold the arc, they also raise the necessary voltage, and hence raise or hold about the same the minimum voltage at which an arc can be held. With just as low an open-circuit voltage, an arc can be held on alternating current as on direct current. With alternating current the guardian voltage is supplied partially by inductive kicks or transformer characteristics, and the normal open-circuit voltage can be lessened. On direct current a reactance gives a like action, but in much less degree, naturally the average voltage across the arc showing the effect of these also, but the open-circuit voltage, at least the quite open-circuit voltage, does not show it. The only method so far discovered of limiting the length of arc, without moving parts and without losing the necessary open-circuit or guardian voltages for puncturing through dirt, oil, slag, and giving good penetration, is by the alternating-current special transformer for arc welding." [11]

No satisfactory technical explanation has been offered for the ability of the arc to deposit metal from below. That is the phenomenon of overhead welding. The same expert, fully cognizant of the theories put forward, looks upon the matter in this common-sense way: "Overhead welding depends neither on the machine nor electrode, except in the case of completely-covered electrodes where a special covering, thinner and harder, *i.e.*, freezing more quickly, is resorted to in order to keep the metal and slag from dropping. Overhead welding is not a function of polarity, or the metal being carried in one direction by the flow of current, but simply a case of capillary attraction of the molten parent metal for the molten electrode metal, and the electrode must be moved ahead at a steady constant rate, so that but the equivalent of one drop is molten at a time, and this drop draws up into the parent metal instead of dropping. For instance, one drop of water will cling to the ceiling, but more than that will fall, leaving one drop remaining. A very close, but not too close, arc must be held for overhead welding,

[11] Communicated to the Author by C. J. Holslag, September, 1919.

and the voltage is then reduced, and hence the current must be increased to give the requisite amount of heat. On the alternating-current machine this change is automatic and inherent. On other systems the current can be arbitrarily increased. On alternating current, also, the progress must be faster, as more electrode is melted with given conditions."

The Physical Behavior of the Welding Arc.[12]—"The phenomena of the electric arc furnish an interesting field for careful study. The production in so restricted a region of a temperature so high as to volatilize any known substance is truly marvellous. The means by which the temperature is automatically held and regulated is still more wonderful. Before the days of electric welding the remarkable temperature effects of the arc furnished the chief interest. The art of electric welding raises a new question: the manner of transference of the material through the arc. On this point, the experiments of the joint Research Committee of the National Research Council and the Electric-Welding Committee of the Emergency Fleet Corporation have yielded considerable information.

"1. Data culled by a sub-committee on the physics of the arc from the experiments of the Research Committee, together with results obtained by Professor R. G. Hudson, of Massachusetts Institute of Technology, and results obtained by Professor C. F. Hale, of Albany Teachers' College, have shown conclusively that the mode of transfer of material through the arc is totally different from the mode of transport through liquid electrolytes.

"The amount of material transferred through the arc

[12] Communicated to the author by Prof. Allison W. Slocum, University of Vermont, November, 1919.

was in some cases three times as great, and in other cases only one-thousandth part as much as would be transported through an electrolyte by Faraday's laws.

" 'Positive and negative ions,' as used by Faraday, have no meaning in the phenomena of the electric arc.

" 2. In the electric arc there is a potential difference between the electrodes which may be measured with a voltmeter. This potential difference proves the existence of an electrostatic field between the electrodes and a consequent electrostatic pull upon the surface of the electrodes tending to remove the molten metal. A simple calculation of the magnitude of this force shows that it cannot be relied upon to transfer the metal across the arc to the plate. It could not even remove the metal from the electrode against the force of surface tension alone unless the surface be so near the boiling point that the surface tension becomes practically negligible. By no possibility could it remove the metal and carry it up against gravity as in the case of overhead welding.

" Moreover, when the temperature of the surface is close to the boiling point of the metal, the electrostatic pull would draw the metal from the surface in threads like glass wool. This is the probable explanation of the sharp point left on the electrodes which have been used for welding with alternating current.

" Professor R. G. Hudson has proposed a theory in which he avoids reliance on the inadequate electric force by supposing the formation of a gas in the electrode beneath the surface which by its expansive pressure explosively propels the molten metal across the arc gap. This theory is published in the *Electric Welding Journal* for November, 1919.

"3. Though the electrostatic field of the electromotive force between the terminals of the arc is ineffective in pulling metal from the electrode, it is, indeed, the all-important factor in the heat-producing effect of the electric current. Electricity produces heat only while moving in the direction of an electric force. This is true whether electricity behaves like an incompressible fluid in its flow or flows like a stream of electrons or thermions.

"The fall of potential, which exists between the terminals of the electrodes, occurs chiefly at the surfaces of the electrodes. This 'electrode fall' is the most important feature of the behavior of the arc. For it is here that the heat is chiefly produced.

"This electrode fall is in part conditioned by the electrostatic force required to pull the electrons or thermions from the metal of the electrodes. At very high temperatures thermions are spontaneously emitted in copious streams. This phenomenon is well known in the behavior of tungsten filament lamps. At such high temperatures the electrode fall is small, a matter of a few volts. At lower temperatures the electrode fall is larger. It is very important to note that the electrode fall diminishes with rising temperature and that in the neighborhood of the boiling point of such metals as iron it changes very rapidly with relatively slight changes of temperature. It is this behavior of the electrode fall that gives to the electric arc its extremely stable automatic regulation of the temperature of the surfaces of the electrodes regardless of the conditions behind the surfaces.

"The rate of heat production is proportional to the product of the current strength and the electrode fall.

When the arc is playing steadily the rate of heat production equals the rate of heat dissipation. If any change occurs which tends to increase the rate of dissipation, this change instantly tends to cool the surface. The tendency to cool the surface is rapidly checked by the increase of the electrode fall and the consequent increase of heat production at the surface.

"4. When an electric current is flowing through an arc it is surrounded by so-called lines of force which behave in some respects as stretched elastic bands exerting a normal pressure inward upon the surface and throughout the interior of the material of the arc. This effect is known as the pinch action of the current upon itself. A calculation of its magnitude in the case of a welding arc shows that its pressure is comparable to that of the surface tension of a stream of water flowing slowly in a long thread from a faucet. The regulative influence of the surface tension on the stream of water is small but apparent. The regulative effect of such a pressure on a stream of vapor of one-thousandth part of the density of water would be one thousand times as great.

"The pinch action of the current may be considered as having the effect of a kind of tube of considerable stability through which the material of the arc is flowing.

"In accordance with the considerations stated above and the general data reported to the Research Committee by various experimenters, the sub-committee on the physics of the arc suggested a vapor theory of the electric arc. Strong evidence for this theory is constantly accumulating.[13]

[13] Hagenbach and Landbein (*Archives des Sciences*, Jan.-Feb., 1919) have shown that for current intensities, not too small, the anodes of metallic arcs (Ag. Cu. Fe. Na. W.) are heated at the tip to the temperature of ebullition.

"According to the vapor theory of the arc, its behavior consists in a process of boiling of the surface of the electrode; the transfer of the vapor through a kind of tube furnished by the pinch action of the current; and the condensation of the vapor on the surface of the plate. In the interior of the pinch-action tube there is a core of pure iron vapor which flows through the core exactly as steam flows through the pipes from the boiler to the radiator in a steam-heating plant after the air has been completely expelled.

"In the case of the boiler, the heat is supplied through the bottom of the boiler and causes the boiling commotion throughout the volume of water. In the case of the arc the heat is applied to the boiling surface and the boiling commotion, when it exists, occurs only in the regions immediately beneath the surface. This is the phenomenon of the spluttering of the arc.

"The boiling of the surface is accompanied with the absorption of heat as latent heat of the vapor. This heat is again set free when the vapor condenses upon the plate. The flow of vapor across the arc is limited by the rate at which the conductivity of the plate can take away the heat liberated by condensation.

"The temperatures of the surfaces of electrode and plate are automatically regulated to approximately the boiling point of the metal by the peculiar action of the electrode fall. The electrode fall at the plate is regulated by the force necessary to supply the positive charges to the arc. The electrode fall at the electrode is regulated by the force required to supply the negative charges to the arc. And both electrode and plate are automatically held steadily at the right temperature for the purpose.

" The vapor behavior of the arc suggests the following rule for welding: Choose the largest current permitted by hub conductance of the plate and choose the smallest electrode that will carry the chosen current.

" The vapor theory is suggested as a tentative theory. Whether it will completely stand the rough and tumble of careful experimenting remains to be seen. In any case, it serves to direct the attention of the welder to the most important factor of successful welding—the heat distribution and the temperature gradients in the neighborhood of the welds."

Practical Aspects.—In reviewing the work of specialists who have investigated the science of arc welding, one very encouraging opinion stands out clearly, that up to the present time no obstacles have been observed that would deter the use of the process for the joining of heavy structural members. The general caution always exercised by technical men centres on the skill of the operator. As previously shown, this responsibility may be relieved by the future development of automatic arc welding. Until that time it will be the duty of those in charge of important electric-welding progress to select and train the best men as arc welders. Practically, the art of arc welding reduces to the man who makes the weld, but this man must have behind him the work and encouragement which comes from those whose advocacy of the process is guided by common sense and sincerity.

For purely practical purposes a test that may prove interesting was made at the Pottstown demonstration to show the effect of the combination of spot and metallic-arc welding. Fig. 43 shows the four sample pieces. No. 1 was a single spot weld made in 12 seconds with the full capacity of the 27-inch portable spot welder. No. 2 was a lap-joint arc welded with direct current on both laps and made in three layers. Nos. 3 and 4 were similar, but the order of the welding was reversed, *i.e.*, No. 3 sample was arc welded first and then spot welded, and No. 4 was first spot welded and then arc welded. The results would indicate little advantage of the combination, but the arc weld parted at the joint under an ultimate tensile which slightly exceeded the ultimate tensile in the combination joint which broke the plate material and left the joint intact. The ultimate tensile for each sample follows:

No. 1.... 46,500
No. 2....106,800
No. 3....106,500
No. 4....106,500

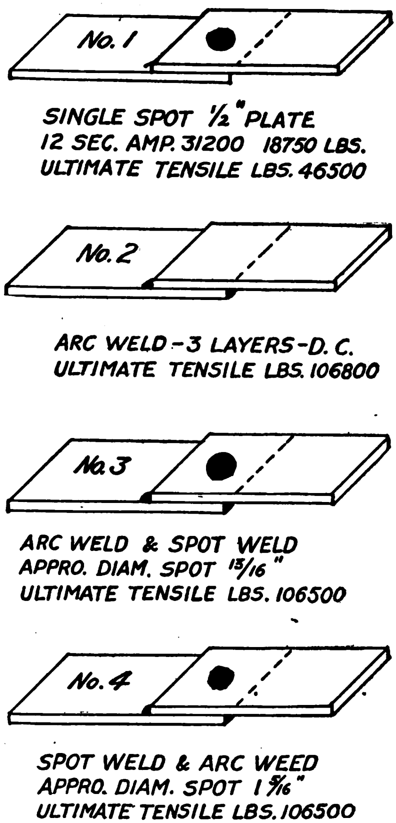


FIG. 43.—Experiment in combination of arc and spot welding.

Nos. 3 and 4 joints were afterwards pried open with a wedge in order to examine and measure the size of spot. In the former this was estimated to be 13/16 of an inch, and in the latter 1 5/16 of an inch in diameter.

Summary.—The differences of opinion of technicians might make the practitioner experience a feeling of doubt. This is a natural stage in the development of any art or practice, and must be so considered in discussing and applying the theories advanced. The only condemnation is for those who obstruct advancement for the sake of gain, or who enhance some trivial characteristic of the process to the detriment of a better understanding of the whole. The work of theorists is mainly to find defects in order to cure them and, with the instrumentalities now available, it is certain to follow that the results of their work will advance the practice to a higher state of efficiency.

APPENDIX

APPENDIX I

THE CLASSIFICATION SOCIETIES HAVE SO FAR CONSIDERED AND APPROVED OF THE APPLICATION OF ELECTRIC WELDING TO THE FOLLOWING PARTS OF VESSELS:

Deck-Rail Stanchions to Plating
Clips for Detachable-Rail Stanchions
Continuous-Railing Rods (Joints)
Attaching Deck Collar (L Rings) around Ventilators
Attaching Deck Collar (L Rings) around Smokestack
Attaching Cape Rings around Smokestack, Pipes, etc.
Attaching Galley Fixtures to Plating
Attaching Bath and other Fixtures in Officers' Quarters
Attaching Cowl-Supporting Rings to Ventilators
Bulwark Rail Top Splicing and End Fittings
Skylights over Galley
(*a*) Engine-room Stairs and Gratings
(*b*) Boiler-room Stairs and Gratings
Attaching (*a*) and (*b*) to Plating Grab Rods on Casing
All Stairs and Ladders, including Rail Attachments
Door Frames to Casing, Hinges, Catches, Holds, Coach-hooks, etc.
Clips for Attaching Interior Wood Finish to Casing
Entire Screen Bhd
Also Coal Chutes
Butts of W.T. and O.T. Boundary Bars on Bulkheads or Floors in Double Bottom
Ventilator Cowls
Stacks and Uptakes
Bulkheads (that are not structural parts of the ship), partition bulkheads in accommodation

Framing and Supports for Engine and Boiler-room Flooring or Gratings
Cargo Batten Cleats
Tanks (that are not structural parts)
Shaft Alley Escapes
Steel Skylights over Accommodation Spaces
Engine-room Skylights
Grab Rods on exterior and interior of Deck Houses
Deck Houses not covering unprotected openings through weather decks
Reinforcing and protecting angles round manholes
Joints of W.T. Angle Collars at frames in way of W.T. Flats
Other parts of a vessel in which electric welding is proposed must be submitted for consideration.

March 25th, 1918.

For Lloyd's Register of Shipping, J. French
For American Bureau of Shipping, Geo. G. Sharp

APPENDIX II

Electrode Material for Metallic Arc Welding *

Welding Circular No. 1.

Chicago, August 1, 1919.

To All Concerned:

It is intended to standardize our materials used for metallic arc welding. A copy of our specifications for welding materials is attached herewith.

You will note that there are now five different electrodes shown as Rock Island Nos. 1, 2, 3, 4 and 5. Any additional electrodes which it may become necessary to purchase and use in the future will be given a Rock Island number, and supplements covering same issued to all concerned.

It is desired that Mr. Sedwick see that each lot purchased meets the specification, except for the actual flowing and weldability of the metal, which will have to be determined by an expert welding operator who shall be designated by Mr. Wanamaker or Mr. Pennington—preferably an operator at Silvis.

When the material is O.K.'d, it can then be placed in Silvis stock, it being assumed that all metallic-arc-welding electrodes will be delivered to the Silvis Store and distributed from that point.

The electrodes should come in boxes plainly marked, showing the Rock Island number and kind of material.

The Store Department should prevent any confusion or mixing of the different specifications or analysis of electrodes, preferably by having their racks or bins divided into different sections, one section for each electrode number. This would hold true not only for the Silvis Store, but all stores where metallic-welding electrodes are handled.

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* Courtesy of E. Wanamaker, E. E., Chicago, Rock Island & Pacific Railway.

These electrodes, at least for the present, will all be received "bare," as called for in the specification. At Silvis, a sufficient percentage of the Rock Island No. 1 electrodes will be coated to meet the demand from the different points. All of the Nos. 2, 3, 4 and 5 electrodes will be coated.

The coating specifications will be furnished by circular letter, detail instructions regarding same to be furnished by Mr. Wanamaker or Mr. Pennington.

All electrodes which are coated at Silvis shall be bound into 16-lb. bundles—each bundle to be tagged, showing the Rock Island number and kind of electrode material.

The electrodes may be coated on shop order and returned to stock, care being used to see that the different numbers do not become mixed or confused.

Copies of all circulars to date affecting the handling of coated electrodes are attached herewith.

W. J. Tollerton.

SPECIFICATIONS FOR ELECTRODES FOR METALLIC ARC WELDING.

The following specifications to be used for purchasing electrode material for metallic arc welding:

Rock Island No. 1—Mild Steel—electrodes, to be used for all ordinary purposes.

Chemical Composition:

Carbon	Not over 0.18
Manganese	Not over 0.55
Phosphorus	Not over .05
Sulphur	Not over .05
Silicon	Not over .08

To be furnished in 3/32″—1/8″—5/32″ and 3/16″ sizes.

Rock Island No. 2—Medium-High-Carbon Steel—electrodes, to be used for purposes where a medium-high-carbon-steel property is desired—preferably for driving-wheel flanges or rail work.

Chemical Composition:

Carbon	—	....	0.65 – 0.75
Manganese	—	....	0.60 – 0.90
Phosphorus	—	Not over	.05
Sulphur	—	Not over	.05
Silicon	—	Not over	.08

To be furnished in 5/32″ size.

Rock Island No. 3—Nickel Steel—electrodes, to be used where strength and elasticity is desired for strength members, such as frames, shafting, axles, etc., or any case where metal of such quality is required

Chemical Composition:

Nickel	—	Not less than 1.50 or over 2.0
Carbon	—	Not less than 0.20 or over 0.50
Manganese	—	Not less than 0.28 or over 0.60
Phosphorus	—	Not to exceed .05
Sulphur	—	Not to exceed .05
Silicon	—	Not to exceed .08

To be furnished in 5/32″ size.

Rock Island No. 4—Manganese Steel—electrodes, to be used for all hard-wearing surfaces, especially so where extreme toughness and medium hardness are required, for instance—track steels, steam-shovel dippers, dipper teeth, frame jaws, and any part of a machine structural work, pressure vessel work, etc., such as would require metal in the weld of extreme toughness.

Chemical Composition:

Manganese	—	....	10.0 to 14.0
Carbon	—	....	1.0 to 1.25
Phosphorus	—	Not to exceed	.05
Sulphur	—	Not to exceed	.05
Silicon	—	Not to exceed	.08

To be furnished in 5/32″ size.

Rock Island No. 5—Medium-Carbon Steel—electrodes, are primarily of value for axles, forgings, piston rods, etc., or in any case where sufficient carbon content is desired to limit abrasive wear.

Chemical Composition:

Manganese	—	....	0.30 – 0.60
Carbon	—	....	0.38 – 0.52
Phosphorus	—	....	.05
Sulphur	—	....	.05
Silicon	—	....	.08

To be furnished in 5/32″ and 3/16″ sizes.

Material:

The material from which the wire is manufactured shall be made by best-approved process.

Physical Properties:

Wire to be of uniform homogeneous structure, free from segregation, oxides, pipes, seams, etc.

Test:

The commercial weldability of the No. 1 wire electrodes shall be determined by means of tests by an experienced operator, who shall demonstrate that the wire flows smoothly and evenly through the arc without any detrimental phenomena.

Surface Finish:

To be absolutely free from oil and grease, and to have a dull, flat finish, free from polish or scale.

Packing:

All wire shall be straight and cut to 14-inch lengths and shipped preferably in boxes or kegs not exceeding 300 lbs. net weight. If shipped in bundles, wrapping material must be free from oil or grease. Each box, keg or bundle must be plainly marked, showing the C. R. I. & P. number, together with the kind of material and weight.

APPENDIX III *

Lesson I

THE ARC-WELDING MACHINE

It is important that the operator become familiar with the welding machine before attempting to use the arc for welding operations. Two drawings are reproduced showing the names of parts of the welder set. It is not necessary for the operator to memorize the names of the detail parts except that he should understand the location and purpose of the essential parts as follows:—Brush, Brush-holder, Commutator, Exciter Commutator, Field Coils, Motor, Exciter, Grease Cup, Ball Bearings, Shaft, Bracket, Frame, Poles. Any electrician can point out these parts on the welder set if the operator is unable to do so.

The arc-welding generator is electrically separate from the motor which drives it. A welding generator may be driven by either a direct-current motor or an alternating-current motor or by a steam or gasoline engine. The source of power to drive the welding generator has nothing whatever to do with the behavior of the welding generator; provided of course, it is furnished in sufficient quantity and turns the welding generator at the proper speed. The motor end of the welding machine is like any other motor of the same rating.

The principle of operation of the welding generator is very simple to the man who has had some experience with direct-current generators, but is difficult for any one else to understand. For the benefit of the man who has had electrical experience, it is sufficient to state that the welding generator is merely a specially-designed separately-excited generator with a differential compound winding and that an inductive ballast is used in the arc circuit. It is desirable for the operator to understand the principle of operation of the welding set

* Courtesy of Lincoln Electric Co., Cleveland, Ohio.

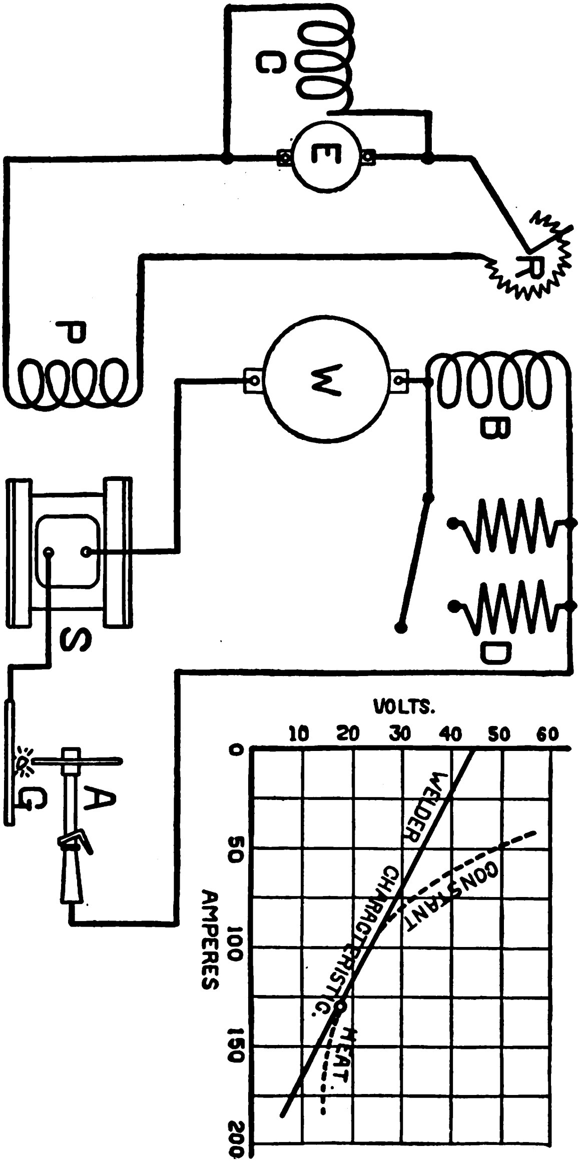

FIG. 44.—Diagram of electrical connections of Lincoln arc welder and volt-ampere characteristic

(A) Electrode holder
(B) Series field (differential connection)
(C) Exciter-shunt field
(D) Diverter resistance
(E) Exciter
(G) Ground plate
(P) Separately-excited field
(R) Rheostat
(S) Stabilizer
(W) Welding generator

as well as the electrician understands it, but it is not absolutely necessary. The accompanying cut shows the volt-ampere characteristic and the wiring diagram of the welding generator.

The welding outfit should always be installed by an electrician. All cables are labelled and the direction of rotation is marked so that no difficulty will be experienced in installing the outfit without the use of a wiring diagram.

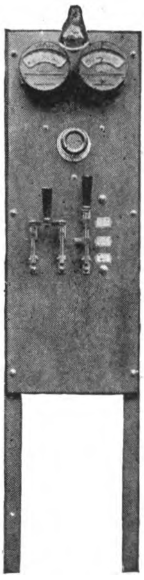

FIG. 45.—Stationary panel.

The stabilizer is made up of coils of wire around a laminated steel core and its purpose is to make the arc steady and easy to operate.

An electrician should explain to the operator the proper method of starting the outfit.

The control panel contains the apparatus with which the operator controls the behavior of the welding generator, adjusting it to give the proper amount of heat for welding. Two cuts are shown showing two types of control panel used. The portable type accomplishes the same thing as the stationary type. The voltmeter and ammeter are left off the portable type on account of the fact that they are too fragile to stand the rough use to which they would be subjected on portable equipment.

Fig. 47 shows the ordinary equipment used by the operator, and welding table. Referring to Fig. 59, the proper clothing for an operator is shown,—it consists of black cap, unionalls, cotton gauntlet gloves, split-leather apron.

ADJUSTMENT OF MACHINE

1. Open main switch and control switch on panel.
2. Start welding set.
3. Turn rheostat as far as it will go to the left.
4. Close control switch into position marked 100. (In this position the current in the arc will be approximately 100 amperes.)
5. Put a piece of 5/32″ welding wire in the metal-electrode holder.

6. Place a piece of boiler-plate scrap on welding table to practice on.

7. Close main switch on panel.

8. Sit down on stool in front of welding table. Take hand shield in left hand, metal-electrode holder in right hand. With shield held in front of face, touch boiler plate with end of welding wire. The

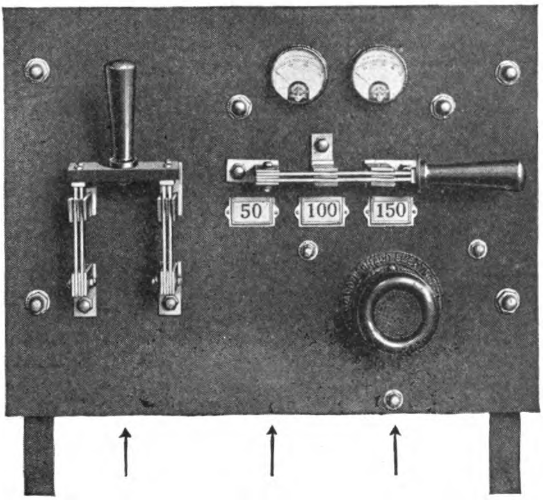

FIG. 46.—Portable panel.

result will be a spark and the welding wire will stick to the boiler plate. Let go of electrode holder and open main switch on panel.

9. With a new piece of welding wire, and face shield in front of face, scratch welding wire sidewise on boiler plate to get spark, then draw welding wire about an eighth of an inch away from the plate. Hold welding wire vertical to boiler plate, otherwise arc will be difficult to start.

Repeat the above operation until an arc can be maintained as long as desirable. The beginner should burn from 75 to 100 pieces of welding wire at this practice, observing through the shield what happens in the arc. As the operator becomes more skilful, he should try to hold a shorter arc. The proper length is about an eighth of an inch. The operator should spend about 15 hours on this kind of practice. The amount of current or amperes required for welding depends principally upon the size welding wire used. Three-sixteenths-inch welding wire requires about 150 amperes. (Turn

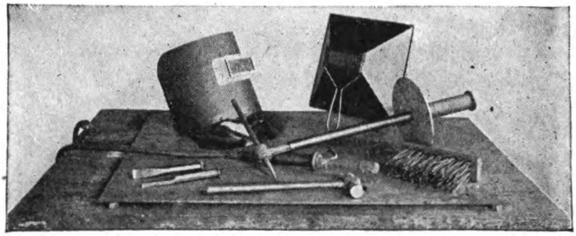

Fig. 47.—Operator's tools.

rheostat as far to left as it will go and close control switch into 150-ampere position.) For points in between 100 and 150 amperes, turn rheostat to right, with control switch in 150-ampere position.

Lesson II

STARTING THE ARC

This exercise deals with the proper method of starting and stopping an electric arc. The beginner usually draws an arc and starts to weld at whatever point the arc happens to start operating properly. In other words, the beginner usually welds where it is possible for him to weld rather than welding in a predetermined place. The purpose of this exercise is to give the operator sufficient control of the arc to enable him to weld at any place he may decide upon.

1. Place a piece of scrap boiler plate on the welding table. With a piece of soapstone mark a line across the plate. Now weld a bead as nearly as possible ½″ to the right of this line. Make the bead as straight as possible. Repeat this operation until a perfectly straight bead ½″ from the predetermined line can be laid down.

2. In this exercise the operator should print his initials on a piece

of scrap boiler plate and weld a bead over the lines. Having produced a perfect set of initials in this manner, take another piece of scrap boiler plate and make the initials the same size without previously printing them with soapstone. The operation should be repeated until the operator can reproduce his initials without following the lines. The purpose of this exercise is to train the operator to control

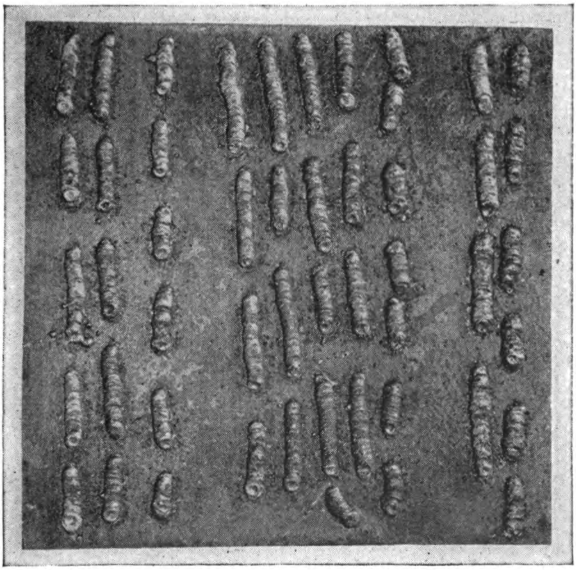

FIG. 48.—Sample of Beads.

an arc and lead it in a predetermined direction. It also involves the training of the operator's eyes to see where he is leading the arc. This will be difficult at first, owing to the fact that the operator can see nothing but the arc itself through the protective glass.

3. The operator should now take hammer and chisel and examine the beginning of several beads which he has made. It will be found that the beginning of the bead is usually not securely welded to the plate. This is due to the fact that the arc was held too long at the

instant the bead was started. The operation of starting the arc at the predetermined point should be repeated with this fact in view until a satisfactory weld is made at the beginning of the bead.

4. The end of the bead is quite as important as its beginning. In referring to beads which the beginner has previously made, it will be found that a considerable crater has been left at the point at which the arc was broken. The objection to this crater is that it is difficult to start welding at this point when it is desirable to continue the bead. The crater may be filled before the arc is finally broken by merely crowding down the arc until the desired amount of metal is added, and breaking the arc suddenly by pulling the wire sharply to one side. The operator should practice this operation until he is able to finish a bead, leaving a crater of not to exceed 3/16 of an inch in diameter.

5. The exercises outlined in the preceding four paragraphs should occupy at least ten hours of the operator's time. The following sample is to be made as to the record of the operator's ability to start and stop an arc properly:

Material required: one 12″x12″x½″ piece of boiler plate; three sizes of electrode are required— 3/16″, 5/32″, 1/8″.

No marking with soapstone is to be done on the plate. Referring to the photograph reproduced herewith, the first three rows of beads are to be made with 3/16″ wire, using approximately 150 ampères, Each bead should be one inch long. The beads should be three-quarters of an inch apart. They should be straight and parallel. Each bead should have a perfect weld at its start and a very small crater at the finish. The next five beads are to be made using 5/32″ electrode and the next two, using ⅛″ electrode, with about 125 and 100 ampères, respectively. One side of the plate should be completely welded in accordance with the above instructions. The plate should then be turned over and the operation repeated and perfected on the other side of the plate.

APPENDIX IV

Lesson III

BUILDING-UP OPERATION

The purpose of this exercise is to show the operator the proper method of building up several layers of welded material. It is assumed that in Lesson II the operator has learned to deposit metal from the welding wire on a piece of boiler plate and have it entirely welded along the line of fusion. Until the operations outlined in Lesson II are completely mastered, it is useless to proceed with the exercise of building-up operations.

Material required: One 10″x12″x½″ piece of boiler plate. One

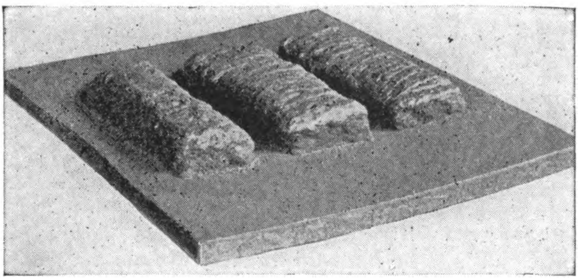

Fig. 49.—Built-up pads of deposited metal.

size of electrode, 5/32 of an inch, is required. The current should be about 125 amperes.

Referring to the photograph reproduced herewith, three pads are to be built up on the face of the plate. These pads are to be 6″ long, 2″ wide, 1″ high. The first pad starting from the left-hand side of the plate is to be built up without any particular design or pattern, and without brushing or cleaning of the oxide-covered surfaces.

The next pad is to be built up following the definite pattern. First, brush the spot on which the second pad is to be built very thoroughly with a wire brush. Second, build up a single layer of metal the width of the pad, using a series of beads laid along the 6″ dimension, always starting at one end and finishing at the other end. Having deposited the first layer, the oxide-covered surfaces must be brushed thoroughly with a wire brush. Each layer should be brushed at least three minutes. The second layer of the pad should be built up so that the beads run at right angles to the beads of the first layer, *i.e.*, the beads are parallel to the 2″ dimension of the pad. This practice is commonly called "lacing." The second layer to be as thoroughly brushed as is required upon finishing the first layer. Each succeeding layer should be thoroughly brushed.

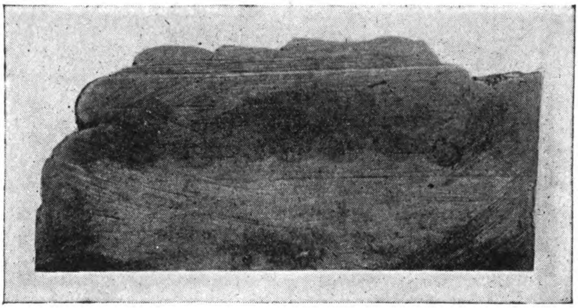

Fig. 50.—Cross-section of pad.

The third pad is to be built up in exactly the same manner as the second pad, with the exception that in place of brushing the work with the wire brush only between each layer, the oxide must be entirely cleaned off by the use of the hammer and chisel. It will be noted that the oxide may be removed by comparatively light blows on the chisel. It is not necessary to cut away any metal to knock the oxide from the top of the layer with a chisel. The wire brush may be used to brush the oxide off the metal after it has been cut away with a chisel.

The operator has now completed three pads. The first pad illustrates how welding should *not* be done. The second pad illustrates a fairly satisfactory practice. The third pad illustrates the best practice. If possible, the operator should have this sample sawed diagonally through the three pads. It should then be set up on a grinding machine and a fine surface ground on the cut section of the pads. This can be done in a tool room. The ground surface should then be painted with diluted sulphuric acid or tincture of iodine. It will then be easy to compare the quality of the metal in the three pads. The operator should also observe carefully the line of fusion between the pads and the original plate. This fusion must be perfect if the weld is of any value. The photograph reproduced herewith illustrates the appearance of a good line of fusion.

Lesson IV

PLATE WELDING

This exercise is one of the most important of the series because the welding of plate is the most frequent application of the electric arc-welding process. The welds which must be made in structures made of plate, such as tanks, are not always horizontal, so that the operator must learn to weld not only in the horizontal position but also in the vertical and overhead positions. Three samples are to be made as the record of the operator's ability to weld in the horizontal position and the vertical and straight overhead positions.

Material required: Six 10″ x 12″ x ½″ pieces of boiler plate beveled 45 degrees on one 12″ edge, 5/32″ electrode with 125 to 150 amperes.

1. The operator should spend approximately ten hours in preliminary practice. Several pieces of scrap boiler plate should be beveled and tacked together as shown in the accompanying photograph. These plates should then be set up vertically and welded, starting at the bottom and welding up. The operator should use his own resourcefulness in arriving at the best way to make a weld in this position, trying several different methods and observing the following points: Does the weld extend completely from the inner to the outer edges of the plate? Does the heating of the plate cause sufficient expansion and contraction to affect the character of the weld? Does the expansion and contraction caused by the heating of

the plate produce a warping or buckling? After the operator has satisfied himself on these points, two pieces of scrap boiler plate should be beveled and placed in position, ready to weld straight overhead, and the operator should try to weld them together in this position, welding from the under side only. The operator should put the pieces approximately one-sixteenth of an inch apart for this exercise. This kind of welding is very difficult and requires a con-

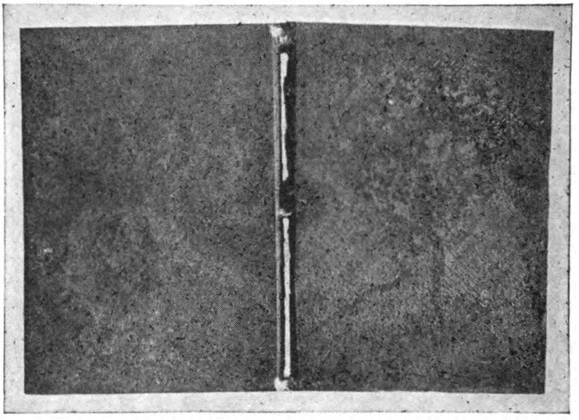

FIG. 51.—Tacked plates.

siderable amount of practice to master. It will be found that the operation will be somewhat easier if 150 amperes is used on 5/32″ electrode at first. In welding beveled plates, the operator should remember that the welding wire or electrode should be held as nearly perpendicular to the surface being welded as possible, and *that good welding can only be accomplished when a short arc is maintained.* The operator should pay particular attention to the difference in sound between a long arc and a short one. A long arc sputters and has a distinct hissing sound. It is impossible to weld with such an arc. A short arc has a rapid-fire metallic click which may be readily distinguished. The operator should maintain a short arc on all classes of welding. Where possible, an electrician should be asked to connect a low-reading voltmeter across the arc, so that the voltage may be read while the operator is welding. The voltmeter should read from 15 to 18 volts while the arc is in operation. The greatest amount of heat is obtained on the work when the electrode holder is

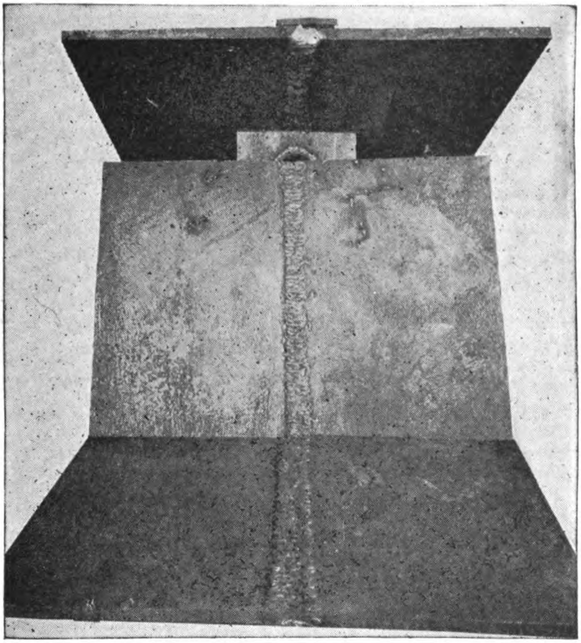

Fig. 52.—Horizontal, vertical and overhead samples.

negative. This is the proper connection for both metal and carbon electrode work.

While the arc is in operation, there will be a circular spot of molten metal upon the work. The operator should concentrate his attention upon the side of this molten spot of metal which is in the direction of motion of the electrode. This may also be described as the forward edge of the circular spot. The arc should be directed on this point, since it is at this point that the greatest amount of heat is desirable. *It is possible to make an electric weld only when* *the globule of molten metal from the welding wire is thrown into molten metal on the piece being welded.* If the globule of metal drops on metal which is not molten, it may stick, but it will not be welded. The operator should study the action of the metal in the heat of the arc very carefully. The operator should begin to realize at this point that merely holding an arc is not necessarily welding but that the art of welding is 90 per cent. brain work and 10 per cent. manual labor.

2. Place the horizontal sample of welding in position on the welding table. Put a 5/32″ electrode under each plate in a position parallel to the beveled edges and about ½″ from the lower edge of the bevel. This will raise the beveled edges higher than the square edges and give the sample a ridge through the centre. The object of this practice is to allow for the warping of the plates by the heating of the arc. After the sample is welded it should be straight with the two plates squarely in line. Place the edges ⅛ of an inch apart all the way across. Tack the pieces together as shown in Fig. 51. Now with 140 amperes and a 5/32″ electrode, weld one layer in the bottom of the bevel in about 3″ sections. By this is meant that the operator should weld 3 inches, skip 3 inches, weld 3 inches, skip, etc., until he has gone all of the way across the plate, then go across the plate again, filling the three-inch gaps. This is to minimize the effect of the heating. The plate will then be welded with one layer all the way across. The operator must manipulate the arc in such a manner as to weld the lower edges of the plate completely together, *i.e.*, the metal from the electrode must run clear through the plates and be firmly welded on the edges. The operator should then take hammer and chisel and clean the oxide from the surface of the welded metal very thoroughly. The second layer may now be welded into the bevel, starting at one end and finishing at the other end. This layer should be thin and should not extend higher than the upper surface of the plates. Chip oxide from surface of welded material, and put the third and finishing layer on the weld. The third layer should extend about 3/16 of an inch beyond the edge of the bevel on each plate, and ⅛″ above the upper plate

surfaces. The plate should now be turned over and a reënforcement of equal width and thickness put on the other side. The purpose of this practice is to make the section of the weld equal on both sides of a centre line through the metal of the plate. If the weld were reënforced on one side and not on the other the stress would be concentrated on the side which was not reënforced when the weld is put in tension.

3. The two plates should be tacked together as in first exercise, but in this case the beveled edges are to be set vertical, as shown

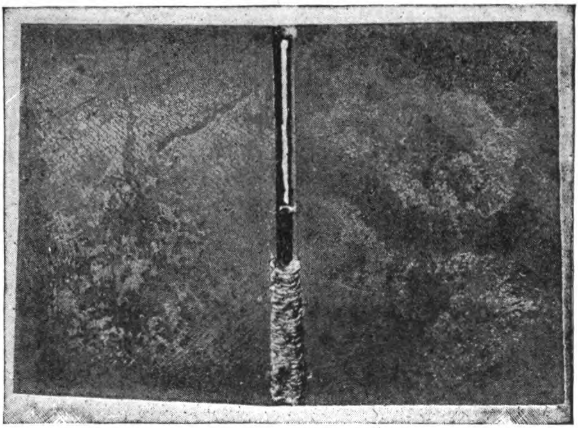

Fig. 53.—Plates welded in vertical position.

in Fig. 53. The weld is to be made according to a definite pattern, starting at the bottom and finishing at the top. This pattern is triangular. The operator should start on the right-hand plate at a point of about 3/16 of an inch to the right of the beveled edge, holding the welding wire as nearly perpendicular as possible to the surface being welded. The movement should be along the beveled edge of the right-hand plate toward the farther edge, then along the beveled edge of the left-hand plate toward the nearer edge, extending to a point 3/16 of an inch to the left of the bevel on the left-hand plate, then across to the starting point. Five-thirty-second electrode with about 125 amperes is to be used. The operator must pay particular attention to see that the farther edges of the plates are securely welded together. A considerable amount of metal should be run through the edges to make this certain.

4. For the sample of overhead welding, the plates may be tacked together as shown previously, except that the opening should be approximately $\frac{1}{4}$ of an anch. The two plates are to be welded in the overhead position after they have been tacked. Several pieces of plate $\frac{1}{8}$ of an inch thick, $1\frac{1}{4}''$ wide and $6''$ long are to be cut, and a $3/32''$ electrode should be stuck on extreme edge of one of the corners so that the electrode stands out perpendicular to the piece. The purpose of the electrode is to serve as a handle. This $\frac{1}{8}''$ piece is to be pushed through quarter-inch opening between the plates from the under side and to be brought into position so that it will form a backing for the weld. Fig. 52 shows the position of this plate. After the plate has been placed in position it may be tacked. The use of this plate makes the overhead welding somewhat easier than welding without its use. Start the overhead weld at the centre of the job and weld toward one end. A definite pattern should be followed. Start at the lower edge of the right-hand plate at a point 3/16 of an inch to the right of the bevel. Continue along the beveled edge of the right-hand plate up to the backing plate, across the backing plate and down the beveled edge of the left-hand plate to a point 3/16 of an inch to the left of the bevel. This will form the first bead. Now start the second bead at the beveled edge of the right-hand plate and on top of the first bead, and fill in, as far as possible, the opening formed by the beveled edges of the plates. A third bead will be required to complete this operation. The operator now has two surfaces to weld on, the surface formed by the welding material, which should be approximately vertical, and the surfaces of the plates to be welded. The pattern of the first pad should be followed out from this point on welding at the junction of the previously-welded material, and the surfaces of the plates being welded together so far as this is possible. This makes the weld more a vertical weld than an overhead weld and considerably sim-

plifies the operation. The operator should use about 150 amperes to start with, cutting it down to 125 or less as the plate warms up. Having completed one end of the weld in this manner, the other end may be welded in exactly the same way. It will be found that the backing plate will warp and tend to get out of contact with the beveled plates. This will not interfere with the welding and will enable the operator to reënforce the weld on the top side, which is very desirable.

Lesson V

THIN-PLATE WELDING

This exercise is to give the operator some experience on thin-plate welding. The difficulties encountered in thin-plate welding are comparatively simple of solution, and the operator is left to use his own resources to a considerable extent in making the sample. The great difficulty in welding thin plate arises from the tendency of the arc to burn through the thin plate, owing to the great intensity of heat. Practically all thin plate is covered with a heavy scale of blue oxide, and it is necessary to get this oxide cleaned off in order to make a good weld. This may be done with hammer and chisel or a sand-blast. The operator has already found that it is necessary to have clean metal in order to make a good weld. The quickest and best way of getting clean metal is to sand-blast the surfaces to be welded. This applies to metal of all thicknesses. The reason blue oxide gives the operator trouble is that it is a very poor conductor of electricity, and it is hard to get the arc started on an oxide-covered surface and also that the oxide gets into the metal of the weld.

Material required: One piece of 24″ x 30″ sheet steel approximately 1/16 of an inch in thickness; 1/8″ electrode with 90 to 100 amperes.

1. The operator should study the drawing reproduced (See Fig. 56) and lay out the pieces to be cut in order to make the sand-blast pot shown. This will leave some scrap material around the

edges which should be cut with a hack-saw into pieces approximately 2″ x 4″. The operator should practice welding these scrap pieces by laying them down on the welding table and welding a straight seam. One sample should also be welded with the two pieces perpendicular to each other as shown in accompanying cut. (Fig. 54.) Approximately two hours should be spent on this practice.

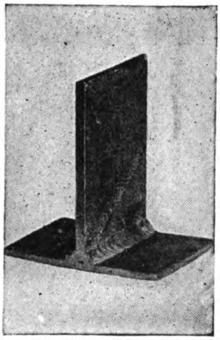

Fig. 54.—Two pieces welded, one perpendicular.

2. The operator should now cut the plates necessary to form the sand-blast pot and weld them together. It is suggested that the heads be made smaller than the shell so that they fit on the inside. They should set back from the edge of the shell about 1/4″. One small hole should be burned through at the location of one of the fittings in order to allow the heated air to escape while the welding is being done. The fitting can be put on the sand-blast pot at some later time by the operator.

Lesson VI

PRESSURE WELDING

This exercise is in the nature of a test of the ability of the operator to make a solid homogeneous weld which is properly and thoroughly done. A great many electric welds are subjected to steam or water pressure and, unless they are properly made, they will show leaks, and will fail at a point below the pressure for which they were designed. It is very important that the operator should know when he is making a good weld. If he does not know this, his work is entirely worthless. He is as poor a workman as the jeweler who must smash an expensive watch in order to find out how it was made. A skilful operator, who has a reasonable degree of judgment and intelligence, knows when he is making a good weld. If he has made a section of a weld which is not good, he should either cut that section out and reweld it or inform the man responsible for the job of the fact that a particular section is faulty. A man who will lie to himself in regard to the quality of his work will lie to the man who is responsible for its quality, and is worse than worthless as a skilled operator.

Material required: One 18″ section of 8″ wrought-iron pipe or seamless tubing, two 5/8″-thick boiler-plate heads to fit on the inside of the pipe or tube. These heads should be beveled 45 degrees on the circumference, 6 pieces of 1″ black wrought-iron pipe 6″ long, one piece of 3/4″ or 1″ pipe according to the size

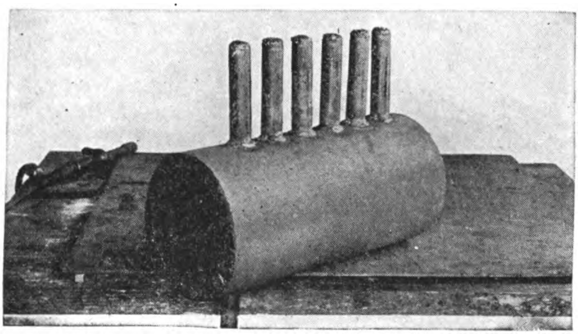

Fig. 55.—Boiler flue welding.

water pipe used in the shop where the welding is done. This pipe is to be connected to the water system so that the completed sample may be tested under pressure. Six holes are to be drilled at intervals of 2″ into the 8″ pipe to take the six 1″ pipes. One hole is to be cut to take the 3/4″ or 1″ pipe.

1. The heads are to be welded into the pipe as shown in the accompanying cut. (Fig. 55.) The operator must be careful to hold a short arc and so far as possible keep the electrode perpendicular to the surface being welded. The surfaces which are to be welded must be clean and the oxide must be removed from each layer of metal before the next layer is welded, by the use of sandblast or hammer and chisel. The 1″ pipes are spaced close enough

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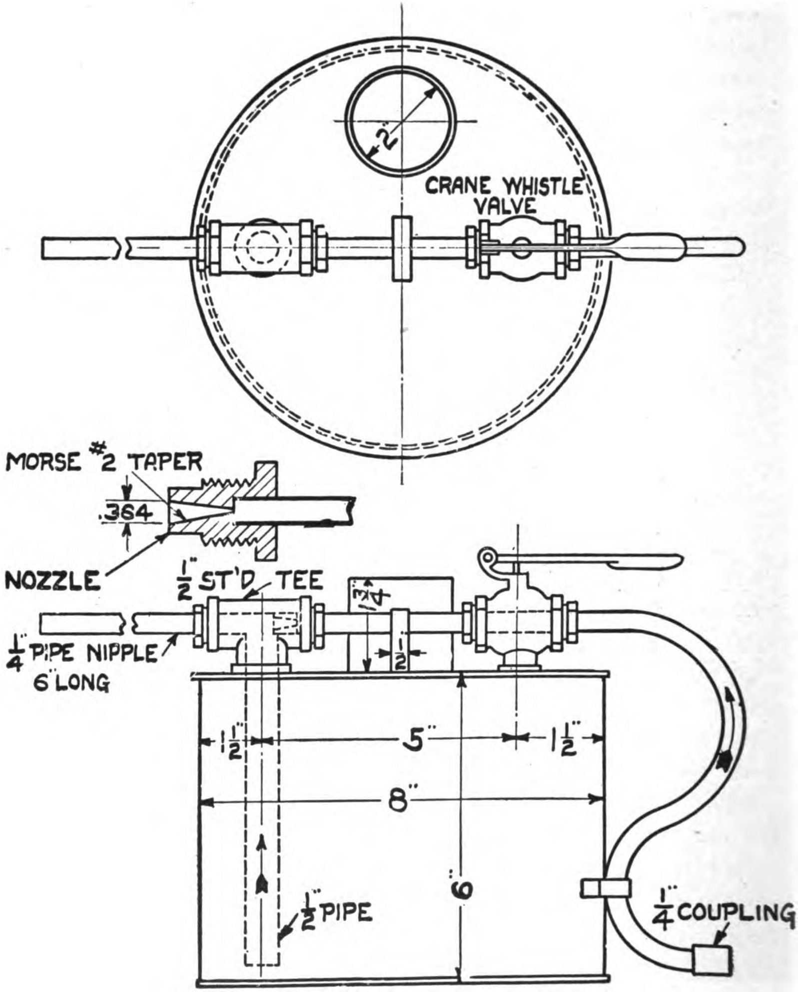

2"
CRANE WHISTLE VALVE
MORSE #2 TAPER
.364
NOZZLE
1/2" ST'D TEE
3/4
1/2
1/4" PIPE NIPPLE 6" LONG
1 1/2"
5"
1 1/2"
8"
6"
1/2" PIPE
1/4" COUPLING

Fig. 56.

together so that some difficulty will be experienced in making a good weld between pipes. This is done purposely because it is a difficulty frequently encountered in practice. The operator should mark with chalk the spots where he believes, owing to the manner in which he welded the sample, that the leaks will occur. Weld the ends of the six 1″ pipes shut.

2. The operator should connect the sample to the water system of the shop and test it for leakage. (It is advisable to pour the sample full of water before the connection is made, so that it will be entirely filled with water when under pressure.) If leaks are found, the operator should cut out that part of the weld, examine the weld and find, if possible, the cause of the leak. The defective spots should be rewelded and the test repeated.

Lesson VII

MISCELLANEOUS JOBS

The object of this exercise is to give the operator an idea of a few of the many different kinds of applications of the process. A great deal depends upon the operator's natural resourcefulness in planning a job. One of the difficulties is in knowing how to go about a job so that it may be done with the least possible exertion. The more highly skilled the operator is, the easier will be the way which he chooses to perform the operation. This involves careful planning of the operation before it is started. The operator who cannot plan in advance exactly how he is going to do the job will have little success in doing it. As has been stated before, success in welding depends more upon the use of the brain than upon the use of the hands. The operator should be able to tell exactly how he proposes to do a certain job, and explain the reasons why he intends to do the job in that particular way.

Material required: One riveted section as shown in Fig. 57, one angle-iron section as shown in Fig. 58. These two samples need not conform to any specified dimensions.

1. For preliminary practice, the operator should take two pieces of $\frac{1}{4}''$ scrap boiler plate, and tack them together in the form of a lap joint. This sample should then be set up in the vertical position and a fillet welded on the under side of the lap, similar to Fig. 57. This operation should be repeated until the operator is able to get

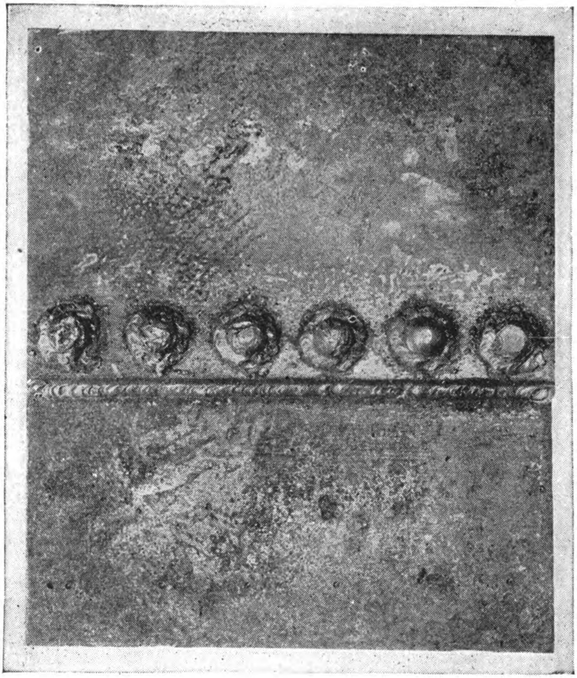


FIG. 57.—Riveted section.

a good weld and the fillet has a uniform appearance. The operator should calculate the number of feet per hour of this work he can do. This work is similar to the operation encountered in the welding of a caulking edge on the riveted seam of a steam boiler. It is necessary to weld only one bead to form the fillet; 140 to 150 amperes should be used. The operator should cut across the seam and examine the fillet to determine whether or not he has made a good weld.

2. With a piece of scrap boiler plate set in the vertical position, the operator should weld a number of circular beads approximately $1\frac{1}{2}''$ in diameter. After eight or ten of these circular beads have been welded, the operator should clean the oxide from the surfaces, and weld a second bead around the first bead. This is an operation similar to that of welding around the head of a rivet. One of these circles should be cut and the weld examined to see that it has been properly done and that the second bead is fused thoroughly to the plate and to the first bead. This is an operation which must be thoroughly mastered before proceeding further.

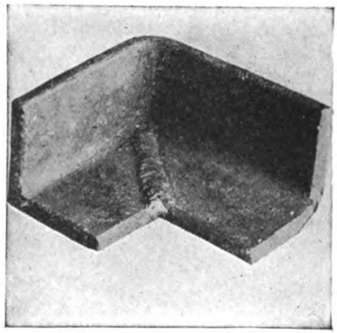


Fig. 58.—Angle iron section.

3. This exercise consists of welding two pieces of heavy plate together without bevelling. If possible, two pieces of $\frac{5}{8}''$-thick boiler plate should be obtained for the exercise. Each edge which is to be welded should be set in a horizontal position and a bead welded along the centre of the plate. The second bead should then be welded in top of the first, removing the oxide from the first before the second is applied. When both edges are thus prepared and put together, the operator will have what amount to bevelled edges to weld together, but it will be necessary to weld from both sides in order to complete the job. One weld of this nature should be made and cut so that the operator may examine it to see that fusion has taken place throughout the entire weld.

4. This exercise is the one shown in the cut (Fig. 57) and consists of welding the caulking edge of a riveted joint and welding around the rivet head. The method of welding the caulking edge has been previously explained. In welding around the rivet head it is advisable to heat the rivet before welding around the head.

With the plate in a vertical position (rivets above the caulking edge), draw an arc on the head of the first rivet, allowing the metal from the electrode to fall clear of the rivet head. This should be continued for about two minutes or until the rivet is thoroughly heated, then the fillet should be welded around the rivet. The operator should then skip two rivets and repeat the operation on the fourth rivet. The idea of skipping rivets is to keep the heat distributed so that contraction in the metal will not set up shearing stresses in the rivets. By following the above practice, a very tight joint will result when the metal of the rivets and plates cools. The result is similar to the result obtained by putting in a hot rivet and peening it over. When such a rivet cools, it contracts and pulls the plates tightly together. The operator may turn the sample over and repeat the operation on the other side, perfecting it, if possible.

5. The exercise of welding an angle-iron section is one which illustrates a type of job which is quite common. The angle may be cut from a straight angle section and the triangular shape cut out with a hack saw. The triangle is cut out so that the angle may be bent at right angles. The tip of the triangular, however, must be cut square off in order to allow a right angle to be bent without the edges coming entirely together. The distance between the edges after the angle has been bent through 90 degrees should be equal to the thickness of the angle. The operator may then bridge cross the two edges from one side allowing as little metal to drop down between the edges as possible. Then the angle should be turned over and the space between the edges completely filled by welding in one or more layers.

Lesson VIII

FLUE WELDING

This exercise deals with the welding of flues into the flue sheet of a boiler. This work is encountered in fire-tube boilers of all kinds. The operation requires a considerable amount of skill in handling the arc. A preparation of the flue sheet for welding in actual practice is usually what makes the job a success or failure.

In practice, the proper way of preparing a flue sheet for welding is to put the flues in exactly as if they were not to be welded. The boiler should then be fired at least once to allow the tubes to take their permanent set. The flue sheet should then be sand-blasted to clean the surfaces to be welded. If no sand-blast is available, the pneumatic tool should be used to knock the oxide off the surfaces, after which the surfaces should be thoroughly brushed with a wire brush, then the welding may be done. If the work is pre-

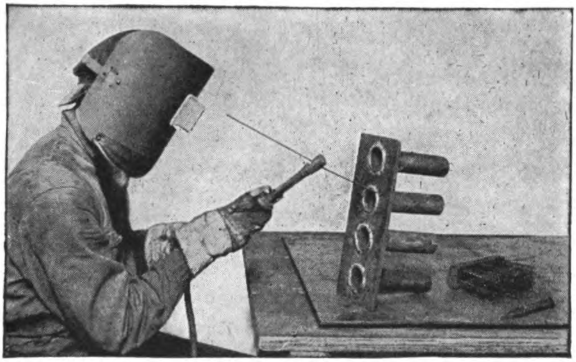


FIG. 59.—Welding boiler flues; showing arc welder's clothing outfit.

pared in this manner and properly welded, the results will be uniformly successful.

Material required: Section of ½″ boiler plate with four 2″ flues rolled in as shown in cut; ⅛″ electrode with 100 amperes should be used.

1. Set the sample as shown in the photograph. Use head shield and hold the electrode holder in both hands as shown in the cut. The first flue at the top should be welded starting at the point shown in the cut and welding one-half way around, moving from right to left. Then the other one-half welded starting at the original point and moving downward to the left. The second flue should then be welded starting at the bottom and welding in two halves so that they meet at the top. The operator may then weld the other two

flues by either of the two methods illustrated, depending upon which the operator likes the better. One of the flues should then be sawed in half to show the quality of the workmanship.

Lesson IX

WELDING STEEL CASTINGS WITH CARBON ARC

This exercise illustrates the kind of work done in a steel foundry and in certain railway shops. The carbon arc is used in the same manner as the flame of an oxy-acetylene torch. From 300 to 600 amperes are required for carbon-electrode work of this nature. The operator must use both hands and therefore the head shield is required. The carbon-electrode holder is held in the right hand and the welding rod is held in the left hand. Carbon-electrode welding is usually considered easier than metal-electrode welding, but there is considerable skill required to handle a carbon arc successfully.

Material required: One small steel casting (Fig. 60), carbon-electrode holder, carbon electrode ½″ in diameter, sharpened to a point at one end, 300-ampere welding capacity (if 300-ampere unit is not available, two 150-ampere units may be connected in parallel), 3/16″ welding rod.

1. For preliminary practice, the operator should use the 300-ampere carbon arc and cut into small pieces several pieces of boiler-plate scrap. For this work the arc should be held approximately a quarter of an inch long. After the operator has practiced sufficiently at this work to be able to make a clean cut along a predetermined line, he should try welding together two pieces of boiler-plate scrap using the carbon arc and the 3/16″ welding rod to fill in with. It will be rather difficult to control the arc and lead it in any desired direction.

2. If 3/16″ carbon electrodes are available, one should be sharpened and placed in the metal electrode holder and some cutting of 1/16″ plate done using 150 amperes. The operator should be able to cut a straight, clean cut upon completing this exercise.

3. Using the riveted sample which was used in Lesson VII, the

operator should use the 300-ampere carbon arc to cut out a section of the upper plate between two rivets. To perform this operation, the plate should be set up in the same position in which it was welded so that when the metal is melted by the carbon arc it can run down out of the cut. The sample should then later be welded flush, using the metal-electrode process. After working with the

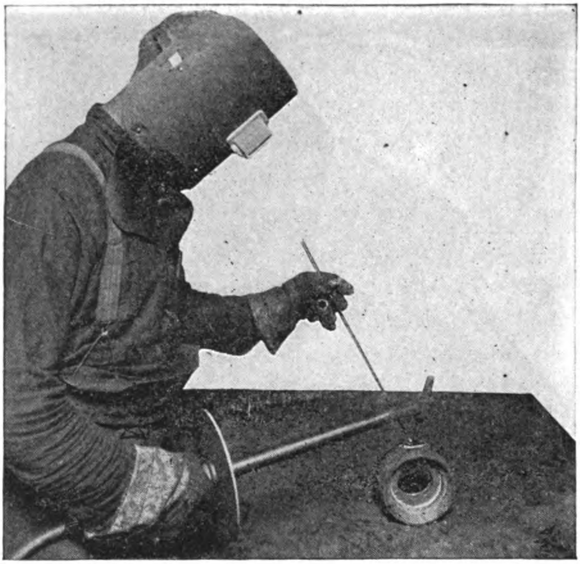


FIG. 60.—Small steel casting.

carbon arc and before working with the metallic arc on this job, it will be necessary to chip the oxide off the surface to be welded, since the carbon arc forms a very thick coating of oxide.

4. This exercise deals with the correction of a flaw in the steel casting due to a sand spot. This defect in the steel casting is caused by the crumbling of the mould. It is necessary to burn the sand spot out with the carbon arc and fill in new material from the welding rod. If there is no sand spot on the casting available, it will be sufficient for the operator to heat a spot approximately 1½″

in diameter to the molten state, then quickly break the arc and strike the molten metal a sharp blow with a ball-peen hammer. If the operator had performed this operation on a sand spot, he would have floated out most of the sand by the heat of the arc. The sharp blow with the hammer throws the molten sand and slag out of the weld. The next operation is to fill in the defect with new material from the welding rod. The operation must be performed as rapidly as possible, otherwise the metal added as well as the metal of the casting in the vicinity of the weld will be ruined by the extreme heat. The arc should be used to cut off short pieces of the welding rod and then these pieces should be melted and puddled in the proper place. In case the arc breaks during the operation, it should be started again on solid metal that is not molten and the arc brought over into the welding area quickly. If the arc is started by touching the molten metal with the carbon electrode, it is very likely that the weld will be hard, owing to the fact that carbon from the electrode has gotten into the weld. As soon as the added material has been fused into the weld, the arc must be broken. There is always a tendency on the part of a beginner to play the arc too long on the completed weld in an attempt to give the weld a smooth-finished appearance; this results in burning of the metal. In steel-casting work to avoid hard spots two points must be observed: (1) Some preheating must be done around the point at which the weld is to be made with the arc so that it will not be cooled too suddenly. (2) The carbon electrode must not be brought in contact with the molten metal as explained before.

This operation should be performed several times by the operator until he can produce a weld which is satisfactory to him.

Lesson X

CAST-IRON WELDING

The purpose of this exercise is to give the operator an idea of what can be accomplished with the electric arc on cast iron. The operator will frequently hear amazing statements as to what some particular operator has done along the line of welding cast iron, but it is a fact that there are only a few commercial applications of the process in the welding of cast iron. The difficulty in welding cast iron with the electric arc is not due to the fact that the metal cannot be properly fused, but is due to the fact that the sudden intense heat of the arc over a local area results in the production of a hard weld and the introduction of contraction stresses which often result

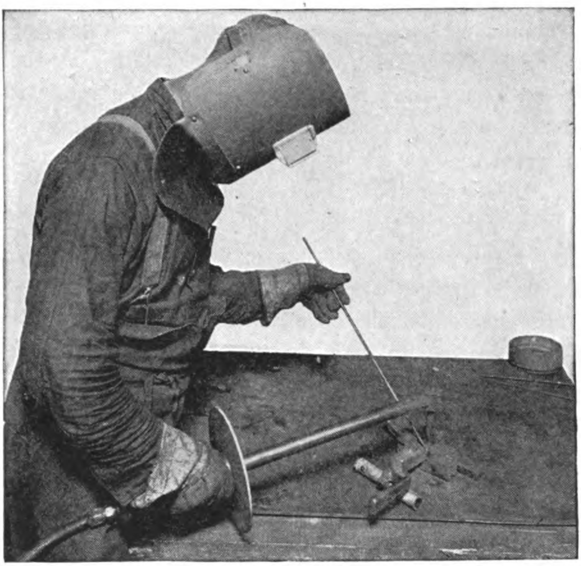


Fig. 61.—Small piece of cast iron.

in cracking. Using the carbon welding process, cast-iron welding rods may be fused into a cast-iron piece. Using the metal-electrode process and a soft iron or steel electrode, it is impossible to make a reliable weld between the added material and the cast iron. Using the metal-electrode process, certain work can be done by the introduction of steel studs in the cast-iron pieces to be welded together, so that a certain amount of strength is obtained by the bond formed between the steel studs by the welded material.

Material required: 300-ampere welding capacity, 3/16" cast-iron welding rod. One small grey-iron casting (Fig. 61).

A small grey-iron casting should be broken and the edges bevelled, using the carbon arc for cutting. The pieces should then be placed in a carbon mould so that the molten iron, when it is added, will not run away from the joint. This is illustrated in Fig. 61. The carbon arc should be used to pre-heat the casting. It is not necessary to heat the piece to a red heat. The carbon arc and cast-iron welding rod should then be used to fuse the added material to the piece. As in Lesson IX, care should be exercised not to play the arc upon the weld any longer than is necessary to give complete fusion. In case the metal gets too hot and runs badly, the arc must be broken, and an interval of time allowed for it to cool slightly to eliminate the trouble. After the weld is completed, the piece should be wrapped up securely in asbestos paper and allowed to cool slowly for 6 or 8 hours (larger pieces require from 18 to 24 hours to cool). As an alternative to wrapping in asbestos paper, the piece may be covered in previously-heated slacked lime. The idea of the lime is the same as the asbestos, to cool the casting slowly. If the work is properly pre-heated and welded rapidly and very slowly cooled, the material in the weld will be as readily machinable as the balance of the piece. No flux of any kind is required, although borax may be used.

APPENDIX V

THIS design was prepared by me * in London with the coöperation of Mr. W. S. Abell, chief ship surveyor of Lloyd's Register. The design is such that a lot of work could be done at constructional works, or could all be equally readily done in the shipyard. The work is closed up by the use of service bolts.

The system of welding in view is the "arc," although "spot" welding could be adopted for the ground work. In general, the position of materials does not differ from that of a riveted ship.

There are no large pieces to handle; therefore, no special lifting facilities are required, but such shipyards as can conveniently handle large sections could complete large sections on the ground, if desired.

The difficulty of doing "overhead" welding has been strongly emphasized by welding experts, and this has been kept in view and obviated, or at any rate so far as the "strength" welds are concerned.

A slight departure from riveted practice is to make some of the side and bottom shell plates much wider than would ordinarily be the case for a ship of this size.

As it happened in this design, a length of plate of 22 ft. fitted in admirably with the arrangements, and has the maximum area which would be supplied from the mills in Great Britain for a plate of the thickness, *viz.:* ½ inch without "extra."

Three longitudinals are fitted on these plates, and are butted at the shell butts in order that the longitudinals can be welded to the plates on the ground. There is no reason why, if desired, two plates or large sections might not be welded together on the ground, and the longitudinals fitted in 44-ft. lengths, but this, as previously mentioned, depends on the builders' facilities.

---

* Courtesy of J. W. Isherwood.

The "clips" of the transverse members being in short pieces are also welded on to the plates on the ground.

The seams and butts of the bottom plating are "butted" and fitted with outside straps.

The seams of the side plating are arranged clinker fashion in order to obviate overhead strength welding.

The vertical stiffeners to the floors are fitted in the shop and in cases like this, *viz.:* of stiffeners and not strength connections and where only an odd hole or two could be saved by welding, it is suggested that riveting be adopted. The same remarks apply to the horizontal "clips" on side transverse and so on.

The longitudinals and "transverse" attachment angles are welded to the plates in the shop similarly to the bottom plates. The gunwale bar in addition to the longitudinal and transverse attachments is welded to the sheerstrake before erection.

The tank-top margin angle is also welded to the shell plate abreast it before erection.

The side transverse members and transverse deep beams are assembled and welded on the ground in such sections as are convenient to the builders, that is, the beam part can be secured to the side transverse frame either before or after erection as desired.

The tank-top plates and deck plates have both the longitudinals and transverse attachments welded to the plate in the shop. It will, of course, be appreciated that where the longitudinal forms the seam strap it can only be welded to the edge of one of the plates. The completion of the connection is, however, a very simple matter, being only an ordinary downward butt weld.

The process of erection and the welding to be done in the ship might be briefly described, bearing in mind that no special facilities of any kind are required for handling the material beyond what would be in use in an ordinary shipyard which would ordinarily build a riveted vessel of the same dimensions.

The keel plates are laid as usual, they have already welded to them the angle bars to take the centre girder and the outside straps in way of the seams and also at one end of each plate to complete the butt with the next plate.

The plates for the next strake are brought into position, they have in addition to the longitudinals and transverse framing clips, edge strips welded along one edge to form the seams for the adjoining strake and edge strips at one end of each plate to form the butt of the next plate.

This procedure is adopted until all the bottom plates are laid in position, the seams and butt strips forming convenient rests for consecutive plates and the service holes for holding the plates in approximate position.

The floors are then dropped into position (it might here be remarked that the floors are widely spaced; in this particular example they are 5 ft. 6 in. apart) and secured to the longitudinal by bolts through the outstanding flanges of the vertical angles on the floors.

When a sufficient number of tank-tcp plates, with the longitudinals and transverse clips already welded on, are laid in position so as to adjust and fair the bottom components, the welding operations on the ship can be commenced.

As soon as the margin plate of tank top is adjusted to its proper position, the transverse frames, which are 11 ft. apart, are erected and shoved in place.

The sooner the sheerstrake, which has already welded to it the longitudinal frame and gunwale bar, can be brought into position, the more readily can the side plating with its framing work be erected and faired.

Welding can, of course, be commenced on the side as soon as a sufficient section is faired and secured.

The deck transverse beams, if not already lifted into position with the side frame, are then placed in position and secured. The deck plates, with the longitudinals already welded on, are dropped into position and the deck faired, when all the welding now to be done in the ship can be proceeded with. I wish to draw attention to the very small amount of welding to be done on the ship.

DOUBLE BOTTOM

Full welds: Butt seams bottom plating.

Butt straps of bottom plating and butts of longitudinals.

Connection centre keelson plate—top and bottom.

Seams of tank-top plating.

Butts of tank-top plates and butts of longitudinals.

I might here remark that Lloyd's chief surveyors have intimated their approval of the butting of the tank-top plating at the centre line in order to obviate overhead full welding.

Light welds: One edge of outside seam strap.

Top and bottom of floor plates to transverse clips; floors 5 ft. 6 in. apart, giving ample room for working.

If the service holes in the seams and butts are filled with plugs and welded and the small connections at the intersection of the longitudinals with the floor plates are welded, then all riveting in the double bottom on the ship is obviated.

It is assumed that the service holes for the work done in the ship were filled up before the material was brought to the ship and before erection.

SIDE PLATING AND INTERNAL WORK

Full welds: Outside edges of shell overlaps.

Butts of shell plates and longitudinals.

Connection of transverse plates to shell clips.

Connection of transverse to inner-bottom plating.

Light welds: Inside edges of shell overlaps.

DECK AND INTERNAL WORK

Full welds: Seams of deck plating.

Butts of deck plating and longitudinals.

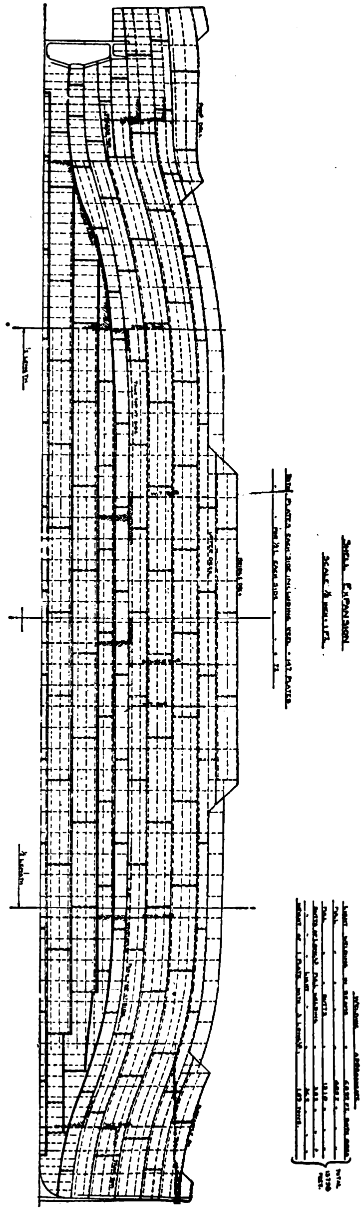
Heel of gunwale bar.

Connection of beam to transverse.

Light welds: Connection of transverse beam plates to clips already on deck.

Pillar and detail work.

The same remarks apply in regard to the filling of service holes.



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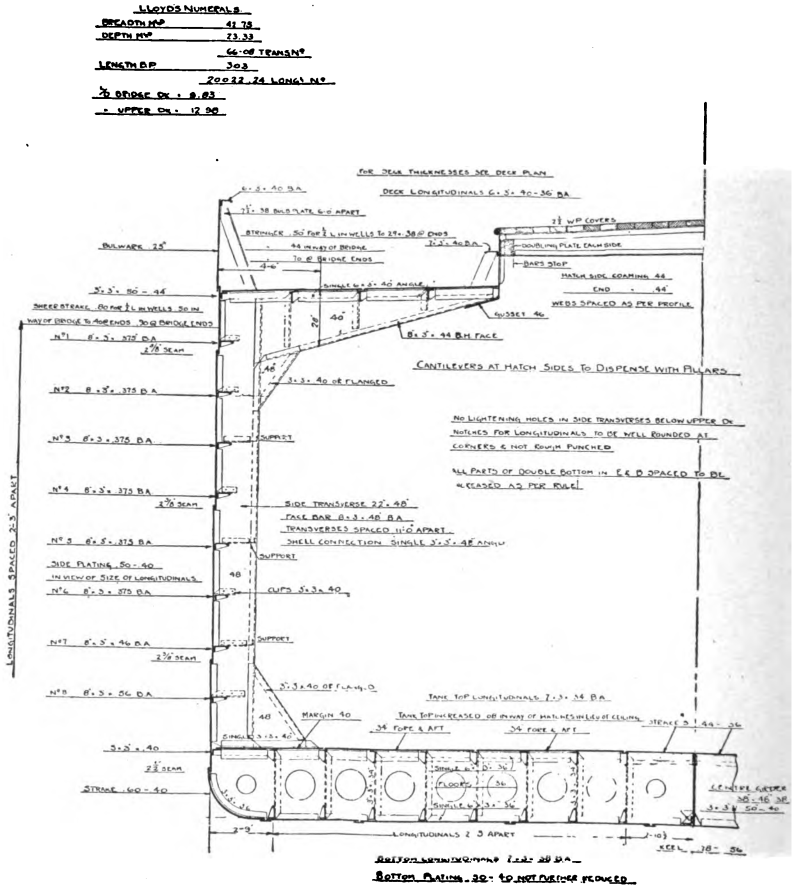
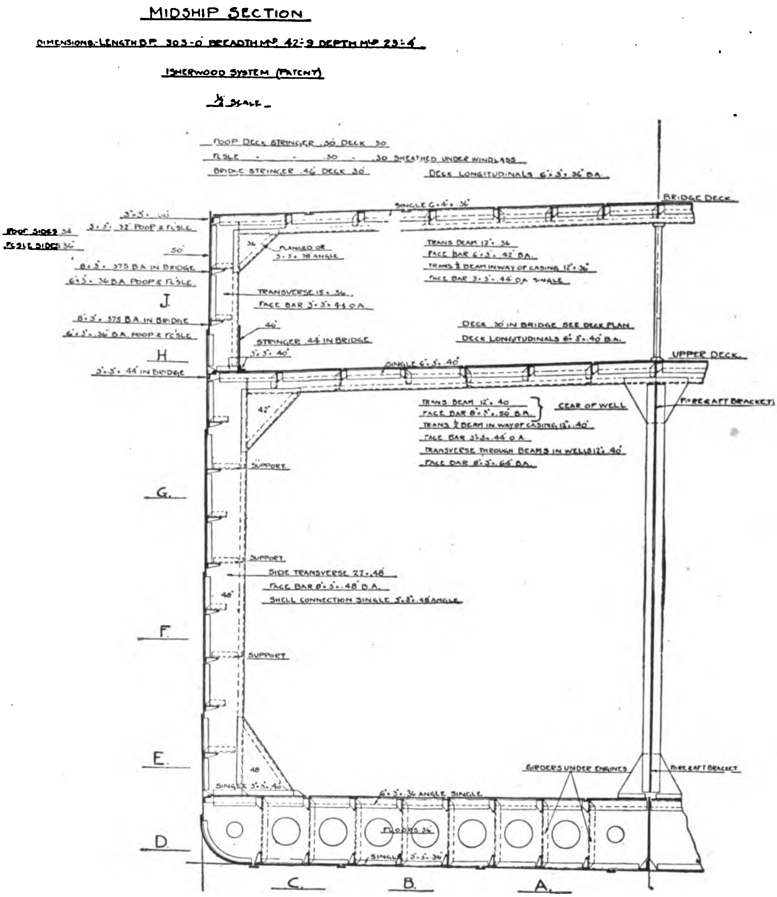
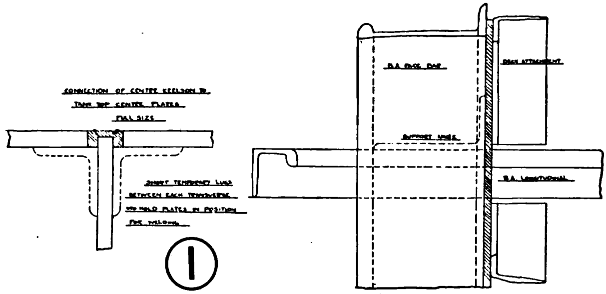
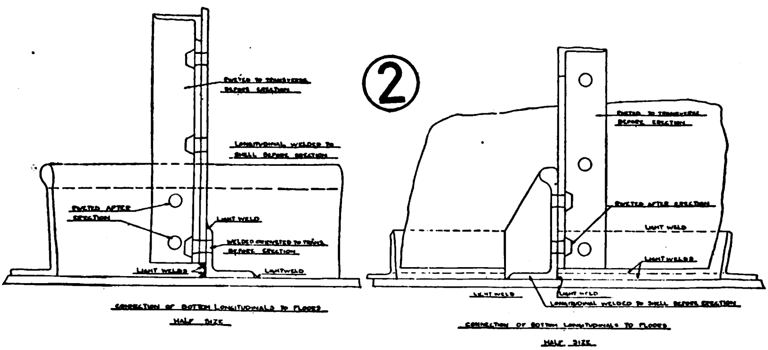
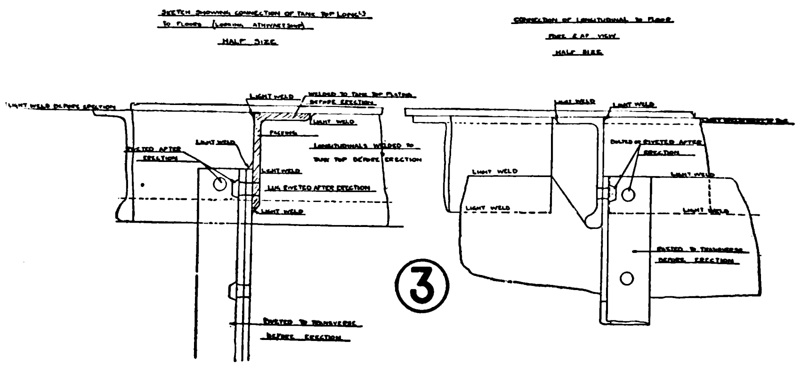
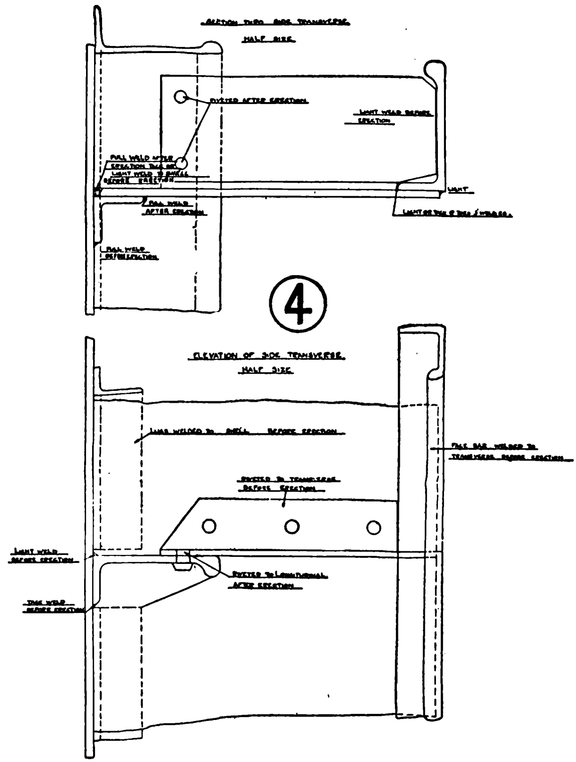

LLOYD'S NUMERALS.
BREADTH MD 42.75
DEPTH MD 23.33
66·08 TRANS N°
LENGTH B.P. 303
20022.24 LONGL N°
½ BRIDGE DK · 9.83
· UPPER DK · 12.98
FOR DECK THICKNESSES SEE DECK PLAN
DECK LONGITUDINALS 6·3·40-36 BA
6·3·40 BA
7½·38 BULB PLATE 6·0 APART
STRINGER .50 FOR ½ L IN WELLS TO 29·38 @ ENDS
· 44 IN WAY OF BRIDGE
· 70 @ BRIDGE ENDS
7·3·40 B.A.
2½ WP COVERS
DOUBLING PLATE EACH SIDE
BARS STOP
HATCH SIDE COAMING 44
END · 44
WEBS SPACED AS PER PROFILE
BULWARK .25
4-6
SINGLE 6·3·40 ANGLE
5·3·50 - 44
SHEER STRAKE .80 FOR ½ L IN WELLS 50 IN WAY OF BRIDGE TO 40 @ ENDS .30 @ BRIDGE ENDS
26
40
GUSSET 46
8·3·44 B.H. FACE
N°1 8·3·.375 BA
2⅜ SEAM
48
3·3·40 OR FLANGED
CANTILEVERS AT HATCH SIDES TO DISPENSE WITH PILLARS
N°2 8·3·.375 BA
NO LIGHTENING HOLES IN SIDE TRANSVERSES BELOW UPPER DK
NOTCHES FOR LONGITUDINALS TO BE WELL ROUNDED AT CORNERS & NOT ROUGH PUNCHED
N°3 8·3·.375 BA
SUPPORT
ALL PARTS OF DOUBLE BOTTOM IN E & B SPACED TO BE INCREASED AS PER RULE
N°4 8·3·.375 BA
2⅜ SEAM
SIDE TRANSVERSE 22·48
FACE BAR 8·3·48 BA
TRANSVERSES SPACED 11·0 APART.
SHELL CONNECTION SINGLE 3·3·48 ANGLE
LONGITUDINALS SPACED 2·3 APART
N°5 8·3·.375 BA
SUPPORT
SIDE PLATING .50 - .40
IN VIEW OF SIZE OF LONGITUDINALS
48
N°6 8·3·.375 BA
CLIPS 3·3·40
N°7 8·3·46 BA
SUPPORT
2⅜ SEAM
N°8 8·3·56 BA
3·3·40 OR FLANG.D
TANK TOP LONGITUDINALS 7·3·34 BA
48
MARGIN 40
TANK TOP INCREASED 08 IN WAY OF HATCHES IN LIEU OF CEILING
34 FORE & AFT
34 FORE & AFT
STRAKES 44 - 36
SINGLE 3·3·40
3·3·.40
2½ SEAM
STRAKE .60 - 40
SINGLE 6·3·36
FLOORS 36
SINGLE 6·3·36
CENTRE GIRDER
38 - 46 38
3·3 50 - 40
2-9
LONGITUDINALS 2 3 APART
1-10½
KEEL 78 - 56
BOTTOM PLATING .30 - 40 NOT FURTHER REDUCED

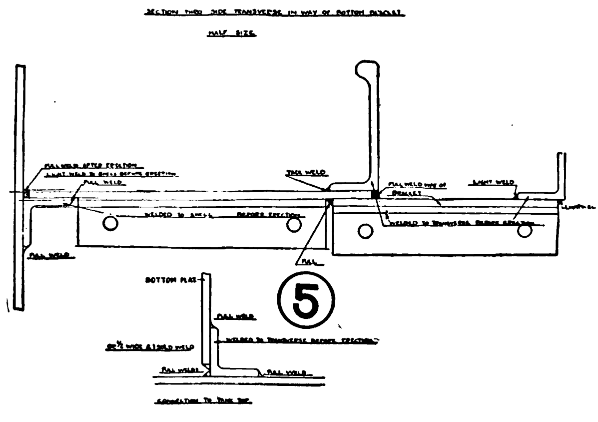

MIDSHIP SECTION
DIMENSIONS.-LENGTH B.P. 303-0 BREADTH M.D. 42-9 DEPTH M.D. 23-4
ISHERWOOD SYSTEM (PATENT)
½ SCALE
POOP DECK STRINGER .30 DECK .30
FC'SLE . . .30 . .30 SHEATHED UNDER WINDLASS
BRIDGE STRINGER .46 DECK .30
DECK LONGITUDINALS 6"·3"·.36 B.A.
SINGLE 6·4·.36
BRIDGE DECK.
POOP SIDES .34
FC'SLE SIDES .36
3"·3"·.32 POOP & FC'SLE
50
8"·3"·.375 B.A. IN BRIDGE
6"·3"·.36 B.A. POOP & FC'SLE
36
FLANGED OR 3·3·.38 ANGLE
TRANS BEAM 12"·.36
FACE BAR 6"·3"·.42 B.A.
TRANS ½ BEAM IN WAY OF CASING 12"·.36
FACE BAR 3"·3"·.44 D.A. SINGLE
J.
TRANSVERSE 15·.36
FACE BAR 3"·3"·.44 D.A.
8"·3"·.375 B.A. IN BRIDGE
6"·3"·.36 B.A. POOP & FC'SLE
46
STRINGER .44 IN BRIDGE
3"·3"·.40
DECK .30 IN BRIDGE SEE DECK PLAN
DECK LONGITUDINALS 6"·3"·.40 B.A.
H.
3"·3"·.44 IN BRIDGE
SINGLE 6"·3"·.40
UPPER DECK.
42
TRANS BEAM 12"·.40
FACE BAR 8"·3"·.50 B.A.
CLEAR OF WELL
FORE & AFT BRACKET
TRANS ½ BEAM IN WAY OF CASING 12"·.40
FACE BAR 3"·3"·.44 D.A.
TRANSVERSE THROUGH BEAMS IN WELLS 12"·.40
FACE BAR 8"·3"·.64 B.A.
SUPPORT.
G.
SUPPORT
SIDE TRANSVERSE 27·.48
FACE BAR 8"·3"·.48 B.A.
SHELL CONNECTION SINGLE 3"·3"·.48 ANGLE
48
F.
SUPPORT
E.
48
SINGLE 3"·3"·.40
GIRDERS UNDER ENGINES
FORE & AFT BRACKET
6"·3"·.36 ANGLE SINGLE
FLOORS .36
SINGLE 3"·3"·.36
D.
C.
B.
A.

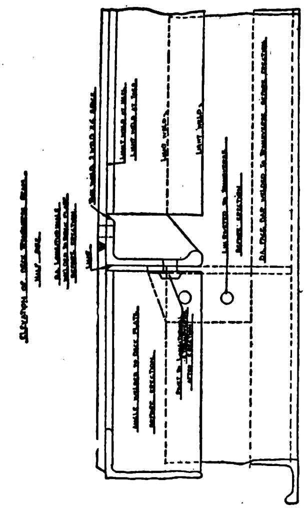

CONNECTION OF CENTRE KEELSON TO
TANK TOP CENTRE PLATES
FULL SIZE
SHORT TEMPORARY LUGS
BETWEEN EACH TRANSVERSE
TO HOLD PLATES IN POSITION
FOR WELDING
B.A. FACE BAR
DECK ATTACHMENT
SUPPORT LUGS
B.A. LONGITUDINAL
1

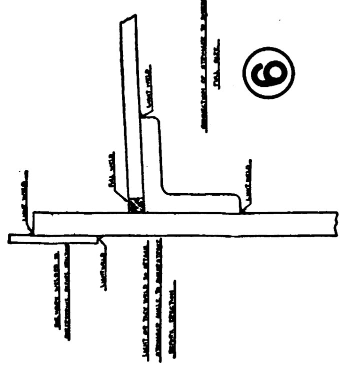

2
RIVETED TO TRANSVERSE
BEFORE ERECTION
LONGITUDINAL WELDED TO
SHELL BEFORE ERECTION
RIVETED AFTER
ERECTION
LIGHT WELD
WELDED OR RIVETED TO TRANS.
BEFORE ERECTION
LIGHT WELDS
LIGHT WELD
CONNECTION OF BOTTOM LONGITUDINALS TO FLOORS
HALF SIZE
RIVETED TO TRANSVERSE
BEFORE ERECTION
RIVETED AFTER ERECTION
LIGHT WELD
LIGHT WELDS
LIGHT WELD
LIGHT WELD
LONGITUDINAL WELDED TO SHELL BEFORE ERECTION
CONNECTION OF BOTTOM LONGITUDINALS TO FLOORS
HALF SIZE

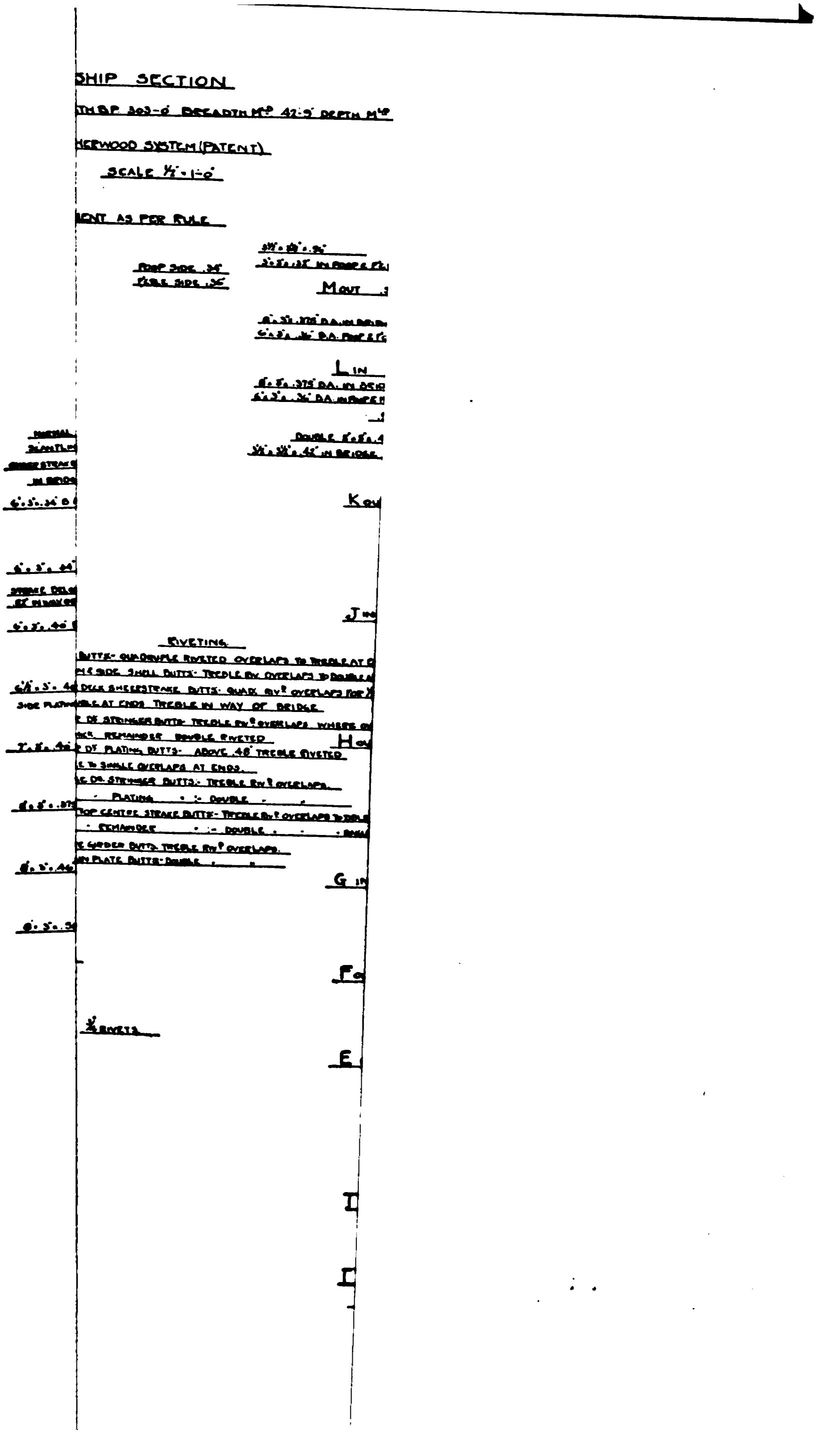

SKETCH SHOWING CONNECTION OF TANK TOP LONG'LS
TO FLOORS (LOOKING ATHWARTSHIP)
HALF SIZE
CONNECTION OF LONGITUDINAL TO FLOOR
FORE & AFT VIEW
HALF SIZE
LIGHT WELD BEFORE ERECTION
LIGHT WELD
WELDED TO TANK TOP PLATING
BEFORE ERECTION
LIGHT WELD
PACKING
LIGHT WELD
LONGITUDINALS WELDED TO
TANK TOP BEFORE ERECTION
RIVETED AFTER
ERECTION
LIGHT WELD
LUG RIVETED AFTER ERECTION
LIGHT WELD
RIVETED TO TRANSVERSE
BEFORE ERECTION
3
LIGHT WELD
LIGHT WELD
BOLTED OR RIVETED AFTER
ERECTION
LIGHT WELD
LIGHT WELD
LIGHT WELD
LIGHT WELD
RIVETED TO TRANSVERSE
BEFORE ERECTION


ELEVATION OF SIDE TRANSVERSE.
HALF SIZE.
4

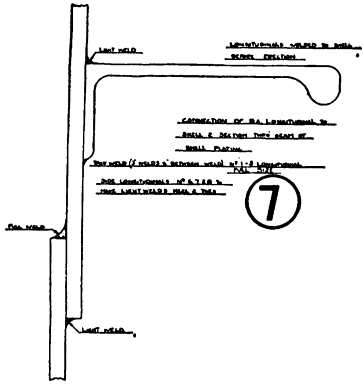

BOTTOM PLATE
5





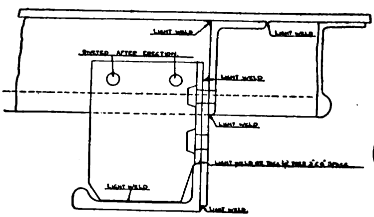


SHIP SECTION
SCALE ½" = 1'-0"
ENT AS PER RULE
RIVETING.
BUTTS - QUADRUPLE RIVETED OVERLAPS TO TREBLE AT
SIDE SHELL BUTTS - TREBLE RV. OVERLAPS TO DOUBLE
DECK SHEERSTRAKE BUTTS - QUAD. RV. OVERLAPS FOR
SIDE PLATING
LE AT ENDS TREBLE IN WAY OF BRIDGE
OF STRINGER BUTTS - TREBLE RV. OVERLAPS WHERE
REMAINDER DOUBLE RIVETED
OF PLATING BUTTS - ABOVE .48" TREBLE RIVETED
TO SINGLE OVERLAPS AT ENDS.
STRINGER BUTTS - TREBLE RV. OVERLAPS.
PLATING DOUBLE
TOP CENTER STRAKE BUTTS - TREBLE RV. OVERLAPS TO DOUBLE
REMAINDER DOUBLE
GIRDER BUTTS TREBLE RV. OVERLAPS.
PLATE BUTTS - DOUBLE
RIVETS

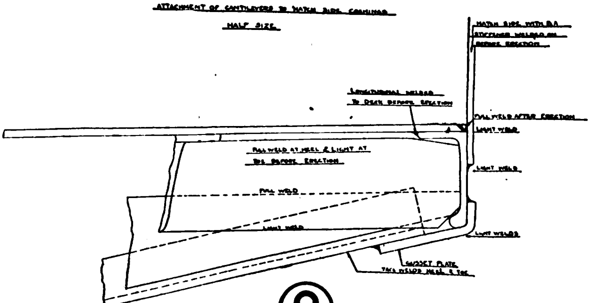


7

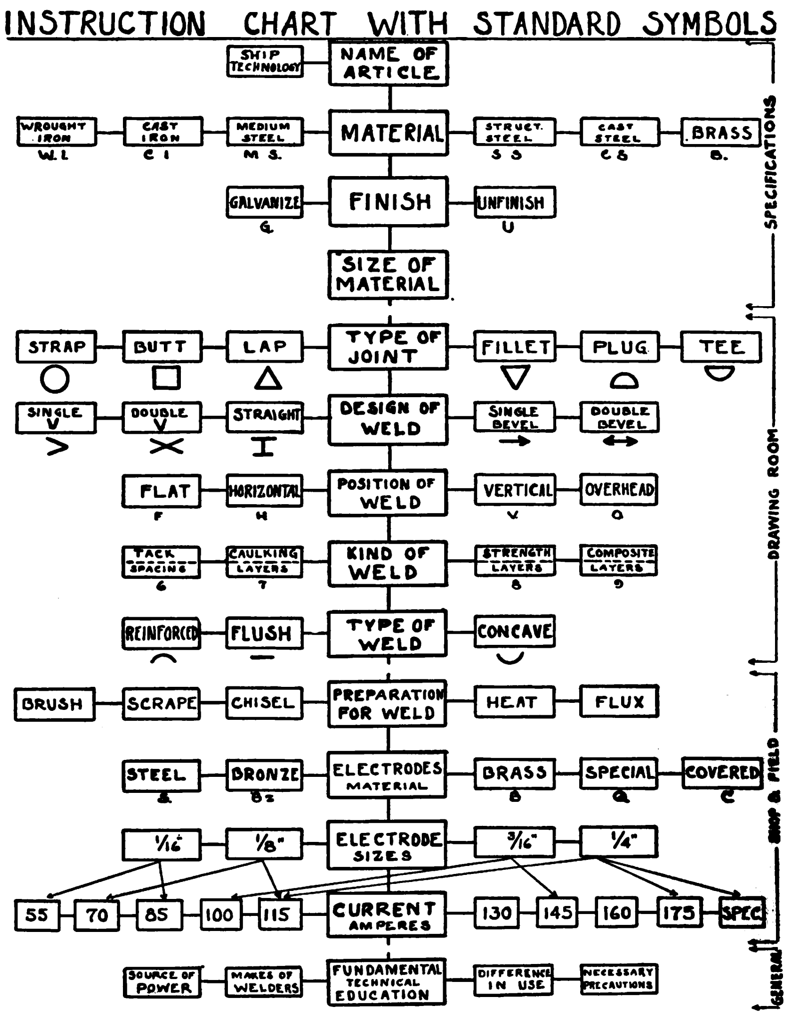
SECTION THRO' DECK TRANSVERSE



8



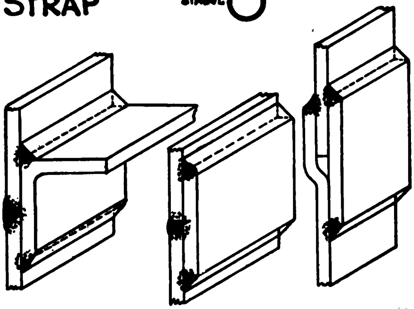
9


INSTRUCTION CHART WITH STANDARD SYMBOLS
SHIP TECHNOLOGY
NAME OF ARTICLE
WROUGHT IRON W.I.
CAST IRON C.I.
MEDIUM STEEL M.S.
MATERIAL
STRUCT. STEEL S.S.
CAST STEEL C.S.
BRASS B.
GALVANIZE G
FINISH
UNFINISH U
SIZE OF MATERIAL
SPECIFICATIONS
STRAP
BUTT
LAP
TYPE OF JOINT
FILLET
PLUG
TEE
SINGLE V
DOUBLE V
STRAIGHT
DESIGN OF WELD
SINGLE BEVEL
DOUBLE BEVEL
FLAT F
HORIZONTAL H
POSITION OF WELD
VERTICAL V
OVERHEAD O
TACK SPACING 6
CAULKING LAYERS 7
KIND OF WELD
STRENGTH LAYERS 8
COMPOSITE LAYERS 9
REINFORCED
FLUSH
TYPE OF WELD
CONCAVE
DRAWING ROOM
BRUSH
SCRAPE
CHISEL
PREPARATION FOR WELD
HEAT
FLUX
STEEL S
BRONZE Bz
ELECTRODES MATERIAL
BRASS B
SPECIAL
COVERED C
1/16"
1/8"
ELECTRODE SIZES
3/16"
1/4"
55
70
85
100
115
CURRENT AMPERES
130
145
160
175
SPEC
SHOP & FIELD
SOURCE OF POWER
MAKES OF WELDERS
FUNDAMENTAL TECHNICAL EDUCATION
DIFFERENCE IN USE
NECESSARY PRECAUTIONS
GENERAL

TYPE OF JOINT

STRAP

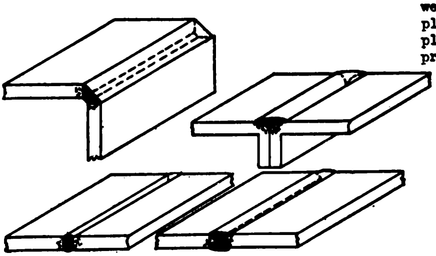
SYMBOL ○



STRAP weld is one in which the seam of two adjoining plates or surfaces is reinforced by any form or shape to add strength and stability to the joint or plate. In this form of weld the seam can only be welded from the side of the work opposite the reinforcement, and the reinforcement of whatever shape must be welded from the side of the work to which the reinforcement is applied.

BUTT

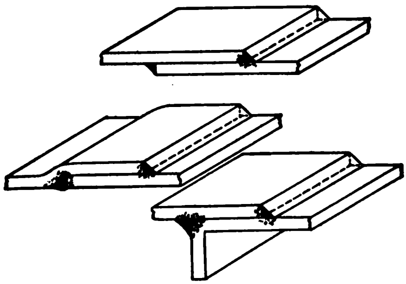
SYMBOL □



BUTT weld is one in which two plates or surfaces are brought together edge to edge and welded along the seam thus formed. The two plates when so welded, form a perfectly flat plane in themselves excluding the possible projective caused by other individual objects as frames, straps, stiffeners, etc., or the building up of the weld proper.

LAP

SYMBOL △

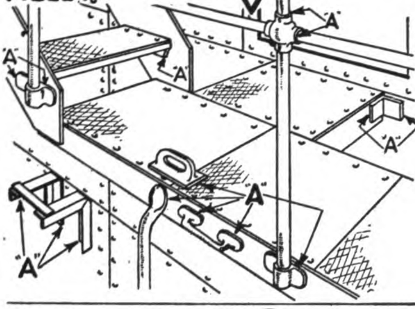


LAP weld is one in which the edges of two plates are set one above the other and the welding material so applied as to bind the edge of one plate to the face of the other plate. In this form of weld the seam or lap forms a raised surface along its entire extent.

TYPE OF JOINT (CONTINUED)

FILLET

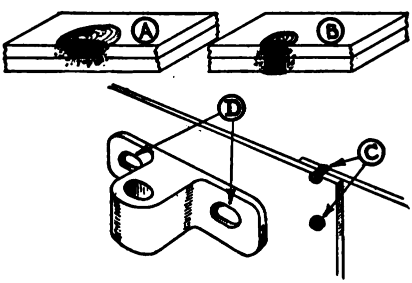
SYMBOL



FILLET weld is one in which some fixture or member is welded to the face of a plate, by welding along the vertical edge of the fixture or member (see "welds" shown and marked "A" on illustration at left). The welding material is applied in the corner thus formed and finished at an angle of forty-five degrees to the plate.

PLUG

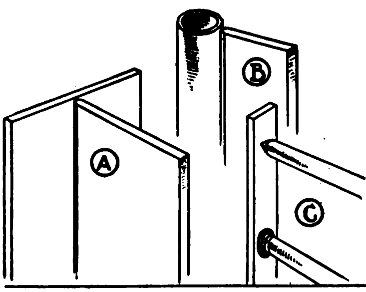
SYMBOL



PLUG weld is one used to connect the metals by welding through a hole in either one plate (Fig. "A") or both plates (Fig. "B"). Also used for filling through a bolt hole as at (Fig. "C"), or for added strength when fastening fixtures to the face of a plate by drilling a countersunk hole through the material (Fig. "D") and applying the welding material through this hole, as at (Fig. "D"), thereby fastening the fixture to the plate at this point.

TEE

SYMBOL

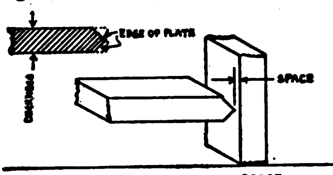


TEE weld is one where one plate is welded vertically to another as in the case of the edge of a transverse bulkhead (Fig. "A") being welded against the shellplating or deck. This is a weld which in all cases requires EXCEPTIONAL care and can only be used where it is possible to work from both sides of the vertical plate. Also used for welding a rod in a vertical position to a flat surface, as the rung of a ladder (Fig. "C"), or a plate welded vertically to a pipe stanchion (Fig. "B"), as in the case of water closet stalls.

DESIGN OF WELD

SINGLE "V"

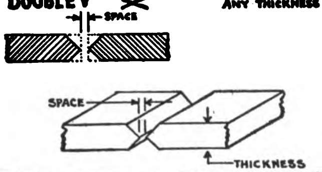
SYMBOL >   SPACE ANY THICKNESS 1/8"



SINGLE "V" is a term applied to the "edge finish" of a plate when this edge is bevelled from BOTH sides to an angle, the degrees of which are left to the designer. To be used when the "V" side of the plate is to be a maximum "strength" weld, with the plate setting vertically to the face of an adjoining member, and only when the electrode can be applied from both sides of the work.

DOUBLE "V"

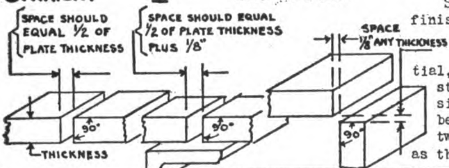
SYMBOL   SPACE ANY THICKNESS 1/8"



DOUBLE "V" is a term applied to the "edge finish" of two adjoining plates when the adjoining edges of both plates are bevelled from BOTH sides to an angle, the degrees of which are left to the designer. To be used when the two plates are to be "butted" together along these two sides for a maximum "strength" weld. Only to be used when welding can be performed from both sides of the plate.

STRAIGHT

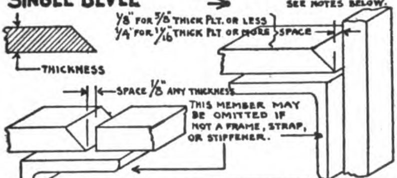
SYMBOL   SPACE SEE NOTES BELOW



STRAIGHT is a term applied to the "edge finish" of a plate, when this edge is left in its crude or sheared state. To be used only where maximum strength is NOT essential, or unless used in connection with strap, stiffener or frame, or where it is impossible to otherwise finish the edge. Also to be used for a "strength" weld, when edges of two plates set vertically to each other,--as the edge of a box.

SINGLE BEVEL

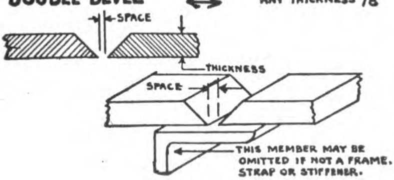
SYMBOL →   SPACE SEE NOTES BELOW.



SINGLE BEVEL is a term applied to the edge finish of a plate, when this edge is bevelled from ONE side only to an angle, the degrees of which are left to the designer. To be used for "strength" welding, when the electrode can be applied from ONE side of the plate only, or where it is impossible to finish the adjoining welding surface.

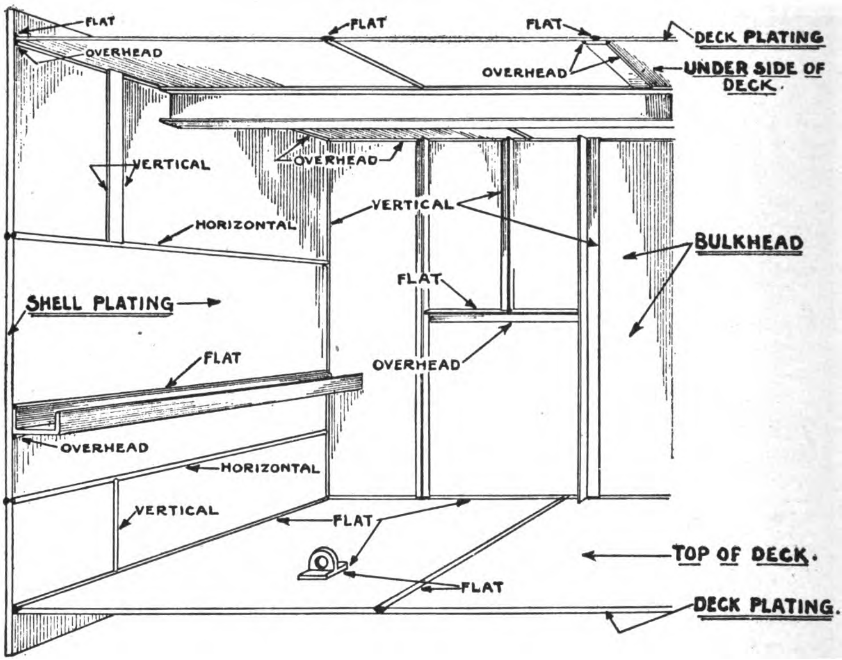
DOUBLE BEVEL

SYMBOL ↔   SPACE ANY THICKNESS 1/8"



DOUBLE BEVEL is a term applied to the edge finish of two adjoining plates, when the adjoining edges of both plates are bevelled from ONE side only to an angle, the degrees of which are left to the designer. To be used where maximum strength is required, and where electrode can be applied from ONE side of the work only.

POSITION OF WELD



FLAT position is determined when the welding material is applied to a surface on the same plane as the deck, allowing the electrode to be held in an upright or vertical position. The welding surface may be entirely on a plane with the deck, or one side may be vertical to the deck and welded to an adjoining member that is on a plane with the deck.

HORIZONTAL position is determined when the welding material is applied to a seam or opening, the plane of which is vertical to the deck and the line of weld is parallel with the deck, allowing the electrode to be held in an inboard or outboard position.

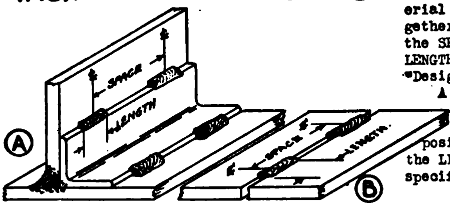
VERTICAL position is determined when the welding material is applied to a surface or seam, whose line extends in a direction from one deck to the deck above, regardless of whether the adjoining members are on a single plane or at an angle to each other. In this position of weld, the electrode would also be held in a partially horizontal position to the work.

OVERHEAD position is determined when the welding material is applied from the under side of any member whose plane is parallel to the deck and necessitates the electrode being held in a downright or inverted position.

KIND · OF · WELD.

TACK

SYMBOL · 6 ·

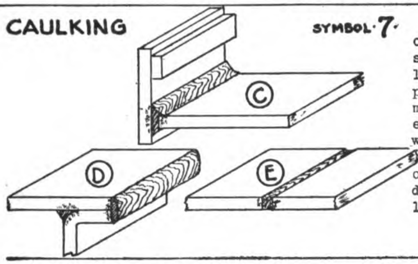


A TACK weld is applying the welding material in small sections to hold two edges together, and should always be specified by giving the SPACE from center to center of weld and the LENGTH of the weld itself. No particular "Design of weld" is necessary of consideration.

A TACK is also used for temporarily holding material in place that is to be solidly welded, until the proper alignment and position is obtained, and in this case, neither the LENGTH, SPACE, or DESIGN OF WELD are to be specified.

CAULKING

SYMBOL · 7 ·

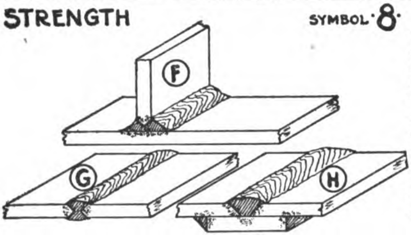


A CAULKING weld is one in which the density of the crystaline metal, used to close up the seam or opening, is such, that no possible leakage is visible under a water, oil or air pressure of 25 lbs. per square inch. The ultimate strength of a caulking weld is not of material importance,- neither is the "Design of weld" of this kind necessary of consideration.

The operator must be the judge in the number of layers needed for a tight weld, although the designer should specify a minimum amount of layers.

STRENGTH

SYMBOL · 8 ·

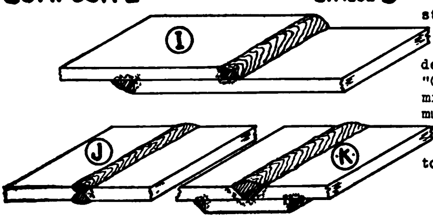


A STRENGTH weld is one in which the sectional area of the welding material must be so considered that its tensile strength and elongation per square inch must be equal at least 80% of the ultimate strength per square inch of the surrounding material. (To be determined and specified by the designer). The welding material can be applied in any number of layers beyond a minimum specified by the designer.

The density of the crystaline metals is NOT of vital importance. In this form of weld, the "Design of weld" must be specified by the designer and followed by the operator.

COMPOSITE

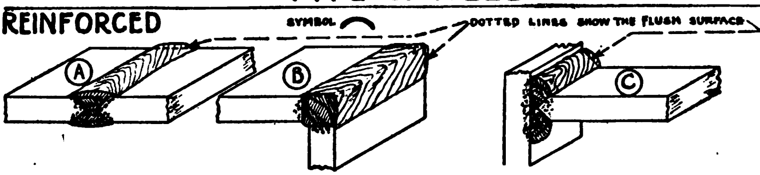
SYMBOL · 9 ·



A COMPOSITE weld is one in which both the strength and density are of the most vital importance. The STRENGTH must be at least as specified for a "strength weld", and the density must meet the requirements of a "Caulking weld" both as above defined. The minimum number of layers of welding material must always be specified by the designer, but the welder must be in a position to know if this number must be increased according to the welder's working conditions.

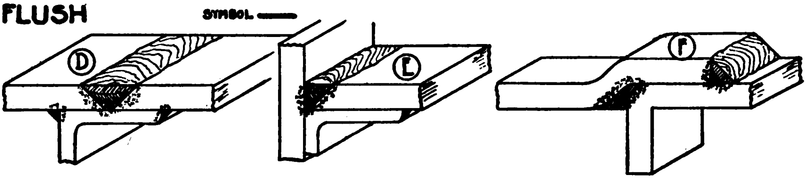
· TYPE · OF · WELD ·

REINFORCED



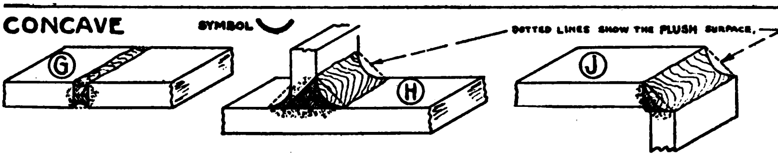
REINFORCED is a term applied to a weld when the top layer of the welding material is built up above the plane of the surrounding material as at Fig. "A" or Fig. "B" above, or when used for a corner as in Fig. "C". The top of final layer should project above a plane of 45 degrees to the adjoining material. This 45 degrees line is shown "dotted" in Fig."C" above. This type is chiefly used in a "Strength" or "Composite" kind of weld for the purpose of obtaining the maximum strength efficiency. and should be specified by the designer, together with a minimum number of layers of welding material.

FLUSH



FLUSH is a term applied to a weld when the top layer is finished perfectly flat or on the same plane as on the adjoining material as shown at Figs. "D" and "E" above or at an angle of 45 degrees when used to connect two surfaces at an angle to each other as at Fig. "F" above. This type of weld is to be used where a maximum tensile strength is not all important and must be specified by the designer, together with a minimum number of layers of welding material.

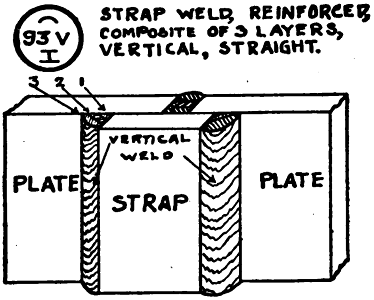
CONCAVE



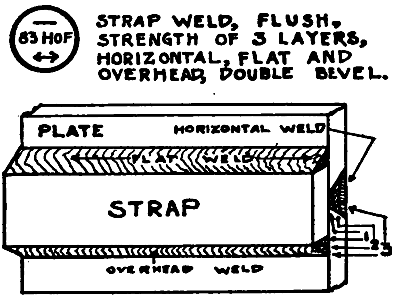
CONCAVE is a term applied to a weld when the top layer finishes below the plane of the surrounding material as at Fig. "G" above, or beneath a plane of 45 degrees at an angular connection as at Figs. "H" and "J" above.

To be used as a weld of no further importance than filling in a seam or opening, or for strictly caulking purposes, when it is found that a minimum amount of welding material will suffice to sustain a specified pound square inch pressure without leakage. In this "Type of weld" it will not be necessary for the designer ordinarily to specify the number of layers of material owing to the lack of structural importance.

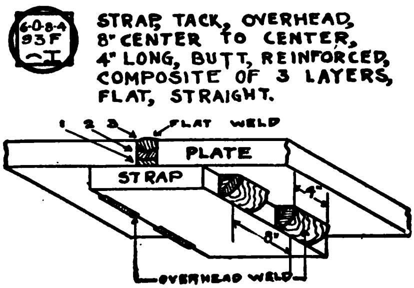
.COMBINATIONS · OF · SYMBOLS.



This sketch and symbol shows a strap holding two plates together, setting vertically, with the welding material applied in not less than three layers at each edge of the strap, as well as between the plates with a reinforced composite finish, so as to make the welded seams absolutely water, air or oiltight, and to attain the maximum tensile strength. The edges of the strap and the plates are left in a natural or sheared finish. This type of welding is used for most particular kind of work where maximum strains are to be sustained.



This illustrations shows a strap holding two plates together horizontally, welded as a strength member with a minimum of three layers and a flush finish. Inasmuch as the strap necessitates welding of the plates from one side only, both edges of the plates are bevelled to an angle, the degrees of which are left to the discretion of the designer. The edges of the strap are left in a natural or sheared state, and the maximum strength is attained by the mode of applying the welding material, and through the sectional area per square inch exceeding the sectional area of the surrounding material.

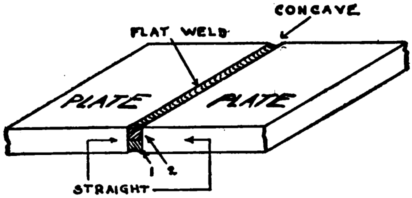


This symbol represents two plates butted together and welded flat, with a composite weld of not less than three layers, and a reinforced finish. A strap is attached by means of overhead tacking, the tacks being four inches long and spaced eight inches from center to center. In this case, the welding of the plates is of maximum strength and water, air or oiltight, but the tacking is either for the purpose of holding the strap in place until it may be continuously welded, or because strength is not essential. All the edges are left in their natural or sheared state.

COMBINATIONS OF SYMBOLS (CONTINUED)

72 F I

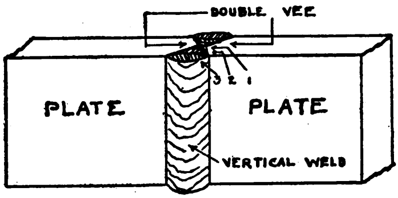
BUTT WELD, CONCAVE, CAULKING OF 2 LAYERS, FLAT, STRAIGHT.



The symbol shown represents a Butt Weld between two plates with the welding material finished concaved and applied in a minimum of two layers to take the place of caulking. The edges of the plates are left in a natural shear cut finish. This Symbol will be quite frequently used for deck plating or any other place where strength is not essential, but where the material must be water, air or oiltight.

83 V x

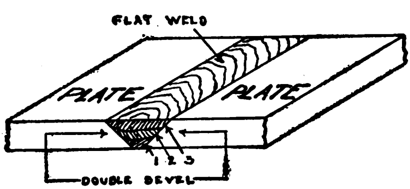
BUTT WELD, REINFORCED, STRENGTH OF 3 LAYERS, VERTICAL, DOUBLE VEE.



This Symbol is used where the edges of two plates are vertically butted together and welded as a strength member. The edges of the adjoining plates are finished with a "Double Vee" and the minimum of three layers of welding material applied from each side, finished with a convex surface, thereby making the sectional area per square inch of the weld, greater than that of the plates. This will be a conventional Symbol for shell plating or any other members requiring a maximum tensile strength, where the welding can be done from both sides of the work.

93 F ↔

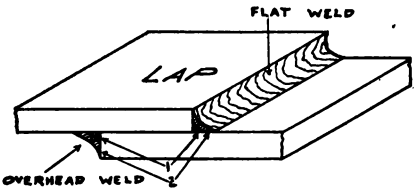
BUTT WELD, FLUSH, COMPOSITE OF 3 LAYERS, FLAT, DOUBLE BEVEL.



This Symbol shows two plates butted together in a flat position where the welding can only be applied from the top surface. It shows a weld required for plating where both strength and watertightness are to be considered. The welding material is applied in a minimum of three layers and finished flush with the level of the plates. Both edges of the adjoining plates are bevelled to an angle, the degrees of which are left to the discretion and judgment of the designer, and should only be used when it is impossible to weld from both sides of the work.

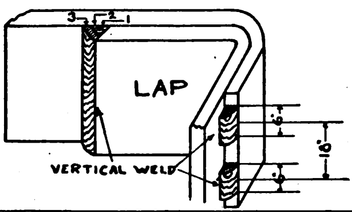
.COMBINATIONS · OF · SYMBOLS · (CONTINUED).

LAP WELD, CONCAVE, CAULKING OF 2 LAYERS, OVERHEAD AND FLAT, STRAIGHT.



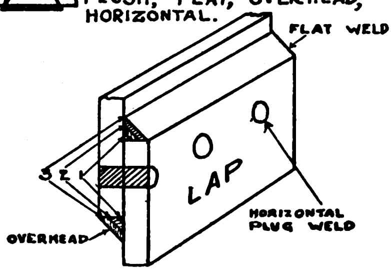
The sketch shows the edges of two plates lapping each other with the welding material applied in not less than two layers at each edge, with a concaved caulking finish, so applied as to make the welded seams absolutely water, air, or oiltight. The edges of the plates themselves are left in a natural or sheared finish. Conditions of this kind will often occur around bulkhead door frames where maximum strength is not absolutely essential.

LAP WELD, REINFORCED STRENGTH OF 3 LAYERS AND TACKING, 18" CENTER TO CENTER, 6" LONG, VERTICAL, STRAIGHT.



The illustration herein shown, is somewhat exaggerated as regards the bending of the plates, but it is only shown this way to fully illustrate the tack and continuous weld. It shows the edges of the plates lapped with one edge welded with a continuous weld of a minimum of three layers with a reinforced finish, thereby giving a maximum tensile strength to the weld, and the other edge of the plate, tack welded. The tacks are six inches long with a space of 12 inches between the welds or 18 inches from center to center of welds. In both cases, the edges of plates are left in a natural or sheared state.

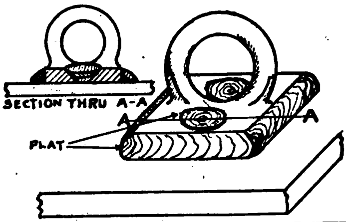
PLUG AND LAP WELD, STRENGTH OF 3 LAYERS, FLUSH, FLAT, OVERHEAD, HORIZONTAL.



The sketch shows a condition exaggerated, which is apt to occur in side plating where the plates were held in position with bolts for the purpose of alignment before being wolded. The edges are to be welded with a minimum of three layers of welding material for a strength weld and finished flush, and after the bolts are removed, the holes thus left are to be filled in with welding material in a manner prescribed for strength welding. The edges of the plates are to be left in a natural or sheared state, which is customary in most cases of lapped welding.

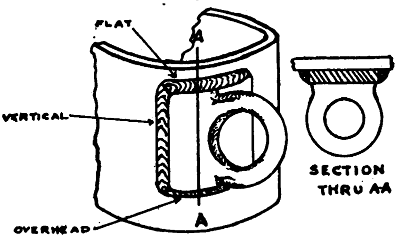
COMBINATIONS · OF · SYMBOLS · (CONTINUED).

PLUG AND FILLET WELD REINFORCED, STRENGTH OF 3 LAYERS, FLAT, SINGLE BEVEL, AND STRAIGHT.



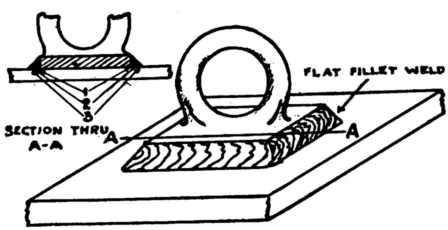
The adjoining sketch shows a pad eye attached to a plate by means of a fillet weld along the edge of the fixture, and further strengthened by plug welds in two countersunk holes drilled in the fixture. The welding material is applied in a flat position for a strength weld with a minimum of three layers and a reinforced finish. The edges of the holes are bevelled to an angle, which is left to the judgment of the designer, but the edges of the fixture are left in their natural state. This method is used in fastening fixtures, clips or accessories that would be subjected to an excessive strain or vibration.

FILLET WELD, REINFORCED, COMPOSITE OF 3 LAYERS, FLAT, VERTICAL AND OVERHEAD, STRAIGHT.



This illustration shows a fixture attached to a plate by means of a composite weld of not less than three layers with a reinforced finish. The fixture being placed vertically, necessitates a combination of flat, vertical and overhead welding in the course of its erection. Although a fixture of this kind would never be required to be watertight, the composite symbol is simply as a possibility of a combination.

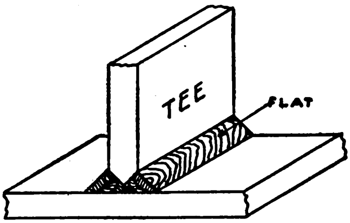
FILLET WELD, FLUSH, STRENGTH OF 3 LAYERS, FLAT, STRAIGHT.



This symbol represents a fixture attached to a plate by a strength fillet weld of not less than three layers, finished flush. The edges of the fixture are left in their natural state, and the welding material applied in the corner formed by the vertical edge of the fixture in contact with the face of the plate.

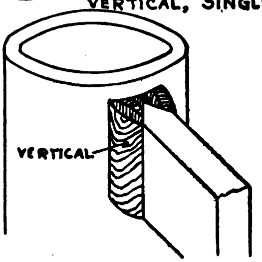
COMBINATIONS · OF · SYMBOLS · (CONTINUED).

TEE WELD, FLUSH, STRENGTH OF 3 LAYERS, FLAT, SINGLE VEE.



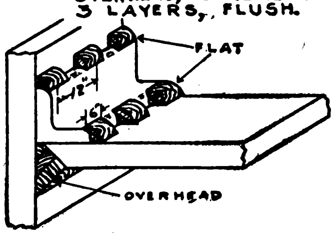
The adjoining sketch illustrates the edge of a plate welded to the face of another plate, as in the case of the bottom of a transverse bulkhead being welded against the deck plating. To obtain a maximum tensile strength at the joint, the edge of the plate is cut to a "Single Vee" and welded on both sides with a strength weld of not less than three layers, and finished flush. This would be a convenient way of fastening the intercostals to the keelsons. In this particular case, the welding is done in a flat position.

TEE WELD, REINFORCED, STRENGTH OF 3 LAYERS, VERTICAL, SINGLE VEE.



This symbol shows another case of Tee weld with the seam setting in a vertical position, and the welding material applied from both sides of the work. The edge of the plate is finished with a "Single Vee" and a minimum of three layers of welding material is applied from each side, finished with a convex surface, thereby making the sectional area, per square inch of the weld, greater than that of the plate, allowing for a maximum tensile strength in the weld.

STRAP AND TEE WELD, FLAT, REINFORCED, TACK, 12" CENTER TO CENTER, 6" LONG, SINGLE BEVEL, OVERHEAD, STRENGTH OF 3 LAYERS, FLUSH.



The illustration herein shown, represents an example of the possible combination of symbols. An angle iron is tack welded to the plate in the form of a strap or stiffener, though in actual practice, this might never occur. The tacks are spaced twelve inches from center to center, and are six inches long, and applied in a flat position, with a reinforced finish. As the strap prevents welding the plate from both sides, the edge of the plate is bevelled, and the welding material applied for strength in not less than three layers in an overhead position and finished flush. Note that in specifying tack welds, it is essential to give the space from center to center of weld, and length of wled by use of figures representing inches placed either side of the circumscribing symbol of the combination.

APPENDIX VI

(*Lloyd's Register of Shipping.*)

Application of Electric Arc Welding to Ship Construction

INTRODUCTORY REMARKS

Although electric welding in various forms has been employed for many years for ship repair work, yet, in practice, owing to many factors, its use has been practically confined to those parts of the structure which are not likely to be exposed to important structural stresses.

It is only in recent times, commencing from the early days of the war, that appreciable progress has been made in the developments of electric welding which would appear to justify the extension of such methods to replace the usual riveted connections of heavy structural work.

The aim has been to secure reliability and regularity of operation in the welding process, and to assist the workmen by improving the means of control over the work. Just as in the case of application of steel to shipbuilding, it was necessary to devise means for the production of the material in large quantities and of constant quality, so also is it necessary that the welding electrodes should be manufactured with the greatest possible degree of uniformity.

Reliability of operation is also facilitated by adjusting the density of the electric current to the size of electrode used, and, further, the size of the electrode should reasonably vary directly with the thickness of material to be connected.

Research was necessary to discover means for minimizing the burning of the deposited material in the direction of preventing oxidation. In the early days of welding, the molten electrode was exposed to air throughout the whole time of deposition and consequently oxidation was more or less certain to occur. With coated metal electrodes, burning is reduced to a minimum by the use of a slag which envelops the molten steel and floats on its surface after contact is obtained with the material to be connected. Even in this system, skilled workmanship is essential, as the production of a long arc obviously increases the chances of burning.

The composition of the material of the electrode in relation to the nature of the steel to be connected is obviously a matter of importance. What the composition is to be can only be gauged by experiment and by wide experience, and it is in devising the physical tests for work of this nature that the greatest difficulties arise.

It is commonly accepted that the tests imposed on manufactured material do not in any way represent the strains which may be experienced in practice. Such tests are rather based on simple means for determining the average reliability of the material. Thus also is this case no one particular test is likely to determine whether the welding process under trial is sufficient for the work it is likely to have to do.

It is therefore necessary to approach the problem rather on the basis of circumstantial evidence and to decide from a number of different types of experiments whether, on the whole, the performance is satisfactory.

The more particular problem in shipbuilding is the connection of mild steel containing a percentage of carbon of about .15. This material in the form of plates and section bars has considerable work done to it during the process of manufacture, with the consequence that it possesses a fine structure and a ductility which is uniform in any direction. The finished material may be said to be practically free from fibrous structure.

With electric welding, molten metal is attached to the miid steel and from the extent of the cooling surface the deposited material is rapidly lower in temperature, with the consequence that the weld tends to become deficient in ductility.

The problem therefore is to select the material of the electrode so that the general elastic properties of the structure are not unduly depreciated.

The investigations were undertaken to determine the possibilities of the application of electric welding to shipbuilding and as it was desired to obtain as good a knowledge as possible of the physical properties of the combination of rolled and welded material, highly skilled operators were employed.

It must therefore be realized that the results of the experiments which have been made represent skilled practice, and that in general such performance can only be equalled with good workmanship and efficient supervision.

NATURE AND DESCRIPTION OF EXPERIMENTS

The general scope of the experiments included:—

- (*a*) Determination of modulus of elasticity and approximate elastic limit.
- (*b*) Determination of ultimate strength and ultimate elongation.
- (*c*) Application of alternating stresses with—
  - (1) rotating specimens,
  - (2) stationary test pieces.
- (*d*) Minor tests, such as—
  - (1) cold bending of welds,
  - (2) impact tests of welded specimens.
- (*e*) Chemical and microscopic analysis.

Tests were carried out on specimens as large as possible, particularly in respect to the static determination of elasticity, ultimate strength and elongation, some of the test specimens being designed for a total load of just under 300 tons. The advantage of these large specimens was that the effect of workmanship was better averaged and the results were more comparable to the actual work likely to be met with in ship construction.

With alternating stresses the specimens were relatively of small size. For the rotating test pieces, circular rods, mainly machined from a welded plate, were used, the diameters selected being 1 inch and 3/4 inch. These bars, about 3 feet in length, were attached to a lathe headstock and a pure bending moment in one plane was applied by means of two ball races to which known weights were attached. The material of the bar was thus exposed alternately to maximum tension and to equal maximum compression once in each revolution. The machine was run at about 1,060 revolutions per minute.

Bars of identical material were tried in pairs, one specimen welded and the other unwelded, and the number of revolutions before the specimens parted was observed for various ranges of stresses varying from $\pm$ 15 tons to $\pm$ 6 tons.

In the second series of alternating stress experiments, flat plates were used of three thicknesses, *viz.*—¼ inch, ⅜ inch, and ½ inch. These specimens were tried in groups of four, each group consisting of one plain, one butt-welded, one lap-welded and one lap-riveted plate. The specimens, which were about 14 inches long by 5 inches broad, were clamped along the short edges, so that the distance between the fixed lines was 12 inches. Each plate was also clamped, near the middle, to the end of a pillar, which by means of a crank arm was caused to oscillate and to bend the specimen equally up and down by adjustable amounts (the maximum total movement in any of the experiments tried was 5/16 inch). The machine was run at various revolutions (not exceeding 90 per minute) and the number of repetitions at which the specimen parted was observed.

Minor tests of various kinds were undertaken, of which the principal ones had reference to the suitability of the welded material to withstand such bending and shock stresses as might occur in the shipbuilding yards. The experiments on bending consisted of doubling the welded plate over a circular bar of diameter equal to three times the plate thickness, and comparing the results with those of the plate of the same material but unwelded.

In the impact tests, heavy weights were dropped from various heights on to the welded portion of a plate 5 feet in length and 2 feet 6 inches in breadth, the weld being across the plate parallel to the shorter edge. The deflections were noted and the condition of the weld was examined after each blow.

The chemical and micrographical examination followed the ordinary practice.

SUMMARY OF EXPERIMENTAL RESULTS

1. Modulus of Elasticity and Approximate Elastic Limit.

(*a*) In a welded plate the extensions in the region of the weld are sensibly the same as for more distant portions of the unwelded plate.

(*b*) With small welded specimens containing an appreciable proportion of welded material in the cross-sectional area, the relation between extension and stress is practically the same, up to the elastic limit, as for similar unwelded material.

(*c*) The elastic limit (or the limiting stress beyond which extension is not approximately directly proportional to stress) appears to be slightly higher in welded than in unwelded material.

(*d*) The modulus of elasticity of a small test piece, entirely composed of material of the weld, was about 11,700 tons per square inch as compared with about 13,500 tons for mild steel and about 12,500 tons for wrought iron.

2. Ultimate Strength and Ultimate Elongation.

(*a*) The ultimate strength of welded material with small specimens was over 100 per cent. of the strength of the unwelded steel plate for thicknesses of ½ inch, and averaged 90 per cent. for plates ¾ and 1 inch in thickness.

(*b*) Up to the point of fracture, the extensions of the welded specimens are not sensibly different from those of similar unwelded material.

(*c*) At stresses greater than the elastic limit, the welded material is less ductile than mild steel, and the ultimate elongation of a welded specimen when measured on a length of 8 inches only averages about 10 per cent. as compared with 25 to 30 per cent. for mild steel.

3. Alternating Stresses.

(*a*) *Rotating Specimens* (*round bar*).

(1) Unwelded turned bars will withstand a very large number of repetitions of stress (exceeding, say, 5 millions) when the range

of stress is not greater than from $10\frac{1}{2}$ tons per square inch tension to $10\frac{1}{2}$ tons per square inch compression.

(2) Welded bars similarly tested will fail at about the same number of repetitions when the range of stress exceeds $\pm$ $6\frac{1}{2}$ tons per square inch.

(*b*) *Stationary Test Pieces* (*flat plate*).

(1) Butt-welded specimens will withstand about 70 per cent. of the number of repetitions which can be borne by an unwelded plate.

(2) Lap-welded plates can endure over 60 per cent. of the number of repetitions necessary to fracture a lap-riveted specimen.

4. Minor Tests.

(*a*) Welded specimens are not capable of being bent (without fracture) over the prescribed radius to more than 80 degrees with $\frac{1}{4}$-inch plate, reducing to some 20 degrees where the thickness is 1 inch. Unwelded material under the same conditions can be bent through 180 degrees.

(*b*) Welded plates can withstand impact with a considerable degree of success; a half-inch plate of dimensions already quoted sustained two successive blows of 4 cwt. dropped through 12 feet, giving a deflection of 12 inches on a length of about 4 feet 6 inches without any signs of fracture in the weld.

5. Chemical and Microscopic Analysis.

(*a*) *Chemical Analysis.*

(1) The electrode was practically identical with mild steel, but there was a greater percentage of silicon.

(2) The material of the weld after deposition was ascertained to be practically pure iron, the various other contents being carbon .03, silicon .02, phosphorus .02, and manganese .04 per cent. respectively.

(*b*) *Microscopic Examination.*

(1) The material of the weld is practically pure iron.

(2) The local effect of heat does not appear to largely affect the surrounding material, the structure not being much disturbed at about 1/16 of an inch from the edge of the weld. The amount of disturbance is still less in thin plates.

(3) The weld bears little evidence, if any, of the occurrence of oxidation.

(4) With welds made as for these experiments, *i.e.*, with flat horizontal welding, a sound junction is obtained between the plate and the welding material.

6. ***Strength of Welds** (Large Specimens).*

(*a*) ***Butt Welds*** have a tensile strength varying from 90 to 95 per cent. of the tensile strength of the unwelded plate.

(*b*) *Lap Welds.*

(1) With full fillets on both edges the ultimate strength in tension varies from 70 to 80 per cent. of that of the unwelded material.

(2) With a full fillet on one edge and a single run of weld on the other edge the results are very little inferior to those where a full fillet is provided for both edges.

(*c*) ***Riveted Lap Joints.*** For plates of about ½ inch in thickness, the specimens averaged about 65 to 70 per cent. of the strength of the unperforated plate.

OBSERVATIONS ON EXPERIMENTAL RESULTS

(*1*) *Static Elasticity.* It will be observed that the statical tests made to determine the elasticity indicate that, in general, the combination of welded and unwelded material behaves practically homogeneously up to at least the elastic limit. Moreover, the experiments show that the process of welding is such that the stress is distributed practically uniformly over the weld, and also transmitted uniformly to the adjacent plates.

The material of the weld is practically pure iron, and from the tests made on a specimen composed entirely of the deposited material of a weld, it will be seen that for a given stress the weld stretches slightly more than mild steel. This property will enable any undue occurrence of load being transferred in a proper manner to adjacent portions of the structure.

When, however, the stress exceeds the elastic limit and is so great that the extension grows continuously without increase of load, the welded material fails sooner than mild steel. This disadvantage is, however, of little practical importance in shipbuilding, and may be regarded as negligible in the particular problem under consideration.

(2) *Dynamic Elasticity.* In a structure, such as a ship, which is exposed to variations and reversal stresses, it is extremely important to know whether the material to be used is likely to break down rapidly under such alternations and ranges of stress as are likely to be experienced. The modified Wohler tests employed in the experiments certainly indicate, if considered solely by themselves, that whereas for a given number of alternations mild steel would withstand a range of stress of, say, $\pm$ 10½ tons, the welded material might be expected to fail at about $\pm$ 6½ tons, a figure which is more nearly experienced in ordinary ship construction.

It would appear to be necessary to design the welded joints in such a manner that the amount of work likely to be thrown on the joint is as small as possible, and to meet such a condition a welded joint requires to be either lapped or strapped.

It will be noticed that the material in the weld appears to be nearly pure iron, and experiments of repetitive stress show that wrought-iron bars are likely to fail under a range of stress of perhaps $\pm$ 7 to 8 tons as compared with mild steel at $\pm$ 10 to 11 tons. The weld has to be deposited electrically and is subject to variations in workmanship; it would consequently be considered satisfactory if the material could withstand a range of stress of, say, $\pm$ 6½ tons.

Consideration of the dynamic-elasticity properties appears to show that in any case the welded material can experience as large a number of repetitions of stress as wrought iron could do, and it is always recognized that although iron could not approach the tests for mild steel, yet it was a satisfactory material for shipbuilding purposes. Further, attention to design of details will increase the performance of the welded joint, and in addition it must not be forgotten that 5,000,000 repetitions of stress is perhaps more than equivalent to 10 years' good sea service.

(3) *Physical Nature and Properties.* It has been mentioned that the welds experimented with are to be regarded as having been produced under most favorable conditions, and that throughout

the experimental welds were made with the specimens horizontal and below the operator. In practice, welds will require to be made vertically and overhead as well, consequently extreme care will be required in such operations.

The physical examinations indicate that the materials of the electrode and the system of welding adopted were suitable and reliable. Moreover, there was little apparent oxidation and the material in the neighborhood of the weld was not affected to any prejudicial extent.

(4) *Strength of Welds and Minor Tests.* Broadly speaking, the tensile strength of butt welds was as great as the unwelded material, but it is considered that greater reliability of workmanship is obtained with joints which are either lapped or strapped.

It was also found that the lapped joint was practically as strong as a riveted lapped joint and would probably remain tight when subjected to more trying conditions than are necessary to disturb a riveted lap joint.

In view of the satisfactory results of the extensive and exhaustive trials which have been carried out on electric arc welds, the Committee have decided to adopt, as a tentative measure, the following Provisional Rules for classification in Lloyd's Register Book of vessels electrically welded, subject to the notations "Experimental" and "Electrically welded."

The approval of the Society will be given to any system of welding which complies with these Regulations and consideration will be given to any alternative constructional arrangements which may be submitted for approval.

APPENDIX VII

TENTATIVE REGULATIONS FOR THE APPLICATION OF ELECTRIC ARC WELDING TO SHIP CONSTRUCTION *

(A) SYSTEM OF WELDING AND WORKMANSHIP

(1) The system of welding proposed to be used must be approved and must comply with the regulations and tests laid down by the Committee.

(2) The process of manufacture of the electrodes must be such as to ensure reliability and uniformity in the finished article.

(3) Specimens of the finished electrodes, together with specifications of the nature of the electrodes, must be supplied to the Committee for purposes of record.

(4) The Committee's officers shall have access to the works where the electrodes are manufactured, and will investigate, from time to time as may be necessary, the process of manufacture to ensure that the electrodes are identical with the approved specimens.

(5) Alterations from the process approved for the manufacture of electrodes shall not be made without the consent of the Committee.

(6) The regulations for the voltage and amperage to be used with each size of electrode, and for the size of electrode to be employed with different thicknesses of material to be joined, are to be approved by the Committee.

(7) The Committee must be satisfied that the operators engaged are specially trained, and are experienced and efficient in the use of the welding system proposed to be employed.

(8) Efficient supervisors of proved ability must be provided, and the proportion of supervisors to welders must be submitted for approval.

* Issued by Lloyd's Register of Shipping.

(B) DETAILS OF CONSTRUCTION

(9) The details of construction of the vessel and of the welds are to be submitted for approval.

(10) Before welding, the surfaces to be joined must be fitted close to each other and the methods to be adopted for this purpose are to be approved.

(11) All butt and edge connections are to be lapped or strapped.

(12) With lapped connections the breadths of overlaps of butts and seams and the profiles of the welds to be in accordance with the following table:—

Thickness of plate. Inches.	Width of overlap seam and butt. Inches	Throat thickness. Inches.
.40 and under	$2\frac{1}{4}$	.28
.60	$2\frac{1}{2}$	.38
.80	$2\frac{3}{4}$	.48
1.00	3	.50

Intermediate values may be obtained by direct interpolation, and for thicknesses below .40 the throat thickness is to be about 70 per cent. of the thickness of the plate.

(13) A "full weld" extends from the edge of a plate for a distance equal to the thickness of plate to be attached, and the minimum measurement from the inner edge of plate to the surface of weld is the throat thickness given in the table above.

(14) A "light closing weld" is a single run of light welding worked continuously along the edge of the plate. Such a weld may, however, be interrupted where it crosses the connection of another member of the structure.

(15) An "intermittent or tack weld" has short lengths of weld which are spaced three times the length of the weld from centre to centre of each short length of weld. Such tack welding may vary in amount of weld between a "full weld" and a "light closing weld."

(16) The general character of welds is to be in accordance with the following table:—

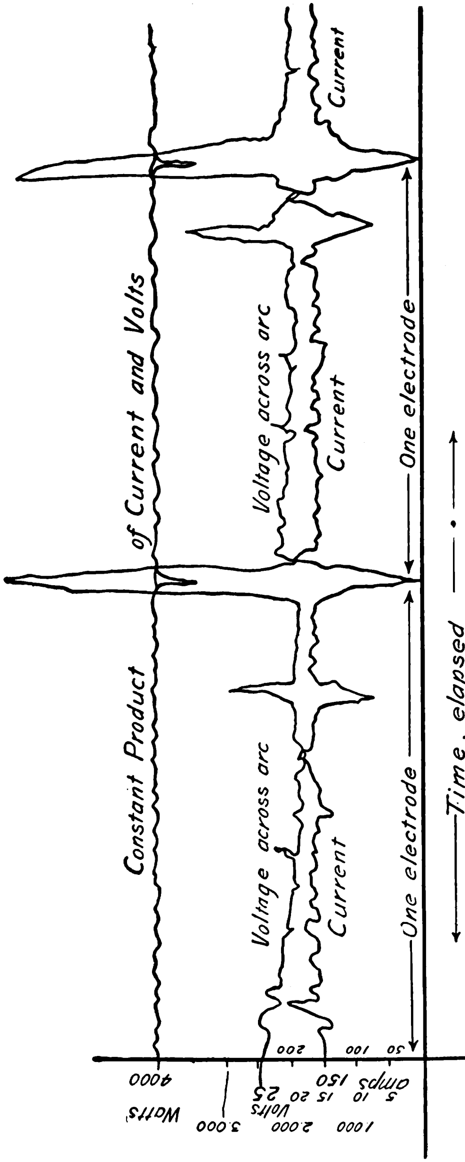
	Inside edge.	Outside edge.
(*a*) Butts of shell, deck and inner-bottom plating		
(*b*) Butts of longitudinal girders and hatch coamings	F	F
(*c*) Edges of shell, deck and inner-bottom plating	L	F
(*d*) Butts and edges of bulkhead plating		
	Toe.	Heel.
(*e*) Frames to shell, reverse frames to frames and floors		
(*f*) Beams to decks		
(*g*) Longitudinal continuous angles	T	L
(*h*) Side girders, bars to shell, intercostal plates, floors and inner bottom		
(*i*) Bulkhead stiffeners		

F = full weld, L = light weld, and T = tack weld.

(17) All bars required to be watertight are to have continuous welding on both flanges with tack welding at heel of bar.

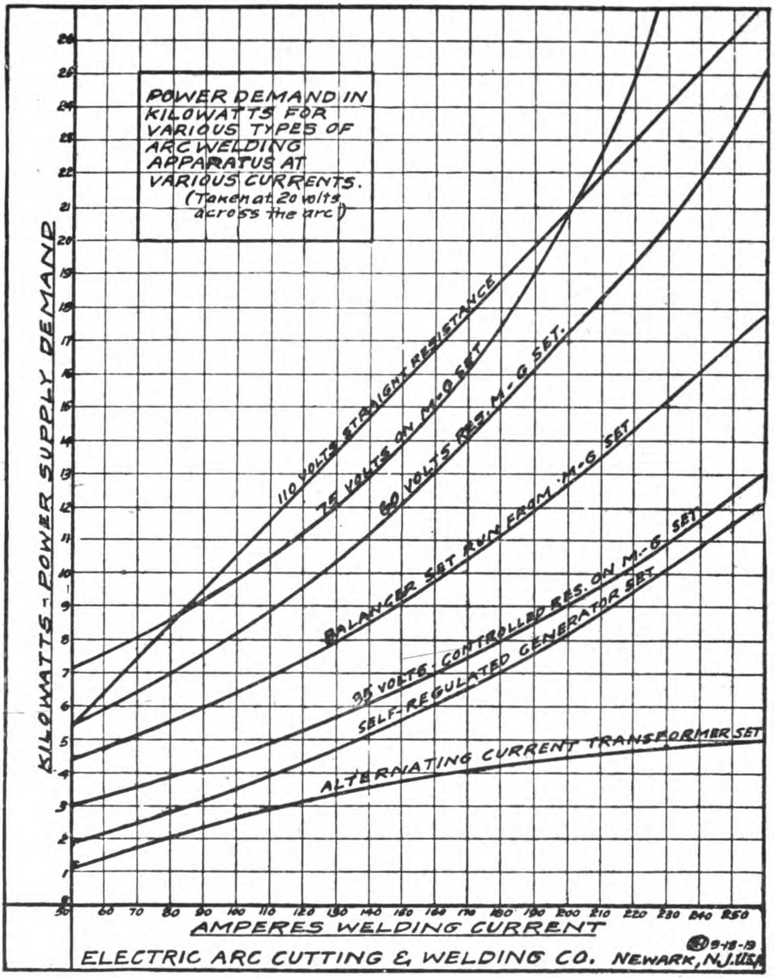
(18) The welded connections of beam, frame and other brackets are to be submitted for special consideration.

(19) The Committee may require, when considered necessary, additional attachment beyond that specified above, and the welding of all other parts is to be to their approval.



Showing constant product of current and volts of alternating current transformer set arc welding, $\frac{5}{32}$" electrode

NOTE: Courtesy Electric Arc Cutting & Welding Co.


POWER DEMAND IN KILOWATTS FOR VARIOUS TYPES OF ARC WELDING APPARATUS AT VARIOUS CURRENTS.
(Taken at 20 volts across the arc)
KILOWATTS - POWER SUPPLY DEMAND
110 VOLTS STRAIGHT RESISTANCE
75 VOLTS ON M-G SET
60 VOLTS RES. M-G SET.
BALANCER SET RUN FROM M-G SET
35 VOLTS CONTROLLED RES. ON M-G SET
SELF-REGULATED GENERATOR SET
ALTERNATING CURRENT TRANSFORMER SET
AMPERES WELDING CURRENT
9-18-19
ELECTRIC ARC CUTTING & WELDING CO. NEWARK, N.J. U.S.A.

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