Electric Arc Welding

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PREFACE

The authors of this work have not attempted to cover the electric welding art in its broadest sense. The book is confined almost exclusively to autogenous electric arc welding.

The phenomena of the welding arc, and the metallurgy of welding, are in such a state of development that the authors' information has been limited to the research which has come under their observation. Many phases of these subjects have been left, therefore, to specialists more adequately equipped both as to electric and metallurgical data as well as laboratory apparatus. The effort has been made to present information that is most in demand for practical purposes.

The material is conveniently and logically arranged for ready reference. A large amount of practical information on many phases of the application of the art has been incorporated; for instance, descriptions of welding systems and their installation, phenomena of the metallic and carbon welding arc, training of operators, sequence of metal disposition for various types of joints and building up operations, electrode materials used, weldability of various metals, weld composition, thermal disturbances of parts affected by the welding process, physical properties of completed welds, efficiency of welding equipments expressed in pounds of metal used or deposited per kilowatt hours, welding cost, etc.

It is desired to lay particular stress on the fact that a very small percentage of the possibilities and advantages of arc welding, from an industrial standpoint, are being made use of at the present time, and if this work will result in a broader application of the art, as well as further and more extensive research, the authors will feel well repaid for their humble efforts.

The book is based largely on an extensive series of articles by the authors which was published in *The Railway Electrical Engineer.* Such parts of these articles as are used here, however, have been thoroughly revised and brought up-to-date.

THE AUTHORS.

Chicago, Ill.

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ELECTRIC ARC WELDING

I

EVOLUTION OF WELDING PROCESSES

There are several methods of joining metals other than by means of mechanical fastenings, such as bolts, clamps, rivets, hinges, etc. The first form of jointure known to man, other than the above-mentioned, was fire or forge welding performed by a smith, the operation consisting essentially of heating the parts to be welded to the proper temperature and perfecting a union by applying pressure by means of hammer and anvil.

As pressure welding was limited in its application man endeavored to find some other way to join metals, or to make additions of metal to other metal, without the use of pressure. He was eventually successful in this endeavor and welding without pressure came to be known as autogenous welding, so called because of its self- or auto-generation; i. e., it is self-produced by the application of intense heat without any physical process of compression or hammering.

We, therefore, have two general forms of welding—one requiring external application of pressure to complete the weld, and one in which the weld is completed without the external application of pressure. In the first form the union is secured by using a comparatively low heat and high pressure. In the second the union is secured by a relatively high temperature without the aid of any external pressure. It will be seen, in view of the fact that welding requires actual fusion of the metals joined or added, that the process differs inherently from those methods of joining metals known as brazing or soldering, in which cold surfaces are united by the interposition of a fused metallic cementing material, which is an example of adhesion rather than cohesion.

Pressure Welding.—The conditions for successful smith or forge welding, which is a form of pressure welding, may be summed up as clean metallic surfaces in contact, with a suitable temperature and rapid closing of the joints. All the variations in the forms of welds are due either to differences in shapes of material or to the different practices of different craftsmen.

The typical weld is the scarf; the joint is made diagonally to give a long contact at the point of union. Abutting faces are made slightly convex. The object is to allow any scale or dirt to be forced out which if allowed to become embedded in the joint would impair its union. It is important to have the proper temperature or else the metal will become badly oxidized (burnt) and will not adhere. This is especially true in the case of steel welding.

Resistance Welding.—Resistance welding is another form of pressure welding in which an electric current is made use of to produce the welding heat. There are two general forms of resistance welding; namely, butt and spot, the name in each case being thoroughly indicative of the service for which each form is particularly adapted.

Butt welding is accomplished by having the surfaces, or parts of the metal to be united, fitted approximately to each other. Clamps of suitable design, generally made of copper, are then attached in as close proximity to the weld as is practicable and in such a way as to permit the desired amount of current to pass through the parts to be joined or welded. The resistance offered to the passage of the current at the point of contact produces the welding heat; whereupon sufficient pressure is applied to effect the union.

Spot welding also utilizes the heat generated by the resistance offered to the passage of an electric current and is similar to butt welding except that heat is generated at the points of contact between the respective electrodes in addition to the heat generated between the surfaces to be united.

Seam welding utilizes the heat generated in a way quite similar to spot welding; in fact, it is an extension of spot welding. A spot weld is equivalent in form to flush riveting; a seam weld is a non-interrupted continuous succession of spot welds.

All forms of resistance welding require primarily a heavy current at a low potential, which practically necessitates the use of alternating current. The welding equipment, therefore, generally consists of a step-down transformer with a regulating device; clamps or electrodes for making the electrical connections to the work; and suitable mechanical parts and devices for supporting the electrodes, supplying pressure to the weld and supporting the parts to be welded.

In general, it may be said that the resistance form of welding is best adapted to standardized operations, especially so in the manufacturing field where the work can be passed through the machine. While it might seem that the application of this form of welding is somewhat limited there is, nevertheless, a vast field for it that has not yet been invaded.

A comparatively recent example of the practical application of electric resistance heating or welding is that of rivet heating, which from all indications will soon largely supplant the fire method of rivet heating. The rivet is heated by placing it between copper electrodes in the form of blocks. A heavy current is then passed through the rivet, and in a few seconds the proper heat is attained. The riveting and handling of the rivets is otherwise the same as with the fire method of heating. Some of the advantages of the electric rivet heater are: Better control of heat resulting in fewer rivets burned; the rivet is more uniformly heated, thus reducing the chances for ineffective riveting; the elimination of smoke and dirt results in better efficiency of workmen; and last, but not least, the fire hazard is greatly minimized.

Thermit Welding.—In the year 1894 it was found that the ignition of finely powdered aluminum, mixed with metallic oxides, produced an exceedingly high temperature because of the rapid oxidation of the aluminum. These facts were turned to practical account by Dr. H. Goldschmidt, who welded two iron bars by molten iron produced by the process to which the name of "thermit" is now commonly applied. This process has been wonderfully successful and has been extensively used especially for welding members of large cross-sections and for emergency repairs on certain classes of work. Thermit welding is sometimes called a casting process, since it requires a mold around the parts to be joined.

Gas Welding.—The oxy-hydrogen blowpipe was first used about the year 1820 chiefly for producing limelight. It was also used in some important industrial applications, one of which was the fusion of platinum. In the latter part of the nineteenth century this process came into extensive use for lead burning, or welding. About the same time it was discovered that by using oxy-acetylene a much higher flame temperature could be secured, which together with improved regulation of heat control, led to the extremely rapid use and extension of the oxy-acetylene torch to the welding and cutting of iron and steel, and other metals to a lesser degree. While other gases have been used in place of acetylene, the oxy-acetylene flame is by far the most widely used. Today the oxy-acetylene welding and cutting process is used in practically all of the metal using industries.

Electric Arc Welding.—Electric arc welding is commercially the most recent and newest process of any form of welding. Benardos and Slavianoff are generally credited with the discovery of the possibilities of the carbon arc and metallic arc, respectively, for the welding of metals. The carbon arc process was the first one to be used for welding metals, and was first used, on a small scale, 30 years ago. This form of arc welding is sometimes called the Benardos process. Not long after the carbon arc process was demonstrated by Benardos, Slavianoff demonstrated the possibilities of the metallic arc process, but it was not until comparatively recent years that either was used to any appreciable commercial extent.

After the first discovery of the more or less vague possibilities of electric arc welding the progress in the development of the art was extremely slow, due to the fact that it was only with great difficulty that the work of development could be carried on. There were several reasons for the existence of such a condition, most important of which was the fact that the men who first conceived and worked to develop and improve the welding art were apparently versed only in one branch or phase of that science.

It must be borne in mind that to develop this art it was necessary to make an extensive investigation into the phenomena existing in the arc, both carbon and metallic, when using it for the fusion of metals. No matter how well versed a man may be in electrical science it does not necessarily follow that he may understand the behavior of an electric arc when used for welding metals. On the other hand, although a man may be well trained in metallurgy it does not necessarily follow that he can understand the behavior of the metals when subjected to the temperature of the electric arc. In other words, the electrical men did not understand, nor were they thoroughly acquainted with the peculiarities manifested by the electric arc when used in conjunction with molten metal during the welding process. And the metallurgical men were not conversant with the behavior of metals under the action of the arc stream with its attendant high temperature variations.

In view of these existing conditions it was necessary that much time be spent in research work by both electrical and metallurgical men. Indeed, it was not until the electrical phenomena and metallurgical phenomena were coordinated that a real beginning was made in the development of the art of arc welding. And not until then did the metal using industries begin to see the possibilities of its use and to lend their financial assistance to its development.

The Electric Arc.—If two carbons which are connected to a sufficiently powerful electric source are brought together and then slowly separated the current will not cease to flow, provided they are not too widely separated. Instead an arc will be formed and the current will continue to flow, since the vapor formed between the two carbons serves as a conductor for the passage of the current across the intervening space. The temperature of the positive electrode of a carbon arc has been estimated at about 7,500 deg. Fahr. If an arc is formed between two metallic electrodes the temperature will be somewhat lower. The temperature of any arc will be at least equal to the vaporization point of the materials forming the electrodes. In electric welding the heat is communicated to the metal by an electric arc. In one method the arc is deflected from the space between the carbon electrodes by a magnetic field. In this case the metal takes no part in the conduction of the current; the heat is communicated by the gases of the arc, and to a small extent by the radiation from the hot carbon electrodes between which the arc is formed. This particular method was inherently not a commercial success, as is evidenced by the mechanical impracticability of applying the arc to the work. Also, minute particles of carbon in the arc stream produced by the consumption of the electrodes were deposited in the weld, thereby leaving the finished weld exceedingly hard.

The form of carbon arc welding generally referred to, is one in which the work, or part on which metal is to be added, forms the positive pole of a direct current circuit, and an arc is drawn between this and a carbon rod to which a handle is attached for manipulating. At the point of arc contact on the work the metal becomes molten. The metal, which it is necessary to add to the weld, is supplied by melting a filler rod in the arc, the minute globules of molten metal commingling and fusing with the molten metal of the parts to be welded. In this method the bad effects of deposited carbon are largely eliminated by making the work positive, in which case the current flows from the metal to the carbon instead of from the carbon to the metal, as was the original and former practice.

A constant potential source of current supply, together with a choking resistance in series with the heating arc so arranged as to permit an adjustment of current strength, has long been used, and is yet to a considerable extent. Sufficient potential is always required (approximately 70 volts) to maintain steadily an arc of proper length. The current required will range from 50 amperes to 600 amperes, and even higher in some instances, depending upon the character of the work.

The carbon arc process has been limited in its scope of application by its practical confinement to down-hand welding; to the tendency to oxidation resulting in brittleness; to the large area heated, resulting in the bad effects of excessive expansion and contraction, loss of energy or heat radiated by the large arc area, and conduction by the metal being welded; and the necessity of heavy currents with the cumbersome equipment required.

During the past two years much has been contributed to the electric welding art. Most of the development has been along the lines of metallic arc welding, consisting of improvements in equipments, electrodes and weld protection, which has in turn led to a more intelligent application of the process, and the resultant greater extension of its use.

Metallic arc welding consists of drawing an arc between the part to be welded and a metallic electrode. The electrode is in the form of a wire, or small rod. It may or may not be of similar composition to the metal which is to be welded. The arc is established by striking the wire electrode to be fused to the work with a dragging touch and withdrawing it a slight distance, approximately 1/8 in., forming what is commonly called the metallic arc. This form of arc welding differs from the carbon arc in the fact that the filler rod or wire forms one terminal of the arc, which is melted and is conveyed in liquid form across the arc and deposited in the crater on the work piece, which forms the other terminal of the arc.

Due to the fact that it is possible to project metal horizontally and vertically upward, it is possible to do welding on a wall or overhead with this form of arc welding, something which is not commercially possible with the carbon arc. This feature has been a contributory factor toward making the metallic arc welding process to all intents and purposes universal, and gives it an extremely wide field of application.

After many years of research it has been conclusively demonstrated that the metallic arc welding process demands a certain close coordination of the equipment and the arc characteristic, if the best results are to be obtained. Great strides have been made in the perfection of welding equipments and electrode materials for various services.

It is the intention of the authors to cover the requirements, design, and installation of electric welding equipments, together with a complete treatise to date on the subject of electric arc welding, carefully treating each phase of the subject in turn, and concluding with examples of detailed application to the various actual operations which have come under their personal observation.

II

EQUIPMENT FOR ELECTRIC ARC WELDING

Due to the well-known characteristics of the electric arc—that its resistance decreases with increases in current, and vice-versa—to overcome the inherent instability, welding arcs must be connected in a circuit having a drooping volt-ampere characteristic so that the tendency for current to rise or fall will be immediately countered and checked by reduction or increase of voltage respectively. In other words, variations in the arc current should cause the arc voltage to vary in the opposite sense. Furthermore, each arc circuit must include its own independent means of producing the drooping volt-ampere characteristic, the properties of the arc above mentioned absolutely preventing the operation of two or more arcs in parallel in a single branch circuit.

When electric arc welding was first originated, direct current power circuits were used to a greater extent than they are now. The first arc welding was done by inserting a resistance in the supply line having a potential of 125 or 250 volts. Water or grid rheostats were used as resistance. These served to adjust the voltage to approximately the proper value for welding. In this scheme the power wasted was considerable, being dissipated in the form of heat in the rheostat and amounting to from 5 to 10 times as much as that consumed by the arc, when a metallic electrode was used. In certain cases of welding such as electric railway work where the power is taken from a trolley wire through a resistance, approximately 95 per cent of the total power used is wasted. When a carbon electrode is used the power wasted is less since a greater voltage across the arc is required. In spite of this large waste of power, the saving effected in making repairs in many industries by electric welding is so great compared to former methods, that the waste is more than offset. This form of equipment is commonly known as a constant voltage system.

Constant Medium Voltage System.—In the evolution of arc welding equipment the first step was the introduction of the constant medium voltage type which consists of a motor-generator and a control panel.

A diagram of connections for controlling a generator and one welding circuit is shown in Fig. 1. The motor for driving the generator can be furnished to operate from either an alternating or direct current power supply at any commercial voltage. The generator is an ordinary compound-wound commutating pole type, so designed as to give a constant voltage at all loads. The

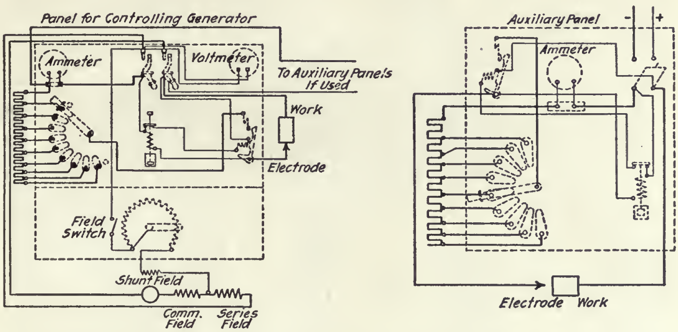


FIG. 1—Generator Control and Auxiliary Panel Circuits with One Welding Connection on Each

generator voltage for this type of equipment has been fixed at 60 volts for machines up to 600 ampere capacity. For machines of greater capacity, a voltage of approximately 75 volts is provided. A variation of the voltage will cause a variation of heat in the arc with an attendant irregularity of deposited metal and fusion. The variation should not exceed five per cent.

An arc welding equipment of this type is known as the constant voltage system, and is distinct from some of the recent equipments as more than one operator can work from the same machine. This system has been in general use for some time, usually where a number of operators work reasonably close together and where both carbon and metallic arc welding is done. When more than one operator is required a control panel is provided for each additional operator. A diagram of connections for the additional or auxiliary panel is shown in Fig. 1. On each panel is mounted an adjustable hand rheostat designed to permit fairly close heat adjustments, a knife switch for disconnecting the panel from the main generator circuit, an ammeter, and, in some cases, protective relays and circuit breakers are provided to prevent error in using

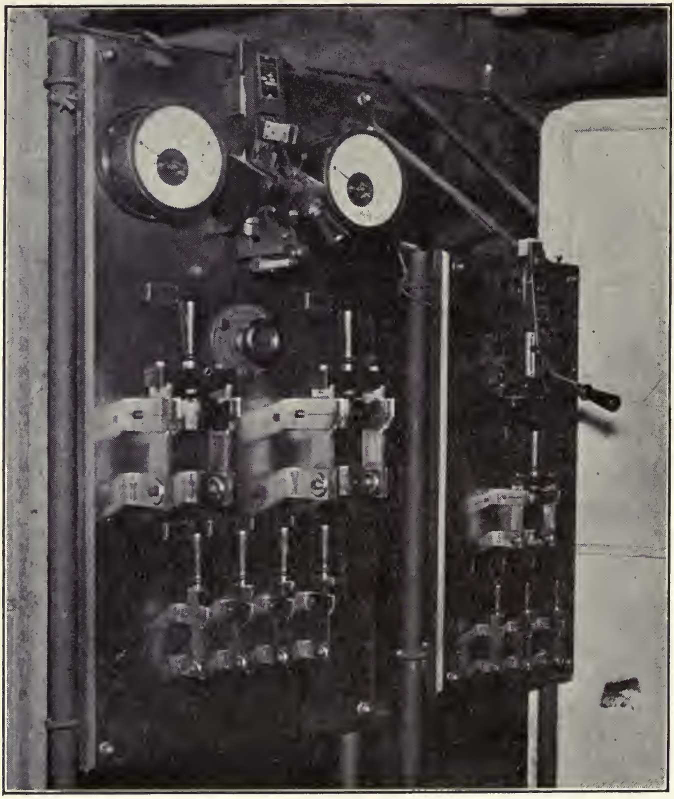


FIG. 2—Generator Control and Auxiliary Panels

the resistance and to protect against overloads by short circuit of long duration. A view of the generator control panel and an auxiliary panel is shown in Fig. 2.

The economy of the constant voltage type over the resistance welder is at once apparent because the power which is taken from the power line is used to operate a motor which drives a generator to provide power for a separate and independent circuit having a medium predetermined voltage value not greater than 60 volts for metallic electrode welding and 75 volts for carbon electrode welding.

To maintain a satisfactorily stable welding arc by this method, however, requires the employment of resistance of such value that the energy expended therein equals or exceeds that usefully employed in the welding arc and the operating efficiency becomes intolerably low.

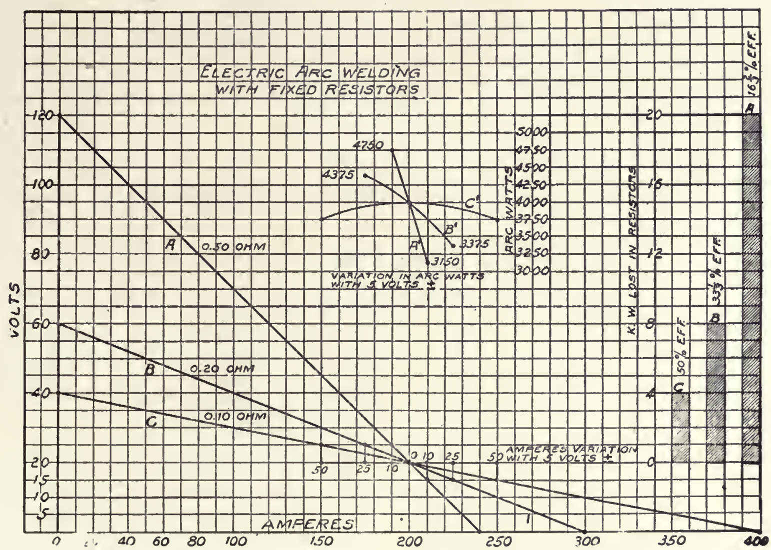


Fig. 2-A—Electric Arc Welding With Fixed Resistors

Fig. 2-A illustrates the conditions existing in three different welding systems employing fixed resistors and constant voltage sources of current wherein, in all cases, it is assumed that 200 amp. at 20 volts, or 4 KW, are usefully employed in the welding arc.

Line A is the volt-ampere characteristic obtained from a 120-volt source with a resistor of 0.50 ohm included in circuit; B is the characteristic of a 60-volt source with resistor of 0.20 ohm, and C, that of a 40-volt source with resistor of 0.10 ohm. Curves

A′, B′ and C′, show the variations in arc watts resulting from 5-volt variations in arc volts, above and below the normal value of 20 volts, in the systems indicated by Curves A, B and C respectively.

In the 120-volt system, with 4 KW usefully employed in the arc, 20 KW are lost in the resistor, thereby giving a circuit efficiency of only 16 2/3 per cent. In the 60-volt system 8 KW are lost in the resistor, making the circuit efficiency 33 1/3 per cent; while in the 40-volt system 4 KW, equalling the energy usefully employed, are dissipated in the resistor and the circuit efficiency becomes 50 per cent. These efficiencies will not be realized in operation, however, as current conversion apparatus, usually in the form of motor-generator sets, must be provided to develop the voltages chosen and this necessity introduces other losses which further reduce the operating efficiency. Motor generators, suitable for supplying a single arc of 200 amperes in welding service, flat compounded to maintain 60 or 40 volts on the line, would probably have an average commercial efficiency of 65 per cent. The best operating efficiency to be expected of the 60-volt, single arc system would therefore be about 22 per cent and of the 40-volt system about 32 per cent. By parallel operation of two or more welding circuits, in reasonably close proximity, from a single motor-generator, these efficiencies might be slightly improved by reason of the higher efficiency of the larger machine, but unless the load factor was maintained at a desirably good value it is conceivable that the efficiency of operation might fall below that obtained from a corresponding number of single circuit machines which may be started and operated just as required.

Curves A, B and C, of Fig. 2-A, show that making steeper the slope of the volt-ampere characteristic improves the stability of the circuit but increases the energy variations in the arc accompanying variations in arc voltage. A 5-volt departure from the normal value of 20 volts produces a current variation of only 10 amperes or 5 per cent in the 120-volt system, 25 amperes or 12½ per cent in the 60-volt system, and 50 amperes or 25 per cent in the 40-volt system, with energy variations in the arc of the three systems shown by Curves A′, B′ and C′, respectively. Experience has shown that it is necessary in the 40-volt system and desirable in the 60-volt system, to include reactance, along with the resistance, in the welding circuit, to reduce the amplitude of current fluctuations accompanying voltage fluctuations inevitable on the welding arc.

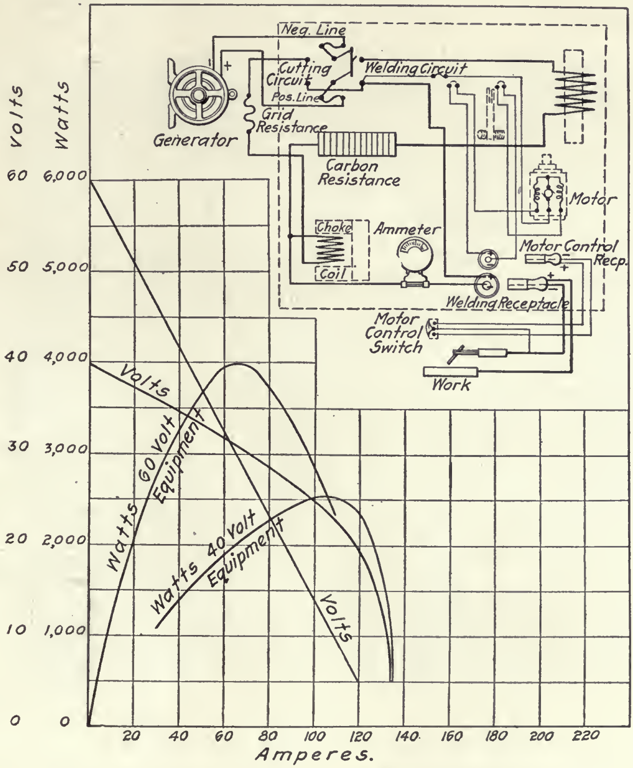


FIG. 3—Constant Current System Circuit and Characteristic Curves

Constant Current System.—A modification of the constant voltage system, commonly known as the constant current equipment or system, is in use in this country. The principal difference in this equipment and the one just described is that the generator voltage is approximately 40 volts instead of 60, and the resistance in series with the arc is automatically adjusted to a predetermined value each time the arc is established, by a carbon pile regulator.

The diagram of connections is shown in Fig. 3. The tendency of the regulator is to maintain a constant current within a certain range of arc voltage. Curves of the volt-ampere characteristics at the arc, with a constant generator voltage of 40 volts and a constant current regulator, also a generator voltage of 60 volts having a fixed resistance in series with the arc, are shown in Fig. 3. The 40-volt system has the advantage over the 60-volt system for electrical efficiency. On the other hand the 40-volt system has the disadvantage that it is more difficult to establish and maintain the arc. Both have their advocates and both are in commercial use. In shops where both systems are in use, the majority of the operators seem to favor the one having the higher voltage.

For either system the arc stability can be made satisfactory by the use of a reactance coil of such capacity as to enable the operator to strike the electrode on the work and withdraw it the proper distance before sticking of the electrode occurs. That a reactor is effective in service is distinctly indicated by oscillograms, which show the actual characteristics with and without a reactor in the circuit. The upper curve in Fig. 4 was taken with no reactor in the circuit. As a result, the operator was compelled to strike the arc three times before he was able to establish it. This is illustrated by the three peak values of current. The lower curve in Fig. 4 was taken with a reactor in the circuit. This shows that the current reached the maximum value the instant the arc was struck; however, the length of time that this maximum current existed was so short that there was no tendency for the electrode to stick. The reactor also stabilizes the arc and prevents it from breaking when the length is momentarily slightly increased, or when dirt and oxides are encountered. Reactance coils are now furnished with some of the constant voltage systems. The variations of current and voltage shown by the oscillograms are produced by the transfer of metal from electrode to plate in globular form, the current increasing, for instance, in a circuit of this characteristic, by the short circuit of each globule and decreasing as it is detached from the electrode.

Progress Made in Developing New Equipment.—In all the equipment so far described more or less power is wasted because of the resistance used in the welding circuit; in order to minimize this waste it was necessary to use a voltage as low as possible and still permit welding to be done. This in turn necessitated the use of extra heavy wires for distributing the power to the different stations in a shop or terminal, thus increasing the installation cost greatly providing the system was made flexible, which is necessary if economy in welding is to be fully obtained. Out of this condition grew the demand for an equipment which would be highly

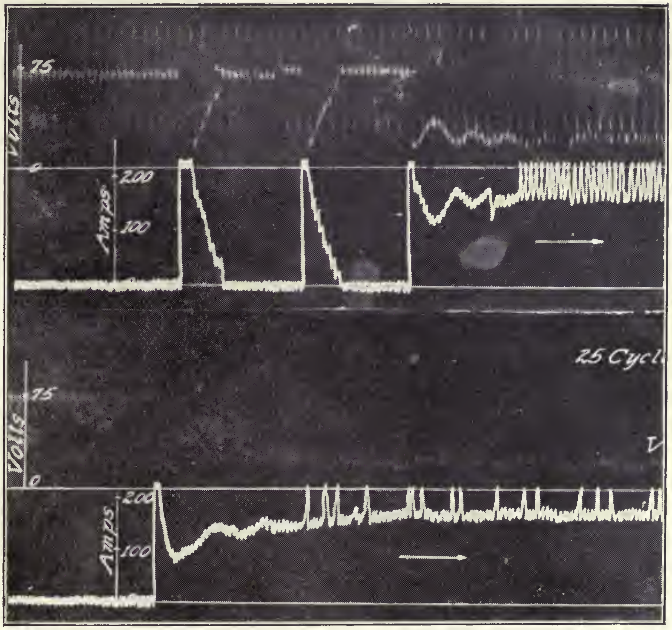


FIG. 4—Oscillograms Showing Effect with No Reactor in Circuit (upper curve); with Reactor in Circuit (lower curve).

efficient, not only for eliminating the power waste, but would be light enough for portable use when conditions demanded. As a result of this demand there are a number of such equipments now on the market, all of which do good work and meet the requirements to a greater or lesser degree.

There are many conditions to be considered in selecting an arc welding equipment, if good and economical results are to be obtained. It is therefore the intention to describe a number of the different equipments and systems with the hope that the information will materially assist the reader to select suitable equipment wisely.

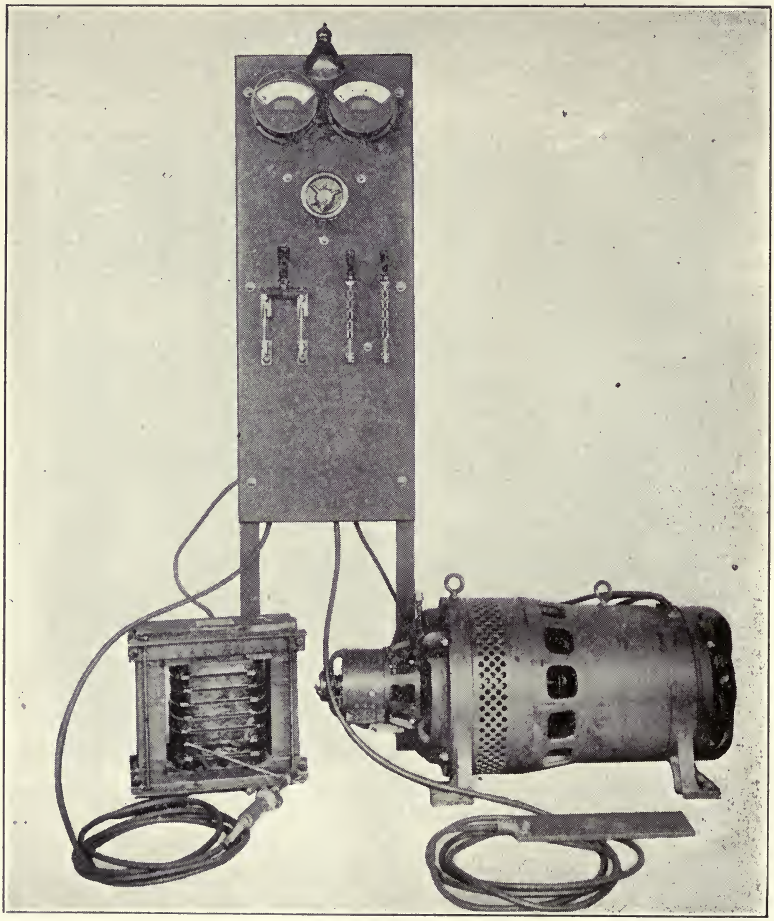


FIG. 5—Control Panel and Welding Generator with Motor and Reactor (Single-Operator Variable Voltage Type).

Single-Operator Variable Voltage Type.—The more recent developments have been along the line of single-operator equipments having what may be termed self-regulating characteristics.

These are more commonly known as the variable voltage type, made so by suitably designed and arranged field and armature windings, in this way eliminating the resistance in series with the arc and increasing the efficiency. Fig. 5 shows a self-regulating, variable voltage, single operator, 150 ampere arc welding equipment. The diagram of connections is shown in Fig. 6. A standard constant speed motor is used for driving the welding generator.

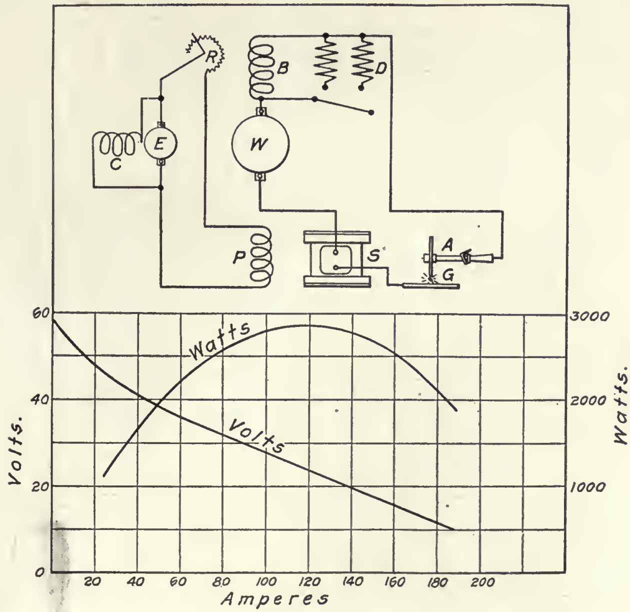


FIG. 6—Circuits and Characteristic Curves of a Variable Voltage Type Welder

ator. Where the power supply is alternating current, a small generator is attached to the armature shaft to provide direct current at a constant voltage for the separately excited shunt field. Where the power supply is direct current the exciter generator is not required, as the shunt field is connected across the power circuit.

The principles involved in the operation of the welding generator includes a separately excited shunt field with a differential compound winding. When the generator is started the voltage is established by the excitation of the shunt field winding P and it can be varied by the small field rheostat R. When an arc is struck current flows from armature W through bucker winding B; the bucker being of opposite polarity to the shunt field winding reduces the effective strength of the shunt winding, thus reducing the generator voltage and as the length of the arc is decreased the current is increased, and vice-versa. If the heat or current is not the proper value when the operator establishes a satisfactory

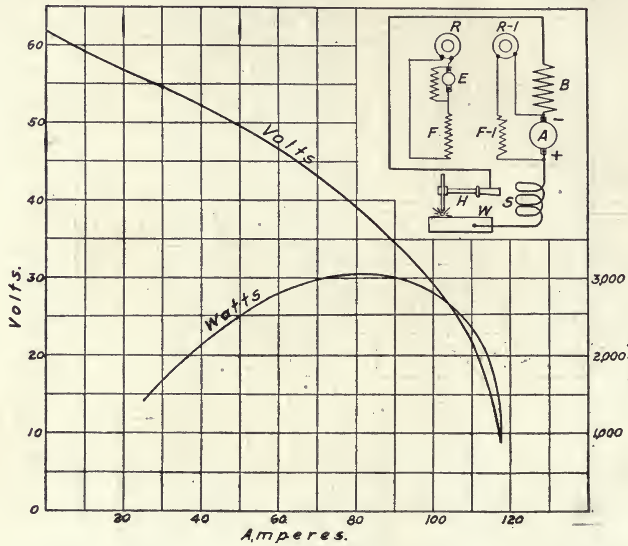


Fig. 7—Circuits and Characteristic Curves of Another Variable Voltage Type Welder

arc length, it may be increased by shunting current around the bucker winding by closing the knife switch which connects shunts D in parallel with the bucker winding, or by increasing the voltage with the rheostat, or by both. To decrease the heat this operation is reversed. Fig. 6 also shows curves for the volt-ampere characteristics of this type of equipment. The reactance coil or stabilizer S is in the arc circuit for the purpose previously stated.

Another equipment is in use similar to the one just described. The diagram of connections is shown by Fig. 7. The shunt field in this case consists of two separate windings; one is self-excited and the other is separately excited. The heat adjustment is made entirely by the voltage rheostats. Referring to Fig. 7 the lettered parts are named as follows: *A*, welding armature; *B*, bucker field; *E*, exciter; *F*, separate excited shunt field; *F-1*, self-excited shunt field; *H*, electrode holder; *R* and *R-1*, voltage adjusting rheostats; *S*, reactance coil, and *W*, work. Fig. 7 also shows curves for the volt-ampere characteristics of this type of equipment.

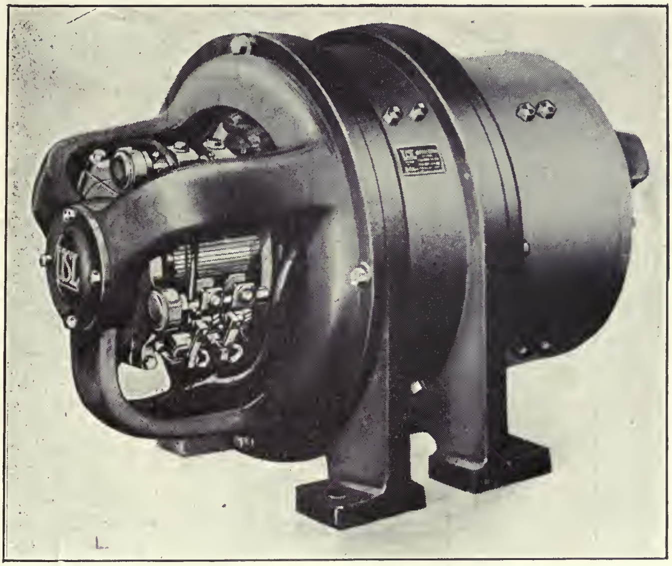


FIG. 8—A Self-Regulating Motor-Generator Welder

The most recent development in the self-regulating type of arc welding generator is a self-excited compound wound type, and is a departure from all previous systems. This equipment is shown in Fig. 8. The driving motor is a standard constant speed motor of from 5 to 10 h.p. rating for metallic arc machines, depending upon the capacity and efficiency of the set. The variable voltage feature in this equipment is accomplished by distortion of the field flux, which occurs when current is taken from the armature by drawing the arc. The diagram of connections for this equipment is shown in Fig. 9. The heat adjustment is made by increasing or decreasing the strength of the shunt field, series field, or both, with the current adjusting switch or voltage adjusting rheostat. The lettered parts in Fig. 9 are as follows: *A*, arc welding generator; *C*, current adjusting switch; *H*, electrode holder; *S*, reactance; *V*, voltage adjusting rheostat, and *W*, work. Fig. 9 also

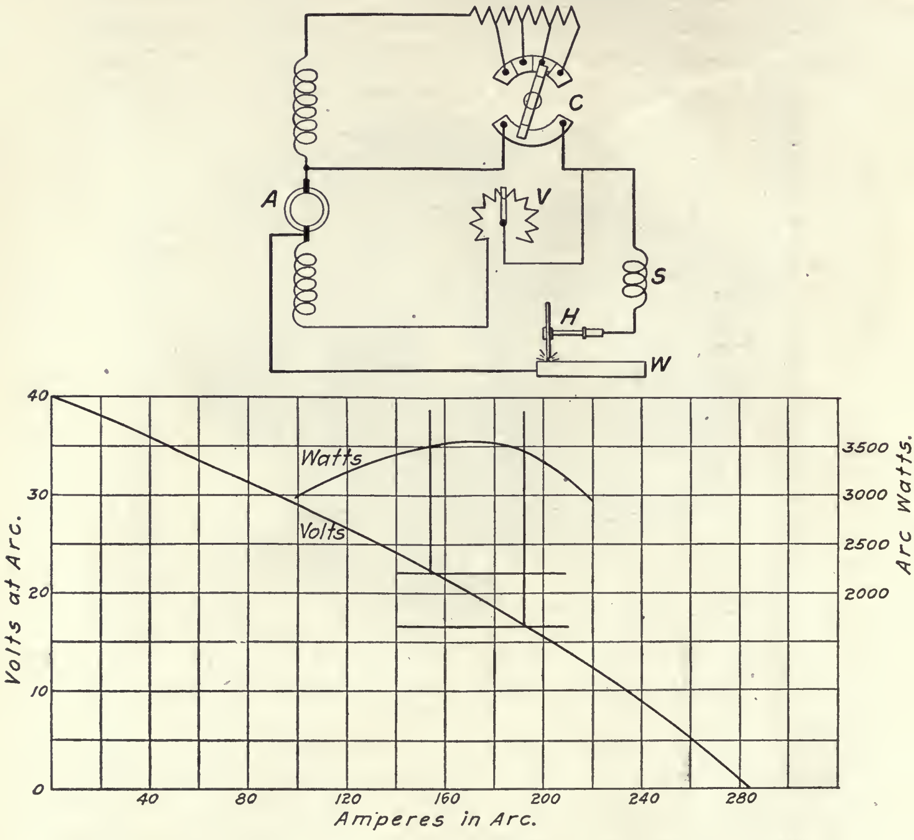


Fig. 9—Characteristic Curves and Circuits for a Self-Regulating Motor-Generator Arc Welder

shows curves for the voltage-ampere characteristics of this type of equipment.

Fig. 9-A illustrates the manner in which inherent regulation is produced by shifting the line of maximum potential difference around the commutator and away from the collecting brushes to

which the welding circuit is connected, in response to current increase through armature and vice-versa. *O F* indicates the field flux developed by the field windings and producing an open circuit voltage distribution around the commutator represented by *O C*, with points of maximum potential difference, in line with the brushes, indicated as 60 volts. Upon closing the circuit, current in the armature will produce a cross flux—*O A*. *O F* and *O A* combine to form *O R*, the resultant flux. As *O F* remains sub-

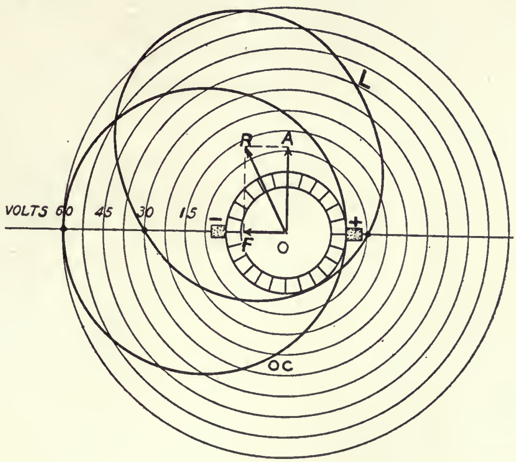


Fig. 9-A—Illustrating How Regulation is Produced by Shifting the Line of Maximum Potential Difference around the Commutator and Away from the Collecting Brushes

stantially constant and *O A* varies in proportion to line current, increase of current will shift *O R* and consequently the points of maximum voltage difference on the commutator, in a clockwise direction, as indicated by *L*, and the voltage effective on the brushes will fall off. On the other hand, decrease of current will reduce *O A*, shift *O R* in a counter-clockwise direction and consequently the voltage effective on the brushes will rise.

A modification of this design employing the same principle for producing the variable voltage is shown by Fig. 9-B, together with the volt-ampere characteristic obtained by varying the open circuit voltage by a single rheostat. In this arrangement, field excitation is produced by self and separate excited shunt fields. The strength of the self-excited field will obviously be reduced when the potential is reduced at the welding circuit brushes by the field flux distortion caused from the cross magnetization force produced by the armature, as previously explained.

The effect of the decreased excitation force is to reduce the variation of arc current in response to arc potential variation, as

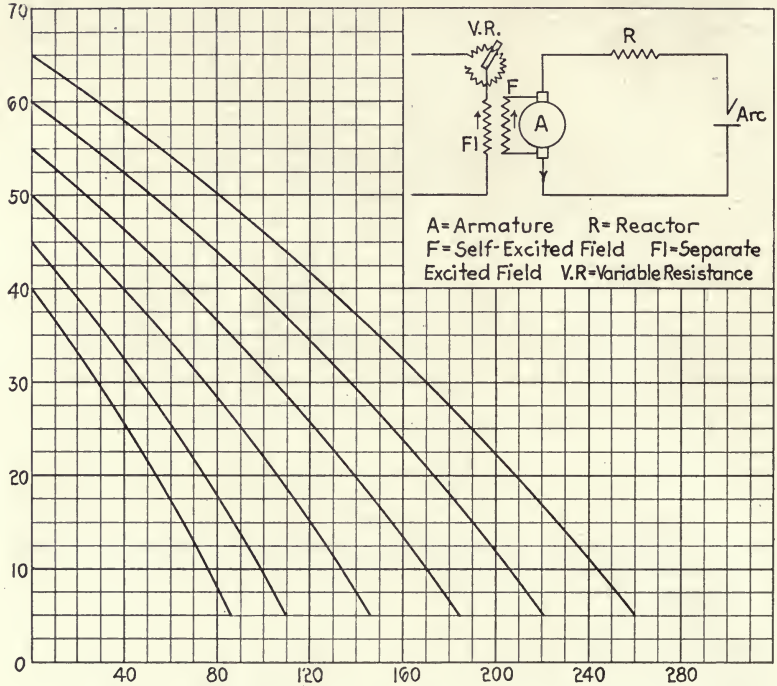


FIG. 9-B—Modification of Design Shown in Fig. 9-A.

well as the short circuit current over that which would be obtained should the strength of the excitation force remain constant.

Another modification of this type of variable voltage generator is one in which two shunt fields are employed, both of which are excited from the welding armature. In this case one field is connected across the welding brushes and the other across two small brushes so located on the commutator that when the line of maximum potential difference is shifted around the commutator the strength of the latter mentioned field will be increased as the strength of the field connected across the welding circuit brushes is decreased in response to increase of arc current. The combined strength of the two fields throughout the voltage range is approximately the same as that obtained by the separate and self-excited shunt fields, as shown by Fig. 9-B.

The reaction type of generator for arc welding will respond to variations of arc resistance with great rapidity. The rapid action is attributed to the greater rapidity of field flux distortion over

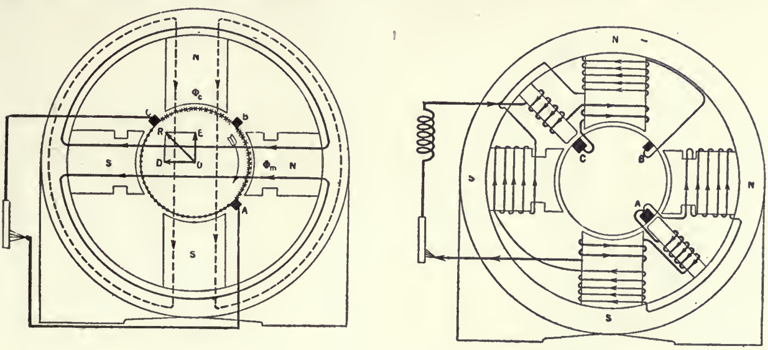


FIG. 9-C—Another Type of Welding Generator in Which Regulation is Mainly Produced by the Armature

that obtained by variation of field flux density, as employed heretofore.

Another type of welding generator wherein the regulation is mainly produced by the armature is shown by Fig. 9-C. In this type of generator there is a group of two north poles followed by a group of two south poles. There are two fluxes at right angles, the horizontal flux being called the main and the vertical the cross flux. In operation the excitation of the cross poles is changed and the excitation of the main poles is held constant resulting in variation of cross flux without variation of main flux. The reason for this independent action of the two fluxes lies in the fact that the poles are symmetrically located and thus one pair of poles belonging to one magnetic circuit lies at points of equal magnetic potential with reference to the other magnetic circuit.

The load of the armature is taken from the brushes *A* and *C* located between poles of opposite polarity. The reaction *O R* of the load current may be resolved into two components at right angles, *O D* in the direction of the main poles and *O E* in the direction of the cross poles. The component *O D* supports the main flux and the component *O E* opposes the cross flux. Owing to the magnetic structure of the main poles being saturated the flux through the main poles remains practically constant. The cross magnetic circuit, however, is not saturated, hence the component *O E* blows out the cross flux, which decreases as the load increases. Shunt field excitation is supplied the generator from

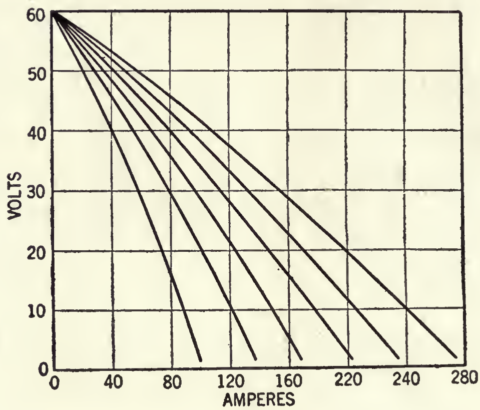


FIG. 9-D—Characteristics of Generator Shown in Fig. 9-C.

two points on the commutator, which possess a constant difference in potential, this being accomplished by a third brush *B*, placed between poles of the same polarity where the voltage *A-B* remains constant.

A series field opposing the cross shunt field and supporting the armature reaction is placed on the cross poles, arranged with a system of taps to facilitate adjustment for different current values in steps of 25 amp.

The generator is designed to give at no load, $A\ B = B\ C = 30$ volts, hence open circuit voltage $A\ C = A\ B + B\ C = 60$ volts. Since the voltage *A B* is constant and *B C* decreases with the load the arc circuit voltage *A C* must decrease with an increase of current, and vice-versa. At a predetermined arc current the cross flux reverses and the voltage $B\ C$ becomes negative, the machine being so designed that this occurs at the maximum arc current. The strength of the series winding is sufficient to limit the arc current to 75 amp. By shunting the series winding the active turns may be decreased to obtain an increase of current up to the capacity of the machine.

The volt-ampere curve obtained from this type of generator is shown by Fig. 9-D.

(The section relating to Figs. 9-A to 9-D inclusive is abstracted

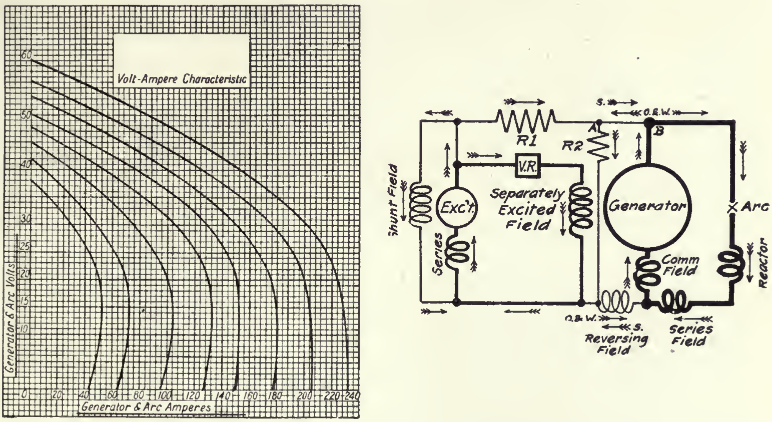


FIG. 9-E—Welding Generator With Inter-Connected, Separate and Self-Excited Shunt Field

from a paper presented to A. I. E. E., June, 1920, by S. R. Bergman and H. L. Unland.)

Inter-connected, Separate and Self-excited Shunt Fields Welding Generator.—Fig. 9-E shows a scheme of inter-connected, separate and self-excited shunt field, the latter acting accumulative on open circuit and differential on short circuit to support the series field in limiting the short circuit current and current variations with variation of arc resistance. The volt-ampere curve obtained from this type of generator is also shown by Fig. 9-E. The separate excited field is connected through the variable rheostat ($V\ R$) directly to the exciter terminals. The reversing shunt field is connected through the field resistance $R\ 2$ to the generator.

The negative terminal of the exciter is connected to this field winding, whereas the positive exciter terminal is connected through the interconnecting resistance *R 1* to the positive generator terminal *B*. The series winding always opposes the separate winding. When the generator is operating under no load (open circuit) and under normal welding conditions, the current through the reversing field is obtained from the generator terminals in direction indicated by arrows marked *O* and *W*. Under these conditions this field is self-excited and is assisting the separate excited field to maintain the generator terminal voltage. When the terminals of the generator are short-circuited, however, as in striking the arc, then the current through the reversing field comes from the exciter circuit through the interconnecting resistance; thence through the wire connecting points *A* and *B* as indicated by arrow *S;* thence through the arc circuit and the reversing field in direction of arrow *S;* and thence to exciter. In this case the reversing field opposes the separate field, thereby assisting the series field in limiting the permanent short circuit current.

When the arc is being operated at 22 volts we will consider the total accumulative excitation produced by the separate and reversing field as 100 per cent, out of which 71.7 per cent is supplied by the former and 28.3 per cent is supplied by the latter field. When the generator is short-circuited the total accumulative excitation is reduced to 71.7 per cent, namely the separate field, whereas the total differential excitation is 34.5 per cent, out of which 17.9 per cent is supplied by the bucking series field and 16.6 per cent is supplied by the reversing field. In other words the latter field has changed from 28.3 per cent accumulative to 16.6 per cent differential excitation and is of almost as much assistance as the series field itself.

The open circuit voltage obtained from self-regulating equipments usually ranges between 45 and 75 volts. The ampere capacity for metallic arc welding is 150, 200 and 300 amperes; for general work 200 amperes are required. An ampere rating of not less than 300 amperes is required for carbon arc welding. In considering capacity of electric welding generators, it must be borne in mind that in speaking of a 150-ampere or 200-ampere rating, as the case may be, it is meant that the generator shall be able to supply the rated current to meet the demands of an experienced operator working continuously, and not necessarily a continuous rate of current flow.

Welding machines may be operated where electric power is not available by driving the generator from any constant speed power source of ample capacity, such as belting to a line shaft, gasoline

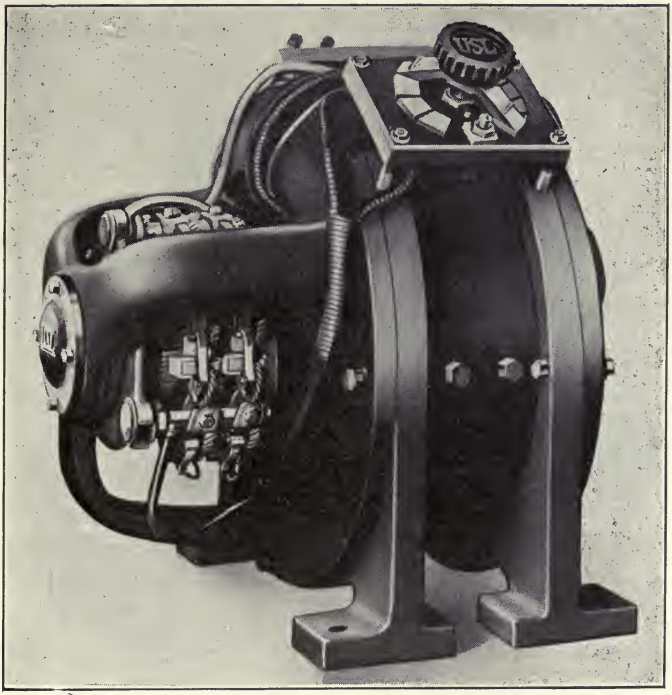


FIG. 10—A Direct Current Welding Converter

engine, etc. This permits the application of arc welding at almost any location.

Self-regulating variable voltage equipments have been developed for operation from a constant voltage direct current circuit of 125 volts. Fig. 10 shows a welder of this type, and Fig. 11 the diagram of connections. The equipment consists of one armature, one commutator, and one set of fields. One wire of the welding circuit connects to the supply line, the other to an extra brush holder on the commutator. The lettered parts in Fig. 11 are as follows: *A,* arc welding converter armature; *C,* current adjusting switch; *H,* electrode holder; *S,* reactor; *V,* voltage adjusting rheostat, and *W,* work. This equipment merely provides a lower variable voltage for the welding circuit, and also means for heat adjustment without the use of any series resistance in the supply line or welding circuit; in this way a high efficiency is obtained. This welding machine is known as a direct current welding converter.

Another welding machine which operates from a direct current power supply of 125 volts is shown in Fig. 12. This welding set

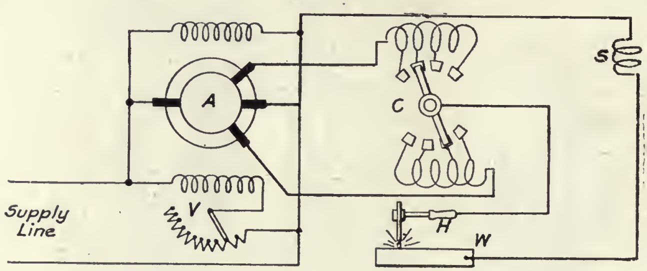


Fig. 11—Circuits for a Direct Current Welding Converter

also provides a lower variable voltage feature together with means of heat adjustment, without the use of series resistance in either the motor circuit or the welding circuit, resulting in good efficiency. The equipment is simply a balancer set having specially designed field windings; a diagram of connections is shown in Fig. 13.

These equipments are better suited than other types for operation from 125 volts direct current supply, when available. Their use also may prove economical under certain conditions by providing a 125-volt circuit by using a motor-generator set, from which a number of converter welders or balancer sets may be operated; in other words, any advantages which may have been offered with the old constant voltage multiple operator systems can be obtained with this type of equipment without the disadvantage of having to provide such heavy distributing circuits or to tolerate the heavy loss of power in resistance ballast. Also the bad effects due to the interruption of one operator by another (more or less experienced when more than one operator is working from the same circuit) is almost entirely eliminated. The saving effected by the use of such a system over the old constant voltage system, would in a reasonable length of time justify the difference in the first cost.

Competitive claims have been made relative to the quality of welds made with certain controls or volt-ampere characteristics,

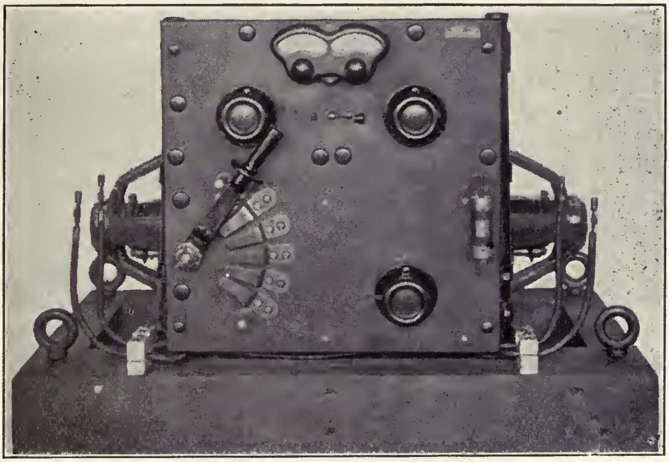


Fig. 12—Constant Energy Arc Welding Set, One-Man Portable Outfit, Norfolk Navy Yard

stabilizing characteristics, etc., the latter often being referred to as long and short arc machines. In this connection a great deal of commercialism has been confused with facts among the users of arc welding equipments. As a matter of fact stabilizing characteristics of a welding circuit are as necessary for good welding as a short arc, and this may be obtained within the machine itself by the aid of a reactance coil in the arc circuit, or by both. Again the shape of the volt-ampere curve and the rapidity with which the current varies in response to variation of arc resistance will influence the arc stability and ease of arc establishment.

The tendency for the electrode to stick seems to increase with an increase of starting current above the normal value, and the tendency of the arc to extinguish seems to increase with a decrease of arc current below that obtained at the normal arc potential. On the other hand, a slight increase in welding current with a decrease of arc potential seems to facilitate fusion and penetration.

The hypothesis commonly accepted as to the form in which the metal exists in passing through the arc is that it exists in both gaseous and liquid globular form; it is estimated that 85 per cent

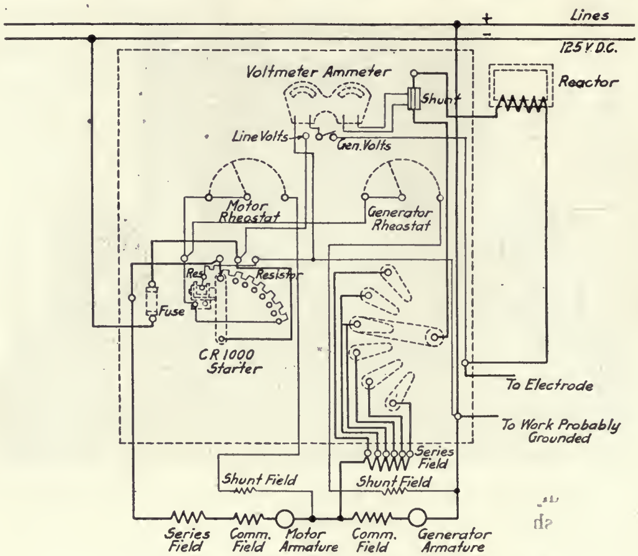


FIG. 13—Circuits for Equipment Illustrated in Fig. 12

of the metal is transmitted in liquid globule form, the cycle of globular transfer presumably occurring as follows:

A. On drawing the arc liquefaction of the electrode end begins.

B. On continued heating the electrode end expands and assumes a globular form.

C. With the continued growth of the globular form the globule short circuits the arc stream when the arc voltage drops to practically zero value and the arc current increases to short circuit value.

D. Heating continues under short circuit conditions until liquefaction at the electrode side of the globule exceeds that at the plate side, when due to the greater thermal capacity at the plate the molecular attraction and surface tension of the plate exceeds that at the electrode at which time this force, plus the force of expanded gas within the electrode, affects the globule detachment.

E. At the instant of detachment the current decreases while the voltage increases until the initial welding current flow is established through the arc gases.

The high rate of globular transfer is shown by lower oscillogram curve of Fig. 4, where the current peaks can be seen at the instant the globule short circuits the arc at the rate of approximately 25 times per second.

From the foregoing it appears that a welding circuit should possess the following characteristics:

1. Ease of arc establishment when the work piece and the electrode are cold.
2. Freedom from undue tendency to sticking or freezing of electrode or extinguishing of arc with maintenance of short arc stream.
3. Stable arc with maintenance of short arc stream.
4. Limited current increase with growth of liquid globule.
5. Limited increase of current at the instant and during the period the globule short circuits the arc stream. An increase up to about 50 per cent of the normal seems essential for adequate penetration. The increased $I^2 R$ energy replacing to a considerable extent the arc terminal energy lost on short circuiting the arc stream. If the short circuit current is too great the tendency for the electrode to overheat due to occasional accidental momentary short circuits becomes a disadvantage.
6. To facilitate re-establishment of a stable arc the arc voltage should increase rapidly at the instant of globular detachment or on breaking a momentary short circuit.

A study of the curves previously referred to will reveal that about the only difference in the more recent variable voltage equipments and a constant voltage system (where a resistance is placed in the arc circuit) is that the straight line characteristic of the constant voltage welder is approximated by the variable voltage welders. The other merits of the improved equipments, however, are of great value and have been an important factor in furthering the application of the process.

Alternating Current Welding Equipment.—Comparatively little welding has been done in this country with alternating current. It has been utilized to a considerable extent in England with coated electrodes. The original equipment consisted of an adjustable ballasting resistance generally constructed for operation from 100 volts. Recently special welding transformers designed with large leakage reactance have been placed on the market. The general scheme of the reactive method of control is shown in Fig. 14. In the operation of this system variable voltage is obtained because of the high leakage across the magnetic shunt between the primary and secondary windings. On account of this high leakage its power factor is low.

The use of coated electrodes greatly assists in holding an alternating current arc, since the coating tends to exclude the air and prevent the arc vapor from cooling and condensing with each

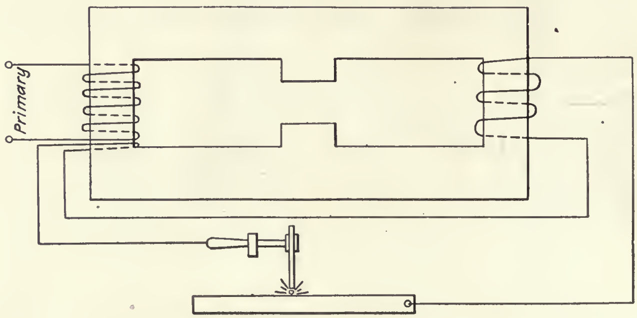


Fig. 14—Alternating Current Equipment

reversal of the current. Where a bare electrode is used it is extremely difficult to start the arc (especially so on cold metal) and it is difficult to sustain the arc owing to the effects of the air each time the current reverses. The field of commercial application of the alternating current arc will therefore probably be limited to small installations where the excessive primary capacity already exists and for use with coated electrodes.

While there are other makes of equipments of which no mention has been made the ones described represent about all the principal types commercially used.

Selection of Equipment.—In choosing an equipment it should always be borne in mind that in a process where the human element plays as important a part as in the case of autogenous welding, the workability of the arc is of primary importance, and should be such as to minimize as far as possible the human element which under the best conditions when welding day in and day out finds it difficult always to do good welding. Efficiency can probably best be calculated on the basis of kilowatt hours input per pound of metal melted with the equipment in the hands of an experienced operator.

As with all electrical equipment, the safety feature must not be ignored. This is especially so in the case of electric welding equipments, since they are almost invariably placed in the hands of operators who are entirely unfamiliar with electrical apparatus. The equipment should be so designed that the welding operator will not in any way be liable to injury from direct or indirect contact with the power supply circuit. The local welding circuit to be entirely safe should have a potential as low as consistent for good welding. Past experience has demonstrated that welding equipments now in use which provide a separate and independent local direct current welding circuit are entirely safe, their potential being not greater than 75 volts.

III

INSTALLATION OF ARC WELDING EQUIPMENTS—WELDING ACCESSORIES

There are two distinct methods for distributing power to arc welding equipments. These may be classified as follows:

(1) The standard or existing power circuit may be used to furnish power to the individual equipments, which may be stationary or portable as conditions demand. If stationary they should be installed in the same manner as an ordinary motor. If portable, receptacles should be located at various points from which the motors of the welding machines are to receive their power.

(2) A separate circuit may be installed to furnish power at the proper value from a motor-generator set or other means operated from the main power circuit. This separate or secondary circuit is usually designed to furnish power at 60-volts to a number of control panels located at different points within the area to be served.

The principal difference between the two systems, as far as distribution of power is concerned, is the cost of installation. The individual operator equipments as a rule are the self-regulating type using no resistance in series with the arc to waste the power, which is not the case with the latter mentioned system of distribution, wherein at least 50 per cent of the total power used is consumed by a rheostat. Therefore, in this method of distribution the circuits would be required to carry double the power needed for the self-regulated equipment, in addition to the increased carrying capacity necessary to compensate for the difference in potential of the two systems; the former using 250 or 440 volts, the latter approximately 60 volts for distribution.

The field for the lower voltage system is therefore limited to installations where the cost of power is not so important, where the waste of power in rheostats may be lost sight of, where the average load factor is sufficient to utilize the capacity of the machine, and where a number of operators are working reasonably close together so that but little copper is required for welding circuits; otherwise the low voltage which is used with this system requires an excessive copper capacity to carry the comparatively high current when it is necessary to distribute the power over a large area.

Stationary and Portable Welding Equipment.—There are conditions where the welding equipment must be brought to the work if full economy of arc welding is to be secured. On the other hand there are conditions where the opposite is true, or again it may be necessary to meet both conditions. Generally in manufacturing plants, a very large per cent of the work can be brought to the welding equipment, but in some industries, such as ship yards, roundhouses, car yards, etc., it would be false economy to move the massive work to the welding machines—for instance, to move a dead locomotive, car or other heavy structural work the cost would be excessive and the job difficult.

At the present time the indications are that a system of both stationary and portable welding equipment, operated from electrical power, will be required for railroad shops, repair yards, roundhouses and similar layouts. For classes of work more or less isolated from a source of electric power, as for instance track work, the welding equipment may be driven by a gas engine. If arc welding is to be used over an entire railroad system, the power supply should be standardized as far as is possible, in order that the equipment (especially the portable type) may be transferred from one terminal to another when conditions demand.

Wiring and Installation—Typical Layouts.—The wiring around railroad terminals, especially roundhouses, presents a difficult problem mainly on account of the gases, and the cost of maintenance will be governed largely by the manner in which the original installation is made. In arranging an installation it is important to keep in mind the safety features; for instance, where portable equipments are used it is necessary for the outlets and switches to be of the approved safety type. To provide ordinary protection from grounds, provision should be made for grounding the frame of the equipment when in operation. Experience has proved that car yards, roundhouses and other similar places require a portable type of equipment for the reason that a small amount of welding is done and in almost any location within a comparatively large area.

A roundhouse installation for portable equipments which has been found very satisfactory over a period of more than two years, is shown in Fig. 15. Power outlets are located every 100 ft. around the house. With this spacing the extension wires from

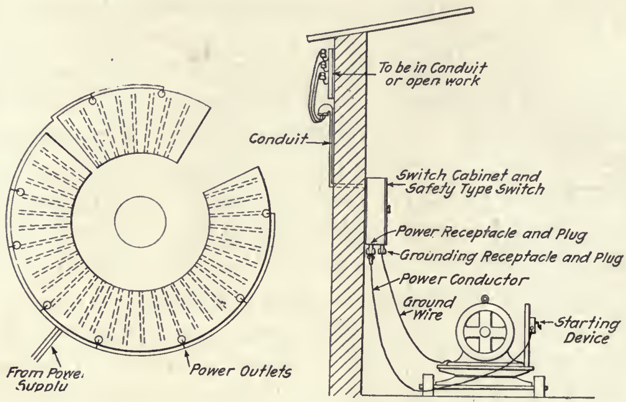


Fig. 15—Layout for Portable Arc Welding Equipment in Roundhouses

the welder to the operator's electrode holder will never be greater than 150 ft. and ordinarily 75 ft. will be sufficient. For metallic arc welding, cable size No. 1 B & S is large enough to carry the current this distance safely without excessive drop in voltage. The twin or triple conductor cable used between the motor starting switch and the power outlet should not be more than 8 ft. long, the object being to compel the operator to set the machine close to the outlet, preventing his laying the power supply cables across the aisle, where they would in time have the insulation damaged which might result in injury to someone. A second plug, or an auxiliary contact to the power plug, serves to ground the frame of the motor-generator set.

When an operator connects a portable welding machine, he first makes sure that the safety type switch is in the open position and then inserts the grounding receptacle; the power plug is inserted next after which the safety switch is closed. The machine may then be started by the motor starting box mounted on the truck. Where the power supply is alternating current an oil switch equipped with overload relays is used for starting the motor. In disconnecting the machine from the power circuit, the motor

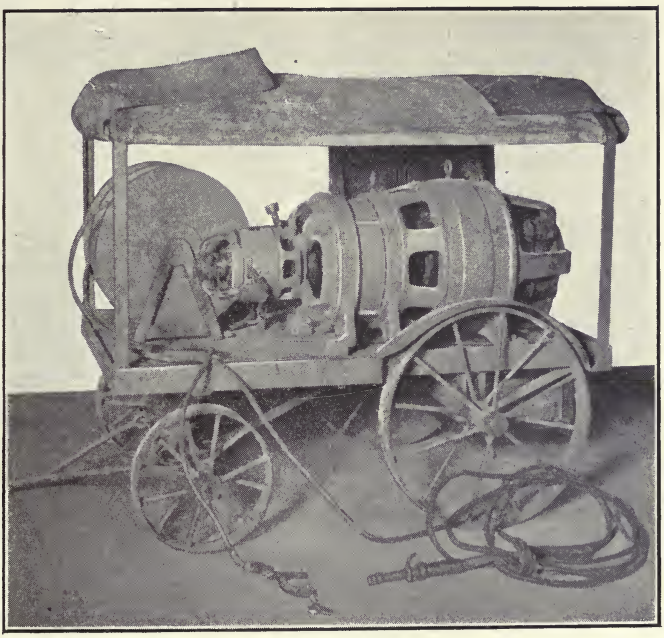


Fig. 16—A Portable Type of Arc Welding Equipment

starting switch is opened, then the safety switch, next the power plug is removed and finally the grounding receptacle is disconnected. A safety switch receptacle and grounding device combined is now on the market. It is so designed that the circuit arrangement is automatically taken care of when the plug is inserted.

A portable type of arc welding equipment for use in a roundhouse is shown in Fig. 16. This equipment is made weatherproof, providing protection against the steam and water which

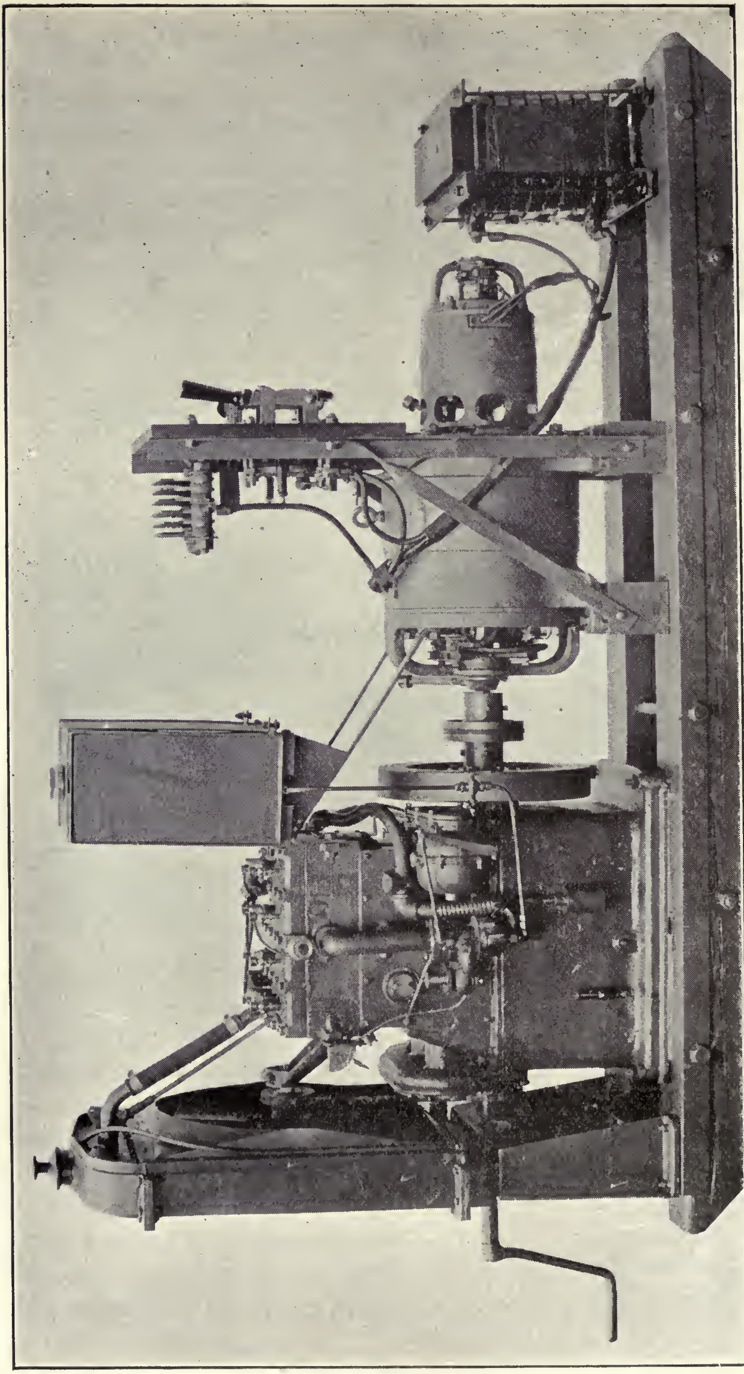


FIG. 17—A Gas Engine-Driven Electric Welding Equipment

usually prevails in roundhouses. The same feature also makes it safe for operation outside, as in car yards where it may be subjected to storms if left out of doors over night. A reel is mounted on the truck, on which the secondary extension cables are wound. Collector rings at each end serve as the connections between the wire cables on the reel and the positive and negative terminals of the welder. The reel provides for the handling the wire cables and offers much to their protection. This method of roundhouse power distribution for arc welding is extremely flexible; its cost is nominal, and by anticipating the future capacity requirements when the original installations are made, for a comparatively small cost additional equipments may later be used without additional installation expense.

A freight car repair yard demands practically the same layout as a roundhouse. As a rule it will not be necessary to wire the entire yard for there is usually a certain zone within which all the welding may be done. Also, there will be a certain class of work that can be done best at a certain station; such a station, however, does not necessarily demand a stationary equipment, as it can be served by a portable type which may be used elsewhere when necessary. When electric power is not available or when a very small amount of electric welding is required within an area so large as to make it almost impracticable to wire it, even if electric power is available, a gas engine driven equipment such as shown in Fig. 17, may be used. A self-propelling car which provides power for arc welding is now being developed for track use. With this car it will be possible to build up worn spots in track and repair bridges and track accessories in a terminal or on a division of a railroad.

The requirements for railroad shops, foundries, ship yards, reclamation stations, etc., will be governed largely by the local conditions. For instance, in railroad locomotive shops and other similar places it is not only necessary to be able to do welding at almost any location within the shop, but at times the work shifts so as to require a number of operators to work comparatively close together. To meet a condition of this kind and at the same time utilize the equipments to the best advantage, an installation of both stationary and portable equipments seems superior to any

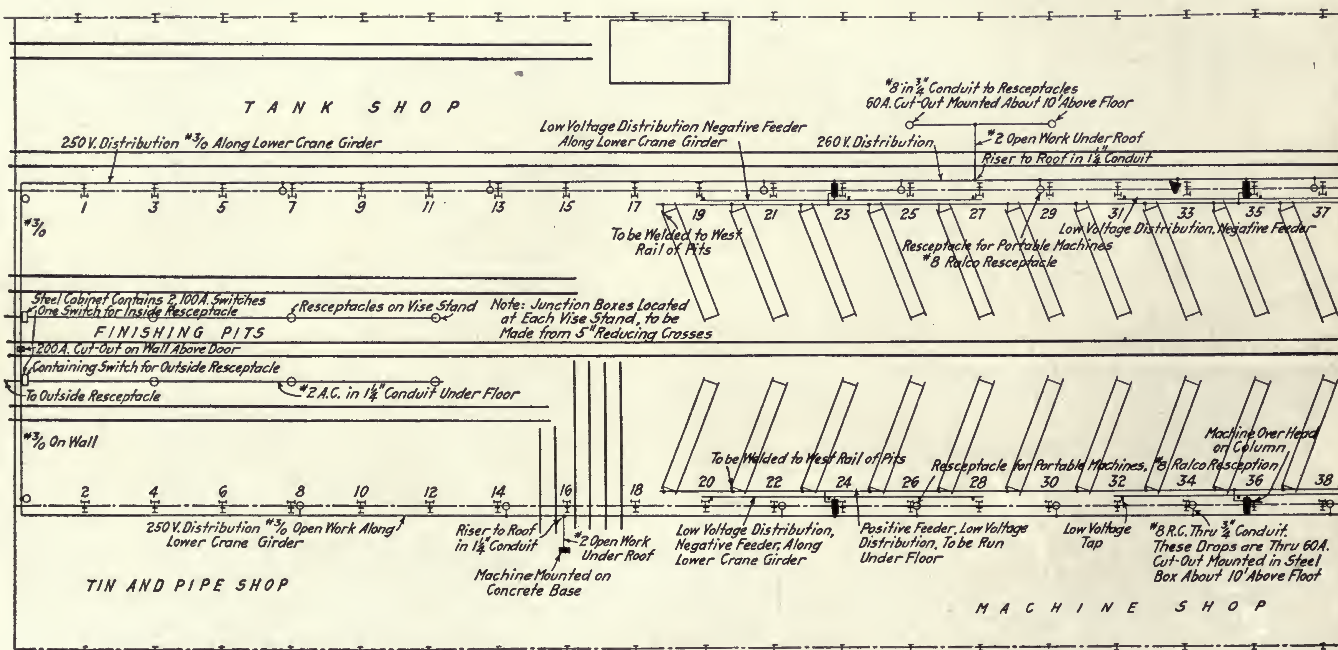
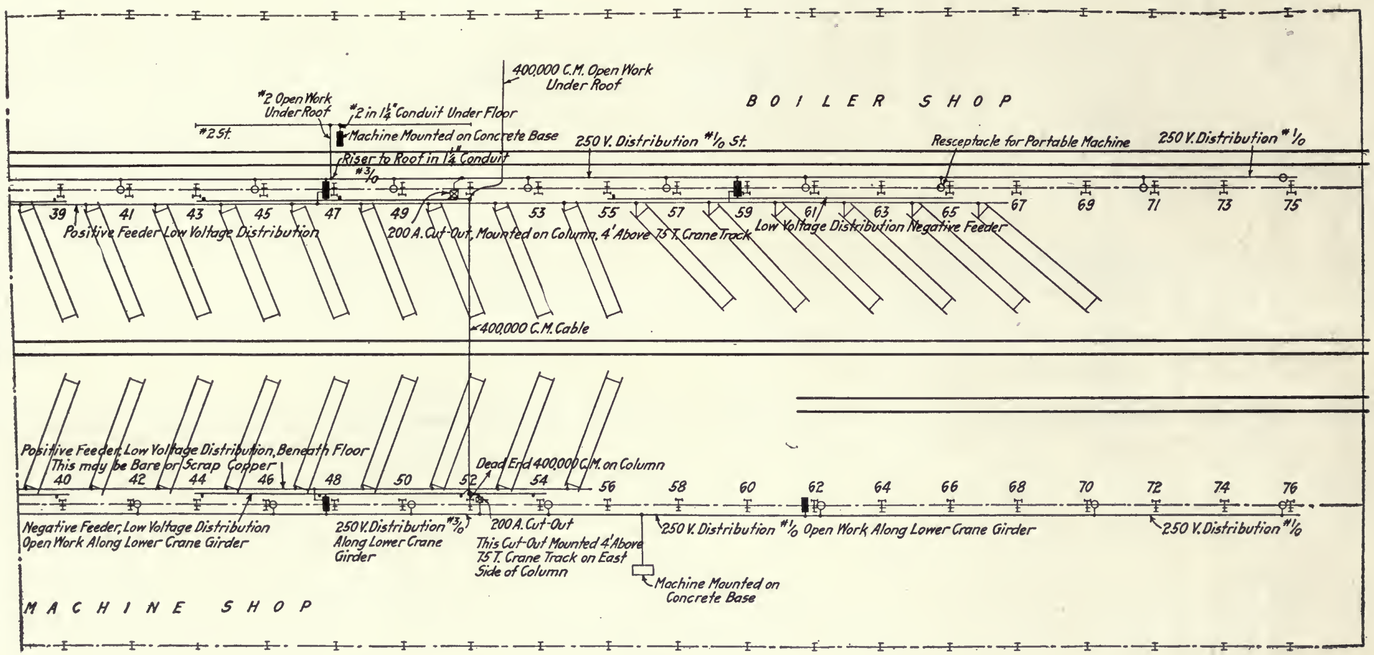


FIG. 18—Locomotive Repair Shop Floor Plan Showing Circuit Layout and Location of Equipment for Arc Welding Installation



Continuation of Fig. 18 Showing the Eastern End of the Shop other method, especially when the floor space is limited, which is usually the case.

A layout for an arc welding system installed in a large railroad shop in the latter part of 1916, which is representative of many other similar locomotive and passenger car shops, is shown by Fig. 18. The main distribution circuit in this shop, which is 250 volts, is run from the power house 500 ft. away. From this circuit are operated 20 single-operator equipments, 11 of which are stationary and 9 portable. In the pit section of this shop, 8 single-operator equipments are mounted overhead on brackets attached to the columns, in the same manner as an ordinary motor is installed. The control panels for each machine are mounted on the same column which supports the machine platform, low enough to be within reach of the operator as shown in Fig. 19. Three other stationary single-operator equipments are included in this shop, two being used for the welding of miscellaneous locomotive machinery parts, and one for miscellaneous tank and boiler work. In the reclamation, forge shop and roundhouse, there are 7 other equipments of the individual operator type in use, making a grand total of 27 in the entire plant.

Referring to Fig. 18 it will be noted that the rails of all the pits are bonded together to form one side of the low voltage welding circuit for all stationary equipments mounted on the columns. The other wire of the low voltage circuit is extended from each equipment to points convenient to serve at least six pits. Provisions are made for connecting to this wire an extension cable (to which the operator's electrode holder is attached) at four different points so as to serve the six pits. If the work within any one section covered by the stationary equipments requires more than one arc, the additional arcs are provided with the portable equipments which may be plugged into the power outlets located between every other pit. If within a limited area there is not sufficient work to insure a fair average number of welding hours per day for an equipment then that particular section can best be served with a portable welder, which can also be used at any other point in the shop, in this way utilizing the equipment to the best advantage.

In reclamation or similar shops where miscellaneous welding is done the equipments can be stationary, and if a number of operators are employed continuously a multiple operator equipment may prove economical. The first cost of a multiple operator equipment will always be less than the same capacity in single-

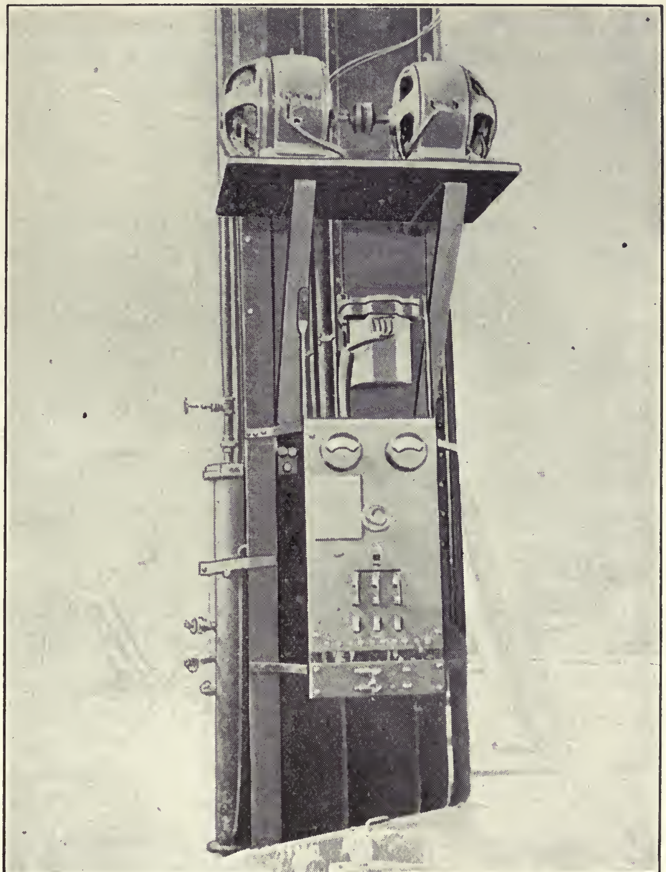


FIG. 19—Single-Operator Stationary Type Welder Mounted on a Column

operator equipments; where there is comparatively little wiring required, and the cost of power is not excessive, their use may show economy over the individual operator equipments.

In concluding the subject of the installation of arc welding equipments, it might be well to emphasize that there are a number of factors which govern such installations to a greater or less degree. To what extent these factors become important depends largely on the local conditions. However, in general, it is safe to say that the use of standard power circuits for the main distribution, together with single-operator equipments (which may be portable or stationary, as conditions demand) will prove more satisfactory than any other method, since the efficiency of an arc welding installation will be determined largely by its flexibility and also by the workability and electrical efficiency of the welder which the individual equipment provides.

Arc Welding Accessories—Eye and Skin Protection.—The glare emitted by an electric arc is exceedingly intense; to observe the arc used for welding purposes and to protect the eyes and skin from the harmful effects, shields are provided with special glasses, the preparation of which has required considerable research work by eminent engineers, scientists and surgeons who have defined fairly well what should or should not be used. Only persons thoroughly familiar with the subject should be allowed to pass on glasses to be used for arc welding. It is sufficient to say here that glasses used for arc welding tone down the erratic glare of the visible rays sufficiently to permit the work to be seen reasonably clearly and also exclude the invisible infra-red rays and the ultra-violet rays. Furthermore, glasses of the proper color tints, besides softening the glare also bring out the details more clearly. Some colors or color combinations amplify this to a greater degree than others. This can be determined by comparing different colored glasses made for the purpose. Amber, or amber tinted with some other color such as green, are the most common colors in general use. The infra-red rays (sometimes called heat rays), even though they are invisible, can be detected by the heat, which is generated when such rays are subjected to a material that is non-transparent. To guard against their harmful effects, a glass must be used which possesses the property of absorbing or reflecting heat.

An arc produced from an iron electrode is rich with ultraviolet rays; these are very dangerous to the eyes, but it is not a difficult matter to eliminate their effect since ordinary clear glass (not quartz) will in a measure furnish the necessary protection, except that such glass does not have the qualities for eliminating the intense glare present in an arc. For that reason glasses of the proper color must be provided.

There are a number of special safety glasses on the market which meet the requirements. One type possesses the properties of toning down the glare, excluding the infra-red and ultra-violet rays, besides permitting a sufficient degree of visibility. Efforts have been made, from time to time, to utilize mica for eye protection, but its non-uniform quality prohibits its use. Objects viewed through it appear blurred. Because of the cost of the special glass its use is limited in many localities, so that glasses or combinations of colored glasses, which give results approaching the special glasses, are extensively used.

A combination of glasses that have been used extensively for arc welding consist of: one emerald green (or rich bright green); one or two ruby (or deep red) and one ordinary clear; one or both of the colored glasses must be of the heat absorbing or reflecting kind. The clear glass is used only for protecting the colored glasses from the flying particles of hot metal.

Experience has shown that the depth of the color tint required for one operator is not satisfactory for another. However, the depth of the color tint varies in the commercial glasses, so that advantage is taken of that fact to enable each operator to select glasses having a color tint favorable for his eyes. In choosing glasses, however, care should be exercised in selecting a color tint as deep as consistent for clear visibility. Only glasses that are uniform in color should be used. If streaks or spots are present the glasses should be discarded; such defects may cause eye strain.

The glasses referred to here have been in use under the observation of the writers for over a period of five years and from service test, they are known to provide proper protection when it is possible to select them free from the imperfections enumerated above. Such special glasses as will insure the user a uniform glass free from optical imperfections and which will provide the proper protection for the operator are preferable to any combination of colored glasses, and in the long run they will be the most economical.

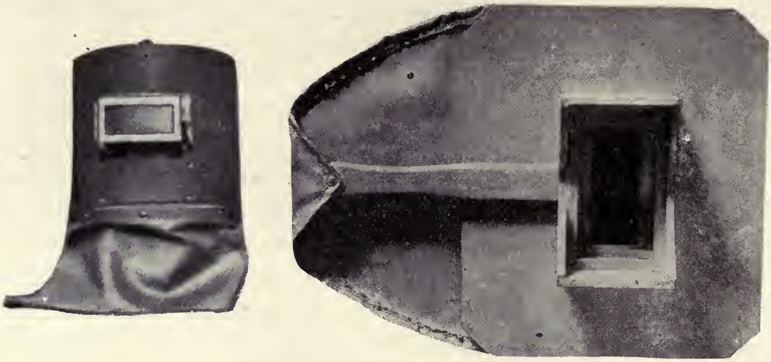


FIG. 20—Helmet and Hand Shields for Welding Operators

Helmets and Hand Shields.—If the skin is exposed to the rays of a welding arc, it will be blistered by the heat. On this account the shield which holds the glasses must be large enough

FIG. 21—Operator Equipped with Helmet, Apron, Gauntlet Gloves and Heavy Closely Woven Shirt

to cover the entire face. Two shields that have been found satisfactory are shown in Fig. 20. The holder for the glasses in the helmet type is hinged so that the door may be opened to enable the operator to see the electrode better when it is necessary to change it or to observe the work more closely. This particular feature is shown in Fig. 21. The leather apron attached to the bottom of

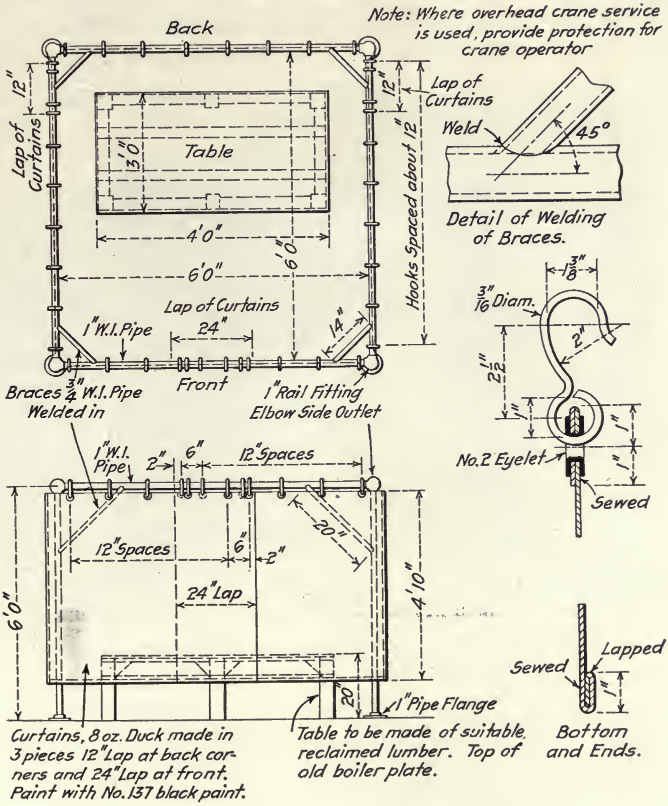


Fig. 22—Booth for Welding Small Miscellaneous Parts

the helmet serves to protect the neck from any harmful effects of the arc. When the hand shield is used it should be held close to the face to prevent reflected light from entering from the back in such a way as to permit it being reflected again from the glass to the eyes. The helmet type shield is used for that class of welding where both hands are required, such as carbon arc welding or metallic arc welding inside a firebox, where it is often necessary to use one hand to steady the body. The hand shield is used with light work, such as bench welding, etc. The glasses used for such work are 2 in. by 4⅛ in. and are of single strength thickness. The dimensions should be uniform in order that the glasses will fit properly in the holder. For protection of the hands and arms from the arc's rays, it is necessary to wear gloves. Canvas gloves,

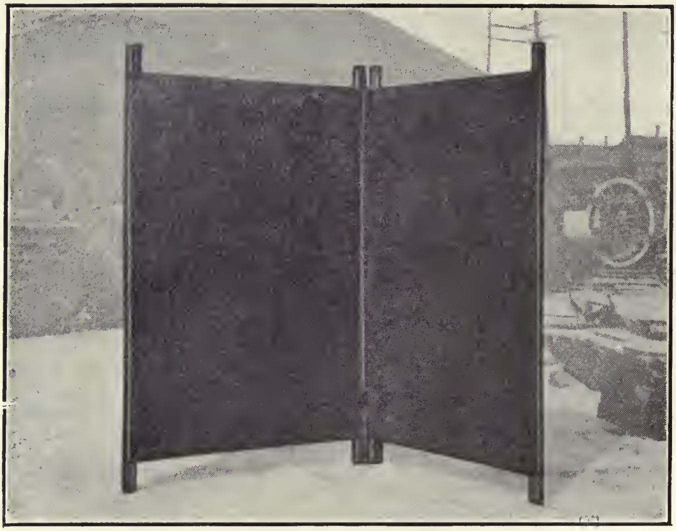


FIG. 23—A Portable Screen for Welding Operators

preferably the gauntlet design, will serve the purpose. Ordinary work shirts made of heavy closely woven material will give ample protection for the arms and body. Bellows tongued shoes should be worn to prevent occasional burns of the feet from the falling particles of hot metal.

The subject of eye and skin protection from the welding arc is an important factor in the arc welding process. Workmen unfamiliar with arc welding often hesitate to become operators because they know of some one who unfortunately has had his eyes severely burned by not having exercised the proper precautions, which may or may not have been his own fault. Such cases as these are often difficult to eliminate from the minds of prospective operators. They can only be eliminated by impressing upon the mind of the beginner that it is absolutely necessary to use safety devices such as herein described; if these are used properly ample protection will be provided for the eyes and body from the harmful effects of a welding arc.

Booths and Portable Screens.—The light rays which shoot out in every direction from a welding arc give an illuminating effect similar to that produced by lightning so that when two or more operators are working close together, or when other work-

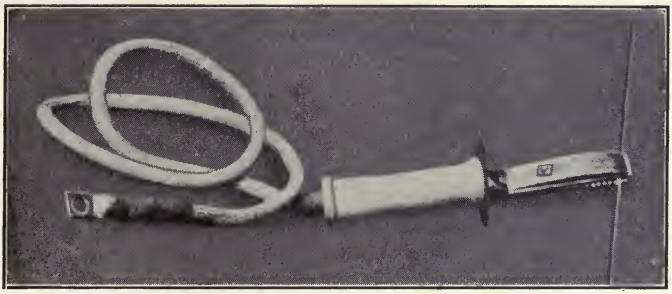


Fig. 24—A Metallic Electrode Arc Welding Holder

men are working nearby, each operator must be totally or partially surrounded with screens in order that this light will not interfere with other work; also to prevent those who are unfamiliar with the process and its effects from looking at the arc.

The stations or booths for miscellaneous work consist of a table having a metal top surrounded with curtains such as shown in Fig. 22. For the class of work that cannot be brought into the booth, portable screens such as shown in Fig. 23 are required. All screens should be painted black in order that they will not reflect the light rays from the welding arc. When arc welding is a new feature in a shop, the protective apparatus just described will be required to a greater degree than will be the case after the shopmen become accustomed to the process, at which time shields of every description such as pieces of sheet metal, boards, etc., will be used to protect workmen in the near vicinity from the direct rays. Screens or shields are also advisable to shield the arc from air drafts, thus reducing the difficulty of arc manipulation and reducing the effects of the oxygen and nitrogen of the atmosphere.

Electrode Holders.—The object of an electrode holder is to hold the electrode firmly so as to permit easy manipulation by the operator and to provide a means for the flow of current from the

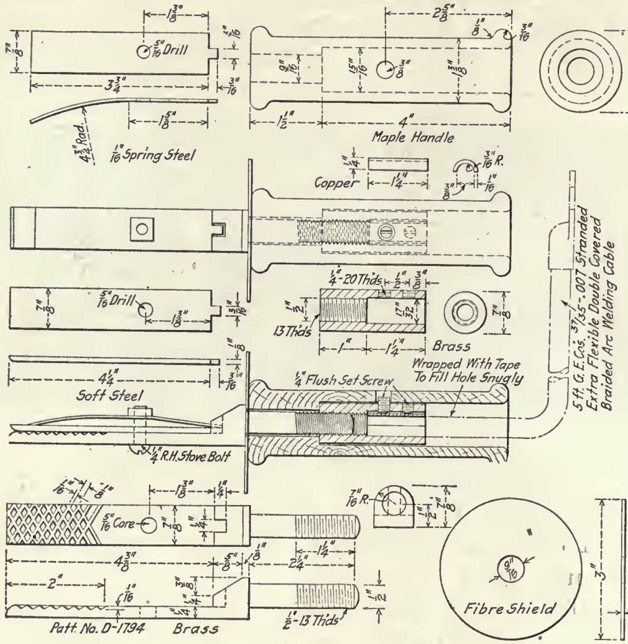


FIG. 25—Details of Metallic Electrode Arc Welding Holder Shown in Fig. 24

welder terminal to the electrode without excessive heating of the holder, which may be caused by poor contact between the electrode and the holder. Inferior work or a waste of welding wire is usually the result of overheating at the point of contact between electrode and holder in metallic arc welding. If the welding wire becomes red hot between the end being melted and the holder the metal will not flow uniformly. In order to facilitate manipulation of the welding arc the cable from the holder must be extremely flexible for approximately five feet. The remaining portion of the cable only needs to be sufficiently flexible to permit easy handling.

A holder of a well known type for metallic arc welding, which has been designed to permit frequent cleaning by the removal of one stove bolt, and which is provided with five feet of extra flexible cable is shown in Fig. 24, details of which are shown in Fig. 25. The type of holder is simple, inexpensive and light. It has been in use for some time; it gives good results and meets the approval of a large majority of the operators who use it. To apply a new electrode in this holder it is only necessary to insert

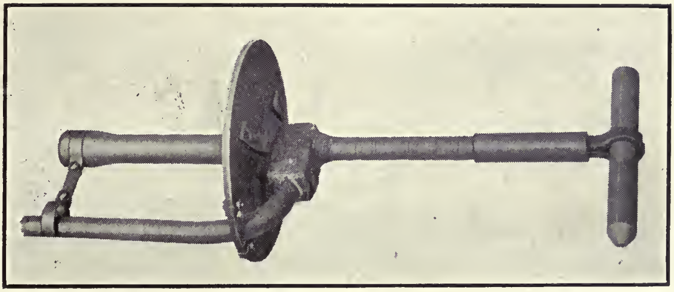


Fig. 26—An Electrode Holder for Carbon Arc Welding

one end of the new electrode between the jaws, then by prying the jaws further apart with the new electrode used as a lever, the stub will fall out and the new electrode will be held firmly in place by the pressure of the steel spring, the tension of which is adjusted by the stove bolt. Changing electrodes in this way consumes the least possible amount of time.

A type of carbon holder used in carbon arc welding is shown in Fig. 26. An operator manipulating a carbon arc is subjected to a degree of heat which is much greater than that developed from the metallic arc. Holders for the carbon arc must therefore be larger to carry the heavy current and to provide a greater distance between the operator's hand and the arc. It is also necessary to furnish additional protection to his hand by equipping the holder with a large heat deflecting disc as shown in the illustration.

Cleaning Devices.—The surfaces of the work on which welding is to be done must be perfectly clean and free from scale, rust or oxide. It is not always an easy matter to prepare the work as described, but to assist in the process of cleaning various devices are being used. For the removal of light loose scale, dirt

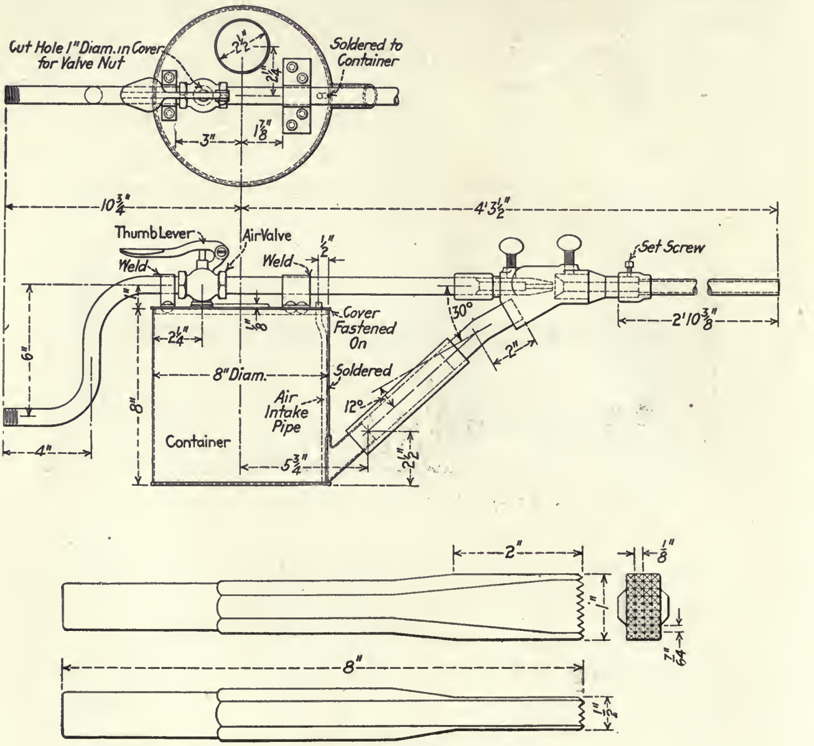


FIG. 27—Small Sand Blast and Roughing Tool

and oxides, a steel wire brush is sufficient. The heavier scale and oxides, such as mill scale, blue oxide produced by an oxy-acetylene cutting torch, etc., require a sand blast or roughing tool to remove them. A small light sand blast, as shown in Fig. 27, is preferable, as it can be taken into small openings and used in close places. A useful roughing tool for loosening scale which may be used either in connection with air or hand hammers is shown in the same illustration. The use of such a tool to loosen the scale and a wire brush to remove it provides a simple and convenient method for cleaning.

IV

ELECTRIC ARC WELDING PRINCIPLES

The current in a direct current electric circuit flows in a definite direction; namely, from the positive pole of the source through the circuit to the negative pole. When a circuit, through which a sufficient amount of current is flowing, is broken, an arc is formed. The ends at the break become heated to an incandescent vapor; it is this vapor and metal particles in liquid globular form expelled from the arc terminals that forms the path through which the current passes across the gap.

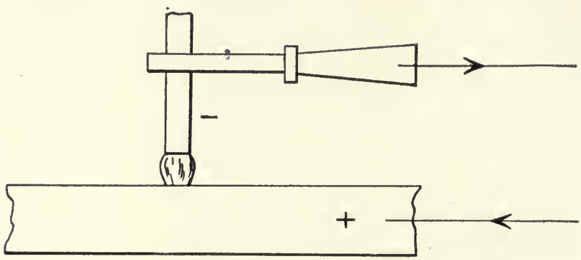


Fig. 28—Sketch Showing the Polarity of the Welding Electrode and of the work

If, for example, a carbon electrode and an iron plate, as shown in Fig. 28, are connected with the terminals of a sufficiently powerful source of electricity and the carbon is brought in contact with the plate and is gradually separated to a distance of about ¼ in.—the direction of the current being such that the electric stream leaves the plate, passes through the arc and enters the carbon rod or electrode—then the plate will be the positive and the carbon rod or electrode will be the negative. The positive electrode is generally indicated by a + (positive) sign and the negative electrode by a — (negative) sign.

In arc lamps used for producing light, the ends of the carbon electrodes are brighter than the flame between them and the carbons are of unequal brilliancy, the positive carbon being much brighter than the negative. Moreover, all parts of the end of the positive carbon are also unequally bright; most of the light comes from the crater. Since the light giving property of a heated body increases rapidly with its temperature, an inspection of the arc will show that the crater at the positive terminal is the hottest part of the arc. The positive electrode is often referred to as the anode, and the negative electrode as the cathode.

It is estimated that at least 75 per cent of the total heat of the arc is liberated at the positive arc terminal. The remaining 25 per cent is in the vapor between and at the negative arc terminal. It is generally believed that in short arcs, such as are used in the arc welding process, more heat is liberated by the negative arc terminal than by the arc vapor.

Polarity for Welding.—Owing to the fact that the greater quantity of heat is produced at the positive electrode, it is necessary to consider the matter of polarity in electric arc welding. In metal electrode welding, the mass of the piece being melted is usually less than the mass of the piece to which the metal is being added so that the amount of heat lost by conduction is greatest on the latter piece. For this reason it is made the positive electrode. In certain cases, such as the welding of very thin sheet metal, and with some special grades and types of electrodes, the wire electrode is made the positive in order to secure better welding characteristics or to increase or decrease the arc penetration.

When alternating current is used for welding, it is obvious that an equal amount of heat will be developed at both terminals of the arc. In view of the fact that an equal heat is imposed on the work piece and on the electrode being consumed in the a.c. arc—instead of 75 per cent at the work piece and 25 per cent at the electrode and in the arc flame, as in the case of the d.c. arc—it has been claimed by some that the speed of welding is greatest with the a.c. arc. This, however, is difficult to demonstrate in practice, due, no doubt, to the fact that in either case the metal cannot be added and fused to the work any faster than the rate of fusing the work piece will permit. It is well known by those familiar with d.c. welding that the rate of depositing metal is greatly decreased when the current value is insufficient to fuse the work piece, even though the current may be sufficient for the electrode. This is because the thermal capacity of the work piece is usually greater than that of the electrode. It would seem that a direct current arc has certain inherent advantages over an alternating current arc when used for general welding.

Temperature of Electric Arc.—If a vessel of water is heated so as to permit the vapor to escape into the air, the temperature of the water will not increase above that at its boiling point, namely 212 deg. Fahr. under ordinary pressure. Under these conditions, the temperature of water at its boiling point is the temperature of its volatilization. This is a general law for volatilization of all substances where the vapor is free to escape. An increase in the temperature of the source has the effect of accelerating the volatilization and increasing the rate of the formation of vapor. In the same way it is believed that the temperature of the positive electrode or crater in the arc is thus limited to the temperature of the boiling point or volatilization of the substances between which the arc is formed. The temperature of boiling carbon has been estimated at 6,300 deg. Fahr.

In the case of metallic electrode welding, where an arc is drawn between two metallic substances, we are led to believe from the foregoing that the temperature of the arc, which will vary depending upon the kind of metal used, is at least that required to volatilize the positive electrode to form metallic vapor. The maximum temperature in the usual converter is approximately 3,270 deg. Fahr., the melting point of the steel being about 2,550 deg. Fahr. The boiling point of steel at atmospheric pressure is approximately 4,440 deg. Fahr. The temperature of the electric arc may, of course, exceed this.

It has been suggested that possibly the vapor of an iron arc is superheated by combustion of some of the elements in the electrode or parent metal when exposed to the atmosphere. The maximum temperature of the metallic arc is confined to a very small spot in the positive crater, and the temperature difference between that spot and the edge of the arc flame is very great. It is this extreme concentration or localization of the heat of the electric arc that reduces the losses by conduction or radiation to an exceedingly low value. A certain amount of material vaporized is oxidized and is therefore lost. The small particles of iron oxide (sometimes called iron wool), seen floating in the air in the vicinity of a welding arc, come from the arc vapor. Deposits of this iron oxide may be found on the surfaces of, and in the vicinity of, the material being welded.

The rate of formation of oxide is governed largely by the extent to which the metal is exposed to the air. In bare electrode welding the amount of metal lost in vapor and in being thrown out of the arc in spherical form is 10 per cent to 15 per cent of the electrode material used. The extent to which the arc or the vapor column is exposed to the air will also affect the stability of the arc. The form in which the steel exists during its passage through the arc in metallic arc welding is at present the subject of much investigation. It is the general belief that the metal is in minute globules or in a stream of finely divided liquid. This conclusion is based on the theory that there must be an interruption in the metallic circuit to permit the formation of the arc.

Relation of Heat and Current in Arc Welding.—The electric arc transforms electrical energy into heat. One kw. hr. of electrical energy is equivalent to 3,413 B. t. u. Thus an arc in which the current value is 150 amperes and the voltage between electrodes is 20 volts, transforms 3 kw. of electrical energy into 10,239 B. t. u. in one hour of continuous operation. Three kw. hr. of electrical energy produces the same amount of heat as may be produced by approximately 6.6 cu. ft. of acetylene burned in 7.5 cu. ft. of oxygen. The heat is localized in a very small area in electric arc welding, and fusion or welding begins at the instant the arc is drawn so that the heat loss by conduction or radiation is exceedingly small as compared to other welding processes. Present practice requires a maximum power demand at the arc of 200 amperes at 20 volts per operator for metallic arc welding. For carbon arc welding the power demand at the arc is approximately 300 amperes at about 35 volts. If extensive cutting is to be done a current of at least 400 amperes is required. The approximate current and voltage required for the various sizes of electrodes, and for the various classes of work, appears elsewhere in this book.

Influence of Air Upon Arc Welding Process.—When an arc is formed between two carbons a dull incandescence can be observed, accompanied by a bluish lambent flame over the ends of the electrodes. This flame is similar to that which exists over the surface of a hard coal fire when the supply of air is insufficient and is due to the burning of the carbon vapor in the oxygen of the surrounding air. It is believed that in the interior of this flame little or no oxidation of carbon vapor occurs, because the vapor tends to fill this interior space and therefore displaces the air. This is analogous to the welding arc; that is, the molten metal is attacked to a certain extent by the oxygen and nitrogen present in the atmosphere surrounding the arc. Oxygen attacks almost all metals at a red heat, and some of them at a lower temperature; and under the temperature and conditions of the welding arc iron absorbs nitrogen readily.

This tendency of the metal to oxidize and nitrogenize is very harmful, and leaves the metal without ductility, so that every precaution must be taken to minimize these effects. Even in bare electrode welding much can be done to protect the metal in the weld. Among the most important things are to work always on clean metal and to maintain a short arc, for should the surface of the work be covered with dirt or scale, the arc will play around and will therefore be unduly exposed to the air. In a long arc the molten metal from the negative electrode must travel through a long heated path to reach the point at which it is to be deposited and since the effect of oxygen and nitrogen depends upon the temperature of the metal and upon the time to which it is exposed to the air, the resultant oxidation and nitrogenization of the deposited metal is far greater than if a short arc is maintained.

The tendency of the arc to extinguish is largely due to the effect of the surrounding air, for should the vapor column be increased sufficiently from the proper dimensions, the increased radiation will cause the vapor to condense and break the circuit, thereby extinguishing the arc; or, should the dimensions of the vapor column be maintained constant and the radiation be increased by a draft of air, the arc will likewise be caused to break.

On the other hand, if the arc is enveloped by molten slag much of the air will be excluded and the arc will be easily maintained.

In case of an alternating current metallic arc the effect of the air is very noticeable as the metallic vapor tends to cool or condense with each reversal of the current. To sustain an alternating current arc where a bare metallic electrode is used, a voltage of at least 110 volts is required and even then it is difficult to maintain the arc.

Arc Crater.—The terminal of the arc formed by the work piece will always appear as a crater or scalloped shaped depression. This crater is formed possibly by volatilization of the liquid metal and volcanic action due to the release of occluded gases or by the gases formed from the elements present in the electrode or parent metal.

The crater of the arc under certain conditions does not maintain its position, but shifts at irregular intervals from point to point over the surface of the positive electrode, or, in the case of welding, over the work or the part to which metal is being added. The cause of this shifting is explained as follows: As the material is consumed the crater becomes unequally worn at different parts and the arc tends to be established at the point where the distance is the least; slight impurities or irregularities either in the wire being consumed or on the surface or in the metal of the part to which metal is being added will cause a shifting of the arc, as that portion of the metal which volatilizes most readily tends to become the center of the crater. As the length of the arc increases the tendency is for the vapor to spread laterally in all directions over the surface of the part to which the metal is being added.

In carbon arc welding where the filler material is melted in the flame between the arc terminals, the arc length is of necessity greater than in the case of metallic arc welding, so that it is difficult to maintain the positive arc crater at any given location on the work piece. This shifting of the arc can be compensated for in carbon arc welding by delaying the melting of the filler rod until the area on the work piece over which the arc plays is heated to the proper state of fusion, thus permitting fusion between the added and the parent metal.

In metallic arc welding the filler rod forms one terminal of the arc and is constantly being melted, so that in order to secure fusion the parent metal must be melted simultaneously with the wire electrode. To accomplish this it is necessary to provide the proper arc current and maintain a uniform short arc not more than 1/8 in., so that on clean work the arc will maintain its position at one location for sufficient time to secure proper fusion and penetration.

Metal Transfer from Electrode to Parent Metal.—There have been a number of theories advanced and in some cases substantial evidence to support them as to the force which causes the transfer of metal from the electrode, in metallic arc welding, to the parent metal. The mystery of the phenomenon is the fact that the transfer takes place regardless of direction the metal must travel, whether downward or upward. It is an established fact that the metal in the arc is in both a liquid and gaseous form, the metal in liquid form greatly predominating. A summary of the research so far conducted on this subject appears to credit the arc metal and vapor transfer to:

(a) Expulsion of liquid metal and vapor by expansion of some gas, possibly carbon-monoxide.

(b) Condensation of vapor formed from electrode material.

(c) Transfer of liquid metal by molecular attraction, gravity, surface tension, adhesion and cohesion.

The authors of this treatise have always had a wholesome respect for the molecular theory, owing to their extensive experience with practically pure iron welding electrodes, which when properly made appear to effect the transfer of metal from electrode to plate material equally as well as materials containing gas forming elements.

AN ABSTRACT OF AN ARTICLE ON THIS SUBJECT IN THE ELECTRICAL WORLD, JUNE 26, 1920, BY O. H. ESCHHOLZ, RESEARCH ENGINEER, FOLLOWS:

"The flow of metal from a wire electrode across the arc to the surface of the fused members is distinctive of metallic electrode arc welding. The phenomena of metal transport, therefore, must be of fundamental importance in the determination of weld and circuit characteristics. As this view is receiving increasing consideration by electrode manufacturers, apparatus designers and welding engineers, the author submits a few pertinent observations with the hope of stimulating further discussion and investigation.

"The conversion of electrical to thermal energy is a well-known characteristic of the arc. The concentration of this energy at the terminal of the wire electrode causes an intermittent flow of metal across the arc stream. Careful examination of the performance of a variety of bare electrode wires indicates that metal transfer may be accomplished in part by:

"1. Vaporization and condensation of electrode material.

"2. Expulsion of vaporized and liquefied metal by the expansion of gases confined or generated in the electrode ends.

"3. Transport of liquefied metal due to the forces of molecular attraction, gravity, surface tension, adhesion, cohesion.

"While all three of these means are available for the deposition of metal, it is the author's conclusion that under good welding conditions at least 85 per cent of the deposited metal is transmitted in liquid form through the action of molecular forces.

Proportion of Electrode Vaporized Is Small

"The importance of this factor may be evaluated by determining the rate at which the filler or wire electrode metal is consumed and comparing the energy absorbed at the bare wire, negative electrode terminal with that obtained by calculating the energy necessary to vaporize an equivalent amount of metal.

"It has been found by test on welding with an 18-volt, 150-amp. arc that a mild steel electrode, 5/32-in. (3.9 mm.) in diameter, is consumed at the rate of 3.1 lb. (1.4 kg.) per hour. The distribution of arc voltage is estimated to be as follows: Anode drop, 9 volts; cathode drop, 7 volts; arc-stream drop, 2 volts.

"The energy input at the negative arc terminal is, therefore, of the order of 1,200,000 watt-seconds per pound of electrode metal. The energy required just to vaporize one pound of iron is of the order of 3,100,000 watt-seconds, assuming a boiling point of 2,450 deg. C., a latent heat of fusion of 1,120 therm-grams and a specific heat of liquid iron of 0.20. It is at once evident that under normal welding conditions only a small proportion of the electrode metal may be vaporized. Overhead welding tests in which the choice of electrodes and arc length were such as practically to eliminate metal transfer due to gas expansion or molecular attraction indicated the amount of metal deposited by condensation to be of the order of 5 per cent. A reasonable estimate of the distribution of negative arc terminal energy on welding downward appears to be as shown in the table."

	Watt-Secs.	Energy Per cent
Liquefaction (2,000 deg. C.) of 90 per cent of wire electrode	720,000	60
Vaporization (2,450 deg. C.) of 10 per cent of wire electrode	310,000	26
Radiation, conduction, convection losses	170,000	14
Approximate energy per pound of wire electrode consumed	1,200,000	100

Most of the pencil electrode metal appears to be transported and deposited in globular, liquid form upon either welding downward or overhead, when the electrode current density is of the order of 8,000 amp. per square inch. The metal transfer appears to be accomplished by:

A. Downward Welding.

(1) Long Arc. Formation and growth of a liquid globule at the electrode terminal until its weight, or the force of gravity, exceeds the sum of the forces of surface tension and cohesion which tend to retain the globule at the electrode.

(2) Short Arc. Growth of globular end until contact is made with a wetted surface (plate metal liquefied by anode energy), the forces of adhesion and surface tension at the plate surface then assisting the force of gravity in drawing the globule to the plate.

B. Overhead Welding.

(1) Long Arc. Slight deposition due only to condensation of vaporized metal or pellet impact.

(2) Short Arc. Globular growth until contact is made with liquefied plate or deposit surface, whereupon the forces of adhesion and surface tension at the plate overcome the combined

forces of gravity, cohesicn and surface tension acting to hold the globule to the electrode surface.

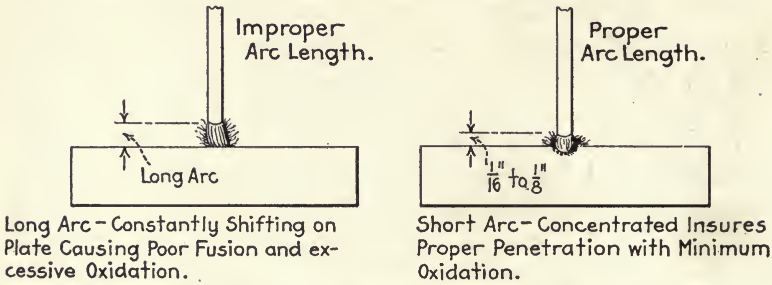
Conditions That Affect Resistance of Welding Arc.—The resistance of a metallic arc (the vapor column between the two electrodes) like that of all ordinary matter, follows Ohm's law; that is, it varies directly with the length, and inversely with the area of cross-section; consequently if the area of the vapor could be maintained as the length of the arc is increased, the resistance of the column would vary directly with its length. This, however, is seldom the case, for as the length of the arc increases the tendency is for the vapor to spread laterally in all directions, increasing its cross-sectional area; it sometimes happens that the increase in the resistance caused by the increase in the length of the arc may be more than compensated by the decrease in its resistance, due to the enlargement of the area of the cross-section.

If the current passing through an arc is maintained constant, the pressure at the terminals of the arc is always increased by increasing the distance between the electrodes. The apparent resistance of the arc is always increased by an increase in its length. All of this increase may not be exactly proportional to the length, owing to the tendency to lateral spreading. If the distance between the electrodes is maintained constant and the current through the arc is increased, then the apparent resistance of the arc may either increase or diminish. It will usually decrease.

In view of the foregoing, it is obvious that a slight increase in arc length may or may not reduce the heat, depending not only on the area of the arc, but also on the characteristics of the welding apparatus which regulates the welding current. In the case of a machine which tends to maintain a constant current flow regardless of the arc length, the power transformed into heat by the arc would be increased with an increase in the length of the arc, whereas the so-called constant watt or constant heat machine may reduce the heat in the arc, when the length of the arc is slightly increased. In either case the metal deposited with a long arc is always brittle and appears to be burnt. Furthermore, it does not unite with the work or mass being welded.

Arc Length.—The arc length will govern largely the extent to which the metal is affected by the atmosphere, the fusion or penetration, over-lap, and arc function; i. e., the smoothness with which the metal flows and the ease of directing the flow. As these are among the most important considerations for good welding the importance of the proper arc length is evident.

For example, in the metallic arc the metal is conveyed in both liquid and vapor form across the arc. With the shortest possible arc that can be maintained the added metal suffers from the effects of the oxygen and nitrogen of the atmosphere. It is, therefore, evident that if the arc length is excessive, the effect of the atmosphere will be increased in proportion to the increased



FIGS. 29 and 29-A—Comparison Between Long and Short Arcs

time the heated metal is exposed in traversing the long arc. Furthermore, it is believed that some of the air is excluded by the gas surrounding the arc formed from the elements in the electrode and plate material. If this theory is correct the arc enclosure would obviously be more complete with a short arc than with a long one, as in the latter case the air drafts would soon displace the major portion of the gas film about the arc. The penetration and overlap may be considered as proper fusion of the parent metal and this is governed by the concentration of the total heat energy liberated in the arc, since some of the heat of the liquid deposit and arc flame serves to melt the parent metal.

The heat concentration on the plate metal in a short arc is at a maximum and the heat losses in the arc stream are at a minimum, with the result that effective fusion is secured.

The heat losses from the arc stream are increased with a long arc. The arc will shift constantly on the plate metal and the total heat will not be sufficient to effect the crater necessary for proper fusion. The arc length may also be gaged by the arc voltage, which can be measured by connecting the terminals of a voltmeter to the positive and negative electrodes between which the arc is formed. The voltage for bare electrodes will range from 15 volts for small electrodes to 20 volts for the larger ones. The average arc voltage will be about 18 volts. A comparison between a long and short arc and their relative effects are illustrated by Figs. 29 and 29-A.

The arc length for carbon arc welding can be varied over a wider range, without bad effects, than in the case of the metallic arc, although it is important that the arc length be within a certain range if the best results are to be had.

In carbon arc welding if the arc length is too short the weld will most likely be hard because the carbon from the electrode will be deposited in the liquid metal in the weld where it will be absorbed. To prevent this the arc length should be such as to permit the atmosphere to diffuse through the arc flame and oxidize the carbon. It will be noted that this is the opposite to what is desired in metallic arc welding. An excessive arc length in carbon arc welding will result, however, in brittle metal in the weld the same as in the case of the metallic arc, although the range of arc length within which a soft weld can be secured with the carbon arc is so great that little difficulty should be experienced in maintaining the proper arc length.

The approximate arc lengths for different current values are given in the following table:

Arc Current in Amperes	Average Arc Length in Inches
200	½
300	¾
400	1
500	1¼

The arc length should not ordinarily vary more than ¼ in. below or above these values.

Arc Stability.—If the vapor of the arc stream condenses, the circuit will be broken and the arc will be extinguished. The tendency of the vapor to condense and the ease of maintaining an arc is governed by the stabilizing characteristics of the welding circuit and upon the nature of the arc gases. A high open circuit voltage or series reactance coil will help materially to sustain the arc. Any condition which affects the temperature of the arc vapor will affect its stability, as mentioned elsewhere. An air draft will tend to cool the arc vapor and make it difficult to maintain. On the other hand a coating on the electrode will partly exclude the air and reduce the difficulty of arc manipulation.

It is often found that the arc is erratic. This is caused by many different conditions, the more common of which are impure or non-uniform structure of welding electrodes and in some cases the plate metal, dirt and oxides on the surface of the part being welded, moisture, and magnetic influence. The latter interference

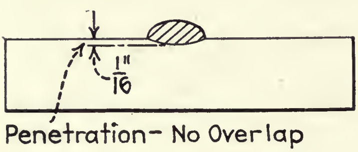


Fig. 30—Penetration

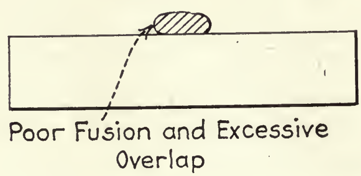


Fig. 30-A—Overlap

can be overcome by arranging the work so that the welding will progress away from the ground connection.

Arc Penetration.—The penetration is governed almost entirely by the relative melting points of the electrode and the parent metal, the arc length, arc current, and the speed of arc travel. The depth of the penetration below the surface of the plate will be indicated by the depth of the arc crater depression; this can be observed at any time by the operator. The penetration obtained when the conditions enumerated above are correct is shown in Fig. 30. The effects of these conditions upon penetration which have not already been mentioned will be discussed later.

Overlap.—An example of no overlap is shown in Fig. 30. It will be noted that the width of the union is at least equal to the width of the deposit. An example of extreme overlap is shown in Fig. 30-A; this may be due to the melting point of the electrode being lower than that of the plate, excessive arc length, insufficient current or too great speed of arc travel. In this case it will be noted that the width of the union is less than the width of the deposit. The overlap can be gaged by observation of the contour of the deposit so that no difficulty should be experienced by the operator in determining when the penetration is sufficient to prevent excessive overlap which results in unfused zones in the weld.

Arc Current for Metallic Electrodes.—The amount of current required for metallic arc welding is dependent upon so many factors that only approximate values can be given for different size electrodes. For example, the current required for proper fusion will vary with the type of weld, scarf, cleanliness of surface, heat conductivity, thermal capacity of the work piece which is determined by its shape and mass, position of work, manipulation of arc, and welding procedure.

The approximate current and electrode size used in welding of mild steel plate of different thicknesses is given below:

Electrode Diameter, Fractions of an Inch	Diameter in Mils or Thousandths of an Inch	Plate Thickness, Fractions of an inch	Current in Amperes
3/32	94	1/4 and under	50–90
1/8	125	1/8–1/2	75–150
5/32	156	3/16 and up	125–175
3/16	188	3/8 and up	140–225

There are a number of conditions which the operator can observe as a guide to indicate when the current is correct for proper fusion, such as the depth of arc crater, deposit contour, and arc function, that is, the smoothness and uniformity with which the metal is expelled from the end of the electrode. If the current is low, even with a short arc the penetration will be insufficient, the same as in the case of a long arc.

A rule, which will usually insure sufficient heat for proper fusion for bare electrodes, is to use as much heat as each size electrode will carry without overheating until the standard 14-in. length has been consumed. If this current or heat does not suit the work at hand a larger or smaller size electrode should be used as the case requires.

Arc Current for Carbon Electrode Welding.—The current that can be used for carbon arc welding, like that for the metallic arc, varies with the thermal capacity of the part to be welded.

For work of a given mass the current for the carbon arc is usually greater than that employed for the metallic arc.

A tempered graphite electrode is preferable to the plain hard carbon electrode as originally used, because of its greater current carrying capacity and lower rate of consumption. Its use also decreases the difficulty of securing a soft weld.

The relation of current to electrode diameter in carbon arc welding is comparable to the relation of gas consumption to tip size in oxy-acetylene welding, i.e., a given size electrode and current value can be used on work varying considerably in thermal capacity. To obtain economy in time and heat energy, however, an electrode and current best suited for the work should be used.

The size electrode for different current values in most common use are given below for graphite rods:

Current in Amperes	Diameter Inches
100	3/16
200	3/8
300	5/8
400	3/4
500	7/8
600	1

To reduce the difficulty of arc control all electrodes should be pointed or tapered to 1/8 in. at the arc end. The filler metal should be American ingot iron or extra soft steel. The usual oxy-acetylene welding rods and sizes—1/8 in. to 1/2 in., depending on current used, are satisfactory.

V

TRAINING OPERATORS FOR ARC WELDING

Before electric arc welding of any kind can be done by a beginner there are a number of fundamental principles concerning the art which must be learned and also a certain knack of arc manipulation which must be acquired. The fundamental principles can be obtained through study, or from a competent instructor, but the knack of arc manipulation can be acquired only by practice.

Classification of Electric Arc Welding Operators.—Electric arc welding has developed many classes of operators and the question has been asked, "Who is a skilled operator?" In our experience we have found that operators are divided into two general classes. These are, universal operators and specialized operators. The first class stands by itself as its name indicates. It is not subdivided as is the case of the second class. Universal operators include those who are able to apply electric arc welding to all classes of work and kinds of materials to which the process is adapted. Their skill has been gained through broad mechanical experience and diligent study of mechanical principles, together with extended study and experience in arc welding. Those men who have become universal operators are high-class artisans and will be much in demand in many industries.

The specialized operators may be subdivided into several classes. Some are highly skilled while others do not require as high a degree of skill because of the class of work they perform. At the present time specialized operators may be classified as follows: First, pressure vessel welding—(a), high pressure—(b), low pressure; second, machinery welding, much of which is alloy steel requiring some knowledge as to the influence of heat on steel of various compositions; third, structural welding; fourth, repeat operations, which requires the least experience.

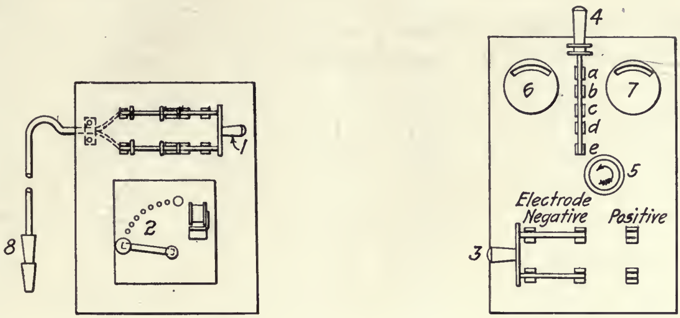
From the foregoing it is apparent that the degree of skill required in the different classes, one from the other, varies considerably; for instance, an operator whose training has been limited to repeat operations would not be competent to do pressure vessel welding, which not only requires first-class work but also a knowledge of the particular service the vessel is to perform including a knowledge of the effect of expansion and contraction.

The selection of men who are to become electric welding operators must be given careful consideration. In many cases operators work under foremen who know little or nothing of the art and who are therefore unable to judge whether or not a weld is being made in the proper manner.

The quality of a weld can be predicted only through observation by one who is familiar with the process, and preferably as the weld progresses. In view of this fact it is obvious that unless the operator is of the conscientious type and a firm believer in quality work, the degree of success will be very uncertain. The material upon which an operator works is always in plain view. If his training has been ample (as it should be before he undertakes to make important welds) and if ordinary judgment is exercised, there should be little excuse for the failure of the weld. Conscientiousness on the part of the operator is one of the most important qualifications necessary for successful welding. Next in importance is mechanical ability. It has been our experience that men who have had mechanical training, and especially those who are willing to disregard any delusion concerning the process, make the most competent operators.

Starting the Student Welder.—Assuming that the proper equipment, accessories and electrode material have been provided, the first step in instructing the beginner will be to teach him to become familiar with the starting of the equipment, and the making of adjustments in order to obtain the proper heat for different sizes and kinds of electrodes for work of various composition and mass. For this purpose brief instructions attached to the control panel of the equipment will serve best, especially when different operators use the same equipment. Instructions of the character mentioned are shown in Fig. 31 for an individual type of equipment.

The next step will be to teach the beginner to make electrical



MOTOR PANEL GENERATOR PANEL

To Start Motor:—Switch *No. 3* on generator panel must be open. Close switch *No. 1* on motor panel. Advance slowly handle of starting box *No. 2* until lever is held in place by automatic release magnet. Motor will start slowly, speeding up as handle is advanced. In case of portable welder, insert power plug *No. 8* having switch *No. 1* open before starting motor.

To Operate Generator:—Close double throw switch *No. 3* on generator panel to negative or positive side depending on character of work. Always use electrode negative except when welding very thin plates.

Heat Adjustment:—For 3/32-in. or smaller electrodes close switch *No. 4* and adjust voltage by rheostat *No. 5* to obtain proper heat according to the work at hand. For ⅛-in. electrodes open point *a* of switch *No. 4* which will provide the approximate heat for this size of wire. If heat is not correct raise generator voltage to increase heat or lower generator voltage to decrease heat as occasion requires. For 5/32-in. electrodes disengage point *b* and for 3/16-in. electrodes disengage point *c*, proceeding for closer heat adjustments as explained above. Switch all the way out provides maximum heat obtainable.

When not welding or making adjustments on panel, open main generator switch *No. 3*. This will avoid accidental short-circuit.

To Stop Motor:—Open generator switch *No. 3;* open motor switch *No. 1;* starting lever of box *No. 2* releases automatically.

Fig. 31—Instructions for Starting and Stopping Individual Type Equipment

connections from the equipment or panel to the part on which welding is to be done. Assuming that a bare metallic electrode is to be used, and that direct current is provided for welding, the positive lead will be connected to the work and the negative to the electrode holder, as shown by Fig. 32. This scheme of connections will concentrate the greater portion of the arc's heat on that part which has the greatest mass and ability to conduct the heat away from the point where the arc is established.

To furnish protection from the glare of the arc a face shield, fitted with glass of the proper depth of color tint, as pointed out in another part of this book, should be selected. Until an operator has had sufficient experience to choose glasses suited best to his

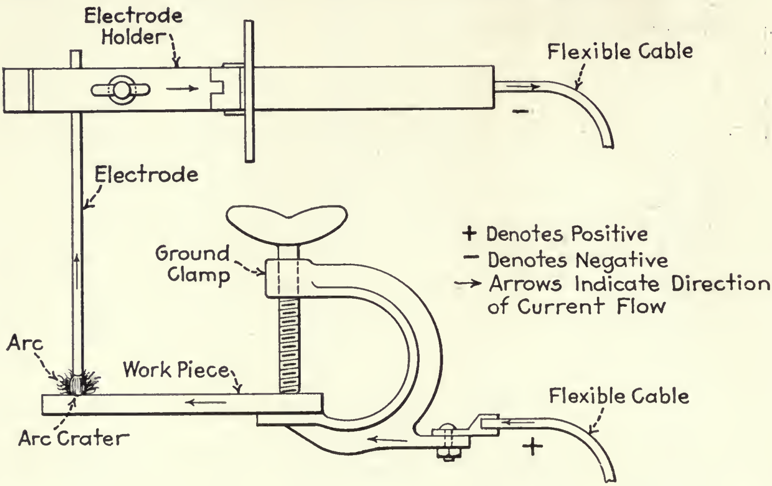


FIG. 32—Diagram for Beginner's Use Showing How Connections Should be Made

eyes, it is safe to begin with glasses having a depth of color tint such that when the light of the sky is observed through them, two to five seconds will be required for visibility. A rule which must be observed is to always have the face shield in position before the arc is struck, as it requires only a few flashes to produce bad effects on the eyes.

An electrode of a given size should be chosen according to the mass and nature of the work. For practice, a ⅝ in. plate, approximately 1 ft. square, will be found convenient and a 5/32 in. diameter electrode 14 in. or 16 in. long will be the most appropriate size to use for work of this dimension. The holder should clamp the electrode midway between the two ends, especially for a beginner, as the shorter distance from the work to the holder will require less effort to hold a steady arc.

The electrode holder should be held in one hand only and to avoid nervousness the hand should not grip the holder. If the handle is held tight the hand will shake and increase the difficulty of arc control. The problem is to acquire absolute control of the arm and hand manipulating the arc and this is best done by steadying the body either by taking a sitting position, or if conditions require welding in a standing position the knee, hip, or shoulder may be rested against something to brace and steady the body. This will leave the arm free to manipulate the arc and

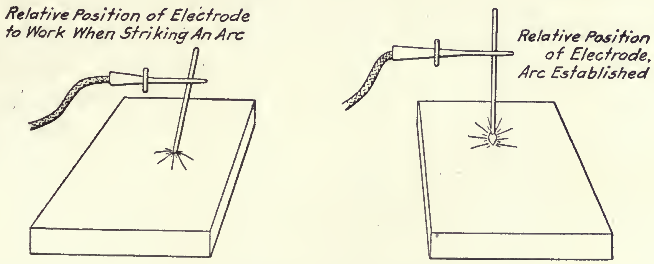


Fig. 33—Methods of Striking an Arc

avoid body movements which will be communicated to the arc and add to the difficulty of arc control. When in a sitting position, if the holder is held by the right hand the left elbow may be rested on the left knee, which will further reduce the effort required to manipulate and control the arc.

With the electrode at approximately right angles to the plate (since the arc tends to establish itself along a straight line to the work), touch the electrode on the plate with a slightly dragging touch, or by a sharp turn of the wrist describing the arc of a circle, and immediately withdraw it approximately ⅛ in. from the plate. This procedure is shown in Fig. 33.

At this stage the beginner will encounter his first difficulty, because of the freezing or sticking of the electrode or being unable to establish the arc. The first trouble is caused by too much delay in withdrawing the electrode from the plate, and the latter to separating the electrode too great a distance from the plate. By calmly touching the electrode to the plate with a slightly dragging touch, after a few trials little difficulty will be experienced.

The use of coated electrodes greatly reduces the difficulty of establishing and maintaining the arc and will greatly assist the beginner in acquiring the knack of starting the arc, as well as in its manipulation. If the hand of the student is guided by an experienced operator for the first few trials, so that he will become familiar with the feel and sound of the proper welding arc and the appearance of the deposit, the knack of arc manipulation will be more readily acquired.

If the electrode is moved at a uniform speed and at the same time is fed towards the plate at the same rate of speed at which it is consumed or deposited (maintaining approximately the 1/8 in. space between the electrode and work), the metal should flow uniformly. If the flow of metal is not uniform when the arc length is correct, the trouble is usually due to one of the following causes: Improper heat, improper polarity, poor electrode material, or dirt and oxides on the surface of the work.

The inability of the student welder to judge when the arc current is correct is usually the cause of a nonuniform flow of the metal when all other conditions are proper. If the current or heat value is too low, it will be difficult to maintain the arc. The arc crater will be very shallow, indicating poor penetration and the deposit will be light and very narrow. If the heat value is too great the electrode will melt rapidly; the arc will bite deep into the work, producing a hissing sound and the deposited metal will tend to boil and will have a porous appearance; the excessive current will also cause the electrode to become red hot or hotter at a distance of 1/2 in. or more from the end, after 4 in. to 6 in. have been consumed. When the electrode approaches a white heat the metal will no longer deposit.

The heat is correct when with the proper arc length the metal flows smoothly and produces an arc crater about 1/16 in. deep, indicating proper penetration, and when the surface of the metal shows no signs of porosity, indicating that the deposit has not been overheated. Under most conditions where a bare electrode is used with the proper heat or current value the arc will produce a mild metallic crackling sound. This is thought to be due to the rapid condensation of the vapor and current interruptions by the liquid metal of the arc stream. If the arc current is somewhat above the normal value, or if the electrode is coated, the arc vapor and liquid metal will cool more slowly and the crackling sound will be less noticeable.

A Test for Polarity.—The polarity may be tested by placing a small carbon rod in the holder in place of the metallic electrode and drawing an arc between the carbon and an iron plate. If the arc is difficult to maintain it is generally an indication that the polarity of the work is negative and the carbon positive; consequently the connections are reversed. If the arc is stable the plate is positive; in which case iron vapor forms more readily than carbon vapor, and the connections are properly made. If tests of the nature just described are made for the benefit of the beginner, and his attention is called to the characteristic features mentioned above, the polarity will soon become apparent to him. Every operator should become familiar with the test. Some operators who have had considerable experience are able to determine the polarity with a metallic electrode instead of a carbon. However, the carbon will serve best for a beginner.

Electrode material unsuitable for welding will usually be indicated by an erratic arc or by the metal melting in large globules, resulting in a nonuniform flow of metal and consequently poor penetration, as well as a brittle porous deposit.

Importance of Clean Work and Proper Arc Length.—If the surface of the work is not clean, the arc will play around and the metal will not flow uniformly. The metal of the electrode will unite uniformly on the work only when all dirt, oxide or any foreign substances have been removed. It is as impossible to have a sound weld where the surface is not clean as it is to heat and unite two pieces of pitch with the surfaces to be united covered with oil. If, however, the oil is removed or floated from between the surfaces to be jointed, a perfect homogenous union will be effected. This fact must not be lost sight of in arc welding if the best results are to be obtained. Poor electrode material is sometimes difficult to detect, as far as the operator is concerned. About the only way he has of determining when the material of the electrode is causing the nonuniform flow of metal or an unstable arc, is by knowing that all other conditions are correct.

Again referring to the proper arc length: while it is judged to be approximately 1/8 in. it is somewhat difficult to determine this, because the shape of the arc tends to obscure the view. In practice if the heat is correct the proper arc length is judged by the appearance of the deposited metal, the depth of the arc crater penetration, extent of overlap of the added metal, and whether or not the arc shifts on the work piece. Once an operator becomes familiar with the sound of the arc under given conditions, his sense of hearing will assist materially in determining the proper arc length.

Arc Current and Voltage.—The approximate current and voltage for different electrode sizes for different plate thicknesses are given in the following table:

Electrode Diameter, Fractions of an Inch	Plate Thickness, Fractions of an Inch	Current in Amperes	Voltage at Arc
3/32	1/4 and under	50–90	14–16
1/8	1/8–1/2	75–150	15–17
5/32	3/16 and up	125–175	18–22
3/16	3/8 and up	140–225	17–20

It is impossible to furnish more definite data as to the arc voltage and current with relation to the size of electrode and plate thickness, as many factors enter into this determination. For example, a 1/8 in. bare mild steel electrode used on a 3/16 in. plate would require approximately 80 amperes. If, however, the same size electrode were used, for instance, on a locomotive frame, the current which would be required to give proper fusion would approximate 140 amperes, and under ordinary conditions that amount of current would overheat the electrode by the time approximately 8 in. were consumed. The difference in the current demand is due to the difference in the thermal capacity and conductivity of the two parts. In the case just mentioned a larger electrode would be more appropriate since it would provide carrying capacity great enough for proper fusion without overheating until the ordinary electrode length had been consumed.

Angle of Electrode.—The angle at which the electrode is held with relation to the surface on which metal is added, as well as with respect to direction of arc travel, will influence the penetration and ease of directing the metal at the point desired in the weld.

It is difficult accurately to give the proper electrode angles for the various conditions. In general, the added metal seems to be more easily directed where desired, for different positions, if the electrode is slightly inclined, approximately 20 deg. from a line drawn at right angles from the face of the weld. The electrode angle with respect to the direction of arc travel will vary with the position of the work and other conditions. For flat welding, the electrode angle would be as shown by Fig. 38. For other positions, such as vertical seam welding, the electrode angle may be inclined in an opposite direction to the direction of arc travel. This will direct the arc to the point where the metal is to be added and minimize the change for poor fusion at the base of the deposit. The penetration or fusion of the parent metal may be varied to some extent by varying the angle of the electrode. This fact can be taken advantage of at times to reduce the tendency of the arc to burn through thin edges or to prevent metal from sagging when welding in positions other than flat. Care should be used in this practice, however, for if the electrode is inclined too much, the penetration will be insufficient.

Practice Exercises.—In order that a beginner may become familiar with holding the proper arc, good practice exercises are suggested, as follows:

First, with the heat at the proper value, deposit a number of layers on a plate in a horizontal position (Fig. 34) until it is possible to deposit a layer approximately 8 in. long without interruption, which will be smooth and uniform in width and depth. This should be repeated a sufficient number of times to check the ability of the operator to maintain a uniform arc.

Second, mark a number of lines on the plate with a piece of chalk, some straight and some crooked; now repeat the first exercise along the chalk marks (Fig. 35). This test will demonstrate one's ability to hold a uniform arc and at the same time follow a certain course.

Third, deposit a pad approximately 1 in. wide in the manner

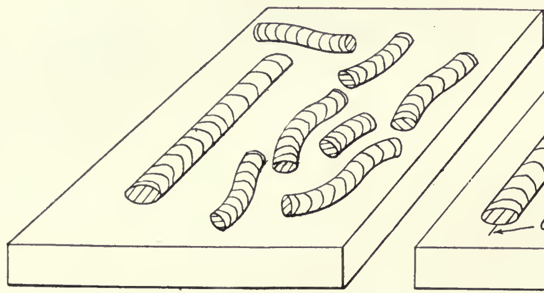


Fig. 34

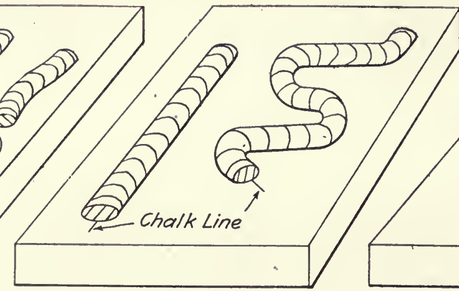


Fig. 35

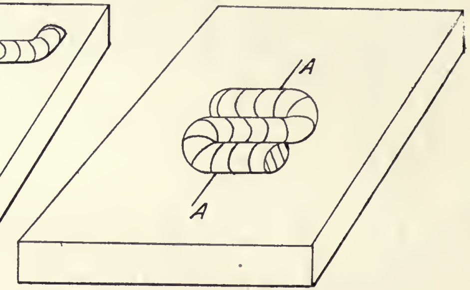


Fig. 36

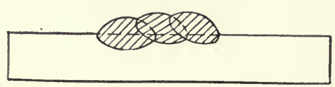


Fig. 37—Section A-A Through Fig. 36 Showing How One Layer Should Overlap the Other

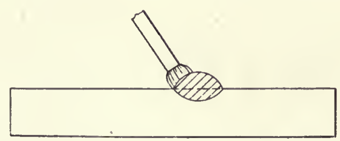


Fig. 38—Angle Electrode Should Be Such as to Give Proper Fusion Between Layers

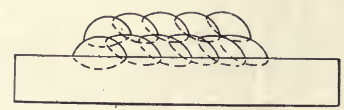


Fig. 39

Figs. 34 to 39—Practice Exercises for Training Operators to Hold an Arc and Follow a Given Course shown in Figs. 36 and 37. At the end of a bead, or layer, where the arc is broken, a bad crater will tend to form, but in order to minimize this condition, it is advisable, when it is desired to break the arc, to shorten the length of the arc as much as possible and then break it quickly by pulling the electrode to one side.

The exercises above outlined should be practiced not less than two days before work of any kind is undertaken.

Building-Up Exercise.—There is a vast amount of building-up work done by means of the electric arc, using either the carbon or the metallic electrodes. Materials of almost every description are reclaimed by this method, and in many cases parts that have been built-up must afterwards be machined. When this is necessary the metallic electrode is generally employed, but the carbon electrode may be used, in which case, however, considerably more skill is required to produce a soft weld. The weld must also be sound. It must be free from slag inclusions, air pockets, etc., in order to give a smooth finish. When the metallic electrode is used the weld will be soft if the proper heat is provided as outlined above with a short arc and the work is kept clean.

A practice exercise, which will serve to train an operator for this class of work is as follows: Deposit pads of metal such as illustrated in Figs. 36, 37 and 38; these show the course the electrode should follow. Additional layers must overlap the preceding ones, as shown by Fig. 37. When a pad approximately 6 in. long has been deposited, clean the surface perfectly with a chisel or roughing tool to loosen the scale, and a wire brush to remove it, or by the use of a sand blast; then proceed to deposit a second pad, following closely the course of the first. At least three layers should be applied in this manner. The finished weld should then be cut diagonally, and the ends ground and polished. By this means the soundness or appearance of the added metal may be observed. The necessity of cleanliness will be appreciated by repeating the above exercise without cleaning between layers and comparing the cross-sections.

The same exercises as outlined with the work in a horizontal position should now be practiced with the plate in a vertical position until vertical welding is no more difficult for the student than down-hand or flat welding. When the practice exercises, as heretofore outlined, have been perfected to a fair degree, the student should be allowed to do unimportant commercial welding for two weeks or more before attempting overhead welding, which is exceedingly difficult, at least until the operator has mastered the art of arc manipulation and is able to judge when the heat value is proper by the behavior of the arc and the appearance of the metal. These things he can learn only by experience.

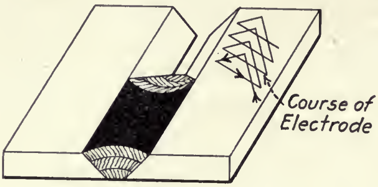


FIG.40.
Flat or Down Position Seams.

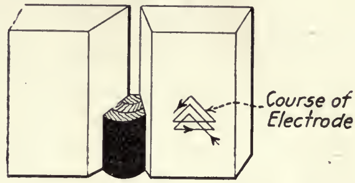


FIG.41.
Vertical Seams.

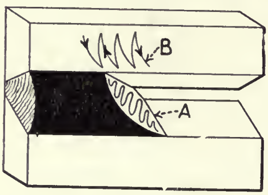


FIG.42.
Horizontal Seams.
A-Shows course of Electrode for finishing with one layer.
B-With more than one layer.

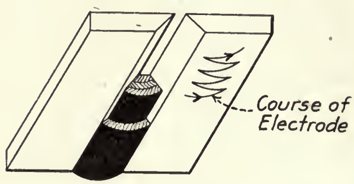


FIG.43.
Overhead Seams.

FIGS. 40 to 43—Adding Metal to Joints, Showing Course of Electrode and Method of Building up Metal

Practice exercises similar to those outlined for the other positions will suffice for overhead welding.

Course of Electrode.—When parts are joined by welding, the joint is usually arranged to form a V-shaped opening into which metal is fused to effect the union. The V may be formed by beveling the edges that form the joint or seam; or, the position of one part with respect to the other may be such as to form a V without beveling. The manner in which the metal is fused in an opening so formed, will determine to some extent, the strength and quality of the weld.

Experience has shown that a stronger joint is obtained when the course of the electrode is back and forth across the V to be filled in, or when the deposit is parallel with the line of stress. The course of the electrode, to allow this procedure for joints or seams in the different positions, is shown by Figs. 40 to 43.

Procedure.—When depositing the first layer between abutting plate edges or member ends, care must be exercised to secure fusion completely through to the bottom of the V; when possible an inspection should be made to see that the first deposit projects through slightly on the reverse side.

Additional layers should be fused to the preceding layers and the scarfed edges. The weld for plates and shapes should be finished with a slight welt 1/16 in. to ⅛ in. above the plate surface. Heavy members should be given a greater reinforcement, depending on the service requirements of the part.

Where plate edges are welded from one side only (when conditions permit) a more efficient weld can be made if the metal projecting through on the reverse side is chipped away and a light layer applied, finishing the weld with a slight welt on both sides of the joint.

Vertical seam welds are started as shown by Fig. 41. When the opening at the bottom of the V is bridged by a slight deposit, a shoulder is formed which provides an almost horizontal surface, upon which additional metal is deposited without great difficulty. To facilitate access for fusion along the beveled edges, the deposit at the bottom of the V should be kept in advance of the back or outer edge of the fused-in metal, to form a declining surface.

Horizontal seam welds are started by fusing together the edges at the bottom of the V with a slight deposit. The fused-in metal on the bottom beveled edge is then kept in advance of that of the top beveled edge, as shown by Fig. 42. Overhead seam welds are made by starting at the apex of the V and forming a shoulder with an initial deposit extending down between the beveled edges. A vertical surface is thus formed and additional metal is then added between it and the beveled edges of the plates—the groove usually present on the top side, due to sagging of the metal between the edges of the plate, is a common weakness of overhead welds. Operators who have had considerable experience on overhead welding can eliminate this by slightly projecting the end of the electrode through the opening between the thin edges when making the initial layer. It may also be prevented by placing thin strips on the top or reverse side from where the welding is done. These may be cut in short lengths 6 in. to 10 in. long. By sticking an electrode to them to serve as a handle, they can then be passed through the opening edgewise and placed and held in position. If conditions permit, when the weld is completed the strips should be chipped off.

Effect of Layer Sequence on Weld Strength.—For some time it has been known that the strength of a weld is greatest when the stress is applied parallel with the direction of the deposit. It is for this reason that joints are most always formed by tiers of parallel layers across the V-shaped opening, rather than parallel with the joint; or when building up a shaft the layers are usually made parallel with the shaft.

Recently tests have been conducted more accurately to determine the strength of the metal according to the direction of the stress with respect to the direction of the deposit. The following is taken from an article in the February 15 issue of Power, by O. H. Eschholz, research engineer, Westinghouse Electric & Manufacturing Co.:

The process of metallic electrode arc welding requires fusion between the members of a joint and an intermediate casting. It is evident that the weld properties are determined by the characteristics of (1) the original or parent metal, (2) the metal adjacent to zone of fusion, altered by thermal cycle, and (3) the arc-deposited metal. Metal deposition is accomplished by transferring small liquid globules from a wire electrode to a crater formed by the arc in the parent metal. By controlling the direction of the arc travel, a sequence of such globules may be fused in layer form to the surface of the scarfed joint or previously deposited metal. In order to build up a surface or completely fill a section, tiers of such parallel layers may be deposited in some predetermined sequence.

It is evident that the completed deposit consists of an aggregate of fused globules. For every pound of metal cast when using a bare, low-carbon steel electrode, 5/32 in. in diameter and 150-

ampere arc current, it is estimated that roughly 30,000 globules are transferred. These attain a temperature of about 2,000 deg. C. at the wire electrode arc terminal, then pass across the arc stream, subject to more or less attack by enveloping gases, to be deposited finally on a surface previously liquefied by the energy developed at the positive arc crater. Owing to the relatively high thermal capacity of the joint members the deposited metal is cooled at a very rapid rate, analogous to that of quenching. The effect of superposing deposits is to partly anneal preceding quenched deposits. It is evident that metal so formed may possess properties differing from those of steel cast in large masses, subjected to mechanical working, and then a prescribed heat treatment. It is also conceivable that changes in arc-metal properties may be achieved by modifying arc and electrode manipulation, electrode constituents, arc gases and circuit characteristics. The evaluation of these factors may be expedited by confining test observations to the properties of the deposited metal, thereby eliminating the many variables introduced by the characteristics of the shank metal, type of joint and the character of fusion that exists between the deposited and the original plate metals being welded.

The preferred method for building up a surface or filling in a joint is to deposit the arc metal in layers and tiers. The *fusion patterns* obtained between adjacent layers are clearly shown in Fig. 43-A.

It will be noted that if load is applied in the direction of *A.*, Fig. 43-A, or in line with the direction of deposition, the fused zones are stressed in parallel. However, if load is applied in the direction *B,* or transverse to the direction of deposition, the zones of adjacent layer fusion are stressed in series. If the load is applied along *C,* or axially, the zones of fusion of superposed layers are stressed in series. To determine the relation between stress and direction, metal was deposited on a plate ½-in. thick, using a 5/32-in. mild-steel electrode, 175 amperes short arc length, and the surface of each layer was cleaned before forming the next layer. After normalizing each sample, by holding at 1,650 deg. F. for 15 min. and cooling in air, the base plate was removed and the following test pieces cut: (1) Standard A. S. T. M. 2-in. gage length, 0.505-in. diameter tensile-test specimen; (2) 2½ in. long, 0.798-in. diameter compression column; (3) ¼ in. x ½ x 9-in. bending, transverse and cantilever test specimens; (4) one centimeter square notched Izod Impact test specimen.

In Table I are given the properties of arc-deposited metal with reference to the direction of deposition. An inspection of this table shows that the best results are obtained when depositing the metal in the direction of stress. The greatest variation in prop-

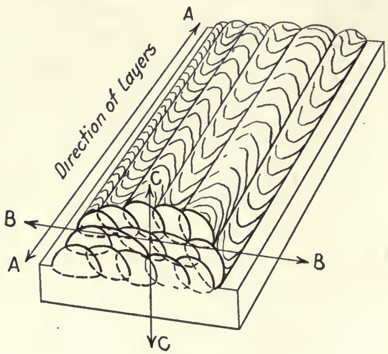


FIG. 43-A

A-A—In line with direction of deposit, fused zones, stressed in parallel, giving maximum strength.
B-B—Transverse to direction of deposit; the zones of adjacent layers fused are stressed in series.
C-C—Direction of stress axially. Here the number of fused zones of super-imposed layers are stressed in series.

erties is secured when subjecting the material of the various specimens to a tension stress. When the direction of stress is parallel to the direction of deposition, the number of fused zones stressed in series is a minimum, while when the direction of stress is axially, as in *C*, the number of fused zones in series, as well as slag pockets, is a maximum. It is interesting to note that the results for sample *B*, which represents the condition existing in most welding, is intermediate between *A* and *C*. These data suggest that the metal deposited should be formed in a direction so that the greatest stress will be parallel to the direction of deposition. When this is not possible, the number of layers in series, case *B*, may be reduced by widening the deposit. Since these observations represent the limitations of the operator as well as

TABLE I. PROPERTIES OF ARC-DEPOSITED METAL.

Metal Constituents:	C.	Mn	S	P	Fe
Analysis of wire electrode, per cent	0.16	0.56	0.024	0.032	99.2
Analysis of deposited metal, per cent	0.05	0.19	0.013	0.024	99.7

Tensile:

Deposit Fig. 43-A	Pounds per Square Inch U.T.S.	Pounds per Square Inch Yield Point	Pounds per Square Inch Elastic Limit	Per Cent Elongation in 2 In.	Per Cent Red. of Area
A	56,100	33,400	27,500	18.1	30.8
	56,075	35,875	29,000	16.0	23.4
	58,225	.....	.....	18.0	27.8
B	51,375	29,050	24,000	14.1	18.8
C	40,875	29,400	24,250	4.4	15.9
	43,500	28,900	20,000	4.9	7.0

Compression:	Load at 10 Per Cent Compression Lb. per Sq. In.	Elastic Limit Lb. per Sq. In.
A	63,250	32,000
B	60,750	30,700
C	60,700	30,400

Cantilever:	Ultimate Stress Lb. per Sq. In., 6-In. Arm.
A	64,600
B	63,400
C	61,000

Transverse:	Elastic Limit, Lb. per Sq. In. (6 In. between Supports)
A	27,850
B	28,000
C	28,500

Shear:	Stress at Shear, Lb. per Sq. In.
A	39,200
B	41,450
C	38,500

Impact, Izod:	Foot-Lb. to Fracture Standard Notched Specimen Test No. 1	Test No. 2	Test No. 3
A	1.5	1.5	1.5
B	1.5	1.0	1.5
C	1.0	1.5	1.5

Bending:	Distance in Inches Between Inner Edges of U at Fracture, at Points 1 in. from Weld.
A	0.625
B	1.00
C	1.25

Hardness: Brinell, No. 114.

those of the process, improvement in either will tend to better the properties of metal formed in sample *B* and *C*.

In the building up of heavy sections it is usual practice to deposit alternate tiers at right angles. It is evident that this method should give results intermediate between those obtained with *A* and *B*. The characteristics of a 14-lb. deposit built up in such a manner are given in Table II.

TABLE II. PROPERTIES OF ARC-DEPOSITED METAL WHEN LAYERS OR SUPERPOSED TIERS ARE DEPOSITED AT RIGHT ANGLES.

Pounds per Square Inch			Per Cent	Per Cent
U.T.S.	Yield Point	Elastic Limit	Elongation in 2 In.	Reduction of Area
58,825	41,000	34,500	9.2	19.9
54,650	35,000	29,000	6.5	13.4

Compression: Elastic Limit, lb. per sq. in., 29,450 and 34,500.
Hardness, Brinell, No. 114.
Shear: 46,200 and 44,600 lb. per sq. in.
Bending: 100 deg. on 1 in. radius, bar ½ in. thick.
Impact Izod: Unannealed specimens 2.2 and 1 foot pounds.

While experience has shown that layer deposition partly anneals the weld, facilitates slag flotation and reduces slag pockets, there are still many operators who completely fill the section between joint surfaces as they progress along the seam without regard to the form of the deposit. This procedure may be termed bulk deposition. The test results from a number of deposits formed in this manner are given in Table III.

TABLE III. TENSILE PROPERTIES OF ARC METAL FORMED BY BULK DEPOSITION.

Pounds per Square Inch			Per Cent	Per Cent
U.T.S.	Yield Point	Elastic Limit	Elongation in 2 In.	Reduction of Area
35,375	22,500	19,000	3.6	10.8
31,875	22,000	20,000	3.2	9.3
Ratio of average results obtained from bulk deposition to Average Results, A and B, Table I and Table II, from layer deposition, per cent:				
60	64	65	24	45

This comparison shows clearly that a marked reduction in strength and ductility occurs when the arc metal is deposited in bulk rather than in layer form. It is evident that difference in procedure in the deposition of arc metal may easily account for the differences in results obtained in both commercial and experimental welding.

Characteristics of Electrode Materials.—Until recently iron or mild steel were about the only grades of welding material commercially used for metallic arc welding. With the growth of the welding industry, however, the demand for welding materials of various compositions of both ferrous and non-ferrous metals has after considerable research and development resulted in a number of different materials being placed on the market until at present there are available ingot iron, mild steel, medium carbon steel, high carbon steel, high manganese steel, vanadium and nickel steels. Some of these materials have been used extensively, while others have been used only to a very limited extent, especially the alloy steels, due largely to the fact that many of the alloy steels require subsequent heat treatment to secure the maximum advantage.

The globular formation at the electrode terminal is a feature common to all such materials when used for metallic arc welding, although conditions required for their use, the character of the globule metal, size and rate of formation vary greatly with the wire analysis, diameter, polarity, covering, current density, arc length, heat treatment, mechanical structure, character of parent metal, etc.

Quantitative information relating to the characteristics of all the materials above mentioned is not available. Sufficient research has not as yet been made to develop definite working data. Reference will be made only to the characteristics so far observed, and the conditions under which these materials have been used.

Iron or Very Low Carbon Content Wire.—This material naturally has a high melting point, and is very susceptible to fluxing agents; i. e., the metal becomes very fluid if any form of fluxing agent is introduced, as for example, silica. This can be noticed when welding on wrought iron where the slag in the wrought iron exercises a fluxing action on the arc-fused metal. Another characteristic of commercially pure iron, which it possesses through a critical range, is that the metal assumes a pasty form in the neighborhood of 950 deg. C. This condition facilitates the penetration of atmospheric gases. This can be noticed by heating the end of an electrode by holding a long arc, when the globule will expand. On examination, the globule will be found hollow. This is thought to be due to the formation and expansion of carbon-oxide gas within the globule, which action is intensified by the penetration of the atmospheric gases.

Mild Steel.—The characteristics of bare mild steel and bare iron electrode materials are so closely related that it is difficult to distinguish between them. The typical hollow globular formation formed by holding a long arc with an iron wire also occurs with mild steel, although to a lesser degree. This is thought to be due to the liberation of carbon-oxide gas, which tends to exclude atmospheric gases. Neither does the metal become so fluid when subjected to the action of a fluxing agent, this being due to the opposition offered by the carbon present in the mild steel to the action of a fluxing agent. The gas formed within the electrode on heating carbon-bearing steel seems to form a blast which assists the globular transfer and facilitates vertical or overhead welding.

The hollow globular formation referred to above exists only with long arc welding; welds made with either iron or mild steel using a short normal arc length are known to be free from perceptible gas pockets.

Medium Carbon Steel.—When welding with medium carbon steel of about 0.35 carbon, both coated and bare, the formation of carbon-oxide gas, and the blast produced by the expansion of gas within the electrode, becomes more pronounced; also the lower melting point of the material, which decreases with an increase of carbon content, becomes noticeable. This necessitates the use of a higher electrode current density to secure adequate penetration. With this material a slightly high arc potential is observed and is thought to be due to a larger globular formation which necessitates a slight increase of the normal arc length. When used bare the surface tension of the deposit, where the chilling action is very great, often develops checks. This trouble is greatly minimized where the wire is coated and is no doubt due to the prolonged cooling affected by the coating, which reduces the surface tension of the deposit. The loss of carbon in passing the metal through the arc is greatly reduced where the wire is coated and the welding characteristics are greatly improved.

High Carbon Steel.—This grade of material is often used for building up track parts or other parts requiring high resistance to abrasive wear. The distinctive features of a carbon steel wire of about 1.0 per cent carbon when used for welding is the absence of the typical hollow globule even when a long arc is held. The envelope of carbon-oxide gas around the arc formed from the large amount of carbon burned is thought to exclude the atmosphere and prevent the penetration of atmospheric gases. The globule is, therefore, free from oxidation and, unlike those formed from iron or mild steel with a long arc, is found to be solid.

In welding with high carbon steel electrode material it has been found that the penetration and arc function is improved if the polarity is reversed, i. e., electrode positive, which is opposite to that used for ordinary iron or mild steel material. When used bare two-thirds to one-half of the carbon content is burned out. This loss, as in the case of the medium carbon steel, is greatly reduced if the wire is coated so that to obtain a given carbon content in the weld; the carbon content of the wire can be considerably less when the wire is coated than would be required if the wire were bare. With this material, as previously stated, the coating improves the welding characteristics and minimizes the locked-in strain and surface tension of the deposit.

Nickel and Vanadium Steels.—The use of these materials for arc welding is in such a state of development that the reliable data available are not thought to be sufficient to warrant comment at this time.

High Manganese Steel.—Steel containing from 12 per cent to 14 per cent manganese when used for welding requires very special processing before using and a special method of application. Unless protected from atmospheric gases and cooled quickly the deposit will be very brittle and practically worthless. This is due to two principal conditions:

1. If the loss of manganese in passing through the arc is such as to reduce the manganese content of the deposit to within the neighborhood of 7 per cent. (Manganese between 1½ per cent and 5½ per cent in steel causes brittleness.)

2. If the metal is cooled slowly the deposit will be very porous and brittle. This is because manganese steel is opposite in this respect to carbon steel; i. e., quick cooling makes the metal ductile while slow cooling makes it very hard and brittle. The bad effect caused by the atmosphere is eliminated by the use of a special coating which serves to confine the arc gases and limit the penetration of atmospheric gas.

The bad effects caused from slow cooling are eliminated by quenching the deposit at the proper time to prevent the brittle structure formation. This feature is greatly facilitated by the use of the arc process since the welding can be interrupted at any time and the deposit quenched without greatly interfering with the welding progress.

With manganese steel, as with the high carbon steel, the welding is facilitated by the use of a reverse polarity; i. e., electrode positive.

Non-Ferrous Metals.—The use of non-ferrous electrode materials has been rather limited. Bronze low in zinc—not over 3 per cent—and pure nickel, and nickel alloy materials are among those which have been used commercially. Generally such materials are used with a reverse polarity. Few or no data have been published regarding the characteristics when used for welding.

Fusion.—When two pieces of metal are melted into one mass they are said to be fused together. Welding, therefore, is one continuous operation of fusing one piece of metal to another. A good weld is one where this fusion is complete. If the metal being added or the surface receiving the metal is not thoroughly melted, or if slag or gas pockets are trapped, the fusion will be interrupted and the weld will not be sound because of the lack of thorough fusion. The factors which determine fusion in arc welding are arc current density, arc length, and arc manipulation.

The arc current density is determined by the thermal capacity, composition and melting point of the work piece and electrode. If the work piece is massive its thermal capacity and conductivity will be high and the arc current density required will be more than in the case of a part of lesser area and section. A short arc must be maintained to secure the proper current density at the work terminal of the arc, to minimize the effects of oxygen and nitrogen of the air, and to prevent large globular formation; these are almost always accompanied by gas pockets and oxide inclusion in the weld.

The fusion is effected by the relative melting points of the work piece and the electrode. For the present, let it suffice to say that for a bare electrode with the usual polarity used, the melting point of the electrode should be greater than that of the part to be welded. The appearance of the deposited metal will be indicative of the degree of correctness of the factors enumerated above, and adjustments can be made according to conditions. The depth of the arc crater will indicate the extent of penetration and the contour will reveal whether or not the added metal has overrun the fused area on the work piece.

By the proper manipulation of the arc, the oxides unavoidably formed can be floated to the top of the weld in the form of scale, which can be loosed by a chisel and brushed away preparatory to adding another layer of metal, thus preventing the unfused pockets caused by slag inclusions.

Thermal Disturbance.—Due to the localized heat of the arc, the difference in temperature at the point of fusion and the metal immediately surrounding it is very great, resulting in a rapid flow of heat from the weld area. This in turn results in a quenching action on the hot metal adjacent to the weld, causing the formation of a hard and brittle zone. The larger the part the greater will be the thermal capacity and conductivity, resulting in a greater temperature difference within narrow limits and a more pronounced quenching effect. The degree of hardness of the zone subjected to the rapid cooling will be governed greatly by the carbon content; when the carbon content is as much as 0.3 per cent. If the part is to be machined or subjected to vibratory stresses, it should be annealed after welding. High carbon steel should be allowed to cool slowly and to do this it is usually necessary to resort to pre-heating. These conditions should not be lost sight of if disastrous results are to be avoided.

Low carbon steel plates and shapes of at least ½ in. thickness are not greatly affected by the localized heat, especially if the proper electrode current density and welding procedure, as previously outlined, are employed, because here the section is heated through and the heat conductivity is not sufficient to effect a rapid flow of heat from the weld. In addition, the low carbon content of the usual plate material is favorable in this respect.

When welding light plate material a factor which must receive consideration is the effect of overheating the plate during welding. Overheating causes a coarsening of the grain and not infrequently so weakens the metal as to cause it to break just outside the weld, giving rise to the mistaken idea that the weld is better than the part welded. This question is largely up to the operator who by regulating the different factors governing the heat can minimize the effect to a large extent.

Expansion and Contraction of Part Welded.—Metals expand more or less under the action of heat with a consequent increase in volume. On cooling they return to their original volume and dimensions. If the entire mass of a body is uniformly heated and is cooled in the same way the expansion and contraction have no bad effects. When, however, the heat is applied at one point the metal expands at this particular place and introduces internal stresses, often of great magnitude.

In welding the expansion and contraction effects are generally localized in the vicinity of the weld. In metallic arc welding difficulties of this nature are less than with other welding processes, yet the question must be given consideration. An example of such a case is that of a crack in a plate, which does not extend to the edge, such as is often encountered in locomotive fireboxes. If there is no free space when the edges are heated they will expand and exert a force at the ends of the crack which will usually further extend the crack. In such cases in beveling the edges a free space or opening should be made between the edges to allow room for the expansion. In some instances, as in the welding of a crack in cast iron, it may be necessary to pre-heat at the ends of the crack.

Contraction of Fused Metal.—The contraction of the fused metal, the major portion of which is the added metal, constitutes the greatest difficulty. Owing to the sudden uneven cooling of the deposit, stresses are trapped in the weld. These "locked in" stresses are governed largely by the welding procedure and the composition of the weld. If the weld is thoroughly annealed, practically all of the stresses will be relieved. If a welding procedure is adopted to prolong the cooling and if the metal is very ductile, the stresses will be greatly reduced.

A method that has been found to give excellent results, and which greatly minimizes the distortion, is called the back-step method (Fig. 44), the object of which is to avoid the concentration of the accumulated stresses which are set up by compelling

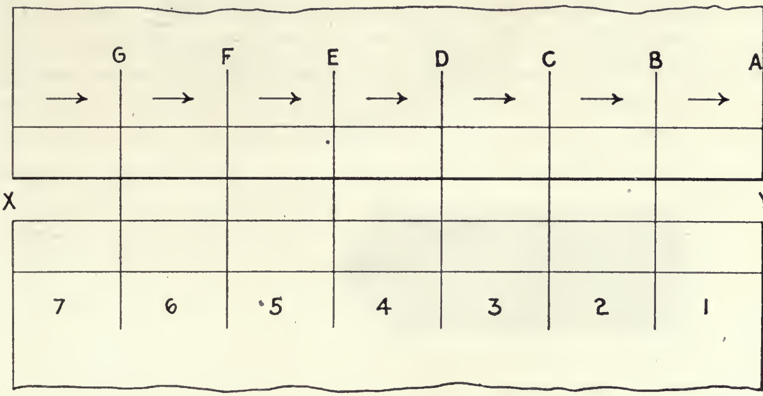


Fig. 44—Work Marked off in Sections Illustrates the Methods of Back Step Welding

a slight giving of the weld. This method of welding is performed as follows:

If the opening is slightly greater at *X* than at *Y*, the welding should progress from *Y* to *X* and each section should be welded in numerical order and in the direction as shown by arrows; i. e., the sections from 1 to 7, inclusive, be welded by starting at *B*, section 1, filling in to point *A;* returning to point *C*, section 2, filling in to point *B*, section 1; starting at point *D*, filling in to point *C;* and so on in this manner until all the sections are completed. Each section should be practically finished before starting the next. The length of each section on any seam should not exceed approximately 15 in. and for short seams should be relatively shorter. The work may be stopped at any time without fear of cracking, provided that the portion of the seam gone over is finished flush.

Methods to Overcome Bad Effects of Contraction Stresses.

—If two pieces of metal are allowed to lie loosely, free to move, they will warp and distort in their relative positions during the process of welding unless the proper procedure is followed. If they are rigid the stresses which are set up will be taken up almost entirely by a slight giving-in of the weld, providing the weld is ductile, so that when the parts are released there is no tendency for them to spring out of shape, nor is there any apparent lack of strength which can be regained by supposedly releasing the stresses with annealing. This point is reassuring in that it indicates that rigid parts may be safely welded and no serious stresses

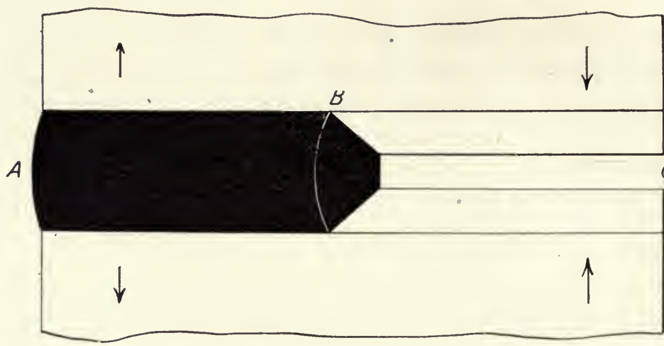


FIG. 45—Arrows Indicate Strains Produced by Cooling of the Metal in the Weld

left in the weld, provided the welding is done properly; i. e., if the weld is not brittle and a method is employed to prevent the contraction strains from accumulating and concentrating at any one point, the total of which may in some cases be sufficient to cause a fracture.

For example, if the edges of two ½ in. plates are beveled and aligned for welding, as shown by Fig. 45, and the welding is started at *A* and continued in the direction of *C*, as the hot expanded metal is added between the beveled edges it will on cooling contract and draw the edges closer together at the point *C*. This would continue as the welding progressed in the same direction, at least until the weld became cool at the point where the welding was started. If now the welding be continued from *B* to *C*, as the hot metal placed in the V contracts it will tend to further draw the edges together at *C*, which will place a strain at *A*, as indicated by the arrows.

Inspection and Examination of Welds.—A visual examination of welds will reveal more than is commonly admitted. The workmanship will be indicated by the uniformity of the deposit surface, showing ability to maintain a uniform arc; the deposit contour will indicate the extent of the overlap, if any. The appearance of the under side of the joint will show the extent of the fusion at the bottom of the scarf. The extent of the porosity and slag is as an index to the correctness of arc current, arc length, and the state of cleanliness in which the work is done, etc.

Examination of sample welds by the operators is advisable in order that they may know their aptitude and their shortcomings. A great deal can be done even without the use of special apparatus by the simple bending to the breaking point and by the corrosion test.

The bending test is made by welding together two pieces approximately 3 in. wide x 4 in. long to form a sufficient total length to facilitate bending. One end is then placed in a vise or some other form of clamp so that the line of welding is just above the edge of the vise. The piece is then bent by striking with a hammer. If the plate is welded from one side it should be bent so that the top or welt of the weld will be in the folds of the bend. When a satisfactory angle is reached the bending may be completed in a press or by other means. The angle should be observed when the weld begins to crack. Bending should then be continued until the piece breaks. This test will not only show the ductility by the angle of the bend before cracking, but the appearance of the fracture will reveal the thoroughness of fusion, extent of slag inclusions, air pockets, etc.

Another test which may be made in the shop is that of chipping and calking with a chisel to ascertain the fusion between added and parent metal, and to determine roughly the ductility, hardness and toughness of the deposit.

The soundness of a weld—i. e., whether or not the joint is steam, gas or liquid tight—may be determined by the penetration test. While there are a number of methods to determine this, the most convenient one at the present time is by the use of kerosene.

By wetting the surface of a weld on one side with kerosene any unsoundness, due to a chain of slag inclusions, air pockets, incomplete fusion or porosity, that extends completely through the section, will be detected by the penetration of the kerosene through to the opposite side.

The corrosion test is made by welding together the edges of two 3/8 in. or 1/2 in plates and cutting the plate perpendicular to the line of weld. The welded section is then polished by filing first with a rough file, then with a smooth one. The filing is followed by a series of polishings with emery papers of increasing fineness until a distinct polish is obtained. Avoid touching the surface with the fingers so that it will not become greasy. At this stage of the corrosion test one always has the impression that the weld is perfect. The defects, however, will not be revealed until the etching liquid is applied. For this purpose a solution of one part concentrated nitric acid in ten parts water may be used. If inspectors or welders apply this test occasionally, much time will be saved in perfecting the proper methods for different metals to secure the best results.

From the foregoing, it is evident that if full advantage is taken of the many resources at the disposal of those associated with welding, the uncertainties of the process will be reduced to a point to where the art will attain recognition as a means of efficient production.

VI

CARBON ARC WELDING AND CUTTING

In general, carbon arc welding is performed in a manner similar to that of the oxy-acetylene welding process. Here, as in the case of the metallic arc, the arc serves to transform electrical energy into thermal energy. The heat liberated at the positive terminal, or work side of the arc, serves to melt the parent metal, while the heat of the arc stream is utilized to melt the filler rod. The ques-

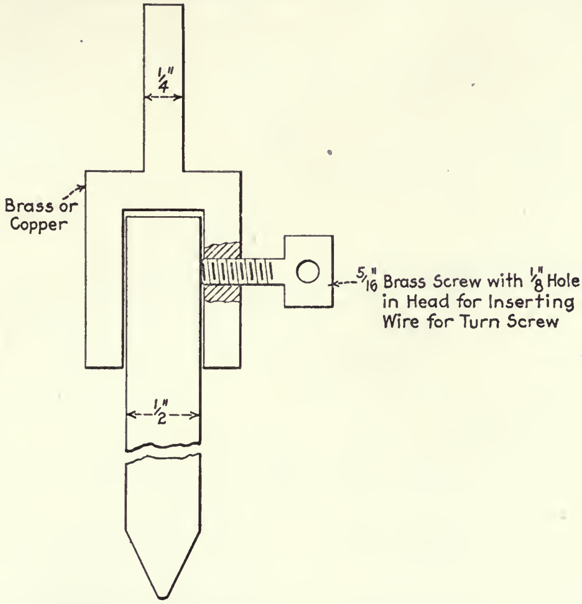


FIG. 46—Adapter Used for Low Current Values and Intermittent Welding

tion of proper arc current, arc length, electrode diameter and filler material, has previously been discussed and needs no further comment.

Equipment.—The equipment required will vary depending upon the nature of the work. The same characteristics of the welding circuit are required for the carbon arc as for the metallic arc.

For thin work the same equipment as used for metallic arc welding may be used for the carbon arc, providing the power required does not exceed the kilowatt rating of the machine. For low current values and intermittent welding an adapter, as shown by Fig. 46, may be used with the metallic electrode holder.

Where the carbon arc is used it is obviously necessary to use a helmet type of face shield and for currents greater than 200 amperes a special holder, as shown elsewhere in this book, is required to protect the operator from the intense heat of the arc and to provide ample carrying capacity for the current.

Movement and Position of Carbon with Relation to Work.—Experience has shown that the arc stream can be controlled more easily if the carbon is inclined slightly from a vertical position. The direction of travel and the melting of the filler rod is also

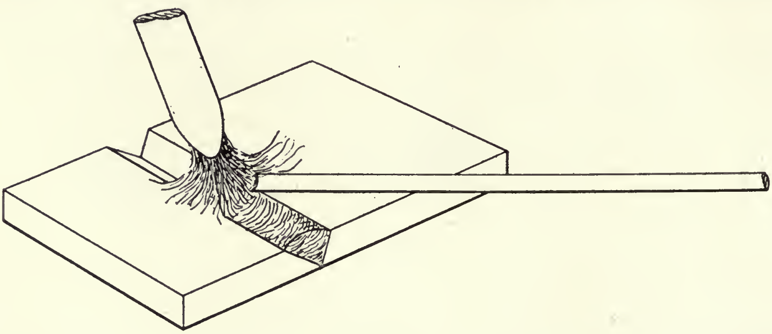


Fig. 47—Correct Position of Graphite Electrode and Filler Rod with Relation to Work

facilitated when the electrode is inclined as shown by Fig. 47.

The manipulation of the arc will vary with the nature of the work and the different operators. The function of the manipulation is to heat the parent metal to the proper state of fusion so that when the filler metal is melted into the weld the two will alloy immediately with each other. If the filler rod is melted before the parent metal is at the proper state of fusion the result will be adhesion and not a weld. It is a question then of relying upon the operator to so conduct the work as to obtain thorough fusion between the parent and the added metal.

Welding by the metallic or carbon arc is but a regular succession of "molten baths" joined one to the other so as to form a homogeneous line. There are certainly methods which must be learned, but these are relatively easy to acquire and are better obtained by practice than by reading. The most important advice which must be given to the welder concerns the simultaneous and uniform melting of the surface to which metal is to be added and of the filler rod.

The most common practice where the addition of metal is necessary is to play the arc on the part to be welded until a small spot is heated to a molten state. At this moment the filler rod is intermittently interposed into the arc stream, care being taken to melt the rod in comparatively fine drops so that the added metal will not overrun the fused spot. This operation is progressively repeated until the weld is completed.

FIG. 48

By regulating the addition of metal so as to maintain the fused spot on the parent metal the chances for unfused sections will be greatly reduced. It is desired here to recall that all the precautions given elsewhere for the regulation of the arc lengths and current should be carefully observed.

To facilitate the building up of flat surfaces carbon blocks or paste, and in some cases metal rods, are used for making forms to confine the metal within certain limits.

An application to which the carbon arc is particularly adapted, where strength is not important, is in the joining of edges simply by melting them together without the use of a filler rod. Usually when this is done the edges are upturned and welded as shown by Fig. 48.

The quality of carbon arc welds, as commercially obtained, is as yet a question. It is an admitted fact that the difficulty in manipulating a carbon arc is somewhat greater than the difficulty of manipulating an oxy-acetylene flame. The reason that the arc is more difficult to manipulate is that the operator must use the full temperature of the arc or break it entirely—there is no intermediate point. With oxy-acetylene if the operator believes he is getting the metal too hot he can merely withdraw the flame from the weld, and thus reduce the temperature, but without breaking the continuity of heat. The particular difficulty encountered in carbon arc welding, owing to this fact, arises in the case of thin sections where the tendency is for the arc to burn through, or when welding on a vertical surface. The temperature of the arc is so high that the metal runs rapidly making it extremely difficult to weld in positions other than flat. With the oxy-acetylene flame the heat may be reduced by varying the distance of the flame from the work; the metal can thus be maintained in such a plastic state that a weld can be accomplished.

While these difficulties tend to impair the usefulness of the process they do not by any means condemn it. In most cases a method of welding can be adopted such that these difficulties may be made almost negligible. At the present time a considerable amount of thin sheet work, such as steel barrels, transformer cases, etc., are welded by the carbon arc process by both automatic and hand welding. Some carbon arc welding has been done by distributing short pieces of wire along the seam formed by abutting plate edges and playing the arc over the seam until the wire pieces and edges are melted into one mass. The object of this method is to increase the area of the weld over that obtained where the edges are simply melted together without any metal being added.

A recent development in carbon arc welding for light work is the use of a comparatively high arc potential—about 75 volts with a relatively low arc current. Working data have not as yet been published for welding of this nature. The results obtained by experiments in this direction, however, warrant further research along this line.

There are a number of chances for defects when welding heavy sections by the carbon arc. The first is lack of penetration, or as sometimes expressed, "not welded through." This takes place when the edges are not beveled, and because of lack of sufficient heat and manipulation to permit the entire scarf to become thoroughly fused. Poor fusion is sometimes caused by the melting down of the edges before the bottom of the "V" is melted, or by the interposition of slag layers. This is generally caused by a supply of molten metal on metal already solidified, or to a lack of liquefaction of the part constituting the weld. Blowholes are a common source of weakness in welds and are thought to be due principally to the carbon monoxide gas formed from the carbon in the arc terminals and filler rod, the gas being trapped by the rapid solidification of the metal.

Effects of Heat on Neighboring Metal.—The heat absorbed by the welded part produces internal stresses due to expansion and contraction. If the mass of the part welded is sufficient to cause rapid cooling, especially when the carbon content is in excess of 0.3 per cent, a hard brittle line will be formed adjacent to the melted metal. This can be removed by annealing after welding. This will not be necessary in most cases, however, as the area heated usually forms a large proportion of the part welded and there will not be a great difference in temperature within narrow limits.

Parts ordinarily difficult to weld with the metallic arc, such as cast iron and non-ferrous metals, can as a rule be welded by the carbon arc. Copper and bronzes, low in zinc and tin, can be welded. By the use of fluxes many other alloys of both ferrous and non-ferrous metals may be welded. Lead or other low melting point metals may be welded by holding the carbon or graphite electrode in contact with the surface to be melted, allowing the carbon to become heated to an incandescence without drawing an arc; the incandescent electrode end serves to melt the surface and metal to be added. The process is used extensively in lead storage battery work.

Cutting or Melting.—The heat of the carbon arc can be used to cut metals; the heat of the arc simply serves to melt the metal and is unlike those processes where oxygen is utilized to effect the cutting by rapid oxidation. The cutting is accomplished by maintaining the arc at one location, as for example at the edge of a plate, until the heat is sufficient to cause the metal to melt and run; the arc is then advanced at the same rate as the section is melted. On heavy sections the cutting is started at the bottom edge to facilitate the escape of the metal; the inability conveniently to dispose of the molten metal constitutes one of the objections to carbon arc cutting. The excessive amount of metal removed—i. e., the width of the cut—together with the seemingly unavoidable ragged edges prevent the process from competing with the oxidizing processes for most purposes. Fig. 49 gives some conception of the appearance of a cut made with a graphite electrode.

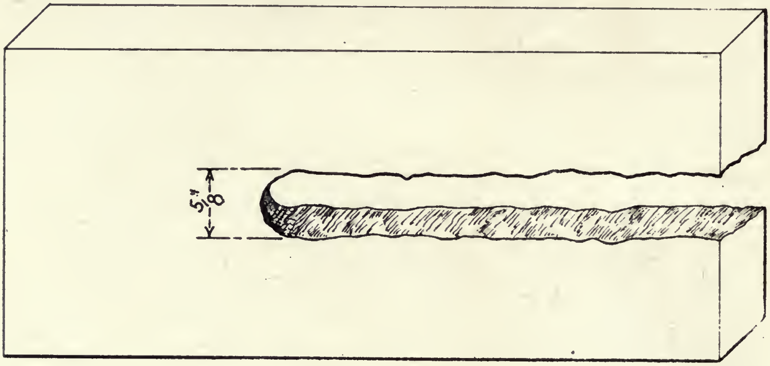


FIG. 49—Illustration of Ragged Edges Produced on Plate Material when Cut by the Carbon Arc

The width of a cut with a 300-ampere arc on ½ in. plate will be about ⅝ in. and the rate of cutting will be approximately 3.5 in. per minute; while with a 500-amp. arc the width of the cut will be about ¾ in. and the rate approximately 6 in. per minute. The arc diameter increases as the square root of the current, so that the width of the cut will always increase with an increase in the arc current. In spite of these unfavorable conditions the carbon arc is used extensively for cutting up scrap metal; cutting off risers and fins from cast iron, cast steel, and non-ferrous metals; melting of surfaces to improve the appearance, etc. Where a great deal of work of this kind is to be done the process will no doubt effect economy over the oxy-acetylene process.

Where only occasional cutting is done on a considerable variety of work and when neat, accurate work is required, the oxy-acetylene process is generally used. Due to the low initial cost of the equipment, as compared to the electric arc process, and its inherent adaptability to the cutting of iron and steel, the process has become an adjunct to most all industries using iron and steel. The fact that the process is used extensively for preparing work to be arc welded, especially with the metallic arc, and since the arc welding operator is often required to prepare his own work by the use of the oxy-acetylene flame, a brief description of the process is furnished with the hope that it will assist the student welder in forming a basic idea of the principle of cutting by oxidation.

Cutting or Burning of Iron and Steel by Oxidation.—In general, the cutting or burning of wrought or ingot iron and steel amounts to the utilization of oxygen to support combustion of the metal, resulting in oxidation and reduction. Ignoring processes of oxidation or reduction simply brought about by heat or some other form of energy, in the actual process the oxidizing agent suffers reduction and the reducing agent oxidation.

Most metals oxidize under the action of the oxygen of the air. This slow combustion continues until the layer of oxide is dense enough to protect the rest of the metal from the action of the air, as in the case of iron for example. This action of the oxygen of the air is greatly intensified as the temperature of the metal is raised, and a very rapid action is secured where practically pure ogygen is concentrated at a point on a piece of iron which has been heated to a red heat. For example, if a thin piece of iron or steel in a spiral form is suspended inside a jar of oxygen after first raising the lower end to a red heat, the iron burns rapidly in contact with the gas. The oxide of iron which is formed is detached from the metal and is projected on all sides in a molten state.

The oxidation commences at a point which has previously been heated to redness, because at this temperature the reaction takes place readily. The combustion of this portion of iron produces heat, a portion of which is absorbed by the neighboring part. This is sufficient to raise it to red heat so that it in turn burns, and this reaction is progressively propagated throughout the metal. The oxide formed has a lower melting point than that of the metal, and is detached, leaving the iron continually clean.

Iron and steel are alone amongst the ordinary metals which can be burnt in a continuous manner by contact with oxygen, because the oxide of iron produced by the combustion is eliminated, in proportion as it is formed, in the molten state. It is almost useless to attempt to apply the process to other metals or alloys which in contact with oxygen have a slower rate of oxidation, and whose oxide has a melting point equal to or higher than that of the metal, which would prevent it from being detached. Copper, brass and aluminum are examples of metals of this character.

High carbon steels, the melting point of which is lower than that of pure iron and near the melting point of the oxide, do not lend themselves well to cutting; there is also the difficulty of eliminating the oxides from the molten metal.

The question of oxidation has been gone into briefly in order to distinguish between the cutting or burning process where the oxygen is used mainly to support combustion of the iron or steel, and the welding process where the oxygen is used entirely to support combustion of the acetylene gas whose heat is utilized to melt the metal which is to be welded.

In the practical application of the principle of oxidation to the cutting of wrought or ingot iron and steel, the heat of the reaction is not sufficient to maintain the temperature necessary for the oxidation of the adjoining portion, as was the case in the example of the thin strip plunged into a jar of oxygen. The conductivity of the metal to be cut is so great and so much of the heat is absorbed that the temperature necessary for the oxidation cannot be maintained without the addition of sufficient heat to replace the losses by conduction and radiation, thus maintaining the metal at a red heat.

Cutting Blow-Pipes.—The cutting blow-pipe consists of an arrangement giving a small pre-heating flame, which is usually oxy-acetylene since the welding as well as the cutting can be done with these gases; as a matter of fact oxy-hydrogen, oxy-gas, oxy-benzole flames, or any good hydro-carbon gas can be used with success for the pre-heating flame for cutting; here it is simply a case of heating the metal and not melting it, so that they do not have the same disadvantages as in the case of autogenous welding.

The oxy-hydrogen flame is long, whereas the oxy-acetylene flame is short, so that on heavy parts the pre-heating extends deeper; because of this, hydrogen is claimed by some to be superior to acetylene for cutting. Independent, but in the same blow pipe, is an arrangement for bringing to the tip the cutting oxygen, regulating it, and projecting it on the metal.

In the earlier days the blowpipes were arranged with a heating jet preceding the oxygen jet, which necessitated the moving of the torch in one direction. Later torches, however, are arranged so that the blowpipe can be moved in any direction; this is accomplished by surrounding the oxygen orifice with a number of small pre-heating jets. The construction of the cutting blow-pipe has an importance which the user should recognize to the extent of analyzing the safety and economical features sufficiently to be able to choose a commercially good cutting blow-pipe. Attention has been drawn to certain research which may be taken to indicate that improvements in the efficiency of cutting by oxidation can be looked forward to in the not far distant future—one possibility which has been suggested is that of pre-heating the oxygen.

It is not believed to be important to describe in detail here the construction, or to attempt to give instructions as to its operation, since this information is always supplied by each manufacturer for his particular design of blowpipe as well as for the accessories, such as the regulators, fittings, etc.

The purity of the oxygen is an important factor in the work of cutting, especially for the fixing of the cost.

Methods of Obtaining Oxygen.—The two processes of obtaining oxygen in general use are the electrolytic, and liquid air. The oxygen made by the electrolytic process is usually very pure. Gas 98 per cent pure should be obtained direct from the cells and when purified it will exceed 99 per cent purity. In the electrolytic process two cubic feet of hydrogen gas are generated for each cubic foot of oxygen. It is of extreme importance that these gases do not become mixed as a mixture even so low in hydrogen as 5 per cent hydrogen and 95 per cent oxygen will explode.

There is little or no danger, however, with oxygen furnished from reputable concerns, some of whom guarantee freedom from danger of this character.

The liquid air process of obtaining oxygen is a refrigeration process. The air is liquefied by expansion after having been compressed. The nitrogen is then allowed to evaporate, leaving liquid oxygen. The liquid oxygen is then allowed to come to a gaseous state, when it is placed in holders, from which it is compressed into steel drums, usually of 200 cu. ft. capacity compressed to about 1800 lb. pressure per square inch. This process is widely known as the Linde air oxygen, Linde being the name of one of the inventors of the process. After one or more processes of purification this oxygen is from 97 per cent to 99 per cent pure. The efficiency of oxygen is greatly decreased by impurities. This is more noticeable in cutting than in welding. One per cent impurity is apparent in cutting, not only in the efficiency of the oxygen but in the appearance of the cut.

Oxygen is a colorless, tasteless gas. It is the most abundant and most widely distributed of all the elements, constituting by weight more than one-fifth of the air and eight-ninths of the water. It is slightly heavier than air, weighing 1.105 times more than air. One cubic foot of oxygen weighs .08921 lb.

Oxygen expands with an increase in temperature, so that an arbitrary figure has been chosen as a standard from which to measure it; this figure is 68 deg. F. to 70 deg. F., depending upon the company furnishing the oxygen. For each one degree change in temperature Fahrenheit there is a corresponding change in pressure of approximately 3.42 lb. It is thus evident that oxygen tanks should not be subjected to high temperatures which may raise the pressure to a value which would jeopardize the safety of the gages, hose, etc.

VII

ELECTRODE MATERIALS FOR METALLIC ARC WELDING

Electrodes for arc welding generally consist of either carbon, graphite or metallic rods. In either case the electrode is the part manipulated by the operator and is one of the two parts between which the arc is formed.

Bare Metallic Electrodes—Sizes, and Chemical Composition.—The metal electrode most commonly used at the present time consists of bare mild steel or ingot iron wire especially drawn and alloyed for welding purposes. The prime requisite for an electrode is that it should possess the necessary qualities which will make it possible to produce a sound homogeneous weld. To secure this result, the metal in passing from the electrode into the weld must be liquid in a uniform, finely divided state, thus permitting a close concentrated arc, which insures the proper state of fusion at the point on the work opposite the end of the electrode, so that when the liquid particles strike this fused spot they will unite and solidify with it.

If the metal is transferred in large globules the arc will not concentrate the heat sufficiently on the work to insure the proper state of fusion, in which case, when the globules strike the work they will adhere without fusion, thus causing a bad weld. It will also be found difficult to direct the metal where it is desired, and the deposited metal in the weld will be found more brittle, due to the increased oxidation, as a result of the long arc necessitated by the large globular formation and the lateral spreading of the arc. Any physical or chemical variation in electrode material must therefore be accomplished without detrimental effect upon the weldability requirements mentioned.

Electrode sizes.—The sizes most commonly used for electrodes are as follows:

Fractions of an Inch	Decimals of an Inch
$\frac{1}{16}$	0.0625
$\frac{3}{32}$	0.0938
$\frac{1}{8}$	0.1250
$\frac{5}{32}$	0.1563
$\frac{3}{16}$	0.1875
$\frac{1}{4}$	0.2500

The use of wire or sheet metal gages, as expressed in terms of B. & S., A. W. G., etc., to designate electrode diameters is confusing and therefore is not recommended. Electrode diameters should be expressed in mils (thousandths of an inch). The allowable tolerance plus or minus should not be greater than six mils. The importance of this will be appreciated by simply calling attention to the close relation of the current density to the electrode diameter, which, however, is not directly proportional to the diameter. Expressed in mils, the sizes most commonly used are 156 mils, 125 mils and 188 mils. The nature of the industry, of course, will determine the quantity of the different sizes to be used. On railroads and in shipyards the demand for the different sizes is in the same order as the sizes given above.

The length of the electrode commonly used is 14 in. In some cases the material is purchased in coils and is then cut into convenient lengths. This is not considered the best practice, however, as the small additional cost of the straight cut material will be more than offset by the cost of the time saved in handling by the operator.

The elements usually present in mild steel electrodes, upon which limitations are generally placed, are carbon, manganese, copper, silicon, phosphorus and sulphur. Little or no attention has been given to the gas content present in solution since the total does not usually exceed 0.1 per cent.

Carbon.—The maximum carbon content in the usual mild steel electrode material does not exceed 0.18 per cent. Some welding engineers contend that the carbon present in the usual soft steel—0.08 to 0.15 per cent—is desirable as it improves the welding characteristics by forming carbon monoxide gas, which on expanding assists in the transfer of the liquid metal from electrode to plate. The theory has also been advanced that the gas formed from the carbon envelops the arc stream and offers a degree of protection to the metal from the atmosphere.

On the other hand, there are some who favor the ingot iron material, which is practically free from carbon or manganese. This material is sometimes called American, Norway or Swedish iron, and is extensively used in oxy-acetylene welding. The ingot iron electrode material when properly made is known to possess good welding characteristics; this fact tends to minimize the importance of the expansion of carbon monoxide gas as a factor in the transfer of the liquid metal from the electrode to plate material, and tends to support the theory that the metal transfer is due principally to the forces of molecular attraction, gravity, surface tension, adhesion and cohesion.

It is a well-known fact that by holding a long arc with either mild steel or ingot iron electrodes, the rate of globular transfer is very slow, and the rate of electrode consumption is decreased. With a short arc, on the other hand, a slight enlargement of the globule brings it in contact with the fused plate where the forces of molecular attraction, surface tension, etc., at the plate overpowers these combined forces to retain the globule at the electrode, resulting in its detachment from the electrode and solidification on the plate material; there is then an attendant increase in the rate of globular transfer and electrode consumption. As the above holds true for both iron or mild steel, the presence of carbon does not appear essential from the standpoint of metal transfer for bare wire.

The hardness of the weld will, of course, be increased with an increase in the carbon content, and to a limited extent the tensile strength will be increased, although practically all the carbon in a mild steel electrode is lost in traversing the arc.

Manganese.—The per cent of manganese in electrode materials varies from about 0.02 in pure ingot iron electrode to a ratio of about three parts of manganese to one of carbon in mild steel. This ratio gradually changes as the carbon is increased until in high carbon steels the carbon and manganese are approximately equal. The presence of manganese between 1.5 per cent and 5.5 per cent is not permissible as the metal is very brittle and unworkable within this range.

Manganese is added in steel to toughen and improve its ductility. It also plays the rôle of dioxidizer and scavenger when fused by ordinary methods. When subjected to the temperature and condition of a welding arc, however, owing to the great affinity of this element for oxygen, it is largely destroyed without much effect in this respect, unless present in very large quantities.

Copper

The inclusion of copper in an electrode is somewhat rare. It is unnecessary for good welding electrodes. However, copper has been used to some extent with the view of resisting corrosion, but there are no data to show to what extent this has been accomplished. The copper content is usually not specified in electrode material, and a copper-plated electrode used for the purpose of introducing copper into the weld to prevent corrosion, or to protect the electrode itself from becoming rusty, is not successful. This type of electrode when used will cause the arc to be erratic, and the copper will be introduced into the weld in lumps. If copper electrodes are used the alloy must be homogeneous.

Silicon

A maximum of 0.10 per cent silicon is usually permitted in electrodes. This limit is not difficult to meet in the basic process; ordinarily, however, the less silicon the better. It has been observed that an excess of silicon will increase the tendency of the metal to boil.

Phosphorus

This element is undesirable in any quantity; however, 0.05 per cent as a maximum is permitted. Phosphorus causes "cold short" or brittleness.

Sulphur

This element, like phosphorus, is undesirable, and is eliminated to the same extent. Sulphur causes "hot short" or brittleness when the metal is red hot or hotter.

Ingot Iron Electrodes.—There is in extensive commercial use an ingot iron electrode guaranteed to be 99.8 per cent pure iron. It surpasses the best Norway or Swedish iron. This material is specially drawn and treated for arc welding, and is found to work very satisfactorily.

The table showing the chemical composition of metal in electrodes indicates that a common agreement has not yet been reached as to the chemical composition of bare wire electrodes for welding iron and soft steel. This table shows the composition of some of the different electrodes in use:

CHEMICAL COMPOSITION OF METAL IN ELECTRODES

Trade name of electrode	Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur	Per cent silicon	Per cent copper
Page steel, "Armco Iron"	0.01	0.025	0.005	0.025	0.005	.....
Norway	0.049	0.021	0.025	0.007	0.08	.....
Central steel, "Sweedox"	0.05	0.018	0.04	0.04	0.05	.....
Siemund Wenzel Company	0.10	0.30	0.05	0.05	Trace	.....
Roebling Company	0.13	0.47	0.025	0.025	0.020	.....
Wilson No. 6	0.15	0.60	0.04	0.04	Trace	0.25

An analysis of the metal deposited in a weld using two of the above electrodes is as shown in the following table:

CHEMICAL COMPOSITION OF METAL IN WELD

Trade name of electrode	Per cent carbon	Per cent manganese	Per cent phosphorus	Per cent sulphur	Per cent silicon
Roebling Company	0.05	0.18	0.031	0.036	0.011
Norway	0.05	0.018	0.020	0.015	0.011

It will be noted that a large percentage of the carbon and manganese is lost in passing through the arc. The small difference in the composition of a deposit made with a mild steel and an ingot iron electrode will obviously produce welds of but little difference in physical quality.

There is one evident advantage of the pure iron material and that is the practical assurance of freedom from impurities which would be detrimental to the weld and its uniformity of composition. Up to the present time this has been a source of much trouble in the mild steel material, due to the fact that but very few concerns have indicated a willingness to exercise the necessary care to make it uniform for the present price and tonnage demand. This condition will, of course, be relieved when the supply is again equal to the demand. Owing to the difference of opinion, both mild steel and ingot iron electrode materials are used for the same class of work.

A copy of the specification No. 1, issued on April 1, 1920, by the American Welding Society, intended to govern the purchase of electrode materials, follows:

Specifications for Bare Iron and Steel Electrodes

General:—1. The following specifications, prefixed by the letter E, are recommended for the purchase of all bare iron and steel electrodes for use in arc welding.

Scope:—2. The electrodes herein specified are recommended as covering the usual railroad, shipyard and industrial requirements as are allowed by authoritative regulating bodies, such as the American Bureau of Shipping and the Interstate Commerce Commission, etc.

Material:—3. Material made by the puddling process is not permitted.

Physical Properties:—4. Electrodes shall be made of commercially straight wire of uniform homogeneous structure, free from irregularities in surface hardness, segregation, oxides, pipes, seams, etc. Diameter shall not vary more than plus or minus 3 per cent from diameter specified.

Nomenclature:—5. The use of the prefix letter E is to indicate that the materials are intended for electric welding.

Chemical Composition:—6. Shall be within the following limits for mild steel:

MILD STEEL

No. E 1 A

Carbon	not over 0.06 of one per cent
Manganese	not over 0.15 of one per cent
Phosphorus	not over 0.04 of one per cent
Sulphur	not over 0.04 of one per cent
Silicon	not over 0.08 of one per cent

No. E 1 B

Carbon	0.13–0.18 of one per cent
Manganese	0.40–0.60 of one per cent
Phosphorus	not over 0.04 of one per cent
Sulphur	not over 0.04 of one per cent
Silicon	not over 0.06 of one per cent

Recommended Sizes:—7. $\frac{3}{32}$ in., $\frac{1}{8}$ in., $\frac{5}{32}$ in., $\frac{3}{16}$ in. diameters.

Uses:—8. For welding mild steel, structural shapes, plates, bars or low carbon steel forgings and castings.

Note:—9. Under the heading "Mild Steel" two analyses of material are specified, both of which are manufactured and acceptable.

Surface Finish:—10. The surface shall be smooth and free from rust, oil or grease.

Tests:—11. In the hands of an experienced welder electrodes shall demonstrate good weldability and shall pass through the arc in flat and overhead positions smoothly and evenly without detrimental phenomena.

Packing:—12. Electrodes shall be delivered in coils or in straight 14-in. lengths, packed and wrapped as follows:

(a) Bundles of 50 lb. net weight, securely wired and wrapped in heavy weatherproof paper.
(b) Bundles of 50 lb. net weight, securely wrapped in heavy burlap.
(c) Boxes or kegs of 100, 200 or 300 lb. net weight, and wrapped as per paragraph (a).
(d) Boxes or kegs of 100, 200 or 300 lb. net weight, and wrapped as per paragraph (b).
(e) Coils of approximately 50 or 100 lb. net weight, and wrapped as per paragraph (a) or (b).

Marking:—13. All bundles, coils, boxes or kegs shall be provided with a metal tag wired or nailed on the outside, bearing the following information:

Make..........................
Specif. No. ....
Dia. ....
Nom. weight....................

Ordering:—14. Material ordered under these specifications shall be known as:

"Electrodes, iron and steel, bare" American Welding Society Specifications No. 1, issued April 1, 1920.

All orders should be specified in pounds.

In addition, requisitions shall show the following:

Specif. No.
Size
Packing

State of Existence of Metal in Arc.—In a previous section it was stated that the metal, when passing through the arc, according to all evidence was in the form of vapor and minute globules. This contention has been supported by Mr. Hudson in the Journal of the American Welding Society. Mr. Hudson, after extensive research, states that "it would appear from observed facts that the metal deposited during metallic arc welding is transmitted, in part at least, in the form of minute particles at the rate of approximately 50 per second, and these are projected from the electrode globule by the internal expansion of some vapor, possibly consisting partly of carbon monoxide gas. The expelled particles pass too rapidly through the arc to become vaporized and reach the plate in a fluid state."

The rate of flow of the expelled particles referred to here was determined by holding an incandescent electrode, just removed from ordinary welding, over the rim of a revolving iron wheel. Furthermore, the arc tends to be established from whichever portion of the work or electrode volatilizes most rapidly. In this connection Mr. Hudson states that, "since the melting points of the different elements usually present in electrode materials, and other thermal constants of these elements and their compounds vary widely, and their chemical affinities are quite different, it is to be expected that the constituents of an electrode subjected to a high temperature will change from solid to liquid or gaseous form successively and not at the same instant. Since the melting point of iron is higher than that of any other constituent of an electrode, with the exception of carbon, which combines rapidly with the oxygen (present in the air) at welding temperatures to form carbon monoxide, it is furthermore to be expected that in the welding process, the iron constituent will melt last.

"In metallic arc welding the temperature changes which take place differ to a marked degree from the changes incident to the usual methods of heating metals, to the extent that in welding a small mass of the electrode is subjected to a high temperature for a very short interval of time. The distinctive thermal feature of metallic arc welding is the sudden rise and fall of temperature in the metal transmitted to the work.

"Under these circumstances it may be seen that the melting of the iron is delayed by the heat absorbed by the other constituents of the electrode, and this fact, together with the limited time of application of high temperature, disproves the possibility that the iron is completely vaporized in the welding process."

The small spherical particles found about a weld are thought to be those particles which strike unfused metal on the work, and bounce along the surface. The gray dust seen floating in the air, and which collects around the weld, is thought to be, partly at least, the vapor carried out of the arc with these particles. These losses are accentuated with poor welding electrodes and may constitute a loss of 14 per cent of the electrode material consumed.

An examination of an electrode which does not work smoothly will usually show that the fused end is enlarged. This may be accounted for by the fact that most materials will show a marked increase in volume with an increase of temperature. An electrode fused by an excessive arc length will also show an enlargement at the end of the electrode.

From the foregoing it would seem that some elements alloyed with the iron or steel may be beneficial to the smooth working of an electrode, whereas others may not. At the present time there does not seem to be an electrode on the market containing a composition which will materially improve its working quality for bare wire welding.

An examination of the fused end of a smooth working electrode will present a cup-shaped appearance which would indicate that the center or core fused first and the shell last. An ideal electrode, therefore, would seem to be one having a high-fusing-point shell, graduated to a lower-melting-point core. Many methods have been employed to produce this effect, and while there are a number of treatments, usually confined to the surface, which work after a fashion, many of them are incidentally detrimental in other ways, such as increasing the slag inclusions in the weld, etc. A method of heat treatment and drawing the electrode material so as to produce a shell having a high melting point and a core having a low melting point is employed at least by one concern. This seems to be an ideal method, as undesirable surface finishes are eliminated.

Physical Properties of Bare Wire Electrodes.—The physical properties of electrode material are of extreme importance to its smooth working quality. The structure must be uniformly homogeneous, free from any structural imperfections such as oxides, pipes, seams, etc. The materials from which the wire is manufactured should be made by the best approved process, open hearth or electric furnace.

At the present time about the only sure check the purchaser of electrodes has on their weldability is through actual test by an experienced operator, who shall demonstrate whether or not the material flows smoothly and in a reasonably uniform, finely divided state without any detrimental effects. The general use of coatings to make an inferior electrode flow smoothly is not considered good practice. In some cases poor welding material, termed "wild iron," may not necessarily be inferior for such purposes when a coating is applied to quiet the arc and prevent sputtering. In most cases, however, this method is grossly misused by applying a coating to electrodes having excessive amounts of impurities, producing results detrimental to the weld.

From the foregoing it is evident that the electrode material for bare wire welding calls for either a practically pure iron electrode or for what is essentially a basic mild steel electrode with the impurities not exceeding those enumerated, and specially treated to meet the requirements. It is also evident that metal deposited with a bare electrode is practically free from carbon or manganese, and, as the fusion of metals under the conditions of the welding process makes for brittleness, the ductility of the weld is greatly impaired. This latter deficiency has proved to be a serious obstacle in the application of the process to some structural and machine members subjected to repeated stresses, such as bridge cord members, ship hulls, car axles, piston rods, etc.

The loss of the constituents of the electrode in bare wire welding prevents the use of certain alloys such as carbon, manganese, nickel, vanadium, etc., to any appreciable extent. These are often added to secure strength and toughness, or to limit abrasive wear, and are needed in many instances.

The tensile strength of welds made with bare electrodes is fairly satisfactory, as indicated by the many tests which have been conducted. In practically every case the average tensile strength was 50,000 lb. per sq. in. It is therefore evident that if the conditions under which welds are made are improved so as to secure more ductile metal in the weld and in some cases certain alloys as mentioned above, the scope of application of the welding process will be practically unlimited. The need of such improvements is indicated by the research and development work now being carried on in this country as well as abroad.

Covered Electrodes for Arc Welding.—A covered electrode, or "flux covered" as it is sometimes called, is manufactured by the Quasi Arc Weltrode Company of England. This electrode is a metallic rod or wire with a covering of blue asbestos yarn, sometimes accompanied with other coatings of ferrous silicate, which, on fusing, is claimed to surround the metal with an inert gas, and prevent oxidation of the deposited metal. The yarn, it is claimed, is coated with sodium silicate, aluminum silicate or a similar compound to vary the fusing temperature of the asbestos. Another claim for this electrode is that the covering forms a fusible insulating coating around the metal core of sufficient thickness so that it may be held at an angle and resting on the work permitting the electrode to feed itself. In addition to the covering an aluminum wire is placed between it and the core for the purpose of preventing oxidation. When aluminum is present in a molten mass of iron, all of the aluminum will be oxidized before any of the iron is attached, since aluminum has a greater affinity for oxygen than iron.

The covered electrode is used extensively in England, mostly in connection with alternating current. When used with direct current the polarity is opposite to that ordinarily used for bare electrode welding; that is, the electrode is made the positive pole and the work the negative pole. An exhaustive series of tests has been made to investigate the claims of this electrode, but the results have not yet been published.

The cost of marketing the covered type of electrode seems to have limited its use in this country; also the somewhat different methods of application necessitated by its use and the removing of the heavy scale formed on the weld have given rise to some objections. The metal expelled from the electrode becomes extremely fluid, and remains in that state for a longer period than in the case of a bare electrode, due to the heavy slag formed over the weld. For this reason its use on work other than practically flat or down-hand welding is more or less difficult. Special electrodes are said to be furnished by this company for vertical and overhead welding, also electrodes of special composition.

Test data to show the percentage of different alloy constituents that can be deposited in the weld by the covered electrode are not available. It has been demonstrated, however, that a weld made by a mild-steel-covered electrode is softer and more ductile than that made with a bare electrode. It is understood that the use of this covered electrode in ship construction in England has been approved by Lloyds Insurance Company.

Coated Electrode for Arc Welding.—The term coated electrode has in the past been taken literally to refer to some form of a flux applied to the surface of the electrode, the function of which was to fuse with the electrode and act purely as a cleanser. As a matter of fact, however, there is at least one "coated" electrode, not necessarily flux coated, in commercial use, which performs practically all of the functions claimed for the heavy "covered" electrode.

The coating is composed of a high-fusion-point material, or materials mixed with a suitable liquid also of a high fusion point, which on drying serves as a binder to hold the material firmly to the surface of the electrode. The thickness of the coating, as compared to the covered electrode, is thin. The welding is performed in the same general way as with a bare electrode; that is, the arc is established and manipulated by the operator, and the coating is not used to separate the end of the electrode the proper distance from the work. The iron or mild-steel coated electrode can be used in a vertical, horizontal or overhead position without difficulty. Electrodes having high percentages of alloys are confined to practically down-hand welding, but generally this class of work is not required to be done in other positions.

The coating on the electrode fuses at practically the same rate as the electrode. Its function is to remain in a fluid condition about the particles or globules as they are rapidly expelled from the end of the electrode and arrange itself over the surface of the deposited metal, thus forming an almost continuous sheath or miniature crucible about the metal when undergoing the changes from a solid to a liquid or a gaseous state, or vice versa, confining the arc gases and excluding to a very large extent the surrounding air, thus securing a more ductile weld by preventing to a great extent the effects of nitrogen and oxygen.

The effectiveness of the coating is evidenced by the fact that a high manganese and carbon content can be deposited in the weld. This is shown by the following test: The metal from an electrode containing 0.99 per cent carbon and 10.50 per cent manganese, with a coating as mentioned above, was deposited on a carbon steel rail by metallic arc welding. Direct current was used, with the work positive and the electrode negative. The appearance of the finished weld was perfect, being smooth and without gas holes or other imperfections. Further examination showed that the union was perfect. An analysis of the electrode and the deposited metal is shown in the table.

Element	Electrode, per cent	Deposited metal, per cent
Carbon	0.99	0.71
Phosphorus	0.043	0.061
Sulphur	0.022	0.018
Manganese	10.51	10.19

The Brinnell hardness of the head of the rail was 154, and the average hardness of the deposited metal was 156. Due to the extreme toughness of the metal much trouble was experienced in pulverizing the deposit for analysis; many tools were broken, and when the sample was finally placed under a steam hammer in an effort to break it up, deep impressions were made in the hammer jaws.

Another test was conducted to determine the loss of constituents, using electrodes containing alloys in a milder form, and with a very thin coating such as would permit welding in a vertical or horizontal position. The results are given in the following table:

Element	Electrode, per cent	Deposited metal, per cent
Carbon	0.18	0.15
Manganese	0.50	0.40
Phosphorus	0.012	0.012
Sulphur	0.032	0.032
Silicon	0.140	0.12
Nickel	2.97	2.08

Ordinary physical tests of welds made with the coated electrodes showed an increased ductility over those made with the same material without the coating.

In the past too much reliance has been placed upon figures of tensile strength. Many welds having fair tensile strength are, on the other hand, weak in transverse strength.

The superiority of coated electrode welds has been demonstrated in many instances in practice, where they have been in use for about 18 months. Incidental advantages have been noticed with the coated electrode that may be of interest. The lack of uniformity in the ordinary welding wire has always been a very serious matter, and even with material made in the most careful manner there will be found some electrodes that do not work well.

When the electrodes are coated, imperfections in the wire may not be noticed; as a result, material is sometimes used which would otherwise be discarded. In this connection it should be understood that it is not intended to infer that an inferior electrode, especially in regard to the composition, can be made suitable for welding by coating it. As a matter of fact, it is just as important that coated electrodes be of the proper quality as it is for bare electrodes. It would be better to tolerate non-uniformity than to deposit metal with excessive constituents which are detrimental to the weld.

Operators using coated electrodes contend that the personal efforts of welding are somewhat minimized when the electrode is coated. Another apparent advantage of the coated electrode is that it provides a scale for the weld, which, when the coating has the right composition, has a greater co-efficient of contraction than the weld, so that when the weld cools somewhat the scale may be readily removed by light tapping with a hammer or chisel, thus exposing perfectly clean metal preparatory to adding the next layer of metal. The scale, by excluding the air, also prolongs the cooling so that the temperature of the weld is not reduced so rapidly. Consequently, the weld does not tend to become brittle to the same extent as welds made with bare electrodes.

The composition of the metal in the electrode, in relation to the part to be welded, is obviously a matter of importance. What this composition is to be can only be gaged by experiment and by wide experience. The complexities encountered in performing welding by the electric arc are so different from those of other methods of heating metals, that few data are available upon which judgment may be based. In view of such conditions many difficulties arise in devising tests to determine the quality of an electrode.

Procedure for Testing Electrodes for Arc Welding.—A standard procedure of testing welds to determine the relative merits of different electrodes was drafted by the welding committee of the Emergency Fleet Corporation. Many elements enter into a test of this nature, so that if the proper consideration is not given to each they will greatly affect the accuracy of the ultimate result. An abstract of this specification with slight variations follows:

This specification describes a test of electrodes and not a combination of an electrode and of an apparatus (or welding equipment). The system used in making such tests may or may not prove to be of importance.

It is sought to minimize the influence of the individuality of the operator by requiring the test to include welds made by at least two operators. Only operators known to be competent should be used for such tests, and the approving and certifying of operators would be within the province of the purchaser, as well as the approving and certifying of systems.

Sample Electrodes.—Sample electrodes should be accompanied by affidavits giving the trade-name under which the electrode is marketed,

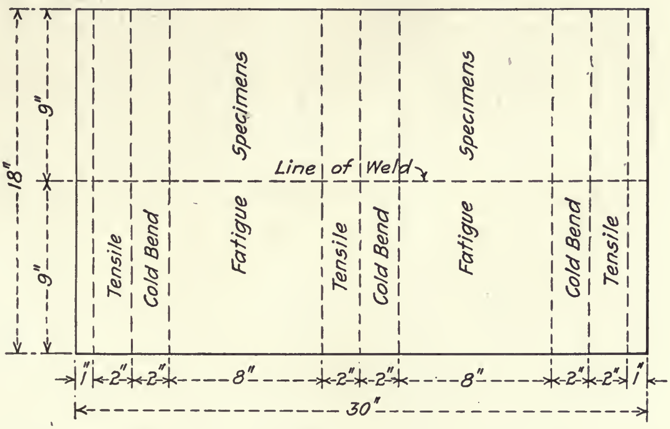


FIG. 50—Test Pieces for Tensile, Cold Bend and Fatigue Specimens

together with certification that all electrodes bearing this trade-name will be substantially the same as the sample submitted, and such other information as is deemed necessary by the purchaser.

Plate Material.—Standard ½ in. ship-plate, as adopted by the American Society of Testing Materials, A 12-16 (page 98, A. S. T. M. Standards, 1918), are specified for the test.

The plates from which tensile, cold-bend and fatigue specimens are to be made shall be cut into pieces 9 in. by 30 in., as shown in Fig. 50.

The plates from which impact specimens are to be made shall be cut into pieces 30 in. by 30 in., as shown in Fig. 51.

Number of Test Welds.—One 30 in. weld for the tensile, cold-bend and fatigue test shall be made, as indicated in Fig. 50.

Three 30 in. test welds for the impact test shall be made, as indicated in Fig. 51.

Preparation of Plates for Physical Test.—(a) Each test weld shall be machined down on both sides to about the surface of the plate.

(b) Specimens shall be cut from each test weld reserved for physical tests, as follows:

1. Three tensile specimens—these shall be machined to a uniform width of 1½ in. unless a weld of great strength makes it necessary to leave shoulders at the ends, in which case the standard A. S. T. M. test specimens for sheet iron and steel shall be prepared.

2. Three cold-bend specimens—these shall be machined to a uniform width of 1½ in.

3. Six fatigue specimens—these shall be machined to about ½ in. diameter and 10 in. long. (The exact dimensions are to be determined by experiment.)

Physical Tests.—(a) *Tensile Strength.* The three specimens shall be tested in accordance with the practice recommended by the A. S. T. M. and shall include the determination of the tensile strength, yield point (by drop-of-beam method), reduction of area and total elongation after rupture in 2 in. and 8 in.

(b) *Cold-bend Test.*—This test shall be made by placing the specimen

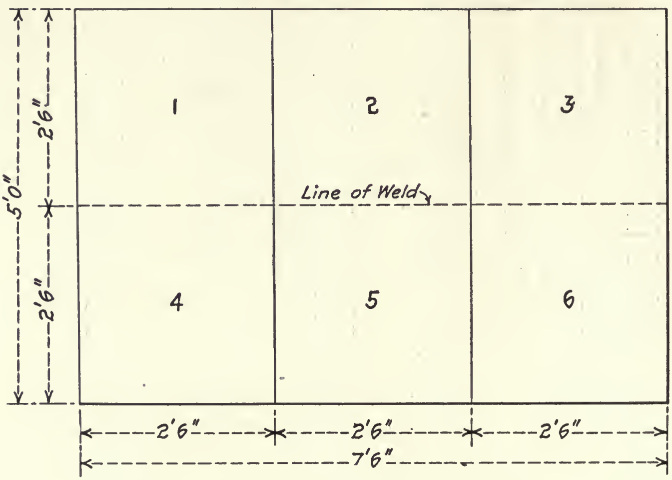


Fig. 51—Test Pieces for Impact Specimens

on two ball-bearing rollers with the apex of the "V" upward and midway between the rollers and loaded at the center of the span thus formed by a cylindrical surface having a diameter of 1½ in. This surface shall bend the specimen downward between the rollers until a fracture appears on the lower side of the specimen. The loading shall then be stopped and the angle noted through which the specimen has been bent.

(c) *Fatigue Test*—Each of the six specimens shall be tested in a special rotating type of machine similar to that used by Lloyd's Register of Shipping. (Exact details to be determined by experiment.)

(d) *Impact Test.*—Each impact test specimen shall be placed on supports 18 in. high and 4½ ft. apart. A spherical weight of 500 lb. shall be allowed to fall freely through a distance of 10 ft., striking the weld, which shall be at the center of the span. The apex of the "V" shall be upward.

(e) *Test of Original Plate.*—In order to establish the physical properties of the unwelded plate, tensile, cold-bend and fatigue tests shall be made on a sample selected at random from the pieces used for the test welds, but before such welds are made.

Chemical Analysis.—A chemical analysis shall be made of:

(a) The original plate in one test-weld selected at random.

(b) The metal at the center of one test-weld selected at random.

Photomicrographs.—Photomicrographs shall be made of one specimen weld selected at random, as follows:

At center of weld; at juncture of weld and original metal; in adjacent original metal; cross-section of electrode; longitudinal section of electrode.

Any information on welding data which might be of importance should be recorded by the authorized representatives during the welding operations, such as identification mark of electrodes, description of electrode, sufficient description of welding apparatus for identification, name of operator, kind of current (i. e., d. c. or a. c.), open circuit voltage, arc current and voltage across arc, working quality of electrode, giving exact description of peculiarities noticed, if any, time per weld, weight of electrodes consumed, and any other information which will assist in determining the performance of the electrode or the quality of the weld.

A test, such as outlined, will involve some expense, but the resultant data and information revealed will constitute a wealth of information which will offset the expenditure many times. The adaptation of a standard form of procedure for testing welding electrodes will at least result in the elimination of much of the inferior material now in existence, and it is hoped it will be an incentive to further the development of electrodes by the manufacturer. The lack of uniformly dependable electrodes has always been a serious obstacle in the progress of arc welding, and with improvements in this phase of the art great extensions in its application will result.

Cast Iron Electrodes for Arc Welding.—Due to the non-homogeneous structure of cast iron, and to the behavior of a material of this composition and the conditions of arc welding, its use has not been successful for metallic welding. Experiments by different parties are now under way, using cast iron rods high in silicon, ingot iron high in silicon, bronzes, etc., which may result in more satisfactory results in cast iron welding.

Non-Ferrous Electrodes for Arc Welding.—Up to the present time no great amount of research has been made of non-ferrous electrodes. Certain aluminum-bronze alloy electrodes, low in zinc, are used with satisfactory results. The presence of more than 3 per cent of zinc is known to be unsatisfactory, as this element vaporizes at a much lower temperature than the other constituents with which it is alloyed. Some experiments that have been made indicate that non-ferrous electrodes properly made can be used, especially if they are coated or flux covered.

Carbon Electrodes for Arc Welding.—Carbon electrodes are furnished in various diameters, ranging from 3/16 in. to 2 in. Various compositions are furnished to vary the conductivity of the rod. They are also furnished plain and copper coated. The

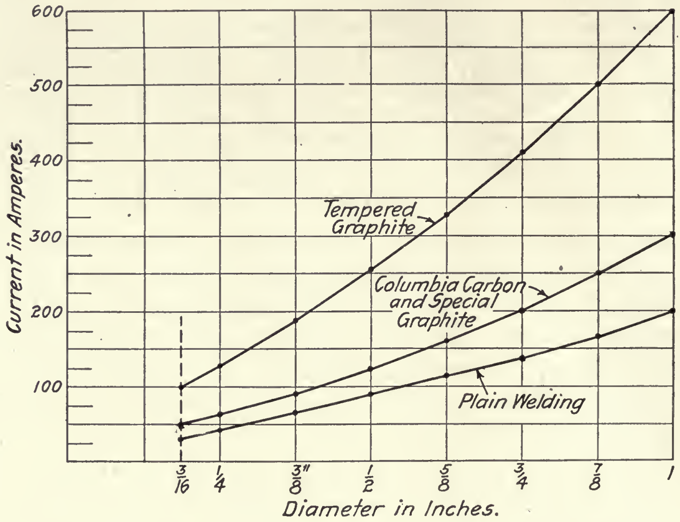


Fig. 52—Current Carrying Capacity of Welding Carbons

usual length is 12 in. and they are always pointed at the arc end, and in some cases the entire electrode is tapered. The approximate current carrying capacity for different sizes and grades of carbon electrodes is shown in Fig. 52, and may assist the user in selecting the proper size and grade of electrode to best suit the work at hand.

VIII

PREPARING WORK FOR ELECTRIC ARC WELDING

In detail, the preparation of work to be welded varies with the characteristics of the metal, the thickness of the parts to be welded and, most of all, the form and position of these parts. However, general rules serve to indicate the methods to be applied in each particular case. When the material to be welded is prepared properly the job is half done, because the execution of the actual welding process depends in a large measure on the accessibility provided for the operator, such as the arrangement and preparation of the parts to be joined. The methods used for welds of various kinds are described in this article, but the following information concerning the preparation of the parts may be of value in a general way:

(1) Expansion and contraction should be provided for when it is possible to do so, otherwise the effective strength may be materially reduced or the work left in a distorted or warped condition.

(2) Accessibility for the operator should be provided for in order to simplify the execution of the welding process. The work or the position of the parts to be welded should be arranged so as to be the least difficult for the operator to get at. Good welding can be done in an overhead position, but other positions require less effort and the probabilities for a good weld are greater.

Proper beveling and spacing of parts, to insure uniform fusion throughout the thickness of the parts to be joined, will also determine to a large degree the ultimate strength of the weld.

(3) It is necessary to know what the service requirements of the parts will be in order to make a study of the stresses to which the work will be subjected, to determine the kind of weld that should be made. Different kinds of welds will be required. The

kind to be used will depend upon whether the strain is great, small, direct tension, bending, torsion, prying, compressive, or a combination of these.

(4) The cleaning of the surfaces on which fusion takes place must never be lost sight of. According to the surface of the metal, this mechanical cleaning may be done with hammer and chisel, wire brush, roughing tool, sand blast, emery wheel, file or a combination thereof. The use of chemical agents to slag the oxides from the surface of the work during welding is not strongly recommended for arc welding. Mechanical methods of cleaning are preferable.

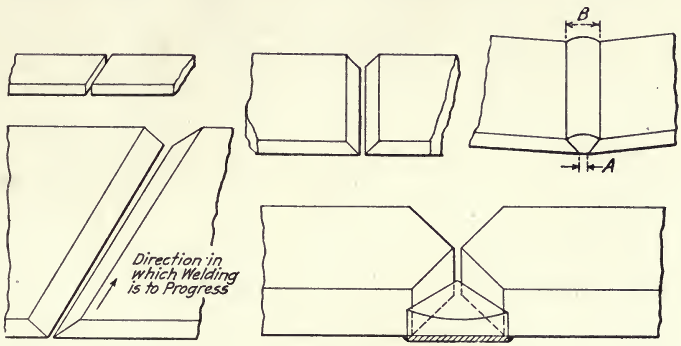
Expansion and Contraction Require Precautionary Measures.—Attention has been drawn to the importance of expansion and contraction in the case of autogenous welding. However, as the preparation and arrangement of parts to be welded are governed largely by this phenomenon, it is necessary to refer further to this subject.

It must be understood that expansion and contraction cannot be overcome by force, and it is useless to try to oppose them. We may only hope to avoid or limit their consequences. Also, it must be remembered that a given volume of metal occupies more space when in a heated or molten state than when in a cool normal condition. For example: Two bars, such as shown in Fig. 53, are to be joined by the addition of molten metal between them. No bad effects of expansion and contraction are to be feared in this case because the opening is uniform and the parts are free to expand or contract.

However, if two plates, such as shown in Fig. 54, with beveled edges are to be joined the situation is different. To begin with, the plates are horizontal; but when the weld is completed their relative positions will have changed as shown (exaggerated) in Fig. 55 provided they are free to move. This is due to the difference in the openings at points *A* and *B;* that is, the amount of hot expanded metal added between points at *A* (to contract on cooling) is smaller than that between points at *B;* consequently contraction is greater at point *B*.

No bad effects of expansion need be feared, since on heating or fusion the beveled edges expand and the parts to be welded approach each other. Also, the tendency for expansion is reduced to almost nothing in the case of metallic arc welding because of the extreme localization of the arc's heat. Distortion may be allowed for by adjustment of parts before the welding begins, so that when contraction occurs the united plates will form a flat surface.

In welding long butt seams of medium thickness, in addition to the tendency for distortion above-mentioned, the contraction of



FIGS. 53 to 57—Parts to be Joined Showing Effect of Expansion and Contraction

the weld will cause the edges to approach each other as the welding progresses. When it is possible to do so this condition should be allowed for by separating the edges of the plates more at the end toward which the welding is to progress than where the welding is to start, as shown in Fig. 56. The amount of allowance for this contraction varies slightly with the speed at which the work is done and the mass and shape of the parts. *It will usually vary from one to two per cent of the length of the weld.* These figures are approximate. The operator will find the exact spacing required, depending upon conditions, after he has had some experience with welding of this character. He can correct a slight mistake in spacing by varying the speed of his work; that is, if it tends to close too quickly the work should be hurried, and if it does not close quickly enough the work should be prolonged.

Closing of the edges and warping may be prevented in some cases by clamping or tack welding to compel a slight giving of the metal on cooling and contracting. This, however, is not the best practice, especially with lighter material where the parts being welded become very hot; but it is practiced to a great extent on heavy work, *and if the metal in the weld is ductile the contraction will not produce breaks or even serious strains.* An example of this is illustrated in Fig. 57 in the welding of locomotive frames, where it is very seldom that any allowances are made for contraction; yet many such frames have been welded successfully.

Even though the members of heavy parts are free to move, there should be very little distortion in the case of metallic arc welding, as contraction will have occurred where the welding was started long before the weld can be completed. Pre-heating may be employed in certain cases, but it is not used to as great an extent with metallic arc welding as it is with oxy-acetylene welding, since the area heated by the electric process is comparatively small. Pre-heating and after-heating, or annealing, are required in many instances to avoid locked up strains and brittleness, for instance when welding cast-iron or medium carbon steel or higher, especially when the mass is so great as to cause rapid cooling. This subject will be discussed more in detail in another section of this book.

The methods to be followed vary in each case. But the practice ordinarily used will be shown in greater detail in the articles devoted to the practice employed for various welds and different conditions. It is necessary, however, to emphasize the fact that the effects of the heat on the structural arrangement of the metal and the phenomena of expansion and contraction are enemies to the welder, and in most cases means must be provided to prevent their effects and avoid their consequences.

Proper Access for the Execution of the Welding Process.—To provide proper access for making a weld, the operator must be free to manipulate the arc and be able to incline the electrode to the proper angle with the surfaces on which metal is to be added. Also the beveling, spacing and arrangement of the work must be such as to permit this manipulation and the use of various electrode angles necessary to secure proper fusion through the entire thickness of a weld.

Preparation of Joints.—There are various types of joints

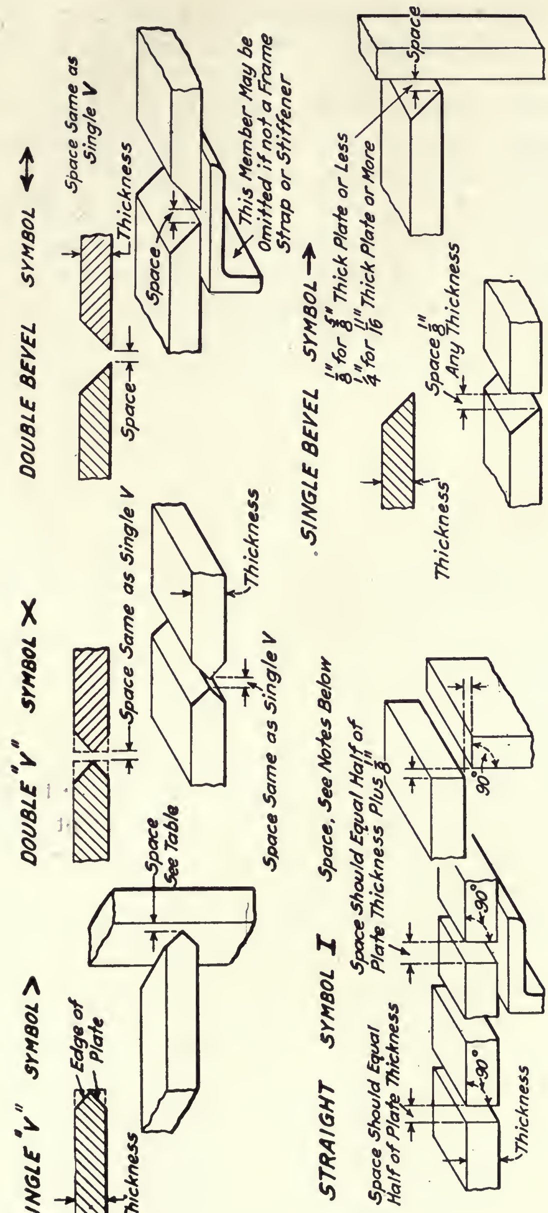


FIG. 58—Designs of Welds Showing Relation of Parts and Spacing

more or less in use depending upon the nature of the work and conditions. The ones used in a great majority of cases, however, are the double bevel and double "V," Fig. 58. The preparation of the edges, free space or opening between edges, dimensions of reinforcement, etc., have an importance which deserves careful consideration if efficient results are to be had.

The usual practice has been to provide an opening sufficiently large (usually not less than a total of 90 deg.) to give a large margin of assurance of ample access for the deposition of the metal. Experience has shown that better results, with considerable saving in time, welding material and heat energy, can be secured with smaller openings. The evident purpose of beveling

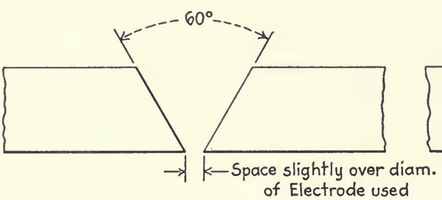


FIG. 59—Showing Free Space Necessary for Best Welding Results

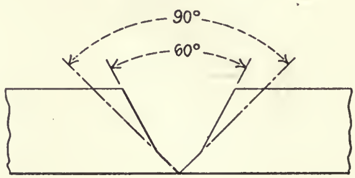


FIG. 60—Method Used Where no Free Space Can Be Allowed at Bottom

the edges is to permit fusion through the entire section of the joint. Any metal removed, not necessitated by this, is a waste of time and material and, moreover, such metal must usually be replaced with a metal inferior to that removed, especially if the part has had mechanical treatment.

A few simple rules, which will be useful in determining the free space (separation between edges), angle of bevel, or total opening for double bevel and double "V" butt joints, and dimensions of reinforcement, are given below:

Free Space: This is shown by Fig. 59.

Total Opening: It is not necessary that the electrode be held at right angles to the surface on which metal is to be deposited. The electrode may be inclined from this position approximately 30 deg. without bad effects. For this reason a total opening of 90 deg. is not required in most cases. A total opening of 60 deg.,

Fig. 59, will permit ample access to the surfaces to be joined and will effect a saving in time and material of at least 10 per cent over the 90 deg. opening.

In cases where no free space can be allowed the bottom of the "V" may be cut to a 90 deg. angle for a short distance, then reducing the angle to 60 deg. for the remainder of the scarf, as shown by Fig. 60.

In certain cases of unavoidable, excessive free space, or on light work of low thermal capacity, a straight edge may be left at the bottom of the "V," as shown by Fig. 61, with a considerable saving in time. As a thin edge would likely be melted down in such a case, leaving a large opening to be filled in, there is basis for the belief that this method of beveling may come into extensive use in the future.

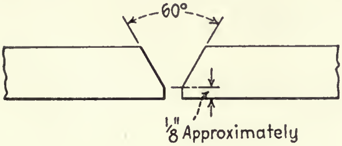


Fig. 61

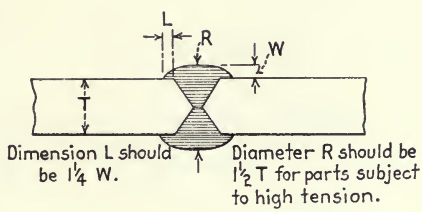


Fig. 62—Reinforced Weld Section

The strength of the weld is not usually equal to that of the original part. To compensate for this and to secure a small factor of safety, the weld section should be reinforced when conditions permit, as shown by Fig. 62. In order that the center line of the weld section will coincide with the center line of the stress, the reinforcement should be equal on each side. The value of excessive reinforcements applied to one side of a joint is impaired when the part is in tension, because of the bending strain imposed on the joint. A joint of this kind is equivalent to a corrugation in a plate and when placed in tension is subject to the same forces.

Various Designs of Welds and Types of Joints Depending on Service Requirements.—The names used under the subjects, Type of Joint, Design of Welds, Position of Weld, Kind of Weld, and Type of Weld, are recognized as being proper, and have been made standard by the United States Navy. It is to be hoped that this nomenclature will be used generally in order that those interested will use the same welding terms. This is especially necessary when preparing plans and specifications for use in field or shop. Figs. 58 and 63 show the various designs of

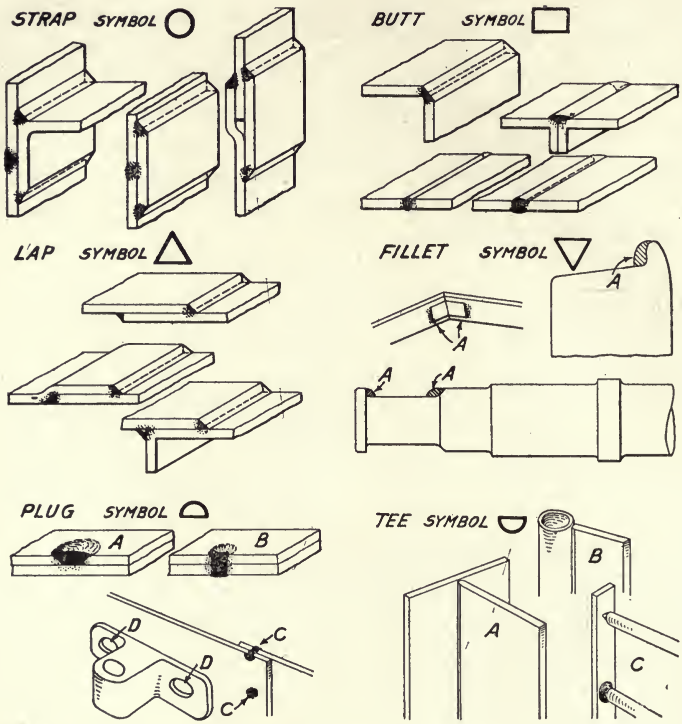


Fig. 63—Types of Joints

welds and types of joints mentioned in the following discussion:

Single "V" is a term applied to the "edge finish" of a plate when the edge is beveled from both sides to an angle; this is 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.

Note: A 45-deg. bevel is the most common angle for a *Single "V"* edge finish. The following table is recommended for spacing indicated in Fig. 63 for *Single "V," Double "V"* and *Double Bevel:*

Thickness Plate	Space
Above 1/16 in. to 1/8 in.	1/32 in.
Above 1/8 in. to 1/2 in.	1/8 in.
Above 1/2 in. to 3/4 in.	3/16 in.
Above 3/4 in.	1/4 in.

Double "V" is a term applied to the "edge finish" of two adjoining plates when the adjoining edges of both plates are beveled from both sides to an angle. 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.

Note: A 30-deg. bevel is the most common angle for a *Double "V"* edge finish.

Straight is a term applied to the "edge finish" of a plate when this edge is left in its crude or sheared state. Should only be used for thick plates where maximum strength is not essential, 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 with plate of not more than 3/16 in. thickness or when the edges of two plates set vertically to each other, as the edge of a box.

Single Bevel is a term applied to the "edge finish" of a plate, when the edge is beveled from one side only to an angle. 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 is a term applied to the "edge finish" of two adjoining plates, when the adjoining edges of both plates are beveled from one side only to an angle. To be used where maximum strength is required, and where the electrode can be applied from one side of the work only.

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 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 projection caused by other individual objects as frames, straps, stiffeners, etc., or the building up of the weld proper.

Lap weld is one in which the edges of two planes are set one above the other, and the welding material is so applied as to bind

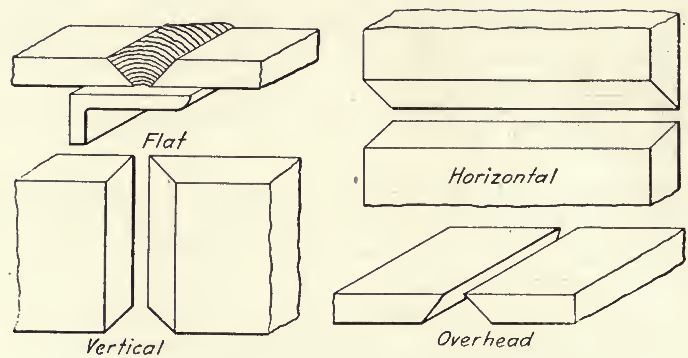


Fig. 64—Position of Welds

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.

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 or when metal is added in a corner as indicated—see "welds" shown and marked *A*, (Fig. 63.) The welding material is applied in the corner thus formed and is finished at an angle of 45 deg. to the plate.

Plug weld is used to connect the metals by welding through a hole in one plate as at *A*, or both plates as at *B;* also used for filling through a bolt hole as at *C*, or for added strength when fastening fixtures to the face of a plate by drilling a countersunk hole through the fixture as at *D* and applying the welding material through the hole, thereby fastening the fixture to the plate.

Tee weld is one where one plate is welded vertically to another as at *A;* also used for welding a rod in a vertical position to a flat surface, as the rung of a ladder, as at *C,* or a plate welded vertically to a pipe stanchion as at *B.*

Position of Weld.—The position of a weld is shown in Fig. 64, and is determined as follows:

Flat when the welding material is applied to a surface such that the electrode is held approximately vertical and the metal flows in a downward direction. *Horizontal* when the welding

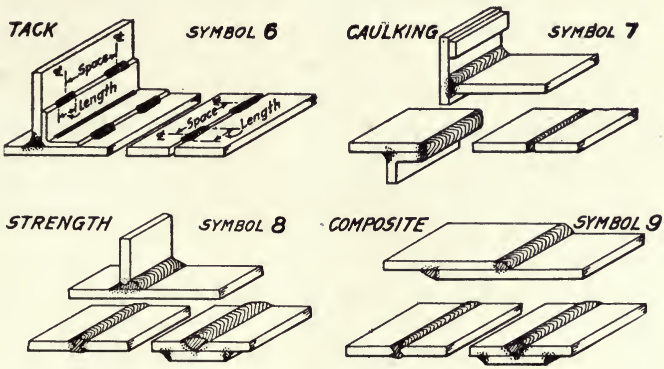


Fig. 65—Kind of Welds

material is applied to a seam, the plane of which is vertical to the floor and the line of weld is parallel with the floor. *Vertical* when the line of weld is perpendicular to a horizontal plane. *Overhead* when the welding material is applied to a surface such that the electrode is held approximately vertical and the metal flows in an upward direction.

Kind of Weld.—A *Tack* weld is one in which the welding material is applied in small sections to hold two edges together, and should always be specified by giving the space from the center of one weld to the center of the next and the length of the weld itself. Can be used with any design of weld. A *Tack* weld is also used for temporarily holding material in place that is to be welded solid until the proper alignment and position is obtained;

in this case neither the length, space or design of weld are to be specified. Illustrated in Fig. 65.

A *Caulking* weld is one in which the density of the crystalline 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 lb. per sq. in. The ultimate strength of a caulking weld is not of material importance. The operator must be the judge as to the number of layers needed for a tight weld, although the designer should specify a minimum number of layers. Illustrated in Fig. 65.

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 to at least 80 per cent 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 crystalline metals is not of vital importance. The design of weld must be specified by the designer and followed by the operator. Illustrated in Fig. 65.

A *Composite* weld is one in which both the strength and density are of 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 operator must be in a position to know if this number should be increased according to the welders' working conditions. Illustrated in Fig. 65.

Type of Weld.—*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 *A* or *B* (Fig. 66), or when used for a corner as at *C*. The top of the final layer should project above a plane which is 45 deg. to the adjoining material; this plane is shown by the dotted line in *C*. This type of weld is chiefly used in a *strength* or *composite* kind of weld for the purpose of obtaining the maximum strength, and should be specified by the designer, together with a minimum number of layers of welding material.

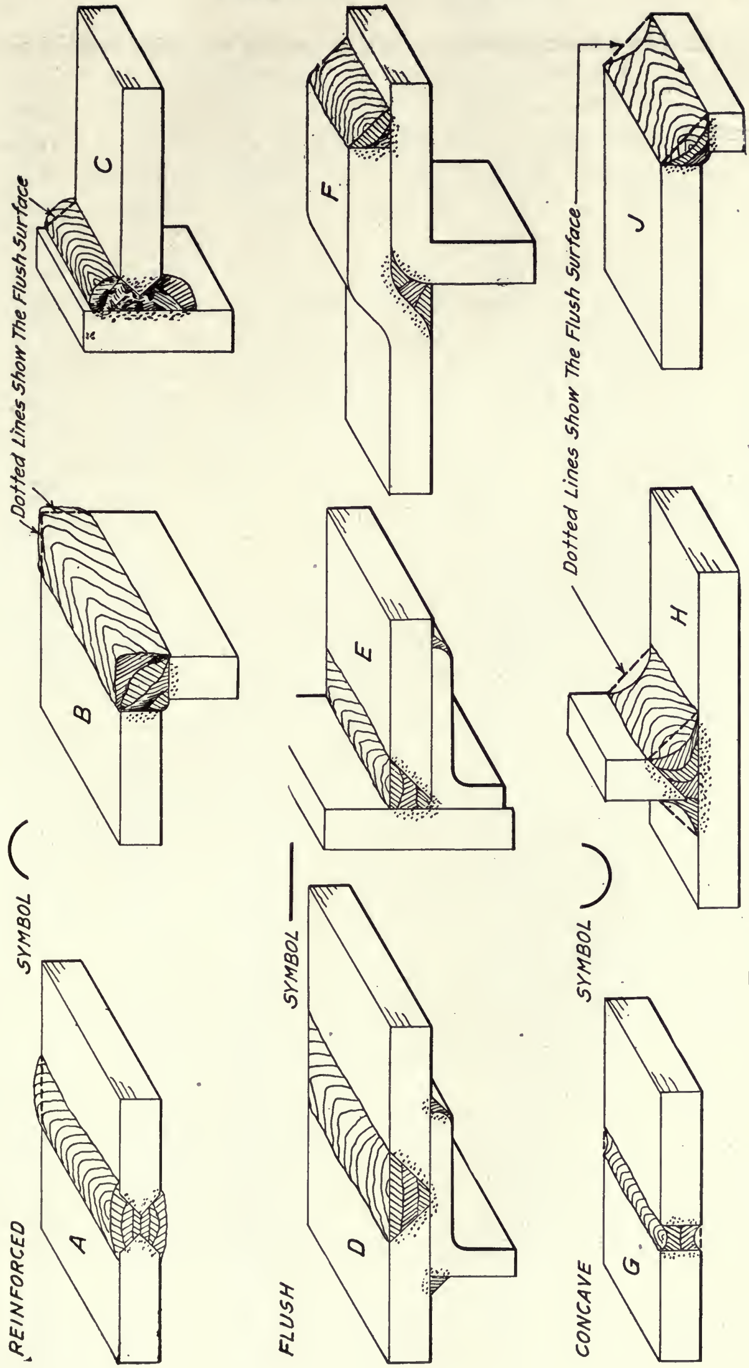


FIG. 66—Type of Weld—Reinforced, Flush and Concave

Flush is a term applied to a weld when the top layer is finished perfectly flat or on the same plane as the adjoining material, as at *D* and *E,* or at an angle of 45 deg. when used to connect two surfaces at an angle to each other as at *F.* This type of weld is to be used where a maximum tensile strength is not important and must be specified by the designer, together with a minimum number of layers of welding material. Illustrated in Fig. 66.

Concave is a term applied to a weld when the top layer finishes below the plane of the surrounding material as at *G,* or beneath a 45 deg. plane at an angular connection as at *H* and *J;* this type of weld to be for work of no further importance than filling in a seam or opening, or for strictly calking purposes, when it is found that a minimum amount of welding material will suffice to sustain a specified pound per square inch pressure without leakage. It will not be necessary ordinarily for the designer to specify the number of layers of material, owing to the lack of structural importance. Illustrated in Fig. 66.

Conditions will determine the design and type of joint that can be used, and the service requirements will determine the kind and type of weld. For example: If a square sheet is to be welded in a locomotive firebox, the vertical seams should be designed for a double bevel and the horizontal seams for a single bevel, with the unbeveled edge below the beveled edges in both cases. A good rule to follow in this connection is never to remove more of the original material than is necessary to secure fusion through the entire thickness of the parts to be joined. The welding positions in this case would be horizontal and vertical. The butt type of joint would be used. The kind of weld would be a *strength,* and the type of weld, *reinforced.*

In preparing plans embodying welds, symbols may be used, some of which are shown in Figs. 58, 63, 65 and 66, to designate Type of Joint, Design of Weld, Position of Weld, Kind of Weld, and Type of Weld.

Welding of Metal—Thin to Thin and Thin to Heavy.—Thin pieces, 3/32 in. and less, require no beveling, and in most cases no metal is added. The edges may be butted together, or preferably upturned. They can then be fused together, using a low current with a ½ in. electrode of carbon or graphite approximately 6 in. long tapered to 1/8 in. at the end. A certain amount of skill is required in welding thin pieces, but a little practice will soon enable an operator to do good work. Wire netting, etc., is welded together in the same manner as thin plates. Carbon blocks, pieces of cast iron or copper are used sometimes for a backing to conduct the heat away and prevent the melting of the edges.

In welding thin pieces to heavy pieces, the conditions will govern the preparation of the work. In some cases this class of welding is more difficult to do than is the welding of parts of equal thickness. In general, however, the electric process is better adapted to such work than any other form of autogenous welding.

An example of this class of work is to be found in the welding of boiler tubes to the tube sheet. The metallic arc is about the only process commercially used. The thickness of the tubes is usually 1/8 in. and the tube sheet 5/8 in. The heat used must be sufficient to bring the thicker part up to fusion; this will tend to penetrate through the thinner part where the difference in thickness is very great. The work is accomplished by playing the greater portion of the arc's flame on the heavier piece.

Preparation of Cylinders and Vessels for Welding.—In general, the preparation of cylinders and vessels upon which welding is to be done will be governed by the service which determines the stresses that may be expected to be imposed upon the line of the weld. For vessels that are not to be subjected to high pressures or rough handling, the least expensive method is the most desirable, two examples of which are shown in Figs. 67 and 68.

For vessels which are to contain gases or liquids under high pressure, the weld should be in tension or compression, and not prying or binding. A butt-weld head of good design with the weld in tension is shown in Fig. 69. A concave head with the weld in compression is shown in Fig. 70, which is by far the better and stronger construction. Vessels having heads welded in as shown in Fig. 70 have been subjected to a pressure of 3,600 lb. per sq. in. before rupture occurred.

Longitudinal Seams and the Preparation of Pipes and Tubes for Welding.—In welding longitudinal seams on round tanks, it is first necessary to have a perfectly round shell; that is, the joining ends of the sheet should *not* have a flattened section, as is customary when coming from the bending rolls. A flat surface along the line of weld has a tendency to round out under

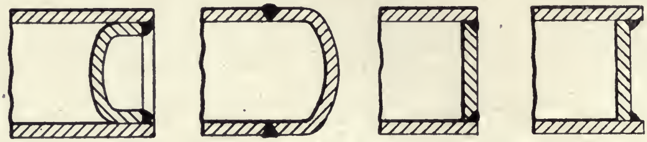


FIG. 67 FIG. 68 FIG. 69 FIG. 70

FIGS. 67 to 70—Preparing Cylinders and Vessels for Welding

pressure, and in so doing places a bending strain on the weld, which is often the cause of rupture. The "edge finish" should be beveled and a butt type of joint used. The contraction can be allowed for by a greater separation at one end than at the other

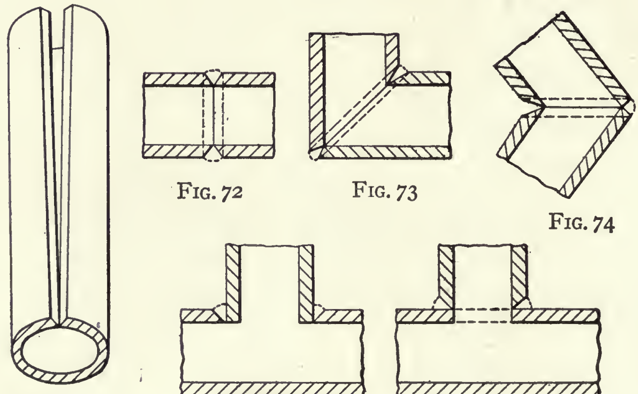


FIG. 72 FIG. 73 FIG. 74

FIG. 71 FIG. 75 FIG. 76

FIGS. 71 to 76—Preparation of Longitudinal Seams, Pipes and Tubes for Welding

as shown in Fig. 71. The amount of opening should be determined as previously explained.

In joining pipes together so as to form a straight piece the ends should be beveled as shown in Fig. 72. Pipes that are to be joined to form angles should have the ends prepared as shown in Figs.

73 and 74. Branches should be prepared as shown in Figs. 75 and 76. Many pipe fittings of various kinds are constructed by the arc process, and their preparation is governed largely by service requirements and the conditions under which the operator must work.

IX

IRON AND STEEL AND THE WELDING OF EACH; WELDING OF NON-FERROUS METALS

Iron ore is combined usually with oxygen, carbon, silicon, sulphur and phosphorus, the combinations being known as iron oxide—brown or red in color—iron carbonate, iron silicate, iron sulphate, iron phosphate, etc. The mining of this ore and its conversion into iron and steel products forms one of the world's greatest industries. The ore is smelted in blast furnaces to produce metallic iron. The process consists essentially of the removal of the oxygen, which is combined with the iron. The product, however, is not chemically pure iron. Pure iron is a laboratory product and on account of the high cost of production, it is not used commercially. The metal which comes from blast furnaces is known as pig iron and contains the following elements: iron, carbon, silicon, manganese, sulphur, phosphorus, and minute quantities of gases, oxygen, nitrogen, etc. Solid solutions and chemical compounds of these elements exist in the metal but for the purpose here desired it is sufficient to state that these elements are present in the metal in some form.

Various Kinds of Iron and Steel.—Cast iron, steel, and wrought iron constitute the group of products which we classify under the names *iron* and *steel.* These products have two points in common: First, iron is present in all cast iron to the extent of at least 92 per cent, and in steel and wrought iron the per cent varies usually from 97 to 100; second, the per cent of carbon present and the form or physical condition in which this carbon exists in the metal is the chief factor governing the physical characteristics of the finished product.

Pig iron is impure, weak, and is brought to its desired form by melting and casting in a mold. Cast iron is pig iron cast into some desired commercial shape.

Steel is purer than cast iron. It is much stronger, and may be produced in the desired form, either by melting and casting in a mold or by forging at a red heat. Forgings usually contain about 98 per cent, or more, of iron and from 1.5 per cent down to almost no carbon, together with small amounts of other ingredients or impurities.

Wrought iron is almost the same as the very low carbon steel, except that it is never produced by melting in a mold, but is forged to the desired size and form. In general it contains less than 0.12 per cent carbon. Its chief distinction from low carbon steel is that it is made by a process which works it in a pasty instead of a liquid form, and leaves about 1 or 2 per cent of slag mechanically disseminated through it.

Cast Iron; Gray, White and Malleable.—Cast iron has three forms; namely, gray cast iron, white cast iron, and malleable cast iron. The following is a typical analysis of cast iron:

Element	Percentage		
Carbon—			
Combined carbon	0.50	to	0.75
Free carbon, or graphite	2.75	to	3.00
Silicon	1.00	to	3.00
Manganese	0.50	to	1.00
Phosphorus	0.50	to	1.00
Sulphur	0.085	to	0.15
Iron	94.665	to	91.10
Total	100.000		100.00

Gray cast iron and white cast iron may have about the same total amount of impurities. The amount of free carbon in the form of graphite in gray iron is very large. This gives the gray appearance which a fracture shows and from which the name is derived. Graphite having no strength of its own and being present in the metal, breaks up the metallic structure of the body, thus leaving lines of weakness. Gray cast iron usually contains 2 per cent or more of graphite, and less than 1½ per cent of combined carbon. The graphite is not in chemical combination with the metal, but is mechanically mixed with it.

Silicon, sulphur, phosphorus, and manganese, all have an influence upon cast iron. Three per cent or less of silicon tends to decrease the amount of combined carbon and consequently decreases the hardness of the product. Sulphur and phosphorus are the impurities which tend to weaken iron most, disregarding their influence on carbon. Manganese has a varying effect. For the purpose here desired it is sufficient to state that manganese assists in counteracting the bad effects of sulphur; also it varies the degree of hardness.

Some of the disadvantages of cast iron are its weakness and lack of ductility and malleability. The last named deficiency renders it undesirable for many commercial and engineering purposes. It is used for castings that are to be subjected only to compression or moderate transverse or tensile strains; as for example, supporting columns, engine bed-plates, water mains, etc.

The chief advantages of cast iron are cheapness and the fusibility which makes it easy to melt and cast the product. The tensile strength of cast iron is about one-half that of steel, being approximately 28,000 lb. per sq. in. for soft iron. Cast iron has no elasticity and there is no elongation before rupture.

Welding of Cast Iron.—It is difficult to weld cast iron by any process under the most favorable conditions, due to the high percentage of impurities, low tensile strength, and above all the effect of a localized heat. Its brittleness, lack of elasticity and weakness also complicate matters. In the case of metallic arc welding, expansion and contraction are minimized to a greater extent than with any other welding process, owing to the extreme localization of the arc flame.

When the electric arc is used for cast iron welding, about the only precaution exercised is to hold the heat in the casting to a low value by using a small size electrode with a correspondingly low heat value, and even in some cases prolonging the work. The metal should be applied in sections as has been described in a previous part of this book.

The welding of cast iron by the carbon arc requires essentially the same precautions regarding expansion and contraction as is required with the oxy-acetylene process, in which case pre-heating is usually employed unless the parts are small and free to move, in which case pre-heating may not be necessary.

The effect of the heat from the arc on the part to which it is applied is the most difficult obstacle to overcome in welding cast iron. The condition produced by the application of an arc on cast iron, especially the metallic arc, is the equivalent to that employed to produce white cast iron; that is, when a localized heat is applied to a piece of cast iron a small area is brought up to a state of fusion and as the localized heat is moved to another location the first point heated will chill, or cool suddenly and prevent the precipitation of the carbon in the form of graphite; in other words the carbon will be left combined in the iron, leaving it very hard and difficult to work.

For example, assume that metal has been added to a gray iron

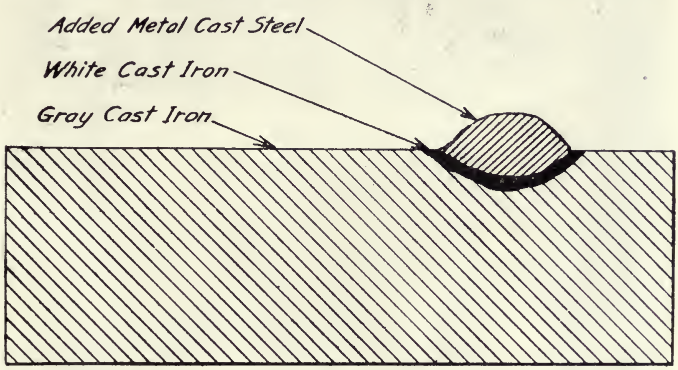


FIG. 77—In the Completed Weld There Are Three Kinds of Metal

casting by the metallic arc process, which requires the use of an iron or steel electrode. In the completed weld there are three kinds of metal as shown in Fig. 77. The original gray cast iron immediately under the added metal or under the line of union has been changed to white cast iron on account of the chilling effect; above the white cast iron is the added metal, cast steel, the first layer of which is very hard, on account of the carbon in the cast iron combining with the steel when the two were in a molten state; in fact a portion of this first layer might be called semi-steel and on cooling small checks usually develop. The second layer is much softer, and can be machined without difficulty.

Machining the Parts Welded.—If the casting is to be machined in the welded section, it must first be annealed. In practice this is seldom done, because there are methods which make it unnecessary to machine through the welded section, thus avoiding pre-heating or annealing. For example, broken cast iron locomotive cylinders are often repaired by first boring them out and applying a bushing. The fracture is then V'd out in the usual manner and iron studs are placed along the line of weld. Fig. 78 shows a weld prepared in this manner partially finished.

The studs serve a double purpose; that is, the welding is started

Fig. 78—Broken Cast Iron Locomotive Cylinder, Left Side Showing Fracture Partially Welded with Arc Welder

around the studs, which makes the depositing of the metal easier, and also since the studs extend through the line of union as well as through the heat affected zone, a factor of safety is assured. Without the studs the heat affected zone usually develops checks, and finally complete rupture when subjected to alternate stresses.

Another method by which machining through the heat affected zone may be avoided in the case of welding cylinders or similar parts, is shown in Fig. 79. The soft iron or copper rod insert can be worked into place with a peening hammer and afterwards be machined, or filed and scraped, to conform to the contour of the cylinder. In either case it is possible to bore the cylinder if necessary. The methods indicated above are used extensively and are known to be successful in connection with metallic arc welding.

There are many cases where a surface can be finished with a grinder; as for example, to secure a smooth surface for a steam tight joint. There are also many cases that do not require finishing of any kind along the line of weld.

The welding of cast iron by the carbon arc, in most cases, requires a method very similar to that used in connection with the oxy-acetylene process, since the area heated by the carbon arc process is not so localized as that of the metallic arc. It is therefore not only necessary to take very special precautions to prevent bad effects from expansion and contraction, but it is also necessary that the line of weld should consist of metal that is workable.

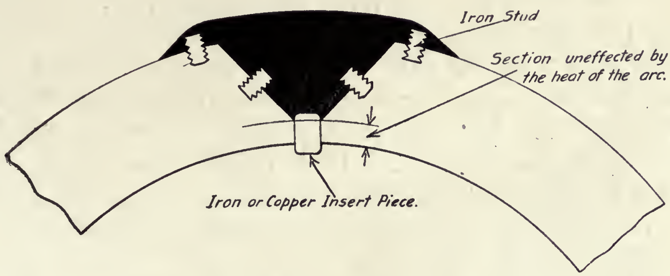


FIG. 79—Method of Welding Used to Avoid the Need of Machining Through the Heat Affected Zone

The conditions to be observed in order to produce a weld in gray iron that is workable are: (1) Slow cooling. (2) Introduction of silicon in the welding bed. (3) Absence of manganese. It will be remembered that rapid cooling of the metal in fusion tends to bring about the combination of the carbon and the iron; that is to say, the formation of white cast iron, which is undesirable. On the other hand, slow cooling tends to bring about the precipitation of the carbon producing a soft iron. The silicon assists in decreasing the combined carbon, thus opposing hardness. The effect of manganese is opposite to that of silicon and is therefore undesirable. The effects of expansion and contraction are provided for by pre-heating every part of the object, or by any other treatment to bring about the same result.

The question of cast iron welding is very important; on this account the authors solicited the following contribution from Robert E. Kinkead, welding engineer.

Reclamation of Cast Iron Parts

"The salvage of broken and defective gray iron castings is one of the most important fields in which welding plays a part.

"A gray iron casting may be worth from three to twenty times its scrap value due to the labor and machinery required to get it into a form which has utility for a particular purpose. If the casting is broken or slightly imperfect in the foundry it has no utility whatever for the purpose for which it was intended. Assuming that the casting is broken in service, the parts have only a scrap value. The labor and other charges which were incurred in getting the metal into the form required are entirely lost. When it is considered that thousands of tons of material of this nature are scrapped every year, the enormous economic waste from this source may be realized.

"Another phase of this subject and one in which the economic loss is inestimable arises from the loss due to the failure of castings which in turn cause loss of production. There is no doubt but the economic loss from this source approaches the economic loss due to the loss of labor and expense in the manufacture of the casting itself.

"The earliest method of welding cast iron was developed in the foundry. In this case the process is called 'burning a casting.' The casting is imbedded in foundry sand and sufficient hot metal run over the fractured part to bring it up to a high enough temperature to make the metal plastic. At this point the pouring of metal is stopped and the metal at the point to be welded is allowed to cool into a homogeneous mass with the metal of the original casting. This method of 'burning' defective or broken castings is entirely successful but is somewhat expensive.

"The introduction of the thermit and oxy-acetylene welding processes brought about successful means of repairing practically any defect or break ever encountered in gray iron castings. The work of these two processes is nothing short of marvelous. It is only necessary to visit a few of the commercial welding shops in the country to see the wide variety of castings that are welded and put back into service, for all practical purposes as good as new.

"The use of the thermit and oxy-acetylene welding process is somewhat expensive. What is saved by their use is in most cases the loss of production or use of the casting due to the fact that a replacement part is not immediately available. In many cases, the cost of applying either of these processes is equal to or greater than the cost of a new casting.

"In applying the electric arc welding process to the welding of cast iron, we are attempting to lower the cost of the welding so that in addition to the saving which can be accomplished using the thermit and oxy-acetylene processes, we can save a large percentage of the cost of the labor involved in manufacturing the casting. The development of the application of the electric arc welding process to the welding of cast iron has gone forward slowly for a number of very apparent causes. The most important cause for the delay in the application of the electric welding process to cast iron is probably the difficulty of its application. Another important factor is that the cost of electric arc welding equipment is comparatively high so that the number of operators who have had an opportunity to work on the problem is somewhat limited. In spite of the difficulties some progress has been made. It seems certain that the electric arc process will be used quite extensively in the future in this class of work for the reason that whenever it becomes possible to do a job at a lower cost than it has been done heretofore that new process becomes economically necessary.

Cast Iron Welding by Metallic Arc

"Some important work has been done with the metal electrode process in the welding of gray iron castings cold. Among certain welding interests the tendency is to over-estimate the importance of this application and to under-estimate the dangers which would be encountered if this practice should ever become general. The work done in this manner is accomplished by merely fusing a steel electrode to the cast iron. Steel studs are inserted in the edges of the cast iron pieces to be welded and the welded material is bridged between the studs as well as being fused to the cast iron of the original pieces.

"The ultimate strength which may be expected from such a joint is the shearing strength of the studs, minus the strength of the original pieces sacrificed by the drilling of the holes for the studs, plus whatever strength is obtained by the fused joint between the steel and the cast iron. This latter strength is sometimes estimated at a maximum of 5,000 lb. per sq. in. However, actual experience shows that no reliance can be placed on such a joint between steel and gray iron. The difficulty with such a joint is fundamental. If a casting is not pre-heated, the cast iron adjacent to the line of fusion is hard and brittle because of the fact that it was melted and cooled very suddenly.

"On the steel side of the weld, if fusion is accomplished between steel and cast iron, owing to the high solubility of carbon in steel a certain amount of carbon from the cast iron is absorbed by the steel added, thus giving a high carbon steel adjacent to the line of fusion on the steel side. There are a number of applications where this kind of welding is entirely satisfactory and results in a large economic saving, but wherever the failure of a welded casting carries with it possibilities of death and destruction, such a joint should be used with great caution.

"A great many attempts have been made to get around the fundamental metallurgical difficulties encountered in this kind of work but so far no one has been able to put anything in the welding wire or on the electrode or on the cast iron that materially changes the fundamental limitations of the process on this application.

Cast Iron Welding by Carbon Arc

"Welding gray iron castings with the carbon electrode electric arc welding process using a cast iron melt bar has been shown to be entirely practicable over a wide range of applications. The only difference between this method of welding and that by the oxy-acetylene process is that the source of heat for welding is an electric arc instead of an oxy-acetylene flame. It is quite true that the difficulty in manipulating an electric arc is somewhat greater than the difficulty in manipulating an oxy-acetylene flame. The reason the arc is difficult to manipulate is that the operator must use the full temperature of the arc or must break it entirely. There is no intermediate point between.

"The corresponding case in the oxy-acetylene welding is that in which the operator believes he is getting the metal too hot and can merely back away from the casting with the torch, thus reducing the temperature but without breaking the continuity of the welding heat. The particular difficulty encountered in the manipulation of the arc owing to this fact arises in the case of thin sections where the tendency is for the arc to burn through; also in the welding of vertical or practically vertical surfaces. The temperature of the arc is so high that the metal runs rapidly and it is extremely difficult to weld on a vertical surface. With the oxy-acetylene flame the temperature may be reduced so that the iron is in such a plastic state a vertical weld may be accomplished.

Future Development of Cast Iron Welding Methods

"Some experiments are being carried on at the present time using a cast iron electrode and using the metal electrode process of electric arc welding. In order to work the metal this way, it is necessary to have some kind of a covering for the cast iron electrode to make the cast iron run with a reasonable degree of smoothness through the arc. The possibilities of this method of welding cast iron with the electric arc process seem to be great.

"In welding cast iron either with the carbon arc and cast iron melt bar, or with the metallic arc using cast iron electrode, it is necessary to pre-heat the casting in exactly the same manner as if it were being welded with the oxy-acetylene flame. Care in cooling must be exercised to the same degree as if the gas flame were used.

"Work is also being done at the present time in the direction of using two carbon electrodes and not using the gray iron casting as one electrode. The object here is to get the carbon arc independent of the casting and to make it possible for the operator to reduce the temperature and total heat applied to the point at which the welding is to be done in much the same manner as he can do when using the gas flame. This, should it prove successful, would enable the operator to work the iron at a temperature at which it is plastic and would overcome the most important difficulties in the way of welding cast iron with the electric arc process. So far the apparatus produced for this method of welding has been cumbersome and difficult to manipulate but there seems to be a field for improvement of the apparatus and there is reason to believe that the difficulties will be overcome.

"Some very interesting and original work was done several years ago by Mr. L. B. Brewster, who was at that time chief chemist of the Ferro Machine & Foundry Company at Cleveland, Ohio. He developed a method of repairing small defects in gray iron castings using a nickel electrode. The advantage of this process as compared with the use of a steel electrode is that the nickel cannot be hardened by the absorption of carbon from the cast iron. The line of demarkation in such a joint between the nickel and the cast iron is an example of adhesion rather than an example of cohesion. There is an inappreciable degree of strength in the joint. Where a small defect is filled with nickel by this process the nickel is peened into the defect with a hammer so that the small spaces are filled up with nickel and the added material is held in place mechanically rather than by a fused joint. This process is in every way similar mechanically to the process the dentist uses in filling a cavity in a tooth using a mercury silver amalgam. Since the coefficient of expansion of nickel is somewhere near the coefficient of expansion of cast iron, no difficulty is experienced from the added material coming out over the heat range encountered in most castings. The nickel is somewhat softer than cast iron and on a wearing surface no difficulty is encountered from this source. However, the limitation of the process comes from the fact that if the cast iron is actually melted by the arc, and it in most cases is, a hard line is left around the margin of the defect filled in this manner. This hard line interferes with machining to a certain extent.

"In spite of the difficulties mentioned, a number of concerns are using this process in the correction of small defects in automobile cylinder engines. In this case by skillful manipulation the nickel is anchored in the bottom of the defect and the arc is not allowed to strike anyway near the machined surface of the cylinder. The nickel is peened securely into the defect and the excess is filed or scraped away.

"Some work has been done using brazing wire for the metal electrode in the electric arc process. A brazing job accomplished in this manner is not very reliable for the reason that fusing the brazing rod, the zinc is vaporized sooner than the other elements of the metal and this causes violent bubbling and porosity of the added brass.

"The status of the application of electric arc welding to the welding of gray iron castings at the present time may be summarized as follows:

"With reference to the oxy-acetylene and thermit processes which are recognized as successful processes at the present time, the carbon electrode method of welding with the electric arc can be used on sections thicker than a quarter of an inch, where the weld may be made in the horizontal position, as well as either of the other two processes and at a considerably lower cost. In this case the electric arc is used as a source of welding heat and the practice followed is from a metallurgical point of view the same as in the case of the oxy-acetylene flame. There is no greater danger of hardness of the weld when properly treated in the case of the electric arc than in the case of the oxy-acetylene flame. On certain specific applications the steel electrode and metal electrode process is entirely practicable and much cheaper than any process so far used,—but great care must be used in its application to avoid disastrous failures."

White Cast Iron.—White cast iron is made of metal of the same chemical composition as is used to make gray iron castings. The molten metal is cast in cold molds and is thereby "chilled." It is evident that no very great change in the chemical composition could take place in this chilling process. However, the sudden cooling denies the carbon the time to change into the graphitic form. Chilled iron is hard and brittle. The white appearance of the fracture of the metal reveals its name, and is due to the comparatively small amount of free carbon present in the metal.

There are cases where it is desirable to have one surface of a casting very hard in order to resist wear, such as the tread of car wheels and the working face of anvils, etc. To do this it is only necessary to chill the surface so as to produce white cast iron to varying depths. There is little occasion for welding white cast iron and besides in most cases it is not commercially practicable owing to the effect of the localized heat.

Malleable Cast Iron.—Malleable cast iron has physical properties between gray iron and steel castings. Its tensile strength varies between 40,000 and 60,000 lb. per sq. in. with an elongation of 2½ to 5½ per cent in 2 in. Malleable castings are made by reheating white iron, packed in some material such as lime, etc., heated to a temperature roughly 840 deg. Fahr. under its melting point. They are kept at this temperature for hours or days and under these conditions the combined carbon as it existed in the form of white iron is freed in the form of powdered graphite, unlike the graphite in gray iron which is in the form of flakes. Since ferrite or free iron is soft and malleable the annealed casting partakes of these properties and is called a malleable casting. Annealed castings seldom show the effects of the annealing throughout the entire mass; as a rule the annealing does not produce a noticeable effect beyond a fraction of an inch below the surface of the casting. Usually fractures of malleable cast iron show black centers and thin white rims or bands around the outer edge. This outer band is practically pure iron due to the burning out of the carbon of the outer portion of the casting.

Malleable cast iron is especially valuable and is used very largely for railroad work. At one time malleable cast iron was used extensively for couplers, but now steel castings are used. Indications are that gray iron is being replaced by malleable iron, while on the other hand malleable iron is being replaced by cast steel. Malleable iron is used extensively for parts of agricultural machinery and for many other purposes to which it is especially adapted.

Welding of Malleable Iron.—The correction of flaws in malleable castings by the arc welding process effects very large savings in the foundry. Such welding is always done after the casting is annealed and made into a malleable casting. Properly annealed castings will show just a thin skin of white iron on the outer edge. The annealed section is essentially low carbon cast steel.

The work may be welded with either the carbon or metallic electrode process. Due to the thinness of the annealed section a current as low as consistent for good fusion is used.

If the casting is to be machined in the welded section, it is reannealed. This is usually necessary owing to the fact that the heat of the arc will in effect reverse the annealing process. That is, the carbon which was set free as graphite by the annealing is dissolved in the iron again when the metal becomes molten in the heat of the arc. The carbon in combination with the iron makes the casting hard. In some cases, such as the welding of heavy sections, the same methods as outlined for gray iron welding are also required for malleable castings.

Until recently it has been a difficult matter to obtain a union between the added metal and the casting. This trouble, however, has been eliminated almost entirely by using a coated electrode for metallic arc welding. The extreme hardness and checks of the added metal, always present, at least in the first layer where a bare electrode is used, are largely eliminated.

Wrought Iron.—In the production of wrought iron the common practice is to place raw material such as scrap, pig iron, etc., in an open hearth furnace. Heat is then applied and as the metal becomes pasty the mass is continually raffled; slagging agents are introduced to purify and deoxidize the charge. After the metal has been raffled sufficiently the pasty mass is placed in what is known as a squeezer and as much of the slag as possible is squeezed out; some slag, however, always remains. The mechanical treatment consists of squeezing this slag out of the metal and rolling it into bars of a convenient shape, called "merchant bars."

The quality of wrought iron is a function of its purity, i. e., its freedom from every substance except iron or ferrite. Norway and Swedish iron has been heretofore the purest iron ore which could be obtained in commercial quantities, due principally to the fact that the ore of these countries does not contain phosphorus or sulphur. The traces of these impurities found in all American iron are sufficient to render it inferior in quality to the imported stock.

Wrought iron is used as a base in the manufacture of the highest quality of crucible steels, owing to its purity. The tensile strength of wrought iron is approximately 50,000 lb. per sq. in. It is malleable and does not harden materially when it is subjected to sudden cooling.

The welding of wrought iron is safe and legitimate and good practice. No bad effects from the heat of the arc flame need be feared since the carbon is usually less than 0.12 per cent, which is not sufficient to give any hardening effect should the mass of the part be such as to cause sudden cooling. It should, however, be remembered that the metal added by the arc process is cast metal and has a lower degree of elasticity.

Steel.—Steel is produced either by the Bessemer or the open hearth process. It is known as acid or basic steel, according to the character of the lining used in the Bessemer converter or open hearth furnace. The basic lining has a fluxing action which assists in removing impurities such as sulphur or phosphorus, whereas in the acid lined furnaces the lining has little influence in the removal of impurities; consequently the raw material used should be of higher purity and grade to begin with. Among the elements which are added are: carbon, manganese, nickel, chromium, vanadium and tungsten. In ordinary boiler plate and structural shapes the controlling elements are carbon and manganese. These two elements are the only ones added. The carbon content determines the tensile strength, while the manganese is added to toughen the metal and prepare it for the mechanical treatment in the rolls. Boiler plates and shapes usually contain from 0.2 to 0.3 of 1 per cent of carbon and from 0.4 to 0.6 of 1 per cent of manganese.

After the steel has been given the desired composition it may be drawn from the converter into the ladles, and later poured into molds to make steel castings or it may be drawn from the converter into ingot molds and be prepared for the rolls. If the steel is to be used for forgings, the ingot is sheared into conveniently shaped blocks or slabs called billets. These billets are then subjected to a final mechanical treatment in the drop forging machine. Plates and shapes are castings of steel which have been subjected to mechanical treatment in the rolls.

The distinguishing and active element of steel is carbon. With increase in carbon, the hardness increases, as does its tensile strength, but the ductility (elongation or stretch) decreases. Carbon is the element which confers upon iron the ability to harden when cooled suddenly from a cherry red heat, as by quenching in water or oil. The degree of hardness that can be obtained will vary with the amount of carbon contained in the iron. Mild steel below two-tenths of one per cent will be affected but little by quenching, while steel, with five-tenths of one per cent or more, can be made extremely hard and brittle by sudden cooling.

At any time hardened steel may be returned to its former condition of softness by the well-known process of annealing, by reheating to the same cherry red heat and slowly cooling. As desired, various degrees of hardness may be obtained according (1) to the percentage of carbon in the steel, and (2) the rate of cooling. To relieve strains caused by the rapid cooling, the hardening is usually "tempered" by heating to a much lower temperature and again quenching.

The heat treatment of steel is a broad subject, but it consists essentially of changing the crystalline structure of the steel without changing its chemical composition in order to get certain desirable properties. Neglecting the effect of heat treatment the physical properties of cast steel are determined by the kind and amount of the several impurities which are contained in the metal. Impurities of various combinations are used to get certain characteristics in the steel which seem to meet the requirements of the service demanded of the casting. While there is almost an unlimited number of combinations which may be obtained, the ordinary steel foundry uses a relatively limited number as compared to the possible combinations. Each element produces its characteristic effect on the metal, but the effect on the tensile strength, ductility, toughness and malleability is not necessarily proportional to the quantity of the added element over a very wide range.

It is more difficult to obtain sound steel castings than sound iron casting, since the shrinkage of steel is greater than of cast iron, and checking is therefore more liable to occur. Blow holes, or gas bubbles, enclosed in the body of the metal are especially liable to develop in mild steel castings.

General Effects of Impurities.—The following is a typical analysis of steel castings:

Element	Percentage
Carbon	0.35
Silicon	0.40
Manganese	0.80
Phosphorus	0.05
Sulphur	0.05

The properties ordinarily desired in steel are strength and ductility. Carbon is the most important strengthener. It will increase the strength of the steel with the least decrease in ductility.

Silicon causes brittleness if a high percentage is present in iron or steel. About the largest amount present in any commercial cast steel is ½ of 1 per cent.

Phosphorus is undesirable in any quantity in steel and is eliminated to as great an extent as possible. It causes "cold short" or brittleness.

Sulphur, like phosphorus, is undesirable in steel. It causes "hot short" or brittleness when the metal is red hot or hotter.

Manganese helps to remove the phosphorus and sulphur; it slags these two elements out of the metal. If manganese is present up to about 5 per cent it imparts desirable properties to steel, such as ductility and toughness. Between 1½ per cent and 5½ per cent it has an embrittling action. If present from 10 to 15 per cent it again produces a tough ductile metal, resisting abrasion, etc.

Nickel increases the tensile strength of steel without impairing the elasticity. Nickel steel does not rust as easily as steel without the nickel. The amount used varies from a small per cent up to 3.5 per cent.

Vanadium is similar to nickel in its effect on steel. It is usually present from 0.15 to 0.35 per cent.

Chromium is similar to manganese in its effect on steel. The amount of chromium varies according to the purpose for which the steel is to be used. Chromium has the property to a limited extent of acting as a self-hardener when used in correct amounts.

Tungsten is used in the manufacture of high-speed steels. Tungsten steel has the property of retaining its hardness at high temperatures. Its composition is shown in the following table:

Element	Percentage
Carbon	0.40 to 2.19
Chromium or Manganese	.00 to 6.00
Tungsten or Molybdenum	3.44 to 24.00
Silicon	.21 to 3.00

In order to have a reasonably definite understanding of the structure of a steel casting, the history of the steel from the time it is originated in the converter until it becomes a cold casting should be investigated. Briefly, it may be stated that at the instant the point is reached in the conversion process at which all of the impurities have been removed, which are removable in practice, the metal in the converter contains ferrite, and traces of silicon, phosphorus and sulphur. The manganese, carbon and any other element which may be desired is then added to the molten metal. The relationship or manner of combination of the elements contained in the metal between the time it exists in the ladle as molten metal and the state of a cooled casting goes through several changes. These changes, so far as the silicon, phosphorus and sulphur are concerned, may be neglected, since the rate of cooling has practically no effect upon the relationship.

If the metal is suddenly cooled from a point within the temperature range in which any of these changes take place, the combination of the elements existing at the time the cooling occurred would continue to exist. In other words, the normal cooling process may be stopped at any stage, and a different structure obtained at each point with a corresponding difference in physical characteristics of the metal. The heat treatment of cast steel amounts simply to a reversal of the changes outlined above; that is, raising the temperature of the casting until the desired structure is produced, then fixing it at that point.

Weldability of Steel Containing Impurities.—Little is known at the present time regarding the weldability of steel containing the impurities given above when present in their usual amounts when the electric arc welding process is used. It is known, however, that steel containing 0.5 per cent or more of carbon is subject to "burning" at much lower temperatures than low carbon steels. This fact can readily be observed in arc welding practice, the tendency being toward "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 steels of comparatively 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.

The intelligent solution of welding problems in cast steel, as far as the metallurgical part is concerned, begins with a study of the casting to determine its nature and its characteristics. The welding process amounts simply to the addition of a certain amount of cast steel of a given composition so that a knowledge of the behavior of the metal of the casting as well as of the metal to be added when subjected to the temperature of the arc flame permits us to predetermine accurately what the nature of the complete job may be.

The photograph, Fig. 80, shows a number of blades arc welded in a large cast steel distributing wheel for a hydro-electric turbine at Niagara Falls; these had been broken by an obstruction getting into the turbine. This should give some conception as to the usefulness of the process in repairing fractured cast steel castings.

The chemical analyses that have been made of the metal deposited in the weld, using a bare electrode, show that most of the carbon and manganese is burned out in traversing the arc. However, by the use of coated electrodes to exclude the air from the metal while in a molten state, thus preventing oxidation and the loss of certain constituent parts during the execution of the weld, it is possible to deposit metal of a composition approximately equal to that of the part being welded.

Welding Steel Forgings.—Forgings are simply castings of steel which have been subjected to mechanical treatment under the hammer. This process creates compressive strains, and as the pressure is relieved at once the elasticity of the metal causes it to recover somewhat from the effect. The result of the treatment is, therefore, superficial. Hammering is comparatively a slow process of reduction, but results in a better and more uniform working of the crystals which is the chief reason for the superiority of hammered over rolled metal. In regard to other working conditions concerning the hammering process, perhaps the most important is the extra control over the operation and over the tem-

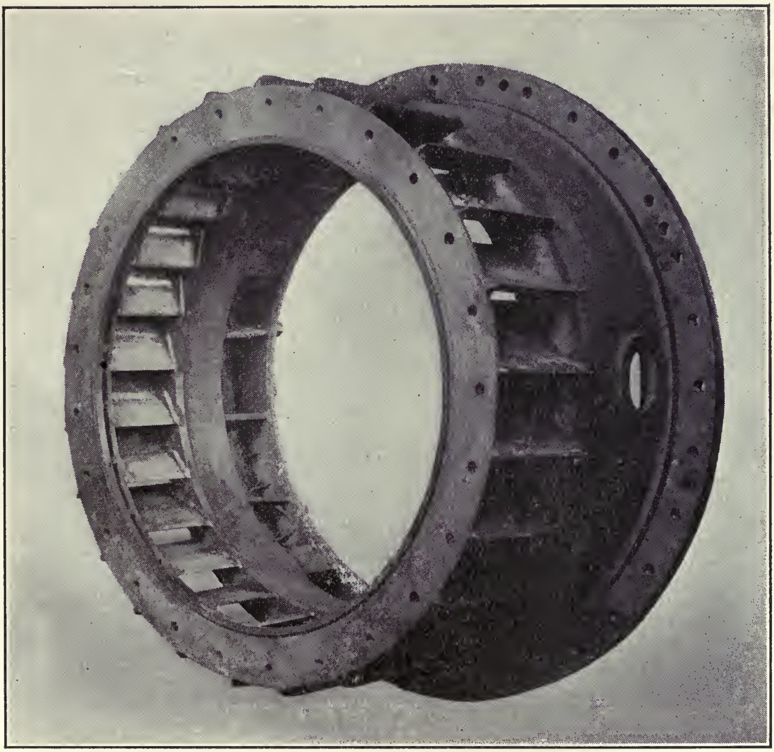


FIG. 80—Fractured Blades Were Welded to This Cast Steel Turbine Wheel by Electric Arc Welding

perature at which the work is finished. These things can be controlled at the discretion of the expert forger.

Drop forgings are directly comparable with steel castings except that they are superior in quality on account of the beneficial effect produced by working. There is a large variety of articles, such as parts of machinery, etc., which are formed by this means. The process consists essentially in placing a piece of heated metal between two dies. The metal is then squeezed into these dies until it has assumed the proper shape. Sometimes more than one set of dies are required to complete the finished article.

Aside from the correction of small flaws before the forging leaves the forge shop, the principal application of the arc welding

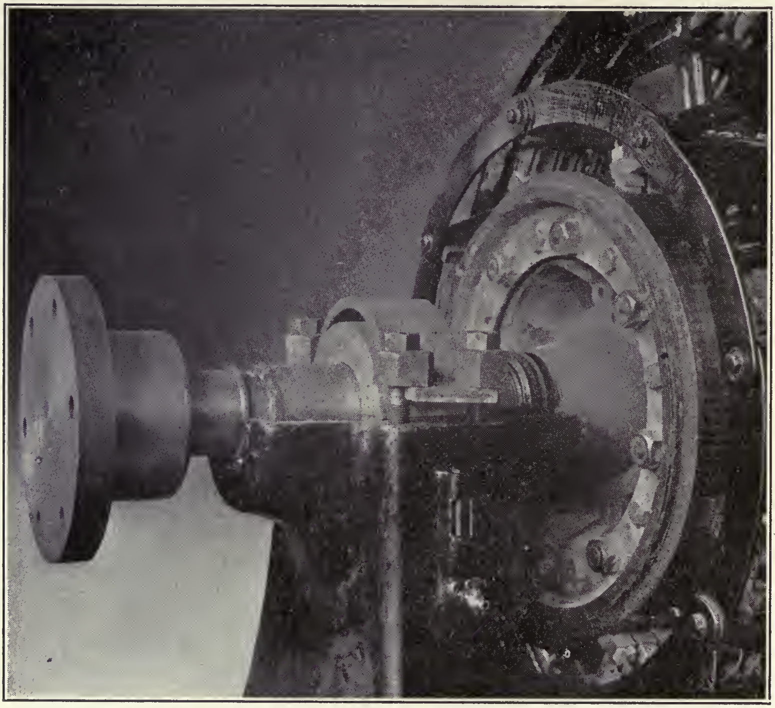


FIG. 81—The Shaft for an Excitor Turbine Was Welded by Metallic Arc Welding Apparatus

process is in the welding of worn and broken parts. The metallurgical problems involved in the welding of forgings are the same as those in the welding of cast steel so far as the character of the metal in the weld is concerned.

In forgings, however, the product has passed through a process of mechanical treatment which improves its quality for certain purposes beyond that of cast steel. The result of this mechanical treatment is greater compactness of the structure with a resultant increase in toughness. Therefore, the welded piece will consist of two grades of metal; the original metal which has received mechanical treatment and the metal added by the welding process which has not received mechanical treatment. In general, the metal added by the welding process will always have the characteristics of cast steel and the original unmelted part will always have the properties of mechanically treated metal. The metal in the weld may be hard or soft, of high or low tensile strength, but it will never have the toughness to resist the tendency to crack in bending to the same degree as the mechanically treated metal.

Up to the present time no cast steel has been produced which has all of the properties to the same degree as are found in any given piece of forged or rolled metal. This limitation of any welding process in which steel is melted should never be lost sight of in welding practice.

The nature of the weld and a study of the stresses imposed upon the part will govern the extent of application of the process to such parts. In a great number of instances forged or rolled parts can be safely and advantageously welded by the metallic arc. Fig. 81 shows a welded shaft of an excitor turbine for a large hydro-electric turbo-generator, which has been completely broken. The weld is located between the two shoulders on the shaft at the end of the bearing case.

The application of the arc welding process on steel plates and shapes which are produced by the reduction of steel ingots in rolls is similar in every way to its application to steel forgings. This is due, of course, to the fact that plates, structural shapes, etc., belong to that class of products which have been subjected to mechanical treatment.

General Conclusions

From the foregoing several general conclusions may be drawn:

(1) The tensile strength of the cast steel in the weld may be made less than, greater than, or equal to the tensile strength of the metal in the original section. This is true for commercial plate only.

(2) The metal may be harder or softer than the metal in the original piece. The tensile strength of the metal in the weld will

vary with the hardness. Burned metal is neglected in this conclusion.

(3) The elasticity of the metal in the weld will always be less than the elasticity of the metal in the original plate.

Thermal Effect of Welding Heat on Parent Metal.—The effect of heat on the material being welded is governed largely by the rate of cooling and the carbon content. The rate of cooling will be determined by the mass of work, shape of the work, and by the manipulation of the arc by the operator. The rate of cooling may be different in different parts of the same weld, with a corresponding difference in character of the metal in different sections. This, of course, is noticeable more in the higher carbon steels than in those which contain around 0.10 per cent of carbon.

When welding steel parts containing carbon above 0.10 per cent that have little or no factor of safety and which are subjected to alternate stresses the effect of the heat must be considered, even though the process is applied only to the extent of building up the part. In some cases, as with parts vital to the operation of machinery, such as piston rods, crank pins, and parts of similar importance, it is advisable to anneal after welding. An example of what may be expected from the effects of localized heat on such parts is shown in Fig. 82 (Fig. 1) which is the result of an investigation of a failed locomotive piston rod on which the cross-head fit had been built up by the metallic arc process. This photographic reproduction shows the area of added metal around the circumference. Between it and the larger section of metal in the rod is an area of metal, scallop shaped, effected by the heat. This illustrates the condition of the metal in the rod at the time it failed. Measurements recorded for the average scleroscope hardness of the section shown in Fig. 1 (Fig. 82) are:

Added Metal	49
Dark Heat-effected Area	80
Metal in the Rod	50

The break resulted from small interior checks resulting in a detailed fracture which developed in the dark heat-effected area after the piston rod had been in service a few months.

Figs. 2 and 3 (in Fig. 82) show sections taken directly opposite to the section shown in Fig. 1. These sections were heated to 1500 deg. Fahr. and held at that temperature for three hours, following which the section shown in Fig. 2 (Fig. 82) was allowed to cool in the furnace, then polished and etched. The section shown in Fig. 3 (Fig. 82) was allowed to cool in the air, then polished and etched. These photographic reproductions show that the

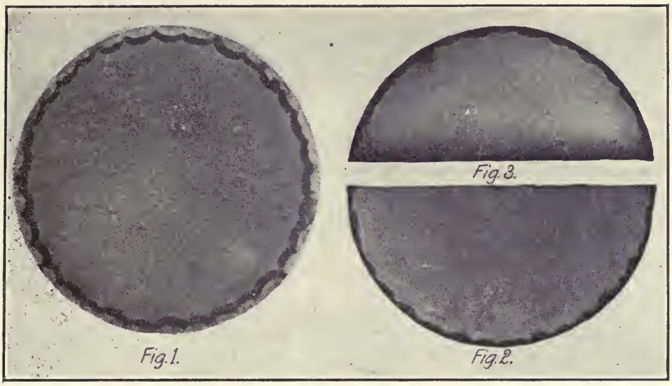


Fig. 82—Sections of Piston Rod Built up by Metallic Arc Showing Effect of Localized Heat and Result of Annealing

annealing process entirely eliminated the hardened area illustrated in Fig. 1 (Fig. 82).

Measurements recorded for the average scleroscope hardness of the section shown in Fig. 2 (Fig. 82) are:

Added Metal	38
Metal in the Rod	55

Measurements recorded for the average scleroscope hardness of the section shown in Fig. 3 (Fig. 82) are:

Added Metal	38
Metal in the Rod	57

The chemical requirements under which the piston rod was purchased were as follows:

Element	Percentage
Carbon—Not less than	0.38 or over 0.52
Manganese—Not less than	0.40 or over 0.60
Phosphorus—Not over	0.045
Sulphur—Not over	0.05

The weld was made with a bare mild steel electrode, which accounts for the difference in the degree of hardness between the added and the original material, as any carbon or manganese that may have been in the electrode material was burned out in passing through the arc. The same conditions develop where other autogenous welding processes are used, and in some cases this heat-effected zone may penetrate further than in the case of the electric welding process.

It is not the intention to convey the idea that it is necessary to anneal all such parts after they have been welded. This would not be consistent with everyday practice. As a matter of fact, most work of this class is done without annealing and with comparatively few failures. However, alloy steels, and especially heat treated steels, are sensitive to heat treatment; this fact must not be lost sight of.

As the question of heat effects is of great importance and has in many cases formed the basis of weld failures the results of an extensive investigation conducted by T. D. Sedwick, engineer of tests, Chicago, Rock Island & Pacific Railroad, is here given. It was included in a paper read before the American Welding Society, Chicago Section, December 22, 1920.

"In case of poor results from fusion welding shown either by laboratory tests or actual service, the inclination is to attribute such results to the material used, the method of making the weld, a poor operator, or the contributing effect of all three of these factors.

"But there are other points that enter into the final results, and two of the important ones are as follows:

"First—Was the metal in the casting or forging in such a physical condition that it was fit to be welded and afterwards give good service; did the metal originally fail on account of the presence of segregation of the various chemical elements; did it contain blow-holes, porosity, or were there thermal stresses left from the original forging or casting operations; had the previous service fatigued the metal to the extent that it was inherently weak?

"Second—Was the original metal adjacent to the weld deleteriously affected by the welding operation?

"Some take the first mentioned factors into consideration, but I do not believe that very many, particularly the shopmen, give much thought to any action which may take place on the original metal. Tests and observations made on failed material and special test specimens have shown that welds fail although good conditions prevail in all other respects.

"Investigation on various welds has shown that in the majority of the cases, especially in certain classes of material, the welding heat or the process of preheating has affected the metal in the sections being welded, causing a transformation of the physical structure of the steel, and in case of localized high temperatures the main body of the material absorbs the heat so fast that there results a quenching action on the heated metal. In the majority of instances the extreme hardening action will be localized near the surface immediately adjacent to the added metal. In some cases of preheating it has been shown that the high temperature causes a change in the physical structure of the metal, and while it is not usually so localized as in the case of the action of the welding heat alone, thermal stresses are set up in addition to those created by the heat of the welding process. These conditions have been found in material of thick sections where the heat would not be readily absorbed throughout the section and where the chemical content, especially the carbon, was such that it rendered the metal readily susceptible to structural changes, resulting in a hardened condition.

"A great many tests were made to demonstrate to shopmen, that in the majority of cases proper annealing should be done after the weld has been completed and that a thorough annealing would improve the physical condition of the metal; thereby causing it to render better service; this thorough annealing to be made by placing the metal in a furnace and giving it a soaking heat and then cooling it so that the whole mass could adjust itself to a uniform condition throughout.

"The idea of causing a self or automatic annealing to take place by preheating is going at the proposition backwards and trusting to luck that we have not done more damage than good. It is necessary at times to preheat to take care of the shrinkage strains which might be set up in certain sections during the cooling after welding. It is advisable after this has been done to follow out a thorough annealing program. In this way any strain or hardened condition that has been set up by preheating, or by the welding heat, will be eliminated and we will then have a product the service of which will depend mainly on the quality of the material in the weld, and the perfection of the weld.

"There are certain zones in any torch flame that are of a higher temperature than others, and as it too often happens that a sufficient length of time is not taken in preheating to permit a soaking heat, more or less locally heated areas are produced that multiply the thermal stresses not eliminated during the subsequent period of cooling.

"In the majority of the shops, especially the larger shops, where special annealing furnaces have not been installed, there are always some furnaces of sufficient size in which at least the smaller castings and forgings could be annealed and this annealing could be done at a comparatively low cost. At the close of the day, as space is unoccupied by the regular work of the shops, the welded material could be placed in the furnace and be annealed over night without any material increase in the cost of fuel. This plan would not check production of the regular work.

"Too little attention is given to annealing in general even in cases where no welding is done. In reclamation plants where old material is re-worked, a worn out or failed forging will be re-forged. When originally forged thermal stresses may have been set up in this material and not removed, or the material may have been overheated or even burnt. Later, during its actual service, fatigue stresses and unsatisfactory physical structure may have been produced. On reforging, further stresses may be set up and then without annealing to refine the grain and remove these stresses the forging will be returned to service. While it may give some service, if we had gone a little further and treated it properly, the extended service in my opinion would have been sufficiently great to more than justify any extra trouble or expense involved in a final annealing after forging. The same thought applies to welding of failed material.

"There are a great many misconceptions of the process of annealing and a great many shopmen fail to observe the rule that it requires time for a piece of steel to adjust itself to the annealing temperature and be uniformly heated throughout. For instance, on one particular forging which the workman was instructed to anneal thoroughly he advised that he was doing so. But later it was found that he was simply sticking the forging into a blacksmith fire so that the welded area was buried in the fire. Under such conditions, while the extremely localized, highly affected areas will be improved, minor stresses will be set up back along the forging. To do the job right the forging as a whole should have been subjected to the annealing heat.

"With such methods it is hardly fair to expect 100 per cent service out of material to which we have added or in which we

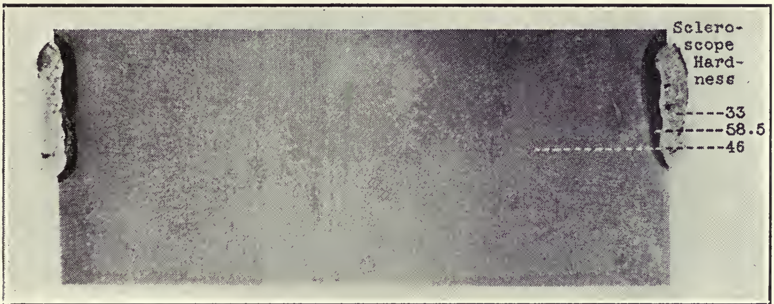


Fig. 82-A—Crank Pin; Metal Added with Electric Arc; No Preheating of Any Kind

have produced unsatisfactory conditions rather than reduced them. I am not looking at this matter from a strictly theoretical standpoint; the tests and the various failed material which have come to our attention justify these remarks.

"A few etched sections were made in an investigation to determine if a system of preheating could be developed to eliminate the hardened zones or heat affected areas created either through the preheating or the welding heat.

"Fig. 82-A is a crank pin, on which no preheating of any kind was done. The scleroscope hardness on the added metal was 33, on the hardened zone 58, and on the rod proper 46. The metal was added with an electric arc. Fig. 82-B shows the previous piece after annealing, the added metal showing a hardness number of 34, and the pin metal proper 45. Fig. 82-C is a piece of crank pin steel to which the patch was made after preheating the parent metal with the arc, resulting in the hardness numbers of 35 in the added metal, 59 in the hardened zone, and 47 in the rod. The metal was added with the electric arc. After annealing, the hardened zones were removed; the hardness number in the added metal was 35 and in the rod 45.

"Another piece of the pin was preheated in the blacksmith furnace and metal added by the electric process; in this case the hardness number in the added metal was 34, in the hardened zone of the pin 59, and in the body of the pin 46. After annealing, as in the previous instances, the hardened area was eliminated, resulting

Fig. 82-B—Crank Pin; Metal Added with Electric Arc after Preheating in Blacksmith Furnace. Annealed after Metal Was Added

in a hardness number in the added metal of 34 and in the rod of 45.

"A pin was preheated with the arc, but no metal added, resulting in a clearly defined hardened zone with a hardness number of 64, the body of the rod showing 44. After annealing this piece the hardness was uniformly 45 out to the edge of the piece.

"Metal was added around the section of a locomotive frame with the electric arc, without preheating. The metal was added in three layers with the idea that the succeeding layers might exert an annealing action on the affected area. The hardness number in the added metal was 34, in the affected area 57, and with the parent metal 47. After annealing this piece the affected zone was removed. The same frame member was preheated with the electric arc and metal again added in three layers, as in the former case, without showing any improvement in the hardening effect of the welding heat.

"Attention is called to the extension of the action of the arc ahead of the added metal, which may be observed in these photographs. It will be noted that the hardened zone extends about the same distance in front and back of the points where the welding operation starts and stops as it does beneath the weld. In a great many cases, in fact in the majority, it appears that a fracture will start by an initial check through the affected zone immediately

FIG. 82-C—Crank Pin; Metal Added by Electric Arc After Preheating with Arc

back of or in front of the added metal, although there have been cases that unquestionably were detail fractures starting from the area underneath the added metal.

"Fig. 82-D is a piston rod which was preheated according to the regular practice and metal added by the oxy-acetylene process, producing the affected zones shown. The hardness of the added metal in this case was 32, in the affected zones 53, and in the rod proper 44. On annealing this piece the affected zones were removed; the added metal then showed a hardness of 34 and the rod 44. Fig. 82-E shows the same affected zones when the metal was added by the oxy-acetylene process without preheating. The added metal shows a hardness of 32, the affected zones 53, and the body of the rod 42. On annealing, the affected areas were eliminated, resulting in a hardness number in the added metal of 35 and in the rod of 45.

"I do not want to leave the impression that all welds fail on account of the structural changes due to the heating, or that I am advocating not doing any welding at all, or that I am in favor of any one particular process of welding. All the various methods of welding have their proper fields, and a great deal of profitable work can be done with them. However, if the points mentioned are taken into consideration by the party laying out the welding work, our welds will show fewer failures.

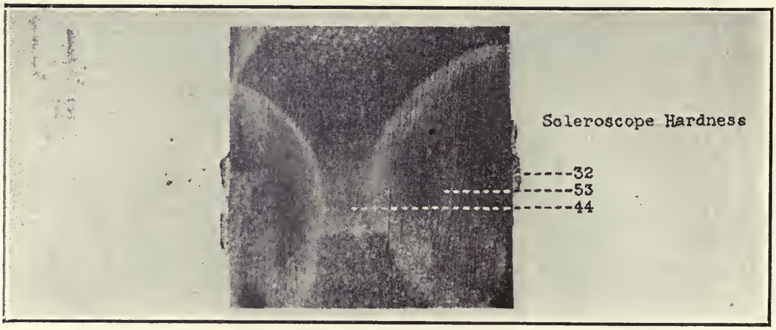


Fig. 82-D—Piston Rod; Preheated in Regular Practice and Metal Added with Oxy-Acetylene

"In the welding of steel plates, shapes, etc., the conditions outlined above do not exist, at least with commercial plate up to ½ in. thick. This is due to the fact that the cooling curve is not so sharp; that is, the difference in temperature over a given area within the vicinity of the weld is much less than in the case of thick sections and heavy mass.

"An intelligent analysis of the problems encountered in the service required of a given joint, together with an application of established welding methods, will leave no excuse for the failure of a joint which has been calculated to hold. The experienced welder does not guess; he knows what the joint will do. The success of the electric arc welding process, like any other manufacturing process, depends ultimately on the exercise of human skill and ingenuity. These factors are by far the most important to be considered. The apparatus itself is inanimate, but in skillful hands under the direction of an ingenious mind, it will take a foremost place among the machines which produce an improved product at a lower cost."

Weldability of Other Metals.—*Chrome steels* are weldable, if the percentage of carbon does not bring them within the category of hard steels, which is usually the case. The difficulties encountered are similar to those mentioned heretofore in connection with high carbon steel.

High Manganese steel can be welded by the metallic arc process, providing a protecting slag is used to protect the metal from

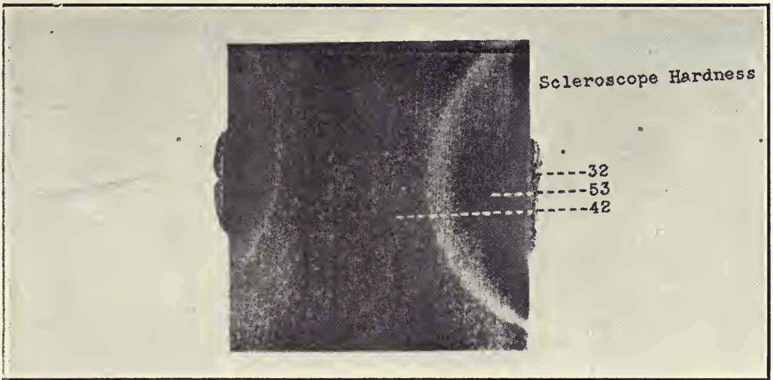


FIG. 82-E—Piston Rod; Metal Added with Oxy-Acetylene, No Preheating

the atmosphere. It has so far been very difficult to obtain electrode materials of a high manganese content, and for this reason no great amount of welding with high manganese steel has been done.

Nickel steel may be welded, providing the nickel content is not too high. Pure nickel cannot be welded commercially on account of the absorption of gas by the metal when melted by the arc. The deposit is porous and possesses practically no strength. Some welding has been done by heating the metal in a reducing atmosphere, such as a hydrogen flame. On account of this difficulty nickel steel electrodes have not been very satisfactory.

Non-ferrous metals as commercially used are more or less difficult to weld by the electric arc.

Brasses are not easily welded on account of the vaporization of the zinc content when subjected to the temperature of the electric arc. The addition of metal to brass is possible, but the use of a brass rod as an electrode material is not.

Bronzes which have a considerable lower percentage of zinc can be welded without difficulty by the carbon arc or with the metallic arc, provided the percentage of zinc and tin is low in the electrode material.

Aluminum can be welded by the arc after a fashion, but not as a commercial proposition.

In welding with almost any of the non-ferrous metals it is necessary to reverse the polarity on account of the comparatively low melting point of such metals, so that the electrode will be positive and the workpiece negative.

X

APPLICATION OF ARC WELDING TO RAILROADS AND STRUCTURAL ENGINEERING

The usefulness and economy of the arc welding process has been demonstrated in many industries to an extent such as to insure its permanency and make its future exceedingly bright. During the World War when labor and material, especially iron and steel, were exceedingly scarce and in some cases impossible to secure on short notice to meet emergencies, every industry was compelled to use every modern means to effect economical production, and to this end no process enjoyed more merited recognition in the fabrication and reclamation of iron and steel than that of autogenous welding.

While all forms of autogenous welding share in this respect, the metallic arc process, being the least used prior to the war, received almost national attention as a result of the miraculous achievements by its use, and as a result the progress in the art was much more rapid than would have been the case in normal times. In many cases the exact method of applications had to be developed. A few of the many advantageous applications of the process, together with the methods employed, are shown on the following pages.

Among the first commercial applications of the arc welding process on the railroads was that of repair work and flue welding; i. e., the welding of the boiler tubes to the tube sheet in locomotive boilers. In this field the process has been constantly expanded and at the present time it is used extensively by many of the large railroads.

In a number of cases the success of the process for joining steel plate has been so thoroughly demonstrated that riveted seams in locomotive fireboxes have been entirely eliminated, and many such fireboxes are in successful operation. That these results have been obtained is due to the development of the art and its application and not to any new fundamental discoveries. There have been, however, great strides in the refinement of the equipment, electrode material, methods of application; and last but not least skilled operators have been produced, which is especially vital in boiler welding.

Completely Welded Fireboxes.—In the application of new fireboxes, the seams of which are to be arc welded, the door sheet

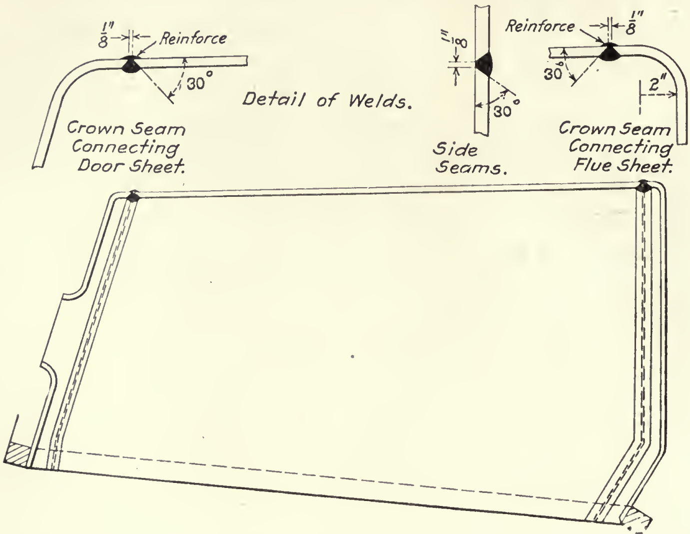


Fig. 83—Preparation of Door and Flue Sheet, Crown Seams and Side Seams for Arc Welding New Firebox

and the flue sheet are prepared with flanges of not less than 2½ in. as shown in Fig. 83. The one-piece sides and crown sheet are set and securely bolted to the mud ring. The door sheet and flue sheet are then likewise set in place. The edges of all sheets should be beveled to a 45 deg. angle from the fire side, leaving an opening between all edges to be joined of approximately ⅛ in.

When starting welds on cold massive parts a greater current density or heat is required for proper fusion than will be the case after the work has warmed up. To avoid readjustment of heat it is good practice to start the weld with a smaller size electrode than that for which the heat is adjusted and when the part warms up change from the smaller electrode to the next larger size.

When it is possible, the top seams of a new firebox should be

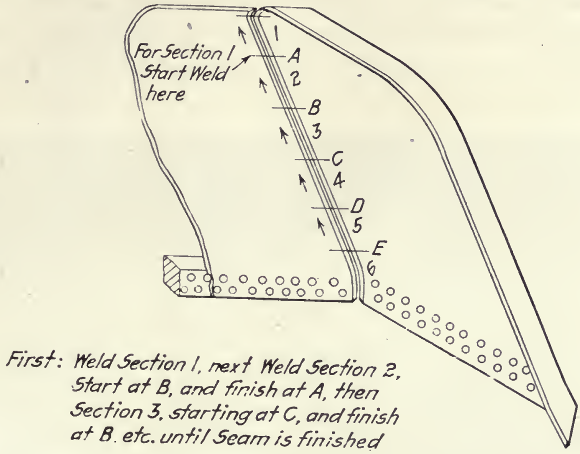


FIG. 84—Method of Procedure in Welding the Four Vertical Seams on a Firebox

welded with the box lying on its side. This will avoid overhead welding and will place the crown seams in a vertical position where they may be welded from the fire side, as shown by sec-

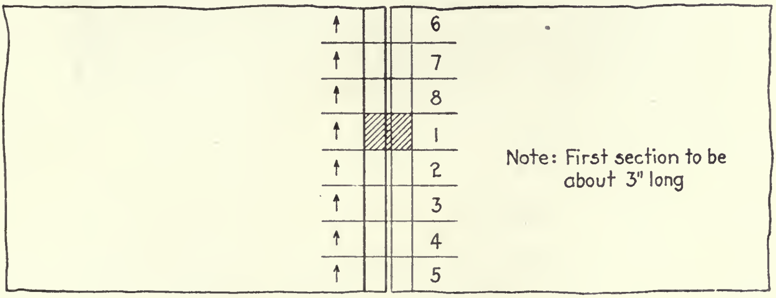


FIG. 85—Weld in Numerical Order and in Direction as Shown by Arrows

tional view, Fig. 84. The crown seams should be slightly reinforced on the water side.

The four vertical seams are welded with the firebox in the normal position. In order to avoid unnecessary distortion of the sheets each seam is welded in sections in the order shown in Fig. 85. The first section welded should be approximately 3 in. long and should be finished flush before starting the second section. The second and remaining sections may be as long as 10 in. In all cases each section should be finished at least flush before starting another. The finished weld should be reinforced approximately

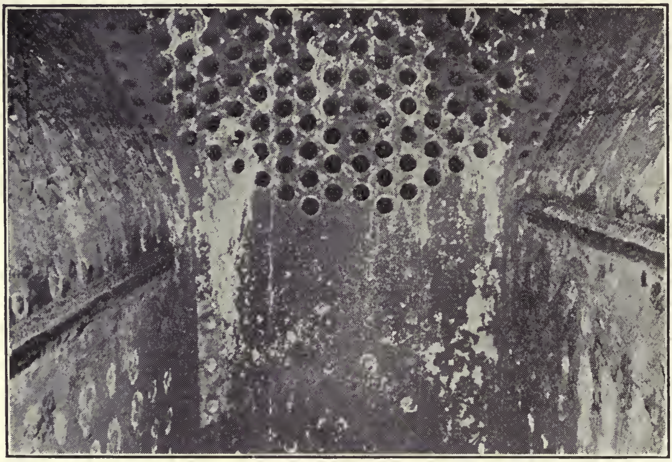


Fig. 86—Side Sheet Joints Welded with Electric Arc

1/8 in. Views of side and crown sheet arc welding are shown in Figs. 86 and 87.

The size of the electrode to be used for firebox plate thickness is 5/32 in. A 3/16 in. electrode may be used, especially between flue sheet and middle sheet, owing to the greater thickness of the flue sheet. The heat value should always be as great as is consistent with good welding.

If "thermic syphons," shown by Fig. 88, are to be applied together with a new firebox, the seams connecting the syphon to the crown sheet should be welded with the box on its side, which will place the long seams of the syphon in a horizontal position. These seams should be reinforced on both the water and fire sides. The diaphragm plates, shown in Fig. 89, may be welded to the flue sheet with the firebox in either position, since the location of the joints to be welded eliminates overhead welding in either case. These seams should also be welded in sections, as previously described.

The object of beveling the edges of all seams from the fire side is that in the event of making any repairs along the line of weld, which of necessity must be done from the fire side in most cases, it would not be necessary to make such large openings to remove

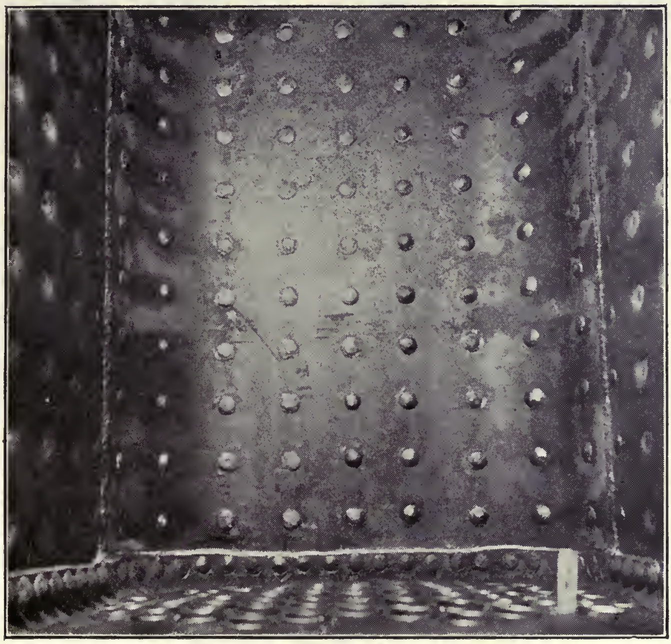


FIG. 87—Joint of Crown Sheet Welded with Electric Arc. Photograph Taken Looking up from Drop Pit

the old welded-in metal. Extreme openings must be avoided, as it has been demonstrated in service that such welds cannot be depended upon. This is due no doubt to the fact that if the weld is not reinforced the cast metal applied in the large opening possesses less strength than the original plate and will break when slightly distorted. If on the other hand a wide section of this kind is built up in an effort to stiffen the line of weld, the greater thickness will result in a greater temperature at that point, which may result in local strains that cause rupture. No more of the original metal should ever be removed than is necessary to provide access to insure fusion all along the entire edges to be joined

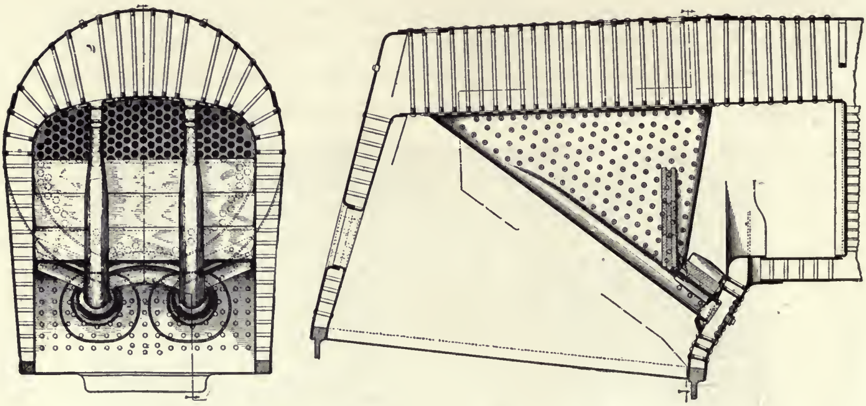


FIG. 88—Two-Syphon Application to a Medium Width Firebox with a Combustion Chamber

and the width of the reinforcement should not be much more than the opening between the beveled edges at the widest point

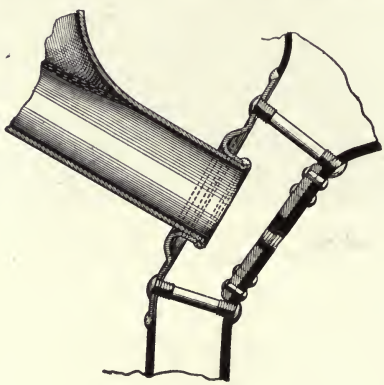


FIG. 89—The Diaphragm Plate Welded in by Means of Electric Arc

for sections of this thickness. Proper and improper reinforcement is shown in Fig. 90. Arc welds do not tend to break along the line of union when properly made; the weakest point is through the cast metal; for this reason the center of the weld should have the greatest thickness.

The door hole flange seam may be butt welded, using the back step method or it may be lap welded, as shown by Fig. 91. Both methods are used and both are in successful operation.

The objection raised by some to the lap weld is that scale will form between the unwelded edges on the water side and produce

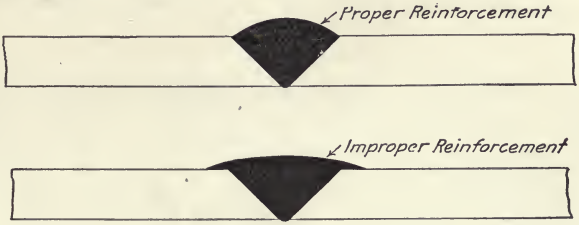


FIG. 90—Proper and Improper Reinforcement

a prying effect. However, no such trouble has developed so far as can be learned from those using the lap type joint at the door hole flange seam. A lap welded joint for the door hole flange seam is less difficult to make than is the butt weld joint and if it is as good, it is preferable. A view showing an arc welded seam across the outside door sheet is illustrated in Fig. 92.

FIG. 91—Two Types of Door Hole Flange Welds

Mud Ring.—It is the practice to weld the edges of the sheet to the mud ring to prevent leaks from developing, as shown by Fig. 93. The edges of the sheet should first be beveled and in order securely to join the sheet to the ring a space on the ring, at least equal to the thickness of the sheet, should be cleaned with a roughing tool. The usual practice is to extend the weld approximately 12 in. from the corner each way. In the case of riveted lap seams in the firebox the weld is also extended along the edges of the flange seams above the grate frame. A 5/32 in. electrode is appropriate for this work.

Many mud ring corners of the above-mentioned type have failed, due to the fact that the sheet extended down so near the bottom edge of the mud ring that only a very light weld could be made, and as the mud rings are usually hammered iron, having laminated characteristics, the corners tear off. This feature must be given additional consideration in boiler construction if the best results are to be obtained from welding the edges of the sheets

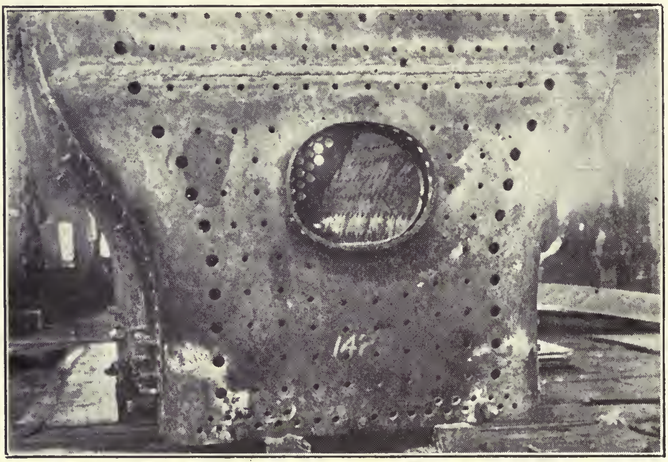


Fig. 92—Arc Welded Seam across Outside Door Sheet

to the mud ring. The edge of the sheet should not extend nearer than ½ in. to the bottom edge of the mud ring. At present it is difficult to obtain ¼ in.

Welding Tubes to the Tube Sheet.—The welding of tubes to the flue sheet is not as simple an operation as it may at first seem. Every conceivable method of flue setting has been tried; many methods had little or no commercial value. For example, flue sheet holes have been countersunk to provide an opening for the added metal, and the flues set flush with the fire side of flue sheet, as shown in Fig. 94. In other cases the flues were simply set and rolled, allowing the flue to extend beyond the flue sheet a slight distance to permit a fillet weld, as shown by Fig. 95. This practice is still in effect to some extent in some parts of the country, especially with the large flues. Among the most important factors that determine the performance of flues is, of course, the

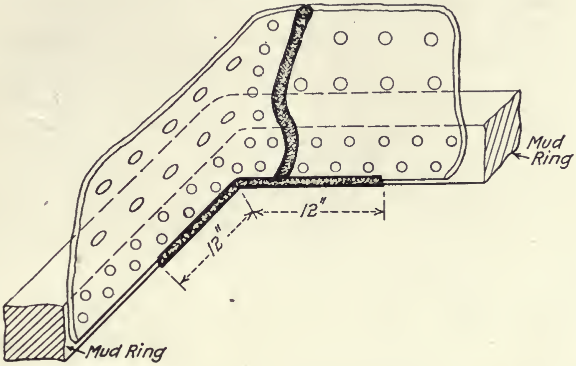
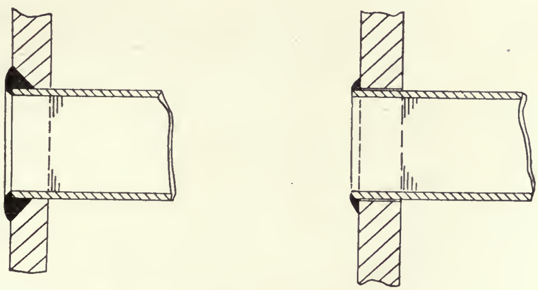


FIG. 93—Welding the Edges of the Sheet to the Mud Ring

water conditions and with welded flues, as with unwelded flues, the water conditions will determine to some extent the method of application.

In general, the best and safest practice is to use the welding



FIGS. 94 and 95—Two Types of Flue Welding

FIG. 94—Flue Sheet Hole Countersunk with Flue Set Flush

FIG. 95—Fillet Weld Flue Extended

process to seal the joint between the flue and the flue sheet and not depend entirely upon the weld to anchor the flue to the sheet, as the relatively small amount of cast metal will not alone withstand the severe strains imposed upon the flue joint, especially when water conditions are bad. The surface of the flue sheet should be as smooth as possible in order to reduce the tendency of honey-combing. This is especially necessary with fireboxes not equipped with brick arches.

The practice that is considered best for preparing and welding locomotive boiler tubes at the present time is as follows:

(*1*) The flue sheet around the edges of the flue hole should be perfectly clean. This may be accomplished with sandblast, roughing tool, or with a wire brush if the scale is not too bad.

(*2*) Copper ferrules placed in the flue sheet holes should be set 1/16 in. back from the edge of the fire side of the flue sheet.

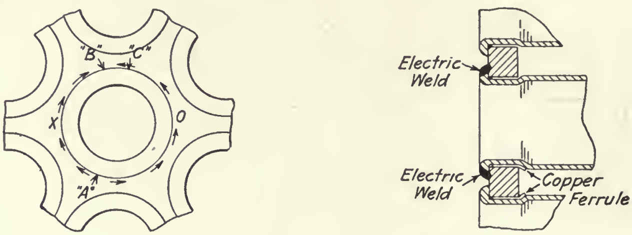


Fig. 96—Method of Procedure in Welding Beaded and Expanded Flues

(*3*) Soap water should be used as a substitute for oil as a lubricant for the expander. Oil must not be present.

(*4*) When the flues are applied they should extend through the sheet approximately ¼ in.; they should then be rolled and flared, after which they should be expanded with a Prosser expander and finished as though they were not to be welded, after which the sheet around the flue heads should be cleaned by sandblasting —or if not too dirty they may be cleaned with a wire brush and then be welded in the following manner:

Start the welding at the bottom of the flue at point *A* as shown in Fig. 96 and weld in an upward direction, *A-O-B;* then return to point *A* and weld in an upward direction, *A-X-C,* lapping over the end of the first bead approximately ½ in. This will avoid the possibility of pin holes where the arc was broken at the finishing point of first bead. The deposited metal should not project farther than flush with the flue bead.

For 2 in. flues a ⅛ in. electrode is generally used, with a heat value slightly above the normal value used for this size electrode. For 5 in. flues a 5/32 in. electrode should be used, with as much heat as is consistent with good welding. In both cases the heat value must be sufficient properly to fuse or penetrate the heavy flue sheet, which will, of course, tend to fuse away the comparatively thin tube bead unless proper care is exercised. To avoid the burning of the bead the major portion of the arc flame should be directed against the flue sheet, or the arc flame should be played upon the flue sheet more than upon the flue bead.

As the thin edge of the flue bead is fused through by the arc, if the surface around the edges of the flue hole is scaly, or otherwise dirty, an excessive heat or undue manipulation of the arc will be required to slag off scale or dirt and secure fusion between the flue bead and the sheet. This will make a smooth weld difficult and will tend to cause burned metal in the weld.

If the copper ferrule extends out under the flue bead when the welding begins, the arc will be erratic, owing to the difference in the conductivity of the two metals from which the arc is established. This will also make a smooth, sound weld practically impossible. If oil is present the oil and the soot formed by the burnt oil will interrupt the arc and the flow of the metal. It has been found that hardness is increased with the presence of oil.

The flues should be applied the same as though they were not to be welded, for the reason previously explained; i. e., to assist the weld in anchoring the flue and to make a smoother finished job. The copper ferrule may be omitted if the water conditions are exceptionally good. If the water conditions do not permit the boiler to be kept clean and free from scale the temperature of the surfaces exposed to the fire will, of course, be increased. For this reason it is evident that the copper gasket or ferrule setting will help overcome the excessive distortion due to the increased temperature.

If a welded flue should develop a leak the old weld of the leaky flue should be entirely removed and the flue thoroughly worked with expander and beading tool and then welded. This can be done best if the original flue setting is made with the copper ferrule.

It is the practice of some roads to have the locomotive fired up or to make a trial trip before welding the flues; this is beneficial if oil is used in applying the flues. If such has been the case the oil will be burned off, this permitting a better weld to be made. The theory has been advanced that the boiler should be allowed to make a trip or be fired up in order to permit the flues to take a setting under heat conditions, but this is not considered necessary when the flues are applied and welded as has been outlined. From the foregoing it is apparent that the welding of flues is an additional expense to be added to the cost of installing flues; however, this added first cost is many times offset by the decreased operating expense.

The following data serve to indicate the present speed and cost of welding tubes and flues, although it has been demonstrated that it is possible to weld double the number of flues per hour.

Cost of Welding Small Tubes

	Per Tube
Average cost per tube, at the rate of 15 per hour, figuring labor at 77 cents per hour, and welding iron and power at 25 cents per hour...........	$ .068

Cost of Welding Large Flues

	Per Flue
Average cost per tube, at the rate of 3 per hour, figuring labor at 77 cents per hour, and welding iron and power at 25 cents per hour..........	0.34
Cost of welding tubes in one engine of 229 tubes at 6.8 cents per flue.........................	15.57
Cost of welding tubes and flues in one engine of 190 small tubes at 6.8 cents per tube, and 30 large flues at 34 cents per flue.................	23.12

The cost of the welding iron and power is based on the average price of iron and upon the power consumption of a modern welding equipment and the average cost per kilowatt-hour for power.

On a central western railroad, where welding of tubes and flues to the tube sheet is standard practice, according to the general boiler inspector the performance is as follows:

The running repairs on flues and tubes on engines with welded flues has been reduced to almost nothing. More than 50 per cent of the locomotives that had flues welded a year or more ago are returning to the shops after running 50,000 to 90,000 miles without ever having any work done on the flues. The condition of the flues on their arrival at the shops was such that only the lower flues, where the scale is heavy, were renewed. The upper small flues on saturated and superheated steam engines, and usually

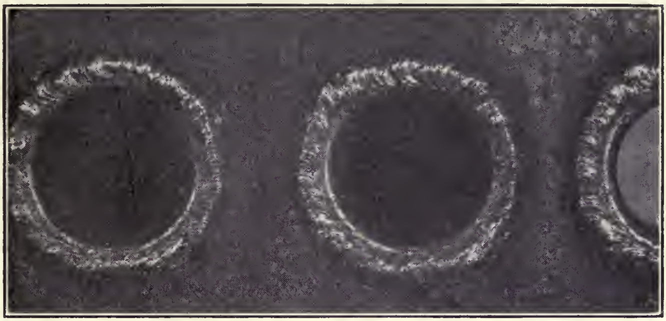


FIG. 97—Showing Beaded and Expanded Flues Welded by Electric Arc

all of the superheated flues on practically all of the superheated engines, ran two shoppings without leaking before they were changed. It is evident, therefore, that the additional expense of

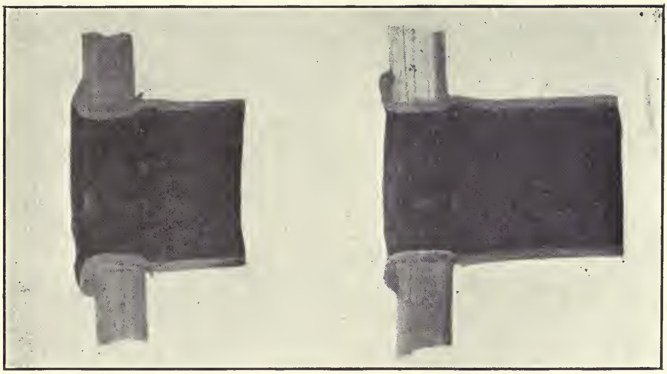


FIG. 98—Sections of Beaded and Expanded Flues Welded by Electric Arc; One with and One without Copper Ferrule

welding the flues is many times offset, especially when water conditions are bad.

The tendency to honey-combing is no greater with welded flues than when they are not welded. Scale and dirt may be more noticeable with welded flues, but this is usually due to the less

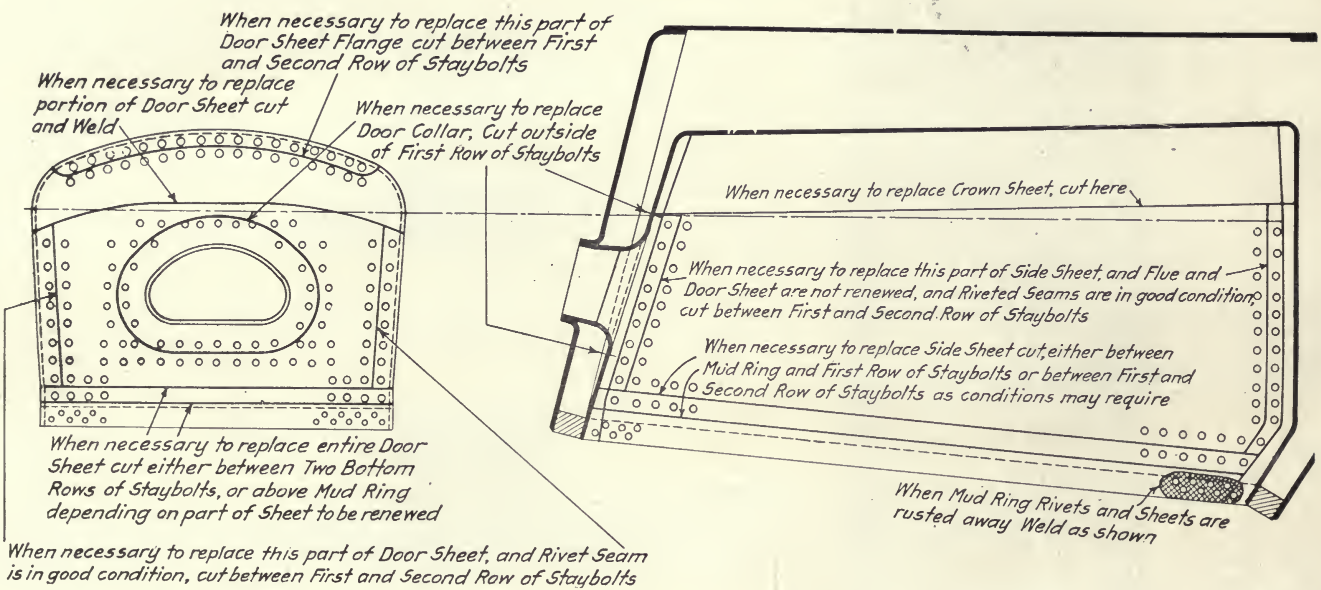


FIG. 99—Showing Where Cuts Are to be Made When Repairing Various Parts of Firebox

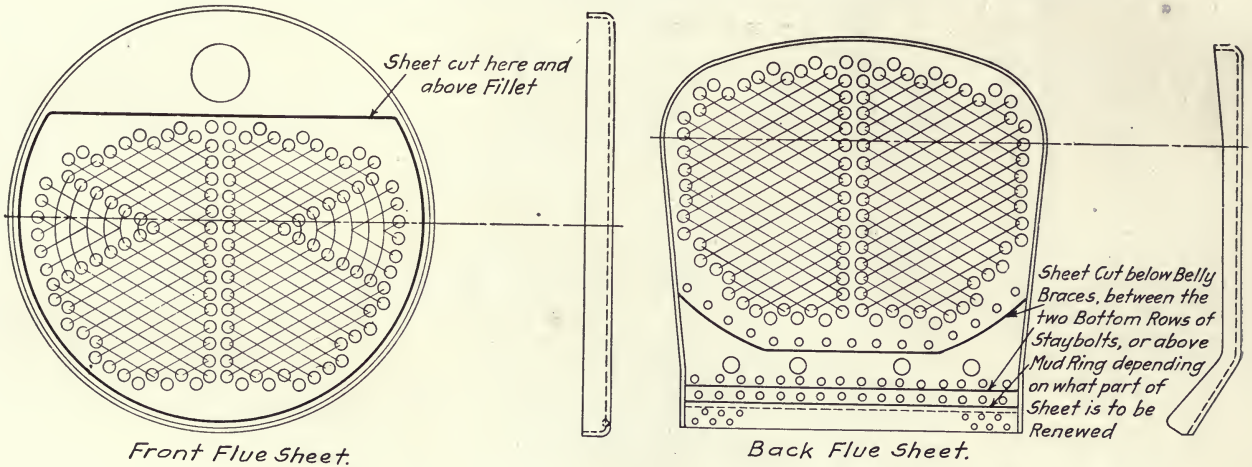


FIG. 100—Showing Where Cuts Are to be Made When Repairing Front and Back Flue Sheets

frequent working and hammering on the flue sheet. For the same reason slightly more scale may form on the water side of the flue sheet. It is, however, certainly less work and expense to clean off the flue sheet occasionally than to expand the flues every few trips and calk them possibly every trip.

The life of a flue sheet is greater where the flues are welded and the liability of cracks is less, since the destructive effects produced by the frequent rolling and working of the flues are practically eliminated. Views of beaded and expanded arc welded flues are shown in Figs. 97 and 98. In the photographic repro-

FIG. 101—Patch on Flue Sheet and around Arch Tube Welded with Electric Arc

duction, Fig. 98, sections of two welded flues are shown one with and one without copper ferrule.

Boiler Repairs.—The manner in which some of the different parts of the firebox are cut out when it becomes necessary for them to be renewed, is shown in Figs. 99 and 100. Views of repaired flue sheets are shown in Figs. 101 and 102. When sheets or patches are cut out, care should be exercised to select locations that will afford good foundations for the weld. Cutting through stay-bolt holes, arch tube holes and old welds should be avoided.

The surfaces of all beveled edges must be finished by chipping. This is necessary to secure a uniform line and opening between the edges to be welded and to insure clean surfaces on which to weld. All foreign substances must be removed to prevent slag inclusions, which if present will greatly impair the strength of the joint.

The bottom edges of all horizontal seams will not require as much bevel as other edges; a 20-deg. angle will be sufficient. All other edges, i. e., the top edges of horizontal seams and both edges of vertical or flat seams should be beveled to a 30-deg. angle. An opening of approximately 1/8 in. between beveled edges has become standard for firebox plate.

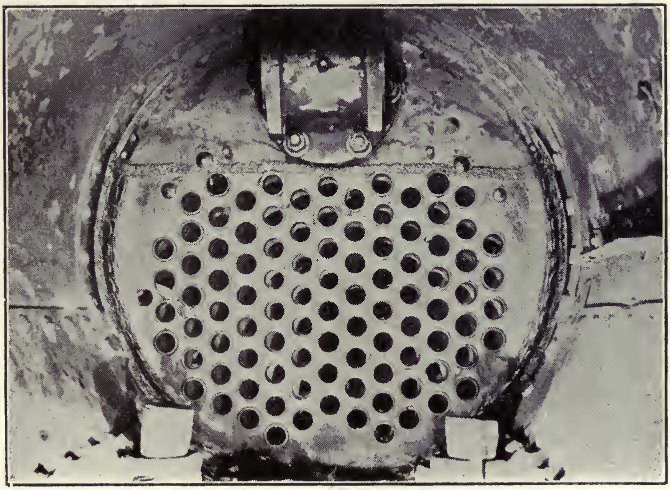


FIG. 102—Front Flue Sheet Joints Welded with Electric Arc

There are two conditions in boiler work under which welding must be done; one is rigid welding, and as its name indicates, the parts oppose free play. The other condition is the opposite. The former condition, however, predominates in boiler work. Rigid welding is not so difficult if properly done, as explained in another chapter under the headings "Expansion and Contraction of Parts Welded" and "Contraction of Fused Metal."

The back step method of welding has been adopted for practically all seams. The method avoids considerable distortion of the sheets and possible concentration of contraction strains at one point which so often causes rupture. This method eliminates much of the expensive corrugating of sheets, etc., which is practiced by a number of roads. The only provisions for expansion and contraction considered necessary with the "back step" method are to give a slight roll to sheets and to slightly dish patches.

Side sheets should be set and bolted in place—stay-bolts screwed in from the wrapper sheet may be used to push the sheet in one direction and bolts to draw in in the opposite direction, thus aligning the edges. Stay-bolts may then be applied every fourth or fifth hole in the row adjacent to the line of weld.

The electrode material most commonly used in firebox welding is mild steel or ingot iron in the 1/8 in., 5/32 in. and 3/16 in. sizes

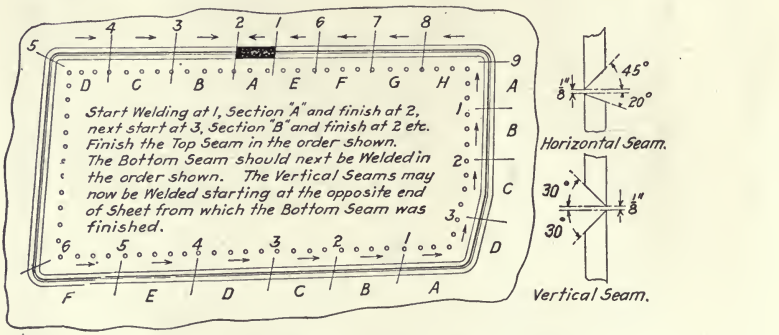


FIG. 103—Method of Procedure in Welding Side Sheets

—of these sizes the 5/32 in. is the most extensively used. The 1/8 in. is often used when the edges are very thin or when the opening between the edges is small. The 3/16 in. is sometimes used for the first layer to fill the opening approximately flush with one run, afterwards applying the finishing layer with a 5/32 in. or 1/8 in. electrode.

The heat value should always be as great as can be used without burning the added metal or overheating the sheet adjacent to the weld. With the proper heat the sheet will develop a dark red heat a distance of 1/4 in. around the point where the arc is drawn, shortly after the welding is started.

It is the usual practice to allow slightly more opening at the top seam which is welded first, than the bottom seam, to allow for the slight drawing. If the opening is greater at one end than at the

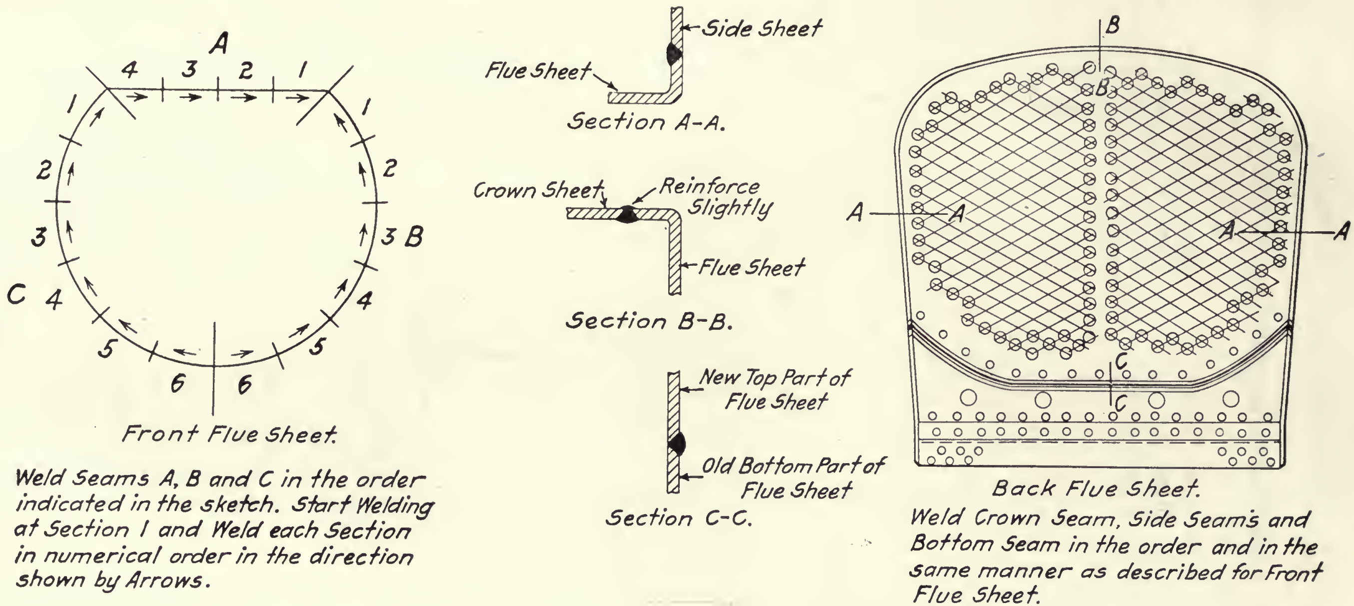


Fig. 104—Method of Procedure in Welding Front and Back Flue Sheets

other, the welding should progress toward the end having the greatest opening.

The seams of side sheets should be welded in the order shown in sketch, Fig. 103. Front or back flue sheets when cut out as shown in Fig. 100, should be welded by laying the seams off in

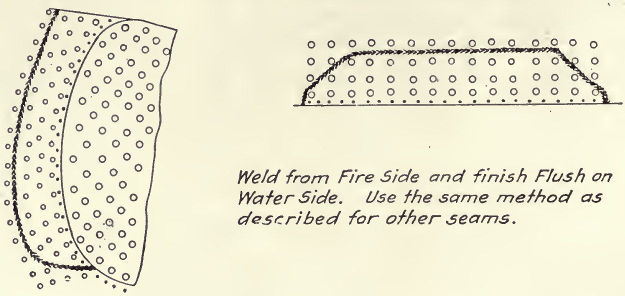


Fig. 105—A Crown Patch Weld

three or four sections and welding in the order shown in Fig. 104.

If seams are welded from an overhead position the metal deposited between the beveled edges will sag slightly, leaving a concave type of weld on the side opposite that from which the welding is done. It is for this reason that crown seams should be gone

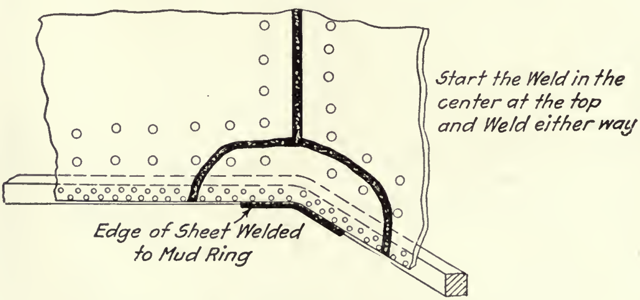


Fig. 106—Welding Corner Patches

over on the water side to secure a flush joint and not necessarily to reinforce the joint.

Side sheet patches should have a slight dish. The weld should be executed in the same general way as that for side sheets or flue sheets. The method used for welding crown patches is shown by Fig. 105. The method used for welding corner patches is shown in Fig. 106.

When cracks develop in the knuckle of the back flue sheet they should be welded from the water side if possible and slightly reinforced on the fire side. The weld should be made in comparatively short sections as shown in Fig. 107, finishing each section before starting another. This holds true for practically all fracture welding in fireboxes or elsewhere if the parts are rigid.

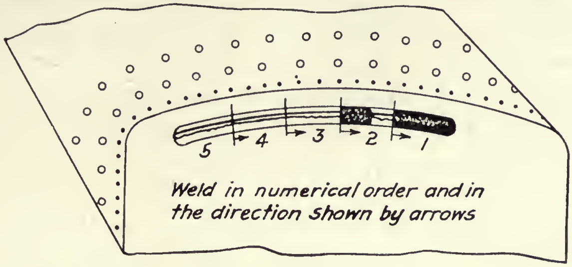


Fig. 107—Procedure in Welding a Crack which Developed in Knuckle of Back Flue Sheet

Fractures extending from one rivet hole to another between the mud ring rivets are welded as shown by Fig. 108. Fractures above the mud ring that extend from one rivet hole to another or arch tube hole cracks should be repaired by applying a patch. It is possible to weld stay-bolt hole cracks by applying a round disc as shown in Fig. 109. It has been found difficult to make a weld hold in this location when made without the disc. One disc is used for each hole through which the fracture extends.

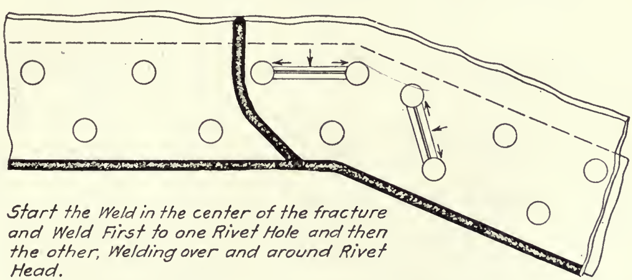


Fig. 108—Repairing Fractures between Rivet Holes at Mud Ring

Vertical flue sheet knuckle cracks are welded from the water side, starting in the center of the crack and finishing first one half and then the other. Fractures in this location should be repaired in this manner only in an emergency. A new top portion or a new sheet should be applied instead when conditions permit. When cracks develop in the door hole radius a new collar should be applied as shown by Fig. 110. In an emergency, cracks are welded by beveling the edges and welding from the center to one end of the fracture, returning to the center and welding toward the opposite end of the fracture. If two or more cracks are

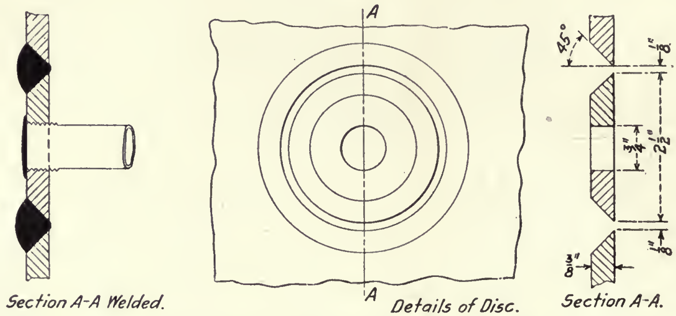


Fig. 109—Repairing Fractures by Means of a Disc

present, each crack should be completed before cutting out and welding another.

Corroded or oversize wash-out plug holes are repaired as shown by Figs. 111, 112 and 113. The washer shown in Fig. 111 is cut in half to permit it to go through the hole and be placed on the water side to serve as a backing for the deposited metal. This same method is often used to fill in stay-bolt holes that have become checked around the edges. The sleeve or round disc provides a better metal than the cast filled-in metal in which to tap new threads.

Old riveted seams that become defective are repaired by removing the rivets or patch bolts and cutting a bevel on the edges exposed to the fire. The old rivet holes are plug welded after which the beveled edge is lap welded to the adjoining sheet as shown by Fig. 114.

Mud ring corners are best welded by cutting out a portion of the sheet on the fire side to permit access for beveling the fractured edges of the mud ring so that the welding may be done from the top side of the mud ring, afterwards fitting a new patch in place and welding.

A new patented flexible stay-bolt has been placed on the market, the application of which utilizes arc welding. One of the assemblies is shown by Fig. 115.

The arc welding process is used extensively for welding calking edges on old riveted seams. One example of this is in weld-

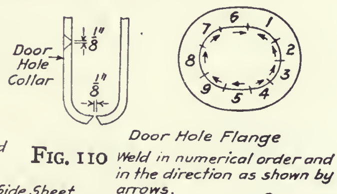
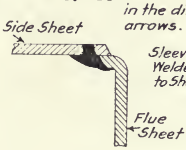


FIG. 110



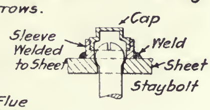


FIG. 115

FIG. 111 FIG. 112 FIG. 113 FIG. 114

FIG. 110—Procedure in Applying New Door Hole Collar
FIG. 111 to 113—Methods of Repairing Corroded or Over-Size Washout Plugs
FIG. 114—Repairing an Old Riveted Seam
FIG. 115—The Sleeve of a Flexible Staybolt Welded to Sheet

ing the calking edge of riveted joints in the smokebox of locomotives, when rivets become loose and effect the vacuum which is required for draft through the firebox. There are many other applications in the construction and repairing of locomotive boilers for the arc welding process of which no mention has been made. The examples cited, however, will serve to indicate the progress that has been made in this field.

Welding in Ship Yards and Other Industries.—The welding of piping, plates and shapes for ships, cars, and building structures is similar to that of locomotive boiler welding, as the materials ordinarily used are about the same considered from an arc welding standpoint. Tentative regulations for the application of arc welding to ship construction have been issued by Lloyds, which signifies merited recognition of the art as a safe means for many purposes in ship construction.

During the war the interest created by the possibilities of the application of arc welding resulted in the formation of a welding committee, known as **the Welding Committee of the Emergency Fleet Corporation.** At the conclusion of the war the committee was discontinued by The Emergency Fleet Corporation. However, in order to continue the research started by it, the American Welding Society was organized, which is composed largely of the same personnel as the original committee. Branches of this society are being organized in all the principal cities of the country. It is hoped that the society will eventually be the recognized body to serve as a guide in the art of welding.

The regulations by Lloyds for ship welding allow either butt joints, with sufficient butt straps, or lap joints. Up to the issuance of these regulations welding in shipyards was generally limited to attachments that were not structural parts of the ship, such as deck collars, joints for continuous railing rods, stairs, bulkhead partitions, grab rods, deck houses, reinforcing and repairing broken castings, angle smith work, forming different parts by angle plates, etc., low pressure tank seams, pipe joints and similar work. Pressure vessels and structural parts of the ship could not be welded unless submitted for consideration.

Some small vessels, barges and sections of barges have been constructed by arc welding. The Chester Ship Building Company constructed a 60-foot mid-ship section in the welding of a 1,200-ton bulk barge, designed for service in Mexico. The shell and deck plates were ¼ in. and the transverse framing members, intercostals, and the like, were all of 5/16 in. plate. The results were very satisfactory and the tight joints were made without punching a hole and for approximately one-fourth the cost of time and material required by other methods. There have been many other similar cases of experimental ship construction involving extensive arc welding, all of which have been given publicity in some of the various business papers and technical journals.

Examples of welding applications in the United States Navy Yards are shown in Fig. 116, corners for hatch hole covers, and Fig. 117, a spray shield for a gun. The nature and kind of materials to which welding is applied in marine work is similar in many respects to that encountered on railroads; so that the

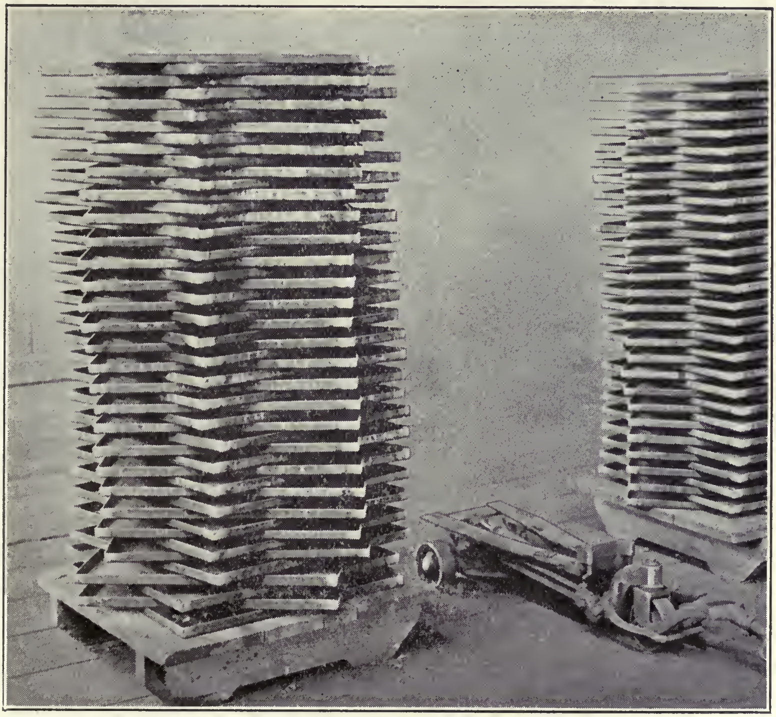


Fig. 116—Hatch Cover Corners Welded in the Navy Yard

methods which have been described in detail would in most cases be applicable to other structural engineering.

A study of the factors which govern the methods of application, such as composition of metals, thermal capacity, arrangements, position of work, service requirements, etc., will be required in each case before the exact method can be determined. Different methods, types of joints, and weld designs will be required depending upon conditions, so that any examples of application that may be given would only serve to suggest methods for like, or similar cases.

A bottom rudder brace for a small lake ship, which had been completely broken and was repaired by arc welding is shown in Fig. 118. It will be noted that the reinforcing was made by welding on round rods; this is similar to the method employed for reinforcing locomotive frames.

Arc Welding in Building Construction.—An example which marks the beginning of the application of arc welding to building construction is to be found in the case of a building erected by the

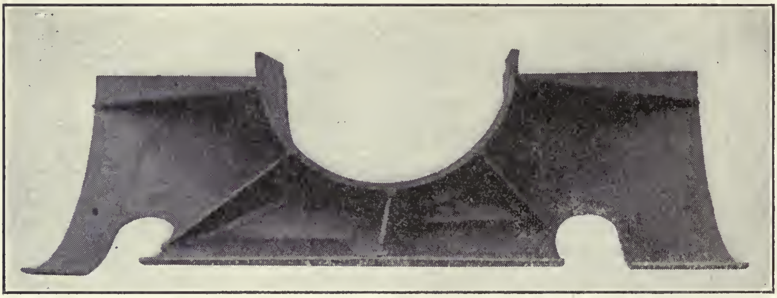


FIG. 117—Spray Shield for a Gun Constructed by Electric Welding

Electric Welding Company of America at Brooklyn, N. Y., for its own use.

Before proceeding with the work of erecting the building entirely by arc welding, it was necessary to obtain permission from the various city building departments, and such permission could only be given if certain tests were made which would satisfy the building officials that a welded structure would be absolutely safe and would compare favorably in other respects with a riveted steel framework.

Certain samples of welded joints were requested for the tests. The samples submitted and the test results were as follows:

First sample, 1¼ in. by ⅜ in. lap welded bars, lapped 1¾ in. and welded across the edges; when subjected to a direct tension of 60,000 lb. per sq. in. a break occurred in the bar 3 in. from the weld. Examination at the line of union between the added and parent metal showed no distinct boundary between them.

Second sample. This sample consisted of two angles (2 in. by 3 in. by ⅜ in.) set at right angles and welded at the intersection. This sample was set in a machine so that there was a horizontal lever arm of 8 in. from the center of pressure to the center of weld and intersection, and developed a beam load of 11,375 lb. at

FIG. 118—Rudder for a Lake Boat which Was Repaired by Electric Welding

the weld, or a torsional stress of 91,000 lb. at the weld, with no apparent distress to the weld.

The tests of these samples were entirely satisfactory to the building officials. Permission was subsequently given to proceed with the erection of the steel framework, but there was still another test to be made of the steel trusses of 40 ft. span, which were to be used to sustain the roof. These trusses were of fan type of design and all members were electrically welded together, no bolts or rivets being used. The trusses were spaced 20 ft. apart, supported by 8 in. x 8 in. H-beam columns 19 ft. high; on the sides of these columns brackets were fastened to carry an overhead traveling crane of five-ton capacity. The weight of each

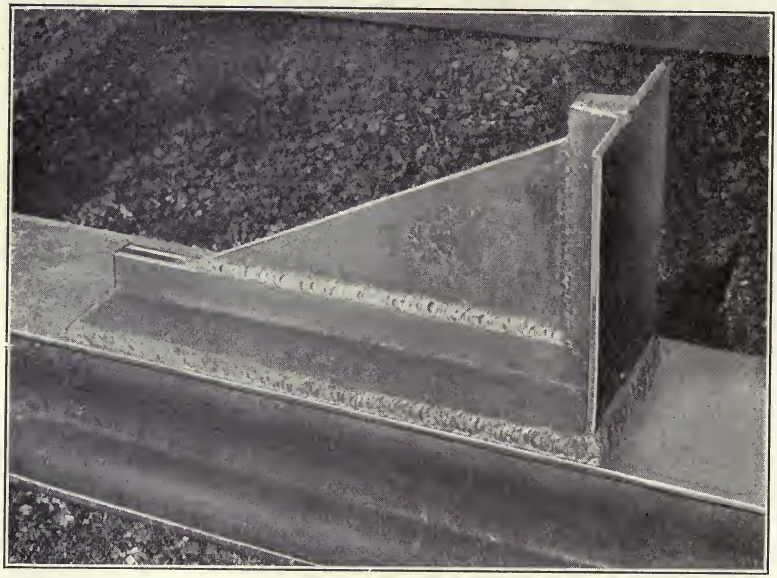


FIG. 119—Bracket Constructed and Joined to Column by Metallic Arc Welding

truss was about 1,400 lb.; the top and bottom chords were composed of 4 in. x 5 in. x 3/8 in. tee irons; the struts were 3 in. x 2 in. x 3/8-in. angles; the purlins were 10-in., 15-lb. channels.

The trusses were designed for a live load of 40-lb. per sq. ft., each truss supporting a panel of 800 sq. ft. They were tested at a load of 120 lb. to the square foot, or a total load of 48 tons on the two trusses. The load consisted of gravel in bags which were piled in tiers on planking arranged for the purpose.

Readings were taken at different increments of the loadings for the deflection in the truss or members.

The trusses were left under load 48 hours and a reading taken showed—East support settled 15/16 in., West support ¾ in. actual; point No. 2, 7/16 in. actual; point No. 4, ½ in. actual deflection; point No. 3, 9/16 in. actual deflection. Two days afterward the load was entirely removed and readings taken at this time showed all points in the trusses had returned to their original positions, leaving no permanent deflection except at point No. 3, where there was a deflection of 1/16 in.

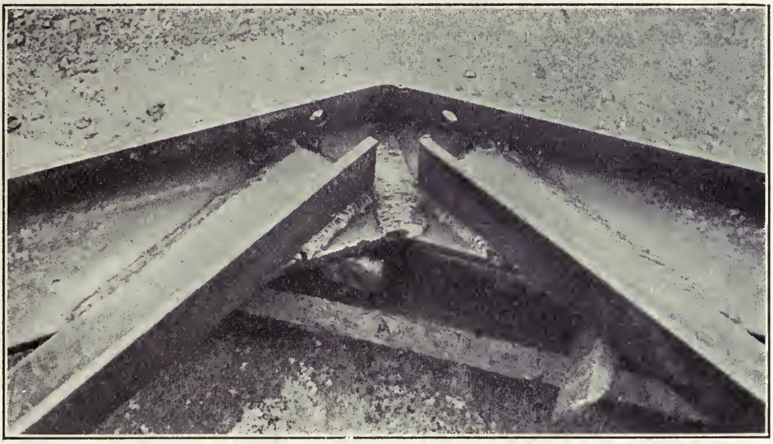


FIG. 120—Peak of Truss Showing Members Joined by Electric Arc Welding

To quote from the official report: "From the above it is evident that electric welding is a dependable method of uniting structural members and is stiffer than riveting if the work is properly performed.

The test was witnessed by members of all the building departments in Greater New York, and as a result a permit was issued for the erection of the first building of its kind.

The time, labor and material saved through the elimination of the fabrication necessary for riveting obviously constitutes an item in favor of the arc welded joint; and actual test on a commercial scale will demonstrate that structural work by electric arc welding can be done at a lower cost than by riveting. As the use of proper materials, methods of application and competent operators become more general, the extension of the process to almost all phases of structural engineering will be inevitable.

Figs. 119 to 121 show some of the joints embodied in the building structure.

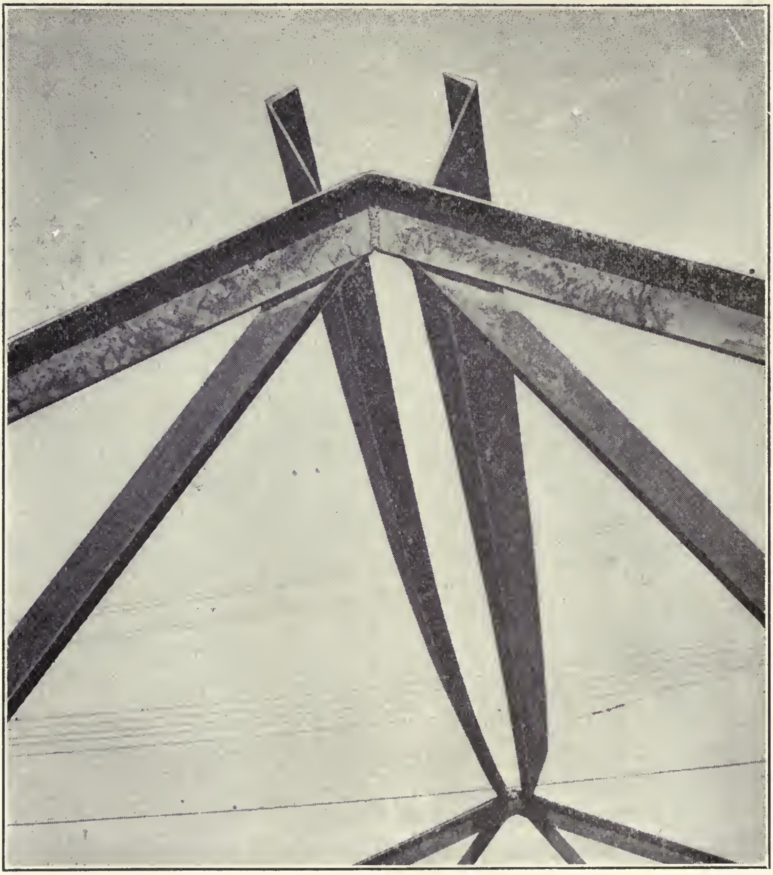


Fig. 121—Members of Roof Frame Joined by Electric Arc Welding

Welding Locomotive Frame Members and Similar Parts.— Broken locomotive frame members have been repaired successfully by the arc welding process when the proper methods were used and when reasonable care was exercised by the operator.

According to the location of the fracture and the position of the members, the edges to be joined should preferably be beveled as shown in Fig. 122. Where the oxy-acetylene cutting torch is used to bevel the edges, the film of blue oxide left on the surface by the cutting process must be removed with a chisel, roughing tool or sand blast; otherwise, when the welding is started, the arc will

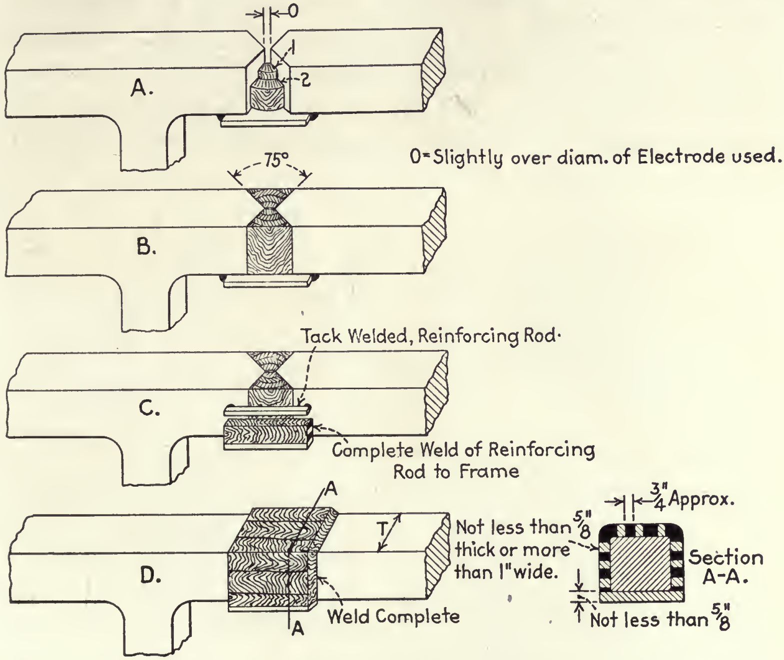


FIG. 122—Method of Welding Horizontal Locomotive Frame Member, Double "V," Side Position

be erratic, which will result in poor penetration and undue oxidation of the added metal. In addition to the cleaning of the surfaces to be joined, the scale which forms on top of the added metal must always be removed before adding another layer. Slag inclusions are a common source of weakness in welds, and can be eliminated only by keeping the work perfectly clean as the welding progresses. The electrode material commonly used is mild steel, 3/16 in. in diameter. Electrodes of ¼ in. diameter may be used if the capacity of the equipment will permit.

To compensate for the contraction of the added metal, prior to starting the welding the abutting members should be expanded or forced apart from 1/8 in. to 3/16 in., depending on size of frame, heat, and method of welding employed. The free space between frame points should be greatest at that end of the opening toward which the welding progresses; the points should not be separated evenly as in the case, for example, of the thermit process where the contraction of the molten mass occurs practically simultaneously. A jack or wedge may be used to force the members apart.

When the point at which the welding was started cools the jacks or wedges may be removed; on heavy members this can

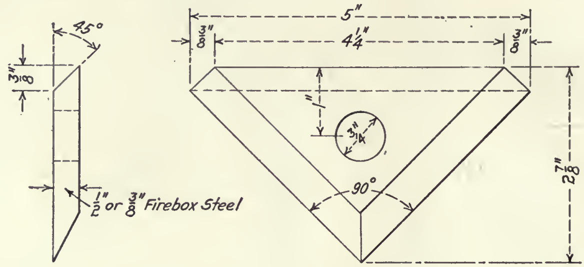


FIG. 123—Filling Pieces for Five and Six-Inch Frames

sometimes be done before the weld is completed. When the opening is filled entirely by metal added from the electrode, the weld is made in vertical layers, starting at the center of the section and welding alternately first on one side and then the other. This method is preferable to that of applying the metal in horizontal layers, as in the former case there is less likelihood of the ineffective long arc welding. To eliminate the necessity of filling all this opening with metal that has passed through the arc, filling pieces as shown by Fig. 123 may be used, providing the operator is of the conscientious type and will take particular care to secure fusion between the edges of the plates and frame scarf. The space between the edges of the filling piece and the beveled edges of the frame should not be less than 1/4 in.

In executing welds such as shown in Figs. 124 to 129 inclusive, the edges of the flush plate should first be welded to the bottom of the frame. A bead of metal should then be deposited in the corner formed between the top side of the flush plate and the bottom beveled edge of the frame. With a filler piece in place, the plug weld should next be made, then the edges welded to the frame, finishing the welds flush with the top of the piece in order that the next piece will lie close to the preceding one. Additional pieces should be welded in place in the same manner, weld-

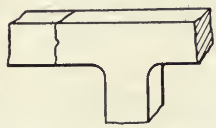


Fig. 124—Frame Fracture

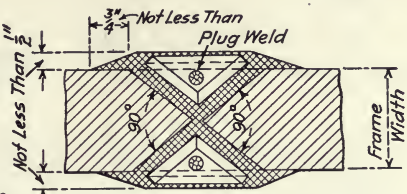


Fig. 127—Longitudinal Section C-D

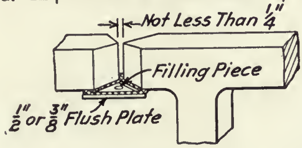


Fig. 125—Frame Prepared, Flush Plate and One Filling Piece Welded in Place

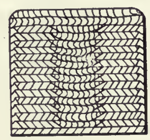


Fig. 128—Vertical Section A-B

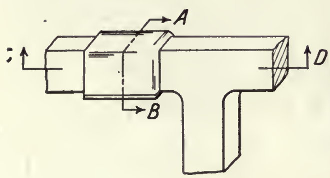


Fig. 126—Finished Weld

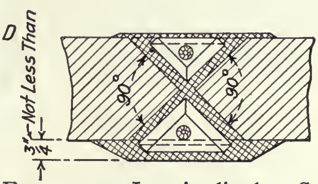


Fig. 129—Longitudinal Section Showing Reinforcing All on One Side in Case of Close Clearance

Fig. 124 to 129—Showing Method when Work Can Be Done from Both Sides of the Frame

ing three or four pieces first on one side and then on the other.

Vertical members are welded, as shown by Fig. 130. When conditions permit all heavy sections of this nature should be prepared and welded from both sides, and should be reinforced 50 per cent to 75 per cent when the nature of the service is severe, as is usually the case. When conditions do not permit welding to be done from both sides, such members may be prepared and

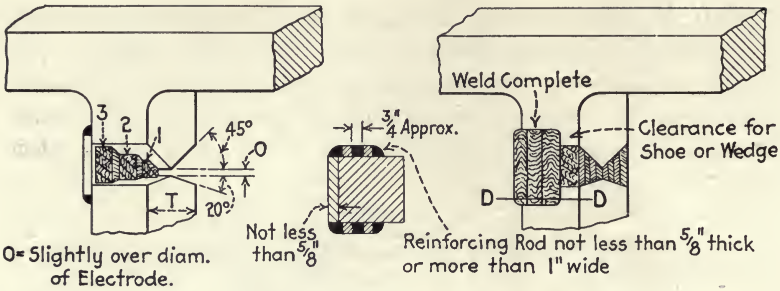


FIG. 130—Method of Welding Vertical Member of Frame Pedestal—Double V, Side Position

welded from one side, in which case the work may be done in the same general way, as described for the double "V" weld.

When the work cannot be done from either side, the methods shown in Figs. 131 to 135 may be used. The edges of the flush plate, also the reinforcing plate, if access permits its use—should first be welded to the frame. The beveled edges should then be

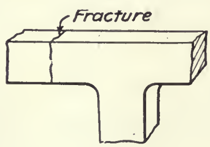


FIG. 131

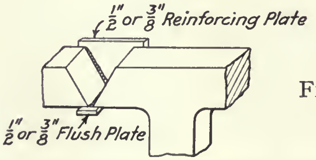


FIG. 132—Frame Prepared, Flush Plate and Reinforcing Plate Tack Welded in Place

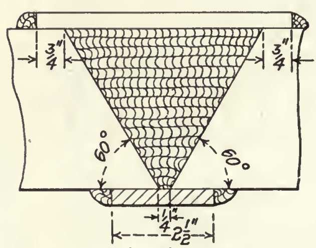


FIG. 134—Longitudinal Section C-D

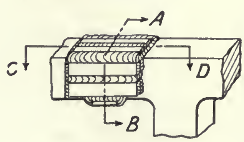


FIG. 133—Finished Weld

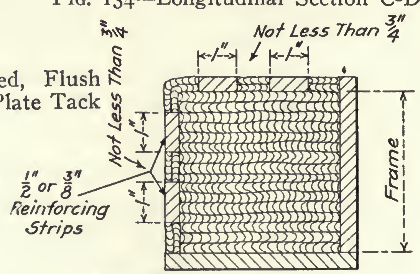


FIG. 135—Vertical Section A-B

FIG. 131 to 135—Showing Procedure when Work Cannot Be Done from Either Side of the Frame joined by welding metal in the opening until the weld is flush with the opposing members. The reinforcing can then be made by welding on strips, as shown in the illustrations. In place of the plate strips for reinforcing, ½ in. or ⅜ in. rods may be used if desired. Plates wider than 1 in. should not be used unless the surface next to the frame can be welded thereto. Plates wider than 1 in. may be used if provisions are made for plug welds. For frame members the strips or rods are less expensive to prepare and are to be preferred.

Fig. 136—A Completed Weld Using Filler Plates in Locomotive Frame

Extreme care must be exercised to obtain a perfect union between the added metal and the beveled edges of the frame members, also between the added metal and the edges of the filling pieces. The use of the filler plates effects a very large saving in time, and the quality of the weld has proven to be just as good as welds made without the plates, if the proper care is exercised. The plates have had mechanical treatment, which makes them superior to metal that would ordinarily be added by the arc. If the plates are carried in stock in two or three standard sizes and the frames are cut out to accommodate the plates, the largest frame can be welded with the arc welding process in approximately the same time as that required for other processes. For small frames less time may be required.

The cost of performing the weld itself has always been in favor of the electric arc process, being on an average of 50 per cent less than that with other methods. The only question which has been raised is that of locomotive delay in the case of large frames; this can be offset by the use of the filler plates. A finished weld made with filler plates is shown in Fig. 136.

Welding Driving Wheels Tires, Rolled Steel Wheels, and Steel Tired Wheels.—The arc welding process is extensively used for building up worn flanges and flat spots on driving wheel tires, rolled steel wheels and steel tired wheels. A typical example of the composition of steel tires is shown in the following table:

Manganese, between	.50 per cent and .80 per cent
Phosphorus, not over	.05 per cent
Sulphur, not over	.05 per cent
Silicon, not over	.35 per cent
Carbon (Class 1), not less than	.50 per cent or over .70 per cent
Carbon (Class 2), not less than	.60 per cent or over .80 per cent
Carbon (Class 3), not less than	.70 per cent or over .85 per cent

Class 1.—Driving tires for passenger engines.
Class 2.—Driving tires for freight engines and tires for trailer wheels.
Class 3.—Driving tires for switch engines.

Offhand it would not seem legitimate to apply the welding process to a driving flange for fear of the effects of localized heat, which in most cases certainly cannot be ignored. The fact that the practice has been so extensive, without any particular regard for the effects of the heat, and that comparatively few failures have resulted, seems to indicate that many parts (even those high in carbon) under certain conditions, with prescribed methods and limitations, can be safely welded.

The method which is considered best for building up flanges is shown in Fig. 137. In this case the added metal or beads extend around the periphery of the tire; the metal is added in sections 8 in. to 12 in. long. One section at a time is finished before starting another. The metal can be applied by this method more smoothly and with less effort than if the arc is operated back and forth across the flange. The main object in the method described is to keep the arc moving, thus preventing the flange from heating to any appreciable depth. This, together with the extreme localization of the arc's heat, and the radiating ability of the massive part, will confine the structure disturbance close to the surface, usually to a depth of about ⅛ in., leaving the main body of the flange or tire structure undisturbed.

No trouble has been experienced with tires welded in this manner. This probably is due to the fact that the tire is not subjected to alternate stresses. It is believed by those who have analyzed this method, its effects and the nature of the service, that the most that could happen would be for the added metal to shell out. Flat spots are built up in the same general way—i. e., in such a manner as to keep the tire practically cool.

A small electrode ⅛ in. or 5/32 in. in diameter should be used with a heat value as low as consistent with fusion. The composition of the electrode should approximate that of the tire. However, such electrodes cannot be used to advantage unless the material is treated "coated," so that the constituent parts of the electrode will not be lost in passing through the arc. This feature is important and necessary if the best economy is to be realized from the work. At present practically all of this class of work is being done with the ordinary mild steel. Even with this material much economy is effected.

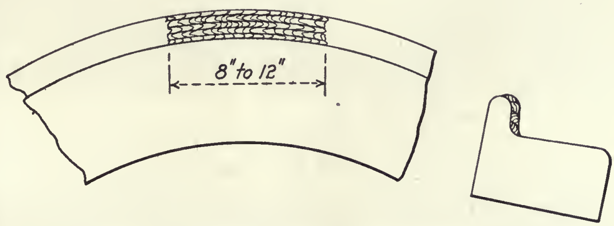


Fig. 137—Building up Flanges of Wheels by Arc Welding Process

Reclamation of Axles.—The nature of the service demanded of axles requires prescribed methods and certain limitations if the welding process is to be applied to them. Axles, unlike flanges, are subject to alternate stresses, and therefore cannot be welded except at the collar, unless the effects of the localized heat are afterwards removed by annealing. The practice on one of the western roads is as follows: For reclaiming axles, the standard sizes and limiting dimensions of M. C. B. axles for passenger, freight and tender trucks, as shown in Fig. 138, should be followed. The figures enclosed in circles indicate the limit of wear.

Axles condemned for lateral wear occurring at the collar and shoulder of the journal can in most cases be returned to service if *only the collar* is built up and turned to the standard dimensions.

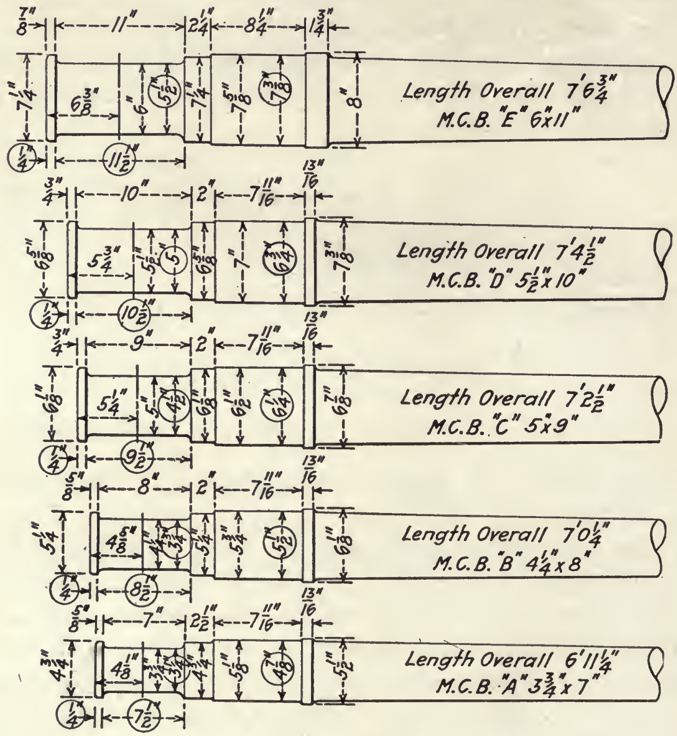


Fig. 138—Working Standards for Reclaiming Axles by Electric Arc Welding

Where this is the case, it shall be done and preheating or annealing will not be required. Welding between wheel seats is not permissible. The welding process may be used to build up worn shoulders, or wear caused by dust guard, etc. If facilities are available for annealing after welding, the annealing should be done by heating to a temperature of 1,450 deg. to 1,500 deg. Fahr., which is equal to a bright red color; the axles should be cooled in

Fig. 139—Fracture Prepared for Electric Welding

Fig. 140—Electric Welded Coupler

the open air free from draft, care being taken not to lay on damp ground or cold massive parts such as would tend to chill the axle and thus produce local strains.

Fig. 141—A Triple Weld in Face of Coupler

Reclaiming Car Couplers, Knuckles, Etc.—On at least one large railroad a vast number of car couplers are being successfully reclaimed. The work includes not only minor repairs such as building up worn shanks, but also the welding of broken eyes, coupler heads and shanks. The latter class of work is only per-

Fig. 142—An Electric Welded Shank

formed by first-class operators. Treated electrode material is used, i. e., the electrode is coated with a material designed to envelope the arc stream and exclude the atmosphere and limit the formation of oxides and nitrides as well as to prolong the cooling of the added metal, thus securing a more ductile metal than that obtained from the ordinary bare electrode.

In this class of work fractures are cut out in the usual way. A prepared piece of work is illustrated in Fig. 139. Fractures which have been welded and which were of considerable length are shown in the coupler head, Fig. 140. This weld was made in two sections by starting in the center and welding to one end, then starting the second section at the opposite end and finishing at the center, each section being completed before starting another.

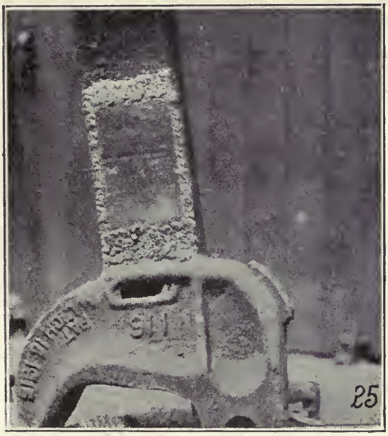


FIG. 143—Built-up Coupler Shank

A triple weld in the face of a coupler head is shown in Fig. 141, and Fig. 142 shows a weld extending half way around the shank.

These examples represent some of the most severe conditions. In most cases there is only one fracture in the coupler body, the majority being located in the face of the coupler head. A worn coupler shank built up to original size by welding on a piece of steel plate is shown in Fig. 143.

Fractured and worn knuckles are repaired or built up in the same general way as couplers. The cost of making such welds is approximately 10 per cent of the cost of new couplers or knuckles.

A method of converting the old 6½ in. coupler butts to the new 9⅛ in. standard is shown in Fig. 144. This is accomplished by applying cast steel shims to increase the dimensions from 6½ in.

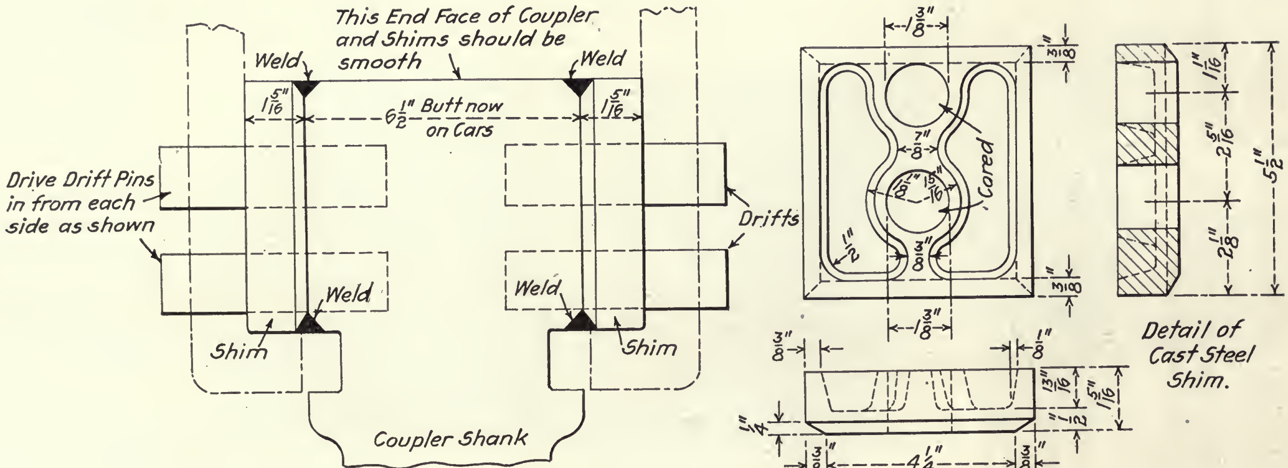


FIG. 144—Method of Applying Cast Steel Shims to Convert 6½ in. Coupler Shank to 9⅛ in.

to $9\frac{1}{8}$ in. One railroad recently converted 8,000 couplers in this manner. The enormous saving effected thereby is apparent.

Metallic Arc Welding of Car Bolsters.—A fractured car

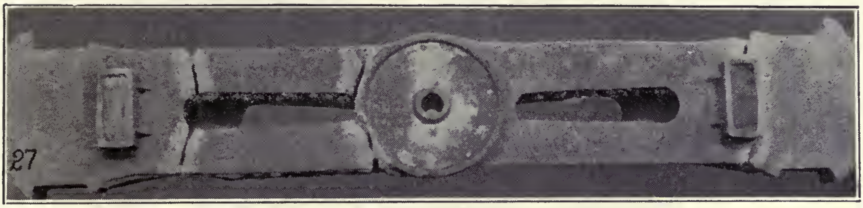


FIG. 145—Fractured Car Bolster Prepared for Electric Welding

bolster which has been cut out and prepared for welding is shown in Fig. 145. The fractures are welded in the same manner as explained for couplers. In addition, reinforcing plates are applied.

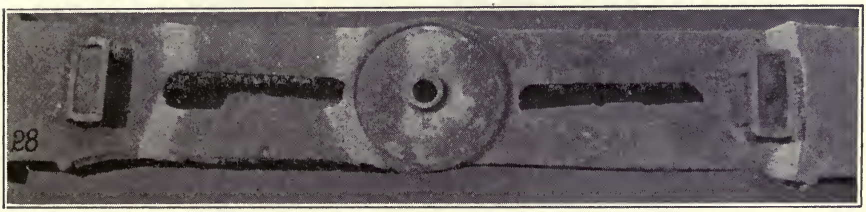


FIG. 146—Welded Fracture (See Fig. 145)

The welded fracture is shown in Fig. 146, and in Figs. 147 and 148 is shown the manner of applying the reinforcing plates.

When fractured bolsters are received which have previously

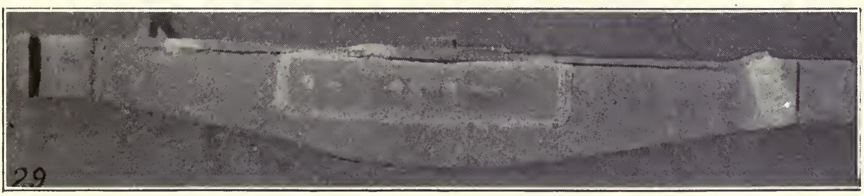


FIG. 147—How Reinforcing Plates Are Applied

been repaired by riveting on straps, these straps and rivets are removed and the fracture is welded. The rivet holes are then welded up and a reinforcing plate is welded on. The reinforcing is extended over the zone within which the particular class of bolster has indicated a weakness.

Welding of cast steel side truck frames can be done successfully by the use of electrode material of such a grade as to give a reasonable degree of ductility in the weld, and by the proper applications. As a rule the fractures encountered in parts of this character are located in the tension members, as shown at A, Fig.

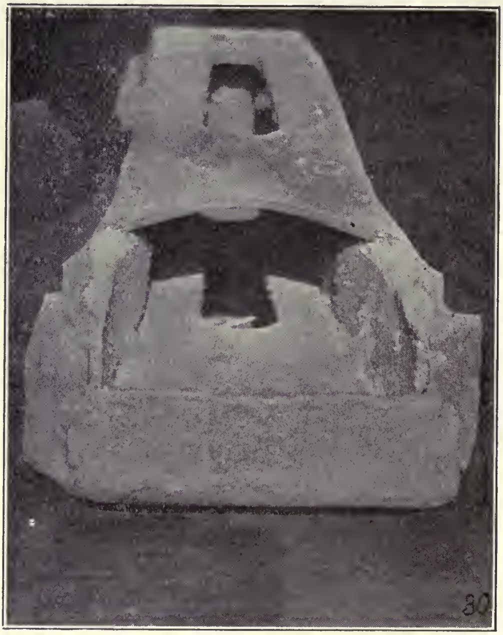


FIG. 148—How Reinforcing Plates Are Applied

149. In order to secure a factor of safety at the joint a reinforcing plate should be applied to the underside of the tension member and the fracture edges beveled and welded from the opposite side, as shown. The examples shown are similar to many other parts and no doubt the same methods would be applicable.

Most steel castings that develop fractures were weak or defective to begin with. A close inspection of a number of such parts will prove this conclusively. Among the most common defects are: air holes, sand pockets and shrinkage cracks. If in repairing such castings these defects are removed, the castings will in many cases be better than they were originally.

All cast steel car castings or similar parts should be annealed after welding by heating to a temperature of about 1500 deg. F. to 1550 deg. F. and keeping them at this temperature for not less than two hours. This will not only remove any bad effects caused by the welding heat, but will also restore the normal structure in

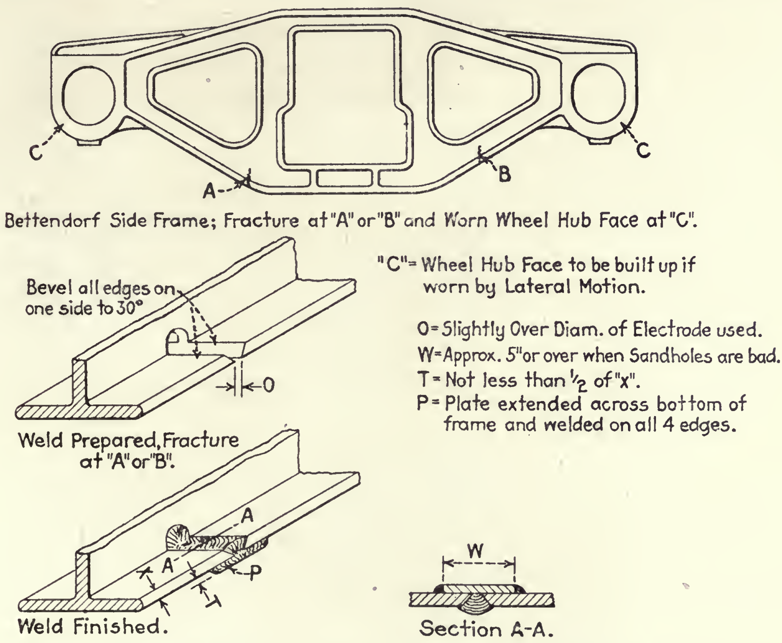


FIG. 149—Repairing a Cast Steel Side Truck Frame by Metallic Arc Welding

case the part has become fatigued, due to prolonged service. With the proper equipment and welding materials, the success of this class of welding depends upon rigid adherence to proper methods of application and subsequent annealing. On one railroad where this practice has been going on for over a year, practically no failures have resulted. In fact, it is almost common practice in many parts of the country to use the arc welding process to repair and reinforce castings and parts to add sufficient strength to enable them to withstand the service. Through work of this character the process has acquired the name of the "putting on" tool in some shops.

Some of the parts on which practical applications of this nature have been made are: drawbar castings on Vanderbilt type of tenders for Mikado (2-8-2) locomotives, draft sill end castings on refrigerator cars, locomotive frames where new and larger cylinders have been applied, crossheads, etc.

Space limitations prohibit the mention of the many applications of the arc welding process to machinery parts on railroads. However, some idea as to the extent of its application is given in the list of parts welded which was taken from the records covering a period of 60 days at a division point on one road which has three portable metallic arc welding equipments for locomotive use. During this period a large number of parts of railroad equipment were repaired, as is evident from the list, which is included here because the question has been quite frequently asked, what parts of railroad equipment are electric welded?

List of Parts Electric Welded and Class of Work Performed

Firebox

Fire door, fracture welded
Fire door, patches welded on
Front flue sheet, fracture welded
Sheets welded to mud ring corners
Side sheets, fracture welded
Side sheets, patches welded in
Side sheets welded in

Boiler

Flue sheets, fracture welded
Flues welded to flue sheet
Superheater pipe built up

Frames and Attachments

Belly braces welded to frame
Binders built up
Binders, liners welded to
Binders, wedge bolt hole plugged
Buckle sheet, holes plugged
Buckle studs welded to boiler
Bumper castings built up

Cab brackets
Deck casting fracture welded
Equalizer fulcrum arms, fracture welded
Frames built up
Frames, fracture welded
Frame braces, holes plugged up
Frame braces welded to frame
Frame jaws built up
Frame splices, holes plugged up
Front end casting, fracture welded
Guide blocks built up
Guide yoke built up
Guide yoke, fracture welded
Guide yoke bracket, fracture welded
Smoke arch brace, fracture welded
Tail pieces built up

Cylinders

Cylinder, fracture welded
Front cylinder head, fracture welded

Running Gear Parts

Crank pins, collars welded to crank pins
Driving boxes built up
Driving boxes, fracture welded
Driving box, shoes and wedges; broken flanges welded
Engine truck pin built up
Hub pin built up
Tires, spots built up
Tires, shims welded to tires
Trailer boxes, lugs welded on boxes
Trailer tires built up
Trailer tires, fracture welded
Trailer tires, spot welded to wheel center
Trailer yoke
Truck, fracture welded
Truck bolsters built up
Truck frames, welded to center piece
Truck side frames, fracture welded
Wheel spokes, fracture welded

Connecting Rods

Main rod built up
Main rod straps built up
Rod straps built up
Rod straps, strips welded to
Side rods reinforced

Side rods, collar-welded on side rods
Side rods, lateral plates welded on side rods

Crossheads and Piston Rods

Crosshead built up
Crosshead, fracture welded
Crosshead, gibs welded on
Crosshead, holes plugged
Crosshead, liner welded to
Crosshead pin built up
Crosshead pin holes built up
Crosshead, strips welded on
Piston collar built up
Piston rod built up

Valve Gear

Blade pins built up
Combination lever, fracture welded
Eccentric arms built up
Eccentric keys built up
Link, holes plugged
Link blocks built up
Link hanger built up
Link pins built up
Link saddles built up
Motion pins built up
Motion plates, fracture welded
Rocker arms built up
Rocker arms, fracture welded
Tumbling shaft arm, fracture welded
Valve yoke built up
Valve yoke lugs built up
Valve yoke, stem built up

Steam and Exhaust Pipes

Dry pipes, fracture welded
Exhaust pipes, fracture welded
Nozzle stands built up
Nozzle stands, holes plugged

Brake and Spring Rigging

Brake hanger, posts built up
Brake hangers built up
Brake hangers welded to frames
Equalizer fulcrum pin built up
Equalizer jaws built up
Equalizer stands built up

Spring equalizer bushing welded
Spring saddles built up
Trailer spring guides built up
Truck equalizer built up

Tender

Axle collar built up
Side bearings built up
Tank, fracture welded
Tank goose neck
Truck bolster, fracture welded

Not Classified

Air pump piston built up
Bell cranks, fracture welded
Bushings spot welded
Chafing iron built up
Chafing iron, steel plate welded in
Draw bar yokes built up
Drill press shafts built up
Dynamo doors, fracture welded
Gasoline engine cylinder, fracture welded
Grease cups welded to rods
Link latch blocks built up
Motor car castings, fracture welded
Reverse lever, fracture welded
Reverse lever latch built up
Running board brackets, extensions welded on
Throttle latch built up

The American Railroad Association committee on welding truck side frames, bolsters and arch bars has recommended that welding of cracks or fractures should not be permitted on axles, arch bars, car wheels or tires, truck equalizers, spring or bolster hangers, brake wheels, coupler bodies or knuckles, knuckle pin, locks, lifters or on parts made of alloy steel or heat-treated carbon steel. It is not surprising that these recommendations were made if the conclusion was based on the average results obtained on railroads throughout the country as was no doubt the case.

It is generally conceded that there is an extremely wide variation in the quality of welds, the strength ranging from almost nothing to values equal to that of the welded part. Considering the results that have been obtained with the small amount of attention that has been given to the factors which determine the quality of welds, such as the training of operators, quality and kind of material that goes into the weld, and methods employed in performing the weld, etc., it would seem that any limitations that

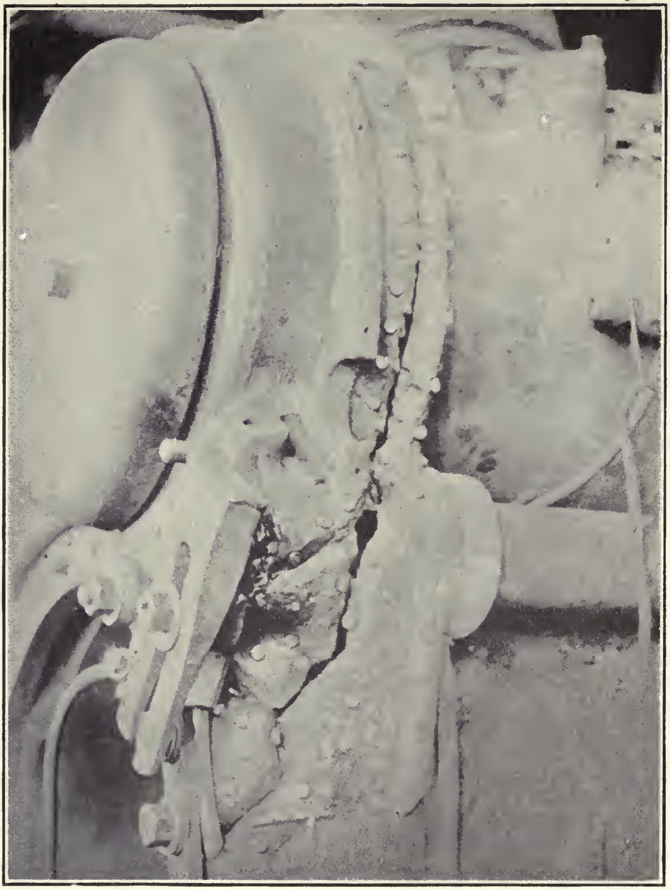


FIG. 150—Fractured Cast Iron Cylinder of a Mikado Type Locomotive Prepared for Arc Welding

are placed on autogenous welding should be designed to encourage the development of the art. With no other process is so much expected from the efforts expended as from autogenous welding. Without any special guidance or training welding operators on railroads are almost daily required to perform welds under practically impossible conditions, and from the results of these hap-

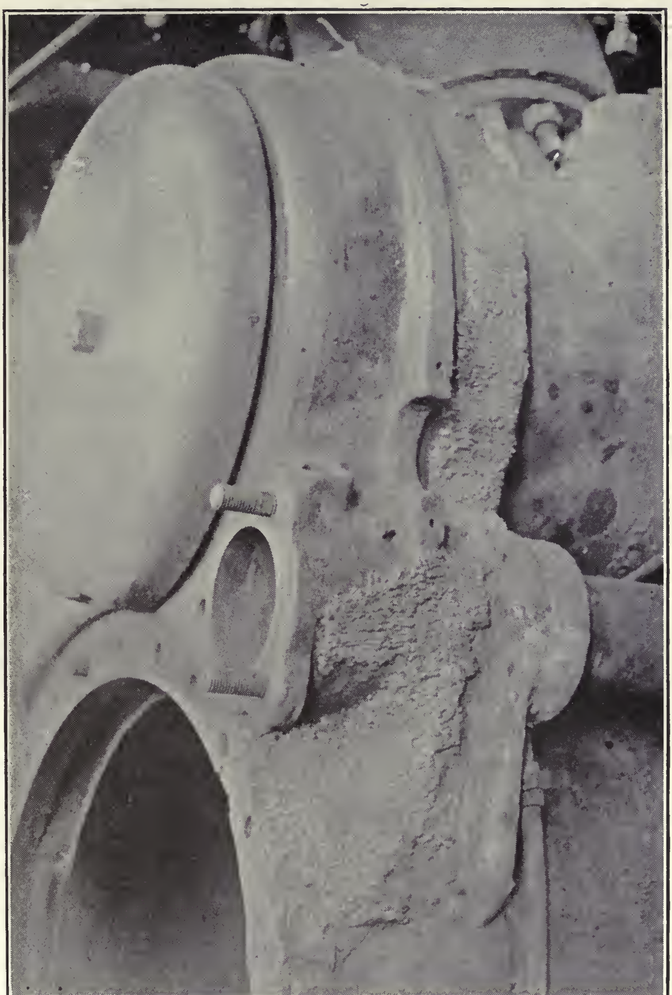


FIG. 151—Welded Cast Iron Cylinder of Mikado Type Locomotive

hazard applications the value of the process is judged by the executives.

The repairing of broken or fractured cast iron cylinders are among some of the applications which have been condemned by many, and while all cast iron parts cannot as yet be advantageously welded many parts can. A very bad break in a cylinder of

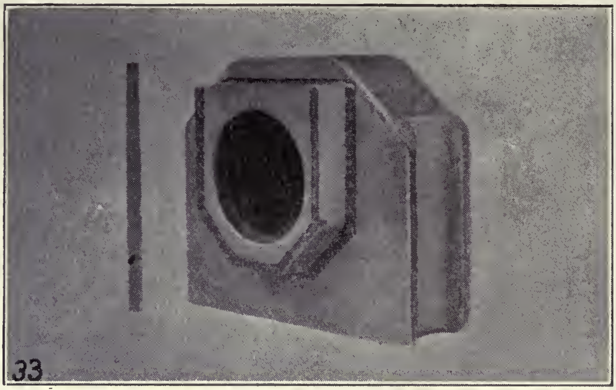


FIG. 152—Journal Box Completely Built up (Foreign Railroad)

a Mikado type locomotive prepared for metallic arc welding is shown in Fig. 150. The fracture is lined with ½ in. wrought iron studs spaced approximately 2½ in. apart. The weld was

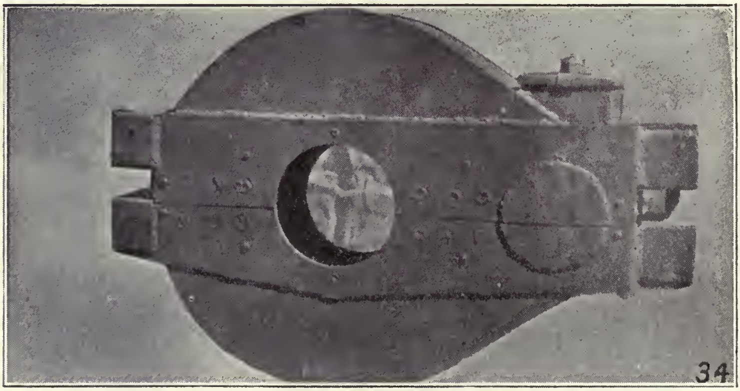


FIG. 153—Gear Casing Built up (Foreign Railroad)

made in sections by the back step method, progressing in an upward direction. The completed weld is shown in Fig. 151. No preheating or annealing was employed; instead, the heat was kept

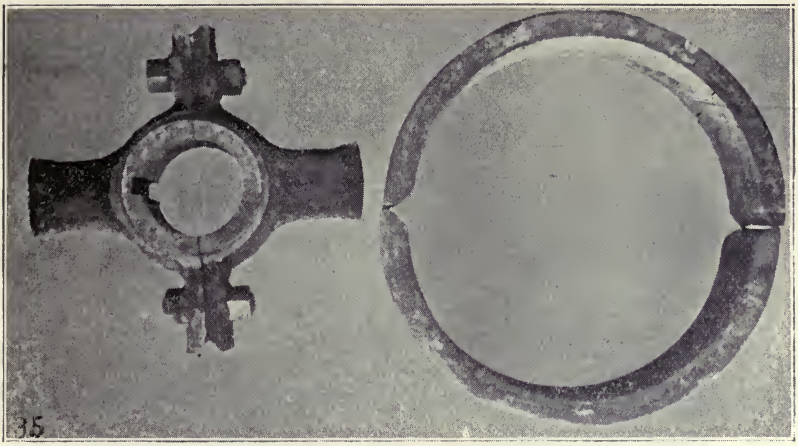


Fig. 154—Wheels Cast in Separate Parts Are Assembled by Arc Welding Process (See Fig. 155)

as low as consistent with good welding by using a small ⅛ in. diameter mild steel electrode. In the past most welds of this kind were made with a bare electrode. It is now considered that better work can be done with a "coated" electrode, in which case the metal flows smoothly and secures a better union with the cast iron. The cylinder referred to above has been in constant service

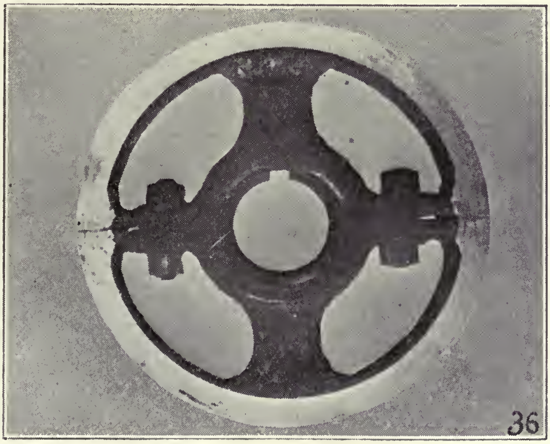


Fig. 155—Wheels Cast in Separate Parts Are Assembled by Arc Welding Process (See Fig. 154)

since April, 1919. Many other welds of its kind have been in service without any trouble being experienced for two years or more.

It may be of interest to know how some of the other countries

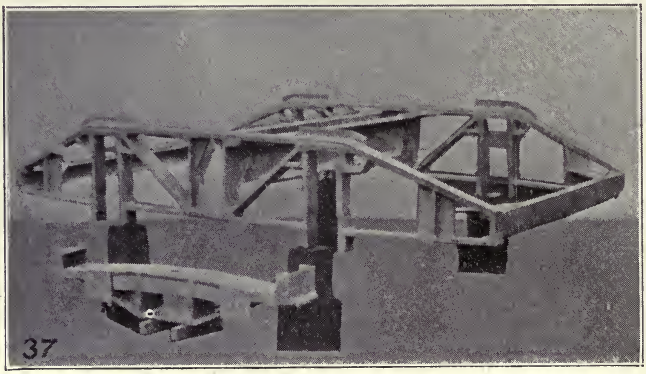


Fig. 156—Truck Frame and Bolster Built up by Arc Welding (Foreign Railroad)

are progressing in the electric welding art. A few illustrations will give some indication.

A journal box completely built up by the arc process is shown in Fig. 152.

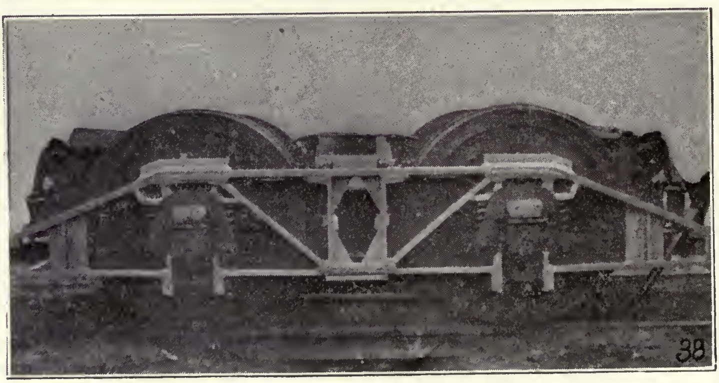


Fig. 157—Truck Frame and Bolster Built up by Arc Welding (Foreign Railroad)

A gear casing of an electrically driven car, completely built up, is shown in Fig. 153.

Gear wheels, which are cast in separate parts, as shown in Fig. 154, are then assembled by arc welding, as shown in Fig. 155.

A truck frame and bolster built by arc welding is shown in Figs. 156 and 157.

This work was done by the New South Wales Government tramways at Sydney, Australia, which recently had a representative traveling through America, gathering information for the purpose of further extending the process of arc welding.

XI

MISCELLANEOUS NOTES AND ARC WELDING DATA

In most all engineering practice it is necessary to know, with a fair degree of certainty, what may be expected of a material intended for any given purpose, especially in cases where human life may be jeopardized in case of a failure in service. For this reason the subjects of greatest interest to the user of arc welding are first the physical properties of a weld, and second the alterations of the physical properties of the part affected by the welding process.

In a weld made by the metallic arc process the metal to be added usually consists of mild steel or ingot iron which has been rolled or drawn into rod or wire form. In the process of welding, the rod or wire is melted and deposited to other metal, also melted, the mass then cooling into a cast form in which the artificial structure produced by the rolling or drawing of the wire is entirely changed. A weld, therefore, is but a casting and will never have all the properties to the same degree as a similar piece which has had mechanical treatment.

The physical properties of the added metal will depend almost entirely upon the following factors: Composition, impurities, slag inclusions, gas holes and crystal structures.

In the making of steel, such elements as carbon manganese, vanadium, nickel, chromium, tungsten, molybdenum, and the like, are intentionally added in varying proportions to impart different properties depending on the service requirements.

Composition.—In bare electrode metallic arc welding the metal is subjected to very high temperatures, some of it actually passing into the form of vapor; the iron constituent melts at a higher temperature than the other elements ordinarily present, except carbon, which combines readily with the oxygen of the air and forms carbon monoxide or carbon dioxide gas. Most of the elements present in an electrode are lost in vapor or oxide in traversing an arc exposed to the air. For this reason, practically all bare wire welding has been done with a mild steel or ingot iron electrode material. Where a mild steel material is used the carbon and manganese are reduced to exceedingly low values. A typical analysis of a deposit from a mild steel electrode of 0.15 to 0.20 carbon and 0.50 to 0.60 manganese will be 0.05 carbon and not over 0.20 manganese. The other elements, such as phosphorus, sulphur and silicon, being low to begin with do not appear to be greatly affected.

The metal obtained in the weld with the bare electrodes ordinarily used is, therefore, a form of cast metal exceedingly low in carbon and manganese and other such elements as are usually added to metal to impart certain desirable characteristics.

Impurities.—The physical quality of welds seems to hinge upon the impurities more than any other factor, since the degree of ductility is largely dependent upon these impurities. The conditions under which welding is done, i.e., exposed to the air, subjects the metal to the effects of the oxygen and nitrogen. The characteristic brittleness by which all autogenous welds are more or less marked was for some time thought to be due entirely to oxidation, because, no doubt, under ordinary conditions of fusion, nitrogen has but little effect on iron. According to the scattered facts the authors have been able to collect on this subject it is now commonly agreed among the metallurgists who have conducted research along this line that the oxygen content will not alone account for the lack of ductility. Nitrogen, as low as 0.06 per cent. is sufficient to reduce the elongation on low carbon steel as much as 80 per cent. It is obviously one of the most effective elements for making steel brittle. Under the temperature and conditions of the welding arc, the nitrogen becomes very effective, resulting in the weld becoming nitroized. Strauss found 0.12 per cent nitrogen in an electric weld. Another metallurgist found that a weld made with a bare electrode contained forty times as much nitrogen as that of the plate material. The usual amount of nitrogen contained in ordinary steel is very small, approximately 0.02 per cent in Bessemer steel and 0.005 per cent in open hearth.

From the foregoing it is evident that to improve the ductility of welds it is necessary to eliminate as far as possible the formation of nitrides and oxides.

A test recently conducted, using a certain type of coating on an ingot iron electrode, showed a 75 per cent reduction of nitrogen in the weld over that of welds made with bare electrodes. Many attempts have been made to eliminate nitrides and oxides by the use of elements which will act as reducing agents. It appears, however, that owing to the great affinity for oxygen and nitrogen of such elements as would perform this function they are destroyed without much effect unless present in quantities objectionable in other respects.

Slag Inclusions.—It is self-evident that slag inclusions will constitute a source of weakness in a weld. The apparent cause of most slag inclusions is lack of cleaning the surface to be welded, so that the scale is not always entirely fused before metal deposition occurs, in which case if the metal cools quickly the slag is trapped in the weld. If the surface to be welded is clean and the proper heat value and manipulation are used to prevent unduly rapid cooling, the slag will be floated to the top of the deposit where it will form a scale and aid in preventing the oxidation of the surface, thus limiting the amount of dissolved oxygen.

Gas Pockets.—The exact nature and origin of the gases trapped in welds has not been definitely determined. The presence of carbon in any appreciable amount is known to produce gas pockets. This is particularly noticeable when welding on medium high carbon steel, and is doubtless due to the combination of the carbon with oxygen, resulting in the formation of carbon monoxide gas, which on account of the rapid solidification of the fused metal is trapped. When welding with a low carbon steel electrode on low carbon steel plate material the weld is comparatively free from gas pockets. On increasing the arc length, however, the tendency to form gas pockets is increased. Since low carbon steel absorbs gas readily when exposed sufficiently while in a plastic state, a long arc is very likely the worst offender in producing gas pockets. Their occurrence, due to dissolved or occluded gas or the gas formed from impurities present in the ordinary electrode material, is thought to be very limited, since these gases are largely liberated as the metal passes through the arc.

Crystal Structure.—The crystal formation is dependent largely upon the rate of cooling, and consequently upon the sequence of depositing the metal; a very fine grain is produced if the metal is cooled quickly enough to prevent the formation of columnar crystals. By adding the metal in layers, each succeeding layer tends to anneal the preceding one, thus effecting a better structure. A refinement of the structure may be obtained, as in the case of any cast metal, by heating and hammering, but this is not usually practicable.

Structural Disturbance of Part Welded.—The heat does not largely affect the surrounding material on plate stock of the usual composition and thickness up to at least ¾ in. The structure is disturbed but little, 1-16 in. from the edge of the weld. When welding parts of larger sections, having a greater thermal capacity or of higher carbon content, consideration should be given to the thermal disturbances.

The nature of the service for which the part is intended will determine the course of action required. When the carbon content is as much as .3 per cent and the section is such as to cause quick cooling, annealing will likely be necessary, if the part is to be subjected to vibratory stresses, or if it is to be machined through the line of weld. It is advisable to investigate each case and determine the treatment, according to the magnitude of the heat effect and service requirements of the part.

Microscopic Examination of Weld.—The following results were obtained from a microscopic examination made of some metal deposited by the metallic arc process on a ⅜ in. piece of boiler plate steel, about 2¼ in. by 1¾ in. in size. The weld was made with a mild steel electrode. Cuts made through this weld in obtaining specimens for the microscope showed perfect union of the deposit metal with the steel plate with no distinct boundary between them. Small holes, however, could be seen in the weld metal after the cut was made.

Three sections through the deposited metal were cut at right angles to each other—two of them also including portions of the steel base—and were polished as usual for the microscope. When examined before etching, the deposited metal was seen in each section to be full of very small particles of iron oxide, and the steel plate showed a large quantity of alumina with a little slag. Photomicrographs showing these inclusions are shown.

When etched with nitric acid the deposited metal was seen to contain abundant small pale angular needles or crystals which, it was thought, might be cementite, martensite, or nitride, as the needles commonly found in steel fusion welds have been identified by various authorities as each of these substances. A portion of the deposited metal was filed off this sample without removing

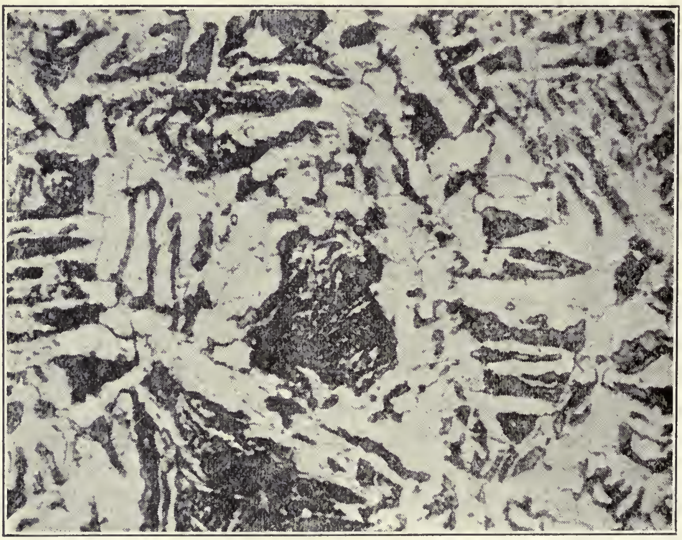


Fig. 158—Typical Structure of Plate Just Below Weld, Etched with Nitric Acid and Magnified 400 Diameters

any appreciable quantity of the underlying steel base, and an analysis of the filings showed 0.04 per cent carbon. Since the deposited metal was shown to be practically homogeneous by examination in three planes at right angles to each other, it is evident from the low carbon content that the needles or crystals cannot be cementite or martensite.

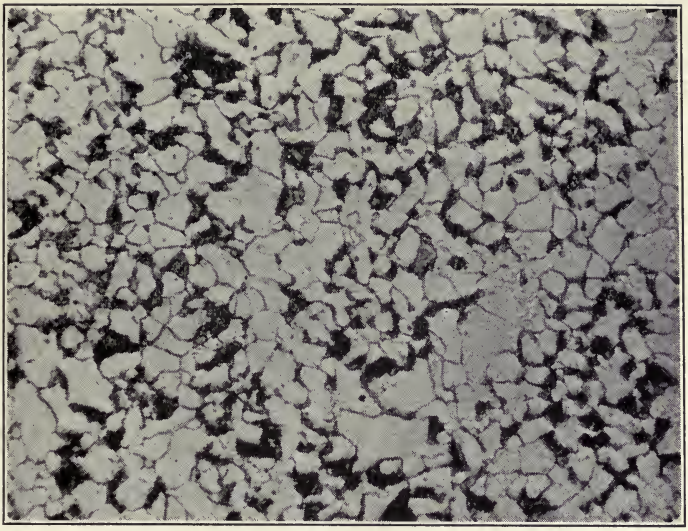


FIG. 159—Typical Structure of Plate a Slight Distance Below Weld, Etched with Nitric Acid and Magnified 400 Diameters

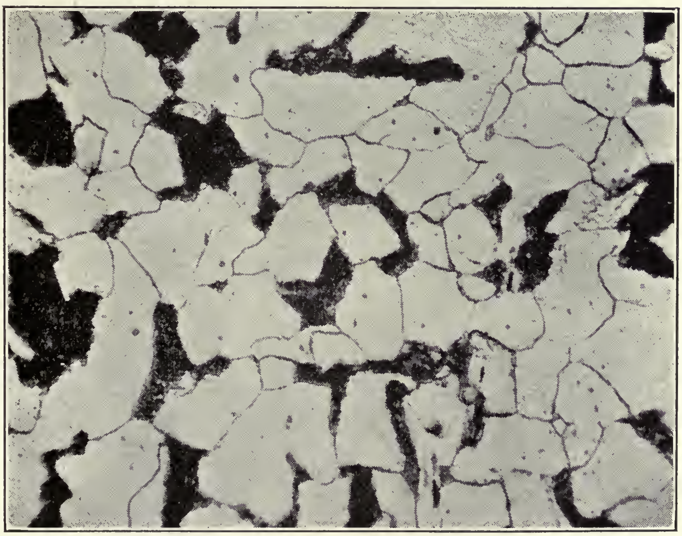


FIG. 160—Typical Structure of Plate Beyond the Influence of the Weld, Etched with Nitric Acid and Magnified 400 Diameters

The steel plate below the welded metal showed interesting variations of structure, some of which are illustrated by photomicrographs. Directly below the weld the structure was very coarse, and showed sorbite or troostite in angular arrangements

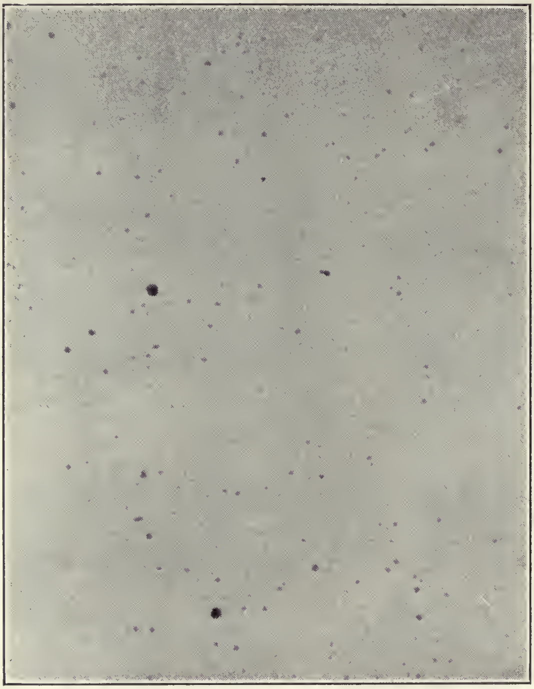


Fig. 161—Average View of Deposited Metal of the Weld, Unetched and Magnified 400 Diameters, Showing Abundant Fine Globules of Iron Oxide

as in a casting. Further down the structure became gradually finer until it was very fine, with many small particles of sorbite. This fine structure passed gradually into the original structure of the plate by coarsening of both sorbite and ferrite, and transformation of some of the former into pearlite.

Annealing experiments were conducted on small sections of this plate, including the welded metal, to investigate the structural changes that would take place. One specimen was heated at about 500 deg. C. for two hours, and cooled in lime. The various zones in the steel plate which were described above were not changed perceptibly by this treatment, but the nitrite inclusions in the deposited metal showed a decided change. After polishing and etching in the same way as before, these inclusions

FIG. 162—One of the Worst Streaks of Alumina Inclusions Seen in the Steel Plate, Unetched and Magnified 200 Diameters

appeared in the form of needles, much darker, thinner, and sharper than before the annealing, having somewhat the appearance of very fine angular pearlite or sorbite. These structures before and after annealing are illustrated by photomicrographs.

Another similar specimen was annealed at 900 deg. C. for four hours and cooled slowly in the furnace. After polishing and etching with nitric acid as before, the nitride in the deposited metal was seen to have partly segregated into irregular shaped bodies

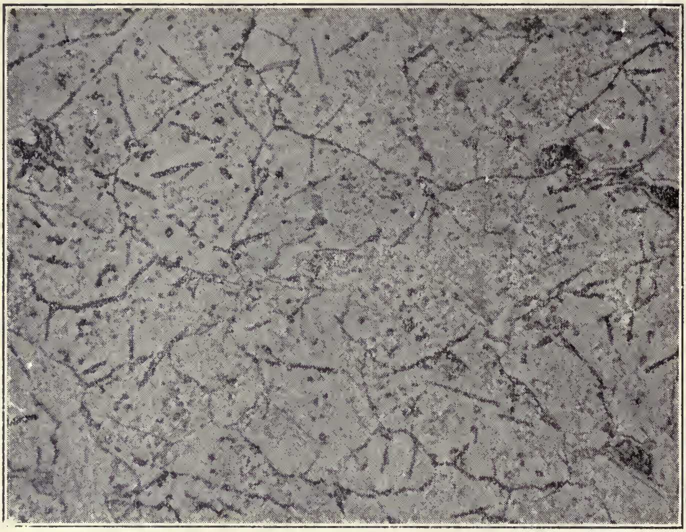


FIG. 163—Typical Structure of Deposited Metal of the Weld after Annealing at 900 Deg. C. for Four Hours, Showing Oxide and Nitride.

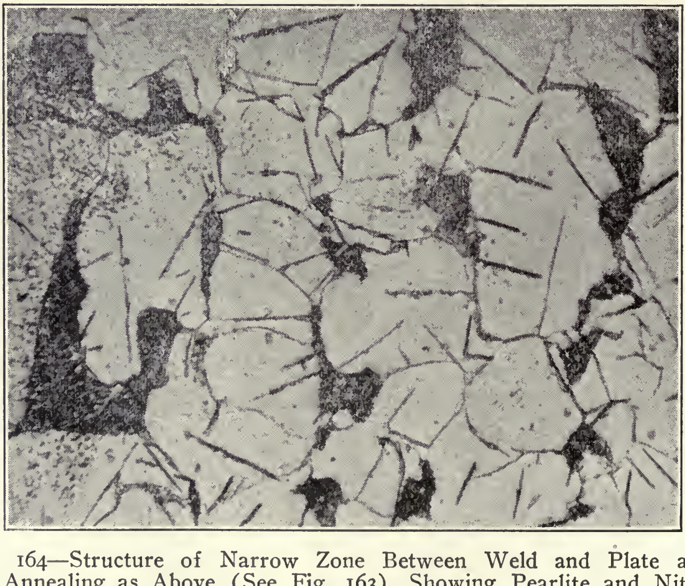


FIG. 164—Structure of Narrow Zone Between Weld and Plate after Annealing as Above (See Fig. 163), Showing Pearlite and Nitride in Ferrite

resembling the segregated cementite in annealed low-carbon steel sheets. The centers of some of these bodies were dark, but were not the same as pearlite, as can be seen from the photomicrographs. Some of the needles of nitrides were present here also, and were darkened by the etching as in the sample annealed at the lower temperature.

The steel plate after the 900 deg. annealing lacked the dif-

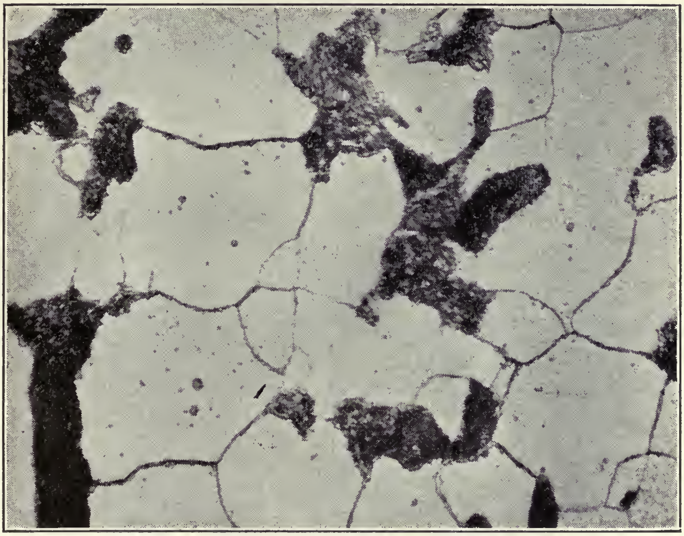


FIG. 165—Typical Structure of Steel Plate below Weld after Annealing as Above (Fig. 163), Showing Pearlite in Coarse Ferrite Without Nitride

ferent zones described in the original welded plate, but was composed entirely of ferrite and pearlite, both coarsened by the heat-treatment. A narrow border between the deposited metal and the steel plate contained both pearlite and nitride needles, which could readily be distinguished from each other, thus furnishing further proof that the original inclusions in the deposited metal were not a carbide product such as cementite or martensite.

The presence of alumina inclusions, which of course do not migrate by diffusion on annealing, in this boundary zone containing both pearlite and nitride, showed that it was the nitride that diffused into the steel plate below the weld. The abrupt termination of the pearlite particles at the upper boundary of this zone showed that the oxide and nitride in the deposited metal had prevented any diffusion of carbide into it from the steel plate beneath.

These experiments show that while the chilling effect of the

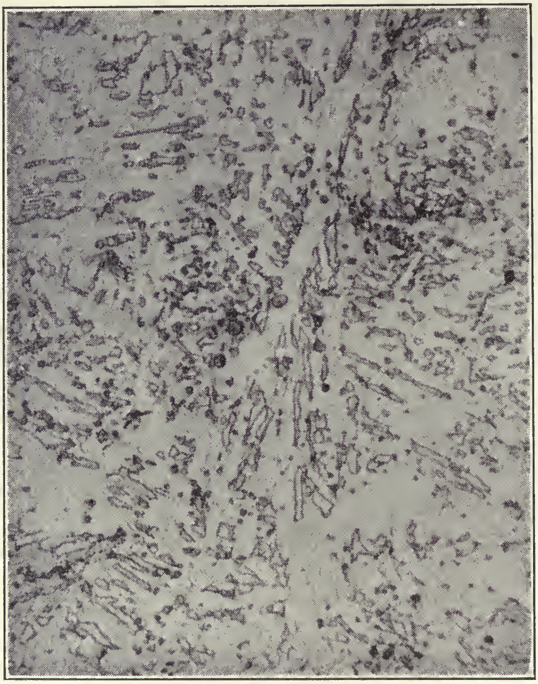


Fig. 166—Typical Structure of Deposited Metal of the Weld as Received, without Annealing, Showing Round Gray Oxide Spots, and Pale Angular Nitride Crystals

welding on the structure of steel plates can be removed by annealing, the idea that nitrogen can be so removed is erroneous. On the contrary, support is given to the opposite view that although steel does not easily absorb nitrogen during ordinary heat-treatments, neither is this element readily removed when once it has been absorbed.

Strength of Weld.—A competent operator, using bare electrodes of mild steel or ingot iron should consistently produce welds having an average tensile strength of 40,000 lb. per square inch. The ductility of the average weld is poor, due to reasons

Fig. 167—Typical Structure of Deposited Metal of the Weld after Annealing at 500 Deg. C. for Two Hours, Showing Nitride Needles Darkened by the Etching, and Round Oxide Dots Unchanged

previously described. A capable operator should produce a weld having an elongation of 5 per cent and a reduction in area exceeding 7 per cent. Further data are given on this subject in the table of the Wirt-Jones investigation of ½ in. arc welded ship plates; it will be noted that the above figures are conservative, since they are intended only to show the reliance which may safely be placed in the process, when using the most ordinary materials.

The tabulation of results of test shown were conducted to determine the efficiency of metallic arc welded joints on half-inch ship plates with different systems and types of electrodes. A study of this sheet will show quite conclusively what may be expected of a welded joint. The authors have compared this test with considerable other test data and find that the results shown are representative of that obtained in a number of other instances where similar investigations have been made.

Speed and Cost of Arc Welding.—*Speed of arc welding* for seams or joints is usually expressed in feet per hour for a given thickness. For building-up operations and the like the speed of welding is expressed in pounds of metal used or deposited per hour.

It is difficult, in either case, to give information in a form which can be used accurately to estimate the time required for a given operator, as the available data on this subject at the present time are not sufficiently complete. The reason more information is not available will better be appreciated when consideration is given to the many factors which determine the speed of weld, such for example as the type of joint, angle of bevel, spacing, position of work, electrode size, electrode current density, whether work is inside or out in the open, efficiency of operator, etc. It is not, however, a difficult matter to secure the speed of welding for any given operation under given conditions.

The following tables will give some idea as to the rate of welding for different plate thickness, arc currents, and electrode sizes:

Data on Seams of Regular Production Work

Plate Thickness Inches	Diameter Electrode Inches	Time in minutes per straight foot	Pounds wire used per foot welded	Arc Current
1/8	1/8	30.	.5	70
1/8	1/8	25	.6	70
3/16	5/32	20	.5	120
1/4	1/8	25	.68	130
3/8	5/32	35	1.5	160
3/8	5/32	33	1.3	135
1/2	5/32	45	1.75	180

U.S. SHIPPING BOARD
EMERGENCY FLEET CORPORATION
ELECTRIC WELDING COMMITTEE
PLATES TESTED BY DIVISION VII-1 AND VIII
BUREAU OF STANDARDS – WASHINGTON, D.C.

WIRT-JONES INVESTIGATION OF ONE-HALF INCH ARC WELDED SHIP PLATES

1	
TE	
YIELD POINT LB. PER SQ. IN.	E… 2 I…
38,400	

WELD															
8	11	12	13	14	15	16	17	20	21	22	27	28	29	30	33
	WELD							ELECTRODE			POWER				
		POSITION									CURRENT IN AMPERES		VOLTAGE		
SERIAL NO. OF COMMITTEE	OPERATOR	FLAT	HORIZ.	VERT.	OVERHEAD	TYPE	RATE IN FT. HOURS	TYPE	DIAMETER IN INCHES	MANUFACT'R OF ELECTRODE	A.C.	D.C.	OPEN CIRCUIT	ARC	REMARKS ON WELD
1	R.B.	✓					3.33		.15625	ROEBLING		170-180	67-68	18-22	Each Weld made in 1 run Plates cleaned by sand b…
2	"	✓				" 1/2"	2.86		"	"		150-160	67-68	18-22	Each Weld made in 1 ru… Plates cleaned by sand …
3	G.D.W.	✓				"	2.35	AM. BASIC ANNEALED	"	AM. STEEL & WIRE		110-120	63	14-17	
4	"	✓				"	3.64	"	.1875	"		140	63	15	
5		✓				"	4.44		.15625	"		140-150	75	18-20	Each Weld made in 2 ru…
6		✓				"	3.99		"	"		140-150	75	18-20	Each Weld made in 2 ru…
7	J.W.			✓		"	3.16		.125	ROEBLING		110-120 130	65	18-20	First side of plate was we… using 110-120 Amp. other side 13…
8	"			✓		"	2.56		.125	"		110-120	65	18-20	
9A	HINES	✓				"	3.68		.1875	ARMCO	150 60CYCLE		117	20-22	
9	"	✓				"	2.78	TONCON	.15625	WASHBURN WIRE CO.		150	75	19	
10	"	✓				"	3.00	"	"	"		150	75	19	
11	H.W.S.	✓				"	1.81		"	ROEBLING		140	37.5	18-22	Each plate welded with 2 r… on 1st. side, 1 run on 2nd. s…
12	"	✓				"	2.49		"	"		140	37.5	18-22	Each plate welded with 2 … on 1st. side, 1 run on 2nd. s…
13	P.K.	✓				"	3.07	SIEMUND WELDING WIRE	"	S.& W.CO.		150-160	63	24-28	
14	"	✓				"	2.85	"	"	"		145-155	63	20-22	
15	D.B.T.	✓				"	1.53	COATED	.134	Q.A.		90	110	35	Weld made in 2 runs
16	"	✓				"	1.81	"	"	"		90	110	35	" " " " "
17	J.M.M.	✓				"	1.37	"	"	"	90		102	35	" " " " "
18	"	✓				"	1.81	"	"	"	90		102	35	" " " " "
19	J.J.	✓				"	1.90	"	.125	Q.A.	150 60CYCLE		115	20-25	Weld made in 2 runs Current used 1.26 K.W.H…
20	"	✓				"	1.48	BARE	.125	E.A.C.& W.CO.	175 60CYCLE		125	15	Weld made in 2 runs Current used 1.6 K.W.H…
21	T.T.	✓				"	1.59	COATED	.134	Q.A.	105 25CYCLE		100	40	Input 5.6 K.W.-1.27 K.W.H…
22	J.J.	✓				"	.97	1/2 "	.125	E.A.C.& W.CO.	160 25CYCLE		100	20	Operator's first experien… with 25 cycle and lost con… able time cleaning out … and changing electrod… Weld made in 2 runs-t… was considerable sputt… when welding. Input 5.…
23	E.L.C.	✓				"	2.10		"	ROEBLING		80-90	63	18-20	
24	J.W.F.	✓				"	1.90		"	"		80-85	63	18-20	
25	"	✓				"	3.19		.15625	"	136 60CYCLE		115	18-20	
26	"	✓				"	2.66		.125	"	94 60CYCLE		230	17	
27	M.B.K.	✓				"	2.85		"	"		110	78	20-22	
28	"	✓				"	2.66		"	"		110	78	20-22	
29	J.G.	✓					3.35		.15625	W.W.& M.CO.		150	35-37	18-20	
30	"	✓				"	2.59		"	"		135	35-37	18-20	
31	GARADO		✓			"	3.84		.166	ROEBLING		150		20	Welded 1 run each sid…
32	"		✓			"	3.12		"	"		150		20	Welded 2 runs each si…
37(104B)	J.J.	✓				"	2.66	COVERED	.1250	E.A.CO.	125 60CYCLE			25	
38(104C)	J.J.	✓				"	3.33	"	.15625	"	150			25	

Note: Columns 9,10,18,19,23,24,25,26,31,32,34,35,36,37 Omitted due to lack of data.
Column No. 17-Rating in ft. hrs. is total time for welding both sides of plate.

TEST OF PLATE MATERIAL (AVERAGE OF TWO TESTS)					
·	3	4	5	6	7
E TEST		TORSION TEST		VIBRATION TEST	BENDING TEST
TION IN PER CENT	ULTIMATE STRENGTH LB. PER SQ.IN.	ANGULAR DEGREES OF PLATE	TORQUE OF PLATE INCH RADIUS LB.	NO. OF OSCILLATIONS OF PLATE	ANGULAR DEGREES OF PLATE
5	64,700	574	6,048		O.K. for 180°

38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
TENSILE TEST				TORSION TEST				VIBRATION TEST			BENDING T.			
IELD OINT B.PER Q.IN.	ELON. IN 2 IN. PER CENT	ULTIMATE LB. PER SQ.IN.		WELD ANGULAR DEGREES	RATIO IN PER CENT	WELD TORQUE IN INCH LB.	RATIO IN PER CENT	CALCULATED FIBRE STRESS IN LB. PER SQ. IN.	NO. OF OSCILLATIONS OF WELD	RATIO IN PER CENT	WELD ANGULAR DEGREES	RATIO IN PER CENT	TESTER'S SERIAL NO.	REMARKS ON TEST
5400	9.0	59800		443	77.2	5338	88.3				42	23.3	H.J.C.	
9000	11.5	62600		464	80.8	5512	91.1				44	24.4	″	
6300	13.0	65470	●											
4300	5.0	50600		322	56.1	4728	78.1				34	18.9	″	
5300	7.0	52280	●											
5650	8.5	61100		306	53.3	4620	76.4				55	30.6	″	
6500	7.0	53700		403	70.3	4583	75.7				45	25.0	″	
9000	8.5	57600		454	79.2	5154	85.2				50	27.8	″	
4500	13.5	59400		645	112.0	5468	90.5				60	33.3	″	Fractured 2" from ℄ of
4300	14.0	58200		518	90.3	5121	84.6							weld in tensile test
3700	4.0	42500		194	33.8	3732	61.6				30	16.7	″	
2800	4.0	36300												
3800	4.0	38100		252	43.9	3732	61.6				15	8.3	″	
4500	4.0	44200									26	14.4	″	
1800	4.5	41300		212	36.9	3385	56.0				25	13.9	″	
2300	4.5	41900									24	13.3	″	
2460	8.0	57340	●											
	4.0	39400		261	45.5	4080	67.5				30	16.7	″	
0280	5.25	58740	●					25000	45,636,720					Failure only after fiber stress
8400	7.00	50250		441	76.8	4788	79.2	50000	31,320		35	19.9	″	had been Increased to 50,000
0480	11.0	61760	●											
7500	6.0	54000		216	37.6	3900	64.5				65	36.1	″	
7000	6.0	65400	●											Fractured 3.2" from ℄ of weld
7200	12.0	62800		320	55.8	4332	71.6				32	17.8	″	in tensile test (weld not machin'd)
2200	11.0	66480	●											Fractured 6.2" from ℄ of weld
2400	9.0	62700		425	74.0	5381	88.9	35000	4,320,000		34	18.9	″	in tensile test (weld not machin'd)
0700	5.0	42200									42	23.3	″	
9000	9.0	66400	●											Fractured 6.5" from ℄ of weld
7100	6.0	50000		274	47.7	4596	76.0				78	43.4	″	in tensile test (weld not machin'd)
6440	5.0	57060	●	238	41.5	4340	71.7							
7850	4.0	51900		249	43.4	4176	69.1	25000	14,645,580					
				191	33.3	4296	71.0							
1800	6.0	45400		148	25.8	3541	58.5	25000	360,180		15	8.3	″	
4700	4.0	47800	●											
5300	3.5	43700		245	47.2	4128	68.2	35000	89,577		26	14.4	″	
				101	17.6	3472	57.4							
	3.0	34200		108	18.8	3177	52.5	25000	1,123,170		15	8.3	″	
1100	7.0	48200	●											
0600	8.0	45800		465	81.1	4668	77.2				42	23.3	″	
6800	6.5	56400		397	69.2	5159	85.2							
7200	6.0	54400		486	84.7	5380	88.9				47	26.1	″	
2700	11.0	53200		453	78.9	4762	78.7							+ Fractured 2.5" from ℄ of
2100	10.5	52000	+	534	93.0	4498	74.3				50	27.8	″	weld in tensile test
				518	90.3	6288	104.0●							Fractured 3.2" from ℄ of weld in
8500	8.0	60900		450	78.4	5856	96.8							Torsion Test (weld not machin'd)
											58	32.2		Fractured in material at edge
				490	85.4	5568	92.1	25000	5,376,000		71	39.4	″	of weld (Vibration Test)
7300	7.0	56400		320	55.7	4557	75.4				42	23.3	″	
8400	7.0	54500		290	50.5	4557	75.4				45	25.0	″	

: Yield Point from Beam Drop. Values recorded are results of individual tests.
Weld not machined marked ●

RESULTS OBTAINED ON ½ IN. PLATE WITH 3/16 IN. DIAMETER ELECTRODE

Arc Current	Feet welded per hr.	Lbs. wire used per hour	Lbs. wire used per foot	Percentage scrap ends	Percentage time oper. welding
150	2.4	2.45	1.02	12.2	58
140	2.9	1.43	.49	13	58
150	4.6	1.8	.38	11.1	70
150	4.12	2.6	.62	10.3	58
140	4.9	2.1	.43	10	70
150	3	2.0	.66	9.7	58
150	3	1.8	.51	8.3	62
165	2.4	2.38	.98	8.6	58
150	4.6	2.5	.52	12.1	70

The cost of electric welding varies widely for different work. The cost of making the weld can best be figured on the basis of average kilowatt hours per pound of metal used or consumed for each make of equipment. For modern equipment this will be approximately 2.5 k.w. per pound of metal used.

By determining the average efficiency of the welding equipment in k.w. hours per pound of metal used, the cost for any given welding operator can be obtained from the record of the time in hours required to perform the weld and the weight of metal used in pounds. This can then be reduced to cost per hour or per foot of weld, as desired.

The following is the result of a test conducted on an arc welding equipment and coated electrodes to determine

(1) K.w. hr. per pound of metal used or deposited.

(2) Waste of electrode material in stub ends and vapor, including the metal thrown off by the arc.

(3) Pounds of metal per hour that can be deposited with a given electrode diameter and current value.

The data shown below were arrived at by depositing metal on a ⅜ in. piece of boiler plate of known weight, with 3/16 in. diameter coated electrodes, which were weighed before being coated. When sufficient metal to give accurate readings had been deposited, the plate and electrode material, including stub ends left over, were again weighed. The coating was removed from the electrodes so that its weight would not be included.

The power consumed during the test was recorded by a test meter, which gave an accuracy of power consumed within a fraction of a watt.

The weld was made in one layer on the plate and all the scale was thoroughly removed from the weld before the plate was weighed.

The welding was done in a building where there was a slight draft.

The results in detail were as follows:

Weight of work piece assembled for test	30.1562 lb.
Weight of electrodes assembled for test	2.5312 lb.
Duration of test started at 10:08—finished at 10:41	33 min.
Current in arc—average	140 amp.
Voltage across arc—average	21 volts
Power consumed during test	2,976.9 watt hrs.
Weight of plate after test	31.4062 lb.
Weight of electrodes left over	.9375 lb.
Weight of electrode stub ends	.2500 lb.
Weight of electrode material lost in vapor or thrown out of arc	.0937 lb.
Weight of metal deposited on plate	1.2500 lb.
Weight of electrodes used	1.5935 lb.
Rate of electrode material consumption, lb. per hour	2.8920 lb.
Rate of depositing metal on plate—lb. per hour	2.2700
Percentage vapor loss	5.88
Percentage stub ends	15.70
Percentage deposited	78.42
K.w. hr. per pound of metal used	1.862
K.w. hr. per pound of metal deposited	2.370

Note:

Percentage vapor loss bare wire	12.
Diff. in vapor loss "bare" and "coated"	6.12
Reduction of loss—coated over bare	51.

Note:

The loss of metal due to vaporization is charged entirely against the electrode. This, however, is not strictly true as some of the vapor is emitted from the plate. This would make the metal actually deposited a little higher than shown, due to the fact that there had to be sufficient metal deposited to make up for the vapor loss on the plate.

Estimated Construction Cost of 166 Ft. by 39 Ft. by 8 Ft. 8 In. Barge

Items	Riveted Design	Welded Type
Plate Fitters	$1,236.00	$618.00
Punching and Shearing	1,045.00	522.00
Countersinking and Reaming	976.00	
Riveting	3,427.00	
Chipping and Caulking	523.00	265.00

Smithwork	557.00	275.00
Assembling	2,010.00	1,320.00
Electric Power	382.00 **	95.00*
Foreman	360.00	360.00
Plant		300.00
Superintendence		900.00
Rivets	780.00	
Liners	142.00	
Shed and Shoring Lumber		145.00

WELDING—ASSEMBLING AND CONSTRUCTION

51,300 ft. Single Fillet—			
Welders—6,000 hr. @ 60c	$3,600		
Current—6,000 x 5			
30,000 K.W. H. @ 2½c	750		
Wire—7,200 lb. @ 6½c	450		
			4,800.00
Incidentals			250.00
Profit			1,000.00
Total		$11,438.00	$10,850.00

* Current used for lighting, punching, shearing and air compressor only.

** Figures for riveted design, based on actual cost of three barges completed during preceding month.

COMPARATIVE DETAILS OF RIVETED AND RIVETLESS SHIP STRUCTURES DEVELOPED BY MEASUREMENTS OF ACTUAL BILGE SECTIONS

Ref.	Particulars	Riveted	Welded
A	Weight of Plates required	2488 lb.	1884 lb.
B	Weight of Angles, Beams and Channels	764 lb.	194 lb.
C	Weight of Straight Bars	none	360 lb.
D	No. of ⅝ in. Rivets	48	none
E	No. of ¾ in. Rivets	231	none
F	No. of ⅞ in. Rivets	108	none
G	Total No. of Rivets	387	none
H	Total Weight of Rivets	200 lb.	none
I	No. of Liners required	4	none
J	Weight of Liners	31 lb.	none
K	Weight of Weld material added	none	120 lb.
L	Total weight of complete section	3483 lb.	2558 lb.
M	Lineal Feet of Heavy Flanging and Shaping	22	none
N	Sq. ft. of Forge Shaped Bilge Plate	24	none
O	Sq. ft. of Machine Rolled Bilge Plate	none	20
P	No. Lineal feet of welds in terms of ¼ sq. in. Section	none	620
Q	No. Lineal feet of Caulked Edges	57	none
R	Total No. of all Rivet Holes in Section	826	none
S	Average Area of Plates of full size	17280 sq. in.	15235 sq. in.
T	Average No. of Rivet Holes in same	550	none

From a report contributed by W. T. Bonner, of Chester Ship Building Co., to the Emergency Fleet Corporation.

METALLURGY OF IRON AND STEEL

(*Reproduced from the Iron Age*)

IRON ORE contains Iron and Oxygen and impurities.
IRON ORE smelted in *Blast Furnace* removing Oxygen and part of impurities and adding Carbon, makes Pig Iron.
FOUNDRY PIG IRON melted in *Cupola* and cast makes Iron Castings.
IRON CASTINGS made from Malleable Pig Iron and heated in Scale, make Malleable Castings.
GREY FORGE PIT IRON melted in a *Puddling Furnace,* then balled, squeezed and rolled, makes Muck Bar.
MUCK BAR, treated as above and rolled into strips, makes Skelp Iron.
SKELP IRON bent into the shape of *Tubes* and welded, makes Iron Pipe.
MUCK BAR or *Steel,* melted in a *Crucible* with Charcoal, makes Carbon Steel, Tool Steel, or Crucible Steel.
MUCK BAR or *Steel,* treated as above with *Tungsten* added to raise the temperature at which it softens, *Chromium* to give toughness, and *Vanadium, Titanium, Aluminum* or other metals to improve the quality, heated to a high, then to a lower heat, makes High Speed Steel.
BESSEMER PIG IRON direct from *Blast Furnace* or melted in *Cupola,* poured into *Converter* with air blown through it to burn out the impurities, makes Bessemer Steel.
PIG IRON molten, or in *Pig,* with or without *Scrap,* when purified in *Open-Hearth Furnace,* makes Open-Hearth Steel.
LOW PHOSPHORUS PIG IRON, treated as above in an *Acid-Lined* (*Silica* or *Sand*) *Furnace,* makes Acid Open-Hearth Steel.
BASIC PIG IRON treated as above in a *Basic-* (*Dolomite*) *Lined Furnace* to remove *Phosphorus,* makes Basic Open-Hearth Steel.
BASIC OPEN-HEARTH MATERIAL with only about 1/10 of 1 per cent impurities is *American Ingot Iron,* and *Genuine Open-Hearth Iron.*
VANADIUM STEEL or *Manganese* (over 7 per cent), *Titanium,* or *Nickel Steel,* is made by the addition of these metals, all being called Alloy Steels.
STEEL, purified in an *Electric Furnace* makes High Grade Steel.
STEEL is cast into *Ingot Molds,* usually about 19 inches square, and about 6 feet long, making Ingots.
INGOTS are rolled into Blooms or Billets.
BLOOMS are rolled into Rails.
BLOOMS are rolled into Structural Shapes.
INGOTS are rolled into Slabs.
SLABS are rolled into Plates.
INGOTS are rolled into Sheet Bars.
SHEET BARS are rolled into Sheets.
SHEETS are cold-rolled and stamped into Forms.
SHEET BARS are rolled into Black Sheets.
BLACK SHEETS cleaned and coated with *Speller* (*Zinc*) make Galvanized Sheets.
BLACK SHEETS cleaned, cold-rolled and coated with *Tin,* make Tin Plate.
BLACK SHEETS cleaned, cold-rolled and coated with *Lead* and *Tin,* make Terne Plate.
INGOTS are rolled into Billets.
BILLETS are rolled into Bars and Small Shapes.
BILLETS are rolled into Steel Skelp.
STEEL SKELP bent into the shape of *Tubes* and welded makes Steel Pipe.

BILLETS are pierced, rolled and drawn through *Dies,* making Seamless Tubes.
BILLETS are rolled into Rods.
RODS are drawn through *Dies* into Wire.
WIRE is made into Nails and Fencing.
RODS are headed into Rivets and Bolts.
RODS are welded into Chain.

TEMPER COLORS OF STEEL

(Hardening, Tempering, Annealing and Forging of Steel—Woodworth)

Color of Oxides	Temperature, Deg.	
	Cent.	Fahr.
Pale Yellow	220	428
Straw	235	455
Dark Straw or Golden Yellow	243	470
Brown	255	491
Brown, Dappled with Purple	265	509
Purple	277	530
Bright Blue	288	550
Full Blue	293	560
Polish Blue	304	580
Dark Blue	316	600
Pale Blue	321	610
Blue, Tinged with Green	332	630

CONVERSION TABLES OF FAHRENHEIT AND CENTIGRADE SCALES

Temperature Centigrade = 5/9 (Temperature Fahrenheit —32)
Temperature Fahrenheit = 32 + 9/5 (Temperature Centigrade)

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
230	446	460	860	690	1274
235	455	465	869	695	1283
240	464	470	878	700	1292
245	473	475	887	705	1301
250	482	480	896	710	1310
255	491	485	905	715	1319
260	500	490	914	720	1328
265	509	495	923	725	1337
270	518	500	932	730	1346
275	527	505	941	735	1355
280	536	510	950	740	1382
285	545	515	959	745	1364
290	554	520	968	750	1373
295	563	525	977	755	1391
300	572	530	986	760	1400
305	581	535	995	765	1409
310	590	540	1004	770	1418
315	599	545	1013	775	1427
320	608	550	1022	780	1436
325	617	555	1031	785	1445
330	626	560	1040	790	1454
335	635	565	1049	795	1463
340	644	570	1058	800	1472
345	653	575	1067	805	1481
350	662	580	1076	810	1490
355	671	585	1085	815	1499
360	680	590	1094	820	1508
365	689	595	1103	825	1517
370	698	600	1112	830	1526
375	707	605	1121	835	1535
380	716	610	1130	840	1544
385	725	615	1139	845	1553
390	734	620	1148	850	1562
395	743	625	1157	855	1571
400	752	630	1166	860	1580
405	761	635	1175	865	1589
410	770	640	1184	870	1598
415	779	645	1193	875	1607
420	788	650	1202	880	1616
425	797	655	1211	885	1625
430	806	660	1220	890	1634
435	815	665	1229	895	1643
440	824	670	1238	900	1652
445	833	675	1247	905	1661
450	842	680	1256	910	1670
455	851	685	1265	915	1679

Conversion Tables of Fahrenheit and Centigrade Scales—Cont.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
920	1688	1150	2102	1380	2516
925	1697	1155	2111	1385	2525
930	1706	1160	2120	1390	2534
935	1715	1165	2129	1395	2543
940	1724	1170	2138	1400	2552
945	1733	1175	2147	1405	2561
950	1742	1180	2156	1410	2570
955	1751	1185	2165	1415	2579
960	1760	1190	2174	1420	2588
965	1769	1195	2183	1425	2597
970	1778	1200	2192	1430	2606
975	1787	1205	2201	1435	2615
980	1796	1210	2210	1440	2624
985	1805	1215	2219	1445	2633
990	1814	1220	2228	1450	2642
995	1823	1225	2237	1455	2651
1000	1832	1230	2246	1460	2660
1005	1841	1235	2255	1465	2669
1010	1850	1240	2264	1470	2678
1015	1859	1245	2273	1475	2687
1020	1868	1250	2282	1480	2696
1025	1877	1255	2291	1485	2705
1030	1886	1260	2300	1490	2714
1035	1895	1265	2309	1495	2723
1040	1904	1270	2318	1500	2732
1045	1913	1275	2327	1505	2741
1050	1922	1280	2336	1510	2750
1055	1931	1285	2345	1515	2759
1060	1940	1290	2354	1520	2768
1065	1949	1295	2363	1525	2777
1070	1958	1300	2372	1530	2786
1075	1967	1305	2381	1535	2795
1080	1976	1310	2390	1540	2804
1085	1985	1315	2399	1545	2813
1090	1994	1320	2408	1550	2822
1095	2003	1325	2417	1555	2831
1100	2012	1330	2426	1560	2840
1105	2021	1335	2435	1565	2849
1110	2030	1340	2444	1570	2858
1115	2039	1345	2453	1575	2867
1120	2048	1350	2462	1580	2876
1125	2057	1355	2471	1585	2885
1130	2066	1360	2480	1590	2894
1135	2075	1365	2489	1595	2903
1140	2084	1370	2498	1600	2912
1145	2093	1375	2507		

METRIC EQUIVALENTS OF COMMON AND DECIMAL FRACTIONS

Fractions of an inch		Decimals of an inch	Millimeters	Fractions of an inch		Decimals of an inch	Millimeters
	1/64	.0156	0.397		33/64	.5156	13.097
1/32		.0313	0.794	17/32		.5313	13.494
	3/64	.0469	1.191		35/64	.5469	13.891
1/16		.0625	1.588	9/16		.5625	14.287
	5/64	.0781	1.985		37/64	.5781	14.684
3/32		.0938	2.381	19/32		.5938	15.081
	7/64	.1094	2.778		39/64	.6094	15.478
1/8		.1250	3.175	5/8		.6250	15.875
	9/64	.1406	3.572		41/64	.6406	16.272
5/32		.1563	3.969	21/32		.6563	16.688
	11/64	.1719	4.366		43/64	.6719	17.085
3/16		.1875	4.762	11/16		.6875	17.462
	13/64	.2031	5.159		45/64	.7031	17.859
7/32		.2188	5.556	23/32		.7188	18.256
	15/64	.2344	4.953		47/64	.7344	18.653
1/4		.2500	6.350	3/4		.7500	19.050
	17/64	.2656	6.747		49/64	.7656	19.447
9/32		.2813	7.144	25/32		.7813	19.843
	19/64	.2969	7.541		51/64	.7969	20.240
5/16		.3135	7.937	13/16		.8125	20.637
	21/64	.3281	8.334		53/64	.8281	21.034
11/32		.3438	8.731	27/32		.8438	21.430
	23/64	.3594	9.128		55/64	.8594	21.827
3/8		.3750	9.525	7/8		.8750	22.224
	25/64	.3906	9.922		57/64	.8906	22.621
13/32		.4063	10.319	29/32		.9063	23.018
	27/64	.4219	10.716		59/64	.9219	23.415
7/16		.4375	11.12	15/16		.9375	23.812
	29/64	.4531	11.509		61/64	.9531	24.209
15/32		.4688	11.906	31/32		.9688	24.606
	31/64	.4844	12.303		63/64	.9844	25.003
1/2		.5000	12.700			1.0000	25.400

Comparison of Wire Gages

No.	American Wire Gage (B. & S.) B. & S. G. Millimeters	American Wire Gage (B. & S.) B. & S. G. Decimal of an inch	Stub's or Birmingh'm B. W. G.	Washburn & Moen W. & M.	Old English or London O. E. G.	New British Standard E. S. G.
0000	11.684	.4600	.454	.393	.454	.400
000	10.404	.4066	.425	.362	.425	.372
00	9.266	.3648	.380	.331	.380	.348
0	8.252	.3249	.340	.307	.340	.324
1	7.341	.2893	.300	.283	.300	.300
2	6.553	.2576	.284	.263	.284	.276
3	5.826	.2294	.259	.244	.259	.252
4	5.19	.2043	.238	.225	.238	.232
5	4.619	.1819	.220	.207	.220	.212
6	4.115	.1620	.203	.192	.203	.192
7	3.665	.1443	.180	.177	.180	.176
8	3.264	.1285	.165	.162	.165	.160
9	2.906	.1144	.148	.148	.148	.144
10	2.588	.1019	.134	.135	.134	.128
11	2.304	.0907	.120	.120	.120	.116
12	2.052	.0808	.109	.105	.109	.104
13	1.83	.0720	.095	.092	.095	.092
14	1.628	.0641	.083	.080	.083	.080
15	1.45	.6571	.072	.072	.072	.072
16	1.29	.0508	.065	.063	.065	.064
17	1.149	.0453	.058	.054	.058	.056
18	1.0236	.0403	.049	.047	.049	.048
19	.9115	.0359	.042	.041	.040	.040
20	.81	.0320	.035	.035	.035	.036
21	.7239	.0285	.032	.032	.0315	.032
22	.6434	.0254	.028	.028	.0295	.028
23	.574	.0226	.025	.025	.027	.024
24	.5105	.0201	.022	.023	.025	.022
25	.4547	.0179	.020	.020	.023	.020
26	.4039	.0159	.018	.018	.0205	.018
27	.3607	.0142	.016	.017	.0188	.0164
28	.32	.0126	.014	.016	.0165	.0148
29	.287	.0113	.013	.015	.0155	.0136
30	.254	.0100	.012	.014	.0138	.0124
31	.2261	.0089	.010	.0135	.0123	.0116
32	.2032	.0080	.009	.013	.0113	.0108
33	.1803	.0071	.008	.011	.0103	.0100
34	.16	.0063	.007	.01	.0095	.0092
35	.1422	.0056	.005	.0095	.009	.0084
36	.127	.0050	.004	.009	.0075	.0076
37	.113	.0045	....	.0085	.0065	.0068
38	.1007	.0040	....	.008	.0058	.0060
39	.0897	.0035	....	.0075	.005	.0052
40	.0799	.0031	....	.007	.0045	.0048

PROPERTIES OF ELEMENTS AND METAL COMPOSITIONS

Elements	Symbol	Density (Specific Gravity)	Weight Per Cubic Foot	Specific Heat	Melting Point	
					Degrees Centigrade	Degrees Fahrenheit
Aluminum	Al	2.7	166.7	0.212	658.7	1217.7
Antimony	Sb	6.69	418.3	0.049	630	1166
Armco Iron	......	7.9	490	0.115	1535	2795
Carbon	C	3.51	219.1	0.113	3600	6512
Chromium	Cr	6.92	431.9	0.104	1520	2768
Columbium	Cb	7.25	452.54	....	2200	3992
Copper	Cu	8.89	555.6	0.092	1083	1981.4
Gold	Au	19.33	1205	0.032	1063	1946
Hydrogen	H	0.070*	.00533	....	—259	—434.2
Iridium	Ir	22.42	1400	0.032	2300	4172
Iron	Fe	7.865	490.9	0.115	1530	2786
Lead	Pb	11.37	708.5	0.030	327	621
Manganese	Mn	7.4	463.2	0.111	1260	2300
Mercury	Hg	13.55	848.84	0.033	—38.7	—37.6
Nickel	Ni	8.80	555.6	0.109	1452	2645.6
Nitrogen	N	0.83*	.063	....	—210	—346
Oxygen	O	1.14*	.0866	....	—280	—472
Phosphorus	P	2.34	146.1	0.19	44	111.2
Platinum	Pt	21.45	1336	0.032	1755	3191
Potassium	K	0.87*	54.3	0.170	62.3	144.1
Silicon	Si	2.1	131.1	0.175	1420	2588
Silver	Ag	10.6	655.5	0.055	960.5	1761
Sodium	Na	0.971	60.6	0.253	97.5	207.5
Sulphur	S	2.05	128	0.173	112.8	235
Tin	Sn	7.30	455.7	0.054	231.9	449.5
Titanium	Ti	3.5	218.5	0.110	1795	3263
Tungsten	W	18.85	1186	0.034	3000	5432
Uranium	U	18.7	1167	0.028	....	....
Vanadium	V	5.5	343.3	0.115	1720	3128
Zinc	Zn	7.19	443.2	0.093	419	786.2
Bronze (90 Cu 10 Sn)	......	8.78	548	....	850–1000	1562–1832
Brass (90 Cu 10 Zn)	......	8.60	540	....	1020–1030	1868–1886
Brass (70 Cu 30 Zn)	......	8.44	527	....	900–940	1652–1724
Cast Pig Iron	......	7.1	443.2	....	1100–1250	2012–2282
Open Hearth Steel	......	7.8	486.9	....	1350–1530	2462–2786
Wrought Iron Bars	......	7.8	486.9	....	1530	2786

* Density compared with air.

Mensuration Factors

Diameter of a Circle × 3.1416 = Circumference.
Radius of a Circle × 6.2832 = Circumference.
Square of the Radius of a Circle × 3.1416 = Area.
Square of the Diameter of a Circle × 0.7854 = Area.
Square of the Circumference of a Circle × 0.07958 = Area.
Half the Circumference of a Circle × half its Diameter = Area.
Doubling the Diameter of a Circle Increases its Area Four Times.
Circumference of a Circle × 0.15915 = Radius.
Square Root of the Area of a Circle × 0.56419 = Radius.
Circumference of a Circle × 0.31831 = Diameter.
Square Root of the Area of a Circle × 1.12838 = Diameter.
Diameter of a Circle × 0.8660 = Side of an Inscribed Equilateral Triangle.
Diameter of a Circle × 0.7071 = Side of an Inscribed Square.
Circumference of a Circle × 0.2251 = Side of an Inscribed Square.
Circumference of a Circle × 0.2821 = Side of an Equal Square.
Diameter of a Circle × 0.8862 = Side of an Equal Square.
Side of a Square × 1.1142 = Diameter of Circumscribed Circle.
Side of a Square × 4.443 = Circumference of Circumscribed Circle.
Base of a Triangle × one-half the Altitude = Area.
Multiplying both Diameters and 0.7854 together = Area of an Elipse.
Surface of a Sphere × one-sixth of its Diameter = Cubical Contents.
Circumference of a Sphere × its Diameter = Surface Area.
Square of the Diameter of a Sphere × 3.1416 = Surface Area.
Square of the Circumference of a Sphere × 0.3183 = Surface Area.
Cube of the Diameter of a Sphere × 0.5236 = Cubical Contents.
Cube of the Circumference of a Sphere × 0.016887 = Cubical Contents.
Radius of a Sphere × 1.1547 = Side of Inscribed Cube.
Square Root of one-third of the square of the Diameter of a Sphere = Side of Inscribed Cube.
Area of its Base × one-third of its Altitude = Cubical Contents of a Cone of Pyramid, whether Round, Square or Triangular.
Altitude of Trapezoid × one-half the sum of its Parallel Sides = Area.
Area of a Rectangle = Length × Breadth.
Side of a Square × 1.128 = Diameter of an Equal Circle.
Side of a Square × 3.574 = Circumference of an Equal Circle.
Square Inches × 1.273 = Circle Inches of an Equal Circle.

ELECTRICAL UNITS

(*Circular No. 60, Bureau of Standards*)

OHM—The international ohm (unit of resistance) is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.300 centimeters.

1 International ohm = 1.00052 absolute ohms.
1 Absolute ohm = 0.99948 international ohm.
1 Absolute ohm = 1,000,000,000 c.g.s. magnetic units.

AMPERE—The international ampere (rate of flow of electricity) is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with the Specification II attached to these resolutions (1908 International Conference on Electrical Units and Standards held at London), deposits silver at the rate of 0.00111800 of a gram per second. One ampere is also equal to one coulomb per second.

1 International ampere = 0.99991 absolute ampere.
1 Absolute ampere = 1.00009 international amperes.
1 Absolute ampere = 0.1 c.g.s. magnetic unit.

VOLT—The international volt (unit of electrical pressure of electromotive force) is the electrical pressure which, when steadily applied to a conductor the resistance of which is one international ohm, will produce a current of one international ampere. The Weston normal cell gives 1.0183 international volts at 20 degrees centigrade. One kilovolt equals 1000 volts.

1 International volt = 1.00043 absolute volts.
1 Absolute volt = 0.99957 international volt.
1 Absolute volt = 100,000,000 c.g.s. magnetic units.

WATT—The international watt (unit of power) is the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt. One watt is also equal to one joule per second. One kilowatt is equal to 1000 watts.

1 International watt = 1.00034 absolute watts.
1 Absolute watt = 0.99966 international watt.
1 Absolute watt = 10,000,000 c.g.s. magnetic units.
Watts × .7375 = foot pounds per second.

COULOMB—The unit of quantity is the coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.

1 International coulomb = 0.99991 absolute coulomb.
1 Absolute coulomb = 1.00009 international coulombs.
1 Absolute coulomb = 0.1 c.g.s. magnetic unit.

FARAD—The unit of capacity is the international farad, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity. The unit generally used is the microfarad, which is one-millionth of a farad.

1 International farad = 0.99948 absolute farad.
1 Absolute farad = 1.00052 international farads.
1 Absolute farad = 1/1,000,000,000 c.g.s. magnetic unit.

HENRY—The unit of inductance is the international henry, which is the inductance in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one international ampere per second.

1 International henry = 1.00052 absolute henrys.
1 Absolute henry = 0.99948 international henry.
1 Absolute henry = 1,000,000,000 c.g.s. magnetic units.

JOULE—The unit of energy is the international joule, which is the work done in transferring one international coulomb of electricity at a pressure of one international volt.

1 International joule = 1.00034 absolute joules.
1 Absolute joule = 0.99966 international joule.
1 Absolute joule = 10,000,000 ergs or c.g.s. magnetic units.
Joule × .7375 = foot pounds.

HORSE-POWER—One horse-power equals 746 watts, or 550 foot-pounds per second, or 33,000 foot-pounds per minute.

KILOWATT—One kilowatt equals 1000 watts, or 1.3405 horse-power, or 737.27 foot-pounds per second, or 44,236 foot-pounds per minute.

KILOWATT-HOUR—One kilowatt-hour equals 1000 watt-hours, or 1.3405 horse-power hours, or 2,654,200 foot-pounds.