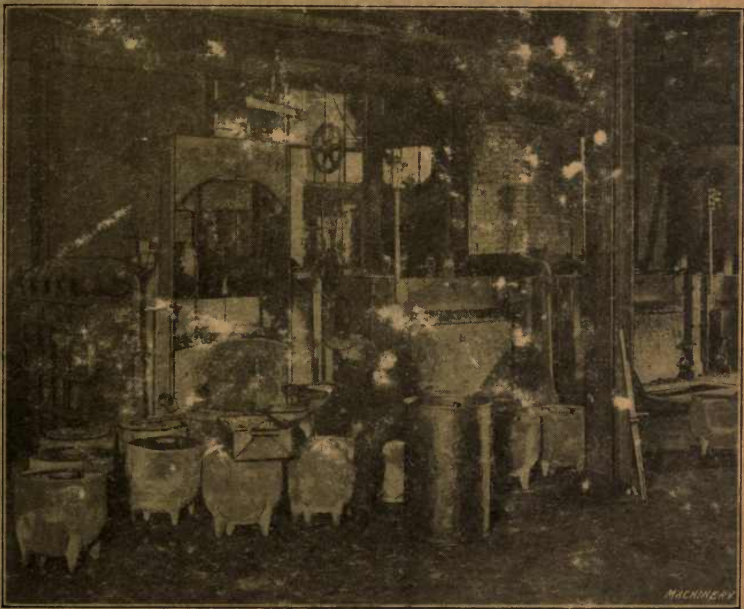
25 CENTS

CASEHARDENING

METHODS EMPLOYED IN THE AUTOMOBILE, BICYCLE, BALL AND ROLLER BEARING AND ALLIED TRADES—CASEHARDENING SHAFTING—NEW CASEHARDENING METHODS—CASEHARDENING BY GAS



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NUMBER 141

CASEHARDENING

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Other books in this series dealing with Heat-treatment of Steel and kindred subjects are as follows:

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INTRODUCTION

Casehardening is the process of increasing the carbon content of the surface of steel comparatively low in carbon, so that it can be hardened by the usual method of being heated to the hardening temperature and quenched in a cooling medium. The term casehardening, by itself, implies the hardening of the surface or skin of an article, and in order to fully understand the process and its object, it is necessary to briefly consider the facts and laws upon which it is founded. Carbon has a very great affinity for iron and combines with it at all temperatures above a faint red heat. Advantage was taken of this fact in the production of steel by cementation, an old process which consisted of rolling wrought iron into thin strips and then placing these in boxes with some material containing a fair proportion of carbon. These boxes were then heated to a very high temperature and the carbon was gradually absorbed by the iron.

The process of casehardening is, in fact, only an improvement on this old cementation process used in times past for making steel from wrought iron. The steel is heated in packing boxes in the presence of a carbonaceous material and when the surface of the steel has absorbed enough carbon so that it will harden the same as high-carbon steel, it can be quenched in oil or water, according to the requirements. For many purposes, in machine work, articles are required which must have a perfectly hard surface and yet be of such internal structure that there is no chance of breaking them when in use. In many instances, this result can be obtained better by using casehardened mild steel than by using high-class crucible steel. For example, in making axles, cups, cones, and many similar parts for bicycles, it is extremely difficult to obtain perfect hardness combined with great resistance to torsional, shearing or bending stresses. For such purposes, nothing meets these requirements so well as do articles which have been casehardened.

A great improvement has been made in casehardening processes during the last few years. The advance was begun with the development of the bicycle industry; and the necessity for casehardened parts of the highest quality in automobile manufacture has caused a still further improvement in this field.

As an example of what has been accomplished by proper casehardening methods, consider the transmission gearing of an automobile. Who would think of throwing in the back-gears of a lathe or any other machine tool without first stopping the machine? In an automobile, however, this very thing is actually done dozens of times a day, by a person who gives little thought to what he is really doing. Yet the gears stand up under this treatment because of being manufactured of special steels developed during recent years and because of being heat-treated and casehardened by improved methods.

There are a number of different questions that must be considered in order to obtain good results in casehardening. In the first place, the proper kind of steel to be used for various purposes must be carefully selected. Another most essential thing is that the casehardening furnace must give a uniform heat. As oil and gas have to a great extent superseded coal as fuels for casehardening furnaces, the changes in furnace construction have, of late, been considerable. Another item which must be given careful consideration is the box in which the material is packed, as well as the carbonaceous material itself used in packing the parts to be casehardened. Still another question to be dealt with is the method used for hardening the parts after they have been carbonized.

Steel for Casehardened Parts

As the casehardening process consists in adding carbon to the steel, a material must be used which will absorb carbon without necessitating overheating or burning. The effect of carbon on steel is, in general, it may be said, to make it dense, and the denser the steel the higher the heat necessary to open the pores through which it must absorb the carbon. A low-carbon steel containing, say, from 0.15 to 0.20 per cent of carbon is, therefore, most suitable for casehardening. It should also be borne in mind when selecting the material that the casehardening process does not eliminate any of the impurities ordinarily found in iron, such as sulphur, phosphorus, etc., and hence, a material as free as possible from these impurities should be selected; besides, the material should be perfectly sound and free from mechanical faults or weaknesses caused by overheating or improper working during the manufacturing processes.

Both iron and mild steel have been employed as materials for casehardening in the past; but this is the steel age, and iron has long passed its day. The steel employed should be prepared, selected and controlled from the beginning with the object of making it suitable for the final requirements. There are many points with relation to the selection of the proper steel, its composition and treatment, which can only be gained by long experience and a study of the requirements, but, as a general rule, the low-carbon steel specified in the preceding paragraph will be found suitable for most purposes.

In the following chapters will be given directions for casehardening, as published in MACHINERY by a number of authorities. It will be seen that opinions differ on certain points, and, therefore, the statements of each author have been given in full. The information given will necessarily overlap somewhat on this account, but, on the other hand, a complete and authoritative presentation of the whole subject has been made possible.

CHAPTER I

CASEHARDENING PRACTICE IN THE BICYCLE, AUTOMOBILE AND ALLIED TRADES

In building or constructing a furnace for casehardening, the size of the work to be hardened should be the first consideration. It is far better to use a small furnace with a small box whenever possible. If the work varies in size, different sizes of furnaces may be used. Small furnaces require less fuel, and small work must be placed in small boxes as otherwise the pieces packed near the sides will be overheated while those in the center will not reach the required temperature. The furnaces should be made right- and left-hand so that they can be placed close together. Thick walls should be used to retain the heat. These walls should be supported by a substantial concrete foundation, so that they will retain their position and shape, even when subjected to a high heat. Large flues should be provided to carry away the smoke and gases.

The furnace should also be so constructed that as much as possible of the heat of the combustion gases may be extracted before they are discharged. The flues and all parts of the furnace should be easily accessible, and a door, the full width of the oven, should be provided so that the tiles can be taken out and the flues cleaned. A pressure blower with a light oil should be used with all the pipes accessible and placed, preferably, above the furnace. If, however, they are placed below ground, they should be arranged in compartments which can be easily reached if repairs are required.

The blower pipes should be run through the furnace so as to preheat the air used; if cold air is used directly it will reduce the heat in the furnace. The furnace fronts should be made in several parts to prevent cracking, with the door properly balanced and lined. A shelf should be provided, projecting at the front, for holding the boxes when they are taken out or put into the furnace. The smokestack should be made of sufficient height to produce a good draft.

Burners should be placed both at the front and rear of the oven and should be arranged in separate compartments, so that the heat will be uniform in the oven. The hot gases will then pass over the top of the compartment wall and strike the boxes on the top, after which they pass out through small openings in the corner of the furnace. They then take a zigzag course under the tiles and pass from there through a flue to the rear of the furnace. A large conduit should be provided just below the ground which will catch all the soot. This conduit should be provided with iron covers which can easily be taken off to remove the accumulation of soot.

The furnace should not be heated too quickly, as this is apt to crack the brickwork. The cooling should also be done gradually.

After the work has been taken out and the heat shut off for the day, all the dampers should be closed to hold the heat. In this way the furnace will cool slowly and cracking or bulging out of shape will be prevented. In addition, it will be easier to heat the furnace the next morning, as it will have retained some of the heat.

When work is to be annealed, it should be placed in the furnace after the work to be hardened has been removed, and then the furnace brought to the proper heat. The material to be annealed can then

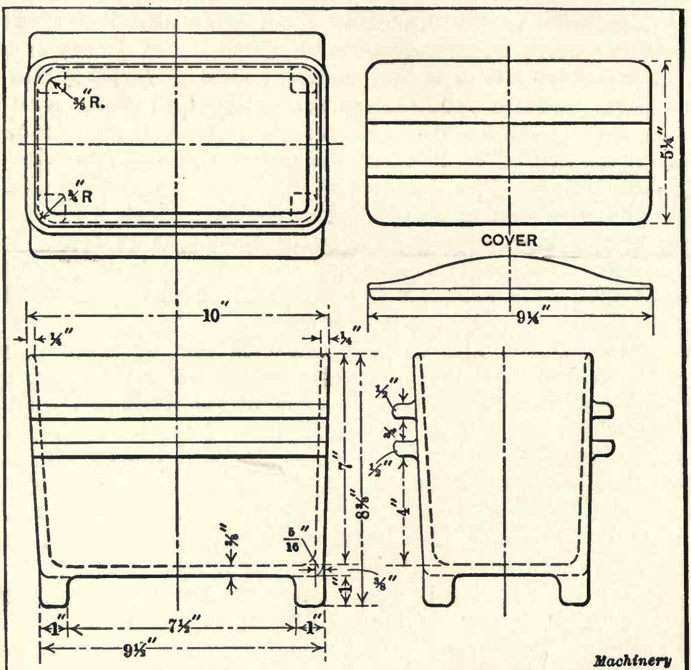


Fig. 1. Box for Casehardening, of Approved Design

remain in the furnace until the next morning with the furnace closed up and the burners turned off.

A light oil should be used. It should have a high heating value and be comparatively free from carbon deposits.

Boxes for Casehardening

The boxes for casehardening should not be made larger than necesray for the class of work being handled. They should be made from a malleable iron, as ordinary cast-iron boxes are not suitable on account of the fact that they are very porous and absorb the carbon of the carbonizing material. The boxes should also be provided with feet, as shown in Fig. 1, so that the heat can circulate all around them. The covers should be provided with ribs on the top to prevent excessive warping, and the sides should be ribbed so that a fork or grapple iron, as shown in the upper part of Fig. 2, can be used for handling the boxes. The sides of the boxes should taper slightly towards the bottom so that the contents can be easily dumped out of them; they are also easier to cast when made in that way.

When very large boxes are required, they should, if possible, be provided with a hole through the center so that the heat can reach the contents from the inside, as well as from the outside. A box of this kind is shown in Fig. 3. For long work, such as shafts, tubing, etc., a wrought-iron pipe with a cap on each end provides an ideal box.

Local Hardening

In many cases it is essential that the piece of work be hardened at a certain place and that other parts be left soft. There are three ways in which this can be accomplished: First, by copper-plating

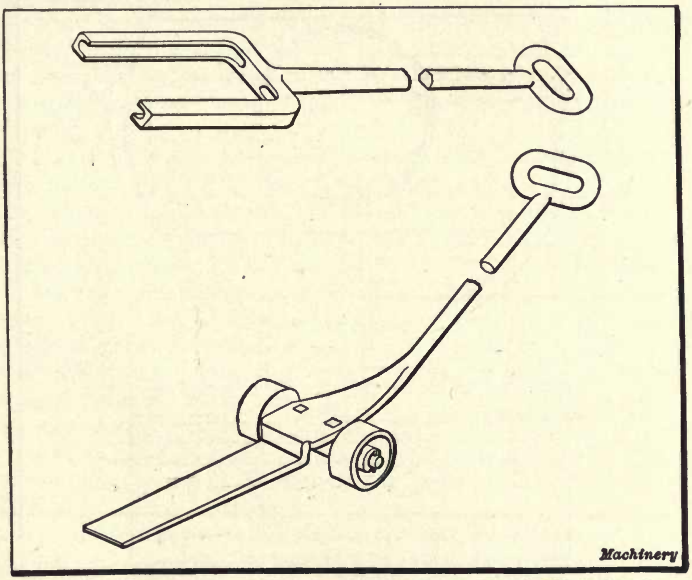


Fig. 2. Grapple Iron or Fork used for Handling Casehardening Boxes and Truck for Handling Heavy Boxes

and enameling; second, by covering the part which is not to be hardened by fireclay; and third, by using a bushing or collar to cover the part to be left soft.

In the first case the article should be painted with enamel where it is to be hardened, the enamel being baked after having been applied. The remainder of the piece that is to be left soft is copper-plated. In the second case, if the article to be hardened has a recess, such as a hole, slot, etc., this may be filled with clay. The third method is used when a shaft, for example, is only to be left soft for a short distance. A collar is then placed on the shaft, and this provides the easiest and least expensive means for accomplishing the purpose.

In the case where enamel and copper-plating is used, the enamel will burn away and allow the surface covered by it to absorb carbon and, hence, to be hardened, whereas the copper will stand a very high heat and prevent hardening of those portions that are covered by it. If the copper is burned off, it is an indication that the work has been overheated. The clay prevents the hardening of a portion of the work in the same way as does the copper. It is also of advantage when dipping the work, as it prevents the formation of steam pockets which are apt to warp or distort the piece. When a sleeve

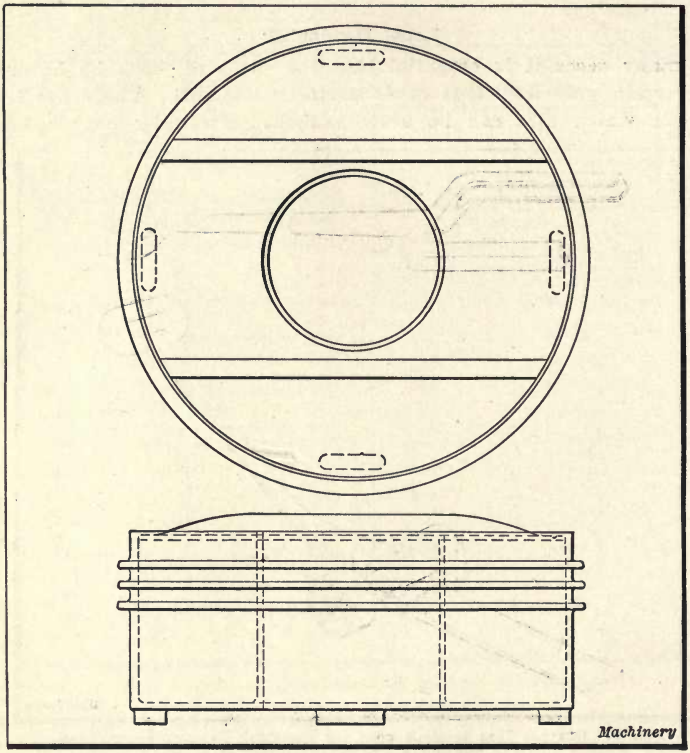


Fig. 3. Large Circular Box with Hole in Center for the Circulation of the Gases of Combustion

or collar is used, this should be made about one-half inch longer than the part which is to be left soft, so as to prevent carbonization near the ends of the collar.

Packing for Hardening

The packing room should, if possible, be separate from the room containing the furnaces, so that the packing can be done without the discomfort of the heat and dust. Tables on wheels, or trucks, provided with shelves of the same height as the shelf in front of the furnace and large enough to hold the required number of boxes for one furnace, should be provided, so that the packed boxes can be easily moved to the furnace and quickly placed in it. The work to be hardened should be classified according to its size and the percentage of carbon required, as it will take a higher heat for larger work, as well as for pieces which are required to absorb a higher percentage of carbon.

There are a great many different kinds of hardening materials, but the old-fashioned method of using ground bone can always be relied upon to give satisfactory results. During the last few years, however, the use of bone in various manufacturers has increased so that the price of ground bone for casehardening purposes is almost prohibitive. Leather has become very extensively used for this purpose, it being first burned and then ground and graded.

A mixing bin is a great advantage in connection with the handling of the casehardening material. Some partly used bone and some new is then used to make a mixture suitable for the size of the pieces to be hardened. Large pieces require a richer material than smaller ones, as during the higher heat required for the larger pieces and the longer application of the heat, more of the carbonizing material will burn away.

When packing a box, first put a layer of the casehardening material on the bottom, the thickness of this layer depending upon the size of the pieces to be hardened. If the articles are heavy, they do not require such great care in packing, but if they are thin or long, or have a peculiar shape, greater care is required. It has frequently been stated that one piece should never be permitted to touch another when packing, but it has been found that this precaution is not necessary. If a box is properly sealed, the parts can touch each other without injury. Thin long pieces should, if possible, be placed in an upright position to prevent their sagging out of shape. Between each layer of pieces, casehardening material is packed according to the size of the pieces to be hardened. It has been found from experience that if there is not enough of the carbonizing material in the box, the work is liable to have soft spots.

About two inches from the top of the box, sheet steel strips about 1/16 inch thick should be laid and these should be covered with a layer of about one inch or more of powdered charcoal. Then the cover is placed on the box and the edges are sealed with fireclay. If there is any doubt about the length of time required for heating the pieces to obtain a certain depth of case, wire a couple of pieces together, allowing the wire to project out of the box. These pieces can then be taken out quickly and hardened, and, in this way, it can be ascertained whether the parts have been sufficiently carbonized. In casehardening very small work, it is advisable to wire the pieces together so that they can be taken out of the box at once; otherwise, they would have to be picked out with small tongs, as it is impossible to sift very small work in a screen because the mesh would have to be so fine that it would take a long time to do the sifting and the work would become too cold for hardening. If it is desirable to color the work, from one-third to one-half of the carbonizing material should be burnt leather.

The boxes should never be put into the furnace under a high heat, but should be placed in it when its temperature is from 800 to 900 degrees F. Then the heat should be slowly brought up to from 1500 to 1800 degrees F. In placing the boxes in the furnace, great care should be taken that the hot gases have an opportunity to circulate all around them. A pyrometer should be put in some convenient place and properly wired so that the heat in the furnace can be readily ascertained at any time. If there is a great deal of night work to be done, a recording pyrometer should be used as it gives the man in charge a record of the heats during the night.

By the aid of the pyrometer it has been found that it is necessary to have an expansion tank in order to get a constant air pressure, otherwise the pulsation from the blower will affect the heat in the furnace. This expansion tank should be situated so that the blower is connected directly with one end while the discharge pipe is connected at the opposite end. This will then act as a reservoir, producing a constant pressure. When oil is used for the heating, it is preferable to pump it from the storage tank in the ground to a stand pipe, which will insure a constant flow of the oil. The intermittent action of the pump, should the oil be used directly as it comes from it, is objectionable. There is also another advantage, in case the pump should have to be shut down on account of break-down. In that case, the furnaces could still continue to operate, as the stand pipe should hold a supply of oil sufficient for several hours. At night and on holidays the oil should be drained back into the storage tank in order to minimize the danger incident to its use.

The supply pipe for the air should come from the outside and should be so arranged that the air passes through a fine wire netting, so as to prevent foreign substances from entering the blower.

On the outside of each furnace a card should be placed telling the kind of work that is in the furnace, when the work was put in, the heat required for it, and when it is to be removed. These cards can be kept as a record which will be of value when comparison is made with the depth of case obtained under any specific conditions.

Carbonizing, Reheating and Hardening

The heat required for casehardening is a great deal higher than that required for ordinary hardening. If, for example, the material to be casehardened was heated only to 1375 degrees F., which would be sufficient for the hardening of ordinary tool steel, the result would be very unsatisfactory. In fact, there would be no result at all. Small parts must be heated to at least 1575 degrees F., in which case sufficient depth of carbonized surface will be obtained in from six to eight hours. The time recorded as the correct one for casehardening should be taken from the time the boxes are heated clear through.

The correct way in which to caseharden is first to carbonize the material and then to allow the boxes to cool down with the work in them, after which they are reheated and hardened in water. The reheating refines the grain of the steel and prevents the formation of a distinct line between the outer hardened case and the soft core. If there is a distinct line between these two sections, the case is liable to flake off when the hardened part is subjected to severe stresses.

A still more refined method of casehardening is to repack the work, after it has been carbonized, in old bone, and after heating for two or three hours take it out and dip the pieces in the hardening tank directly as they come from the boxes. This will produce a very fine grain and in many cases prevent warping. If the work is large and it is required to toughen the inner core, it should be reheated to a higher heat than otherwise; then, after dipping, reheat again to 1500 or 1600 degrees F. according to the size of the work, and redip.

However, if the work to be hardened consists of bolts, nuts, screws, etc., it is satisfactory to dump them into water directly from the furnaces, without any reheating. A regular iron wheelbarrow with two

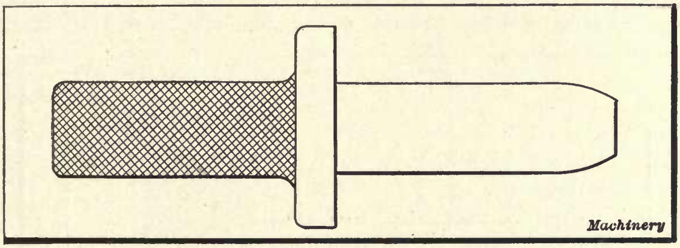


Fig. 4. Mandrel used when Hardening Collars, etc., on the Outside

pieces of flat iron placed across it lengthwise should be provided. On top of these bars is placed a sieve made from 1/8-inch wire with 1/4-inch mesh, about 18 inches square by 6 inches deep. This sieve should have a handle 6 feet long and 5/8 inch in diameter. The boxes are emptied into this sieve, and after sifting, the heated material is dumped into a tank of cold water which should be of sufficient size to prevent the water from heating too quickly. Care should also be taken in emptying the contents of the boxes into the water that they are not all dumped in one place, but scattered about in the tank. A constant flow of water should be available while the work is being hardened. The work should under no circumstances be removed from the furnace until the heat has been lowered, as the steel should be treated as tool steel after it is carbonized, and it would be injurious to the steel to harden it at the high carbonizing heat.

Gears and other parts which should be tough, but not glass hard, should preferably be hardened in an oil bath. There is then less liability of warping the work, and the hardened product will stand shocks and severe stresses without breakage. Cotton-seed oil is the best hardening medium to be used in this case.

After the work has been properly carbonized, the next operation in the case of all parts, except those mentioned as exceptions above, is to reheat. This may be done either as already explained, or it may be done in a regular muffle gas furnace in which the work can be put in rows on the tile. In this way the work can be heated very slowly, a new piece being put into the furnace to take the place of each piece as it is removed. Collars, etc., which are required to be hardened on the outside, but ought to be left soft on the inside, should be hardened on a mandrel, such as shown in Fig. 4, the diameter of the mandrel being from 0.001 to 0.003 inch smaller than the hole in the piece to be hardened. If the inside of the piece only needs to be hardened and the outside should be left soft, a cup-shaped holder, such as shown by the dash-dotted lines in Fig. 5, may be used. In this case the work will harden at *B* while it is left soft at *A* and *C*.

The hardening tank should be about 30 inches in diameter and 36 inches deep and have a constant flow of water from a pipe in the center about 6 inches below the surface.

Straightening the Work after Hardening

On account of the manner in which steel is rolled, drawn or forged, the density varies in different parts of the steel, and no matter whether

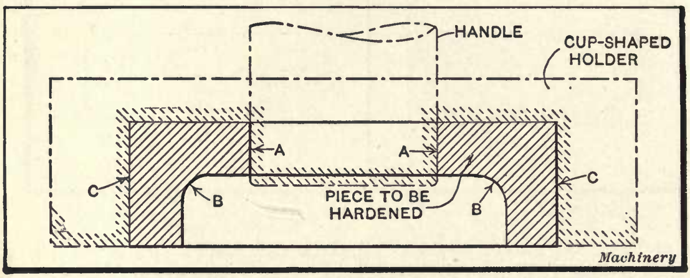


Fig. 5. Holder for Parts which are to be hardened locally

the material is heat-treated or not, it will warp more or less when hardened. It is, therefore, necessary to provide apparatus for straightening the work. In straightening, it is necessary to bend the work about twice as much as would be required to merely keep it straight while the pressure is applied, as, on account of its elasticity, it will have a tendency to work back to its original form. Small rollers and shafts can best be straightened in a vise by having a three-point contact on the jaws. For large diameters a special straightener will be required. A surface plate placed to the height of a man's eye, and at a slight angle towards the light, provides the easiest means for testing work of this character while being straightened.

When there is a large quantity of rings to be straightened or trued up, a surface plate can be readily rigged up in the following manner: A solid strap is provided on one side and a compound lever on the other, adjustable to any place along the plate by means of a slot in the latter. By a slight movement of the lever the ring can be trued up. An indicator should be placed at the front of the plate so that the operator can try a ring to see at which points the ring is out, and also the amount necessary for making it round. In straightening washers or flat pieces of any kind, the hydraulic press provides the best possible means. It might be well to mention that washers or flat pieces should be ground by taking a small amount off each side alternately, as, otherwise, they will return to their original warped shape. Another precaution, relating to the grinding of cylindrical surfaces, is to use a copious supply of water, as otherwise the heat of the grinding operation will draw the surface, producing soft spots. These will appear to have been caused by improper casehardening, but as a matter of fact, they are wholly produced during the grinding operation.

Standard Practice for Small Work

In dealing with the subject of casehardening in a paper before the Cycle Engineers' Institute, Mr. D. Flather covered partially the same ground as has been covered in the preceding pages. A number of his recommendations will, however, prove of value, and are given in the following pages. He states that the furnace should be so constructed as to be capable of being raised to a full orange heat (1830 degrees F.), and maintained at that heat with great regularity. It should be so constructed that neither the fuel nor the direct flame can come in contact with the charge. The flames should uniformly impinge on the sides and roof of the muffle in such a manner as to raise them to a high temperature, thus heating the contents of the muffle by radiated and not by direct heat. A furnace designed on this principle not only gives the best result but is also most economical in the matter of fuel. The muffle chamber and flues must, of course, but constructed of firebrick, and the doors should fit closely and also be lined with firebrick. It is important that there should be a small peep-hole in the door, with a cover plate; a hole 1½ inch in diameter is quite large enough. This latter is a most important detail, as it provides against the need of opening the doors in order to judge the heat, and is indeed the most accurate means of estimating the temperature by the eye. The furnace must be fitted with a reliable damped plate or other effectual means of controlling the draft.

Hardening pots are made in both cast and wrought iron, the former being cheaper in first cost, but the latter bear reheating so many times that they are cheaper in the end. The pots should not be of too large dimensions, or there is great risk of articles in the middle of a charge not being carbonized to a sufficient depth. No pot should be above 18 by 12 by 11 inches for such parts as cycle axles, pedal pins, and the like; while for small articles like cups, cones, etc., 12 by 10 by 8 inches is large enough. The pots should each have a plate-lid fitting closely inside.

The carbonizers in general use at the present day are animal charcoal, bones, and one or two other compositions sold under various names, consisting of mixtures of carbonaceous matter and certain cyanides or nitrates. For very slight hardening, cyanides alone are still found very useful, but no great depth of casing is ever attempted with these. Theoretically, the perfect carbonizer should be a simple and pure form of carbon, and good charred leather gives the most certain and satisfactory results. Care should be taken to avoid poorly charred leather or that made from old boots, belting, etc.

As clay must be used for a luting around the pot lid, and is also frequently used for stopping off portions to be left soft, it is important to see that a good clay is used, and that it is free from grease. Clay contaminated with grease in any way will cause irregularity in the product.

Reheating Muffles

As all casehardened articles have to be reheated before quenching, it is important that a suitable furnace should be employed for the purpose. It is not advisable that the reheating should be done in the casehardening muffle, unless it is run specially for the purpose and at a lower heat. If possible a small gas muffle should be used for reheating, and indeed for all hardening work. A properly constructed gas muffle can be regulated with great exactness, and this is very important in all hardening.

Packing the Muffles

The carbonizer having been thoroughly dried and reduced to a fine powder, a layer of not less than 1½ inch in depth is placed in the hardening pot and well pressed down. Upon this are placed the articles to be hardened. Care must be taken to leave sufficient space all around each piece to prevent its touching the others or the walls of the pot; a space of 1½ inch should be sufficient. Another layer of carbonizer is then put in and well pressed down, taking care not to displace any of the articles already packed, continuing until the pot is nearly full, and then finishing off with another layer of 1½ inch at the top. The object in view must be to make the contents of the pot as compact as possible, consistent with a sufficiency of carbonizer in contact with the articles. The more solidly a pot is packed the more complete is the exclusion of air. The lid is then put on, and the joint all around well luted with clay. By the time the proper number of pots have been filled, the furnace must have been raised steadily to the full working heat.

Furnace Heat

The proper heat for casehardening is about 1800 degrees F., or a full orange heat and this should be maintained with great regularity throughout the operation. The length of time occupied in carbonizing is regulated by the depth of casing required, and indirectly by the dimensions of the article. At the close of the carbonizing period the pot is withdrawn from the furnace and placed in a dry place, where it is allowed to become quite cold. It is then opened, the articles taken out and brushed over to remove all adhering matter. If the pot has been properly packed and luted up, the articles should be quite white, or at least have only a slight film or bloom of a deep blue color; the denser and more inclined to redness is the surface, the more imperfect has been the packing and sealing of the pot.

Reheating and Hardening

The carbonized articles are now placed in a muffle furnace and steadily raised to a good cherry red (1470 degrees F.), and then quenched in cold or tepid water or oil, according to the purpose of the articles required. They should remain in the cooling liquid until they are quite cold right through the body of the metal, thus completing the process.

Although the proper temperature for casehardening is about 1830 degrees F., this temperature may be modified to suit the purpose in view. The absorption of the carbon commences when the steel reaches a low cherry-red heat (1300 degrees F.); it begins, of course, at the outer surface and gradually spreads until the whole of the steel is carbonized. The length of time this requires depends upon the thickness of the metal being treated. The percentage of carbon absorbed is governed by the temperature, and although the increase of carbon is not in uniform proportion to the rising temperature throughout, it is perhaps sufficient for our present purpose to note that at 1300 degrees F., iron, if completely saturated, can contain no more than about 0.50 per cent carbon; at 1650 degrees F., about 1.5 per cent carbon; and at 2000 degrees F., about 2.5 per cent. These results, however, are only obtainable when the whole section of the iron has received all the carbon it is capable of absorbing at the given temperature, and is therefore in a state of equilibrium. From this it will be seen that if the process is stopped before the action is complete, the central parts of the iron must contain less carbon than the outside, and upon this fact the process of casehardening is founded.

If we take two pieces of ⅝ inch diameter round mild steel, and heat one of them with a carbonizer at a cherry-red heat, and the other at a bright orange heat, for six hours, the first will be cased to a depth of about 1/32 inch, and the other to a depth of nearly 1/16 inch, while the amount of carbon taken up will be about 0.50 and 0.80 per cent respectively; so that, so far as regards the hardness of the skin, the piece carbonized at the higher temperature gives the best result. From this we learn that a temperature of 1830 degrees F. will give us sufficient hardness of case.

We have next to find which temperature has the least harmful effect on the mild steel core, and this can best be found by heating pieces of the mild steel at varying temperatures at and above the selected one for the same length of time, using lime or other inert substance in the pot instead of a carbonizing material, and afterward reheating and quenching in water. Suppose, for example, we take three pieces, heating at 1830, 2370 and 2730 degrees F., or full orange, white and bright white respectively. We shall find that those at 2370 and 2730 degrees break very short and have lost nearly all their original tenacity, while that at 1830 degrees appears tougher and altogether stronger than before.

Having arrived at a knowledge of the right temperature, it remains now to inquire as to the length of time requisite to yield a sufficient depth of case. At a full orange heat a bracket cup of ordinary dimensions should in two hours be hardened 1/32 inch deep, and a bracket axle 11/16 inch diameter in 6 hours would have a case 1/16 inch deep. From this it will be seen that the speed of penetration is not in exact proportion to the time of heating.

Results of Hardening without Reheating

We now arrive at that part of the process where a most important improvement has been made—*i. e.*, the final hardening by quenching in water. It formerly was customary at the end of the carbonizing period to open the pot and fling the contents headlong into a tank of cold water. Here and there some of the more careful workers took each article separately, but direct from the pot, and plunged it into water. These latter obtained better results, but even they had a great deal of trouble in the way of breakages and want of regular hardness. Finding that axles taken singly from the pot and quenched were better than those quenched in bulk, and that if allowed to cool down to cherry red they were better still, an application of the old rule to harden on a rising heat led to the now established principle of allowing the pot and its contents to become quite cold, afterward reheating to cherry red and quenching with water. By this means we obtain a case of great hardness with a very tough core—that is, of course, provided a suitable steel is employed.

To understand the reason of this improved method of working we must remember that the exterior of the steel is now of about 0.80 per cent carbon, and that steel of all kinds raised to and maintained at the high temperature employed for casehardening will, unless subjected to mechanical work, show evidence of overheating, being very brittle and liable to easy fracture; and though quenched in water, and consequently hardened, the metal has little or no cohesion and readily wears away. Steel so hardened breaks with a very coarse crystalline fracture, in which the limits of the case are badly defined. It is known that when steel is gradually heated there is a certain point at which a great molecular change takes place, and that perfect hardness can only be obtained by quenching at this critical point. If quenching takes place below the critical temperature, the steel is not sufficiently hard; if above, though full hardness may be obtained, strength and tenacity are lost in part or completely, according as the critical temperature is exceeded by much or by little. This critical point lies between 1380 and 1470 degrees F., or cherry-red color heat. It may be asked why it is not sufficient, when taking the article out of the pot, to allow it to cool down to cherry red and then quench it. To this the answer is that the high temperature has already created a coarsely crystalline condition in the steel, and that until it has become quite cold and has again been heated up to the critical temperature, a suitable molecular condition cannot be obtained. When steel is cooled, whether slowly or not, it bears in its structure a condition representative of the highest heat it was last subjected to.

Casehardening Practice of Pennsylvania Railroad Shops

It may be of interest to note the casehardening practice followed by the Altoona shops of the Pennsylvania Railroad Company. The compound for casehardening is made from 11 pounds prussiate of potash, 30 pounds sal soda, 20 pounds coarse salt, and 6 bushels powdered charcoal (hickory preferred). These ingredients are mixed thoroughly, using 30 quarts of water in mixing. The following method is pursued in packing the material to be casehardened. The bottom of the box is covered to a depth of 2 inches with the compound. The parts to be hardened are placed solidly so that the compound is in contact with the bottom surface of the part, care being taken that the work does not touch the sides of the box or other pieces. After the first layer of the material is placed, it is covered on all sides and on top with the compound and solidly packed. After the first course is packed the process is repeated, care being taken to have a sufficient amount of compound between every course. There should be not less than 2 inches of compound on the top of the last course. Then the lid is thoroughly sealed with a luting of fireclay.

In the furnace the box rests on rollers to allow the flames to pass under it. When the material has been in the furnace a sufficient length of time, the box is withdrawn to a trestle flush with the floor of the furnace and parallel with and close to a water tank, after which the material is removed from the box and plunged into the water. This method makes it possible to obtain a depth of case on large material of from 1/16 to 5/32 inch in 14 hours, and of about 1/16 inch on bushings and small parts in from 2½ to 3 hours. All parts to be casehardened are thoroughly cleaned so as to be free from oil or grease.

American Society for Testing Materials Standard Casehardening Practice

The following practice for heat-treating casehardened carbon steel has been recommended and adopted by the American Society for Testing Materials.

1. When hardness of case only is desired and lack of toughness or even brittleness is unimportant, the carburized objects may be quenched from the carburizing temperature, as for instance, by emptying the contents of the boxes into cold water or oil. Both the core and the case are then coarsely crystalline.

2. In order to reduce the hardening stresses and to decrease the danger of distortion and cracking in the quenching bath, the objects may be removed from the box and allowed to cool before quenching to a temperature slightly exceeding the critical range of the case, namely, 800 to 825 degrees C. Both the core and case remain coarsely crystalline.

3. To refine the case and increase its toughness, the carburized objects should be allowed to cool slowly in the carburizing box within the furnace or outside to 650 degrees C., or below, and should then be reheated to a temperature slightly exceeding the lower critical

point of the case (in the majority of instances a temperature varying in accordance with the carbon content and thickness of the case between 775 and 825 degrees C., will be suitable), and quenched in water, or, for greater toughness but less hardness, in oil. The objects should be removed from the quenching bath before their temperature has fallen below 100 degrees C. This treatment is more especially to be recommended when the carburizing temperature has not exceeded 900 degrees C. It refines the case but not the core.

4. To refine both the core and the case and to increase their toughness, the objects should be allowed to cool slowly from the carburizing temperature to 650 degrees C. or below and should then be (*a*) reheated to a temperature exceeding the critical point of the core, which will generally be from 900 to 950 degrees C., followed by quenching in water or in oil; and (*b*) before they have cooled below 100 degrees C., they should be reheated to a temperature slightly exceeding the lower critical point of the case (in the majority of instances a temperature varying in accordance with the carbon content and thickness of the case between 775 and 825 degrees C. will be suitable), and again quenched in water or oil.

The objects should be removed from the quenching bath before they have cooled below 100 degrees C., in order to lessen the danger of cracking, and they should be placed in the reheating furnace while still at a temperature of at least 100 degrees C., likewise to lessen the danger of cracking, it being inadvisable (*a*) to allow steel to cool completely in the quenching bath and (*b*) to place hardened steel in a hot furnace. Obviously, if the furnace is cold the hardened steel may likewise be cold when placed in it for reheating.

5. In order to reduce the hardening stresses created by quenching, the objects, as a final treatment, may be tempered by reheating them to a temperature not exceeding 200 degrees C.

CHAPTER II

CARBONIZATION OF SHAFTING

The increasing use of anti-friction bearings in various forms, as well as other developments in the construction of machinery, has made necessary the use of harder and better surfaces for shafts than has heretofore been considered good practice. Before entering into any detailed discussion of this subject, we should first have some understanding of what the problem really is, expressed, if possible, in concrete figures. Let us take a piece of soft steel which has been turned and ground to a definite size. We find its hardness, as measured by the Shore scleroscope, to be somewhere between 15 and 25, whereas with a piece of cold-rolled shafting, we obtain 30. Alloy steel of suitable analysis and properly treated will give 60, and if we take still another piece of material, carbonize it and follow this by suitable heat-treatment, we can obtain 80, as shown by the scale of the instrument. Therefore, we can see from these approximate figures, that the method and material to be used is largely a matter of the specific result desired and, obviously, it is impossible to utilize any one method or material for all requirements. The information given in the following is based on a paper read by Mr. J. G. Weiss, before the National Machine Tool Builders' Association.

Aside from the condition of the surface, there are other important considerations. Taking the elastic limit of the material as a measure of its load-carrying capacity, we find 40,000 pounds per square inch an average result for soft steel and 170,000 pounds not excessive for properly heat-treated alloy steels. Hence, we see the possibility, in alloy steels, of not only obtaining the required surface, but, at the same time, materially increasing the factor of safety of the shaft, or using a smaller shaft with the same factor, as may be preferable. In the case of carbonized shafts, there is no material increase in the elastic limit, the improvement being entirely a matter of surface condition.

If the surface requirements are represented by a scleroscope reading greater than approximately 60 to 65, the problem must be approached from the standpoint of carbonization, unless we are willing to use expensive alloy steels which, in this discussion, are considered neither possible from the standpoint of first cost nor a necessity. Carbonization gives ideal results as to surface conditions but no increase in the elastic limit. On the other hand, if a scleroscope reading of 60 to 65, or less, is considered to be a satisfactory standard, it is feasible to use many alloy steels at low cost which, when of the proper analysis and suitably heat-treated, will not only give equally good results as to surface conditions, but a material increase in strength as well. The problem then is naturally divided into two general divisions each requiring a different discussion. First, carbonized shafts having a surface hardness greater than 60 to 65 scleroscope reading; second heat-treated shafts having less hardness than the figures stated. The first of these conditions only will be dealt with here.

Carbonized Shafts

Perhaps no branch of the heat-treatment of steel has been more thoroughly investigated than that of carbonization, but the results show conclusively that there is no standard American practice, either in regard to methods or material. This is doubtless due to variation in local conditions. For instance, one who carbonizes arbors or shafting is not so much concerned about the toughness of the core as one who treats pieces of thin cross-section. Again, one so-called authority will insist that the transition from case to core should be gradual with no sharp line of demarkation, whereas one who is carbonizing very thin sections or shells knows from experience that the case must, necessarily, be distinctly defined and concentrated in order to use to the best advantage the small space allowable to obtain such conflicting properties as toughness and hardness.

Where the number of parts requiring carbonization is comparatively small, a high-speed carbonizer whose strength is spent on the first run may prove satisfactory, but if the number of parts runs up into the thousands daily, a more economical material would be adopted. If our problem is that of a few pieces a week, the irritating effect of prussiate of potash is not particularly objectionable, while with a condition involving many thousand pieces daily, in all extremes of weather, its effects are more in evidence. Thus, the authority who endeavors to lay down a hard and fast rule is treading on dangerous ground. Bearing in mind, therefore, the wide divergence of conditions, even when limiting ourselves to shafts, let us first consider the best material for our specific purposes.

Steel for Carbonizing

In considering the steel to be used naturally the carbon content is the point at issue. A material varying from 0.15 to 0.20 per cent carbon is the most satisfactory from every viewpoint. Many authorities recommend a carbon content as high as 0.27 per cent, but others claim that it has not been found possible to obtain uniform and satisfactory results, in a large way, with such material. Irrespective of the particular analysis that may be decided upon, the matter of uniformity is of even greater importance. No matter what the source of supply may be, it is advisable to analyze ten per cent of the material received, in order to avoid irregularities which sooner or later develop.

Carbonizing Mixtures

Most of the carbonizing compounds upon the market contain simple ingredients which can be mixed readily upon the premises, although some are almost beyond the realm of chemical analysis. In fairness it may be stated that a few of them give very good results, but the price is generally set in proportion. For all-around purposes, those which can be mixed easily upon the premises are best. If this method be adopted, the metallurgist in charge can superintend the entire grinding and mixing process and keep the quality of each ingredient up to a standard. The two following mixtures, which for convenience are designated "A" and "B," are easily prepared, reasonable in cost and have given satisfaction in the treatment of several million pieces of the most exacting requirements.

MIXTURE A

	Per Cent
Raw bone	35
Bone black	27
Charred leather	11
Wood charcoal	27
	100

MIXTURE B

	Per Cent
Potassium ferro cyanide	5
Sal soda	14
Coarse salt	9
Powdered wood charcoal	72
	100

The characteristics to be considered in a carbonizing mixture are: Hardness imparted to the work; rate of penetration; cost per pound and renewal cost; ease of manipulation in grinding, mixing, packing, etc. The following table shows mixtures "A" and "B" compared in the first three respects, with one of the best carbonizers on the market, which for convenience is designated as mixture "C."

Material	Scleroscope Reading	Time to Penetrate 5/64 inch	Cost Per Pound, Cents	Per Cent of New Material Required for Renewal
"A"	70	13 hours	2.6	55
"B"	75	12 hours	1.3	30
"C"	75	14 hours	2.5	80

The hardness was determined by using properly carbonized heat-treated and polished specimens and naturally varied somewhat, the values given in the table being averages of several readings. The time to penetrate to a given depth was obtained on specimens of shafting one inch in diameter. The carbonizing process was similar to that recommended in the following. By referring to the preceding table, it will be seen that mixture "B" shows a gain of about 14 per cent over mixture "C" and about 8 per cent over "A," in respect to speed of penetration. In initial cost, material "B" is the cheapest, while "A" and "C" are about the same. The quantity of fresh material which must be added to that which has already been in the furnace, to restore it to the desired strength, shows a marked advantage in favor of "B." Moreover, material "C" was practically useless after one heat. While cost is an item of minor importance, and quality is cheap at any price, if the other properties are balanced, cost might judiciously be considered in selecting carbonizing mixtures; hence, this data was added for the sake of completeness.

Packing Shafts to be Casehardened

If the shafts are not too long, they should preferably be packed in pots standing on their ends, but if the length does not permit of this arrangement, they may be packed in rectangular pots in horizontal layers. Irrespective of the method of packing, each piece should be kept 1½ inch from adjacent pieces and 2 inches from the pot walls. This clearance, which may seem excessive, allows for any settling of the mixture while in the furnace, for if the pieces should come in contact with each other, the penetration would be retarded and the surface would be defective at that point. A layer of mixture 2 inches deep should be placed in the bottom of the pot and be thoroughly tamped down; every successive layer should also be tamped. The pot cover should be thoroughly sealed or luted with fireclay.

Large pieces which are too long for pots may be packed in pipe, the latter having a cap on each end, the threads of which have been coated with graphite to facilitate removal. With this arrangement, all moisture must be excluded from the mixture to prevent the formation of steam which might result in an explosion. The pots should be spaced in the furnace so that 2 inches of space is available for the circulation of heat around every part of the pot surface. Even with this precaution, the pot nearest the furnace door will not be heated exactly the same as those farther back, and this should be allowed for. The best material for the pots is either cast steel or white iron.

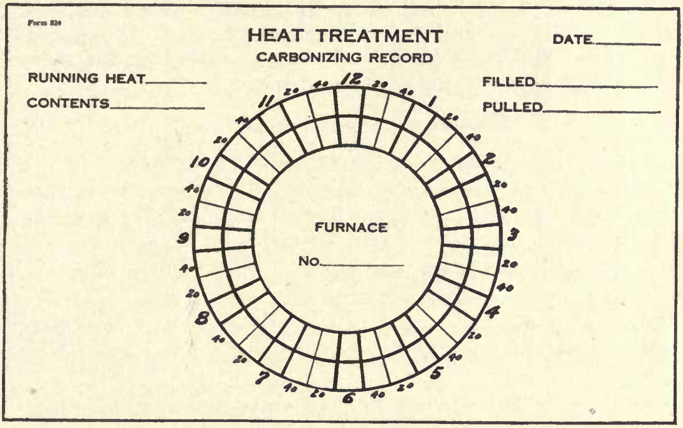
The Carbonizing Heat

There is a difference of opinion as to the proper temperature for carbonizing. Temperatures ranging from about 1600 degrees F. to 1800 degrees F. are used quite generally. The writer has found that 1725 degrees F. is a safe heat, which does not endanger a good steel. Higher temperatures may be used, but while the duration of the "run" is shortened, the quality of the work is likely to be impaired.

For the accurate measurement of this temperature, only the very best make of pyrometer should be employed, those of the high-resistance type being preferable. They have the great advantage of simplicity, as the wiring does not need to be especially calibrated for each location, within reasonable limits, and it is possible to attach recorders to the same circuit without affecting the indicator reading. The pyrometer should penetrate the furnace wall and be placed as near to the work as possible, without liability of actual contact. When located vertically, the life of the porcelain jackets is increased, but the temperature of the cold junction is kept higher owing to the direct radiation from the top of the furnace. By inserting a pyrometer of sufficient length horizontally into the furnace wall, the cold junction may be kept at a lower and more uniform temperature.

At the beginning of the heat the temperature may be kept, say, 50 degrees F. higher than normal, until the heat begins to penetrate the work, when it should be reduced to normal. No fixed rule can be given for the time of complete saturation, as the size, shape and thickness of the pot wall, as well as the size of the work and kind of mixture, are determining factors. The duration of the run can be determined only by actual trial, depending upon such factors as the nature of the steel being treated, the carbonizing material, the degree of temperature and depth of case required. The best practice is to put a trial piece of the material into one of the pots in each furnace and remove this piece about an hour before what experience has shown to be ample time. This trial piece is then heat-treated, as described later, and the depth of the hardened case of a cross fracture is observed. A very accurate estimate can then be made as to the time to remove the rest of the work.

With mixture "B" (see table given on preceding page) twelve hours will produce a case about 5/64 inch deep on a 1-inch shaft of 0.15 per cent carbon content, with a temperature of 1775 degrees F. for the first two hours and 1725 degrees F. for the remainder of the run. A complete temperature record of each run in each furnace should be kept, the temperature being tabulated at least every twenty minutes. A convenient blank for this tabulation is shown in the accompanying illustration. The temperatures are first recorded in the outer radial spaces, and if the run exceeds twelve hours' duration the inner spaces can then be used. Uniformity of temperature is, of course, a very



Blank for recording Furnace Temperatures

important factor and no matter what type of furnace or fuel is used, more or less regulation is necessary. A brief description of the method employed at the Hyatt Roller Bearing Co.'s plant to effect this control is of interest.

Colored Light System of Controlling Furnace Temperatures

In the Hyatt plant, there are approximately twenty-five large carbonizing furnaces fired with fuel oil and over one hundred semi-automatic gas furnaces for heating alloy steels. The gas furnaces are supplied by a battery of gas producers having a total capacity of 2500 horsepower. The physical laboratory is located on one of the floors of the heat-treating building, and the temperature control room is a part of this laboratory. The furnaces are distributed on the four floors all over the building. Each furnace has a pyrometer which is connected by wires in an iron conduit, with the temperature control office. Over each furnace there is a small signal board with three lights; one white, one red, and one green. These lights are also connected with the temperature control office. All these circuits lead to a marble switchboard which has three signal lamps for each furnace, these being in series with corresponding lamps over that particular furnace. There are two operators at the switchboard, each one having control of the furnaces of two floors.

By touching a key, the operator can set the pyrometer of any furnace. If the temperature indicated by the pyrometer is normal, or within the allowable tolerance, an observation of the next one is taken, and so on. If the temperature is found to be too high, by touching another key the light over the furnace is changed to red, and if it should be found to be too low, the light is changed to green. At the same time, the corresponding light on the furnace signal board changes. Each attendant has under control six furnaces, and by simply looking at the signal boards he can determine readily whether the temperatures are high, low, or normal, and make the necessary regulations. After signaling a red or green light, the switchboard operator soon returns and takes another reading of the furnace to ascertain if the proper regulation has been made.

Heat-treating after Carbonizing

When the steel emerges from the carbonizing furnace, it is of a dual nature, the case containing, say, 0.80 to 1.25 per cent carbon and the core 0.10 to 0.20 per cent carbon. Consequently, the carbonizing temperature is considerably above the critical range of both the case and the core, especially the latter, and as the duration of the run is several hours large crystals form readily in both case and core under these conditions. To restore the steel to the best grain size, two heats are required; a high one for refining the core, and a lower one for refining the case.

Of course, it is possible, as well as quite common, to quench the work directly from the pot, using this heat as the first or "core heat" and then following with a second or "case heat," or the second may be omitted entirely. In the latter instance, the temperature is too high to produce the best refinement of the case, although the core structure may be satisfactory. Again, if the work is allowed to cool so that the temperature is about right for the case, the core will not be perfect. Another disadvantage is due to delays in getting the work from the pot to the quenching medium, the pieces cooling more or less, and thus giving results that are far from uniform. In view of these facts, it is greatly advantageous to apply two heats after the work has cooled from the carbonizing temperature.

We now come to the important question as to what are the correct heats. There is apparently a great difference of opinion on this subject, owing to such varying factors as the rate of penetration of different quenching mediums, the effect of the mass of the article quenched, and the temperature of the quenching medium. As previously mentioned, the first heat is usually between 1600 and 1800 degrees F. The second heat varies between 1375 and 1475 degrees F.

If a single heat is used, the range will vary still more, running high or low, according to whether the quality of the case or core is to be sacrificed.

Quenching

Perhaps nothing connected with the heat-treatment of steel is of more importance than quenching. Slight variations in the angle of immersion often result in distortion of the work, apparently out of all proportion to what might be expected. Shafts should be immersed vertically and moved in the same position up and down until the quenching is complete. No matter how large the work, the results obtained will pay for any special apparatus necessary to carry out this method.

Where the maximum hardness is desired and only one heat is to be taken, water will give the best results, but the danger of distortion is greater than when oil is used; this applies even more to brine and cold water. When two heats are employed, it is advisable to quench first in oil, for as the first temperature is higher, distortion is more likely to occur. After the second heat, the work may be quenched in water. Good results may be obtained by using water in both instances, as far as the structure of the steel is concerned, but there would be greater danger of distortion. When oil is used, care should be taken to maintain its temperature fairly constant.

The advantage of drawing after carbonizing is much disputed. Opponents of this method claim that the core should have the requisite toughness and that any temperature which would toughen the case would soften the core. While this may be true to a certain extent, it has been found that in some instances good results can be obtained by drawing at about 400 to 450 degrees F., as this temperature relieves the strain in the case somewhat, without materially sacrificing its hardness.

CHAPTER III

CASEHARDENING ROLLER BEARING PARTS

The manufacture of bearings of either the ball or roller type has grown remarkably in the past few years. The automobile industry is responsible for a large part of this growth, as it would have been difficult, if not impossible, to make the automobile a success without these anti-friction bearings. They must be made as small and light as possible and, at the same time, strong enough to carry the load of the car.

The first essential of either type of bearing is a steel that possesses the qualities that will enable it to withstand the strains to which the bearings may be subjected. The second essential is correct machining operations, as the parts must be made within a fraction of a thousandth of an inch of the correct size. The third essential—and perhaps the most important one—is the heat-treatment that these parts receive. This must be of such a nature as to make the steel resist the crushing, vibrational, frictional, or other strains to which all bearings are submitted.

Annealing

After the steel parts of bearings have been machined to their correct size and shape, it is essential that they be thoroughly annealed before they are carbonized, hardened and tempered. This relieves any internal strains, making the physical properties the same in all parts of a piece. Sometimes steel is annealed before any machine work is performed. This first annealing is usually done at the steel mill before the steel is shipped, but it will not take the place of the annealing that should be done after the steel is manufactured into the different pieces.

In heating steel, the temperature will reach a point at which there occurs a change in the grain, or a new grain structure is born. With this rearrangement of the grain structure any unequal strains will disappear. Annealing consists of raising the temperature of the steel high enough to be assured that the metal has had time to thoroughly complete this change of structure. The steel is then allowed to gradually cool to the temperature of the atmosphere. The slower this cooling takes place the more thorough will be the annealing and the obliteration of any internal strains. If cooled too quickly, a hardening of the metal takes place and other strains are likely to be set up; this is especially true if it cools unevenly or more quickly in some sections than in others. If the steel is heated too high above the transformation point the grain will become coarse, as each degree of temperature above this point adds to the coarseness of the grain structure.

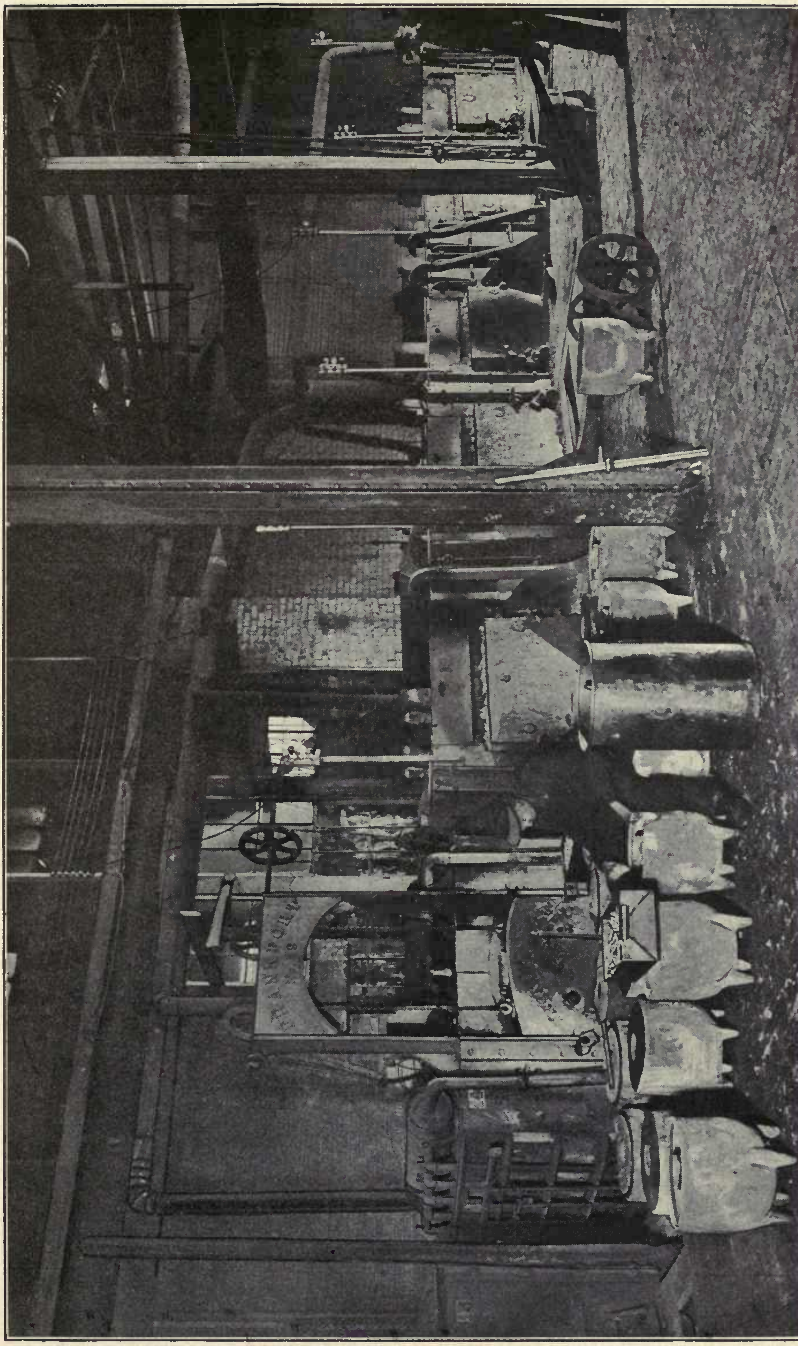


Fig. 1. Casehardening Pots and Special Heating Furnaces used by the Timken Roller Bearing Co.

This information is the basis of three rules that it is well to follow when annealing all steels. First, heat the metal to a temperature above the highest transformation point, but not far enough above to coarsen the grain; second, hold the temperature at this point long enough to allow the transformation to be completed but do not prolong it beyond that; third, make sure that the rate of cooling is sufficiently slow to prevent even a superficial hardening.

Carbonizing

Some parts of bearings withstand the strain much better if made from low carbon steel and carbonized than if made from high carbon steel. This gives the outer surfaces of such parts a high carbon content that can be made hard to resist frictional wear or any tendency to crush or deform, while the low carbon center, or core, will remain soft and ductile, and thus make it difficult to break the piece with any of the severe shocks or strains it receives when in use. This carbonizing is done after the piece has been machined to the proper size and shape. Grinding is the only kind of work that is practical after the steel has been carbonized.

In performing the carbonizing operation, the work is packed in iron pots and heated in furnaces in the same manner as already described in preceding chapters. Fig. 1 shows the bank of furnaces used by the Timken Roller Bearing Co., Canton, Ohio, for carbonizing. The first of these is a Frankfort furnace, which was installed by the Strong, Carlisle & Hammond Co., while the others were built by the Brown & Sharpe Mfg. Co. The special annealing furnaces built by the company for their own use are shown in Fig. 2.

In the lower left-hand corner of Fig. 2 will be seen part of a pot that has been sealed up ready to insert in the furnace with the two-wheeled truck. Beside it are two pots that are only partly filled, indicating the way the work is laid in the carbonizing material. Each steel piece is kept at least one inch away from all other pieces. Then the carbon can penetrate all parts of the outer surface when the pot and its contents are heated to a temperature that is high enough to make the steel so hot that it will absorb carbon.

The amount of carbon that is thus injected into the outer surfaces of the steel and the depth to which it penetrates are governed by the composition of the steel; the nature of the carbonizing material; the temperature of the furnace; and the time the work is held at this temperature. The outer shell of the steel piece is usually made to absorb enough to give it 1.00 per cent of carbon. This percentage of carbon gradually diminishes toward the center of the piece until the low carbon content of the original metal is reached. This will vary from 0.10 to 0.20 per cent of carbon, as it is such grades of steel that are used for parts that are to be carbonized. Many of the high-grade alloy steels, as well as the ordinary carbon steels, are carbonized to various depths and with various percentages of carbon. These alloy steels give much better results in bearings than any of the carbon steels, and are nearly always used for the parts of bear-

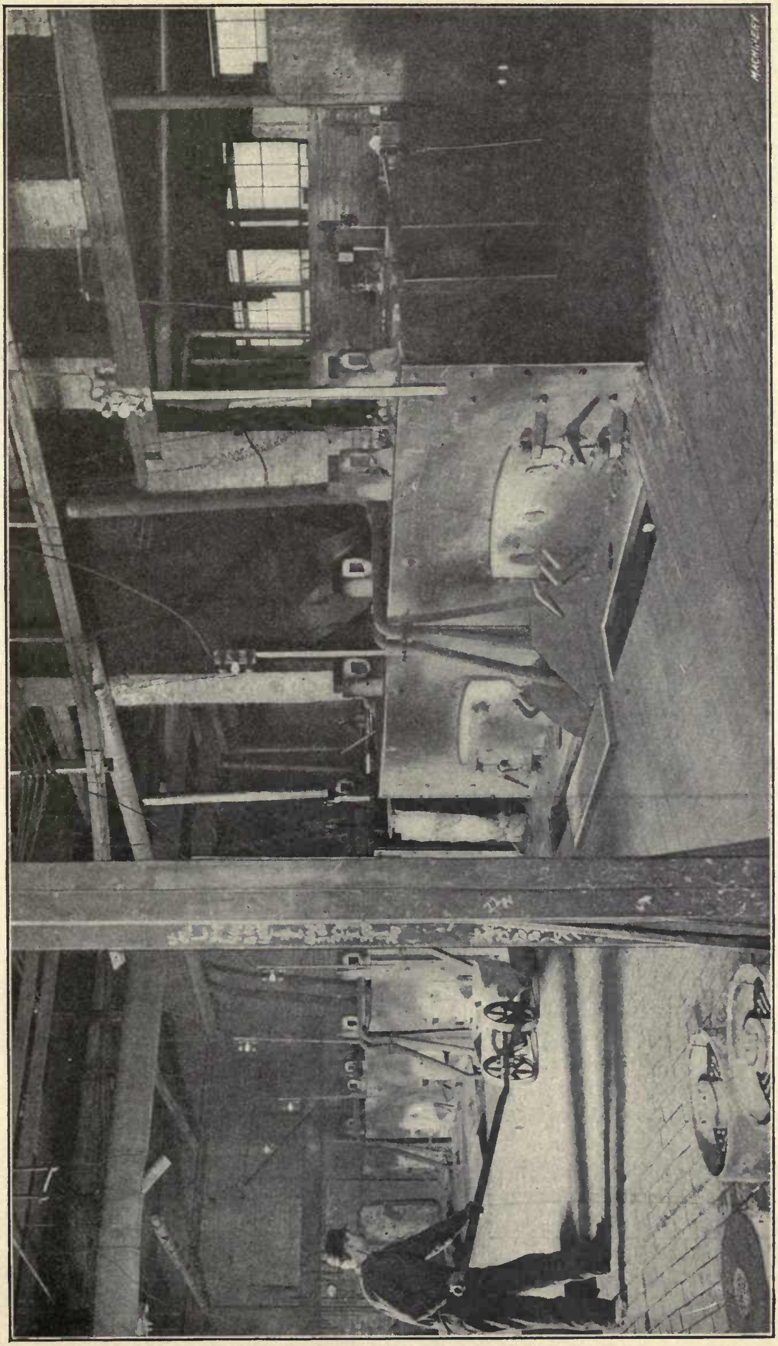


Fig. 2. Furnace with Floor-plate removed to show Burner

ings that have to withstand great strains. They are more expensive, however, and hence some of the cheaper bearings are made from the carbon steels.

The higher the temperature to which the steel is raised, the more quickly will it absorb carbon to a given depth; the larger will be the amount of carbon that it will absorb in a given time; and the greater the depth to which it is possible to make the carbon penetrate. Owing to the grain of the steel becoming gradually coarsened by each degree that the temperature is raised above the transformation point, there is a limit to the heat that can be successfully used when carbonizing steels. When heated too far above the transformation point the grain begins to crystallize, and at still higher heats the crystals begin to separate from one another. When these small cracks appear between the crystals the usefulness of the metal has been destroyed and it can only be restored by remelting and rerolling or reforging. Before the crystals begin to separate, the original fineness of grain can be restored by allowing the steel to cool and afterward heating it to a little above the transformation point and then suddenly cooling it by quenching in oil or water. This is the hardening operation and if properly done it will put the steel in as good a condition as though the grain had not been coarsened by overheating.

Therefore, carbon steels with a transformation point of 1500 degrees F. or below can be held at a temperature of 1650 degrees for several hours, when carbonizing them, and the coarsened grain can then be brought back to its greatest degree of fineness by the subsequent hardening operation. Some of the alloy steels with a transformation point of 1650 degrees F. can be heated to 1750 degrees for the carbonizing operation. These temperatures will give a rapid penetration of carbon; they also give as high a percentage in the outer shell as is required for practical work and to the necessary depth. Under ordinary conditions, a temperature of 1650 degrees F. maintained for one hour will cause the carbon to penetrate to a depth of 1/64 inch; three hours will give a depth of case of 1/32 inch; nine hours a depth of 1/16 inch; and twenty-four hours will give a depth of 1/8 inch. It is very seldom that the high carbon content is required for a depth of more than 1/16 inch and thus each lot of steel parts can usually be carbonized in a day's run.

After deciding what is the best temperature for the carbonizing heat, the best results can only be obtained by keeping the furnace uniformly at that temperature during all the time the work is in the furnace. Hence the same pyrometer is installed on these furnaces that is used on the annealing furnaces and on all other furnaces used in the heat-treating department. Then the time will decide the depth of penetration, and when the desired depth has been obtained the pot should be taken out of the furnace and allowed to cool slowly to below 600 degrees F. After that, the work can be taken out of the pot and allowed to cool quickly. Then it is ready for any hardening and tempering that is required. In Fig. 3 is shown the way the work is removed from the pot and sorted. The square pots are used for carbonizing work and the round ones for annealing. Thus there is no excuse for getting the work mixed in these two operations. Some take the pot out of the furnace and dump the work directly into the quenching bath for the hardening operation. The carbonizing temperature is usually too far above the transformation point, however, to give the steel the finest grain that it is capable of assuming. Thus it is far better to allow the work to cool down from the carbonizing temperature and then reheat it for the hardening operation.

Hardening

In hardening carbonized bearing parts, the best results are obtained by giving them a double heating and quenching to get the proper degree of hardness in both the hard outer shell and the soft core.

Fig. 3. Dumping and sorting Work that has been carbonized

This is due to the fact that the transformation points of high and low carbon steels occur at different temperatures, which are often 200 degrees apart. The steel should first be quenched from the high transformation point of the low carbon steel in the core and then reheated to the lower transformation point of the high carbon steel of the outer shell and again quenched. This produces bearings that it is almost impossible to break or crush under the load that they are designed to carry. It also gives them a wearing surface that will last a long time, as its grain is very fine and dense.

Some parts of the bearings are made from steel that contains the desired amount of carbon. These parts are hardened and tempered without being subjected to the carbonizing process. Such work is inserted in furnaces and heated to the hardening temperature without being packed in iron pots. When it has reached the correct heat for hardening, it is quenched in tanks of oil or water. If the harden-

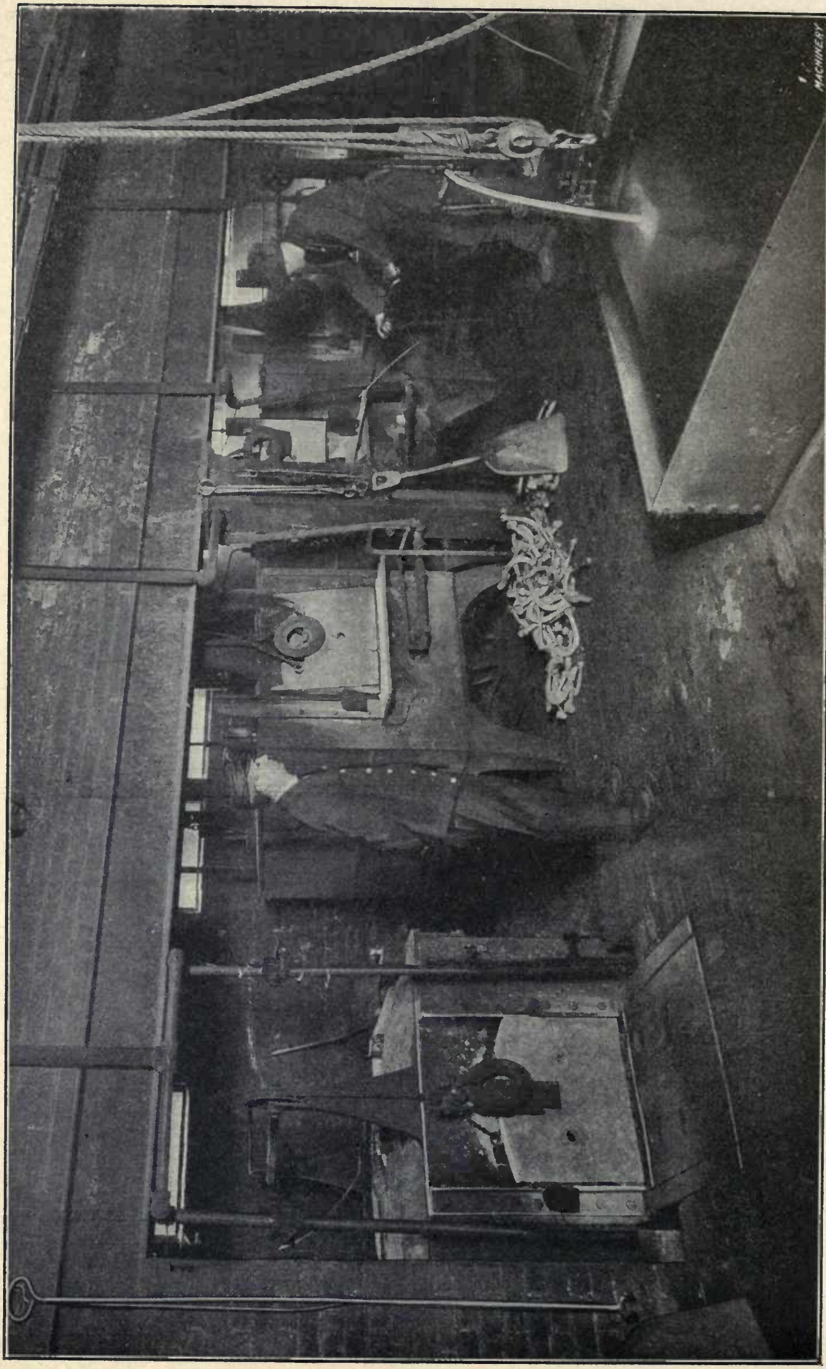


Fig. 4. Arrangement of Hardening Furnaces and Quenching Tanks

ing temperature has been just right, *i. e.*, just above the transformation point, the steel will then be in the hardest state to which it can be brought. It will be what is termed "glass hard," and hence brittle, and must be heated again to a high enough temperature to draw out enough hardness to obtain the desired degree of toughness.

The hardening temperature is the most important one and will not allow of as much variation as the annealing and carbonizing temperatures, if the best results are to be secured. If the steel is not heated up to the transformation point before it is quenched, the change in grain structure will not take place and the steel will be no harder than when it leaves the rolling or forging operations. If heated above the transformation point the grain coarsens in proportion to the number of degrees of temperature above this point. As it coarsens, the physical properties of the steel deteriorate. Each rise of 50 degrees F. above the transformation point will lower the elastic limit of carbon steels something like 5000 pounds per square inch, and other physical properties in like proportion. Thus the greatest strength that can be given the steel can only be obtained at a certain temperature. Any variation from this means weaker metal. Its capacity to resist fatigue also loses somewhat over 15 per cent with each 50 degrees rise above the transformation point.

In hardening the various parts of Timken roller bearings, furnaces similar to those shown in Fig. 4 are used. These are the Strong, Carlisle & Hammond Co.'s furnaces. When the correct temperature has been obtained, the work is thrown into one of the tanks shown at the right, so it will suddenly cool. The hot steel would naturally raise the temperature of this bath, and when raised too high the steel would not be cooled quickly enough to produce the greatest degree of hardness. To overcome this difficulty, the liquid is kept constantly in circulation by allowing the hot fluid to overflow at the top of the tank and run into a larger tank which is located below the level of the floor at a considerable distance away. This allows the liquid to cool by radiation, and it is then pumped back into the tank. The stream than can be seen steadily flowing into the tank is the cool liquid coming from this pump. A wire basket lies in the bottom of the tank and covers nearly the entire bottom. When the hot steel is thrown in the bath it is caught in this basket. The block and tackle shown is used to raise the basket out of the tank when it becomes filled with work which has had time to cool. The basket is merely raised above the level of the tank and the work dumped into cars or trucks that convey it to the other parts of the shop where it is to be used. Thus large quantities of work can be handled during a regular work day at a very small cost.

The accuracy of the drawing temperatures is also very important. When too much of the hardness is drawn out, the bearing parts will be too soft and will compress when under load. When too little of the hardness is drawn out, they will be too hard and brittle and thus likely to crush or break. To get the greatest accuracy in the drawing temperatures, the furnaces shown in Fig. 5 are used. The heating

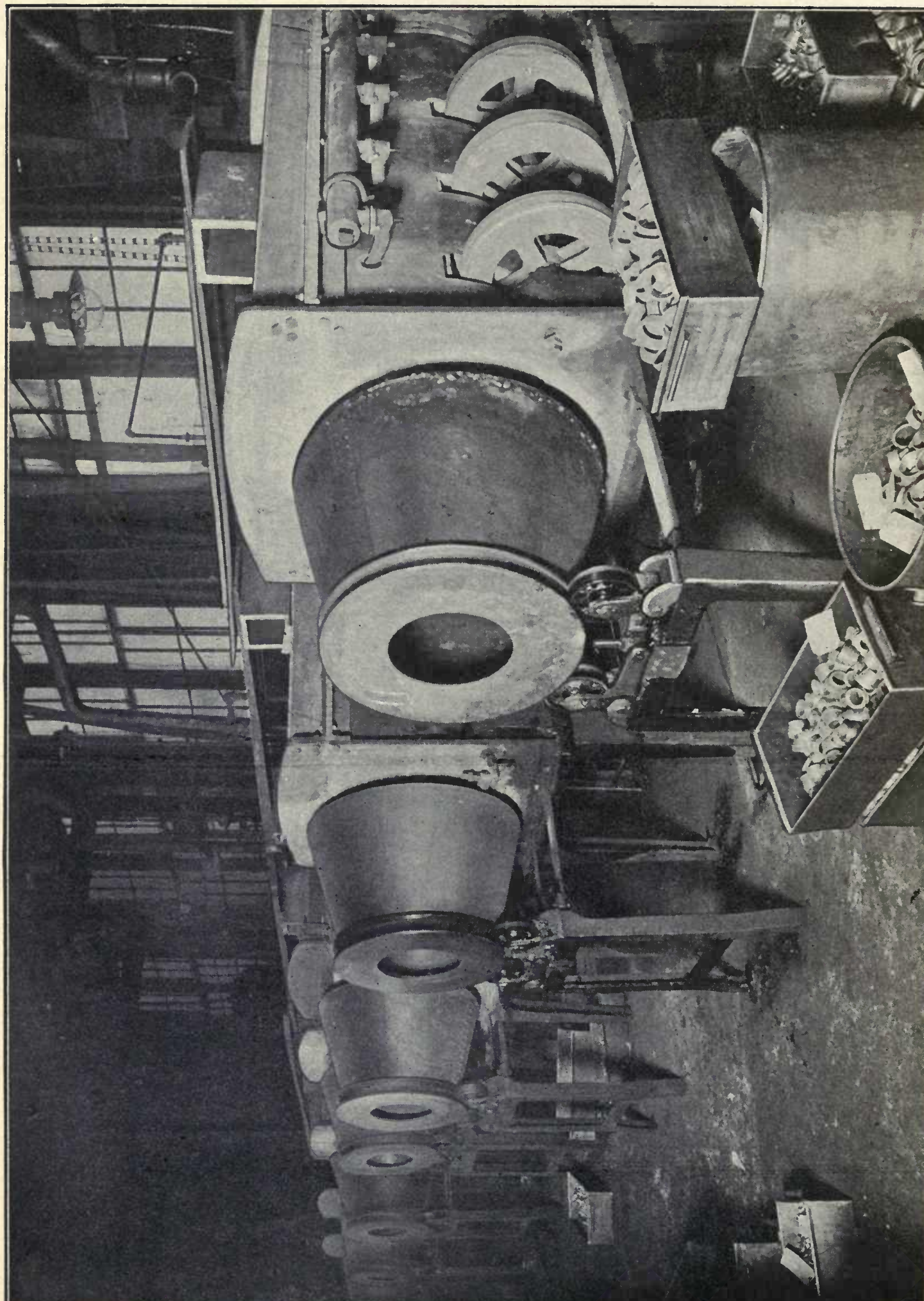


Fig. 5. Rotary Furnaces used for drawing the Temper of Roller Bearing Parts

chambers of these furnaces are revolving retorts through which the work slowly travels until it has absorbed the highest temperature of the furnace. It then drops out at the far end into receptacles which are removed when they are full. The retort has a spiral web on the inside and this, in connection with the speed at which the retort is revolving, controls the time that is consumed for the work to travel through. The work is dumped into the round hole shown at the near end of the furnace. Thus the tempering is done automatically and the furnace operator can devote most of his time to adjusting the burners, so that the furnace will be maintained at the correct drawing temperature. These furnaces can also be used for automatically heating bearing parts to the hardening temperature and then dropping them into a quenching bath at the far end of the furnaces. The retort would then have to travel slower to allow the work more time in which to reach this higher temperature.

CHAPTER IV

NEW CASEHARDENING METHODS

During the past decade there has been a great deal of investigation relating to the conditions under which the various carbonaceous gases may be used in place of the familiar solid carbonizing materials. The old well-known casehardening process described in the preceding chapters was the only one known for many centuries. It was used without a question of its superiority until the manufacturer of armor plate became such a large industry that efforts were made to find a better, or cheaper, way of causing the carbon to penetrate this plate.

The first method employed was to place an armor plate in a pit and cover it with a layer of charcoal, and then lower another plate onto it. The cover was then put on the pit and the plates heated to (or baked in) a temperature that was sufficient to cause them to absorb the carbon from the charcoal. Gas was generally used for the fuel, owing to the ease of controlling the heat. The next method tried was to send a current of carbonaceous gas between the two plates, in place of the charcoal. This caused the carbon to "soak in" in less time and was found more economical. Later, electricity was used for heating the plates, and with the carbonaceous gas and electricity, the carbon penetration was found to be more uniform over the entire surface of the plate.

The results obtained from the action of carbonaceous gas on armor plate have been such that a muffle carbonizing furnace has been built and placed upon the market. This machine, illustrated and described in detail in succeeding pages, holds the work in a revolving retort, through which is sent a current of carbonaceous gas. This retort serves as a muffle that is surrounded with the flames of the heating gases. With this furnace, small pieces can be carbonized in much less time than formerly, and at about one-half the cost as compared with packing in iron boxes and then baking in an oven furnace. All of the labor of packing materials is done away with; carbon will penetrate the metal in less time and more evenly; its depth and percentage can be controlled more easily; and the work can be heated to the carbonizing temperature more quickly and maintained there more easily. A steady flow of carbonaceous gas can be kept passing through the retort, and thus any depth of carbon can be obtained without repacking the work.

Comparison between Old and New Methods

When considerable depth of carbon is required, this is impossible with the old method of packing with bone and charcoal in an iron box and sealing on the cover. This is due to the fact that only a certain amount of carbon is present, and the longer the work is baked, the more there will be in the steel and the less in the charcoal. When an equilibrium is established, no more carbon will penetrate the metal, and to obtain a greater depth, the work must be packed in fresh carbonaceous material and the heating repeated.

With the gas process, however, the percentage of carbon in the gas surrounding the work can be maintained at a permanent figure until the carbon has penetrated to the center of the metal, the percentage of carbon possible to impart to the steel being far above that which is used for any kind of commercial work. Some of the gases that have been experimented with are methane, ethylene, illuminating gas, carbon monoxide, carbon dioxide, and gases that are made from liquids like petroleum, naphtha and gasoline. Most of these gases have been used in combination with ammonia, in order to ascertain to what extent this would aid in the penetration of the carbon.

From the numerous experiments that have been conducted, it has been found that carbon monoxide is far superior to any of the solid carbonaceous materials in the specific, direct carbonizing effect it has upon steel. It is also better than all other gaseous materials in this respect. Carbonizing materials that do not contain nitrogen cost only from one-tenth to one-twentieth of the nitrogeneous materials. It has been found, however, that nitrogen acts as a carrier for the carbon, and when it is not present, carbonaceous materials have a very weak carbonizing effect; some investigations have shown that the effect is absolutely nil without the intervention of gaseous carbon compounds. When solid carbonaceous materials are used, the specific effect of the nitrogen is very weak, and it is only when these contain a high percentage of the cyanogen compounds that they have any marked carbonizing effect.

While carbon monoxide is capable of rapid penetration, it has an oxidizing effect on steel, and is liable to form a scale that will spoil small work which cannot afterwards be ground. This oxidizing effect is more pronounced in chromium and manganese steels. When carbon monoxide alone is used for the carbonizing medium, there is a distinct demarkation between the carbonized zone and the core of the metal. This is also a detrimental feature, in that when the piece is hardened, it has a tendency to crack at this demarkation, causing the outer shell to peel off.

The Giolitti Process

To overcome these bad effects of carbon monoxide, a new process has been developed by Dr. F. Giolitti, Genoa, Italy. In this process the work is packed with wood charcoal in a cylinder, and when heated to the carbonizing temperature, a current of carbon dioxide is injected into the cylinder. It was demonstrated that when a slow current of carbon dioxide traversed a mass of wood charcoal, the carbonizing gas was supplied with great rapidity and without any excess of carbon monoxide. Thus, an equilibrium with free carbon was established at the carbonizing temperature. The exhaust gas contained less than three per cent of carbon dioxide, it being almost entirely carbon monoxide, and its volume being about double that of the carbon dioxide which was introduced into the apparatus. Some results that were obtained with carbon monoxide alone, and in combination with charcoal, are shown in Table I.

With the use of this new process, a more rapid penetration can be obtained than with any of the solid or gaseous materials, except pure carbon monoxide. The carbon is evenly distributed in the carbonized zone, and the peeling of the outer shell, when hardened or tempered, is reduced to a minimum. Any desired depth of penetration can be obtained without renewing the carbonizing material, and there is absolute security against the introduction of any foreign substance. Variations in the percentage and depth of the carbon can be obtained by diluting the carbon monoxide in nitrogen; by limiting the contact of the solids with the metal; and by varying the temperature during the carbonizing operations. Expansion or contraction and warping of the pieces being carbonized has also been reduced to a minimum. In fact, there are so many features that make it superior to the old method of packing and sealing the work to be carbonized in iron boxes, that it is safe to say that the new process is incomparably better.

TABLE I. RESULTS OF CARBONIZING STEEL WITH CARBON MONOXIDE FOR TEN HOURS AT 2000 DEGREES FAHRENHEIT

Depth from Surface at which Sample was Analyzed, Inches	Percentage of Carbon			
	Carbon Steel		Nickel-chromium Steel	
	CO Gas Alone	CO_2 and Charcoal	CO Gas Alone	CO_2 and Charcoal
1/64	0.70	1.17	0.86	1.16
3/32	0.67	0.81	0.87	0.81
3/16	0.53	0.34	0.75	0.50
5/16	0.39	....	0.59	....

After much experimenting, Dr. Giolitti decided that the double muffle furnace, shown in Fig. 1, was the most efficient and economical for carbonizing small or medium size pieces of varying shapes. By providing two muffles, one could be filled with work and kept at the carbonizing temperature, while the other was being emptied and refilled. If the amount of work would warrant, many more muffles could be used in the same furnace. The muffle to the right is shown by a sectional view through the center of the furnace, but the retort that holds the work is not sectioned, while the muffle to the left is shown by a sectional view on the center line, thus revealing the interior.

Cylindrical muffles *A* are made of some refractory material and are built into the brick-work of the furnace. Surrounding them are passages *B*, in which the combustion of the heating gases take place. These passages are lined with firebrick or fireclay and the furnace is

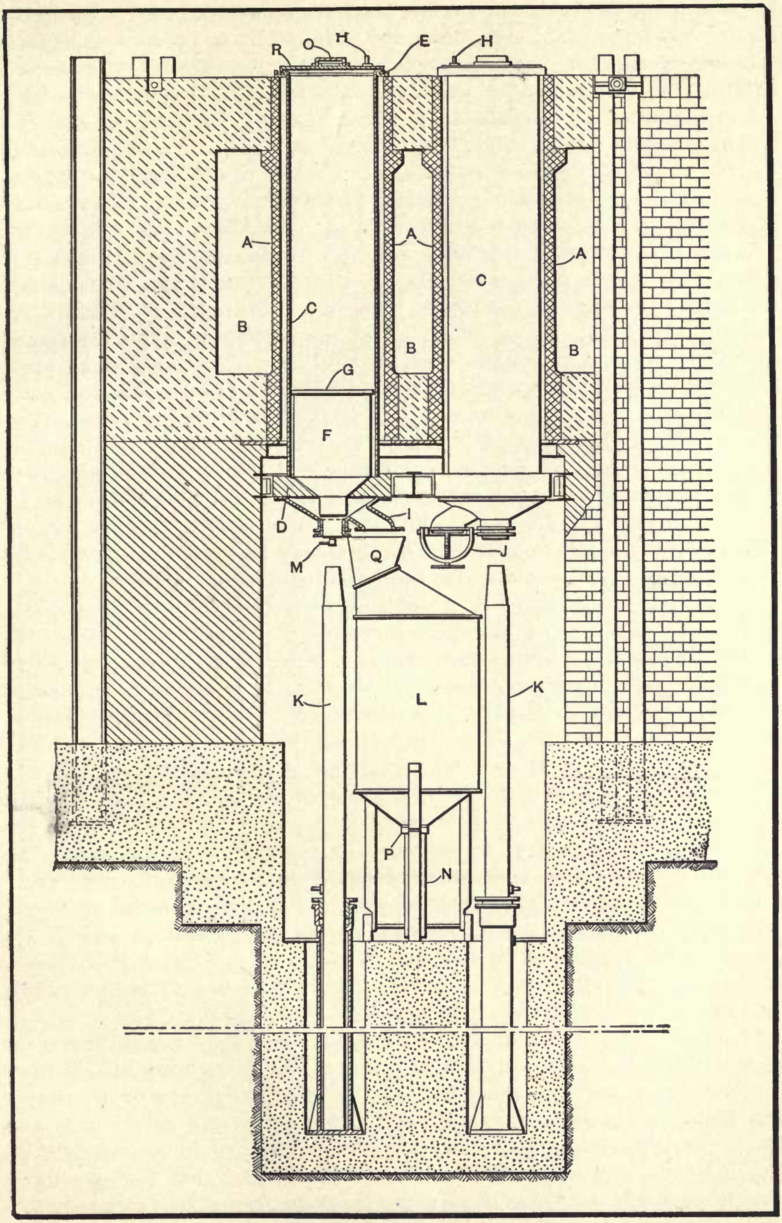


Fig. 1. Muffle Furnace for Carbonizing Steel with Charcoal and Carbonaceous Gas

provided with regenerators, so that the fuel gas, which is furnished by producers, can be used in the most economical manner. By this arrangement and the valves that are supplied, it is possible to maintain the work at a uniform predetermined temperature. The work-holding retort *C* is made of seamless steel tubing and sets into flange *D*, which latter is attached to a frame that fits into the brickwork underneath the heating chamber. Flange *E*, which is made U-shaped to hold cover *R*, supports retort *C* at the top of the furnace. Thus, it is only the work of a few minutes to take out retort *C* and replace it with a new one, when it has warped out of shape or burnt through.

Inside of retort *C* is located a hollow cast-steel cylinder *F*, and inside of this is located a device that evenly distributes the carbonizing gas around the work in the retort, by sending it through cover plate *G*, which is filled with holes. When all of the carbon is taken from the gas, it is allowed to escape through vent *H*. The work to be carbonized is stacked up on cover plate *G*, which rests on casting *F*, and this, in turn, rests on the same flange *D* that supports the retort. To the bottom of this flange is attached the cast-iron nozzle *I*, which is closed at the bottom by the non-return valve *J*. Underneath the muffles are located two hydraulic rams *K* and a cylindrical iron tank *L*, mounted on wheels, for handling the solid carbonizing material, which is in a granular condition. Tank *L* may be turned on its wheels so that spout *Q* will come under the nozzle *I* of either muffle.

In operating this furnace, a continuous method can be employed. When a batch of work has been carbonized, the granular carbon is drawn off through nozzle *I* into tank *L*. After that, pipe *M*, through which the carbonizing gas enters the retort, is unscrewed, and ram *K* raises steel pot *F* towards the top of retort *C*, thus pushing the work that rests on plate *G* up with it, so that it can be removed as the ram proceeds upwards. When casting *F* has reached the top of its stroke, which is a little below the top of the furnace, and the old work has been taken out, new work is placed on disk *G*, which is lowered by ram *K* as fast as the work is located. When the retort is filled with work, tank *L* is wheeled out from under the muffles and raised over the top of the furnace with a hoist on a swinging arm. When over the top of the furnace, pipe *N* at the bottom of tank *L* is lowered into opening *O* in the center of cover *R*. Valve *P* is then opened to allow the hot granular carbon to flow out of tank *L* and fill the interstices surrounding the work.

If granular carbon is held at or near the carbonizing temperature, it acts very much like a liquid, and readily flows into all of the crevices surrounding the articles in the retort that are to be casehardened. When it is drawn off at the bottom of the retort it is at the carbonizing temperature, and the time consumed in removing the finished work and replacing it with new is so short that the granular carbon does not cool down to a temperature below 1500 degrees F. Thus, it retains its mobility and flows around the work. An operator on top of the furnace might assist this flow by using iron rods that can be inserted into the retort through holes in the cover.

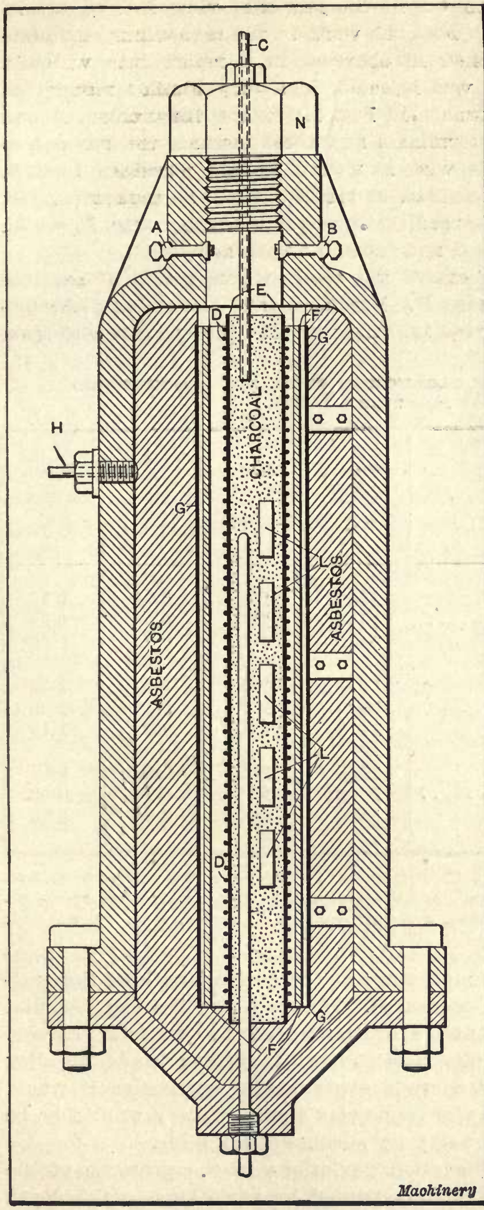


Fig. 2. Carbonizing with Compressed Carbonaceous Gas, using Electric Heating Means

When the retort is properly filled, butterfly valve *P* is closed and tank *L* is lowered and wheeled to its position underneath the muffler. The work is then allowed to stand until the carbonizing temperature has been reached. In the meantime, pipe *M* has been screwed into position, and when the carbonizing temperature has been reached, the carbonaceous gas is injected into the retort through this pipe. While the work in the retort to the left is being carbonized, the retort to the right can be emptied and filled, without in any way disturbing the process in the other.

Another method that has been tested by the designers of this furnace is that of compressing the carbonizing gases, and some very good results have been obtained. The tests demonstrated that when carbon monoxide acts on ordinary steel in the presence of free carbon, as in the furnace shown in Fig. 1, an increase in the depth of carbonization will be obtained with an increase of the pressure on the gas, and there will also be an increased concentration of carbon within the carbonized zone.

In carrying out some experiments of this nature, a cylindrical retort was used, like that shown in the sectional view in Fig. 2. In this, electricity was used to heat the work to the carbonizing temperature. The work was packed in charcoal in a retort into which a current of carbon dioxide was injected, in a very similar manner to the method used in the furnace in Fig. 1. In the illustration, *A* and *B* are the clamps for the terminals and these conduct the current to nickel-wire spiral *D*. This wire is wound around porcelain tube *E*, which can easily be inserted into, or taken out of, the apparatus. By taking off nut *N*, tube *E* is readily slipped into fireclay tube *F*, which is surrounded by steel tube *G* and insulated with asbestos.

The carbon dioxide gas enters the retort through tube *C* and the used gas escapes through pipe *H*. Porcelain tube *I* contains a thermo-electric couple that is inserted into the retort at the opposite end from

TABLE II. RESULTS OF CARBONIZING STEEL WITH COMPRESSED GAS FOR THREE HOURS

Kind of Steel	Carbonizing Temperature, Degrees F.	Pounds Pressure of Carbonizing Gas	Percentage of Carbon at a Depth of	
			1/64 Inch	1/32 Inch
Nickel steel *	1600	235	0.71	0.12
	1775	235	0.99	0.29
	1650	400	0.73	0.36
Chromium steel †	1750	235	2.22	1.03
	1925	235	3.10	1.39
	1875	400	2.37	1.40
Chrome-nickel steel ‡	1525	235	0.45	0.54
	1650	235	0.76	0.49
	1525	400	0.54	0.56

* Composition in per cent: Nickel, 5.02; carbon, 0.118; silicon, 0.20; manganese, 1.53.
† Composition in per cent: Chromium, 2.33; carbon, 0.41; silicon, 0.15; manganese, 1.02.
‡ Composition in per cent: Nickel, 3.17; chromium, 1.5; carbon, 0.33; silicon, 0.06; manganese, 1.15.

gas tube *C*. With it the temperature of the entire length of the case-hardening chamber can be measured. Blocks *L* are the experimental pieces to be carbonized, and are surrounded by granular carbon. Table II shows some results obtained with various kinds of alloy steels. While this is only a crude experimental apparatus, it would seem to suggest some ideas or principles that can very profitably be used for carbonizing steel parts on a commercial scale.

Definite proof was obtained that variations in the pressure of the carbonizing gas were always accompanied by variations in the depth of carbonization, and also in the percentage of carbon in the carbonized zone. It was found, however, that when the pressure was too high it would cause an oxide to form on the steel and this was more pronounced with chromium and manganese steels than with others. It was also found that as the carbonizing temperature was raised, the pressure could be increased without causing this oxide to form. Thus, the higher the carbonizing temperature, the higher can be the pressure used on the carbonizing gas, with an absolute assurance that no oxidation will take place.

A rod of soft steel, 2⅜ inches in length and three-eighths inch in diameter, was casehardened for about three hours by heating three-fourths of an inch of its central portion to about 1800 degrees F. and allowing this temperature to decrease towards the two ends, so that at these the temperature was about 900 degrees F. Unmistakable carbonizing took place in all portions that were above 1450 degrees F. The surface was absolutely unaltered in the hottest portion in the center, which was also the most intensely carbonized, while a distinct layer of oxide was seen in the cooler portions, this oxide thickening as the temperature lowered towards the ends.

Such good results were obtained by compressing the carbonizing gas as it was injected into the bed of charcoal in which the work was packed in the retort, that this method promises to become a commercial success. While the mixed agent, carbon monoxide and charcoal, increased both the speed of penetration and the percentage of carbon in the carbonized zone over all previous methods or materials used for carbonizing steels, compressing the carbon monoxide has still further increased these factors. Like all methods and processes, however, it must be handled properly. The amount of compression, as well as the carbonizing temperature, varies with different kinds of steels. Therefore, these must be discovered and properly adjusted, if work is to be turned out that is free from oxide and scale, and that has the desired penetration uniformly distributed over all portions of the exposed surfaces.

Whether work is carbonized with an ordinary flow of carbon dioxide into and through the charcoal, or by compression, the advantages which vertical muffles, as shown in Fig. 1, have over horizontal muffles are in the greater speed of charging and removing the work, due to the greater simplicity of the operations, the uniformity of the treatment of all pieces forming the charge, and the more uniform distribution of the carbonizing gases, due to the spaces being reduced to a minimum.

Time Required for Operation

The time for the various operations with the furnace shown in Fig. 1 is as follows: Charging the pieces to be carbonized, from 1 to 5 minutes, according to their size and shape; completely filling the retort with granular carbon, from 1½ to 4 minutes; lowering ram *K*, replacing pipe *M*, removing tank *L*, and closing down cover *R*, 1 minute; drawing the granular carbon from retort *C* into tank *L*, 4 minutes; raising ram *K* and removing the work from the retort, 2 minutes. The time consumed in all the operations, where ordinary work is being handled would, therefore, be about ten minutes, but with specially shaped pieces and unfavorable conditions, this time might be extended to 30 minutes.

By pre-heating the work to a carbonizing temperature before putting it into the retort, no time will be lost in fully heating it in this furnace. The temperature of the granular carbon can then be maintained nearly up to the carbonizing temperature, as it will not be chilled by cold work. The process can thus be made strictly continuous. Under these conditions, a depth of carbon penetration of 1/32 inch can be given the work in one hour, and of 1/16 inch in two hours. Thus it will be seen that from 1¼ to 2½ hours is all that is required for the complete carbonizing operations in one retort.

By using gas for fuel and gas for carbonizing, the work can be controlled within closer limits than with any other process, unless it should be an electric one, and the arrangements of this furnace are such that its capacity for producing work is greater than that of any furnace which has been designed with the same size of work holder. If there is not enough work to keep both muffles going on pre-heated work, one of the muffles can be used as a pre-heating furnace, while the other is doing the carbonizing. By alternately using the muffles for preheating and carbonizing, an amount of work will be turned out that will compare favorably with any other casehardening furnace. If desired, the current of carbonaceous gas can be used for a whole or any given part of the carbonizing time, and thus the results obtained can be made to cover a wide range. Where localized casehardening is required, the granular carbon can be drawn off until only enough is left to insure the chemical equilibrium in the gas, and by thus isolating the carbon monoxide, it will intensify its specific action.

American Gas Furnace Co.'s Apparatus for Casehardening by Gas

The casehardening process described on the preceding pages is intended for specially large work. The American Gas Furnace Co. has brought out a casehardening plant, using gas as the carbonizing material, which is suitable for small and medium work. Briefly stated, the process as performed by the apparatus brought out by this company consists in placing the work in a slowly revolving, properly heated, cylindrical retort into which the carbonizing gas is injected under pressure. From the gas, the work absorbs the volatile carbon. The absorption of carbon begins as soon as the work is sufficiently heated to attract it, and continues throughout the process, because the work is constantly and uniformly exposed to a carbon charged atmosphere under pressure, instead of to solid carbonaceous material which turns to ashes wherever it is in proximity to the heated parts. All the parts of the same piece of work and all the pieces contained in one charge in the retort are, therefore, continuously subjected to exactly the same condition as regards the presence of carbon, and the result is a uniformity and speed of operation not obtainable by other methods.

The complete gas casehardening plant consists of a generator of carbonizing gas and revolving retorts used for the carbonizing process.

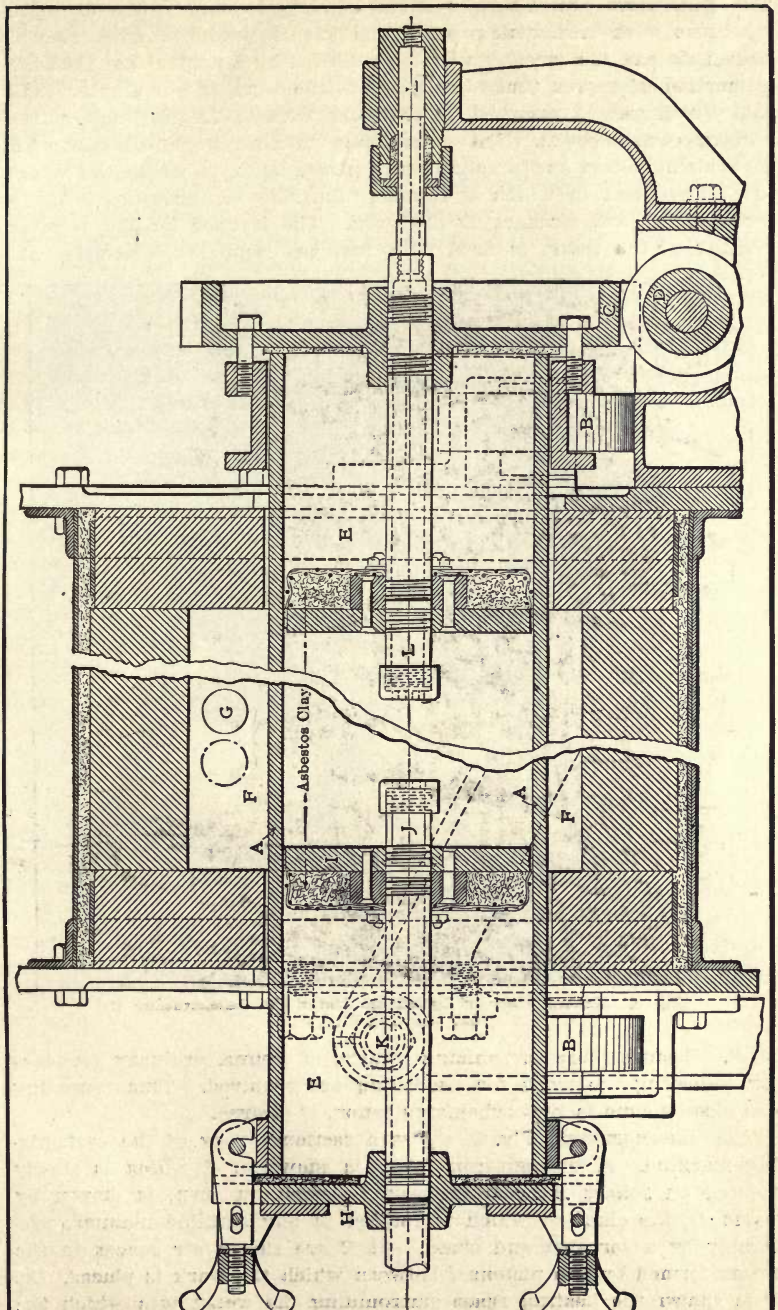


Fig. 3. Revolving Cylindrical Retort brought out by the American Gas Furnace Company for Casehardening by Gas

The generators are generally made in sizes to supply two or more machines with carbonizing gas. The gas is produced from refined petroleum and the carbon vapor is so diluted by a neutral gas that the proportion of carbon that is supplied to the work is not greater than that which can be absorbed by the work without forming obstructive carbonaceous deposits. The carbonizing machine proper consists of a carbonizing retort and a cylindrical furnace body, in which the retort is enclosed and in which it rotates. Suitable arrangement is made for charging and discharging the work. The furnace for the exterior heating of the retort is fired with fuel gas requiring a positive air

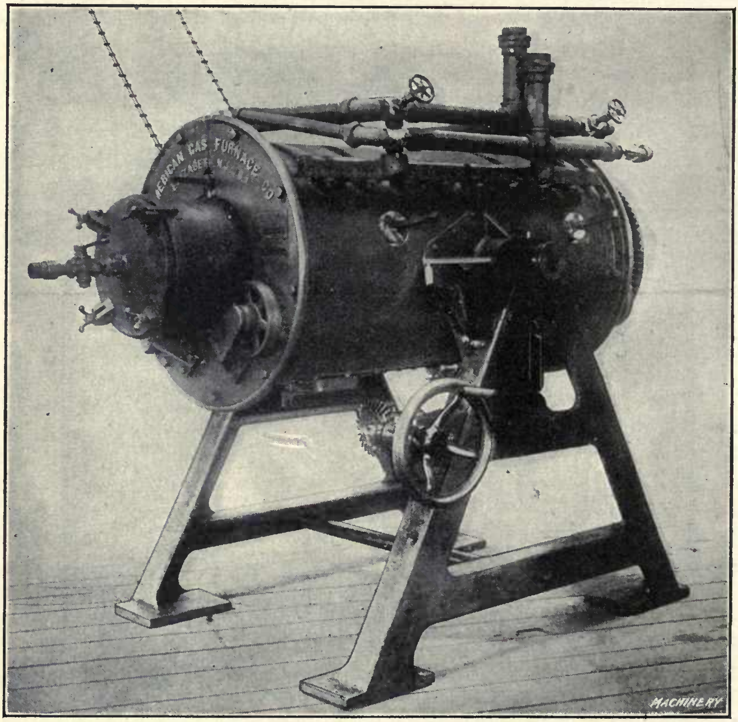


Fig. 4. General View of Cylindrical Retort for Casehardening by Gas, shown in Fig. 3

blast. Besides these carbonizing retorts, of course, ordinary furnaces for reheating the work for hardening are required. This reheating can also be done in the carbonizing retort, if desired.

The line-engraving, Fig. 3, shows a sectional view of the carbonizing machine. A wrought-iron retort is shown at *A* which is slowly rotated on rollers *B* by worm-gear *C*, which, in turn, is driven by worm *D*, the shaft of which is rotated in any suitable manner, preferably by a sprocket and chain. At *E* are shown air spaces in the retort formed by two pistons *I* between which the work is placed. At *F* is shown the heating space surrounding the retort into which the fuel gas and air are injected under pressure from two rows of burners, indicated in the upper half of the casting at *G*. The cover *H* closes the retort. It is connected to the piston *I* by pipe *J*, which also provides a vent for the retort. Cover *H* and this pipe are withdrawn to charge and discharge the retort, and are replaced after the work is inserted, before beginning the carbonizing process.

Steel to Use for Gas Casehardening

For casehardening by the gas method, it has been found that articles made from machine steel containing from 0.12 to 0.15 per cent carbon give the best results, although steel containing from 0.20 to 0.22 per cent carbon may also be used to advantage. The length of time that the work is required to remain in the carbonizing retort depends upon the depth of carbonized surface required. A thin shell will be produced in one hour, while the thickness will constantly increase if the work is left in the retort up to nine or ten hours. The treatment after the work is carbonized is the same as that which should be given to ordinary casehardened work. As already stated, it is rarely the case that work is properly hardened, if quenched directly from the carbonizing retort, but, as a general thing, it should be allowed to cool slowly and then be reheated to harden the carbonized surface at the proper hardening heat.

The heat of the retort while carbonizing the work must be varied for different classes of steels, and the proper degree can only be determined by trial. The higher the heat, the quicker the carbon will be absorbed from the carbonaceous gas, but the higher heat tends to make the core coarse. As a rule, about 1500 degrees F. will be found a suitable temperature, and this should not be exceeded unless tests have been made to determine that higher temperature may be used without detriment to the structure of the steel.

The gas casehardening process can be carried out more rapidly and more uniformly than is possible with solid carbonaceous materials. Another advantage is that the volatile carbon will find its way into slots, holes and cavities which could not receive the carbon from the granulated bone or any other solid packing material, and, hence, the uniformity of the product is greater. In many cases, low-carbon steel treated by the gas casehardening process may, therefore, be substituted for tool steel in machine construction.