CHAPTER X

Hardening Steel

ALTERATIONS IN STRUCTURE, INFLUENCE OF COMPOSITION, AND RESULTS
OBTAINED

HARDENING, when applied to steel, is generally understood to mean
the heating of the metal to a high temperature and then plunging it into
a bath for the purpose of suddenly cooling it. While this definition holds
good on most steels, a few alloying materials now used reverse this and
make the metals air-hardening, that is, their hardest and toughest state
is obtained by a slow-cooling process rather than a sudden one.

Two reasons might be assigned for the desirability of hardening steel,
and these are: First, to give the steel a cutting edge such as is required
for all cutting tools, and, second, to alter the static strength and dynamic
qualities of the metal so it will give the best results for the moving parts
of machinery.

In this second case steels may be altered by quenching from a high
temperature and tempering, to an extent that will greatly improve their
wearing qualities, tensile strength, elastic limit, magnetic qualities, or
resistance to shock, and yet not be capable of attaining a hardness that
will not allow a file to cut it; this being the usual test of hardness applied
in the shop. Thus, generally speaking, all steels may be hardened,
although some may have a low carbon content.

To harden steel, therefore, it is necessary for the heating to produce
a change in the structure, and the quenching, which follows the heating,
retains a whole or a part of the changes produced by this change of struc-
ture. It is therefore necessary, as in annealing, that the temperature of
the steel be raised to a point slightly above the point of transformation
or recalescent point.

As the point of transformation varies with different ingredients which
are alloyed with steel, it is necessary to find out where it is in the
steel to be hardened. A steel may be heated to 1300° F. — which is
above the point of transformation in some steels — and no change in
structure will take place, and therefore no results in hardness will be
obtained. If the same piece is heated to 1650° — which we will consider
the point of transformation in this piece — the intermolecular transforma-

tion, which consists of the passage of the carbon from the combined into
the dissolved state, will take place and the steel will assume the hardest
state it is capable of, if properly cooled.

Thus the factors that have an influence on the results of hardening
are: First, the nature and composition of the metal; second, the tem-
perature of the metal when quenched, and, third, the nature, volume,
and temperature of the quenching bath.

MICROSCOPICAL EXAMINATION

The nature of these different factors is shown to a large extent by
quenching the metal at different temperatures, polishing the surface,
attacking it with picric acid, tincture of iodine, hydrofluoric acid, or
any other etching materials and examining it under a microscope.

FERRITE. — Steel containing less than 0.85% carbon will show small
dark masses, if etched with picric acid, which are the more numerous
the closer the carbon content is to 0.85%. At this percentage they cover
the entire surface. These masses show alternate layers which are fer-
rite — pure iron — and an iron carbide called cementite. The ferrite
being the softest constituent of steel, it will indent when polished and
the cementite will stand out in relief.

Ferrite is the carrier for all of the alloying elements in the high-grade
steels. It is the principal constituent of all steels and the predominating
one in low-carbon steels. It has one peculiarity which is very important,
and that is, that when heated to about 1400° F. it undergoes a sudden
change which is shown by its absorption of heat. It then loses its power
to attract a magnet as well as changing its specific heat and several other
properties. No alteration, however, takes place in its chemical com-
position.

At 1550° F. it again shows changes by absorbing heat and its prop-
erties are again changed. (See chart 1, page 67.) Its electrical conduc-
tivity has changed and also its crystalline form. These changes occur both
in the rise and fall of the temperature, and have been called by different
metallurgists the points of transformation, the recalescence points, and
the critical temperatures; all of which mean the same.

Ferrite is shown in Figs. 111, 112, 113, 114, and 117.

CEMENTITE is the carbide of iron, and is expressed by the following
formula: Fe_3C, which means ferrite — which is pure iron — 3 atoms
for every one atom of carbon. It is the second constituent in importance
in steel — ferrite being first — and is very hard and brittle. Practically
all of the carbon is present in this form, and it usually crystallizes in
thin flat plates. Cementite does not exist in pure iron, which contains
no carbon, and of itself contains about 6.6% of carbon, which is about

one-fifteenth of it. Two extremes of cementite formation are shown in Figs. 111 and 112.

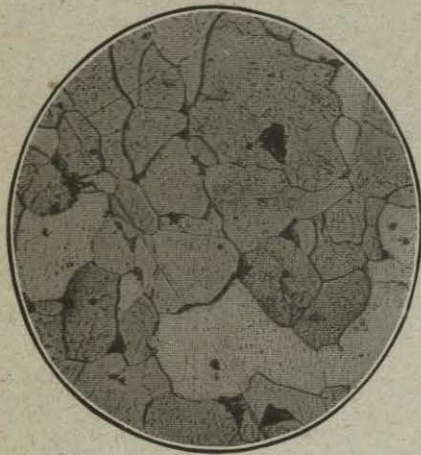PEARLITE. — Pearlite is an intimate mixture of ferrite and cementite

FIG. 111. — Ferrite with very thin continuous cementite skeleton. Low carbon. Magnified 250 diameters.
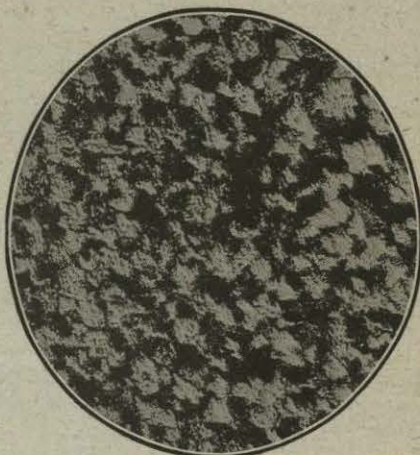
FIG. 112.—Ferrite, white. Cementite, black. Magnified 250 diameters.

in the definite proportions of 32 parts ferrite to 5 of cementite, equivalent to .85% carbon. It has the appearance of mother of pearl, from which
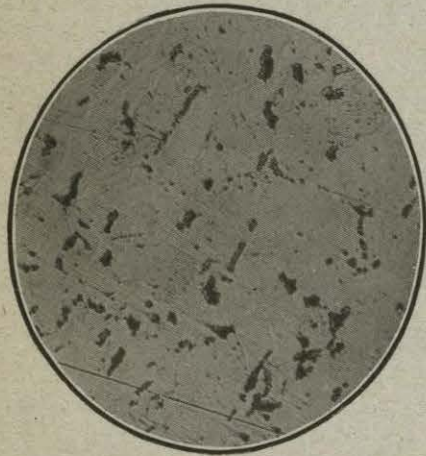
FIG. 113. — Ferrite matrix with separated pearlite islands. Magnified 250 diameters.
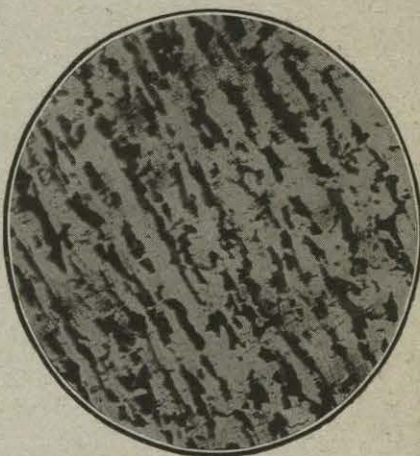
FIG. 114. — Ferrite, white. Pearlite, black. Magnified 250 diameters.

it derives its name. It exists in a lamellar formation, which is alternate plates of ferrite and cementite, or in a granular formation, which is inter-

mingling grains of ferrite and cementite. A normal steel, containing 0.85% carbon, consists of 100% pearlite; below this carbon content it contains pearlite and excess ferrite; while if the total carbon exceeds 0.85% the constituent excess would be cementite instead of ferrite. Pearlite is shown in Figs. 113 and 114.

MARTENSITE AND HARDENITE. — Leaving the steels that have been cooled slowly, and taking up those which have been quenched from a given temperature, and hardened, we find that a steel containing about 0.85% carbon, if heated to about 1400° F. and quenched, will show under the microscope extremely fine lines intersecting each other in the direction of the sides of an equilateral triangle. This constituent has been named martensite in honor of Professor Martens. It is the principal constituent of all ordinary hardened steels that have a carbon content above 0.16%, and tempered steels owe their quality of hardness to it. It is so hard that a needle will not scratch it after the metal has been polished.

In steels containing over 0.85% carbon the martensite is said to be saturated and shows slightly different under the microscope. This has been called hardenite by some, which word is often used in French and German books.

Martensite is shown in Figs. 115 and 116.

SORBITE is a constituent between martensite and pearlite, and chiefly differs from pearlite by the constituents not quite perfectly developing. This is drawing the line pretty fine, but the sorbitic structure is finer than the pearlitic, and it is considered the extreme opposite of the crystalline structure. The sorbitic structure is considered necessary in metals that have to resist wear and erosion, and the natural formation of this structure is rendered possible by the addition of certain alloying elements. In hardened steel, sorbite is considered as the transition from martensite to pearlite.

The sorbitic structure may be obtained when the cooling is not as rapid as that of quenching, but still much faster than the slow cooling for annealing; by quenching immediately below, or just at the end of cooling through the critical range; by cooling pretty fast through the critical range without actual quenching; or by rapidly cooling the steel and then reheating to about 1100° F. Sorbite is not clearly defined in micro-photographs, but Fig. 117 shows it fairly well, with ferrite.

AUSTENITE. — High-carbon steels that contain over 1.10% of carbon and are suddenly cooled from a temperature of 2000° F. will show a constituent, in addition to martensite, which may be distinguished from it by a different color. If etched with nitrate of ammonia, or with a 10% solution of hydrochloric acid, it will show white. This constituent is

softer than martensite, and is easily scratched with a needle. It is essentially a solid solution of carbon in gamma iron. It has been named austenite after Prof. Robert Austen.
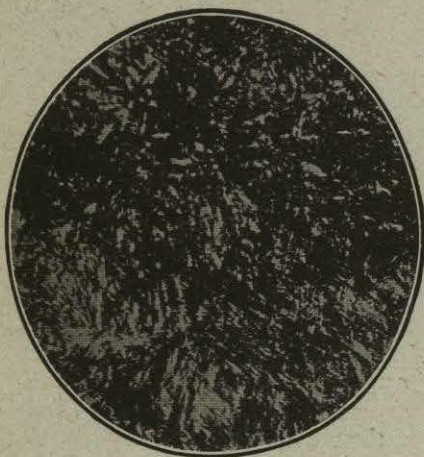

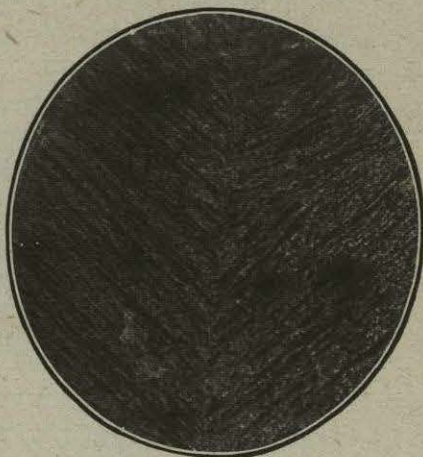FIG. 115. — Martensite formation. Magnified 250 diameters.

FIG. 116. — Martensite. Magnified 200 diameters.

Austenite is difficult to preserve throughout the whole structure of the steel. Quenching in a bath that has a temperature below the freezing point, or any other means which will cool it rapidly, will aid in preserving

FIG. 117. — Ferrite and sorbite. Magnified 250 diameters.

FIG. 118. — Austenite, white. Troostite, black. Magnified 50 diameters.

it. Tempering the metal afterward, however, loses the austenite, and it is not of much practical use owing to the high temperature at which it is obtained. Fig. 118 shows the austenite formation.

TROOSTITE. — If the steel is quenched during or just above its transformation in a bath of little activity, such as oil, or if it is hardened in the usual way, and then tempered, we obtain a constituent which will show jet black if polished and etched with picric acid, or if etched with a tincture of iodine it will show white. This has been named troostite in honor of Prof. M. Troost.

Troostite is also softer than martensite, as it can be scratched with a needle. It is a transition product between martensite and sorbite, and is found plentifully in tempered steels as it is a product of the usual tempering operations. It shades gradually into the sorbite, but is very sharp in its divisions from martensite. Troostite is shown black in Fig. 118 and white in Fig. 119.

FIG. 119. — Martensite, black. Troostite, white. Magnified 350 diameters.

In subjecting steel to different heat treatments we can change the constituents from pearlite to martensite or hardenite, sorbite, austenite, and troostite, and back again through these different stages, and by examining them with the microscope we can judge very closely the treatment they have been subjected to.

By making these changes we also change its constitution, its static strengths, and its dynamic properties. This is where the practical application of this knowledge aids the engineer or designer in designing the moving as well as other parts of machinery so as to get the best results from the smallest quantity of material.

EFFECT OF COMPOSITION AND HARDENING

The constitution of a given steel is not the same in the hardened as in the normal state, owing to the carbon not being in the same state. In the annealed or normal steel it is as cementite, while in a hardened

steel it is in a state of solution, which we may call martensite; and this contains more or less carbon according to the original carbon content of the steel. The composition, and therefore the mechanical properties, depend principally upon the carbon content, the mechanical properties being changed slowly and gradually by an increase in carbon.

TABLE 1.   COMPOSITION

	Carboniz- ing Steel	Very Low Carbon	Low Carbon	Medium Carbon	High Carbon	Very High Carbon
Carbon..................	0.10	0.14	0.23	0.52	0.60	0.72
Silicon..................	0.09	0.05	0.15	0.18	0.10	0.17
Manganese..............	0.19	0.33	0.45	0.35	0.40	0.38
Phosphorus	0.016	0.023	0.091	0.021	0.035	0.03
Sulphur.................	0.025	0.052	0.062	0.043	0.025	0.06

MECHANICAL PROPERTIES WHEN ANNEALED

Tensile Strength (in pounds per square inch)........	60,300	61,500	66,500	97,800	116,400	130,700
Elastic Limit (in pounds per square inch)	36,300	35,200	41,200	52,600	66,500	75,800
Elongation (percentage in 2 inches)	29	27	26	20	14	9

MECHANICAL PROPERTIES WHEN HARDENED

Tensile Strength (in pounds per square inch)........	66,400	73,100	99,400	132,100	153,400	180,100
Elastic Limit (in pounds per square inch)	40,300	39,600	54,000	81,400	102,100	105,500
Elongation (percentage in 2 inches)	24	22	14	9	4	0

EFFECT OF COMPOSITION AND HARDENING ON THE STRENGTH OF CARBON STEEL

This is best shown by the above table , in which it will be seen that the tensile strength and elastic limit gradually increased with the increase in the percentage of carbon, both in the annealed and hardened state, while the elongation gradually decreased. These tests were made with a bar ½ inch in diameter and 4 inches in length. It will also be seen that there was considerable change in the steels that were too low in carbon to be made so hard that they could not be filed. The reduction in elongation when the test bars were heated and quenched showed that the metal was harder than when in the annealed state.

A hardening process that will produce a steel that is as homogeneous

as possible is always sought for in practice. This is easily obtained in a high-carbon steel, and especially if it contains 0.85% carbon, by passing the upper recalescent point before quenching. The desired homogeneity is not so easily obtained, however, in the low-carbon steels as they have several points of transformation. If these are quenched at a point a little above the lowest point of transformation, the carbon will be in solution, but the solution is not homogeneous. To obtain this result it is necessary that the quenching be done from a little above the highest point of transformation. This is higher in low- than in high-carbon steels. In practice this calls for a quenching of the low-carbon steels at about 1650° F., while a high-carbon steel should be quenched at about 1450°.

The degree of temperature, above the critical point, to which steel can be heated in practical commercial work and still give good results is also quite important. If a piece of steel be quenched from different temperatures above the point of transformation and examined under a microscope we find that the higher we go the coarser will be the martensite, and the lines will be more visible. If we raise this temperature a few hundred degrees above the critical point and quench in a very cold bath, austenite makes its appearance. In regard to the mechanical properties the higher the temperature above the critical point the lower will be the tensile strength and the less will be the hardness of the steel. The elongation will also show a decrease and this will mean that the steel becomes more brittle with each increase in the temperature.

This coarsening of the martensite, the reduction of both the tensile strength and elongation and the crystallization spoken of some few paragraphs back, have led to the conclusion that, in practice, 40° F. above the highest point of transformation is the extreme limit that steel should be raised to obtain the best results in hardening. The same figure also holds good for annealing.

The following results are obtained in hardening steel: All steels may be hardened, but if the carbon content is over 0.30% the effect is more pronounced. Hardening increases the tensile strength and elastic limit and reduces the elongation, the effect being greater the greater the carbon content. Quenching at the proper temperature gives the metal a greater homogeneity and this aids the resistance to shock, especially in low-carbon steels; steel should not have the hardening temperature raised more than 40 degrees above the highest point of transformation, as beyond that it no longer has the same qualities.

BATHS FOR HARDENING

As it is necessary to maintain the metal in the state it was at the moment quenching begins, the quenching bath is a very important part of the process of hardening. The rate of cooling is never swift enough

to secure perfection, and the intermolecular transformation will be more or less complete according to the rate of cooling. The better the bath the nearer to perfection we will be able to arrive.

The baths for quenching are composed of a large variety of materials. Some of the more commonly used are as follows; they being arranged according to their intensity on 0.85% carbon steel: Mercury; water with sulphuric acid added; nitrate of potassium; sal ammoniac; common salt; carbonate of lime; carbonate of magnesia; pure water; water containing soap, sugar, dextrine, or alcohol; sweet milk; various oils; beef suet; tallow; wax. These baths, however, do not act under all conditions with the same relative intensity, as their conductivity and viscosity vary greatly with the temperature, and their curves of intensity are therefore very irregular and cross each other frequently. Notwithstanding the many special compounds that have been exploited for hardening, there are no virtues, or hardening and toughening properties, in any quenching bath beyond the degree of rapidity with which it conducts the heat out of the piece being quenched.

With the exception of the oils and some of the greases, the quenching effect increases as the temperature of the bath lowers. Thus water at 60° will make steel harder than water at 160°. Sperm and linseed oils, however, at all temperatures between 32° and 250° F., act about the same as distilled water at 160°. The influence of the bath depends upon its nature, its temperature, and its volume; or, in other words, on its specific heat, conductivity, volatility, and viscosity. When the bath is in constant use, the first piece quenched will be harder than the tenth or twentieth, owing to the rise in temperature of the bath. Therefore, if uniform results are to be obtained in using a water bath, it must either be of a very large volume or kept cool by some mechanical means. In other words, the bath must be maintained at a constant temperature.

In Fig. 120 is shown the effect of different hardening temperatures on the tensile strength and elongation when quenching in different baths. These tests were made at the Watertown arsenal.

The mass of the bath can be made large, so that no great rise in temperature occurs by the continuous cooling of pieces, or it can be made small, and its rise in temperature used for hardening tools that are to remain fairly soft. If this temperature is properly regulated, the tool will not have to be reheated and tempered later, and cracks and fissures are not as liable to occur. A lead bath, heated to the proper temperature, is sometimes used for the first quenching. Another way of arriving at the same results would be to use the double bath for quenching, that is, to have one bath of some product similar to a salt which fuses at 575° F. Quench the piece in that until it has reached its temperature, after which it can be quenched in a cold bath or cooled in the air.

The specific heat of the bath is an important factor, as the more rapid the cooling from 1650° to 200° F., the more effective will be the hardening process. A bath that consists of a liquid which volatilizes easily at the highest temperature it reaches, from plunging the metal into it, forms a space around the steel that is filled with vapor, and this retards the further cooling action of the liquid. The motion of the bath will throw off these vapors as it brings the liquid in contact with the metal and tends to equalize the temperature. The agitation of the piece to be hardened
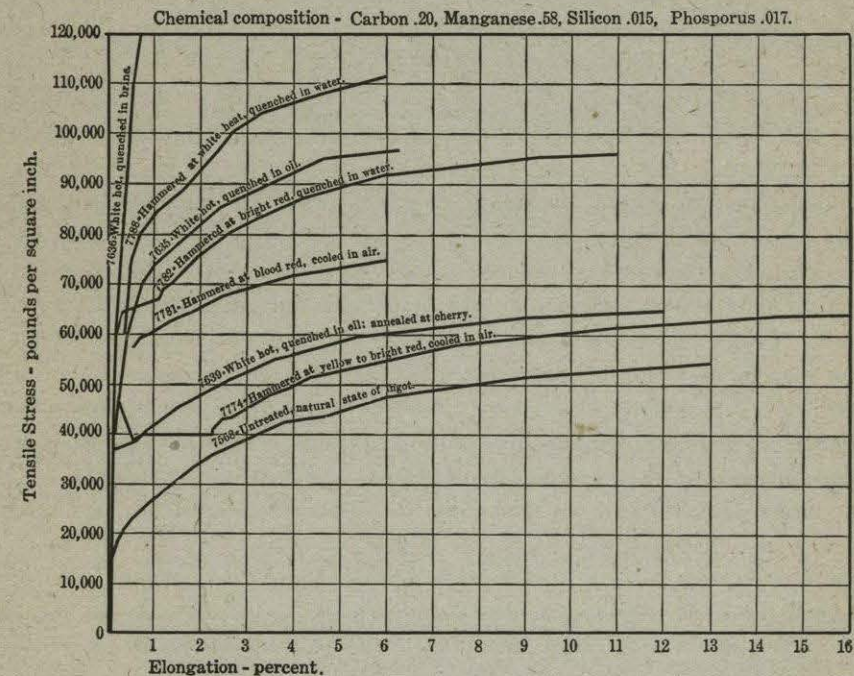

FIG. 120. — Effect of heat and mechanical treatment on the tensile stress and elongation.

will give better results than trusting to the motion of the bath, as it is more energetic in distributing the vapors.

The viscosity of the bath has an influence on the phenomenon of convection, which is the principal means of the exchange of heat; the higher the viscosity the less its hardening effect.

The conductivity of the bath has its effect on the exchange of heat between the piece to be hardened and the bath; therefore the greater the conductivity the more quickly the metal cools.

As a rule little account is taken of the specific heat of the bath, but it is an important factor. As soon as the heated metal is plunged into

the bath, the liquid begins to heat. The number of calories necessary for raising the temperature of the liquid a certain number of degrees will be the greater the higher the specific heat. Thus the cooling of the metal will heat the bath less the higher the specific heat of the latter, and consequently a bath is the more active the higher its specific heat. The less rapidly the equilibrium is established between the hardening bath and the metal quenched in it, the more active will be the bath.

The specific heat of mercury is much less than that of water, and the cooling of quenched steel is three times as rapid in water as in mercury. The hardening effect is therefore much lower than that of water, but surface cracks and fissures are not nearly as liable to occur.

METHODS OF KEEPING BATHS COOL

The baths, for hardening, that give the best results are those in which some means are provided for keeping the liquid at an even temperature. Of course, where but few pieces are to be quenched, or a considerable time elapses between the quenching of pieces, the bath will retain an atmospheric temperature from its own natural radiation. Where a bath is in continuous use, for quenching a large number of pieces throughout the day, some means must be provided to keep the temperature of the bath at a low, even temperature. The hot pieces from the heating furnace will raise the temperature of the bath many degrees, and the last piece quenched will not be nearly as hard as the first.

When plain water is used it is easy to keep the bath cool by providing it with a pipe connecting it to the supply main and an outlet into the drain, and thus have a steady flow through the bath. Where a large amount of work is done and the water is paid for at meter rates, as in cities, this might be more expensive than having a large tank at an elevation above the bath and a pump to force the water into it, thus using the water over and over again. This flowing of the liquid would do away with the necessity of agitating the steel in the bath, as when it is of the ordinary stationary kind, owing to the flowing liquid carrying away the coating of vapor which forms around the piece and prevents its cooling rapidly.

A hole in the center of the bottom with an outlet on top is not a very good arrangement, as the cool current, striking the bottom side of the piece, is liable to cause it to warp. If the cool liquid is taken in at the bottom it should be taken in through several openings. A good method is to have the inlet covered with a spherical piece of sheet metal punched full of small holes that would deliver the liquid in fine streams similar to that of a sprinkling can. This would send the cool liquid to all parts of the bath.

A still better arrangement would be to have an extra inner wall with a large number of fine holes punched in the sides and solid at the bottom. This would cause the cool liquid to flow in from all sides, which would give the bath a complete agitation and subject the pieces to less irregularity of temperature, and would therefore reduce the tendency of the pieces to spring or warp from not cooling equally on all sides. A variation
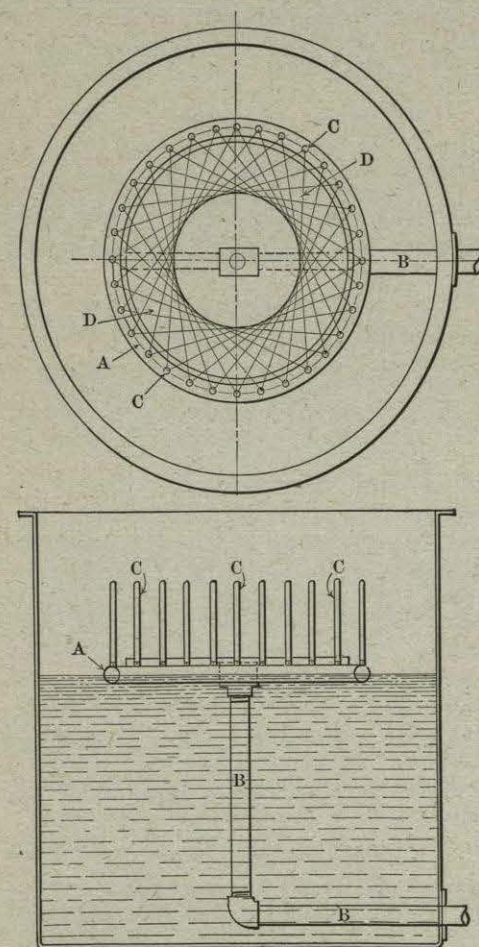

FIG. 121. — Water spray quenching bath.

of this is shown in the spray bath in Fig. 121. In this A is a circular gas pipe, into which is screwed the perforated upright pipes C, C, and B is the intake pipe. The water comes through the fine holes in pipes C, C, and forms a spray on the lines D, D.

With liquids, other than water, this method is not practical owing to the large volume of liquid needed for the bath, and its consequent high cost. Then again the losses from evaporation might be too great. For

this kind of bath a water-jacketed receptacle could be used and a steady current of cold water kept flowing through it, or the bath could be fitted with a coil of rope, over the bottom and around the sides, through which a circulation of cold water could be maintained, and thus keep the bath cool. Another method that has been used successfully is to blow fine sprays of air through the bath from the bottom similar to the method used in the Bessemer converter on molten steel. One way of doing this is shown in Fig. 122.

With many classes of work a bath whose liquid is stationary and has no mechanical means of cooling can be used by having the volume of the bath large enough so that the heat left by the quenching of the pieces is negligible in proportion. Baths of this character are sometimes fitted with conveyors that carry the work through the bath, and out after cooling sufficiently. Some of these also carry the work through a pickling bath after it has been quenched.
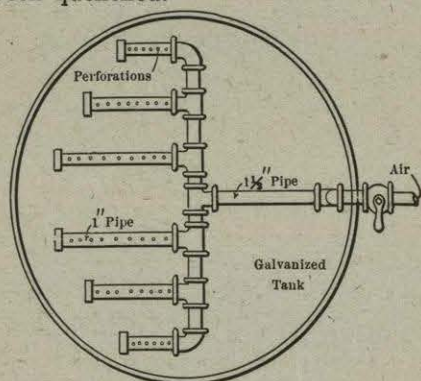

FIG. 122. — Pipes for cooling a quenching bath.

ELECTRICAL HARDENING

There is another method of hardening that is coming into use, and promises some interesting developments in the future. It consists of connecting the piece of steel to the positive and negative wires of an electrical circuit, and inserting it into a quenching bath. The current is then turned on and controlled by a rheostat, so that the metal can be heated to the proper temperature. This takes but a few seconds, and when the correct temperature is reached, the current is turned off and the steel is suddenly cooled or quenched in the bath in which it was heated, without being removed. In one case the bath was made of a solution of carbonate of potash and water. The piece is heated so quickly that is does not raise the temperature of the bath to a degree that retards the hardening effects.

This process prevents the scaling or blistering of the steel, as it is not brought into contact with the air when hot, and hence oxidization cannot take place. It also is capable of many variations, as a piece can be locally heated and hardened in the bath, or annealed in spots by heating it outside of the bath. The piece can also be placed on a copper plate and an electric arc used to heat any desired portion of it. It can then be quenched to harden, or annealed, as desired. In drawing the temper on the inside of a hollow object, a rod can be inserted in the hole and this heated up until the desired color of the steel has been reached and the current then turned off. By noting the amount of current consumed on a few test pieces, it can be regulated, by means of the rheostat, so that uniform results can be obtained on any number of pieces. The possibilities that this method suggests may make it an important factor in the future in heat-treating steels.

CRACKING AND WARPING

Much serious trouble has been caused by cracks and fissures that have been produced by the abrupt cooling of steel. Many times a piece separates abruptly from the part quenched. The reason for this is easily given, as during the cooling different parts of the steel are at different temperatures. This is many times caused by thick and thin sections in the same piece, but it also occurs in pieces of an even thickness, owing to the change in temperature not taking place everywhere at the same time. This causes internal strains, which many times attain enormous value and result in the lessening of the cohesive force that holds the molecules of the metal together. This causes brittleness and rupture at the places so affected.

In practical work the main thing to keep in mind is that these fissures only occur in high-carbon steel or some of the special alloys. There are several ways of overcoming this, and the three which are the easiest to use and most certain in their results are as follows:

First. — When a water-quenching bath is used it may be covered with from $\frac{1}{2}$ to 1 inch of oil, which will reduce the rate of cooling.

Second. — A quenching bath of comparatively small size may be used, in which case the sudden cooling will be followed by a slight tempering effect, caused by the rise in temperature of the bath.

Third. — The piece may be withdrawn from the bath before it is completely cooled. Uniform results are hard to obtain by this last method, owing to the difficulty of judging the temperature of the metal when withdrawn.

Warping may be caused by several factors, the two most important of which are, not having the steel in a proper condition of repose before

it is hardened, and not putting the piece in the quenching bath properly. As any operation of working steel is liable to set up internal strains it is always best after rolling, forging, or machining steel to thoroughly anneal the piece before hardening it. This allows the metal to assume its natural state of repose. In the machining operations the roughing cuts could be taken off, the piece annealed, then the finishing cuts could be given it and the piece hardened. This would also make the steel easier to machine, as the metal is more uniform and in its softest state.

There are several rules that can be followed in hardening a piece of steel to prevent warping, and these rules always assume that the piece has been properly annealed before starting the hardening operations.

First. — A piece should never be thrown into the bath, as by laying on the bottom it would be liable to cool faster on one side than the other and thus cause warping.

Second. — The piece should be agitated, so the bath will convey its acquired heat to the atmosphere, and also destroy the coating of vapor that is liable to form on certain portions, and thus prevent its cooling as rapidly here as in the balance of the piece.

Third. — The liquid of the bath should instantaneously cover the largest possible amount of the surface of the piece when plunged into it.

Fourth. — Hollow pieces, such as spindles, should have the ends plugged, as they could not otherwise be quenched vertically on account of the steam that would be produced in the hole and cause it to throw hot water.

Fifth. — Pieces with thin and thick sections, or of intricate shapes, should be immersed so the most bulky parts would enter the bath first.

Sixth. — To harden one part of a piece only, it should be immersed so that it hardens well beneath the heated part.

Seventh. — Pieces which are very complicated should be rigged up with hoops, clamps, or supports to prevent their warping.

The hardening of large pieces gives somewhat different results as the transformation is not always complete, in which case there is a partial return to the normal stable state, that is, toward pearlite. Thus a small piece quenched from a high temperature in cold water is very hard and quite brittle, while a large piece quenched at the same temperature and under the same conditions is not quite as hard and only slightly brittle. If the large piece is examined with the microscope it would indicate martensite to be present in the surface layer, while at a certain distance below the surface would be seen troostite and sorbite. This would show that the transformation was not as complete as in the small piece and would account for the lower degree of hardness and brittleness.

This might lead one to suspect that the constituents in the center of a large piece were the same as in annealed steel, as the coefficient of expansion and the electrical resistance seem to be the same. From this might

be drawn the conclusion that the mechanical properties of the two steels were not the same. These, however, are not the facts as the strengths and hardness are but little different from those of the small pieces that showed martensite.

On all steels, it is a very good rule that insists on a slow preheating of the metal before it is submitted to the high temperature of the hardening furnace. If followed, this will prevent, to a large extent, the checking, cracking, warping, etc., that is met with so often in the hardening room. To get the best results, low-carbon steels should consume

Fig. 123. — Tempering plate with sheet iron oven.

about one hour in being heated up to a temperature of not less than 600° F.; high-carbon steels should be preheated to about 800°, and some of the special alloy steels, especially high-speed steel, to not less than 1000°. If even a higher temperature than this is reached in the slow heating, it will benefit rather than harm the metal, although at about these temperatures a transformation in the grain of the metals takes place that enables it to be heated more rapidly without any practical injury to the steel.

The preheating need not be made a matter of much expense to a hardening room, as low heat tempering furnaces are nearly always available,

or if not ovens could be placed over the high heat furnaces. One of the simplest arrangements for slowly preheating is the hot plate that is 16 × 24 inches and covered with a sheet-iron oven, as shown in Fig. 123. It has 6 rows of 30 small gas jets underneath the plate, and any desired temperature can be attained in the oven. A small muffle furnace, similar to that shown in Fig. 124, is also very useful for preheating, and this can be used for reheating carbonized work. Both of these furnaces can be easily and successfully used for tempering, and thus the preheating not made an item of expense.
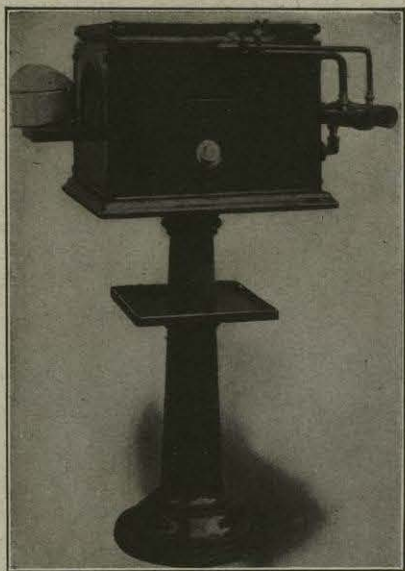

FIG. 124. — Muffle gas furnace.

The principles and practices of hardening are practically the same for the special alloyed steels as for the ordinary carbon steels, except that some of the alloying materials alter the point of transformation.

HIGH-SPEED STEELS

There is one notable exception to this, however, and that is in the case of high-speed or self-hardening steels. These are made by alloying with the steel, tungsten, and chromium, or molybdenum and chromium, or all three. These compositions completely revolutionize the points of transformation. Chromium, which has a tendency to raise the critical temperature, when added to a tungsten steel, in the proportions of 1 or 2%, reduces the critical temperature to below that of the atmosphere. Tungsten and molybdenum prolong the critical range of temperatures

of the steel on slow cooling so that it begins at about 1300° F. and spreads out all the way down to 600°.

These steels are heated to from 1850° to 2450°, and cooled moderately fast, to give them the property known as "red-hardness." Sometimes they are cooled in an air blast, and sometimes they are quenched in various liquids. This treatment prevents the critical changes alto-
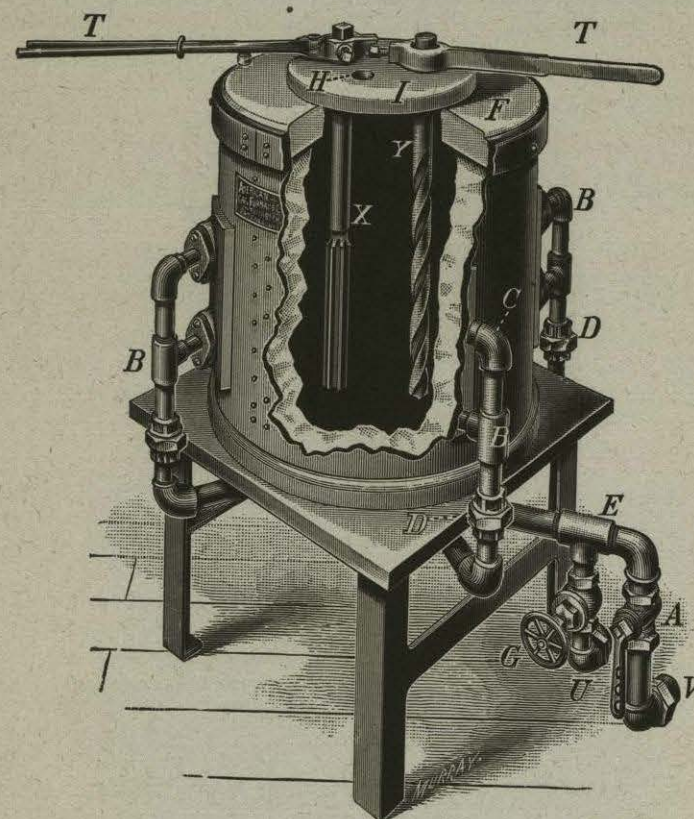

FIG. 125. — Cylindrical gas, hardening furnace.

gether, and preserves the steel in the austenitic condition. The austenitic condition is one of hardness and toughness, and it is peculiar that under this heat treatment the steel is not transformed into the pearlitic condition.

One rule that has given good results in heat-treating some high-speed steels is to heat slowly to 1500° F., then heat fast to from 1850° to 2450°; after which cool rapidly in an air blast to 1550°; then cool either rapidly or slowly to the temperature of the air.

HARDENING FURNACES

The furnaces used for heating steel up to the necessary temperatures for hardening should be so arranged that the oxygen of the air will not attack the metal when it is hot, as then oxygen has its greatest affinity for iron, and will combine with it to form oxides that result in scale blisters, etc. The flame must therefore be a reducing one, that is, contain a deficiency of oxygen so it will not attack the metal, or a retort for holding the work must be used, and this heated from the outside by flames that are not permitted to enter the retort.
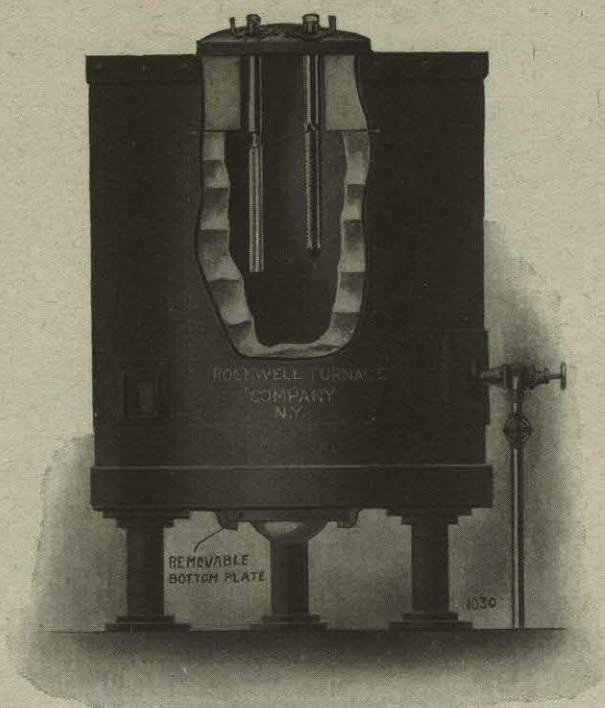

FIG. 126. — Cylindrical oil, hardening furnace.

Many furnaces that are suitable for hardening steel are shown in Chapter VIII, but there are various other styles. On long slender work it is often necessary to heat them, in a liquid or otherwise, with the ends hanging down, and for that reason furnaces of the style shown in Figs. 125 and 126 are the most suitable. These can be made to use either gas or oil for fuel.

When it comes to the high temperatures that are needed for high-speed steel, specially designed furnaces are the most economical. The

furnace shown in Fig. 127 is one of these, and the details of its construction are shown in Fig. 128. A temperature of 2500° F. can be attained in 20 minutes, and maintained at that figure. The blast pressure generally used is about 2 pounds per square inch. Though usually confined to small work, the furnace can be used for long articles, as an opening at the back allows for the introduction of long bars, or drills. Two horizontal burners, each conveying air and gas in concentric tubes, enter the furnace on opposite sides and at different levels. By an arrangement of channels in the lining of the furnace, the flame is given a rotary
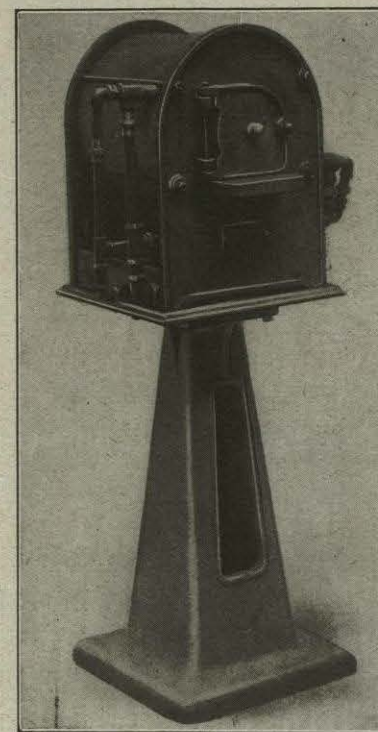

FIG. 127. — Wizard high-speed steel furnace.

motion, with the result that the whole of the interior of the heating chamber is filled with flame, which passes round the circular walls of the chamber, at a high speed, and out through the flues at the back. Hence the products of combustion pass to the exhaust box, that is located under the actual furnace. Through this box pass the pipes conveying the incoming gas and air, so that a regenerative action is set up, and as soon as the furnace is in blast, both the gas and air are preheated.

Another style of high-speed steel furnace is shown by the vertical type in Fig. 129. A movable fire-clay plate, which can be raised or low-
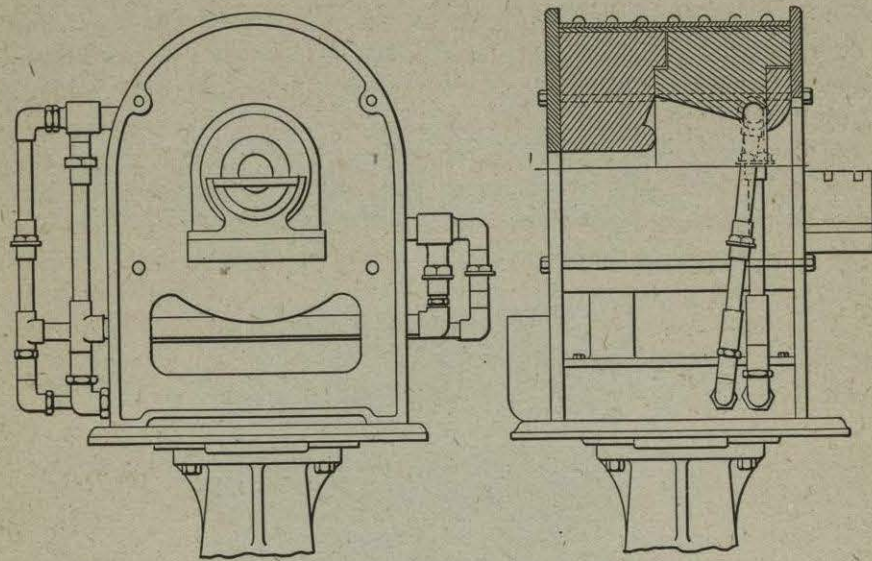
Fig. 128. — Sectional view of wizard high-speed steel furnace.

Fig. 129. — Vertical high-speed steel furnace.

ered by means of a rack and pinion, is used for inserting the work in the furnace. When raised, it forms the bottom of the furnace, by fitting into a circular cavity, and the hardener need not stand in the full glare of the opened furnace while he extracts the tool. It has the flame injected into the heating chamber at an angle so it will be given a rotating motion and thereby heat all parts of the chamber uniformly. As hot gases rise and cold gases descend the temperature of the furnace is not reduced as much when it is opened at the bottom to insert the tools as would be the case with a side or top-opened furnace. For this reason, also, the flame is inserted near the bottom of the furnace. The entire top is a cover that is made of fire-clay and held together by a steel band, with handles for lifting it off. In its center is a small peep-hole with a cover fitted in.