The pyrometer can be used successfully in measuring the temperature of the bath. The temperature of the bath is proportional to the current, and one careful determination with the pyrometer is enough to afterward judge the temperature of the bath entirely by the current.

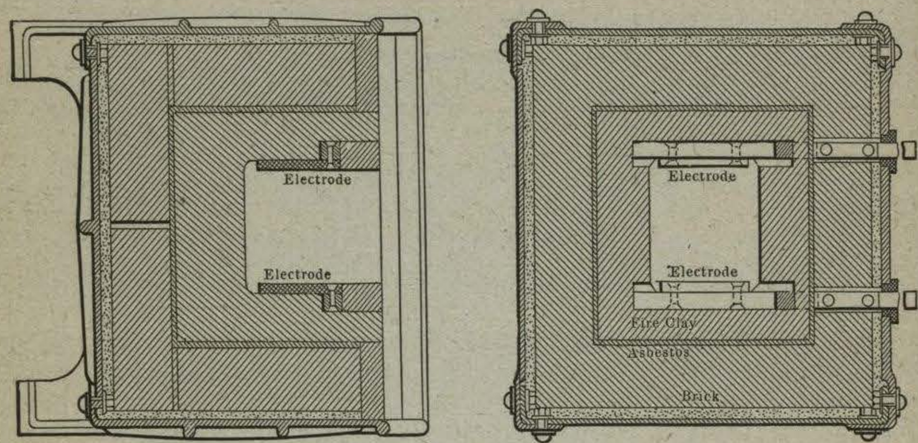

Fig. 108. — Sectional views of electrode furnace.

This style of furnace requires from 15 to 40 minutes to start, according to the size. The cold furnace can be started by passing the current through a piece of carbon until this becomes white hot and melts the surrounding salt, which then becomes conductive and in turn melts the whole mass. When finished using the current is shut off and the salt bath can be kept molten for a long time by putting a cover over it.

CHAPTER IX

Annealing Steel

THEORY, METHODS, MATERIALS USED AND APPLICATION

If the best results are desired from steel, after it has been rolled, forged, pressed, cast, or put into workable shapes in any other way, it should be annealed before any other work is done upon it. This removes the internal strains that are set up in the metal, when working it into the desired shape for future operation, and also softens the steel. It can then be more economically machined with any kind of cutting tools, can be heat-treated in various ways without the danger of cracks forming, and will have greater strength and endurance when put to its intended use.

The annealing of steel consists in carrying it above the temperature at which its highest point of transformation occurs, and then allowing it to cool gradually. This point of transformation is that at which the steel becomes non-magnetic and its physical structure changes. If a pyrometer is used to indicate the temperature of the steel in heating or cooling, it will show a point at which the rapid change in temperature ceases for a time, and the recording chart will show a line nearly at right angles to that of the rise or fall curve. At this point all the molecules have become non-magnetic and a new crystal-size of grain is born. This refines any large or coarse crystals that may have been produced in the steel by former methods of heating or working. This change in structure releases any strains which may have been set up in the metal, and allows them to readjust themselves so that they are equalized throughout all parts of the piece.

This temperature of the point of transformation varies considerably in different steels. This is partly shown by Fig. 109, which was plotted from two recording pyrometer charts. Steels vary more widely than this, however, in their highest recalescent point; it being affected by the various ingredients that are alloyed with the metal.

Another operation, sometimes called annealing, is that of partially destroying the effects of sudden cooling or quenching. In this the annealing temperature is kept below the highest point of transformation. This operation is more properly named tempering, and will be dealt with under that title.

As a general rule all steel should be annealed after every process in manufacturing that tends to throw it out of its equilibrium, such as forging, rolling, and rough machining, in order to return it to its natural state of repose.

When a steel ingot has been poured and subjected to the hammering process, that is often its first mechanical working, there is a tendency of the crystals to crush. This will bring the particles of the metal closer together, but there is a limit to the increase in the density which can be

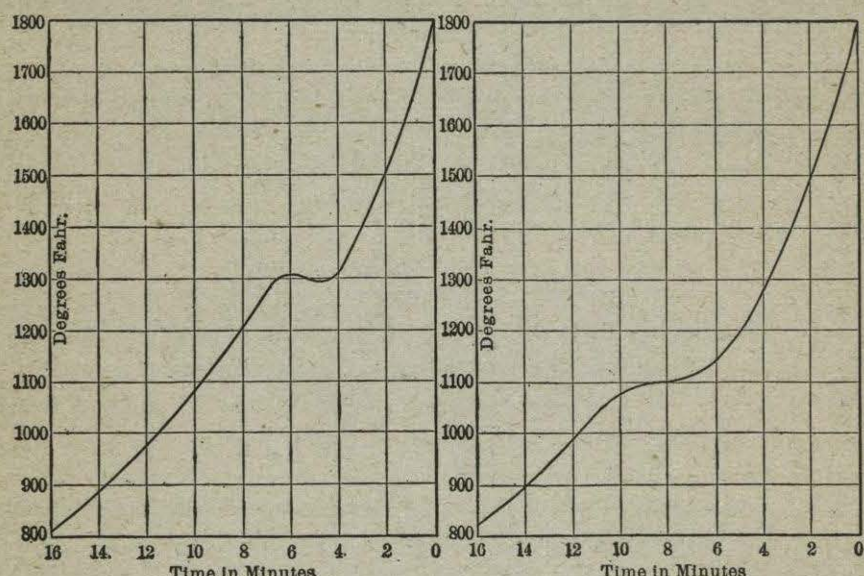

FIG. 109. — Recalescent point curves, plotted from two pyrometer charts.

attained in this manner as a great deformation is eventually given the metal. This metal is called "hammer-hard," and some metals will show about twice the tensile strength after being hammered to the limit of compression that they will when in the normal state.

The limit of compression is difficult to gage, and if passed, as it usually is in practice, the hammering is liable to cause coarser crystals to form where it has squeezed out from under the hammer blows. To remove this crystallization and refine the grain, annealing has to be resorted to, and certain laws have been formulated which hold good on annealing hammered metal, as follows:

First. — Annealing cannot be done instantaneously, but its effects are the greater in proportion to the time consumed. A rapid change takes place at the start, but this is slower and slower as the time progresses, and there is a tendency toward a fixed limit for the decrease in hammer-hardness at each degree of temperature.

Second. — The higher the annealing temperature, the lower will be the limit toward which hammer-hardness tends; in practice the more rapidly will this limit be attained.

Third. — The annealing effects are practically completed when a certain temperature has been reached, and any increase above that does not further reduce the tensile strength as this has reached the lowest point possible for the steel operated on.

The effect called "crystallization of annealing" may start at this temperature and become more pronounced as the annealing process continues. It causes the reduction of area to decrease, and if very pronounced this may become *nil*, together with the elongation, while the tensile strength is much reduced. Another phenomenon might be mentioned here, and that is spontaneous annealing. Thus, if hardened steel be left to itself it will anneal of itself, the only factor entering into this phenomenon being time. As this time, however, covers such a long period and the annealing process is such a slow one the principle is of no importance from a practical standpoint.

From the above may be deduced three practical rules to adopt in annealing steel, these being:

First. — A quenched or hammered piece must be heated to a temperature above its highest point of transformation, but as close to this point as possible.

Second. — This temperature must be retained long enough to allow the entire piece to reach an even temperature, but it must not be prolonged beyond it.

Third. — The rate of cooling must be sufficiently slow to prevent any hardening taking place, not even superficial hardening.

In applying these rules we find that extra low-carbon steel should be annealed at 1650° F., and extra high-carbon steel at 1375°. The time of annealing varies with the size and shape of the piece as well as with the work which it has to perform. The more important this work is, the more prolonged should be the annealing process. Intricate pieces with thin and thick sections have to be handled with extra care, and sometimes materials are brought into use to retard the cooling of the thin section, as ordinarily a thin section will cool quickly in comparison with the thick one, and consequently be that much harder.

To insure slow cooling, when a slow-cooling furnace is not obtainable, the work should be packed in some non-carbonizing material, in an iron box lined with fire-brick similar to the one shown in Fig. 110. The whole can then be heated in a furnace and set out on the floor to cool as the thickness of the materials prevents rapid cooling. This will also tend to prevent the pieces from scaling as they do not come in contact with the oxidizing influences of the atmosphere. When the temperature of the pieces has dropped to 550° F. they may be removed from the box as the annealing process has ceased, and there will be no danger of their air-hardening.

As it is generally agreed upon that steel should not be heated much above the point of transformation in the annealing process it would be well to give the reasons. The nine laws formulated by Prof. H. M. Howe, after many tests by himself and others, cover the ground so thoroughly that they are here given.

First Law. — When a given steel is heated to a temperature above the highest point of transformation the grain assumes a definite size, characteristic of the temperature. We call this the normal size.

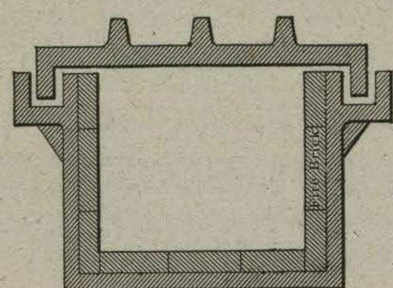

Fig. 110. — Cast-iron box for annealing.

Second Law. — The size of the grain increases in proportion to the temperature, counted from the highest point of transformation.

Third Law. — The influence of the temperature is the more pronounced the greater the carbon content of the steel. In other words, for the same annealing temperature the normal grain of the steel is coarser the greater the carbon content.

Fourth Law. — If a steel is raised to a temperature above its highest point of transformation, and if in consequence of previous treatment the steel possesses a finer grain than the normal, the grain of the metal becomes coarser until it is equal to the normal grain.

Fifth Law. — In order to attain the normal grain for any temperature, the metal must be maintained at this temperature for some time.

Sixth Law. — If the metal is heated to a certain temperature and has assumed the normal grain for this temperature, and if it is then maintained at a somewhat lower temperature, but still above the point of

transformation, the size of the grain is not reduced, provided the metal is not reduced below the point of transformation.

To illustrate this, if a steel is carried to 2200° F.; the grain then becomes of the size characteristic of this temperature; if the temperature is then lowered to 1650° there will be no change in the size of the grain. It would be quite different, however, if instead of cooling the metal directly to 1650°, it had been cooled down to 925°, which is much below the point of transformation, and then reheated to 1650°.

Seventh Law. — If the temperature of a steel remains below the point of transformation its grain does not change.

Eighth Law. — If a steel is cooled slowly after having been heated to above its point of transformation, it possesses substantially the same grain as that which it possessed at the maximum temperature.

Ninth Law. — From this it may be deduced that the grain of a metal, after annealing, is the coarser the higher the temperature to which it has been raised above the point of transformation.

While the relation existing between the annealing temperature and the mechanical properties has not been fully determined, enough is known to establish certain rules that are beneficial in a practical way. A coarse-grained metal is more brittle than a fine-grained, and therefore any change in the size of the grain will affect the strength of the steel. As the annealing temperature affects the size of the grain, a steel that is heated to a variable temperature and slowly cooled will alter its mechanical properties about as follows:

First. — The tensile strength slightly increases with the increase in temperature up to 2375° F., after which it rapidly decreases.

Second. — The elastic limit passes through a minimum at the highest point of transformation, but increases slightly when the temperature passes this point, and then decreases as this point is exceeded by 175° F. The slower it is cooled from the point to which it has been heated the lower will be the elastic limit.

Third. — The elongation decreases as the annealing temperature increases, and this decrease is very important when the temperature attains 2375° F. This makes it necessary to keep the annealing temperature a little above, but as close to the point of transformation as possible.

With these points taken into consideration it will be seen that the annealing of steels cannot be too carefully done if the best results are to be obtained, and especially is this so of the high-grade alloy steels which are being used more and more every day. It has been shown that if the heat treatment is carried out in a manner that will produce sorbite, the tensile strength is much higher and the elongation is slightly greater than when the metal is simply annealed. To obtain sorbite it is necessary to quench above the point of transformation and then reheat to from 575° to 1300° F., according to the composition of the metal and the hardness desired, then cool in air or in water.

APPARATUS FOR ANNEALING

The furnaces used for annealing are the same as those used for other heat-treating operations, unless enough pieces are annealed to install a slow-cooling furnace, and then it is only the accessories that are different. The materials in which to pack the metal are nearly as numerous as the baths for quenching, and where a few years ago the ashes from the forge were all that were considered necessary for properly annealing a piece of steel, to-day many special preparations are being manufactured and sold for this purpose.

The more common materials used for annealing are powdered charcoal, charred bone, charred leather, mica, slacked lime, sawdust, sand, fire-clay, magnesia, and refractory earth. The piece to be annealed is usually packed in a cast-iron box, similar to Fig. 110; using some of these materials or combinations of them for the packing, the whole is then heated in a furnace to the proper temperature and set aside, with the cover left on, to cool gradually to the atmospheric temperature.

For certain kinds of steel these materials give good results; but for all kinds of steels and for all grades of annealing, the slow-cooling furnace no doubt gives the best satisfaction, as the temperature can be easily raised to the right point, kept there as long as necessary, and then regulated to cool down automatically and as slowly as is desired. The gas, oil, and electric furnaces are the easiest to handle and regulate.

As an example of this a maker of high-grade files uses a gas furnace in which to anneal the files, and they are packed in this with the tangs outward. The furnace is heated up and kept at a temperature of 1500° F. for 4 hours, and then allowed to slowly cool during two nights and one day. The flame is from a vaporized naphtha preparation that is free from injurious elements, such as sulphur, and is supplied with a slight undersupply of oxygen, so there will be no danger of its oxidizing the metal. The files are submitted to the direct action of this flame, which fills every part of the heating chamber, so that the end and sides, as well as the center, can be maintained at the same even temperature. By having a constant pressure and volume for the air and gas the flame is easily controlled and is non-oxidizing, therefore there is no pitting or blistering of the files. They do, however, have a very thin scale, that is caused by the air that leaks into the furnace while it is cooling, but this is not enough to do any practical damage.

There is one notable exception to these annealing rules, and that is in the case of Hatfield's manganese steel, which is so brittle when cast

as to be useless. It is toughened, or tempered, by heating and quenching, and is hardened by slow cooling.

While high-speed steel has heretofore been annealed in practically the same way as the carbon steels, and therefore subject to the above rules, it is hardened by rules altogether different from those governing the carbon steels.

A new method of annealing high-speed steel that is a great improvement over this old one has been discovered and perfected by C. U. Scott of Davenport, Iowa, at the Rock Island arsenal. He places the high-speed steel in a furnace that is heated to not over 750 °F., and raises the temperature slowly to 1300° F. He then shuts off the heat and allows both the steel and the furnace to cool to not over 750° F., or to atmospheric temperature if desired. The steel is then reheated to a temperature of 1300° F., and held there for 30 minutes and then cooled in the air.

In this way any high-speed steel that is not over 1 inch square can be annealed in 40 minutes, and it does not take over one hour for large stock. The metal is made as soft and it machines as readily as steel annealed by any other method. Whether the steel is entirely cooled after the first heating or whether the temperature varies a few degrees from the 1300 is immaterial.

Another hardener on trying out this method got his data mixed and obtained the same degree of softness in another way. He heated the steel to a low red, and held the temperature at that point for 30 minutes. He then let it cool down and afterward reheated it and immediately let it cool down until it was at the correct temperature for water annealing and then laid it in the ashes until it was cold enough to handle.