CHAPTER XI

TEMPERING STEEL

METHODS, MATERIALS USED, AND RESULTS OBTAINED

NEGATIVE quenching consists of cooling the metal through the critical zone at a rate equal to or below that which will give to the metal the greatest elongation when cold. This rate of cooling separates the mechanical results of quenching into the two distinct divisions mentioned farther back, namely, that for giving a cutting edge to tools, and that for increasing the static strengths and dynamic qualities. It varies as an inverse function of the carbon content unless the elements used in the special alloys influence it.

Negative quenching gives a tensile strength and elastic limit about equal to that obtained in annealed steel, and produces the highest possible elongation and a high reduction of area. This usually gives the steel the highest obtainable resistance to shocks.

As positive quenching becomes more and more pronounced it increases the tensile strength and elastic limit; at first slowly, then more and more rapidly, and reduces the elongation and resistance to shock in the same ratio. Thus, by variations in the factors governing the activity of the quenching bath, any steel may be given its most suitable state for any given purpose. In fact, all possible methods of quenching are but means of varying the rate of cooling, and the selection of the cooling mediums which will give the desired rate of cooling through each of the critical temperature zones of the metal in order to give it the desired properties is the real art of heat treatment.

Tempering steel, therefore, is to return it in part to a state of molecular equilibrium at atmospheric temperature by relieving any strains in the metal which have been caused by sudden quenching, and to correct any exaggeration of certain properties which have been caused by the hardening process.

The temperature to which a piece should be raised for tempering depends on the use to which it is to be put, the condition in which it has been left by quenching, and the composition of the metal. The maximum temperature desired should only be maintained long enough to be sure that the piece is evenly heated. The martensite which is retained in steel by the sudden cooling has a natural impulse to change into pearlite. By reheating slightly after hardening a certain amount of molecular freedom is given and changes take place that lessen the molecular rigidity set up by the hardening process. The higher the temperature is carried in reheating, the more it will lessen this molecular rigidity, and the more will the martensite give way to a pearlitic formation.

Steels heated to 150° F. will be slightly tempered, but if heated to the temperature at which the straw color is formed on a brightened surface by the appearance of an iron oxide, namely 450°, a greater tempering will result, and the temperature at which this oxide assumes a permanent blue color, namely 575°, will effect a still greater tempering. Each increase in this temperature of reheating reduces the hardness and brittleness, reduces the tensile strength and elastic limit, and increases the elongation as well as the resistance to shocks.

Steels that are not exposed to shock, and require a great hardness so that a fine cutting edge can be given them, such as razors, can have a marked degree of brittleness. A reheating to 450° F. for tempering will be the best condition that such steel can be given. Tools which have to withstand violent shocks such as cold-chisels and still retain a good cutting edge should be reheated to 575° to further remove some of the brittleness. This will lessen the hardness, and consequently the cutting powers, but is the lesser of the two evils. These two cases might be taken as the two extremes of temper desired in cutting tools.

The temperature to which it is best to draw or temper tools is about as follows:

430° F., or a Faint Straw Color:
  Tools for Metal Planers.
  Small Turning Tools.
  Hammer Faces.
  Steel-engraving Tools.
  Wood-engraving Tools.
  Ivory-cutting Tools.
  Bone-cutting Tools.
  Paper Cutters.
  Scrapers for Brass.

460° F., or a Dark Straw:
  Punches and Dies.
  Screw-cutting Dies.
  Leather-cutting Dies.
  Wire-drawing Dies.
  Taps.
  Milling Cutters.
  Metal-boring Cutters.
  Reamers.
  Tools for Wood Planers.
  Inserted Saw Teeth.
  Knife Blades.
  Wood-molding Cutters.
  Tools for Cutting Stone.
  Rock Drills.
  Half-round Bits.
  Chasers.

500° F., or a Dark Brown:
- Wood-boring Cutters.
- Edging Cutters.
- Hand-plane Cutters.
- Coopers' Tools.
- Flat Drills.
- Twist Drills.
- Drifts.
- Wood Gouges.

530° F., or a Light Purple:
- Hack Saws.
- Axes.
- Wood Bits and Augers.
- Dental Instruments.
- Surgical Instruments.
- Springs.

550° F., or a Dark Purple:
- Cold-chisels for Steel.
- Chisels for Wood.
- Circular Saws for Metal.
- Needles.
- Gimlets.
- Screw-drivers.

570° F., or a Light Blue:
- Cold-chisels for Iron.
- Saws for Wood.
- Molding Cutters to be filed.
- Planer Cutters to be filed.

The temperatures of the different colors used for tempering are about as follows:

Faint Straw, 430° F.
Straw, 460° F.
Light Brown, 490° F.
Dark Brown, 500° F.
Purple and Brown, 510° F.
Light Purple, 530° F.
Dark Purple, 550° F.
Light Blue, 570° F.
Dark Blue, 600° F.
Blue Green, 630° F.

These colors of steel, at a given temperature, cannot always be depended upon, however, as the various ingredients that enter into the composition of different grades of metal are liable to influence the color. That the carbon contents of steel has an influence on the colors is shown by the samples in Fig. 130. These pieces were carbonized and hardened, then tempered at various temperatures, as measured by a pyrometer, and it is to be regretted that the colors cannot be shown, although the contrast between the low-carbon center and the high-carbon outer shell can be seen. Some of these pieces were left rough, as they were broken and others were ground and polished before hardening.

The pieces *A* and *B* are $\frac{1}{2} \times 1\frac{3}{4}$ inches, and *A* is untreated, while *B* was hardened and then drawn until the high-carbon outer shell was a greenish-blue color. The difference between the two colors showed a decided contrast; *C* and *D* were ground and polished and then hardened and drawn until the outer shell was a dark blue. This left the low-carbon center a dark brown. These pieces were $\frac{3}{4}$ inch diameter. *E* was hardened and not drawn. This left the shell a bright steel color, while the center was almost a black; *F* was drawn to a dark blue, and this left the center a dark brown, similar to the pieces *C* and D; piece *G* was drawn to a purple, and this left the center a yellow brown or dark straw color; the *H* piece was drawn to a dark brown in the shell, which left the center a light straw color; *L* was drawn to a full purple, which left the center a spotted red brown; *M* was drawn to a full blue in the shell, and this left the center a brown purple; *J* was drawn to a dark blue, which left the center a dark brown, while piece *K* was hardened and drawn to a purplish blue, and this left the center a light brown. Pieces *I*, *N*, *P*, and *O* were drawn to a dark blue on the high-carbon outer shell, and this left the low-carbon center a dark brown.

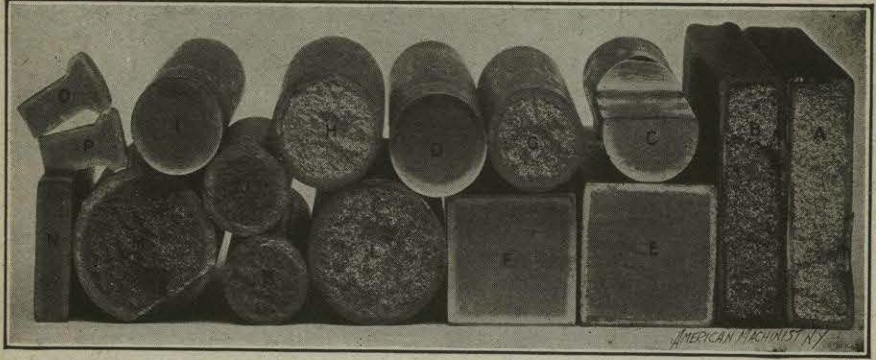

FIG. 130. — Carbonized steel after being hardened and drawn to color.

While the hardening of steel by colors has been successfully done in the past, and will be done many times in the future, these pieces would seem to make it imperative for the hardener to test a sample piece from each lot of steel before attempting to harden it by color. A much better way, however, would be to use a pyrometer for measuring the temperatures as, if the pyrometer is kept in order, a positive knowledge of the temperature at which the metal is treated can be instantly obtained, and the differences in the light in the shop or even in color-blindness will not affect the hardener.

Steels that are used in the building of machinery, as a rule, have the temper drawn much more than this, and the variation in temper is only limited by the work that the parts have to do, the composition of the metal, and the different degrees of temper which steel can be given. Leaf springs, such as carriage springs, are usually reheated to about 800° F.

Gears which are in constant mesh without any undue pressure will give the best results as to wear, strengths, and resistance to shocks if reheated to about 675°. Crank-shafts on internal-combustion engines have to withstand considerable torsion, vibrational strains, and impact stresses and seem to stand the work best when reheated to about 1000°.

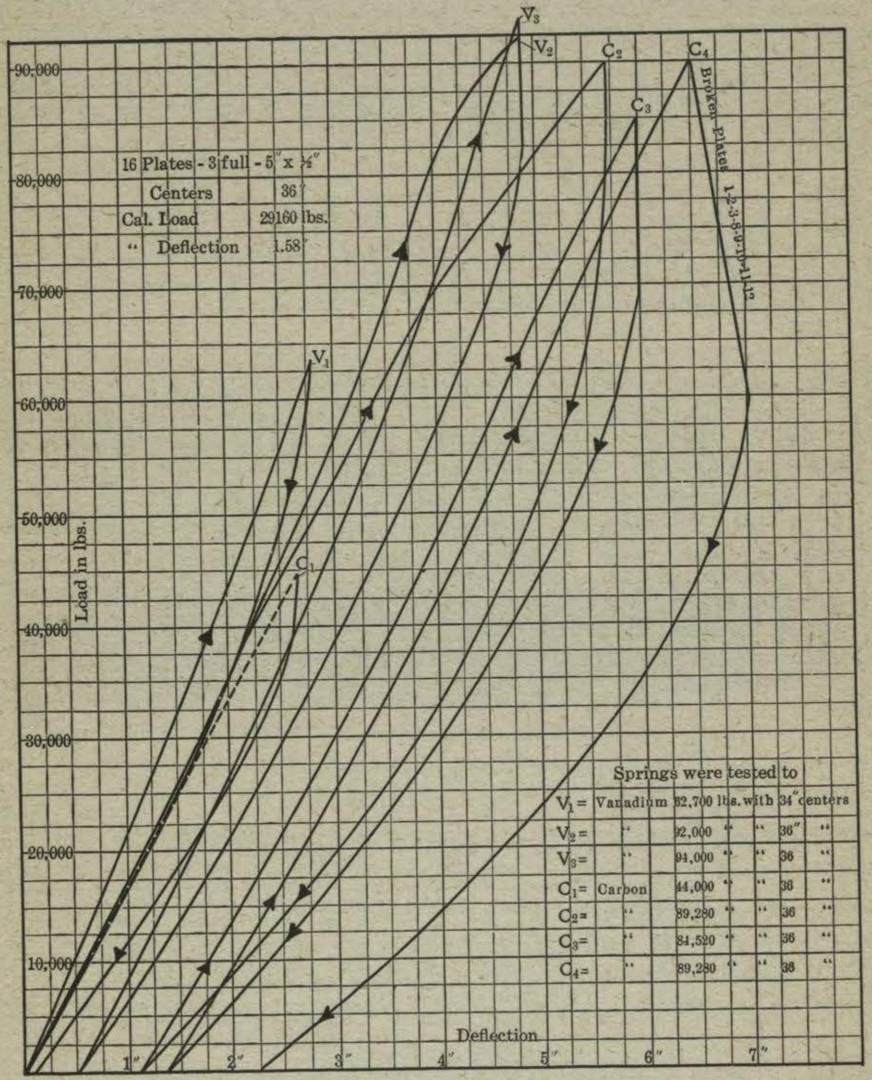

Fig. 131. — Spring deflections. Comparative tests.

Fig. 131 and 132 show the effect of the above heat treatment for springs on two kinds of steel which might be said to show the two extremes in deflection, fiber stress, and their resultant permanent set. In Fig. 131 the elastic limit was reached on the second test. This for the vanadium steels was 85,000 pounds, or 234,500 pounds fiber stress with a permanent set of 0.48 inch. In the carbon steels it was 65,000, or 180,000 pounds fiber stress with a permanent set of 1.12 inches. The carbon steel took an additional set of 0.26 inch on the third test and broke on the fourth in the center. The third test was repeated three times on the vanadium steel without any change in recorded hights. The tests were made by the American Vanadium Company.

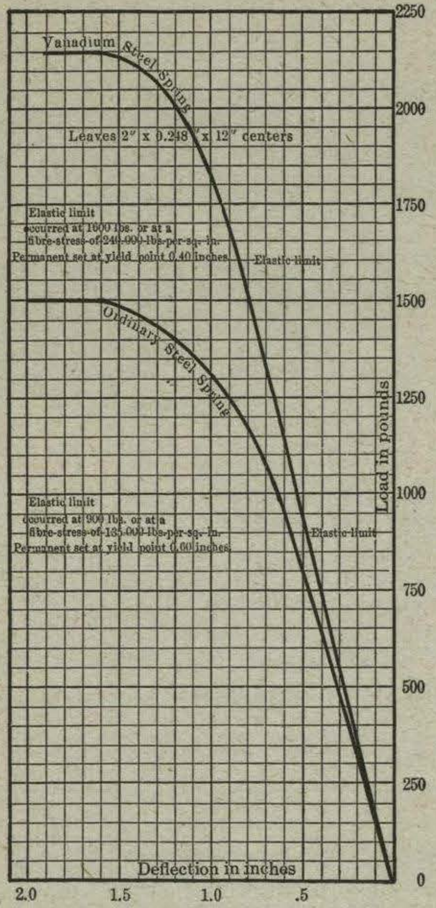

Fig. 132. — Comparative tranverse tests.

The changes that can be made in the strengths of steel are very forcibly shown in the following Table No. 2, which explains itself:

TABLE NO. 2

	Tensile Strength Lb. per Sq. In.	Elastic Limit Lb. per Sq. In.	Elongation in 2 In., Per Cent.	Reduction of Area, Per Cent
Annealed at 1475 degrees.....	87,640	64,400	29	59
Hardened at 1650 degrees, oil tempered at varying temperatures.....................	125,000	103,000	21	56
	127,800	110,100	20	58
	130,500	124,000	17	62
	138,000	127,500	18	65
	147,000	140,750	17	57
	212,000	200,000	12	51
	232,750	224,000	11	39

TEMPERING EQUIPMENT

The furnaces used are sometimes the same as those used in hardening. But furnaces that will permit of maintaining a constant temperature with appliances for measuring the heat so the correct temperature can be attained are the best kind. Thus, wherever possible it is best to have furnaces that are designed especially for tempering. These can be built cheaper than hardening and annealing furnaces, as it is not necessary to construct them so they will withstand the high heats used in hardening, and special appliances can be attached that are not needed on the hardening or annealing furnaces.

The oven gas furnace shown in Fig. 133 is a very handy one in which to temper work, and oil fuel can be used on this style of furnace if desired. The hot plate with a sheet metal oven, that is shown in Fig. 123, is also very useful for tempering. Another type of the gas furnace for tempering is shown in Fig. 134. This is very useful for small work which is inserted through the opening *S* into the drum *D*, and the door *E* closed. The drum is then rotated by a gear and worm on shaft *N*, and the work tumbled so all the pieces will be uniform in temper and heated on all sides. Drum *D* can be pulled out of the furnace by handle *H*, to empty out the work when it is finished. The heat can be accurately controlled at the desired temperature by gas valve *G*, and air valve *A*, and reference to the thermometer *T*.

Lead baths are used a great deal, as it is easy to heat these to a certain temperature and hold them at a constant temperature for any length of time. With this the bath is heated to the temperature at which the

steel needs to be tempered or drawn, the piece is placed in the bath and allowed to remain until it has attained the temperature of the bath, and it is then taken out and cooled. One of the simpler gas-heated lead baths is shown in Fig. 135. These, however, can be heated with coal, coke, oil, or any other fuel as well, and they should be supplied with a hood that is piped to the outside, as any fumes that may arise from the molten lead are injurious.

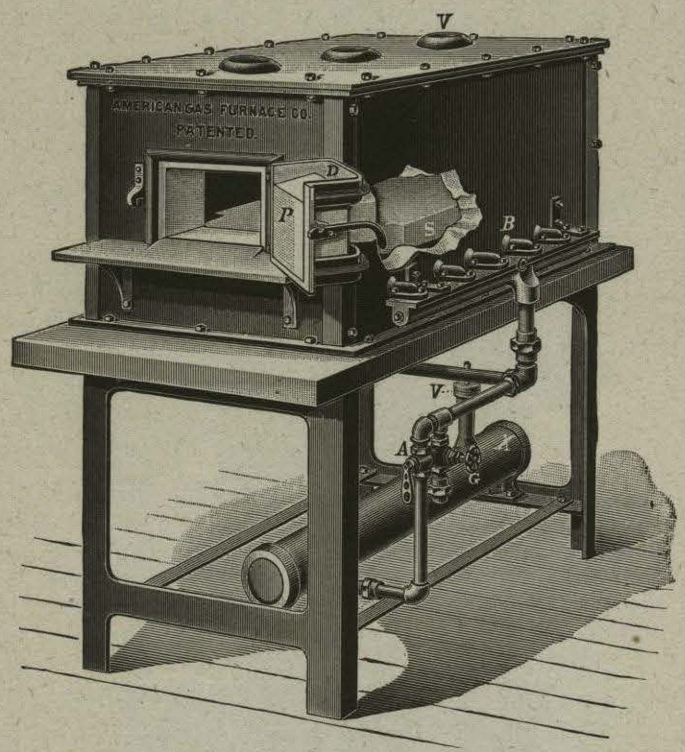

FIG. 133. — Oven furnace with gas for fuel.

As the pure lead melts at about 620° F., it is necessary to mix it with some other metal to get the lower tempering temperatures. Tin is the most often used for this purpose, as it lowers the melting temperature sufficiently, and is a comparatively cheap metal. As low as 360° F. for the melting point can be obtained by combining these two metals. The alloys that will melt at given temperatures are as follows:

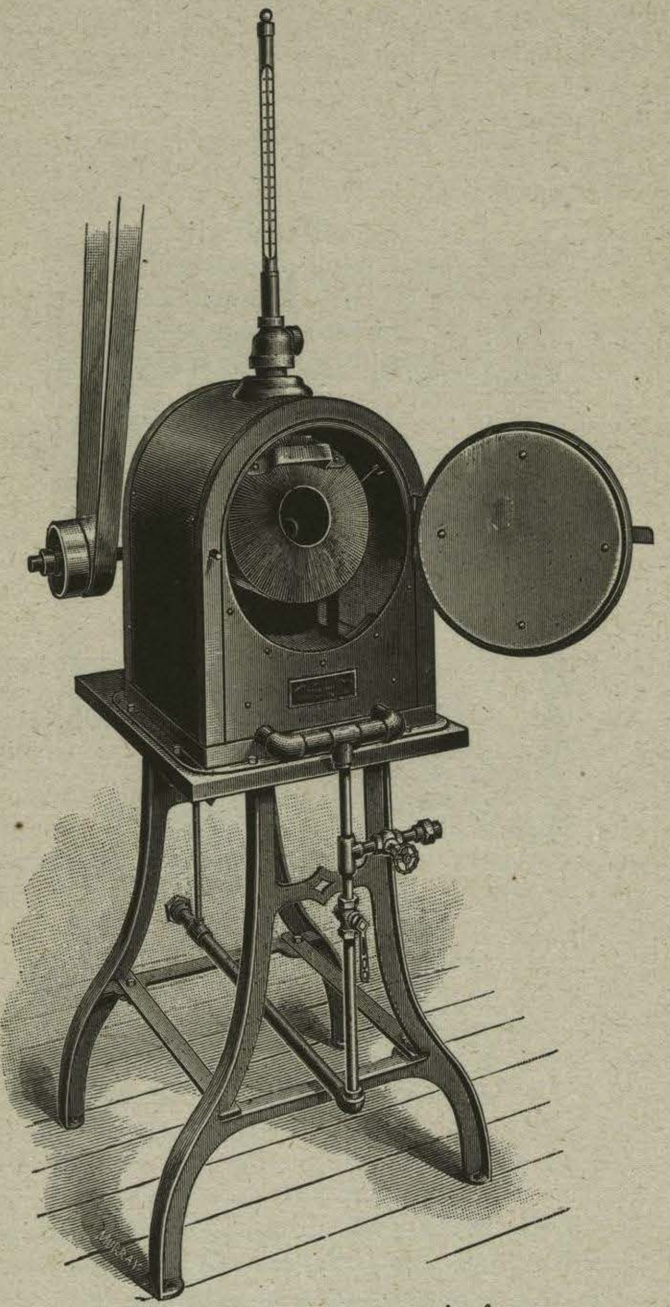

FIG. 134. — Revolving drum tempering furnace.

Pure Lead melts at 619° F.

200 parts Lead and 8 parts Tin melt at	560° F.
100 parts Lead and 8 parts Tin melt at	550° F.
75 parts Lead and 8 parts Tin melt at	540° F.
60 parts Lead and 8 parts Tin melt at	530° F.
48 parts Lead and 8 parts Tin melt at	520° F.
39 parts Lead and 8 parts Tin melt at	510° F.
33 parts Lead and 8 parts Tin melt at	500° F.
28 parts Lead and 8 parts Tin melt at	490° F.
24 parts Lead and 8 parts Tin melt at	480° F.
21 parts Lead and 8 parts Tin melt at	470° F.
19 parts Lead and 8 parts Tin melt at	460° F.
17 parts Lead and 8 parts Tin melt at	450° F.
16 parts Lead and 8 parts Tin melt at	440° F.
15 parts Lead and 8 parts Tin melt at	430° F.
14 parts Lead and 8 parts Tin melt at	420° F.

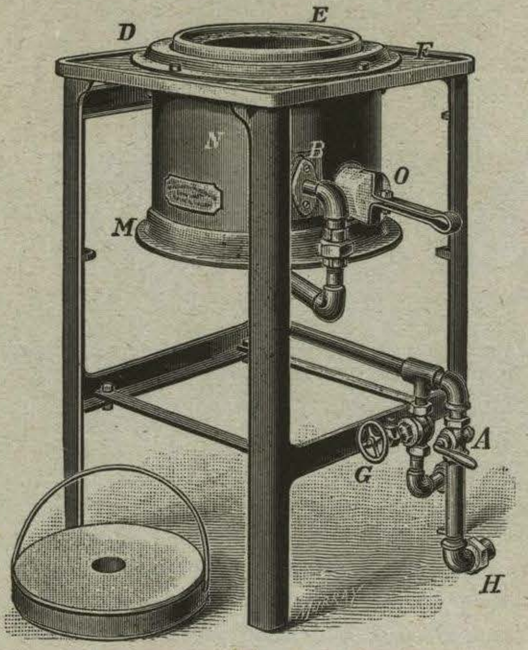

FIG. 135. — Gas-heated lead bath.

Oil baths are also used quite extensively for tempering, and like the others the bath should be maintained at the temperatures to which it is desired to draw the temper, and the work immersed until it has attained the temperature of the bath and then taken out to cool in the air. One of the best oil bath furnaces is that shown in Fig. 136, but equally good results are obtained with oil-fired or electrically heated baths. The temperature can be easily controlled by means of the gas and air valves, as in the other furnaces shown, by using the high temperature thermometer for a guide. The wire basket shown in front of the furnace is to hold the work so it can be easily removed from the oil.

Temperatures of 600° F. can be easily obtained and maintained in the oil baths with the ordinary oils, but for temperatures that are much higher than this other materials should be used. Some of the tallows can be successfully worked at temperatures as high as 800°. Steel is not injured by soaking in the oil for an indefinite time, provided the desired temperature for tempering has not been exceeded. This makes it possible to temper large and small pieces at the same time, as while the large pieces are lying in the bath to thoroughly absorb the heat in all their parts, the smaller pieces can be tempered. It is always best to slowly preheat the work to from 300° to 400° before submitting it to the tempering bath, as this allows the molecules of the metal to readjust themselves more thoroughly than if the piece is plunged immediately into the tempering bath.

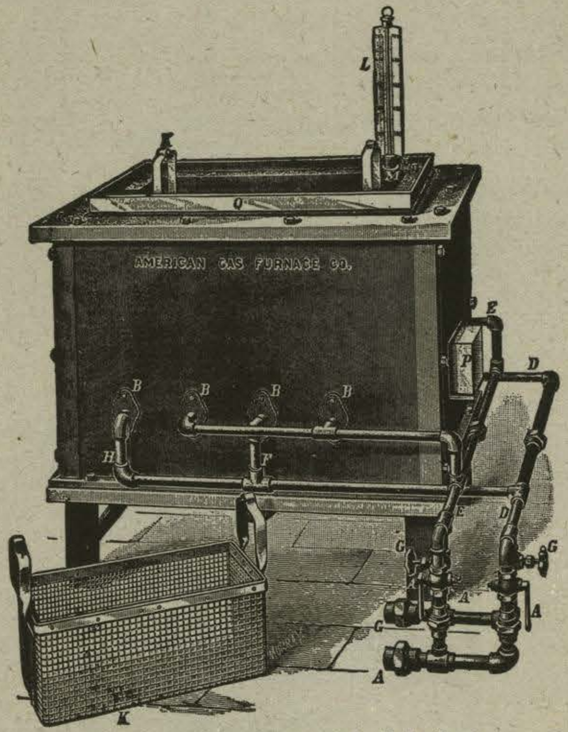

FIG. 136. — Gas-heated oil bath.

The electrically heated oil bath is doubtless the best, as by means of the rheostat the temperature is very easily controlled. When the exact amount of current that is required to heat a given oil up to a given temperature is known, the rheostat can be set at this and no further attention paid to it until the work is ready to be taken out of the bath. When starting with a cold bath no preheating of the work is required, as the rheostat can be set and the work heated up with the oil. To maintain a temperature of 600° F. in one style of electrical oil bath, it required 6 kilowatts per hour for 9 gallons of oil, 7.2 kilowatts for 11 gallons, and 12 kilowatts for 20 gallons.

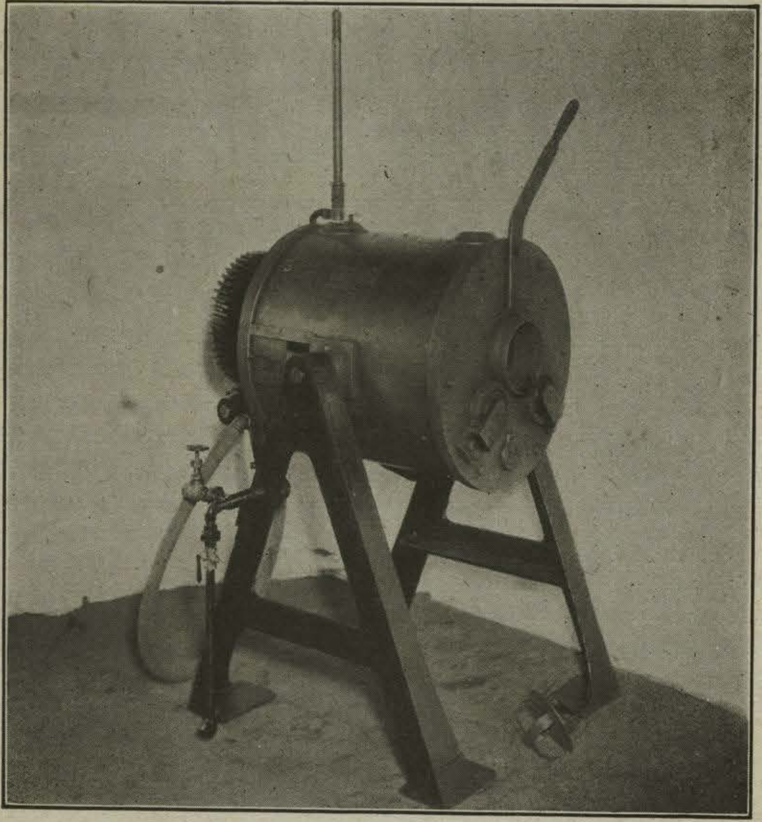

FIG. 137. — Tempering furnace with revolving retort.

Salt baths are sometimes used where the drawing temperature desired is 575° F. Some salts fuse at this point, and a certainty of obtaining this temperature in the steel is assured. In using this the salt is heated to 700° or 750°, and the steel placed in the bath. When this is done the cold metal will cause the salt which surrounds it to solidify and plainly show a white crust around it. When the steel has attained a temperature of 575° the white crust will disappear as the salt which made it has melted and mixed with the rest of the bath. This clearly shows that it is time to take the piece out of the bath and allow it to cool. This method can be used for tempering above 575° and below 900°, but is not practical for higher or lower temperatures owing to the alteration in the salt of which it is composed.

Another method that is used considerably on some classes of work is sand tempering. This consists of covering the work with sand, and heating both up at the same time. Clean and well-dried sand is sometimes used in a pan, and the metal heated up in it over a fire. Some special gas furnaces have also been built for sand tempering in which the sand is permanently kept at the required temperature. The work is placed in this until it has thoroughly attained the temperature of the sand, and then cooled in the air. Continuous operating automatic gas furnaces have also been made for sand tempering. In these the work and sand travels through the furnace, from one end to the other, by the aid of a worm. The work is then dumped out, while the sand is brought back to the other end, inside of the furnace, by means of a second worm.

A gas furnace, with a revolving retort, that is used for tempering is shown in Fig. 137. The outer shell of the furnace is lined with fire-brick, and this is heated by the gas. The round retort, the opening of which is shown at the end, is placed inside of the outer shell, and revolves on 4 wheels, two of which are at each end of the furnace. It is revolved by means of bevel gears, sprockets and chains, and a pulley and belt. The whole is mounted on trunnions, and can be tilted to any angle so the work will travel through the furnace automatically. This furnace is also used to give metal parts a gun-metal finish. This color can only be given to pieces that will stand tempering to 600° F., as it takes that temperature to put the color on the metal; this being done by means of charred bone and chemicals.

CHAPTER XII

CARBONIZING

METHODS AND MATERIALS USED — EFFECT OF ALLOYING MATERIALS AND HEAT TREATMENT

MANY of the steels that give very high figures in their strength tests are made hard enough to resist wear for such parts of machinery as gears, cams, ball races, etc., by hardening and tempering; but when the proper degree of hardness is obtained to reduce wear to a minimum, they are too brittle to withstand shock strains.

For this reason case-hardening, carbonizing, or, as it is called in Europe, "cementation," is resorted to, as by this process the outer shell can be made hard enough to resist wear, and the core of the piece can be left soft enough to withstand the shock strains to which it is subjected. By this method gears can be made from some of the special alloy steels that will reduce the wear to a point that would have been considered impossible a few years ago, and at the same time resist shock to such an extent that it is very difficult to break out a tooth with a sledge hammer.

Several methods different from the old established one of packing the metal in a box filled with some carbonizing material, and then subjecting it to heat, have been devised in the last few years. Among them might be mentioned the Harveyizing process which is especially applicable to armor plate. This in turn has been followed by an electrical and a gas process, which claim to be great improvements over the Harveyizing process. Very recently another process has been invented which uses gas for carbonizing in a specially constructed furnace. This is very useful for carbonizing small work.

The Harveyizing process uses a layer of charcoal between two plates which are heated in a pit furnace by producer gas. The weight of the upper plate brings the charcoal in close contact with the surfaces and facilitates the soaking in of the carbon.

This process has been a great success, but it also has its faults, as the carbon soaks in to a good depth in some places, while at other places, sometimes only a foot away, the carbon will not be so deep, so that when tested a shot will glance off from one spot, and when it hits a short dis-