High Carbon Steel.

Hardening High Carbon Steel; Tungsten Steel; Recalescence; Phenomena of Recalescence and Reheating; Heat Gauges; Quenching; Annealing; Temperature for Hardening; Tempering High Carbon Steel; Colors for Tempering.

All varieties or grades of carbon steel are altered by being suddenly cooled or "quenched" when heated and this alteration varies greatly according to the heat at which the steel is cooled, the quality and composition of the material, the quenching medium used and other causes. In the high carbon steels this effect is particularly noticeable and such steels, when so treated, become hard, brittle, or tough according to the exact heat treatment and manner of quenching given. The change in the steel takes place during a very short range of temperature and the more rapidly the cooling occurs throughout that range the harder the steel will become. This particular range of temperature for hardening is known as the "critical range" or "point of recalescence" and varies with the carbon percentage in the steel. This point of recalescence indicates the proper quenching temperature and most complex and exhaustive tests have

been carried on to ascertain the exact points of recalescence best adapted to various steels and various purposes.

Quenching the steel at the lowest temperature at which hardening will occur produces the toughest tools, whereas, if the same tool be heated to the utmost temperature of the critical range and then cooled suddenly great hardness but very brittle results will be obtained. Connected with this peculiar point of recalescence are numerous physical and chemical phenomena which are difficult for the layman to understand and cannot be fully dealt with or explained in a work of the present scope but a few words of explanation and some data of experiments that have been carried on will prove an aid in more thoroughly understanding and appreciating the subject. High carbon steels contain a very complex material commonly called "Martensite," which in slow cooling is altered to "Pearlite" and produces a softness or lack of temper in the steel. When rapidly cooled this is again transformed to the so-called "Hardenite," which produces extreme hardness and brittleness.

Oddly enough steel does not cool steadily and evenly, but at about 1237 degrees (F.) the cooling ceases and the temperature even rises a trifle. The point of recalescence having passed the cooling continues, but as radiation is continually drawing heat from the steel during this period, it is obvious that the temporary retardation of cooling must be brought about through some alteration within the material itself. This alteration, which in large masses makes the steel glow more brightly, marks the point at which the steel should be quenched to obtain certain results. In heating soft steels for hardening the point of recalescence is reached when heat is absorbed without raising the temperature brought about by the transformation of the Pearlite to Martensite or exactly the reversal of the other process. When tempered, however, a portion of the Hardenite or Martensite in the hard steel is transformed into Pearlite by means of "baking" or gentle heating until the steel contains both Martensite or Hardenite and Pearlite. A most remarkable feature of these properties of steel is the fact that at the

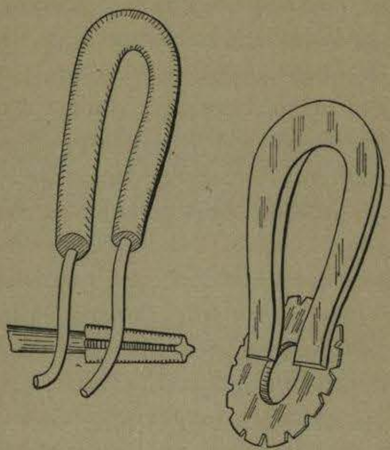

Fig. 164. Magnets for heat gauges.

exact point of recalescence the steel loses its magnetic property and can neither attract nor be attracted by this force. This phenomenon has resulted in very accurate gauges for testing the heat of steel and ascertaining the exact point of recalescence. Several forms of these magnetic gauges are made, some of which are shown in Fig. 164.

The simplest form for small tools and similar objects consists of a magnet provided with arms of any

desired shape. The tool to be heated is then attached to these arms by magnetic attraction and heated in a blow-pipe flame over a quenching bath. When the critical point of heating is obtained the steel loses its magnetic properties and drops from the magnet to the bath below. A very simple manner of ascertaining the critical point where magnetic gauges are unavailable is to test the magnetism of the heated steel by placing it near a small compass. When the needle ceases to vary by its proximity to the steel the proper point of recalescence is determined. Other adaptations of this magnetic phenomenon are developed on large scales in the magnetic furnaces wherein the steel is so arranged that upon the loss of its magnetic force a bell rings, or colored lights appear, thus indicating that the point of recalescence is reached.

Extensive experiments carried on in this connection give some most interesting and remarkable tables, figures and results, which in a simplified form are interesting and of value to all those handling high carbon and low tungsten steels. In these experiments the materials used were "Low-tungsten" steel and carbon steel of about 1.16 per cent carbon. These experiments showed that nearly the entire hardening change occurred within a margin of about 9 degrees F., and that the difference between steel quenched from 1355 degrees F. and 1364 was so great that it was difficult to believe that the hard bar and soft bar only differed by being treated to 5 degrees variation in heat. In its fractures these carbon and tungsten steels also exhibited wonderful properties, for while ordinary tool steel may be heated to 180 degrees beyond its hardening point without a noticeable difference in fracture, yet the steels experimented upon displayed a marked difference when the heat varied but 54 degrees.

In heating these steels it was determined that the temperature did not rise regularly but for several minutes remained stationary while in cooling a long period ensued at which the temperature remained constant. These peculiarities were recorded on a Callender recorder as illustrated in Fig. 165. It is evident from these observations that during these stationary periods of temperature the heat that entered the steel was utilized in effecting the hardening process. When the steel was cooled slowly the temperature fell very regularly until at 1315 F.; steel at this temperature was still radiating great heat, but, nevertheless, the temperature ceased to fall and in fact it actually rose 5 degrees. During this halt the steel changed from its hard state and assumed

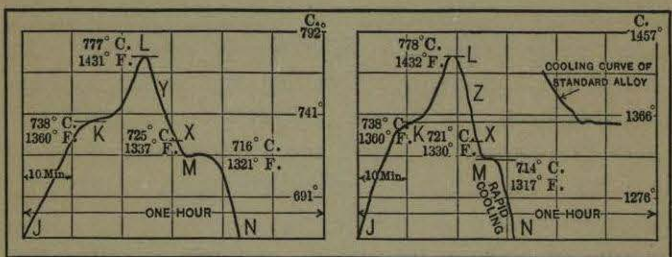

Fig. 165. Recalescence curves of low-tungsten and high-carbon steels.

an annealed condition, the heat that had previously been absorbed in producing hardening being released and maintaining the temperature. This peculiar phenomenon is analogous to the melting of ice for we can understand that if ice at 20 degrees, or below, is heated to a temperature of 60, or more, there would be a long period at

the temperature of 32 degrees, during which the temperature would remain stationary, as all the heat applied would be expended in melting the ice and transforming it to water instead of increasing the temperature, and that if the process were reversed there would be a time when the freezing point was reached, when the latent heat necessary to retain the water in a liquid state would be realized as the ice formed, but when thoroughly congealed the temperature would again fall.

The result of the experiments and heating and cooling curves obtained in the experiments mentioned was to prove that there is a place at which an absorption of heat takes place during heating and another where an emission of heat or recalescence occurs during cooling and that these two points do not occur at the same temperature and are not directly related to one another.

This demonstrated that annealed steel will not change into a higher state until a certain temperature is reached and held for some time but that as soon as the change has taken place the higher state is sufficiently stable to overcome alteration back to its former state until there is a decided variation, or in other words, if the steel is brought to the proper hardening temperature, merely cooling it too much below the temperature will not undo the work accomplished by heating it. This valuable discovery has a most important bearing on hardening treatments, for if a tool has been properly heated for hardening it may remain for some time at a lower temperature and still be perfectly hardened when quenched, but, nevertheless, continued exposure to the high temperatures, after the proper hardening point is reached, will result in softening as may readily be proved by treating two bars of steel, allowing one to reach just the critical point before quenching while allowing the other to remain "soaking" for some time before it is quenched. Moreover, if the steel is overheated and then quenched it will be even softer than if "soaked" for a long period at the proper temperature.

Having thus entered more or less into the little known and less understood question of the phenomenon of recalescence we will take up the matter of preparing high carbon and similar steels for hardening.

Steel forgings do not pass direct from forge to hardening room as they are at first coated with a thin film of oxide which cannot be hardened and must be removed by grinding with a wet grindstone. If a carborundum or emery wheel is used for this purpose glazing may result which is in reality a burning of the surface, rendering the spots so affected incapable of hardening and resulting in uneven work and poor tools.

Work that has been machined before hardening must be carefully inspected before treating, as sharp angles, scratches and other faults often develop into serious flaws or cracks in the heating and quenching process.

It pays to be most careful in this regard as it is far better to refinish or reforge an article before hardening rather than expend the time, labor and money on careful hardening only to have a faulty object in the end.

The source of heating for hardening may be either a common forge with a coke fire, a reverberatory or muffle furnace, a salt-bath furnace or special hardening ovens or furnaces. Small articles may be heated in an iron box or pipes and excellent results may be obtained by heating small tools in a piece of ordinary gas pipe plugged at the ends and heated in a common furnace or

forge. Very small articles may be heated by blow-pipe or even by placing them on another piece of heated steel and testing for the point of recalescence by a magnetic gauge. The main object is to produce a bright, cherry red heat at the proper temperature without allowing air to reach the heated surface and thus oxidize the steel and also to avoid sulphur in the fuel; for this reason coke is better than coal and charcoal is better than coke, while oil or gas is superior to either, and electrical heat is best of all.

The substance used as a bath for quenching, or rapidly cooling, the steel varies with different operators and different steels as well as according to the grade of hardness or temper desired. Water, oil, brine, mercury, melted lead, are used extensively. The whole object of the quenching medium is to cool off the hot steel as rapidly as consistent with safety, and oil and water are most generally used; a very cold medium is not desirable, as cracks often result, and as the melting point of lead is far below the hardening point of carbon steel and as that metal is an excellent heat conductor, the lead bath is frequently used. Oil is used where extreme brittleness is undesirable, while mercury is used where extreme hardness is required. Care must be taken to immerse the entire parts to be hardened at practically the same instant for otherwise distortion and unevenness will result. If properly hardened the steel when first taken from the bath will have a mottled, whitish appearance and if not mottled the steel is not properly hardened. If hard a file will slip over it, whereas if soft, it will cut. If soft it shows that either the steel was not heated sufficiently or else that it was cooled too slowly during the period of recalescence.

Table of temperatures

Table of Temperatures for hardening high carbon steel:

Approx. temperature —degrees F.	Color in full Daylight.
430	Pale yellow
450	Straw
470	Dark straw
500	Brown yellow
530	Light purple
550	Purple-blue
560	Blue
580	Polish blue
600	Deep blue
750	Bright red
880	Red, dull
980	Nascent red
1,080	Red
1,290	Dark red
1,470	Nascent cherry
1,660	Cherry
1,830	Bright cherry
2,010	Dull orange
2,100	Light orange
2,190	Lemon
2,280	Light straw
2,400	White
2,550	Brilliant white
2,730	Dazzling white

Tempering high carbon steel.

Tempering high carbon steel is for the purpose of reducing the brittleness produced by hardening and it is accomplished by heating or "baking" the hardened steel to a moderate temperature the degree of which determines the temper and not the method of quenching as commonly supposed. The lower the temperature to which it is subjected the less will be the loss of hardness by tempering, and as a rule the proper temperature to produce a given temper is recognized by the color that is assumed by the oxidized film upon the surface. The color deepens as the temperature rises, and while this method is far from perfect, it is very simple and widely used, and a man accustomed to the work can judge wonderfully well just where to stop by the color alone.

For a beginner this process is very difficult, for the color changes with time, as well as temperature, and a dark blue may show by heating an object to 652 F. in one minute or by keeping it at 392 for four minutes, and thus practice, care and judgment are essential to this work.

By heating in a bath of oil, lead, salts, etc., or in an electrical or special oven the exact temperature may be ascertained, but even then experience and judgment is very necessary to insure even and accurate tempering. The following table indicates the colors usually employed for tempering certain common tools. It must be borne in mind, however, that the colors will not show unless the steel is clean and the object to be tempered should always be brightened by emery or similar methods. It is also hard to judge the colors by artificial light, and tempering should, therefore, be done by daylight.

Melted lead and tin in varying proportions makes an excellent heating bath for tempering, for as lead melts at 612 F., various degrees of the melting mass may be determined by adding more or less tin. If a layer of powdered charcoal is spread over the surface oxidation of the lead will not occur and there will be little waste. Boiling linseed oil may be used for a temperature of about 600 F., while sulphur, tin, zinc, antimony, etc., may be employed for obtaining definite heats. Where a large object is tempered the heat cannot be judged by color, and in such cases the object may be placed upon a small piece of bright steel—an old saw blade is good—and the color assumed by this will act as an index. Air-tempering furnaces, electric ovens, oil heaters and various other methods of accurate heating are now on the market, as well as a sand-tempering machine, in which a rotating drum is heated by gas while sand or ground stone is sifted in streams upon the objects being treated. The drum rotates slowly over the flame and pockets, provided with perforations, pick up the sand as it rotates and sift it as they reach the top. The work under treatment is placed in a wire basket in the drum, when small pieces are heated, but large objects rest upon the bed of hot sand and move constantly about by the rotation of the drum.

Table for colors for tempering tools.

Approximate color.	Kind of Tool.
Yellow.	Brass scrapers, lancets, steel gravers, burnishers, small turning tools, steel planers, hammers, ivory-cutting tools.
Straw yellow.	Slotters for metal, paper cutters, shear blades, engraving tools, boring tools, bone cutters, screw dies and taps.
Brown yellow.	Leather cutters, chasers, insert saw teeth, reamers.
Light purple.	Rock drills, bits, pocket knives, stone tools, twist drills, hard-wood moulders and planers, dies and punches, gouges, plane irons.
Dark purple.	Circular saws for metal, brass drills, augers, drifts, circular wood cutters, dental and surgical instruments, cold chisels, axes, gimlets.
Pale blue.	Bone saws, chisels, needles, soft wood cutters.
Blue.	Hack saws, screw drivers, wood saws, springs.