CHAPTER XLIV.—HARDENING AND TEMPERING.

HARDENING and tempering processes are performed upon steel for three purposes:

1st. To enable it to resist abrasion and wear.

2nd. To increase its elasticity.

3rd. To enable it to cut hard substances and increase the durability of the cutting edge.

Of these, the first is the simplest, because the precise degree of hardness imparted is not of vital importance.

The second is more difficult, because the quality of the steel employed for such purposes is variable, and hence the tempering process must be varied to suit the steel. The third is of the greatest importance, because the articles to be tempered are the most expensive to make, the duty obtained is of the greatest consequence to manufacturing pursuits, and the fine grade of steel employed renders it more liable to crack in the hardening process.

In those mechanical parts of machines which are hardened to resist abrasion and wear, the quality or grade of the steel is very often selected with a view to obtain strength in the parts and ease of mechanical manipulation in cutting them to the required shape, rather than to the capacity of the steel to harden. Hence, tougher and more fibrous grades of soft steel termed "Machine" steel, are employed, meaning that the steel is especially suitable for the working parts of machines. This class of steel is of a lower grade than that known as "tool" steel. It is softer, works, both on the anvil and in the lathe, more easily, and will bear heating to a higher temperature without deteriorating. It approaches more nearly to wrought iron, and is sometimes made of so low a grade as to be scarcely distinguishable therefrom.

The kinds of steel used where elasticity is desired are known as spring steel, blister steel, and shear or double-shear steel, although, for small springs, steel of the tool-steel class is often employed.

The word *temper*, as used by the manufacturer of steel, means the percentage of carbon it contains, the following being the most useful tempers of cast steel.

Razor Temper ($1\frac{1}{2}$ per cent. carbon).—This steel is so easily burnt by being overheated that it can only be placed in the hands of a very skilful workman. When properly treated it will do twice the work of ordinary tool steel for turning chilled rolls, &c.

Saw-file Temper ($1\frac{3}{8}$ per cent. carbon).—This steel requires careful treatment, and although it will stand more fire than the preceding temper should not be heated above a cherry red.

Tool Temper ($1\frac{1}{4}$ per cent. carbon).—The most useful temper for turning tools, drills, and planing-machine tools in the hands of ordinary workmen. It is possible to weld cast steel of this temper, but not without care and skill.

Spindle Temper ($1\frac{1}{8}$ per cent. carbon).—A very useful temper for mill picks, circular cutters, very large turning tools, taps, screwing dies, &c. This temper requires considerable care in welding.

Chisel Temper (1 per cent. carbon).—An extremely useful temper, combining, as it does, great toughness in the unhardened state, with the capacity of hardening at a low heat. It may also be welded without much difficulty. It is, consequently, well adapted for tools, where the unhardened part is required to stand the blow of a hammer without snipping, and where a hard cutting edge is required, such as cold chisels, hot salts, &c.

Set Temper ($\frac{7}{8}$ per cent. carbon).—This temper is adapted for tools where the chief punishment is on the unhardened part, such as cold sets, which have to stand the blows of a very heavy hammer.

Die Temper ($\frac{3}{4}$ per cent. carbon).—The most suitable temper for tools where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, boiler cups, &c. Both the last two tempers may be easily welded by a mechanic accustomed to weld cast steel.

The preference of an expert temperer for a particular brand of steel is, by no means, to be taken as proof of the superiority of that steel for the specific purpose. It may be that, under his conditions of manipulation, it is the best, but it may also be that, under a slight variation of treatment, other brands would be equal or even superior. It may be accepted as a rule that the reputation of a steel for a particular purpose is a sufficient guarantee of its adaptability to that purpose, and all that is necessary to a practical man is to be guided by the reputation of the brand of steel, and only change when he finds defects in the results, or ascertains that others are using a different steel with superior results.

Where large quantities of steel are used the steel manufacturers in many cases request customers to state for what particular purposes the steel is required, their experience teaching them what special grade of their make of steel is most suitable.

To harden steel it is heated to what is termed a "cherry red" and then dipped into water and held there until its temperature is reduced to that of the water.

Tempering steel as the blacksmith practises it consists in modifying, lowering, or tempering the degree of hardness obtained by hardening. The hardening of steel makes it brittle and weak in proportion as it is hardened, but this brittleness and weakness are removed and the steel recovers the strength and toughness due to its soft state in proportion as it is lowered or tempered.

When therefore a tool requires more strength than it possesses when hardened, it is strengthened by tempering it. Tempering proceeds in precise proportion as the temperature of the hardened steel is raised. When the steel is heated to redness the effects of the hardening are entirely removed, and the steel, if allowed to cool slowly, is softened or annealed. To distinguish maximum hardness from any lesser degree the terms to give the steel "all the water," or to harden it "right out" are employed, both signifying that the steel was heated to at least a clear red, was cooled off in the water before being removed from the same, and was not subsequently tempered or modified in its hardness. If a piece of steel has its surface bright and is slowly heated, that surface will assume various colors, beginning with a pale straw color (which begins when the steel is heated to about 430°) and proceeds as in the following table:—

	Fahr.
Very pale yellow	430°
Straw yellow	460
Brown yellow	500
Light purple	530
Dark purple	550
Clear blue	570
Pale blue	610
Blue tinged with green	630

It happens that between the degree of hardness of hardened steel and the temper due to reheating it up to about 600° Fahr. lie all the degrees of hardness which experience has taught us are necessary for all steel-cutting tools. Hence we may use the appearance of colors as equivalent to a thermometer, and this is called color-tempering. The presence of these colors or of any one of the tints of color, however, is no guarantee that the steel has been tempered or possesses any degree of hardness above the normal condition, because they appear upon steel that is soft or has not been hardened. To obtain exact results by color tempering, therefore, the steel must first be thoroughly hardened, and this is known in practice by the whiteness of the hardened surface.

Any number of pieces hardened so as to have a white surface may be tempered to an equal degree of color, or heated to an equal thermometrical temperature, with the assurance that they will possess a degree of hardness sufficiently uniform for all practical purposes; but if their hardened surfaces have dark patches, tempering to an equal tint of color is no guide as to their degree of temper. Successful tempering, therefore, must be preceded by proper hardening.

The muffle should therefore bear such a proportion in size that when heated to a blood red, and taken from the fire, its temperature will be reduced to nearly that of the steel when it has acquired its proper degree of temper.

The shape of the bore of the muffle should always conform to that of the article tempered; for round work, a round muffle; for square work, a square one; and so on. The muffle should be shorter than the work, so that the tempering of either end of the work may be retarded, if it is proceeding too fast, by allowing that end to protrude through the muffle.

Color tempering, it will be observed, gives us no guide or idea of any of the degrees of temper which occur while the hardened steel is being heated up to about 430° Fahr.; and thus it leaves us in the dark as to all the ranges of hardness existing in steel thoroughly hardened and tempered to any degree less than that due to about 430° degrees of reheating. How wide this range may be can be appreciated when it is remembered that in the color test there are only 200° of heat between the hardness known as straw color, which is hard enough for almost all cutting purposes, and blue, tinged with green, which is almost normal softness.

It is for this reason (among others) that where very exact results are to be obtained and a large number of pieces are to be tempered, fluxes, heated to the required temperature, are very often employed.

Color tempering is conducted in different ways. In a muffle, in heated sand, with hot pieces of flat iron, and in boxes heated to the requisite temperature in an oven, the temperature being indicated by a pyrometer or heat-gauge. The articles to be tempered remain in the oven a length of time determined by experiment or experience, these being influenced by the size and substance, or thickness, of the pieces.

A muffle is a tube or cylinder receiving its heat from the outside and open at the end or ends to receive the steel. Where tempering is carried on continuously the muffle is kept in the fire, although it is claimed by many that better results are obtained by removing it from the fire when heated. It is obvious that if the muffle is heated evenly the steel will temper most evenly by being held in the centre of the muffle, or the piece may be revolved and moved endways in the muffle in order that the steel may heat evenly. The tempering should always proceed slowly, otherwise the heat may not have time to penetrate the steel to the centre, the outside tempering more quickly, thus the tool will be weak because of the undue hardness of the interior metal. Furthermore, protruding edges, or slight sections of the steel, may reduce to the required temper before the main body of the steel, which induces either serious weakness of the insufficiently tempered part, or softness in the thin sections, providing that the steel is kept long enough in the muffle to temper the main body to the proper degree.

In heating steel to harden it, especial care is necessary, particularly when the tool is one finished to size, if its form is slight or irregular, or if it is a very long one, because unless the conditions both of heating and cooling be such that the temperature is raised and lowered uniformly throughout the mass, a change of form known as *warping* will ensue. If one part gets hotter than another it expands more, and the form of the steel undergoes the change necessary to accommodate this local expansion, and this alteration of shape becomes permanent. In work finished and fitted this is of very great consideration, and, in the case of tools, it often assumes sufficient importance to entirely destroy their value. If, then, an article has a thin side, it requires to be so manipulated in the fire that such side shall not become heated in advance of the rest of the body of the metal, or it will become locally distorted or warped, because, though there may exist but little difference in the temperature of the various parts, the more solid parts are too strong to give way to permit the expansion: hence the latter is accommodated at the expense of the form of the weakest part of the article.

Pieces, such as long taps, are very apt to warp both in the fire and in the water. In heating, they should rest upon an even bed of coked coal, and be revolved almost continuously while moved endways in the fire; or when the length is excessive, they may be rested in a heated tube, so that they may not bend of their own weight. So, likewise, spirals may be heated upon cylindrical pieces of iron or tubes to prevent their own weight from bending or disarranging the coils.

Experiments have demonstrated that the greater part of the hardness of steel depends upon the quickness with which its temperature is reduced from about 500° to a few degrees below 500°, and metal heated to 500° must be surrounded by a temperature which renders the existence of water under atmospheric pressure impossible; hence, so long as this temperature exists the steel cannot be in contact with the water, or, in other words, the heat from the steel vaporizes the immediately surrounding water. The vapour thus formed penetrates the surrounding water and is condensed, and from this action there is surrounding the steel a film of vapour separating the water from the steel, which continues so long as the heat from the steel is sufficiently great to maintain the film against the pressure of the water and the power of the water which rushes toward the steel to fill the spaces left vacant by the condensation of the vapour as it meets a cooler temperature and condenses. The thickness of the vapour film depends mainly upon the temperature of the steel; but here another consideration claims attention. As the heated steel enters the water the underneath side is constantly meeting water at its normal temperature, while the upper side is surrounded by water that the steel has passed by, and, to a certain extent, raised the temperature of. Hence, the vapour on the underneath side is the thinnest, because it is attacked with colder water and with greater force, because of the motion of the steel in dipping. For these reasons it is desirable, especially with thick pieces of steel, to inject the water in a full stream upon the article, as is done in the Brown & Sharpe hardening tanks.

In cases where a great many pieces are to be hardened and tempered to an even degree, the steel is heated for the hardening in a flux, with the advantage that contact between the heated steel and the impurities (as sulphur or silicon) of ordinary fuels is avoided, and also that all the pieces may be heated, and therefore hardened, to a uniform degree. The capacity of this system is great, because a number of pieces can be heated without fear of any of them becoming overheated if not attended to immediately. Thus the Waltham Watch Co. heat their mainsprings for the hardening in a flux composed of melted salt and cyanide of potash, the latter serving to clean the surface of the steel; but as the latter wastes it requires to be added occasionally.

The Watch Company, however, find this mixture will not do for the hair springs, as it alters (to a very small degree, however) the nature of the steel; hence these springs are heated for hardening in melted glass.

The Pratt and Whitney Co. heat their taps, &c., for hardening in a composition of equal quantities of salt and cyanide of potash, adding the latter as it wastes, and temper them by the cold test.

The Morse Twist Drill Co. use a similar compound for heating to harden, and the following apparatus for dipping. In a large tank having a free water circulation, stand two pots of a capacity of about five gallons each, one of these contains cyanide of potash and salt, and another sperm oil. The heated work is dipped for an instant into the pot containing the potash and salt, which clean the surface of the steel, and then cooled in the main water tank; but if the work is, from its shape, liable to crack, it is at the final cooling dipped in the pot of sperm oil instead of in the water.

Before heating the steel it is dipped in soft soap to prevent oxidation, and on dipping it into the potash and salt pot it causes a cracking sound, the operator knowing from the sound if the mixture is proper, and how long to hold the steel therein.

This company first fill the heating pot with salt, and then add cyanide of potash until a trial of the tool gives quite satisfactory results, adding cyanide of potash as the work proceeds to make up for the evaporation and keep the mixture of the compound correct.

In many cases it is considered an advantage to harden the outside of an article, keeping the inside as soft as possible so as to increase the strength. In such case the article may be heated in red-hot lead, the surface of which may be covered with charcoal. Under these conditions the outside of the article, especially if thick, will get red hot in advance of the inside.

Articles having thick and thin sections may be heated in fluxes to great advantage, the thick side being immersed first, and the article being lowered very slowly into the pot of lead. If the shape of the article is such as to render it liable to crack in the water because of containing holes or sharp corners in weak parts, these holes and sharp corners may be filled with fire-clay, the dipping water may be heated to about 50°, and salt (1 lb. per gallon of water) added to it.

The Monitor Sewing Machine Company harden and temper their spiral springs at one operation, by heating them to a blood-red heat and quenching them in a mixture of milk and water, which will give an excellent result, providing that the springs are heated to precise uniformity and the mixture of milk and water is correct. For a process of this kind (which is very expeditious, because the hardening and tempering is performed at one operation), the steel should be heated to a very uniform temperature, and a mixture of, say, two-thirds milk and one-third water tried at first, more milk being added to lower the temper, or more water to increase it if necessary.

Saws are hardened in compositions of animal oil, such as whale-oil, with which resin, pitch, and tallow are sometimes mixed.

Resin hardens but somewhat crystallises the metal, but it is used because, on common saws, the scale will not strike properly without it. Tallow gives body to the liquid and causes it to extract the heat quickly from the steel (and the hardening is solely due to the rapid extraction of the heat). In addition to this, the saws hardened in oil and tallow show a very fine grain if fractured, and are tough. The effect of pitch is much the same as that of resin. In place of tallow, bees-wax is sometimes used, giving an excellent result. A very little spirits of turpentine mixed with the oil every time it is used (that is, for every batch) is an excellent ingredient to cause the scale to strike, but being very inflammable, it is somewhat dangerous. If none of these ingredients are used, and the scale does not strike, it acts as a fine separating lining, preventing the contact between the metal and the liquid, and hence retarding the cooling, and therefore the hardening.

Let us suppose some thin saws of the finest grade of steel are to be tempered. The liquid would be about half a barrel of tallow to a barrel of whale-oil (which will harden as hard as glass). After the temperature of the saw is reduced to that of the bath, it is removed, the adhering oil is removed, and the surface dried by an application of sawdust, and the tempering process may be proceeded with.

There are three methods of drawing the temper. One is with the saw lying in the open furnace; a second, an English plan, is with the saw stretched in a frame, so as to prevent its warping, and in fact, to cause the tempering to aid in straightening the saw; and the third is to temper between flat dies.

In the first, the temper is determined by the appearance of the saw in the furnace. The saw absorbs some of the liquid in which it was quenched to harden it; and as it is reheated to temper it, this oil passes off as a cloud, or rather as a breath passes off the surface of a window-pane. This action takes place first on the lower surface of the saw, nearest to the furnace bottom, the oil exuding in a mist-like form. The length of time the saw must remain in the furnace after the cloud has passed off is determined by the thickness of the saw and the heat of the furnace, the operator being guided entirely by experience; but when the saw is taken from the furnace, it will have a very dark-red glimmer, and must be laid flat and allowed to cool off in the air, for if again dipped it would be too hard. When cool, the saw thus tempered will be of a sky-blue color, and will spring from point to butt without bend or break. This process requires skilful management and good judgment, but will give most excellent results. The main objection to it is, that it is expensive, since it gives no aid to the straightening processes.

The straightening frame, or English tempering system, is as follows: The plates of steel are made of a size that will cut into four saws. The furnace front is provided with a tramway extending to the floor of the furnace, and on this runs the stretcher-frame. The plates are stretched in the frame, which is run into the furnace so that the plate is heated under a tension, which operates to straighten them As the temper lowers, the screws of the stretcher are turned, increasing the tension; when the tempering is done, the screws are made to stretch the plates very tight just previous to taking it from the fire, and the plates are allowed partly to cool off while kept in the frame. In this process the indications of the temper are determined as in the first process. In the third process, the saws are placed between a stationary and a movable die provided in the body of the furnace, the movable one descending and pressing the saw to the other die; thus the tempering is accompanied by a flattening process (the dies being operated by pressure). The degree of temper is regulated by the temperature to which the saws are heated, which is ascertained by a pyrometer. The furnace is kept at a constant temperature, and the length of time the saw remains between the dies is varied to suit the thickness of the saw. The gain due to this system is, that less straightening is required and a determinate temperature is secured. Some makers claim that in this system the vapour of oil that exudes from the saw has no means of escape, and that a chemical effect injurious to the steel ensues; and furthermore that the temperature of the dies will be greatest at or near their circumference, and hence the teeth and back and the ends of the saw will be softer than the middle of the width and length of the saw, and that if two saws, one above the other, be placed on the dies at once, the contacting surfaces of the saws will be the hardest, and those surfaces will be black by reason of the oil burning into the steel, instead of exuding, as in the open furnace process.

The floor of the tempering furnace should be flat and even; for if any part of the saw-plate lies suspended, it will sag when heated, greatly increasing the amount of straightening required. The furnace must be so constructed as to heat evenly all over, otherwise the temper of the saw will not be even. The air must be carefully excluded to prevent the steel from decarbonizing, which being thin, it is very apt to do. Thin saws warp proportionally as they are heated more, and if they are allowed to remain longer in the furnace and not heated too quickly, existing buckles or bends will partly straighten themselves in the furnace. Care must be taken to keep the tongs clear of the teeth, and in taking the saws from the furnace the length of the saw must stand at a right angle to the operator (two pairs of tongs being used), so that the saw's own weight shall not cause it to bend. The saw must be transferred from the furnace to the bath very quickly, to prevent, as much as possible, its cooling in the air; for such cooling would take place unequally, causing the saw to warp, as well as impairing the temper. It should be dipped with the length horizontal, the teeth downward and the side faces vertical, and plunged quickly into the bath. On being dipped in the hardening liquid, they warp again, but the dipping may be manipulated to partly regulate the warping. From the moment the cold air strikes the plate a warping process sets in, hence quickness in transferring from the furnace to the bath is a great point. When the saw is hot enough to temper, the scale will begin to rise upon its surface, and if the furnace is unequally heated, the scale will rise first at the hottest part, instantly notifying the operator of the defect.

From the appearance of the surface of the saw after it comes from the hardening bath, the operator can see if it is properly hardened. If so, the scale will be what is termed "struck," that is, it has come off, leaving the surface from a grey to a white color; while if the scale remains in dark patches, the saw is too soft in those parts.

After the saws are tempered they are allowed to cool in the open air, and then require to be straightened by the hammer, and in this process the tempering has been interfered with, inasmuch as that the elasticity due to the tempering has been counterbalanced to some extent by the local condensation of the metal induced by the immediate effects of the hammer blows. The condensation of the metal has impaired the natural grain or fibre of the metal, and stiffens it so that if the saw be bent these stiffened hammer marks will cause it to remain set instead of springing back straight, as it should do. To remove this defect the saws are what is termed *stiffened*, that is, they are heated until the surface assumes a yellow color, when they are removed and allowed to cool. This causes the metal condensed by the hammer to assume its natural structural condition, and permits the tempering to spring the saw back straight, even though it be bent until the two ends touch, and the bend carried half way along the blade by carrying one end forward along the blade surface. The yellow color is subsequently removed by an application of a solution of muriatic acid.

The method employed by the Tomlinson Carriage Spring Company for carriage springs is as follows :—

The spring plates are heated to bend them to the *former*, which is a plate serving as a gauge whereby to bend the plate to its proper curve, which operation is performed quickly enough to leave the steel sufficiently hot for the hardening ; hence the plates after bending are dipped edgeways and level into a tank of linseed oil which sets in a tank of circulating water, the latter serving to keep the oil at about a temperature of 70° when in constant use. About 3 inches from the bottom of the oil tank is a screw to prevent the plates from falling to the bottom among the refuse.

To draw the temper the hardened springs are placed in the furnace, which has the air-blast turned off, and when the scale begins to rise, showing that the adhering oil is about to take fire, they are turned end for end in the furnace so as to heat them equally all over. When the oil blazes and is freely blazed off, the springs are removed and allowed to cool in the open air, but if the heat of a plate, when dipped in the oil to harden is rather low, it is cooled, after blazing, in water. The cooling after blazing thus being employed to equalize any slight difference in the heat of the spring when hardened.

The furnace is about 10 inches wide and about 4 inches longer than the longest spring. The grate bars are arranged *across* the furnace with a distance of $\frac{3}{8}$ inch between them. The coal used is egg anthracite. It is first placed at the back of the furnace, and raked forward as it becomes ignited and burns clearly. For shorter springs the coal is kept banked at the back of the furnace, so that the full length of the furnace is not operative, which, of course, saves fuel. By feeding the fire at the back end of the furnace, the gases formed before the coal burns clearly pass up the chimney without passing over the plates, which heat over a clear fire.

For commoner brands of steel, what is termed a water-chill temper is given. This process is not as good as oil-tempering, but serves excellently for the quality of steel on which it is employed. The process is as follows : The springs are heated and bent to shape on the *former* plate as before said ; while at a clear red heat, and still held firmly to the *former* plate, water is poured from a dipper passed along the plate. The dipper is filled four or five times, according to the heat of the plate, which is cooled down to a low or very deep red. The cooling process on a plate $1\frac{1}{2} \times \frac{1}{4}$ inches occupies about 6 seconds on an average, but longer if the steel was not at a clear red, and less if of a brighter red, when the cooling began. Some brands of steel of the *Swede steel* class will not temper by the water-chill process while yet other brands will not harden in oil, in which case water is used to dip the plates in for hardening, the tempering being blazing in oil as described. In all cases, however, steel that will not harden in oil will not temper by the water-chill process.

The Columbia Car Spring Company temper their springs as follows :—Using "Gregory crucible steel," heating is performed in a furnace consuming gas coke, but the furnace has a number of return enclosed flues, and between these flues (one over the other), are ovens, the heat passing through the brick-work forming the flues into the ovens. To facilitate renewing the ovens (which of course also renews the flues), the floor of each oven (which forms the ceiling of the oven below), is built on iron supports, protected by the brick-work and suitable fire clay, the bricks all being made to pattern, thus involving very little labor in building. The furnace doors are at the ends, and are kept closed as much as possible. In this way the steel has no contact with the products of combustion of the fuel, and the air is excluded as far as practicable (two valuable features). The furnaces are long and narrow, and not being connected with the flue there is but little disposition for the cold air to rush in when the furnace doors are opened.

The hardening and tempering of springs whose coils are of thick cross-section is performed at one operation as follows: The springs are heated in the furnace or oven described, and are first immersed for a certain period in a tank containing fish oil (obtained from the fish "*Moss Bunker*," and termed "*straights*"), and are then removed and cooled in a tank of water. The period of immersion in the oil is governed solely by the operator's judgment, depending upon the thickness of the cross-section of the spring coil, or, in other words, the diameter of the round steel of which the spring is made.

The table below gives examples of the hardening and tempering in this way of springs of the following dimensions :—

Number of coils in spring	$5\frac{3}{4}$
Length of the spring	6 inches.
Outside diameter of coils	$4\frac{3}{4}$
Diameter of steel	1

Examples.	Time of Immersion in Oil.	Number of Swings in Oil.
	Seconds.	
First	28	35
Second	36	46
Third	27	36
Fourth	38	40

As will be seen, the spring in the first example was immersed in the oil and slowly swung back and forth for 28 seconds, having been given 35 swings during that time. Upon removal from the oil the spring took fire, was redipped for one second, and then put in the cold water tank to cool off.

The following are examples in hardening and tempering springs of the following dimensions :—

Number of coils in the springs	6
Length of the springs	9 inches.
Inside diameter of coils	$3\frac{1}{4}$
Size of steel	$1 \times 1\frac{1}{2}$ square.

Examples.	Time of Immersion in Oil.	Number of Swings in Oil.
	Seconds.	
First	9	12
Second	8	12
Third	8	12
Fourth	9	12
Fifth	9	12
Sixth	9	12

To keep the tempering oil cool and at an even temperature, the tank of fish oil was in a second or outer tank containing water, a circulation of the latter being maintained by a pump. The swinging of the coils causes a circulation of the oil, while at the same time it hastens the cooling of the spring. The water tank was kept cool by a constant stream and overflow. If a spring, upon being taken from the oil, took fire, it was again immersed as in the first example. Resin and pitch are sometimes added to the oil to increase its hardening capacity, if necessary.

The test to which these springs were subjected was to compress them until the coils touched each other, measuring the height of the spring after each test, and continuing the operation until at two consecutive tests the spring came back to its height before the two respective compressions. The amount of set under these conditions is found to vary from $\frac{3}{8}$ inch, in comparatively weak, to $\frac{7}{8}$ inch for large stiff ones.

The New Haven Clock Company heat their springs in a furnace burning wood, the springs being *kept in the flames only*, and quenched in a composition of the following proportions :— " To a barrel of oil 10 quarts of resin and 12 quarts of tallow are added."

If the springs " fly," that is, break, more tallow is added, but if the fracture indicates brittleness or granulation of the steel, rather than excessive hardness, a ball of yellow beeswax, of about 6 inches in diameter, is added to the above.

These springs are tempered, singly, to a reddish purple by being placed on a frame having horizontally radiating arms like a " star," which is attached at the end of a vertical rod. The spring is laid on the " star " and lowered into a pot of melted lead, being held there a length of time dictated by the judgment of the operator.

The star-shaped frame is termed a sinker, and if upon being lifted from the lead the colour of the spring is too high, a second immersion is given.

APPENDICES