T H E S I S

O N

Heat Treatment of Carbon Steel.

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All carbon steel that is used in tools, springs, and machine parts where tempering is necessary undergoes three distinct heat treatments: first, heating for forging; second, heating for hardening; and third, heating for tempering.

HEATING TO FORGE: The primary requisite for a good forging heat is a clean regular fire in order that the piece being heated will heat uniformly throughout. The fire should be keen enough to heat the piece as rapidly as possible and at the same time heat it clear through without over heating the corners. The piece should be taken from the fire as soon as it is hot enough for forging, as to let it soak in the fire is to injure the texture of the steel. If care is taken, a piece may be heated safely even up to a bright yellow heat when much forging is to be done on it. When ready for forging, the work should be done as quickly as possible; and as the red is leaving the parts intended for cutting edges, they should be refined by light, fast blows continued until the red has disappeared. The advantage gained by this refining is emphasized by a comparison of the grain specimens of the original stock and of the same stock after forging, as shown in Plate 3. In the second specimen, the grain is finer, more uniform, more compact, and is altogether much more to be desired in a tool than the grain in specimen one. The forging of the piece is purely mechanical and may, with ordinary precautions, be successfully done.

HEATING AND HARDENING: The hardening of any tempered piece is of great importance and must be done carefully because it is upon the degree of hardness obtained and the structure of the hardened piece that the efficiency of the resulting tool or part depends. A through and uniform heat as low as will give the required hardness is the best for hardening. The effect of an irregular heat is to cause irregular grain, internal strains, and temper-cracks as shown in specimen no. 10, Plate 3.

The following experiment on the hardening of a high carbon steel bar shows the effects of hardening at different temperatures:- A flat bar, as specimen no. 2, Plate 3, was nicked at distances of about 1/2" beginning at the end and running back for eight spaces. The extreme end of the nicked section was placed in the fire and heated to point of fusion, the heat running back along the bar and becoming less intense at each succeeding nick. The whole bar was then suddenly quenched in cool water and left until all signs of heat had left it. By trying the hardened bar with a file, it was found that that part which was the hottest when quenched was the hardest and that as the parts were less hot when quenched they were less hard. Then the bar was broken at each nick and by examining the grain at the fractures it was comparatively easy to pick out the best specimen. The first and burned piece showed an open crystalized grain, as specimen no.9 Plate 3; the succeeding pieces becoming closer in grain until finally one was found that showed a fine even and velvety grain. This grain shows the best texture for the particular steel when hardened and the temperature at which it was hardened will give the best results. For any carbon steel, this grain should be finer than the grain in the piece before hardening, as no's. 3 and 8 compared to no. 2, Plate 3, and if, in attaining a great enough degree of hardness, the grain is raised, it is certain that a steel higher in carbon must be used for the purpose. The best all-around steel for tools in general is that containing about 1.0 % carbon, better known perhaps as 10 points of carbon. For tools such as scrapers, scribers, small drills, graving tools, etc.in which great hardness is desirable, a steel containing as high as 15 points of carbon may be used successfully. The best temperature for a hard, strong steel must be high enough to harden the metal through but not sufficient to raise the grain. Good practise hardens in water at a cherry red and in oil at a bright red.

An abundance of cooling medium is of primary importance as the quenched piece must be cooled quickly and uniformly. A large piece is more safely hardened in a running stream of the cooling liquid. Several different baths are used for quenching, the most common and most practical of which are water and raw linseed oil. By comparing no's. 3 and 8, the hardened specimens, and no's 7 and 11, the corresponding number one blue tempers, we find that in each case the oil bath gives the best grain. The respective hardness of the two hardened specimens was the same; thus showing that for light pieces, at least, the oil gives the best texture for the same degree of hardness and would, in all probability, give a stronger and more durable tool. In cases where the pieces to be hardened are so large as to overheat an oil bath, it is found that water as a cooling medium will give better satisfaction. The use of an oil bath lessens the liability of uneven hardening and temper cracks and facilitates the tempering of cheap springs as will be shown under the head of spring tempering. Another marked advantage of an oil bath is that the piece does not cool so rapidly and while being hardened throughly, it may be taken from the bath while there is still considerable heat in it and treated to keep it straight.

In hardening any flat or thin piece of steel there is always a tendency for it to warp and twist out of shape and unless some method is employed for either holding it straight while hardening or of straightening it while it still retainssome of the hardening heat, the piece will set in a warped shape. This warping tendency is met by various schemes for straightening the hardened piece and holding it straight until cold. In the case of hardening blades or simple flat springs, they may be taken from the oil while still hot and either placed between two flat surfaces under a weight, clamped down or kept straight by holding them in the hands as shown in no. 1, Plate 4. Heavy pieces such as planer blades, spring leaves, etc. must be clamped to retain their original shape while being hardened. A hardened piece may be straightened as long as it still feels fairly warm. This shows the necessity of keeping a clamped piece under pressure until cold in order to be certain that no warping will occur. A blade that is hardened and kept straight until cold will not warp during tempering, hence the shape of the hardened piece when cold is the final shape of the blade.

TEMPERING: Tempering steel is the act of giving it, after it has been shaped, the hardness necessary for the work it has to do. This is done by first hardening the piece, generally a good deal harder than is necessary and then toughening it by slow heating and gradual softening until it has just the desired hardness. The effect of tempering the hardened piece is to refine the grain and soften and toughen the steel, thus making it stronger and more ductile.

The effect of tempering on the structure or grain of the steel is shown on Plate 3. Starting with the hardened piece no.3, we draw it to a straw (460 F) and then on down through the scale. Fracturing the bar through the colors shown in the order in which they come, we get the specimen grains as shown in no's. 4,5,6,7,and 12 respectively. For each succeeding color or increase of temperature the grain is finer and more compact and the piece tougher. The structure is always crystaline in nature but the crystals are smaller and closer together in each succeeding fracture, no.12 being the finest grained at the highest temperature.

Under ordinary shop conditions, the only guide that a workman has as to the hardness or temperature of the piece which he is tempeing is the color which shows on it as it is heated. These colors are merely the colors of the oxide which appears upon the brightened steel when heated through a given range of temperature. Each color may be relied upon to appear always at a certain temperature but the colors are meaningless unless the relation between the color and the quality of the steel for that color is throughly understood. Hence if a workman knows the color of the oxidefor a particular degree of hardness which he desires in the tool, he can draw the temper to that color and then is reasonably certain that he has the correct texture.

The temper colors run from a light yellow or straw at 460 F through one complete scale to pale blue at 610 then repeating through a second and third scale, the second and third colors being much less distinct and having a wider range of temperature than do those of the first scale. Plate 1 shows color specimens of all the colors used in tempering nearly every class of work. The specimens are made from forged carbon steel hardened in oil, polished, and tempered by hand over a piece of hot metal as shown in no. 2 Plate 4. The colors show distinctly on brightened steel free from oil or grease and are brighter and more distinct the higher the polish on the surface of the hardened piece. The color is only on the surface and will tarnish from handling, hence it is suggested that the specimens should not be touched.

Specimen no.0, Plate 1 was tempered by heating it slowly nearly to a red at each end. This caused the colors to run out in series and the scales to come in order, the number one colors being in the first scale each side of the middle, the numher two colors showing outside the number one, and the number three colors showing faintly still farther toward either end of the piece. It will be noted that the colors in the first scale are closer together than those in either the second or third; a fact which shows that a wider range of temperature is necessary to obtain the complete second or third scale than that required for the first.

The number one colors or colors of the first scale are those generally used for tool work and are shown individually in specimens no's. 1 to 6 inclusive. The number two colors are used for springs and for soft pliable blades and are shown in no's.7 to 10 inclusive. The number three colors are rarely used except on spring steel tempered for watch springs etc. and are never used in shop practise.

Since both number one and number two colors are used in the tempering of springs and only number 1 colors enter into tool tempering, it may be well to take up the subject of springs before touching on tool work. As a foreword to spring tempering, the difference between a No.1

and a No.2 colormust be emphasized. It must be remembered that there is as much difference in the grain, hardness and strength of a No.1 and a No.2 of the same color as there is between two No.1 colors on opposite ends of the scale. This is shown by comparing specimens no's 7 and 12, Plate 3. The difference in structure is as marked as it is between no's 4 and 7 of the same Plate.

Spring tempering is greatly simplified by the use of some such diagram as shown in Plate 2. Plate 1 may be used in connection with this diagram when the workman is not framilar enough with the colors as listed on the diagram. Plate 2 is self-explanatory as regards flat springs and may with a word of further explanation be used to determine the t emper for helical springs. Let N be the total number of turns in the spring, D the maximum deflection in inches, and d the mean diameter of the spring in inches; Then the deflection for each turn is $\frac{D}{N}$ inches, and the of each turn is the mean circumference of the spring or πd inches. Then this spring would require the same temper as a flat spring having a length of πd inches and a maximum deflection of $\frac{D}{N}$ inches and the color for such a spring is obtained from the diagram as indicated.

A diagram similar to Plate 2 may be obtained for any special steel by preparing a set of straight and uniform flat samples and tempering them as no's 1 to 10, Plate 1. Now fasten one end of no.1 securely as in a vise and let this original position be the base line of the diagram. By pulling the outer end of the spring sidewise until it breaks and marking the maximum deflection, we obtain the deflection line for a gold temper. Taking each color of spring and breaking it in a similar manner, always being careful to have the same base line for each spring, we get the maximum deflection for each color and determine the deflection lines by drawing from the points of maximum deflection to the origin O.

In using such a diagram, it is well to remember that it is essential that a spring should be tempered to the full color indicated or even to the next color past, since a safe spring even if slightly weaker is more to be desired than one working under a stress equal to the braeking load.

Methods; Flat springs are most successfully tempered by heating them over a piece of hot steel as shown in No. 3, Plate 4, when a tempering furnace is not at hand. Helical springs are tempered by slipping them on over the end of a piece of hot round stock slightly smaller in diameter than the insine diameter of the spring. This gives the uniform heat which is so necessary for a uniform temper and a reliable spring.

A good method of tempering for cheap springs and one which is fairly reliably is to burn the oil off immediately after hardening. The spring is heated and quenched in oil then taken from the oil and held in the flame until the oil catches fire when it is taken away and the oil allowed to burn off. The haet generated by the burning oil heats the spring and draws the temper. For light springs one burning is sufficient for heavy ones such as helical and heavy flat springs it is generally necessary to burn two or three times, depending upon the size. The temper of a "burned off" spring is about equal to a No. 2 blue.

Tool tempering: Many a tool that has been well forged from good stock and hardened successfully is spoiled in tempering, either by being made too soft or by being left too brittle. This is due entirely to either a misunderstanding of the colors or to a misjudgment of the requirements of the tool. The special qualities desired in tools of various kinds have been determined by long experience and the requirements of them for different work are now met by an exact classification, each class having the same general qualities and being tempered to the same color. By using a classification which has been used in successful practise and supplementing this classification by a color scale for determining exact shades, any general or special tool may be tempered accurately and be depended upon to do the work required of it if that work is within the capacity of a carbon steel tool. The colors should be drawn accurately if the highest efficiency of the tool is to be realized as there is a marked difference in texture for each color and only one color can give the best results.

Following is a classification of tools which covers ordinary shop practise and may, by using Plate 1 as a guide to the colors listed, be relied upon. The correct temper for special tools or for tools not listed may be determined by comparing the rquirements to those of some classified tool. The colors appear the same for either a water or oil hardening bath and the selection of cooling medium does not effect the following classification of colors.

For boring tools, milling cutters, glass cutters, drills for glass, files, hack saws, and lettering tools for granite; Harden in oil and do not draw any color.

Lathe tools and planer tools for cutting iron and steel; Light yellow or straw, (460 F.)

Taps and dies, reamers, razors, marble cutters tools, and shear blades for cutting iron and steel; Gold.

Drills for iron and steel, blacksmith hammers, nippers, wire cutters, butcher cleavers, centre punches, press punches and dies, and bolt cutters; Wine.

Rock drills, stone hammers, picks, and other quarry tools; Wine or Red and blue.

Edge tools, as plane bits, chisels, draw-knives, spoke-shaves, augers, planer blades, wood lathe tools, axes, adzs, hatchets, pocket-knives, durk knives, lances, probes, and physicans knives; Red and blue.

Chipping and cape chisels, keyseat chisels, boiler makers punches, and general all-around cold chisels;

Purple or blue, and repeat on Red for toughness.

Grub-hoes, coal picks, coal augers, horseshoers knives, and tools used in dust; Blue.

Stone cutters tools, as tooth chisels, points, and tools for dressing lime stone and sandstone.; Pale blue.

Butcher knives, carving knives, paring knives, bread knives, and table cutlery; Blue No. II.

For tools that must be harder than either a water or oil bath will harden, harden in quick-silver and do not draw any color.

Methods of tempering: Various methods of drawing the temper are applied, the primary advantage of each being that it gives a uniform heat to the tool. In shop practice a furnace is very rarely at hand and some other means must be used for heating the hardened tool. Any scheme which will give an even heat to the piece to be tempered and at the same time be simple and quick enough to be practical is good. Some tools such as chisels may be tempered with part of the hardening heat by only quenching the part intended for the cutting edge and then, as the heat runs the temper out again, by quenching again as the right color comes to the cutting edge.

A slightly slower though more reliable method is to temper with heat from a separate piece as shown in Plates 4 and 5. No. 2 shows the tempering of a thin bar, as the blade of a knife or a flat spring. No's 3 and 4 show a method of tempering drills, reamers, taps, short lengths of bars, etc. by holding them through a heated ring. The advantage of the ring for round work or that which is nearly round is that it heats uniformly on all sides at the same time. No. 5 shows tempering a hammer in a similar manner. It will be noticed that the temper is drawn from the centre toward each end and that while the ends or faces are drawn to an exact temper, the eye is thoroughly softened. This method also admits of drawing both ends of the hammer at the same heating.

No. 6 shows a method of heating the blade of a pocket-knife for hardening without taking the blade from the handle and without heating the handle. It is simply closed in a pair of hot tongs heated to a bright red heat and when the blade becomes red may be quenched as usual. No. 7 illustrates drawing the temper on the same blade. No. 8 is merely descriptive of tool making by hand.

CASE-HARDENING: When tools or machine parts must be case-hardened, this may be done by putting Potassium Cyanide or Prussiate of Potash on the steel when at a bright red heat and cooling in water at a dull red.

CHILLING: Ball bearings, roller bearings, cone plates, and tools that require it may be chilled by heating and quenching in the following solution: aqua ammonia 2 oz., common soda 2 oz., and common salt 15 lbs., dissolved in one barrel of water.

ANNEALING: Annealing or softening is accomplished by heating steel to a red heat and then cooling it very slowly to prevent rehardening. To anneal any piece of steel, heat it thoroughly and uniformly to a red heat and then allow it to cool as slowly as possible. It is good practise to anneal by cooling in air slaked lime. Annealed steel will cut very soft; it will harden very hard without cracking; and when tempered will be strong, have a fine uniform grain, and will hold a durable edge.

FLUX FOR WELDING: The best welding flux for carbon steel is clean, finely powered borax. The pieces to be welded are heated to a bright red, the borax is placed on the ends to be stuck, and after a few moments in the fire, the pieces may be welded as successfully as wrought iron.

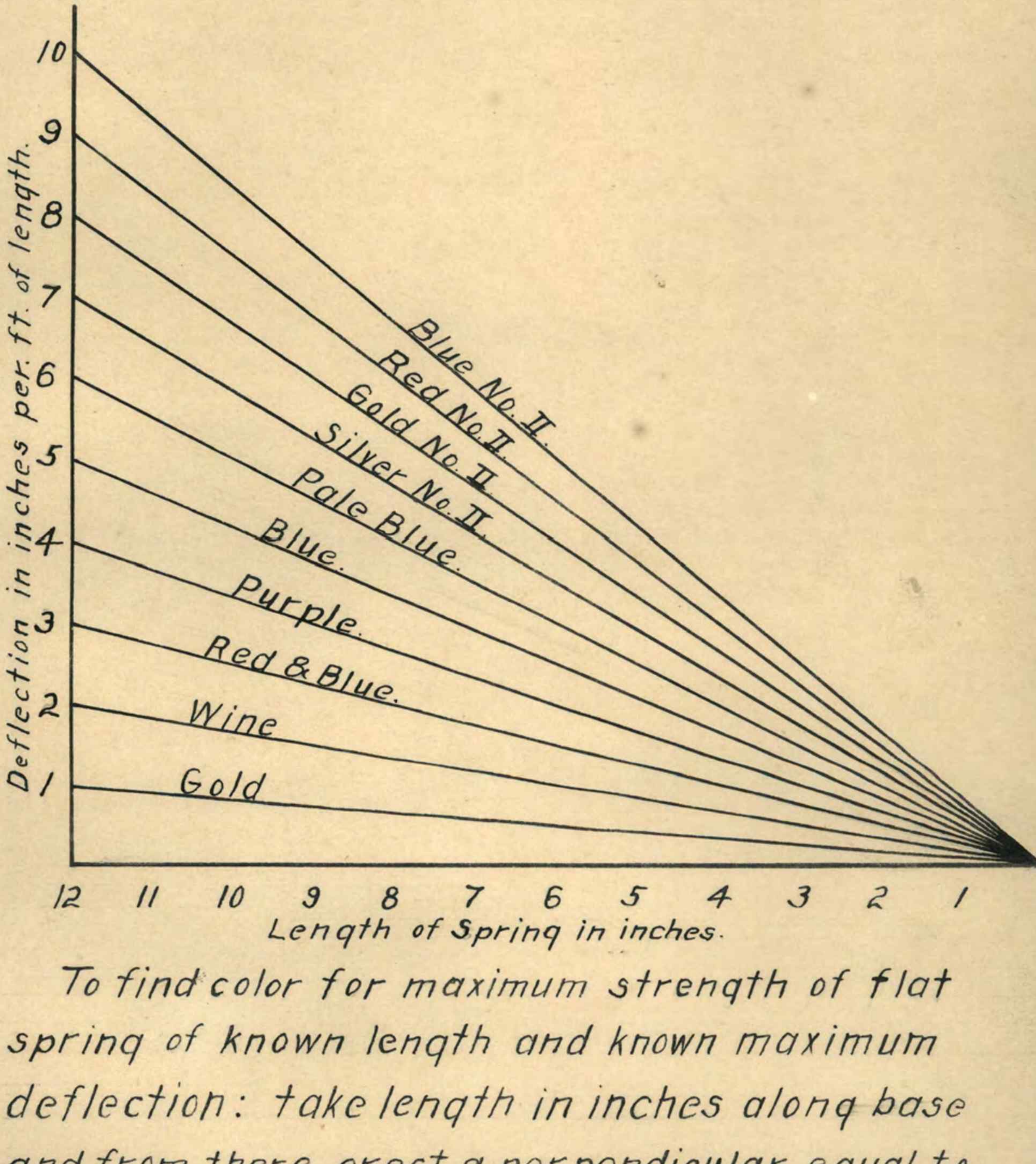
Finis:-

COLOR SPECIMENS

No. 1.	Gold	500° F.
No. 2.	Wine	520° F.
No. 3.	Red & Blue	540° F.
No. 4.	Purple	560° F.
No. 5.	Blue	575° F.
No. 6.	Pale Blue	610° F.
No. 7	Silver No. II.	640° F.
No. 8.	Gold No. II.	680° F.
No. 9.	Red No. II.	710° F.
No. 10.	Blue No. II.	750° F.

Complete Double Scale. No. 0.

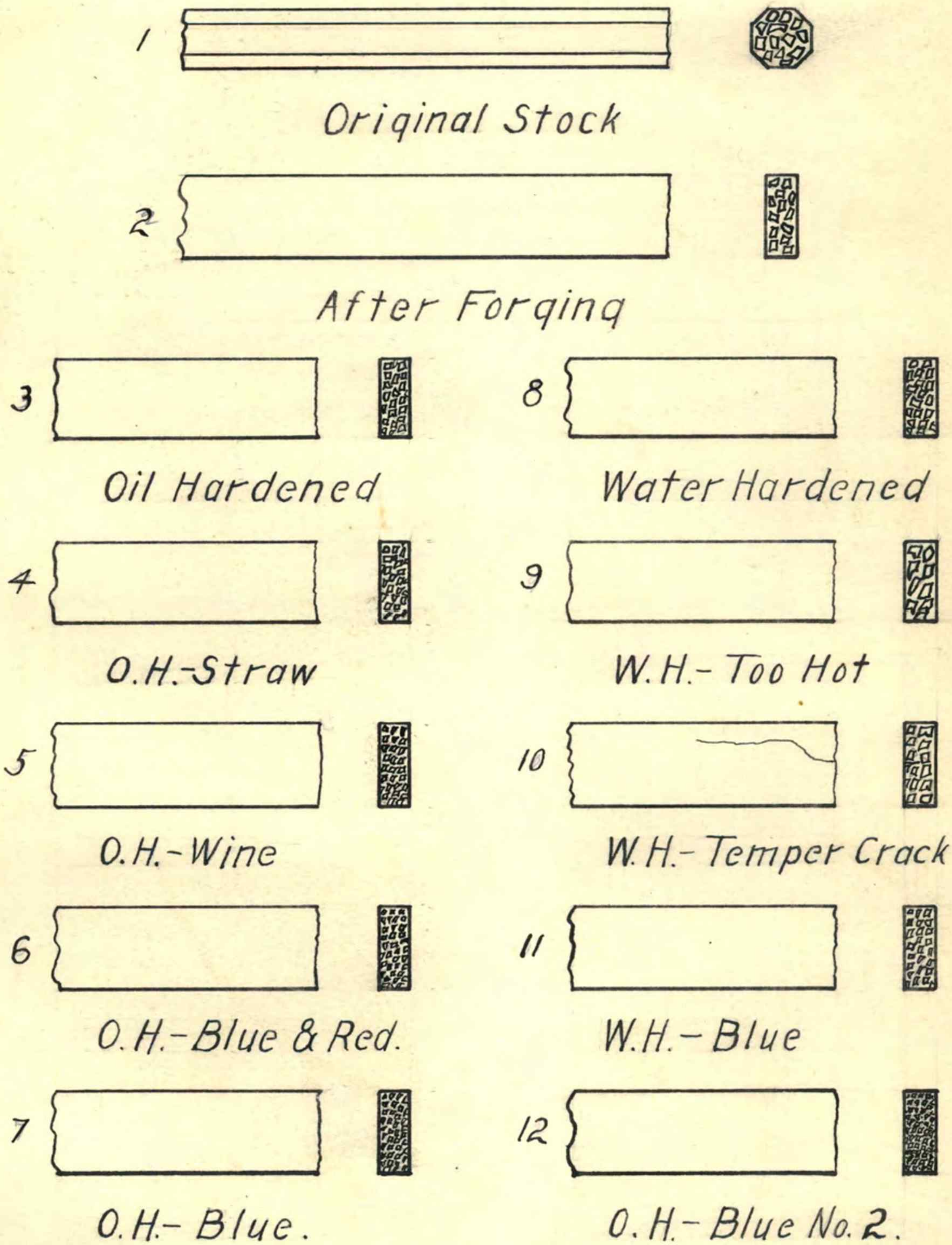
COLOR SCALE FOR SPRINGS



To find color for maximum strength of flat spring of known length and known maximum deflection: take length in inches along base and from there erect a perpendicular equal to deflection in inches and find color on first line above top of perpendicular.

Scale of Drawing :- 1" = 2."

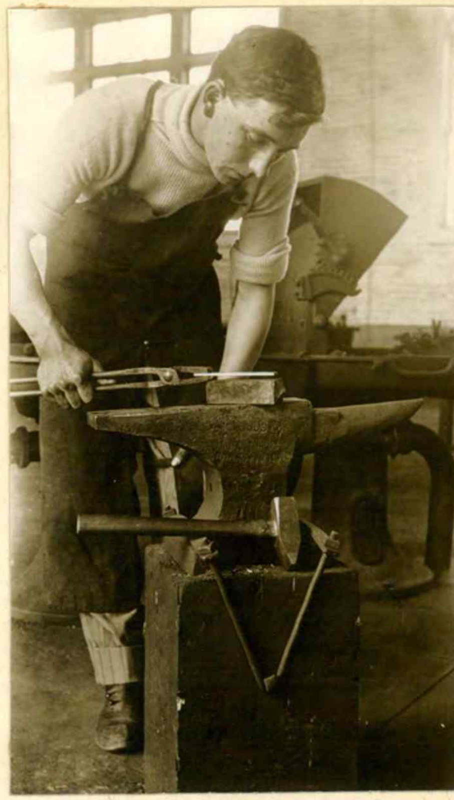
GRAIN SPECIMENS



Note: The grains shown hereon are drawn from steel specimens enlarged to 200 diameters.

Plate No. 1.

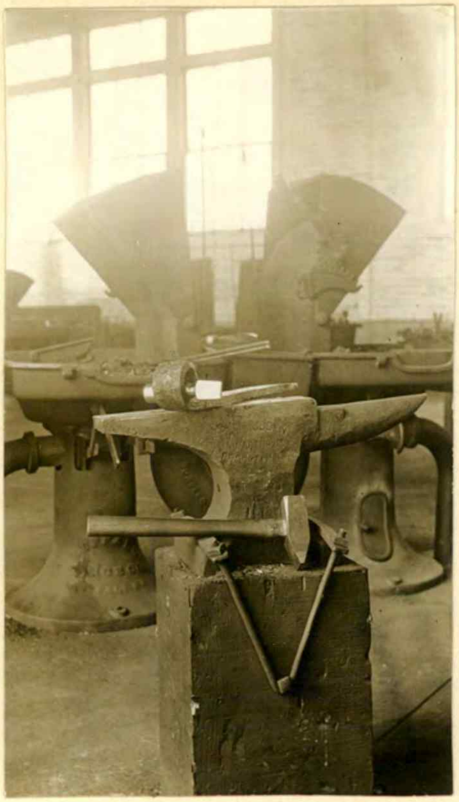
No. 1.



No. 2.

No. 3.

No. 4.



No. 5.

No. 6.

No. 7.

No. 8.