## VIII.

## HARDENING AND TEMPERING.

For nearly all structural and machinery purposes steel is used in the condition in which it comes from the rolls or the forge; in exceptional cases it is annealed, and in some cases such as for wire in cables or for bearings in machinery, it is hardened and tempered.

For all uses for tools steel must be hardened, or hardened and tempered. The operations of hardening and tempering, including the necessary heating, are the most important, the most delicate, and the most difficult of all of the manipulations to which steel is subjected; these operations form an art in themselves where skill, care, good judgment, and experience are required to produce reliable and satisfactory results. It is a common idea that all that is necessary is to heat a piece of steel, quench it in water, brine, or some pet nostrum, and then warm it to a certain color; these are indeed the only operations that are necessary, but the way in which they are done are all-important.

An experienced steel-maker is often amazed at the confidence with which an ignorant person will put a valuable tool in the fire, rush the heat up to some bright color, or half a dozen colors at once, and souse it into the cooling-bath without regard to consequences. That such work

does not always result in disastrous fractures shows that steel does possess marvellous strength to resist even the worst disregard of rules and facts.

On the other hand, the beautiful work upon the most delicate and difficult shapes that is done by one skilled in the art cannot but excite the surprise and admiration of the onlooker who is familiar with the physics of steel, and who can appreciate the delicacy of handling required in the operation.

There are a few simple laws to observe and rules to follow which will lead to success; they will be stated in this chapter as clearly as may be, in the hope of giving the reader a good starting-point and a plain path to follow; but he who would become an expert can do so only by travelling the road carefully step by step. The hair-spring of a watch, or a little pinion or pivot, so small that it can only be seen through a magnifying-glass, the exquisitely engraved die costing hundreds or thousands of dollars, and the huge armor-plate weighing many tons, must all be hardened and tempered under precisely the same laws and in exactly the same way; the only difference is in the means of getting at it in each case.

Referring now to properties mentioned in the previous chapters, we have first to heat the piece to the right temperature and then to cool it in the quickest possible way in order to secure the greatest hardness and the best grain. In doing this we subject the steel to the greatest shocks or strains, and great care must be used.

The importance of uniformity in heating for forging and for annealing has been stated, and it has been shown how an error in this may be rectified by another and a more careful heating; when it comes to hardening, this uniformity must be insisted upon and emphasized, for as a rule an error here has no remedy.

There may be cases of bad work that do not cause actual fracture that can be remedied by re-heating and hardening, but these are rare, because even if incurable fracture does not occur the error is not discovered until the piece has been put to work and its failure develops the errors of the temperer.

If the error is one of merely too low heat, not producing thorough hardening, it will generally be discovered by the operator, who will then try again and possibly succeed; but if the error be of uneven heat, or too much heat, the probabilities are that it will not be discovered until the piece fails in work, when it will be too late to apply any remedy.

Referring to Table I, Chap. V, treating of specific gravities, it is clear that all steel possesses different specific gravities, due to differences of temperature, and that these differences of specific gravity increase as the carbon content increases; it follows that if a piece of steel be heated unevenly, internal strains must be set up in the mass, and it is certain that if steel be quenched in this condition violent strains will be set up, even to the causing of fractures.

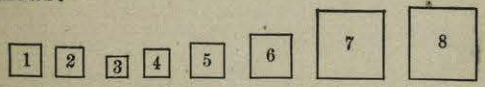
The theory of this action, as of all hardening, is involved in discussion which will be considered later; in this chapter the facts will be dealt with. When a piece of steel is heated, no matter how unevenly or to what temperature below actual granulation, and is allowed to cool slowly and without disturbance, it will not break or crack under the operation. If a piece be heated as unevenly as, say, medium orange in one part and medium lemon in another, and is then quenched, it will be almost certain to crack if it contains enough carbon to harden at all in the common

acceptance of the term, that is to say, file hard or having carbon 40 or higher.

This fact is too well known to be open to discussion; therefore the quenching of hot steel, the operation of hardening, does set up violent strains in steel, no matter what the true theory of hardening may be.

Referring to Chap. V, to the series of squares representing the apparent sizes of grain due to different temperatures, similar results follow from hardening, with the exceptions that the different structures are far more plainly marked, and the squares should be arranged a little differently; they are shown as continuously larger in Chap. V, from the grain of the cold bar up to the highest temperature; this is true if a bar has been rolled or hammered properly into a fine condition of grain. Of course if a bar be finished at, say, medium orange it will have a grain due to that heat—No. 3 in the series of squares. Then if it be heated to dark orange and cooled from that heat it will take on a grain corresponding to square No. 2, and No. 1 square will be eliminated.

The series of squares to represent hardened grain will be as follows:

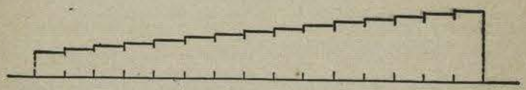


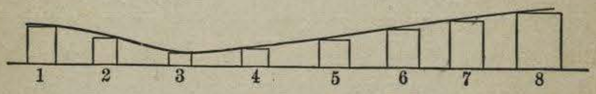
The heat colors being the same as before, viz.:

1. The natural bar—untreated.
2. Quenched at dark orange or orange red.
3. " " medium orange—*refined.*
4. " " bright orange.
5. " " dark lemon.
6. " " medium lemon.
7. " " bright lemon.
8. " " very bright lemon or creamy.

Heats 6, 7, 8 will almost invariably produce cracks although the pieces be evenly heated.

These squares do not represent absolute structures with marked divisions; they are only the steps on an incline, like the temper numbers in the carbon series; thus, the carbon-line is continuous, but the temper divisions represent steps up the incline. So with the series of squares, the changes of grain or structure are continuous, as represented by the doubly inclined line; the squares being only the steps to indicate easily observed divisions. The minuteness of the changes is illustrated by the fact that in a piece heated continuously from creamy to dark orange and quenched, differences of grain have been observed unmistakably on opposite sides of pieces broken off not more than ⅛ inch thick.





In practice the differences due to the colors given in the list above are as plain and surely marked as are the differences in the structure of ingots due to the different temper carbons already described.

In this hardened series each carbon temper gives its own peculiar grain; in low steel, say 40 carbon compared to

1.00 carbon or higher, No. 3 will be larger and No. 8 will be smaller in the low temper than in the high—another illustration of the fact that low steel is more inert to the action of heat than high steel. All grades and all tempers go through the same changes, but they are more marked in the high than in the low steel.

The grain of hardened steel is affected by the presence of silicon, phosphorus, and manganese, and doubtless by any other ingredients, these three being the most common.

It is in the grain of hardened steel that the conditions described in Chap. V as "sappy," "dry," and "fiery" are the most easily and frequently observed, although the same conditions obtain in unhardened steel in a manner that is useful to an observing steel-user. But it is in this hardened condition that the excellences or defects of steel are brought out and emphasized.

When a piece of steel is heated continuously from "creamy," or scintillating, down to black, or unheated, and is then quenched, the grain will be found to be coarsest, hardest, and most brittle at the hottest end, and with the brightest lustre, even to brilliancy, and to become finer down to a certain point, noted as No. 3 in the series of squares, or at a heat which shows about a medium orange color; here the grain becomes exceedingly fine, and here the steel is found to be the strongest and to be without lustre. Below this heat the grain appears coarser and the steel is less hard, until the grain and condition of the unheated part are reached. This fine condition, known as the *refined* condition, is very remarkable. It is the condition to be aimed at in all hardening operations, with one or two exceptions which will be noted, because in this state steel is at its best; it is strongest then, and it would seem to be clear without argument that the finest grain and the strongest will hold the best at a fine cutting-edge, and will do the most work with the least wear, although a coarser grain may be a little harder, the coarser and more brittle condition of the latter more than counterbalancing its superior hardness.

The advantages of this refined condition are so great that it is found to be well to harden and refine mild-steel dies, and battering- and cutting-tools that are to be used for hot work, although the heat will draw out all of the temper in the first few minutes, because the superior strength of the fine grain will enable the tool to do twice to twenty times more work than an unhardened tool.

The refining-heat, like most other properties, varies with the carbon; the medium orange given is the proper heat for normal tool-steel of from about 90 to 110 carbon. Steel of 150 carbon will refine at about a dark orange, and steel of 50 to 60 carbon will require about a bright orange to refine it.

This range is small, but it must be observed and worked to if the best results are desired.

A color-blind person can never learn to harden steel properly.

In studying this phenomenon of refining, the conclusion was reached that it occurred at or immediately above the temperature that broke up the crystalline condition of cold steel and brought it fairly into the second, the plastic condition. Farther observation led to the conclusion that the coarser grain and greater hardness caused by higher heats were due to the gradual change from plastic toward granular condition that takes place as the heat increases. Later investigations have given no reason for changing these conclusions.

When the phenomenon of recalescence was observed and investigated by Osmond and others, different theories were advanced in explanation.

Langley concluded that if recalescence occurred at the change from a plastic to a crystalline condition, then the heat absorbed and again set free during such changes would account for the visible phenomenon of recalescence.

Again, if it should prove that recalescence occurred at the refining point, the conjunction of these phenomena would indicate strongly, first, that refining does occur at the point where this change of structnre is complete in the reverse order, from crystalline to plastic; and second, the first being true, recalescence would be explained as stated, as indicating the inevitable absorption and emission of heat due to such a change.

Langley fitted up an electric apparatus for heating steel, in a box so placed that the light was practically uniform, that is, so that bright sunlight, or a cloudy sky, or passing clouds would not affect seriously the observation of heat-colors.

Pieces of steel were heated far above recalescence, up to bright lemon, and then allowed to cool slowly; in this way recalescence was shown clearly.

It was found to occur at the refining heat in every case, shifting for different carbons just as the refining heat shifts.

Immediately under the pieces being observed was a vessel of water into which the pieces could be dropped and quenched. After observing the heating and cooling until the eye was well trained, pieces were quenched at different heats and the results were noted. It was found that in the ascending heats no great hardness was produced until the recalescence heat was reached or passed slightly; and in the descending heat excessive hardening occurred at a little below the recalescent heat, although no such hardening occurred at that color during ascending heats. This apparent anomaly is due simply to lag. If, in ascending, the piece be held for a few moments at the recalescent point, no increase being allowed, and then it be quenched, it will harden thoroughly and be refined. If, in descending, the cooling be arrested at a little below the recalescence for a few moments, neither increase nor decrease being allowed, and then the piece be quenched, it will not harden any better than if it be quenched immediately upon reaching the same heat in ascending.

Time must be allowed for the changes to take place, and lag must be provided for.

These experiments show that refining and recalescence take place at the same temperature.

### AS TO HARDNESS.

Prof. J. W. Langley showed by sp. gr. determinations that steel quenched from 212° F. in water at 60° F. showed the hardening effect of such quenching, the difference of temperature being only 152° F.

Prof. S. P. Langley, of the Smithsonian, proved the same to be true by delicate electrical tests, and these again were confirmed by Prof. J. W. Langley in the laboratory of the Case School of Sciences.

A piece of refined steel will rarely be hard enough to scratch glass. A piece of steel quenched from creamy heat will almost always scratch glass. The maximum hardness is produced by the highest heat, or when temperature minus

cold is a maximum; the least hardness is found by quenching at the lowest heat above the cooling medium, or when temperature minus cold is a minimum—the time required to quench being a minimum in both cases.

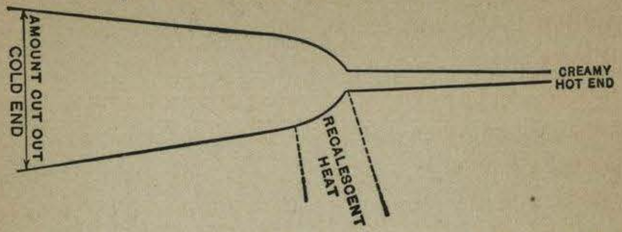
What occurs between these limits? Is the curve of hardness a straight line, or an irregular line?

Let a piece of steel be heated as uniformly as possible from a creamy heat at one end to black at the other, and then be quenched.

Now take a newly broken hard file and draw its sharp corner gently and firmly over the piece, beginning at the black-heated end. The file will take hold, and as it is drawn along it will be felt that the piece becomes slightly harder as the file advances, until suddenly it will slip, and no amount of pressure will make it take hold above that point. The piece has become suddenly file hard.

Next try the same thing with a diamond; the diamond will cut easily until the point is reached where the file slipped, then there will be found a great increase of hardness.

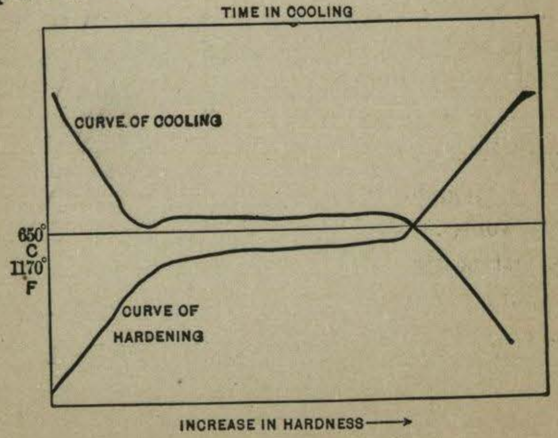
From this point to the end of the piece it is observed readily by the action of the diamond that there is a gradual increase of hardness from the hump to the end of the piece to the creamy-heated end. Attempts were made to measure this curve of hardness by putting a load on the diamond and dragging it over the piece; but no diamond obtainable would bear a load heavy enough to produce a groove that could be measured accurately by micrometer. An examination of such a groove, through a strong magnifying-glass revealed the conditions plainly; the groove of hardness may be illustrated on an exaggerated scale ; thus:



The next question was, Where does this hump occur, and what is the cause of it?

Careful observation showed that it occurred at the point of recalescence, at the refining-point. This word point must not be taken as space without dimension in this connection; it is used in the common sense of at or adjacent to a given place. There is of course a small allowable range of temperature above any given exact point of recalescence, such as 655° C. or 1211° F.

By superimposing Langley's curves of cooling and of hardening (see Trans. Am. Soc. Civ. Eng., Vol. XXVII, p. 403), the relation between recalescence and the hardening-hump is obvious.



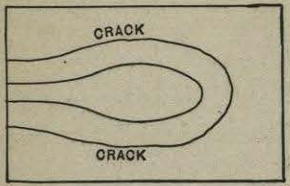
It is safe to say that experience proves that the *refined* condition is the best for all cutting-tools of every shape and form.

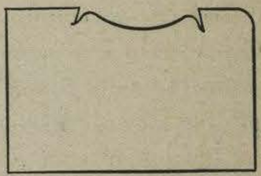
It seems to be obvious; the steel is then in its strongest condition, and when the grain is finest, the crystals the smallest, a fine edge should be the most enduring, because there is a more intimate contact between the particles. That a steel will refine well, and be strong in that condition is the steel-maker's final test of quality.

No steel-maker who has a proper regard for the character of his product will accept raw material upon mere analysis; analysis is of the utmost importance, for material for steel-making must be of a quality that will produce a certain quality of steel, or the result will be an inferior product. This applies to acid bessemer and open-hearth, and to crucible-steel especially; the basic processes admit of a reduction of phosphorus not obtainable in the others.

In making fine-tool steel a bad charge in the pot inevitably means a bad piece of steel. It may happen also that an iron of apparently good analysis will not produce a really fine steel; then there must be a search for unusual elements, such as copper, arsenic, antimony, etc., or for dirt, left in the iron by careless working. The refining-test then is as necessary as analysis, for if steel will not refine thoroughly it will not make good tools. Battering-tools, such as sledges, hammers, flatters, etc., should be refined carefully, for although their work is mainly compressive they are liable to receive, and do get, blows on the corners and edges that would ruin them if they were not in the strongest condition possible.

The reasons for refining hot-working tools have been stated already. Engraved dies for use in drop-presses where they are subjected to heavy blows are undoubtedly in the most durable condition when they are refined, but they are subjected not only to impact, but to enormous compression, and therefore they must be hardened deeply. When a die-block is heated so as to refine, and then is quenched, it hardens perfectly on the surface and not very deeply, and it is quite common in such a case to see a die crushed by a few blows: the hardened part is driven bodily into the soft steel below it, and the die is ruined; thus:





To avoid this, such a die should be heated to No. 5, or a dark lemon, and quenched suddenly in a large volume of rushing water.

It will then have the enormous resistance to compression that is so well known in very hard steel, and it will be hardened so deeply that the blow of the hammer will not crush through the hard part. This is the best condition, too, of an armor-plate that is to resist the impact of a projectile.

It will be brittle, a light blow of a hammer will snip the corners, but it cannot be crushed by ordinary work. Dies made in this way have turned out thousands of gross of stamped pieces, showing no appreciable wear.

To harden a die in this way is a critical operation, because the strains are so enormous that a very trifling unevenness in the heat will break the piece, but the skill of expert temperers is so great that they will harden hundreds of dies in this way and not lose one if the steel be sound.

### HEATING FOR HARDENING.

A smith can heat an occasional piece for hardening, in his ordinary fire by using care and taking a little time. Where there are many pieces to be hardened, special furnaces should be used.

For thousands of little pieces, such as saw-teeth or little springs, a large furnace with a brick floor, and so arranged that the flame will not impinge on the pieces, is good.

The operator can watch the pieces, and as soon as any come to the right color he can draw them out, letting them drop into the quenching-tank, which should be right under the door or close at hand.

For twist-drills, reamers, etc., a lead bath, or a bath of melted salt and soda, is used. The lead bath is the best if care be taken to draw off the fumes so as not to poison the heaters. Because a bath of this kind is of exactly the right color at the top it is not to be assumed that pieces can be heated in it and hardened without further attention.

Thousands of tools are ruined, and thousands of dollars are thrown away annually, by unobserving men who assume that because a lead bath appears to be exactly the right color at the surface it is therefore just right.

A dark orange color surface may have underneath it an increasingly higher temperature, up to a bright lemon at the bottom, and tools heated in such a bath will have all of the varying temperatures of the bath; then cracked tools, twisted tools, brittle tools, tools too hard at one end and not hard enough at the other, will come out with exasperating regularity.

All of this can be avoided by a simple thorough stirring of the bath, to be done as often as may be necessary to keep it uniform.

In heating toothed tools, taps, reamers, milling-cutters, and the like, care should be taken that the points of the teeth never get above the refining-heat, the dark or medium orange required. It is no easy matter to do this except in a uniform bath, but it must be done. If the teeth are bright lemon, or even bright orange, when the body of the tool is at medium orange refining-heat, the probabilities are that they will shell off from the hardened tool as easily as the grains from a cob of corn.

Even if they are not so bad, if they do not crack off, they will be coarse-grained and brittle; they will not hold a good edge, and they will not do good work. If a long tool, such as a drill, etc., be heated medium orange on one side and bright orange on the other,—a difference of 100° to 200° F.,—and be quenched, it will come out of the bath curved; it must be curved. In quenching a long tool which it is desired to have straight it should be dipped vertically, so as to cool all around the axis simultaneously. If such a tool be dipped sideways, it will come out bent. In heating edge-tools of all kinds it is best to heat first the thicker part, away from the edge, and then when the body has come up to the refining-heat to draw the edge into the fire and let it come up last; as soon as a uniform color is reached quench promptly. If the edge be exposed to the fire in the beginning of the operation, it will almost certainly become too hot before the thicker parts are hot enough.

When a smooth, cylindrical piece is to be hardened, it should be rolled around from time to time while heating, unless it is in a lead bath; if it be left to lie quietly in a furnace until it is hot, it will have a soft streak along the part that was uppermost.

The cause of this is not clear; the fact is as certain as hundreds of tests can make any fact. The experiment can be made by re-heating the piece with the soft streak down; then the original soft streak will come out hard, and another soft streak will be found on top. The changes can be rung upon this indefinitely.

A maker of roller-tube expanders had great trouble with his expander-pins; they cut, and wore out on one side. He tried many makes and many tempers of steel with the same result. He was told to turn his pins over and over as he heated them and his troubles would end. He replied: "Why, of course; I can see the reason and sense in that." If he did see the reason, he is the only person known, so far, who has done so. His pins worked all right from that time.

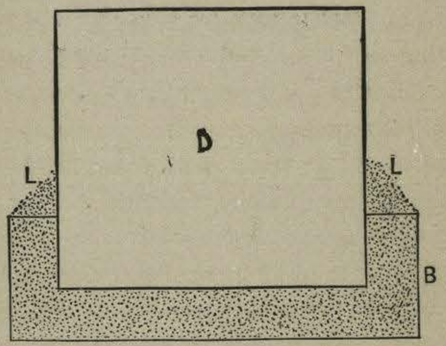
*In hardening* ROUND SECTIONS it is necessary to use great care to have the heat perfectly uniform and not too high, because the circular form is the most rigid, offering the greatest resistance to change. For this reason a round piece will be almost certain to split if it be heated above a medium orange, or if it be heated unevenly. Many a round piece is cracked by a heat, or by a little unevenness of heat, that another section would endure safely. A roll with journals is perhaps the most difficult of all tools to harden successfully; the most expert temperers will not be surprised at losing as many as one roll in five.

*Engraved dies* require to be hardened without oxidizing the engraved face, so that the finest lines will be preserved clear and clean.

This is done by burying the engraved face in carbonaceous material in such a way as to prevent the flame or any hot air from coming in contact with it.

There are many ways of doing this, and many different carbonaceous mixtures are used ; one simple, and known to be satisfactory, plan will be explained as sufficient to give any intending operator a good starting-point.

The carbonaceous material preferred is burnt leather powdered—and the older it is the better—until it is reduced to ash, so that the material should be saved after each operation to be used again mixed with enough new material to make up the necessary quantity.



*D* is the die to be heated ; *B* is an open box about two inches deep and one inch larger each way than the die; *L* is the burnt leather packed in thoroughly, and as full as the box will hold. The engraved face is down, embedded in the burnt leather, and secure from contact with flame or air.

Sometimes powdered charcoal is used, with or without a mixture of tar, according to the fancy of the operator.

Some operators prefer to have the box so high as to leave only the top surface of the embedded die exposed, but the most successful workers prefer the plan sketched, because they can see more of the die, and so regulate better the even heating.

The die and box are put in the furnace, and the heating is watched, the die being turned and moved about in the furnace so as to obtain a perfectly even heat.

When the right temperature is reached, the whole is withdrawn from the furnace; the die is lifted out of the box and plunged into the water immediately. There must be no delay at this point whatever; a few moments' exposure of the hot die to the air will result in oxidation and scaling of the engraving.

In heating such a die a furnace should be used. It can be done in a smith's fire, but it is a hazardous plan, and gives many chances for a failure.

A furnace with an even bed of incandescent coke is good, and such a furnace is very useful for many other purposes.

Where many dies are to be hardened, the handiest appliance is a little furnace with brick floor and lining, and heated by petroleum or gas, so arranged that the flames will not impinge upon the piece to be heated.

Such furnaces are now made to work so perfectly that illuminating-gas is found to be an economical fuel.

For quenching there should be plenty of water. For small dies that can be handled easily by one man a large tub or tank of water will answer if the operator will keep the die in rapid motion in the water.

Running water is the best. A handy plan is to have the inlet-pipe project vertically a short distance through the bottom of the tank, producing a strong upward current which will strike directly against the face of the submerged die.

Some prefer a downward stream; others a side stream; others, again, prefer a shower-bath; and, again, some use side jets.

A very efficient tank has a partition running from a few inches from the bottom to within a few inches of the surface of the water, and so placed as to separate, say, nine tenths of the tank from one tenth. In the smaller compartment there is an Archimedean screw driven at a speed of 200 to 300 revolutions; this drives the water under the partition and out over the top in a violent current. The steel is quenched in the larger space. Where water is an item of expense, this plan is economical, and it is certainly efficient.

An excellent way of quenching large faces, such as anvils, is to have a tank raised twelve to fifteen feet from the floor. In the bottom of the tank is a pipe with a valve, to be operated by a lever. The whole is enclosed in a sort of closet with a door in one side. When the piece is hot, it is placed immediately under the pipe, the door is closed, the valve is opened, and a great body of water is dashed down upon the face that is to be hardened.

A slight modification of this plan is used in hardening armor-plates, where many jets are used to insure even quenching of the large surface. This plan is supposed to be patented, or, more properly, it is patented; but as it is very old and well known the patent should not be allowed to disturb anybody.

Water only has been mentioned so far as a quenching medium, because it is the simplest and the cheapest generally. Oil is used frequently where extreme hardness is not necessary and toughness is desirable. Oil gives a good hardness with toughness, and it is used almost universally for springs, and it is sometimes used to toughen railroad axles and similar work. The oil acts more slowly than water and leaves the piece in more nearly a tempered condition; it is neither so hard nor so brittle as it would be if quenched in water. Straits fish-oil is good and cheap; lard-oil gives greater hardness than fish-oil; mineral oil is too fiery to use safely; but there are mixed oils in the market made expressly for hardening which are cheap and efficient.

If it is desired to get the greatest hardness, brine will harden harder than fresh water; and mercury will give the greatest hardness of all. It is a rather expensive cooling medium.

Acid added to water increases its hardening power; but those who know the effects of acids will be very chary of using them.

As to heating, too much emphasis cannot be given to the importance of even temperature throughout the mass. The illustration of the painted piece mentioned in connection with heating for forging applies more forcibly here. Every piece that is to be quenched should look as if it were covered with a perfectly even coat of paint of the exact tint necessary to give the best result.

All hardening should be done on a rising temperature, because then the grain and strains cannot be greater than those due to the highest heat, and this maximum heat can be watched and kept within limits. If a piece be quenched from a falling temperature, the grain and strains will be those due to the highest temperature, modified slightly by the distance through which it has cooled, and always coarser and more brittle than if quenched at the same heat produced by rising temperature. If by accident a piece gets too hot to be quenched, it should be allowed to go entirely cold, and then be heated again to the right color.

After a piece of steel is hardened it is usually tempered to relieve some of the strain, reduce brittleness, and increase the toughness.

This is done by heating; usually the piece is held over the fire, or in contact with a large piece of steel or iron heated for the purpose, until it takes on a certain color which indicates the degree of tempering that is wanted.

Where great numbers of pieces are to be tempered, a bath is very convenient. Boiling in water produces only a slight tempering sufficient for some purposes. Steaming under given pressure will produce even heating and uniform tempering.

When pieces are quenched in oil, they can be tempered easily and nicely by watching the oil that adheres to them. When the oil is dried off and begins to char, the tempering is good, about right for saw-teeth. If the heat is run up until the oil flashes, the tempering is pretty thorough and is about right for good springs. If the oil be all burned off, there will be little temper left except in very high steel. High steel becomes much harder when quenched than low steel; consequently very high hardened steel may be heated until it begins to show color and still retain considerable hardness or temper, whereas a milder steel, under 90 or 100 carbon, when heated to such a degree will retain no temper, it will be soft.

Saw-teeth, tap, reamer, and milling-cutter teeth, may be drawn, and usually should be drawn, down until a file will barely catch them; then they will do excellent work. Many

inexperienced temperers are apt to complain if such tools can be filed at all when drawn to the proper color, forgetful or ignorant of the fact that a file should always contain about twice as much carbon as a tap or reamer, and that if both are drawn to the same color the file must necessarily be the harder. Such men often destroy much good work by trying to get the tools too hard. If a tap-tooth be left file hard, it will be pretty certain to snip off when put to work.

### TEMPER COLORS.

When a clean piece of iron or steel, hardened or unhardened, is exposed to heat in the air, it will assume different colors as the heat increases. First will be noticed a light, delicate straw color; then in order a deep straw, light brown; darker brown; brown shaded with purple, known as pigeon-wing; as the brown dies out a light bluish cast; light brilliant blue; dark blue; black.

When black, the temper is gone. It is well established that these colors are due to thin films of oxide that are formed as the heat progresses.

These colors are very beautiful, and as useful as they are beautiful, furnishing an unvarying guide to the condition of hardened steel.

The drawing of hardened steel to any of these colors is *tempering*.

So we have the different tempers:

| | |
|---|---|
| Light straw........ | For lathe-tools, files, etc. |
| Straw............ | " " " " " |
| Light brown....... | " taps, reamers, drills, etc. |
| Darker brown...... | " " " " " |
| Pigeon-wing....... | " axes, hatchets, and some drills |
| Light blue........ | " springs |
| Dark blue......... | " some springs; but seldom used |

This is the unfortunate second use of the word temper, which must be borne in mind if confusion is to be avoided in consulting with steel-makers and steel-workers. The meanings may be tabulated thus :

| Temper. | Steel-maker's Meaning. | Steel-worker's Meaning. |
|---|---|---|
| Very high.......... | 150 carbon + | light straw |
| High .............. | 100 to 120 C | straw |
| Medium.............. | 70 to 80 C | brown to pigeon-wing |
| Mild................ | 40 to 60 C | light blue |
| Low................. | 20 to 30 C | dark blue |
| Soft or dead soft...... | under 20 C | black |

The uses given for temper colors are not meant to be absolute; they merely give a good general idea; experienced men are guided by results, and temper in every case in the way that proves to be most satisfactory.

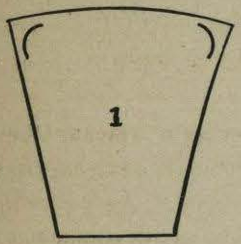
### DIFFERENCE BETWEEN CRACKS AND SEAMS.

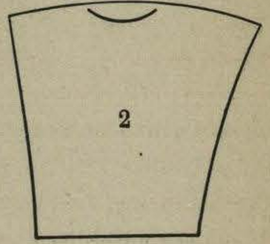
When temperers find that their tools are cracking under their treatment, they are apt to assume that, as they are working in their ordinary way, there must be something wrong with the steel. It is either seamy, or harder than usual, or not uniform in temper, or it is of inferior quality.

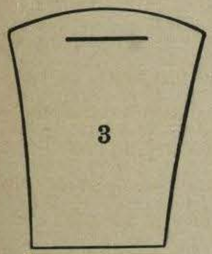
All or any of these conditions may exist and be the cause of the trouble; but every man should bear in mind that he is also a variable quantity; he may be unwell and not see and observe as closely as usual; there may be a long spell of unusual weather giving him a light differing from that to which he is accustomed; or, as is often the case, he may simply have unconsciously departed from the even track by not having his mind carefully intent upon the routine which has become a sort of second nature to him, so that for a time he ceases to think, makes of himself an animated machine, and the machine left to itself does not run with perfect regularity.

If personal pride, egotism, or ill temper be set aside, it is always easy to find out whether the fault is in the steel or in the man ; that once determined the remedy is easily applied, and the sooner the better for all parties.

*How to Break a Tool.* Let an ordinary axe be considered.







If the axe be cracked as shown in Fig. 1, the corners have been hotter than the middle of the blade; probably by snipping the corners and the middle and comparing the fractures the coarser grain at the corners will tell the tale.

If the crack be as shown in No. 2, the middle of the blade has been hotter than the corners ; snipping and comparing the grains will tell the story.

If the crack be more nearly a straight line, as shown in number 3, the chances are that there is a seam there and the steel is at fault.

*How to Tell a Seam from a Water-crack.*—A seam is caused by a gas-bubble in the ingot which has not been closed up by hammering or rolling; it always runs in the direction of the work; in bars it is parallel to the axis.

The walls of a seam are always more or less smooth, the surfaces having been rubbed together under heavy pressure during hammering or rolling, and they are black usually, being coated with oxide.

The walls of a water-crack are never smooth, they are rough and gritty, and they may have any of the temper colors caused by the action of water and heat.

There need never be any question as to which is which.

If a long tool cracks down the middle, it may be from too much heat, from seams, or from a lap.

A lap is caused by careless working under a hammer, or by bad draughts in the rolls, folding part of the steel over on itself. Laps, like seams, run parallel to the axis of a bar, and usually in very straight lines.

Any long piece of steel may be split in hardening by too much heat. In making the experiment of heating a piece continuously from scintillating, or creamy color, down to black, to show the differences of grain due to the different heats, the sample almost invariably splits down the middle as far as the strong, refined grain, or nearly that far.

As stated before, a round bar will be almost certain to split if it be heated up to medium lemon, although a square bar may endure the same heat without cracking.

An examination of the walls of a split will settle at once whether it is a seam, a lap, or a water-crack.

A seam will not necessarily be long; its walls will be smooth.

A lap usually runs the whole length of the bar, and the walls are smooth.

By smooth walls of seams and laps comparative smoothness is meant; they are sometimes polished, but not always, and they are never granular like the walls of water-cracks.

If the split be a water-crack, the walls will be rough and granular.

After a temperer has straightened himself out, and brought his work to usual accuracy and uniformity, if his tools continue to crack and indicate weakness in the steel, it is time for him to suspect the character of his material and to require the steel-maker to either show up the faults in tempering, or improve the quality of his product.

### A WORD FOR THE WORKMAN.

*Give him a chance.* A steel-worker to be expert must have a well-trained eye and know how to use it. He must work with delicate tints, ranging in the yellows from creamy yellow to dark orange or orange red as extremes, and most of his work must be done between bright lemon and medium orange in forging, and between rather dark to medium orange, or possibly nearly light orange, when hardening and tempering.

Probably in no other business is there such ridiculous waste as is often found in steel-working where the manufacturer economizes in his blacksmiths.

A large, wealthy railroad condemns a brand of steel. The steel-maker goes to the shop and is informed by a bright, intelligent blacksmith that the steel will not make a trackchisel. It is a hot summer day; the smith is working over a huge fire with a large piece of work in the middle of the fire and a number of small pieces of steel stuck in the edge of the fire.

He is welding large iron frog-points, and in the interval he is filling a hurried order for four dozen track-chisels for which the trackmen are waiting. He is not merely forging the chisels, he is hardening and tempering them. The glare of the welding-work makes him color-blind, the hurry gives him no time for manipulation, and the trackmen have no chisels.

After a thorough expression of sympathy for the smith the steel-maker turns upon the foreman and master mechanic, and gives them such a tongue-lashing that they turn away silenced and ashamed.

Page after page of such cases could be written, but one should be enough.

A steel-maker has a thoroughly skilled and expert steel-worker; he rushes into the shop and says, "Mike, refine this right away, please; I want to know what it is."

Mike replies, "I will do that to-morrow; I am welding to-day."

That is entirely satisfactory; those men understand one another, and they know a little something about their business.

A temperer should do no other work when he is heating for hardening, and he should always be allowed to use as much time about it as he pleases, assuming that he is a decently honest man who prefers good work to bad; and as a rule such honest men are in the majority, if they are given a fair chance.

# IX.

## ON THE SURFACE.

THE condition of the surface of steel has much to do with its successful hardening and working.

A slight film adherent to the surface of steel will prevent its hardening properly; the steel may harden under such a film and not be hard upon the immediate surface, and, as in almost every case a hard, strong surface is necessary to good work, it is important that a piece of steel to harden well should have a clean surface of sound steel.

It has been stated already that all bars and forgings of steel have upon the surface a coat of oxide of iron, and immediately beneath this a thin film of decarbonized iron.

Neither of these substances will harden, and in every case where a hard-bearing surface or a keen-cutting edge is desired these coatings must be removed. Polished drill-wire and cold-rolled spring-steel for watches, clocks, etc., should have perfect surfaces, and it is the duty of steel-makers to turn them out in that condition. All black steel, or hot-finished steel, contains these coatings.

In the manufacture of railroad, wagon, and carriage springs it is not necessary or customary to pay any attention to these coatings; the body of the steel hardens well, giving the required resilience and elasticity, so that an un-