remarks apply to this method as to heating in cyanide of potassium.

Glass heated in a crucible until it is red-hot is the means used by some watch makers to heat the hair springs of the watches. It is claimed that the nature of steel heated in this manner will not change in the least.

Very little attention is paid in most shops to the location of the forge or furnace used in heating steel; generally any out-of-the-way place is selected. If there is any portion of the shop that cannot be utilized for anything else, it is given up to this purpose.

The fire for heating steel should receive more consideration, so far as location is concerned, than almost any other part of the equipment. It should never be located where the direct rays of the sun or any strong light can shine in it, or in the operator's eyes, for uneven results will surely follow. It should never be located in or near a window, neither should the roof be constructed with skylights which allow any of the sun's rays or any strong light to enter the portion of the room where the furnace is located.

An ideal place for the location of a furnace used in heating steel for hardening, is in a room so constructed that no rays of sunshine or direct light can enter it.

It is extremely important that due consideration is given the subject of ventilation. Some means should be provided whereby pure air can be freely supplied without creating drafts, which would cause the operator, who is perspiring freely, to take cold. The room should be so located that it will not be damp, or the health of the workman would be hazarded.

Too often in the past the precautions noted have

received very little consideration, because those in charge did not realize the importance of a properly equipped or located room in which to do this class of work.

Heating Tool Steel.

Tool steel is very sensitive to the action of heat. A slight difference in temperature after a piece has reached the proper hardening heat will be noticeable in the grain of the steel. When heating for hardening, the lowest possible heat that will give the desired result should be used. The amount of heat necessary to produce this result depends on the make of the steel, the percentage of carbon it contains, the percentage of other hardening elements that may be in the steel, the size of the piece, and the use to which it is to be put when hardened—all these must be taken into consideration. A steel low in carbon requires a higher heat than a piece of high carbon steel in order that it may be as hard. A small tool does not require as much heat as a larger one of the same general outline. A tool with teeth or other projections will harden at a lower heat than a solid piece of the same size made from the same bar of steel. There is a proper heat at which a piece of steel *should* be hardened in order to produce the best results, but *this heat varies*, as previously explained.

If two milling machine cutters were made from two different makes of steel the writer has in mind, and were heated in a manner that would give excellent results in the case of one, the other would not harden satisfactorily. Now, were the operator to heat both to the proper hardening heat for the other make, the first one mentioned would be unfitted to do what was expected of it. Either make of steel would give good results if heated to its proper heat.

The commonly used expression of degrees of heat which tool steel should receive is a cherry red. The writer cannot dispute the appropriateness of this term, but cherry red is a varying color when applied to the hardening heat of tool steel, and also when applied to cherries. Mr. Metcalf, in his work on steel, styles this heat as the refining heat, and this seems to express the idea nicely.

Steel should be heated to a temperature that, when hardened and broken, the fracture will show the grain to be the finest possible, and the steel will be hard. Now, if we heat a piece from the same bar a trifle hotter and break it, the fracture will show a coarser grain. The hotter the piece is heated, the coarser the grain becomes; and the coarser it is, the more brittle the steel is. While, to be sure, steel heated a trifle above the refining heat will be somewhat harder than if heated to the refining heat, yet the brittleness more than offsets the extra hardness; and if it is to be used, it will be found necessary to draw the temper in order to reduce the brittleness to a point where it is practical to use the tool.

After taking the necessary means to reduce the brittleness as described, an examination of the tool will reveal the fact that in drawing the temper we have

softened the piece to an extent that it is not as hard as the piece hardened at the refining heat. Neither will it do anywhere near the amount of work, as the grain is open and when the pressure is applied in the operation of cutting, the surface caves in because of the open grain. The surface has not the backing it would have, were the grain close or fine.

A method which the writer has used in his experiments and also in demonstrating the effect of heat on the grain of steel is to take six pieces of steel that can

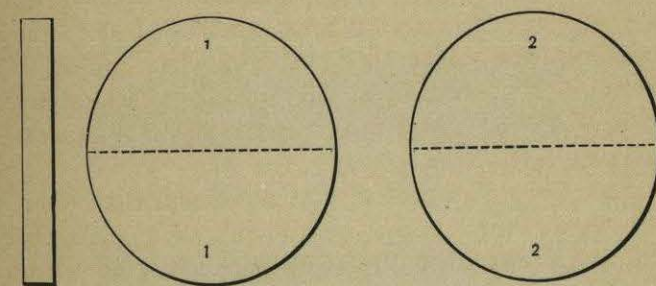

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Figure 21. Test pieces.

be readily broken. Cut the required number from a bar 1 inch to 1½ inches diameter, having the pieces about $\frac{3}{16}$ of an inch thick. Now heat the pieces one at a time in a furnace so situated that no rays of the sun or any strong light can shine either into the fire or into the eyes of the operator. It is advisable to have the furnace located in a room that can be darkened so that it is neither light nor extremely dark, but it must be uniform throughout the experiment. Now heat one piece until it shows somewhat red, yet a certain black is discernible in the center of the piece. Dip into the bath and work it around well; leave until cold. Now heat another piece until it shows the lowest red possible throughout with no trace of black. Heat the third piece a trifle hotter, and continue to heat each piece hotter than the preceding one until they are all hardened, heating number 6 to what is familiarly termed a *white* heat.

Previous to heating, each piece should be stamped in two places, as shown in Fig. 21, in order that the pieces may be broken across the center, as indicated by the dotted lines, and yet the halves of the same piece be easily recognized. When heating, commence with the piece marked 1, and heat consecutively. After hardening them all at the different heats, dry thoroughly in saw dust or by any means whereby the surface may be made perfectly dry, after which they may be broken. This can be done by screwing the piece in the jaws of a vise, putting about one half of it below the tops of the jaws. With a hammer the upper part may be broken off, being careful that the piece does not fly and strike so as to stain the walls of the fracture; or the part projecting above the vise may be caught between the jaws of a monkey wrench and the piece broken.

An examination of the piece marked Fig. 22 will show it to be somewhat hardened. The grain will not be especially fine and will have a peculiar appearance. No. 2 will be very hard and the grain will be very fine. It will break with very ragged walls, as shown. No. 3 will also be very hard and the grain not as fine as No. 2. The grain of No. 4 will be coarser than No. 3. No. 5 will be coarser than No. 4, while the grain of No. 6 will be extremely coarse and the steel unfitted for anything but the scrap heap.

It will pay any man who is desirous of learning to

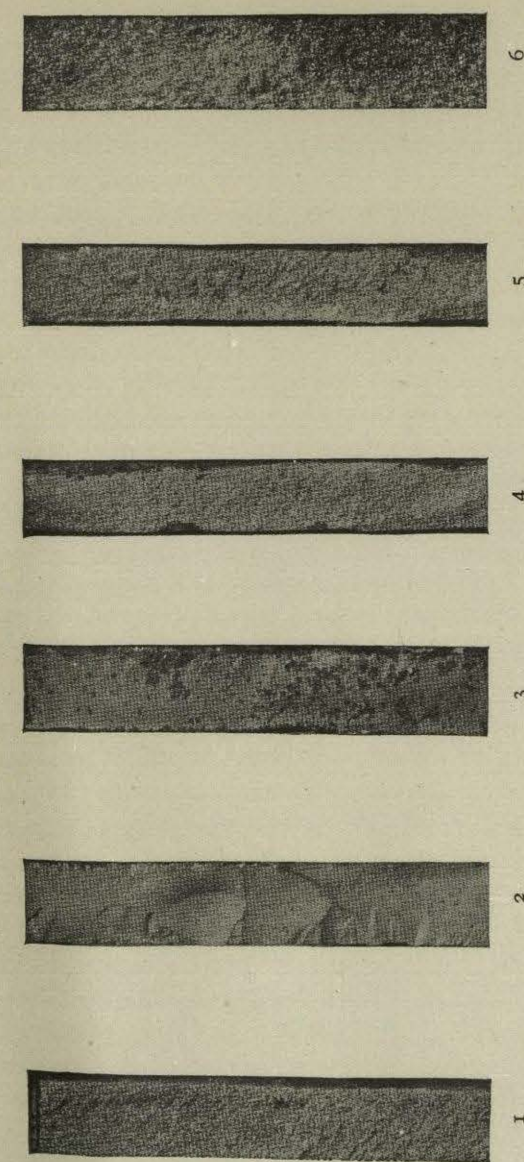

Fig. 22. Test Pieces of Steel broken to show grain due to different heats.

harden steel *properly* to try this experiment. The steel will cost him but a few cents, and it need take but a short time to heat it; but the knowledge gained of the action of heat on tool steel will be of inestimable value to him, as he can readily see the effects of proper and improper heating on the structure and strength of steel.

If the operator notes carefully the heats, he will be surprised at the difference in the amount of force necessary to break a piece of steel hardened at the refining heat and one heated slightly above this temperature, which, in fact, is hardly discernible to the eye in the light of an ordinary blacksmith's shop. The difference in the strength of a piece hardened at the refining heat and one heated to a *full red* is especially noticeable. In the former case it seems almost impossible to break it by a blow of a hammer, and it seldom can be broken across the center, so great is the adhesion between the molecules that make up the piece of steel, while in the case of a piece heated to a full red, the piece may be broken easily, as compared with the other. When one takes into consideration the fact that the ordinary workman heats steel when hardening to a full red oftener than to the refining heat, it is wonderful that the results obtained are as satisfactory as they are.

As stated, the temperature to which a piece of steel must be heated in order to refine it, depends on the composition of the steel. Tests of different steels have led authorities on this subject to the conclusion that it is necessary to heat a piece of steel to a temperature between 800° and 1200° Fahr. in order that it may harden when plunged in a cooling bath. Jarolineck places the temperature at 932° F. (500° C.) as determined by experiments made by him, while other authorities claim best results when the steel was heated to 1200° F. (about 650° C). As this difference (268° F.) involves a wide range of heat, it is evident that steels containing different percentages of carbon were used in the various tests.

If a piece of steel be heated to the refining heat and then quenched as soon as the heat is uniform throughout the piece, the steel is in the best condition possible for most uses. It should be quenched as soon as it is uniformly heated to the proper temperature. If subjected to heat after it reaches this temperature, it will become somewhat hotter. In fact, it has been ascertained by experiment that after steel is heated to a low red the temperature may be raised, and the difference in the heat not be discernible to the eye. For this reason it is advisable, if *best* results are desired, to quench *as soon as the desired uniform heat is attained.*

It is also important that steel should be heated uniformly. If a square block be heated so that the center is of the proper heat and the ends and corners are hotter, strains are set up in the piece, and it is very liable to crack when hardened. This also applies to a piece of any shape. While it is extremely necessary that the operator observe the greatest possible care in regard to the quantity of heat given steel, yet it does not harm steel as much to heat it a trifle too hot as it does to heat it unevenly, for while the higher heat unfits it for doing the maximum amount of work possible, the uneven heat is very liable to cause it to crack when hardened.

A piece of steel should not be heated faster than is possible to maintain a uniform heat. By this is meant

the heating should not be forced so that the outside is red hot while the center is black because in all probability the furnace would be so hot that the outside of the article would keep growing hotter while the center was getting to the desired heat. The result would be an uneven heat. Neither should a piece of steel be any *longer* in heating than is necessary, because after it is red hot, it will, if exposed to the action of the air, become somewhat decarbonized on the surface, thus materially affecting the steel. Tool steel should be heated as fast as it will take heat, and no faster. A piece should not be forced by heating the furnace to a temperature that will affect the surface while the heat is equalizing. Steel should never be heated too hot, and allowed to cool to what is considered the proper heat, and then hardened, as the grain will be as coarse as if dipped at the high heat.

The grain of steel remains in the condition the highest heat received leaves it, until it is reheated, when it is adjusted to that heat. The condition of the grain of the steel is an unvarying guide as to the amount of heat it received the last time it was heated. For instance, a piece of steel is heated to the temperature of the piece marked 4 Fig. 22 in our experiment. Now, take one of the broken pieces and reheat it to a temperature given the piece marked 2, which was the refining heat. Break this piece. An examination will reveal the fact that the grain has the same structure as the piece marked 2, thus proving that the grain of steel conforms to the last heat given it. This does not necessarily prove that a piece of steel is capable of doing the amount of work after it has been heated hotter than it should have been, and then reheated to a lower heat, thus closing the pores; but it is better than if in the condition the high heat would leave it.

Steel should always be hardened on what is known as a "rising" heat, never on a "falling" heat, is the advice an old hardener gave the writer when a boy, learning his trade, and he has found it true. It also agrees with the advice of most writers on this subject. It is quite necessary, in order to get uniform results, to move the articles around in the furnace and turn them over occasionally. When round (cylindrical) pieces of steel, having no teeth, projections, or other irregularities on its surface, are being heated for hardening, it is necessary to turn them occasionally, as, if left in one position without turning, until it is red hot, no matter how uniform the heat may be, it will, in all probability, have a soft line the entire length of the top side as it lay in the fire. It will also be found by experiment that round pieces are more liable to crack from uneven heating than pieces of almost any other shape; neither will they safely stand as high a degree of heat as some pieces, on account of their shape, which makes them offer greater resistance to a change of form.

If possible, when heating articles having heavy and light sections adjoining each other, as shown in Fig. 23, heat the heavy portion first, then the lighter one; but if this is not possible, have a slow fire, in order that the light part may not be overheated before the heavy one is to the required heat. The muffle furnace furnishes a very satisfactory method of heating steel, because the products of combustion cannot come in contact with the steel, and oxidation from the action of the air is done away with or reduced to the minimum. If it is not possible to use a furnace of this description,

very good results may be obtained by enclosing the article in a piece of pipe or tube and heating in an open fire, because in this case the steel is not exposed to the action of the fire. It is necessary to turn the work over occasionally in order to get a uniform heat.

It is never advisable to use any kind of fire where the air from the blast can strike the piece being heated, or it will crack in innumerable places. The steel will look as though it were full of hairs. For this reason, if obliged to use a blacksmith's forge, build a fire high enough to do away with any tendency of this trouble. A fire of old coals *should not* be used if the article to be heated is of any size, as the goodness is burned out of the coal, and it will be found necessary to use a strong blast in order to have a fire hot enough to heat the piece. As a consequence, the air strikes the piece with the result mentioned.

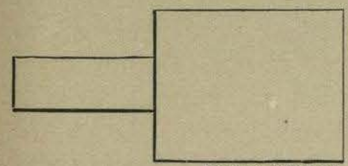

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Figure 23. A piece for a slow fire.

Steel should not be heated in a manner that leaves one side exposed to the air, or the exposed side will become oxidized to a considerable extent, and as the piece is turned in the fire the whole surface becomes oxidized and resembles a piece of burnt steel. The surface is not of any use, as the carbon is burned out, and it cannot be hardened. Some makes of steel give off their surface carbon very readily if exposed to the air when red hot. If a tool made from one of these steels be heated in a manner that allows the air to come in contact with it, the outside becomes decarbonized, and consequently is soft, while the metal underneath the surface is extremely hard. Now, this might not be harmful in the case of a tool whose outer surface was to be ground away, but if the surface of a tap, formed mill or similar tool becomes decarbonized, it is practically useless. Now, if these same tools had been heated in a muffle furnace or in a piece of pipe in the open fire, removed from the action of the fire and the air, the result would have been that the tool would have given excellent satisfaction. While all makes of steel are not so sensitive to the action of the fire and air when they are red hot, yet any steel gives better results if it is removed from their action while in this condition.

A man experienced in the effects of heat on steel is surprised at the apparent indifference of some hardeners when heating steel. A tool hardened properly and tested for strength in a testing machine will be found very much stronger than if heated a trifle hotter. When we consider that hardness, toughness and closeness of grain are the qualities desired in a cutting tool, we realize that there is nothing gained by heating tool steel above the refining heat for most work. Steel quenched at this heat is very hard, tough, and the grain is the finest possible. Now, every degree of heat which it receives above this point unfits it for doing the maximum amount of work possible, because it causes the steel to be brittle and makes the grain coarse.

The writer has made exhaustive experiments in regard to the effects of heat on the strength of steel, and assures the reader that a piece of steel hardened at the refining heat requires a much greater force to break it than one heated to a full red. Knowing this,

the reader can judge how much heavier cuts can be taken with a tool properly heated than with one heated too hot, as the steel is made brittle, and in this condition is more liable to chip or flake off under pressure. The grain being coarse does not present a dense body, but the internal structure has a honeycomb appearance; consequently when pressure is applied the surface caves in, because it does not have the backing it would if the grain were compact.

Reheating to Remove Strains.

As steel heated red-hot and cooled quickly contracts, and as the outer surface hardens and becomes rigid before the interior of the piece has ceased contracting and altering its form and the position of its molecules, the molecules that make up the interior of the piece cannot assume the exact positions they should; consequently, strains are set up. Now, if the outer portion of the article is sufficiently strong to resist the tendency of the interior of the piece to alter its form, it may not crack or it may resist the strain for a considerable length of time. But for some cause a certain portion of the exterior of the piece becomes weakened, or the conditions are such that the outside can not longer resist the internal strain, and the piece is cracked, or it may burst. Many times large, heavy pieces of steel will burst with a report as loud as a gun, and pieces of the steel will be carried for some distance by the force exerted.

Now, in order to avoid this tendency, it is necessary to reheat the piece as soon as it is taken from the hardening bath, to a temperature that allows the various portions of the piece to conform to one another. A piece of hardened steel becomes pliable to a degree when heated, the amount of pliability depending on the temperature to which the piece is heated. This is illustrated elsewhere in the case of articles crooked in hardening, which are straightened after heating to a certain temperature. After cooling they remain the shape given, but were we to attempt to spring them as much when cold, they would certainly break.

It is advisable, after taking a piece of hardened steel from the bath, to hold it over a fire or in some manner subject it to heat, in order that it may become pliable enough to remove the tendency to crack from internal strains.

The method pursued in removing the strains varies. If an open fire is at hand, the piece may be held over this until heated to the proper temperature. It should be constantly turned, in order to insure uniform results. When pieces are hardened in large quantities, this is a very expensive practice. In such cases, it is advisable to have a tank of oil, which is kept at the desired temperature, this being gauged by means of a thermometer.

A very satisfactory method, and one used by the writer for many years, consists in using a tank of water, the contents of which are kept at the boiling point (212°). When a piece of hardened steel is removed from the bath, it is immediately dropped in the boiling water. The tank has a catch pan to receive the work, as shown in Fig. 24. A steam pipe is connected with the tank in order to keep the water at the

desired temperature. It is, of course, necessary to provide an overflow pipe, as represented.

When it is not considered advisable to procure a tank, as represented, a kettle of water may be placed over a fire and brought to the boiling point and used as described.

When it is thought to be advisable to remove the tendency to crack from internal strains and draw the temper at the same time, it may be done by heating a kettle of oil to the desired temperature, gauging the heat by a thermometer. The pieces, as they are taken from the hardening bath, may be dropped in this and left long enough to insure uniform heating.

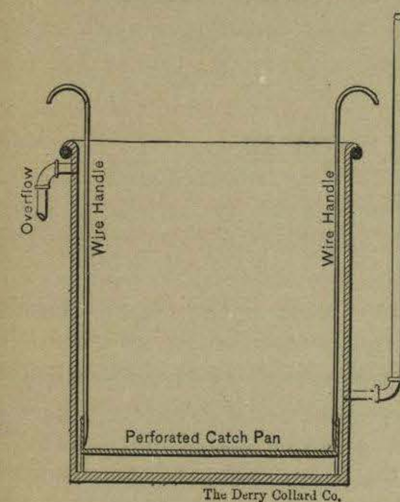

Figure 24. Tank of boiling water for removing internal strains.

Should it be considered advisable to heat articles of irregular shape, having heavy and light portions adjoining each other, it would not be advisable to suddenly immerse them in liquid heated to 300°, 400° or 500° Fahr., as the unequal expansion might cause the pieces to crack where the heavy and light portions joined. In such cases it is sometimes considered advisable to place them in a kettle of boiling water first, removing them from time to time and placing in the kettle of oil, heated to the temperature to which the pieces must be heated in drawing temper; or two kettles of oil, heated to different temperatures, are sometimes used, the first being kept at 250° or as as near that as possible, the other being the desired temperature. When the pieces are removed from the first kettle and placed in the second, it, of course, reduces the temperature of the oil, but it gradually rises to the desired point when the articles are removed.

Forging.

It is not the writer's intention to devote much space to explanation of the method in which steel should be forged for the various cutting tools. In order to do the subject justice, it would be necessary to devote more space than can be spared, but the forging and hardening of a tool are so closely identified, it seems necessary to briefly consider the subject.

Many tools are rendered unfit for use by the treatment they receive in the forge shop, and as it is the custom in many shops to have the forging done by one man, and the hardening by another, a great amount of trouble is experienced, because each tries to lay any trouble that comes from the hardened product to the other.

Heating is the most important of the operations to which it is necessary to subject steel, whether it be for forging, annealing or hardening.

Unless steel is uniformly heated throughout, violent strains are set up; when the piece is hardened these manifest themselves. If the steel is not heated uniformly throughout the mass, it cannot flow evenly under the blows of the hammer, consequently the grain is not closed in a uniform manner.

While it is necessary, in order to get satisfactory results, to heat steel hot enough to make it plastic, in order that it may be hammered to shape, care should be exercised that it is not overheated, or the grain will be opened to an extent that it can not be closed by any means at hand in the ordinary forge shop.

If a large piece of steel requiring considerable change in size is to be forged, and means are at hand to forge it with heavy blows, it can safely be given a higher heat than a smaller article which does not require much change of size or form.

If tool steel is hammered carefully, with heavy blows while it is the hottest, and then with lighter, more rapid blows as it cools, the grain will be closed and become very fine.

When the temperature is reduced to a low red, care should be exercised, for when traces of black begin to show through the red, it is dangerous to then give it any heavy blows, as they would crush the grain.

By actual test it has been proven time and again that steel, which has been properly hammered, is superior to the same steel as it comes from the steel mill, but unless the work is done by an intelligent smith, who understands the effect of heat on the structure of steel, the forging will have the opposite effect to the one desired.

Many steel manufacturers advocate the purchase