fixtures are designed to protect certain portions of the piece of work from the action of the contents of the bath.

The writer was at one time in charge of work in a

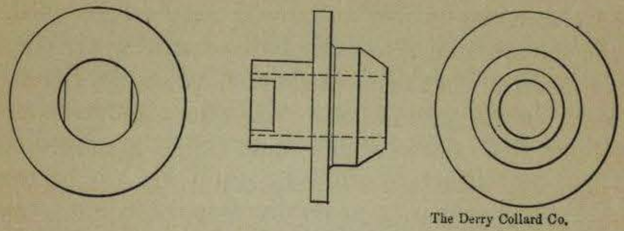


Figure 113. A hard piece to harden.

shop manufacturing bicycles. In order to accomplish a desired object, the axle cones, which had formerly been made of machinery steel, were made from a high grade of tool steel. The front axle cone was of the

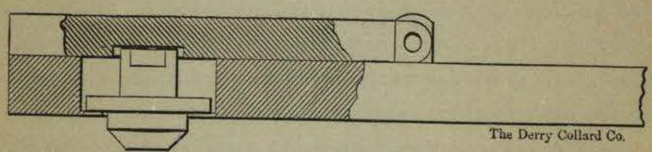


Figure 114. Device for hardening piece shown in Figure 113.

shape shown in Fig. 113. It was necessary to harden the beveled portion extremely hard, in order to resist wear. It was found very difficult to harden this portion without hardening the flange. If this were hardened, it showed a tendency to break when in the wheel, as it was very thin.

In order to harden the bevel and leave the flange

soft, a fixture was made, as shown in Fig. 114. The cone was heated in a crucible of red-hot lead. When it reached the desired temperature, the cover of the fixture was raised and the cone taken from the lead by means of a wire hook made for the purpose. It was placed in the fixture, as shown, the cover lowered, and the fixture immersed in a bath of water, working it around well until the cone was cold, when the fixture was inverted over a tank of boiling water, and the cone dropping into this and remained until a sufficient quantity was in the catch pan, Fig. 45, to warrant emptying it. This tank was found very valuable, as it furnished a means whereby the strains incident to hardening could be removed, and at the same time the temper was drawn sufficiently.

Pack Hardening.

When articles which are *small* or *thin* are heated to a red and plunged in oil, they become hard enough for most purposes, but not as hard as if immersed in water. Articles hardened in oil seldom crack from the effects of cooling, as the heat is not absorbed as quickly as if water were used, neither are they as likely to spring.

The fact that articles quenched in oil showed no tendency to crack, and very little liability to spring, has led the writer to make exhaustive experiments in perfecting a method whereby articles which gave trouble when hardened by ordinary methods might be hardened in oil and produce a surface as hard as if it were heated red-hot and plunged in water. The results have been more gratifying than were ever dreamed of before trying. It is not claimed that this method was originated by the writer. It was suggested by a man in his employ, who had seen it practiced with varying results in a shop where he formerly worked.

The fact that milling machine cutters, punch press dies, and similar articles, could be treated in such a manner that they might be hardened in oil without danger of cracking, led to experimenting, which resulted in a method whereby tools could be hardened with *absolutely* no danger of cracking. The tendency to spring was also reduced to the minimum. Unexpected results were accomplished in some ways, for it was found by experience that milling machine cutters could be run at a periphery speed, two, and in some cases four, times as great as when a similar cutter made from the same bar was heated red-hot and plunged in water. Punch press blanking dies would do from six to ten times the amount of work as when hardened by methods formerly used.

It was also found extremely satisfactory when applied to taps and screw thread dies, because the tendency to alteration of pitch was reduced to the least possible amount. Neither would they change so far as diametrical measurements were concerned. Gauges hardened by this method gave results fully as satisfactory as other articles hardened in a similar manner. Long reamers, stay-bolt taps, and similar tools, have been hardened by the thousands and shown results more than satisfactory.

Tool steel is made with a sufficient quantity of

carbon to harden in a satisfactory manner and accomplish the results intended when the tool is made. To make steel with a higher percentage of this hardening element, and put it on the market, would be folly, as the average man hardening steel would treat it the same as the ordinary tempers are treated, with the result that the tools made from it would be ruined when hardened.

Now, tool steel may be treated with carbonaceous materials when red-hot, with the result that the surfaces will be extremely hard if the article is quenched in oil. The depth of the hardened surface depends on the length of time the article is subjected to the carbonizing element. In order to accomplish the desired result, the piece of work must be packed in a hardening box with the carbonaceous material; the top must be closed with a cover slightly smaller than the opening in the box, and the space between the cover and sides of the box covered with fire-clay. This operation is familiarly known as sealing. Sealing the box has the effect of preventing the gases escaping. It also prevents the direct heat of the fire from entering the box, as that would be very injurious to the steel. Then again, the oxygen in the air is excluded from the box, or, if present in a degree, does not oxydize the surface of the piece, as it is taken up by the packing materials in the box.

It is very necessary when charging steel by the process under consideration, that a carbonizing material be used which contains no elements injurious to tool steel. For this reason no form of bone should ever be used, as bone contains a very high percentage of phosphorus, and phosphorus, when present in tool steel, has the effect of making it extremely brittle. The processes the steel maker puts the steel through in order to remove injurious impurities is one reason of its high cost as compared with the ordinary cheap grades of steel. The lower the percentage of phosphorus, the more carbon it is safe to have in the steel; so it will readily be seen that any process which results in an addition of this harmful impurity should never be used. The writer has used a mixture of equal parts, by measure, of granulated charcoal and granulated charred leather in most of his work for the past nine or ten years with the best results; although in exceptional cases, where extreme hardness was desired, charred leather alone was used.

The work is packed in a hardening box. This box may be either wrought iron or cast iron. Best results are claimed by some when wrought iron boxes are used. But the writer has never in practice been able to notice any difference, so he has used cast iron boxes altogether for the past eight years, as they are cheaper and more readily obtained. The work should be placed in the box in a manner that does not allow any of the pieces to come within 1½ inches of the bottom or top of the box, or within 1½ to 1¾ inches of the sides or ends, for two reasons. If they are placed too near the walls of the box, they are affected by every change of temperature in the furnace. Then again, cast iron has a great affinity for carbon, and will extract it from a piece of tool steel if it comes in contact with it. If one end of an article, packed as described, comes in contact with the walls of the box, the piece will not harden at that point, or, if it does, it will not be as hard as the balance of the piece. And, as a chain is no stronger than its

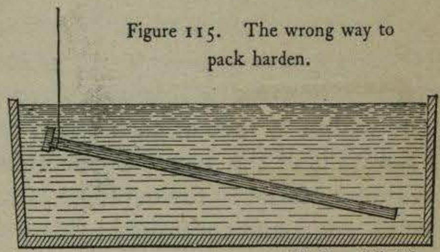
weakest link, so a hardened tool is no better than its softest spot, provided it is on any cutting portion, because, when that dulls, the whole tool must be ground.

This method of pack hardening is not only a means of getting good results, but when work is hardened in large quantities, it is a much cheaper method than that ordinarily used, because quite a number of pieces may be packed in the box at a time. Or, if the furnace used is of sufficient capacity, several boxes may be heated at the same time.

When packing work in the hardening box, place about 1½ inches of packing material in the bottom, then lay a row of work on this, being careful that no pieces come within ½ inch of each other, or within 1½ inches of the walls of the box. Cover this row of work with packing material to the depth of ½ inch, put in another row of work, and continue in this way until within 1½ inches of the top of the box. After covering each row of work with the packing material, it should be tamped down lightly to insure its staying in place. When the box is filled to within the distance of top mentioned (1½ inches), the balance should be filled with packing material, the cover put in place and sealed with fire-clay mixed with water to the consistency of dough, and allowed to dry before placing in the furnace.

Before the articles are packed in the box, a piece of *iron* binding-wire should be attached to each piece of work in such a manner that the article may be removed from the box and dipped in the bath by this means, unless the piece is too heavy to be handled in this manner, in which case it must be grasped with a pair of tongs. The wires should extend up the sides to the top of the box and hang over the edge, in order that the operator may readily see them when removing the articles from the box. If several rows of work are placed in the box, it is necessary to place the wires in a manner that allows the different rows to be readily distinguished. As it is necessary to draw the pieces on the top row first, each succeeding row should be drawn in its order, because if an article were drawn from the bottom row first, it would probably draw one or more of the pieces located above along with it. As a consequence they would lay on the top of the box exposed to the action of the air, and would cool perceptibly while the first piece was being quenched in the bath. For this reason it is advisable to draw the pieces in the top row first, as described.

Figure 115. The wrong way to pack harden.



As the length of time a piece of steel is exposed to the carbonaceous packing material after it is red-hot determines the depth of hardening, articles packed in a box should all be of a character that need carbonizing alike, or some pieces will not receive a sufficient depth of carbonizing and others will receive too much. Knowing this, one may select the articles accordingly, packing those requiring charging for one hour in one box, those requiring two hours in another, and so on. A little experience will teach one the proper length of time to give a tool of a certain size to accomplish a given result.

Attention must be paid to the shape of the piece when packing in the box. If it is long and slender, it should not be packed in such a manner that it will be necessary to draw it through the packing material, as shown in Fig. 115, or it will surely spring from doing so, it being red-hot, and consequently easily bent. If but a few pieces of this character are to be hardened, it would not be advisable to procure a box especially

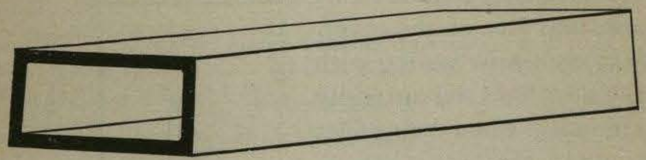


Figure 116. Box for pack hardening.

adapted to it. In that case the articles could be packed two or three in a box. When they have run the proper length of time, the box should be removed from the furnace, turned bottom side up on the floor, provided the floor is of some material that will not catch fire. The piece of work may be pulled out lengthwise from the mass, and in that way all danger of springing is done away with.

If, however, quite a number of pieces are to be hardened, it is advisable to procure a box adapted to pieces of this description. This may be done by adopting a design opening at the end, as shown in Fig. 116. This may stand on end with the opening uppermost while packing the pieces. If a furnace of the design shown in Fig. 117 is available, it should be used, as the box can stand on end. If this form of furnace is not at hand, the box may be placed on its side in any furnace large enough to receive it. If necessary to use a furnace where the box must lay on its side, it will be advisable to provide some way of fastening the cover in place. This may be done by drilling a ½ inch hole on opposite sides of the box and running a rod at least $\frac{1}{16}$ of an inch smaller than the hole across the face of the cover, Fig. 118, before sealing with fire-clay. This rod can easily be removed when the articles are ready for immersion in the bath.

In order that the exact time at which the work becomes red-hot may be ascertained, it will be necessary to use test wires. Several ¼ inch holes may be drilled near the center of the cover, a $\frac{3}{16}$ inch wire run through each of these holes to the bottom of the box, as shown in Fig. 26. When the work has been in the furnace for a sufficient length of time to become heated through, according to the judgment of the operator, one of the test wires may be drawn and its

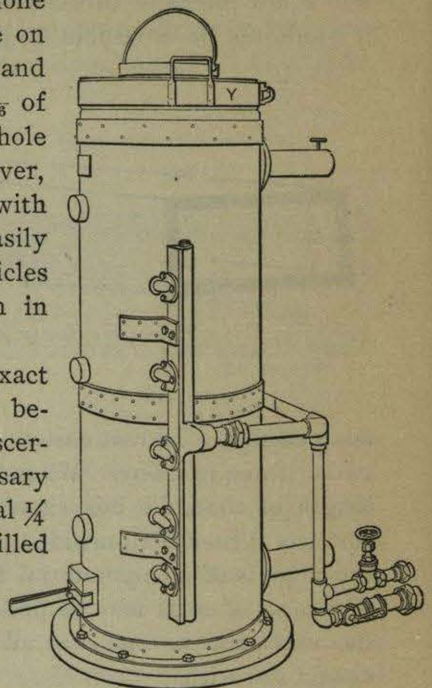


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Figure 117. Furnace for use in pack hardening.

condition noted. If it shows red-hot the entire length, note the time. If not, wait a few minutes (say, 15 minutes) and draw another wire. When one is drawn that shows the proper temperature, time from this.

The length of time the pieces should be run cannot

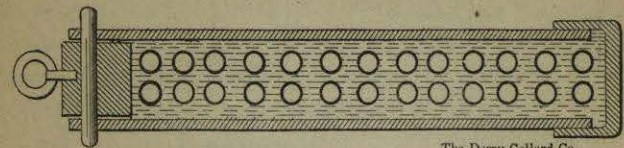

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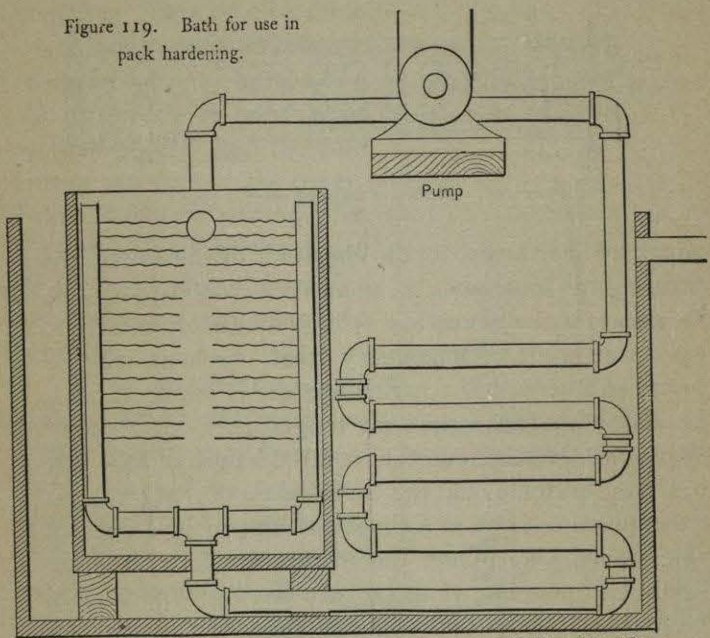
Figure 118. Method of fastening cover in place.

be stated arbitrarily, as the character of the work to be done by the tool must, in a measure, determine this. However, if the pieces are ½ inch diameter, and are to cut a soft grade of machinery steel, one hour may be found sufficient. If a harder surface is required, it is necessary to run somewhat longer (say, 1½ hours). When the work has run the required length of time, the box may be removed, the cover taken off, and the articles taken out one at a time and dipped in a bath of raw linseed oil. When the articles are long, it is advisable, if possible, to use a bath having a perforated pipe extending up two opposite sides of the tank, as shown in Fig. 119. A pump should be connected with the oil in the bath, pumping it through a coil of pipe in a tank of water and forcing back into the tub through the upright perforated pipes shown. This method insures evenly hardened surfaces, as the jets of oil forced against the sides of the article drive the vapors away from the piece, thus insuring its hardening. It is necessary to move the work up and down and to turn it quarter way around occasionally in order to present all sides to the action of the oil.

When milling machine cutters, or similar tools having projections, are to be hardened by this method, they should be packed in the box, using the packing

Figure 119. Bath for use in pack hardening.



material mentioned. Previous to placing the cutters in the hardening box, a piece of iron binding-wire should be attached to each cutter and allowed to project over the edge of the box. Test wires should be run down through the holes in the cover, as shown in Fig. 26. The length of time the cutters should run is determined by the character of the work they are to do; but for

ordinary milling, a cutter 3 inches diameter, if of the ordinary design, should run about 3 hours.

If the teeth are heavy, of the style known as formed mills, Fig. 120, they should be run 4 hours after they are red-hot. When the box is removed from the furnace, the cutters may be removed one at a time, placed on a bent wire of the form shown in Fig. 81, and immersed in the oil, working them around well until all trace of red has disappeared, when they may be dropped to the bottom of the bath and left until cold.

A milling machine cutter of the form shown in Fig. 120 will not as a rule require tempering. The teeth may be left as hard as they come from the bath, but those of the ordinary form of tooth should have the temper drawn. This may be done by the method described under Hardening and Tempering Milling Machine Cutters, or, if there are many cutters, a saving of time will result if the articles are placed in a kettle of oil and the temperature gauged by a thermometer, drawing them to 430 degrees.

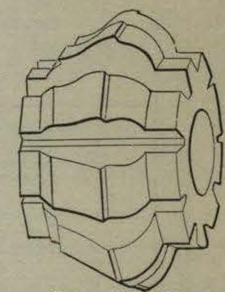


Figure 120. Formed milling cutter.

Punch press blanking dies give excellent satisfaction if hardened in this manner. The die is packed in a box. Test wires are run down through the opening in the die to the bottom of the box. When drawing the wires to test the heat, do not draw them way through the cover. After observing the heat, place the wire back in its original position. A wire can be raised from time to time, the amount of heat observed and the wire returned. In this way the operator can tell from time to time the exact temperature of the piece being heated, and as the same laws governing the heating of steel in the open fire apply when heating to harden by this method, it is advisable to keep the heats as low as possible; for steel treated by this method will harden in oil at a lower heat than if treated in the ordinary way and hardened in water.

Blanking dies for the class of work usually done on punch presses (if they are 1 inch to 1½ inches thick)

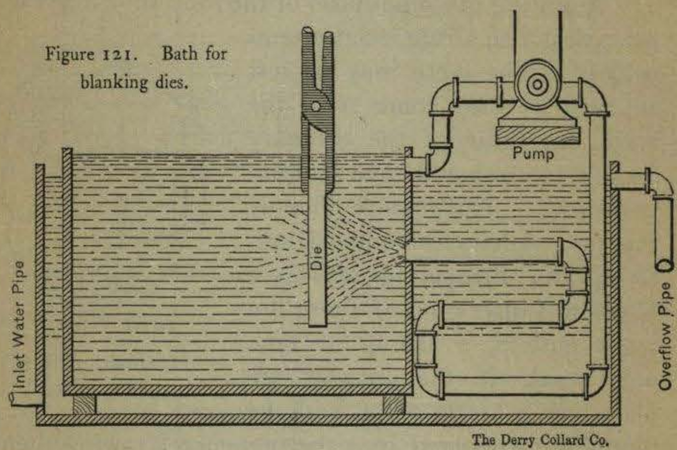


Figure 121. Bath for blanking dies.

should run about four hours after they are red-hot. At the expiration of that time the box may be removed from the furnace, the die grasped by one end with a pair of tongs and immersed endwise down into a bath of raw linseed oil. It is a good plan to have the bath rigged as shown in Fig. 121. A pipe is connected with the tank near the top, and runs in a coil through a tank of water. A pump draws the oil from the tank through the coil, and forces it back into the bath, as represented.

The inlet pipe may be so situated as to cause the oil to circulate with considerable force through the bath. This, striking the face of the die, passes through the opening, insures good results. If no means are provided for the circulation of the oil, the die may be swung back and forth in the oil, and it will harden in a satisfactory manner. Forming and bending dies, if hardened by this method, must be run longer, and heated somewhat hotter, yet not hot enough to injure the steel.

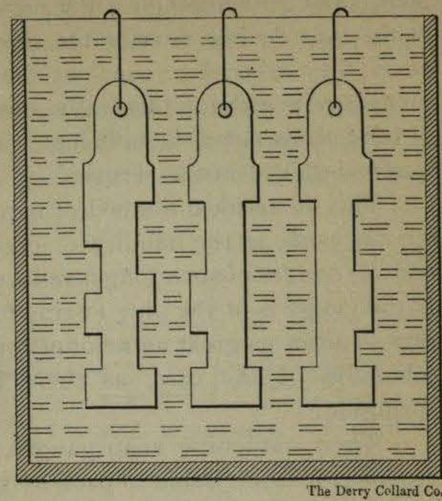


Figure 122. One method of packing snap gauges.

Pack hardening furnishes a method whereby taps may be hardened without altering the pitch very perceptibly; neither will the diametrical measurements be changed, provided the blanks were annealed after blocking out to shape, and by this method the teeth are made exceedingly hard without being brittle. A tap from one to two inches

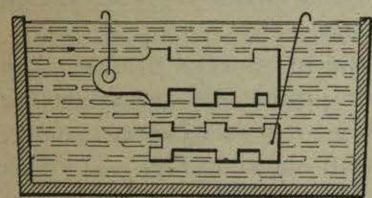


Figure 123. Another method of packing snap gauges.

in diameter should be run about two hours. It should be worked around rapidly in the bath, in order that the teeth may be hardened. For general machine shop work, taps do not require the temper drawn as low as if they were hardened by heating red-hot and plunging in water. Generally speaking, 430 degrees (a faint straw color) is sufficient, provided a low heat was maintained in the furnace.

This is an ideal method of hardening gauges and similar work, as the liability of cracking is eliminated and the danger of springing is reduced to the minimum. If the gauge is of the plug or ring form, it is not necessary to allow as great an amount for grinding as would otherwise be the case, as there is little danger of springing.

When hardening snap gauges, especially if they are long, it is advisable to pack as represented in Fig. 122, provided a box deep enough is at hand. If obliged to pack in a box so that the gauges lay lengthwise in the box, they should be so placed as to have the edges up and down, as shown in Fig. 123, thus doing away with the tendency to spring when they are drawn through the packing material.

Articles of a form which betokens trouble when hardening can, if proper precautions are taken, be hardened by this method in a very satisfactory manner. Take, for instance, the shaft shown in Fig. 124. This was made of ⅞ per cent. carbon crucible steel, and turned within a few thousandths of an inch of finish size. It was packed in a mixture of charred leather and charcoal, and subjected to heat for 1½ hours after it was red-hot. It was then dipped in a bath of raw linseed oil, heated to a temperature of 90°. It was found

upon being tested between centers to run nearly true.

The designer does not always take into consideration the difficulties which may be encountered when a piece of irregular contour is hardened, consequently we sometimes run across articles which call for serious study on the part of the hardener when the article reaches him. Then again, such articles are many times made

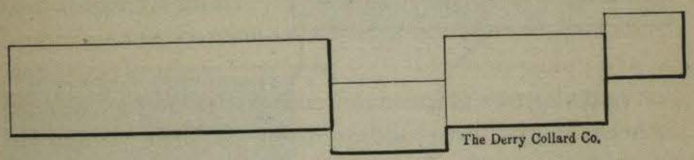


Figure 124. A peculiar piece to harden.

of a *high* carbon *tool* steel, when a low grade steel would answer the purpose as well, and not cause nearly as much trouble.

At one time the writer was called to a shop where they were experiencing all kinds of trouble in an attempt to harden a gauge of the description shown in Fig. 125. As it was not practical to grind the interior of this gauge with a grinding machine, it was necessary that it should retain its shape when hardened. In order to accomplish this, the gauge was surrounded with a mixture of fire-clay, to which was added sufficient hair (obtained from a plasterer) to hold it together. It was moistened with water to the consistency of dough. The hole in the gauge was filled with finely granulated charred leather.

It was then placed in a small hardening box, in the bottom of which was placed 2 inches of granulated wood charcoal. The box was filled with charcoal, the cover placed in position, and sealed with fire-clay.

The box was subjected to heat for one hour after the contents were red-hot, this being ascertained by means of the test wires, as described. The gauge was then taken from the box, the leather removed from the hole, and a jet of raw linseed oil

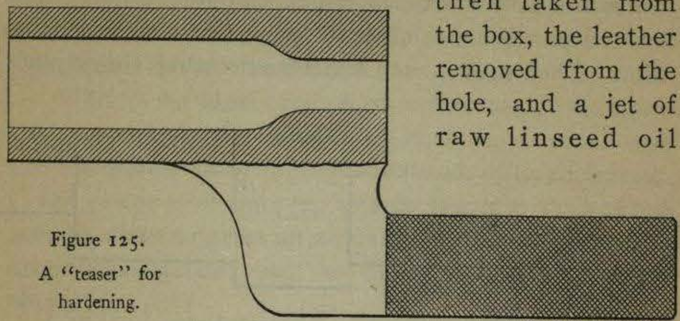


Figure 125.
A "teaser" for hardening.

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forced through the hole until the piece had cooled off. The walls of the hole were very hard, and the gauge was found by test to have retained its shape. The coating of fire-clay prevented the exterior hardening of the piece, thereby eliminating the tendency to spring or go out of shape. The walls of the hole, hardening *first*, retained their shape, and the balance, being red-hot, conformed to this portion.

While it would be impossible to enumerate the various articles of irregular contour that may be hardened by applying this principle—namely, protecting the portions that do not require hardening, by the use of a mixture of fire-clay and water, adding sufficient hair to hold it together—it can safely be said that many thousand dollars' worth of tools are ruined annually, which might have been saved had this precaution been observed.

As this process of charging the surface of the steel with carbon is a process of cementation, it is necessarily slow. When extremely high carbon steel is used in making tools, it is considered advisable by some to use hoofs and horns as packing material rather than leather. At times it is not considered desirable to subject the articles to heat for so great a length of time. In such cases it is necessary to treat the surfaces to be hardened with some material that will act more quickly than charred leather. In fact, at times it is necessary to prevent any portion other than the ones to be hardened from becoming red-hot.

This can be effected by covering the parts with the fire-clay mixture to a considerable depth, applying heat to the portions that need hardening. When it is not desirable to subject the article to heat for a length of time sufficient to charge the steel with the necessary amount of carbon to cause it to harden (if it was to be carbonized by means of charred leather), excellent results may be had by the use of a mixture of 5 parts of rye flour, 5 parts table salt, 2 parts yellow prussiate of potash, filling the hole or covering the portions to be hardened with this.

Mandrels, or any form of arbor which it is considered advisable to harden, will harden in a more satisfactory manner by this method than by any that has come to the writer's notice. If the article is long and slender, do not pack in the box in such a manner that they will spring when drawn out; but if the shape of the box is such that this cannot be avoided, the box may be turned bottom side up on the floor when the articles are ready for hardening, as previously explained. If, however. the mandrels are made of the proportions usually observed when making for general shop use, there is very little liability of springing when drawing them through the packing material. The mandrel may be wired as represented in Fig. 126, or it may be grasped with a pair of tongs of a form that allows the contents of the bath to have ready access to the end of piece; but as tongs of this form are not in general use, the wires will answer unless the pieces are very heavy. In this case it is advisable to procure tongs of a suitable shape rather than to have an unsatisfactory article when it is finished. As stated under Examples of Hardening, it is never advisable to hold a mandrel with any form of tongs that in any way interfere with the hardening of the walls of centers in the ends of a mandrel.

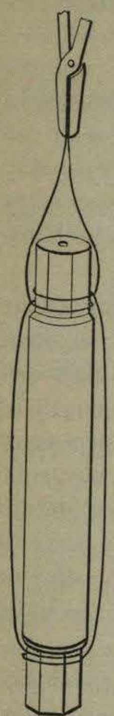

Figure 126. How to dip in bath.

If the work is wired, it should be done in a manner that makes it possible to dip the mandrel in the bath in a *vertical* position, to avoid any tendency to spring. The wires may be grasped by means of tongs which close together very nicely, as shown in Fig. 126, in order that they may not lose their grip and the piece fall to the bottom of the bath before the red had disappeared from the surface. It should be worked up and down in the oil until all trace of red has disappeared, when it may be lowered to the bottom and left until cooled to the temperature of the bath.

Circular forming tools, especially those having long, slender projections and sharp corners, as shown in Fig. 127, are safely hardened by this process, as they

can be given any degree of hardness desirable without making them brittle. Being solid in form, they must be heated for a longer period of time than if there were teeth on the surface—as a milling machine cutter. As with other cutting tools, the length of time a tool of this form should be subjected to heat depends on the nature of work to be performed by it. A tool 4 inches in diameter and 2 inches wide for ordinary work should run about 4 hours after it is red-hot. If there are slender projections from the face of the tool, it will be found necessary to draw the temper somewhat; but as a rule it should not be drawn as low as if it were hardened by the methods ordinarily employed.

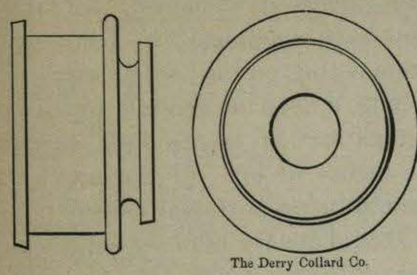

Figure 127. A forming tool.

The writer has in mind a forming tool of the same general outline as the one represented in Fig. 127, which gave excellent results when drawn to 350 degrees after hardening by the method under consideration. It was hard enough to stand up in good shape, and yet tough enough to stand very severe usage.

If the formed surface is of a shape that insures strength—that is, if there are no projections—the cutter should be left as hard as when it comes from the bath.

Stay-bolt taps and similar tools may be packed in a box of the proper shape and run for a length of time, depending on the size of the piece. They should then be taken one at a time and immersed in a bath of raw linseed oil and worked up and down in a vertical manner, moving to different parts of the bath, unless there is a jet of oil coming up from the bottom. Or, better still, having perforated pipes coming up the sides of the bath, as represented in Fig. 119. In either case it is advisable to work the articles up and down, to avoid the vapors which always have a tendency to keep the contents of the bath from acting on the heated steel.

If the articles are long, a deep tank should be used for the bath. If the taps are 24 inches long, there should be a depth of 40 inches of oil. If the articles are longer, the tank should be proportionally deeper.

A precaution that should always be observed when hardening *large* pieces of work, when they are to be quenched in a bath of oil, consists in protecting the hands and arms of the operator to prevent burning from the fire, which results when a piece of red-hot steel is immersed in oil. This is, of course, simply a burning of the surface oil as the steel passes through it, but it is liable to flash high enough to burn the hands and arms unless they are protected in some manner.

When hardening *long* articles, it is found much more convenient if the tanks containing the cooling liquid are so located that the tops of the tanks are nearly on a level with the floor—say 12 or 15 inches above it.

The toolmaker should, when making adjustable taps, reamers, etc., of the description shown in Fig. 128, leave a portion on the end solid, as shown in Fig. 129, to prevent the tool springing out of shape. The hole for the adjusting rod should be filled with fire-clay, the article packed with the mixture of charcoal and

charred leather, and subjected to a very *low* red heat, and dipped in raw linseed oil, warmed to about 90 degrees Fahr. The length of time it should be subjected to heat after it is red-hot depends on the size,

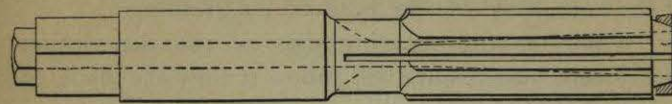

Figure 128. An adjustable reamer.

quality of steel used, and the work it is to do. It will vary from 1 to 2½ hours. The temper may be drawn to a light straw or a full straw color. The shank, and ends of flutes nearest the shank, should be drawn to a blue. When drawing the temper, the reamer or tap may be placed in a kettle of oil heated to the proper degree for the cutting edges. The shank may be drawn lower in a flame, or heat may be applied at the shank end by means of a flame from a gas jet, Bunsen burner, or any other means, allowing the heat to run toward the cutting end. After the reamer has been hardened and ground to size, the extreme end may be ground off enough to allow the slots to extend to the end.

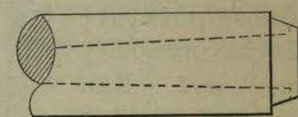

Figure 129. Solid portion of reamer.

Dies used for swaging tubing are a source of annoyance when hardened by methods usually employed, as the unequal sizes of the different portions cause them to spring out of shape, and their shape is such that it is next to impossible to grind them in a manner that insures satisfaction when they are used.

Pack hardening furnishes a method whereby this class of work can be made hard enough to do the work required of them, and they do not alter in shape enough to require grinding. For this reason the extremely hard surface, which comes in contact with the contents of the bath, need not be removed by grinding.

When making swaging dies of the description mentioned, best results will follow if they are made of tool steel of 1⅛ to 1¼ per cent. carbon. Block to shape, anneal thoroughly, and finish to size. When hardening, the dies should be wired and packed in a box, as shown in Fig. 130, placing charred leather all around the die for a distance of ¾ inch to 1 inch. The balance of the box may be filled with packing mixture that has previously been used. Run for about 4 hours after they have reached a medium red heat. It is necessary to give articles of this description a trifle higher heat than if hardening cutting tools made from the same stock.

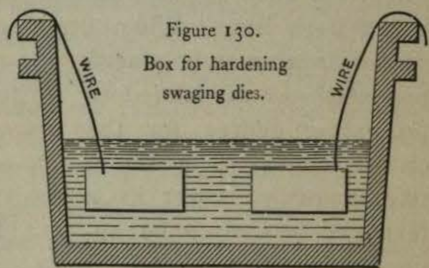

Figure 130.
Box for hardening swaging dies.
The Derry Collard Co.

As hardness is the required quality, the dies should be left as hard as when taken from the bath, which should be raw linseed oil at a temperature of about 60 degrees Fahr.

A careful study of the pack hardening method will help every one handling steel. It often makes possible the use of lower grade steels, and it enables pieces to be made of any desired shape with the knowledge that they can be hardened without cracking.

Case Hardening.

When wrought iron or machinery steel—especially the latter—will answer the purpose as well as tool steel, they are generally used. The first cost is less, and it can be machined much more cheaply, and in many cases it is better adapted to the purpose.

Machinery steel is made by two entirely different processes, namely: the Open Hearth and the Bessemer processes. Each method produces steel adapted to certain classes of work. There are many grades of steel made by each of these processes, these being determined by the amount of carbon or other elements present in the steel. Machinery steel is not only valuable to the manufacturer on account of its low first cost, as compared with tool steel, and the ease with which it may be worked to shape, but it possesses the quality of toughness, and is not so susceptible to crystallization from the action of shocks and blows. A very valuable feature is, that by subjecting it to certain processes, the surface may be made extremely hard, while the interior of the steel will be in its normal condition, thereby enabling it to resist frictional wear and yet possess the quality of toughness.

The hardening of surfaces of articles made of wrought iron and machinery steel is generally termed