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.

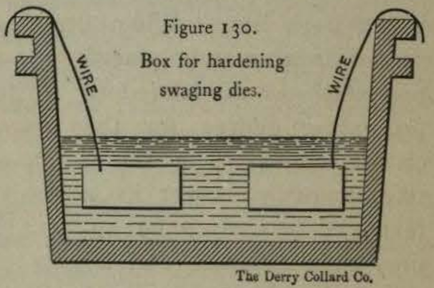


Figure 130. Box for hardening swaging dies.

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 "case hardening," and consists in first converting the surface of the article to steel, then hardening this steel surface. In order to convert the surface to steel, it is necessary to heat the piece red-hot, then treat it while hot with some substance which furnishes the necessary quality to cause the steel to harden when plunged in a cooling bath.

Most machine shops have some means whereby they can harden screws, nuts and similar articles. Where there is only a limited number of pieces to harden, it is customary to heat the work in a blacksmith's forge, in a gas jet, or in any place where a red heat can be given the piece. When hot, sprinkle with a little granulated cyanide of potassium, or some yellow prussiate of potash, or a mixture of prussiate of potash, sal ammoniac and salt. If cyanide of potassium is used, it is advisable to procure the chemically pure article, as much better results may be obtained. The reader should bear in mind that this is a violent poison. Re-heat to a red and plunge in clear, cold water. When there are large quantities of work to harden, this is an expensive as well as a very unsatisfactory way. To case harden properly, one must understand the material of which the article is made and the purpose for which it is to be used—whether it is simply to resist friction or wear, or to resist sharp or heavy blows, a bending or twisting strain, or whether it is merely desired to produce certain colors.

We will first consider the case hardening of work that simply needs a hard surface, with nothing else to be taken into consideration. Pack the articles in an iron box made for this purpose, as shown in Fig. 131. The size and shape of the box used depend, as a rule,

on what can be found in the shop. But when results are to be taken into consideration, it is advisable to procure boxes adapted to the pieces to be hardened. It is not policy to pack a number of small pieces, which do not require a deeply hardened portion, in a large box, especially if it is desirable to have a uniformity in the hardened product, as the pieces which

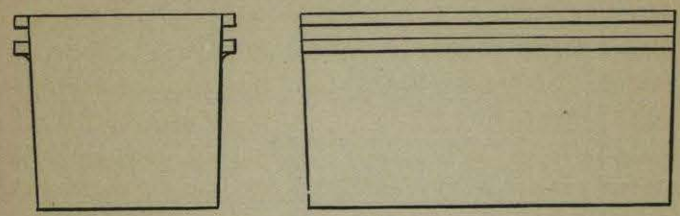


Figure 131. Box for case hardening.

are near the walls of the box will become red-hot long before those in the center. And as steel or iron absorbs carbon only when red-hot, the pieces nearest the outside would be hardened to a greater depth than those near the center of the box.

For small articles, where but a few pieces are to be hardened at a time, a piece of gas-pipe may be used. Screw a cap solidly on one end or plug the end with a piece of iron, using a pin to hold it in place. The outer end may be closed by means of a piece made in the form of a cap to go over the end, or it may be a loose-fitting plug held in place by a pin, as shown in Fig. 118. When a hardening box of the description shown in Fig. 131 is used, the heat may be gauged nicely by running test wires through the cover to bottom of tube, as shown in Fig. 126. Pack the pieces of work in a mixture of equal parts, by measure, of granulated raw bone and granulated charcoal mixed thoroughly together. Cover the bottom of the hardening box to a depth of 1½ inches with the mixture, pack a row of work on this, being sure that the articles do not come within ¼ to ½ inch of each other, or within 1 inch of the walls of the box. Cover this with the packing material to a depth of half an inch.

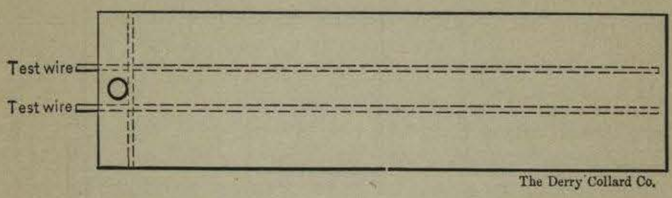


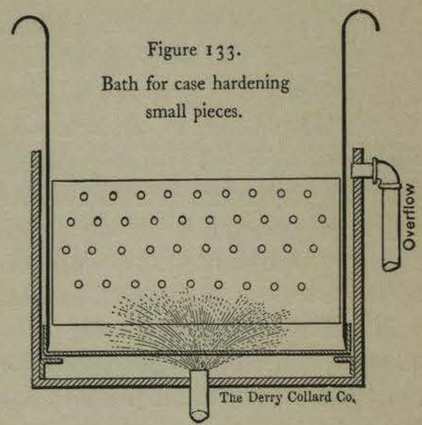
Figure 132. A method of using test wires.

Tamp down, put on another layer, and so continue until the box is filled to within 1 inch of the top. Fill the remaining space with refuse packing material left over from previous hardenings, if you have it. If not, fill with charcoal or packing material, tamp well, put on the cover, and lute the edges with fireclay to prevent as much as possible the escape of the gases. This is necessary, as the carbon is given off from the packing material in the form of a gas. Then again, if there are any openings, the direct heat will penetrate these and act on the work in a manner that gives unsatisfactory results.

If the articles are so large that they would not cool below a red heat before reaching the bottom of the bath, they should be wired, as shown in Fig. 130, before put-

ting in the hardening box. Use *iron* binding wire, sufficiently strong to hold the piece when it is worked around in the bath. If the articles are too heavy for wiring, we must devise some other way of holding—either tongs or grappling hooks. If the pieces are small, they can be dumped directly from the box into the tank, sifting the work out of the box somewhat slowly, so that the articles will not go into the bath in a body. If the tank is large enough, it is a good plan to have wires across from side to side, about 4 inches apart in horizontal rows. Have the rows 3 or 4 inches apart. Do not put any two consecutive rows of the wires underneath each other, but in such a manner that the work will strike the wires as it passes to the bottom of the tank. In striking these wires, the work will be separated, and any packing material adhering to it will be loosened by the jar. The work will also be turned over and over, thus presenting all sides to the cooling effects of the bath as it passes through. These wires can be arranged as shown in Fig. 133 by taking two pieces of sheet metal, a little shorter than the inside length of the tank, drilling holes in them as described in the arrangement of wires, and wires can be passed through these holes and riveted, thus making a

Figure 133.
Bath for case hardening small pieces.



permanent fixture that can be placed in the tank and taken out at will. The distance the wires are apart can be varied to accommodate the particular kind of work that is to be done. They must be far enough apart so that the work cannot become lodged on them.

This simple device does away with the liability of soft spots in pieces of work that are case hardened. Do not have any wires within 8 or 10 inches of the bottom of the tank. Have a coarse screen or a piece of sheet metal drilled full of holes somewhat smaller than the piece we are to harden. Block it up about 4 inches above the bottom, to allow a free circulation of water underneath it. This also allows the water to pass through it around the work, and the packing material will pass through it, giving the water a better chance to get at the work. The water inlet should be at the bottom of the tank, and we should have an outlet about 2 inches from the top to allow the surface water to escape. The cold water coming up from the inlet at the bottom should be turned on before we dump the work, allowing it to run until the work is cold. In heating the work, any form of furnace that will give the required heat and maintain it evenly for a sufficient length of time will do.

The cover of the boxes should have several ¼ inch holes drilled in the center, as shown in Fig. 26. After putting the cover in place, put pieces of $\frac{3}{16}$ inch wire through these holes down to the bottom of the boxes, allowing them to stick up an inch above the cover, to enable us to get hold of them with the tongs. The boxes may now be put in the fire, and subjected to a heat which should vary according to the character of the work. The work should be heated to a red, and

for some classes of work it may even be brought to a bright red. When it is thought that the work has been in the fire long enough to heat through, draw one of the wires with a long pair of tongs. If the wire is red the entire length, time from then. If not, wait a few minutes and draw another, and so on until one is drawn that is red the entire length.

The writer considers this the proper method to employ in timing all work being heated in the fire, whether it is to be annealed or case hardened, charging for hardening by the Harveyizing method, or when we are pack hardening tool steel. If the work is timed from the time it is put in the fire, the results will be uncertain, as the fire is hotter one day than it is another. Sometimes the fire acts dead, another day lively, so the box is longer in heating at one time than at another; but if it is timed from the period when the work commences to take carbon, the results will be as nearly uniform as it is possible to get them, provided the heat is uniform, which can be gauged quite closely by the eye. Better results can be obtained by the use of the pyrometer, although for ordinary work this is not necessary. After running the work the proper length of time, which varies according to the nature of the steel and the purpose for which it is intended (small articles, ¼ inch or less, which do not require anything but a hard surface, should be run one or two hours after they are red-hot), dump into the water.

If it is desired to have them colored somewhat, hold the box about a foot or 18 inches above the tank, allowing them to pass this distance through the air before striking the water. If we are hardening small screws having slots for screw-drivers, and are hardening simply to keep the screw-driver from tearing the slot, we can use expended bone as packing material—*i. e.*, bone that has been used once before. It will make the work hard enough for all practical purposes, yet not hard enough to break. If we wish to harden deeper, we must run about five hours after the work is red. By running sixteen or twenty hours, we can harden to a depth of ⅛ inch. In the case of small articles, it is best to use a bone not coarser than what is known as No. 2 granulated raw bone. When we are to run for a long period of time in the oven, we should use a coarser grade.

When it is necessary to harden very deep, it is advisable to pack the work with coarse bone, letting it run from 15 to 20 hours in the fire, then taking out and repacking with fresh material. Work that is allowed to run for too long a time with the same packing material is very liable to be not only insufficiently carbonized, but to be in a measure decarbonized and highly charged with phosphorus, which is very injurious to the material we are using. The charcoal used in the mixture should, if possible, be the same size granules as the bone. The commercial article is much superior to anything we can pound and sift, so it is policy to buy it. The first cost may seem a trifle stiff, but if account is taken of the time it takes to pound and sift a barrel of charcoal, it will be found the cheaper article.

There are many special preparations used in case hardening, some of which are excellent for special work, while some are good for all kinds of work. When we wish to harden deep in a short space of time, it is advisable to use bone black in place of granulated raw bone. Bone black, or animal charcoal, as it is

commercially called, is prepared by burning bones in a special furnace. It comes in the form of a powder. It leaves a finer grain in the work hardened, and it will make it stronger than if hardened with raw bone. Another form of bone which gives excellent results is called hydrocarbonated bone, a form of bone black treated with oil so that it gives off its carbon more readily than either form mentioned before. It is not generally used, but for nice work it is very satisfactory.

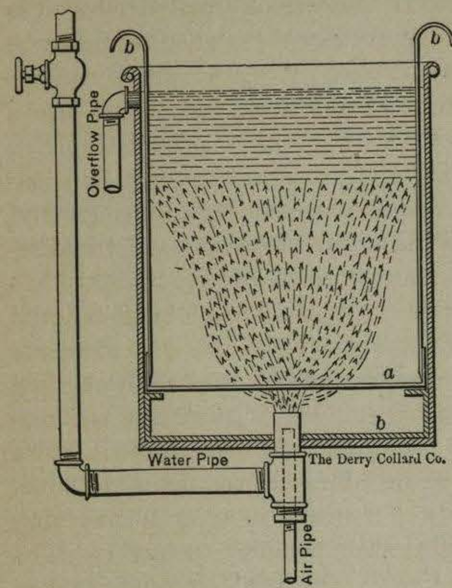


Figure 134. Bath having an air inlet with water, for obtaining colors.

If we wish to give a nice color to our work, it is necessary to first polish it and be sure it is clean when packed in the hardening box. Use the following mixture when packing:

10 parts No. 1 granulated raw bone.
2 parts bone black.
1 part granulated charred leather.

Mix thoroughly before using. The results will be much more gratifying, if a pipe which is connected with an air pump is run up into the water inlet pipe, as shown in Fig. 134. By this means a jet of air is forced into the water at the bottom of the tank in such a manner that it will be distributed through the whole bath, in order that each piece of work may come in contact with it as the work passes through the water.

When articles are hardened by the first process mentioned, heating in the fire and treating with cyanide of potassium, very nice colors can be obtained by taking a piece of gas pipe, putting one end in the bath and blowing through it, passing the work through the air in the water when we dip it. When the articles are thin, and must be very hard, yet tough, it is best to use a bath of raw linseed oil.

If this bath is used, it is advisable to attach a piece of iron binding wire to each piece when we pack the work, allowing the wires to hang over the sides of the box. When we take the box from the fire, the articles can be removed from it and immersed in the oil by means of the wires. They should be worked around well in the bath until the red has disappeared, but in such a manner that broad sides are not moved against the cool oil, or the articles may spring. By taking this precaution, there will be no difficulty in obtaining satisfactory results in practically all cases.

The advent of the bicycle opened the eyes of mechanics to the fact that a low grade steel could be used to advantage for many purposes, where formerly it would have seemed necessary to use tool steel under similar conditions.

As competition made it necessary to produce a machine weighing less than one half of what it originally weighed, and capable of standing up under greater strain, methods were devised whereby low grade steel

could be hardened in a manner that insured its standing as well as if the article was made of the more costly tool steel.

Crank axles were made of 40-point carbon open hearth steel, which was given sufficient stiffness by heating red-hot and plunging in *hot* oil. When the percentage of carbon was lower than that mentioned—40-point—it was sometimes found necessary to pack the axles in a box with granulated wood charcoal, subjecting them to a red heat for a period of from 2 to 6 hours; they were then dipped in hot oil. If the percentage of carbon was too low to insure hardening by this process, they were packed in a box with equal parts of charred leather and charcoal, run for a sufficient length of time, and quenched as described.

It was found necessary to make handle bar binders very light. When made of tool steel, hardened and tempered, the cost was too great, and if made of ordinary machine steel, case hardened, they were elastic, but stretched when strain was put on them. By using a 30-point carbon steel packing in charcoal, and running 1 hour after they were red-hot, then plunged in hot oil, they gave as good satisfaction as though made of tool steel, while the cost of machining was not one-quarter as much.

Hardening bevel gears for bevel gear chainless bicycles caused a great many anxious moments in shops where it was attempted. One prominent manufacturing concern lost at one time 75 per cent. of all gears hardened, according to their own statement.

At the time mentioned the writer was connected with a concern manufacturing a high-grade chainless wheel. The gears were of the design represented in

Fig. 135. They were made of 40-point carbon open hearth steel, which was extremely low in phosphorus. When hardened, they were packed in a hardening box

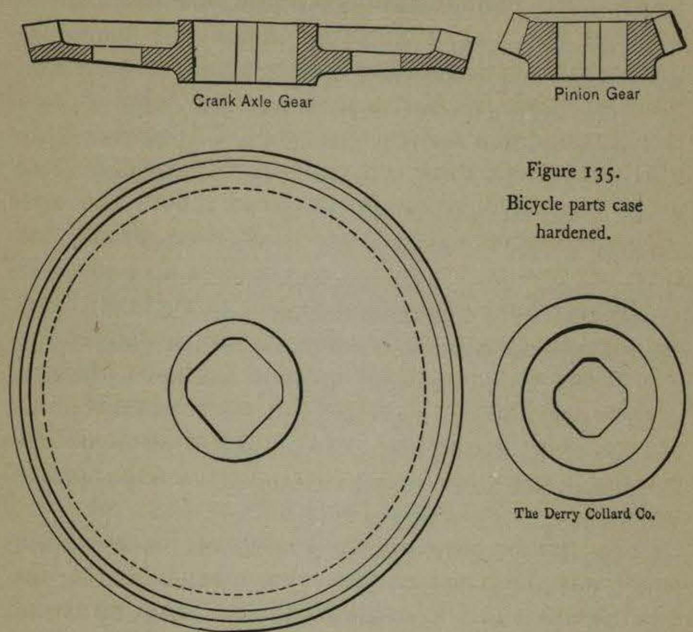


Figure 135.
Bicycle parts case hardened.

with a mixture of granulated charred leather and charcoal, run at a red heat for a sufficient length of time to make the teeth hard enough to resist wear, yet not brittle enough to break when in action. This was the reason it was necessary to use a steel of a very low percentage of phosphorus.

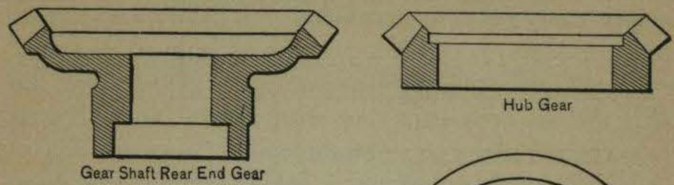
The crank axle gear, as shown above, was run 1¾ hours after it was red-hot, then dipped in a bath of raw linseed oil at a temperature of 100 degrees Fahr.

The surfaces of the teeth were extremely hard; the gear, being made light to reduce weight, necessarily had to be very stiff, yet tough. They gave the best of satisfaction. Another concern in the same line of business packed their gears in granulated raw bone, with the result they were so brittle it was found impossible to use them. Still another packed their gears in raw bone, run them for one hour after they were red-hot, then allowed them to cool, reheated and hardened. The gears were so brittle the teeth would break when the surfaces were not sufficiently hard to resist wear. Both concerns adopted the method in use in our factory and had excellent results.

While bone is an excellent hardening agent, it is not good practice to pack steel in it for case hardening, if brittleness is objectionable in the hardened product, because, as previously stated, raw bone contains phosphorus, and phosphorus when present in steel, especially in combination with carbon, causes the steel to be brittle.

The pinion gear, shown in Fig. 135 on preceding page, was hardened in the same manner as the one mentioned, with the exception of the temperature of the bath, which was about 60 degrees. When hardening the small gears, it was found possible to wire several on the same wire, being careful to have sufficient space between them to insure good results. The advantage of this method of wiring was that a great amount of time was saved when dipping in the bath. While it was necessary to dip the large gear in the bath in a vertical position, working it up and down, the small gears were dipped in any position, as their shape prevented their springing.

The gears, shown in Fig. 136, were used on the rear end of the gear shaft and rear hub, and were hardened in the same manner as the crank axle gear.



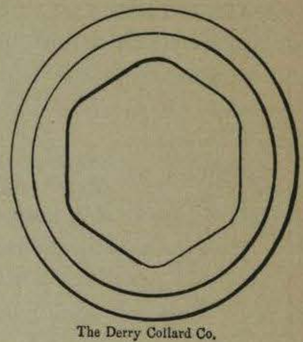


Figure 136. Bicycle parts case hardened.

While the critic might claim that some of the examples given do not properly belong under the head of case hardening, it has seemed advisable to group them under this head, because they are, as a rule, so classified in most shops.

It is generally advisable when case hardening screws made of Bessemer steel wire, to pack in *expended* bone. In this way the extreme brittleness incident to the use of raw bone is done away with in a great measure. The writer has seen batches of small screws ($\frac{3}{16}$ inch and under) made of Bessemer screw stock, which was packed in raw bone and hardened, so brittle that they would break from the necessary power applied to a screw-driver to screw them into the hole. At the same time, when annealed, they filed easier, and were apparently softer than a piece of the rod they were made from. They had been heated to the different temper colors in order to toughen them, but it did no

good. They were so brittle, even when annealed, that they were useless.

Yet screws made from stock out of the same batch, packed in *expended* bone and run for the same length of time, were apparently all right. Had charred leather been used, it would have made them tougher, but the expended bone made them tough enough for all practical purposes. As it is much cheaper and more readily obtained, it is generally used for work of this class.

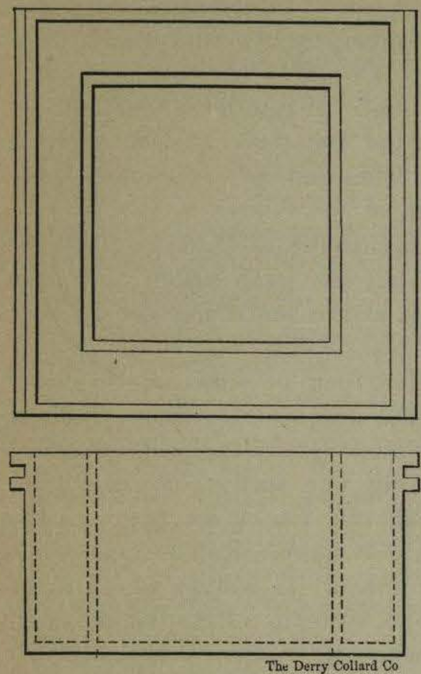


Fig. 137. Another form of box for case hardening.

When case hardening small pieces, which do not require a deeply hardened portion, but which must be uniform, as bicycle chain links, it is advisable to use boxes made especially for them, in order that all the pieces in the box may become heated at about the same time. The writer has in mind a certain stock used for making bicycle chain block links, which was packed in a box of the de-