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 of steel in bars of the desired size, and do not advise forging, claiming best results if the article is machined to size and shape. The reason for this is, that there are many careless, ignorant workers of steel in the various blacksmith shops—men who either do not know the effects of improper methods of heating and hammering, or knowing, do not care. As a consequence, a great quantity of steel is annually rendered unfit for doing the work it might do were it treated properly.

For this reason it is advisable to machine a piece of steel to shape, rather than to have it forged by any but a skillful smith. Yet the fact remains that a piece of steel heated and hammered properly will do more work than a tool of the same description cut from the same bar and machined to shape, even if it is hardened in exactly the same manner.

A piece of steel properly forged is known by tool makers as "hammer refined" steel, and is highly valued by them for tools which are expected to do extra hard work. Tool steel is furnished in bars, blanks or forgings of almost any desired shape.

The smith should bear in mind that heats which are too high open the grain, thereby weakening the steel and making it incapable of doing the largest amount of work possible. If steel is hammered when too cold, the grain is crushed, causing it to crack when hardened; or if it does not crack, the cutting edges will flake off when in use. If the steel is unevenly heated, that is, the outside heated hotter than the inside, the outside portion being softer will respond to the action of the hammer more readily than the less plastic interior, and the outer portion will be torn apart.

Too often it happens that when the smith is rushed

with work he will attempt to heat a large bar of iron for forging, and while that is heating, will try to forge or harden tools someone is waiting for. The spirit of willingness to accommodate is commendable, but a decided lack of judgment is noticeable, because a fire suitable for heating a piece of iron to a forging heat is in no ways adapted to heating a tool either for forging or hardening.

Then again, if the smith is heating iron to its proper forging heat, his eyes are in no condition to properly discern the correct heat to give a piece of *tool steel.*

Annealing.

According to the generally accepted definition of the term, the object of annealing steel is to soften it in order that it may be machined at the minimum cost of labor and tools.

The method pursued in annealing steel depends, as a rule, on the facilities which the shop possesses for doing this class of work. A piece may be softened somewhat by heating red-hot and laying it to one side to cool in the air, provided it is not placed on any substance that will chill it. Neither should it be placed where any current of air can strike it, or it will cool too quickly to become soft. In fact, it would very likely be harder than if worked without attempting to anneal it.

The young hardener should understand that a piece of steel is hardened by heating red-hot and cooling quickly; the more rapid the process of cooling, the harder the steel will be. Annealing has the opposite effect. Steel is annealed by heating red-hot and cooling slowly; the greater the amount of time consumed in the cooling operation, the softer the steel will be, everything else being equal. Now, it is evident that, if a piece of steel be heated to a red and placed on an anvil or other piece of cold metal or thrown on the floor, the portion laying on the cold substance will chill and the process of hardening, rather than annealing, will be carried on.

The same is true if a piece is placed where a current of air can strike it, even if it is warm air, as it will be cooler than the steel and the heat in the steel will be taken up by the air. Thus, the operation will be the opposite of the one desired.

It is the custom in many shops to anneal steel by heating and putting it in a box of ashes or lime. Now, this may be advisable, or it may not be, according to the condition of the contents of the annealing box. If the room in which the box is kept is damp, the ashes or lime, especially the lime, will absorb enough moisture to chill the piece of red-hot steel, particularly if it be small or thin. So we have again a piece of steel hardened to a degree, instead of annealed. When steel is to be annealed by this process, it is advisable to heat a piece of iron or scrap steel and bury it in the ashes or lime, leaving it there until the piece to be annealed is properly heated, when it may be removed, and the piece to be annealed put in its place. The ashes or lime being heated, and every trace of moisture removed, the process of cooling will be slow and the results

satisfactory. A box of lime furnishes an excellent method of annealing steel, if the precaution mentioned is observed.

A very satisfactory method of annealing, which has been used by the writer many times where there was only one or two pieces to anneal at a time, consists in taking an iron box, putting two or three inches of ashes in the bottom and laying a piece of board a trifle larger than the work on them. Heat the pieces to be annealed to the proper degree, lay them on the board, lay another piece of board on top of them, and fill the box with ashes, as shown in Fig. 25. The pieces of board will smoulder and keep the steel hot for a long time. The process of cooling will be very slow.

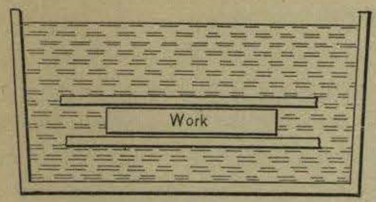

Figure 25.

An iron box filled with ashes for annealing between boards.

There is a method of annealing practiced in some shops which, while it has many advocates, cannot be recommended by the writer, except as a means of annealing a piece of steel that is wanted right away. It is known as cold water annealing. This method has advocates among old hardeners, some of whom get excellent results; but as a method of annealing to be practiced by one who is not thoroughly familiar with the action of fire and water on tool steel, its use is hardly to be advocated. The steel is heated to a red and allowed to cool in the air where no current of air can strike it, held in a dark place, and when every trace of red has disappeared, plunged in water and left until cold. The steel will be softer if plunged into soapy water or oil.

This answers in an emergency, but on account of the ends cooling faster than the center and the smaller portions cooling more rapidly than the larger ones, it is apparent that the piece of steel must be of an uneven temperature throughout when cooled.

The method practiced in many shops of heating a piece of steel in a furnace to the proper annealing heat, using gas, oil or gasoline as fuel, then shutting off the supply and allowing the work to cool down with the furnace, is attended with varying results. While many mechanics advocate this method and claim excellent results, and it has been used by the writer to his entire satisfaction, yet several cases have come to his notice of late where parties had annealed this way with results that were far from satisfactory. Investigation showed that in heating the steel the furnace had been forced in order to heat the piece quickly, and as the steel was heated by radiation it was necessary that the walls of the furnace should be hotter than the piece of steel being heated.

When the steel had apparently reached the proper heat, the supply of fuel was shut off, but the inside walls of the furnace, being much hotter than the work, imparted heat to the steel after the fire was put out, with the result that the steel was overheated and injured, and in some cases entirely unfitted for the use it was intended for. A steel maker of national reputation says that "many thousand dollars' worth of steel are

ruined annually in this way, and it is in every way about the worst method of annealing that was ever devised."

Knowing the vast amount of trouble caused by attempts of various parties to use this method, the writer feels it his duty to condemn a method he has used successfully under favorable circumstances, because all mechanics are not so favorably situated. They do not use the same care in heating steel, especially when it is nearly to the proper temperature, but insist on forcing it, not only to the detriment of the edges and corners, which are bound to heat faster than the center. In this way the whole piece is ruined or injured, because the furnace is hotter than the steel, and when the fire was extinguished, the furnace was closed and there was no means of looking in to determine the amount of heat the steel was receiving, but the results showed it had been heated too much for its good.

Now, if a comparatively small furnace is used, or one having light walls, which will not hold the heat for a very great length of time, the danger of over-heating by radiation after the fire is extinguished is reduced to the minimum. But on the contrary, if the furnace has heavy walls of masonry, capable of retaining the excessive heat for a considerable length of time, the liability of overheating is very great.

A method of annealing that gives universal satisfaction when properly done, and is used in many shops, consists in packing the steel in iron boxes and filling the spaces between the pieces of steel with powdered charcoal. It is necessary when annealing by this method to place one or two inches of charcoal in the bottom of the box before putting in any steel. Do not allow the pieces of steel to come within one-half inch of each other in the box, or within one inch of the box at any point.

When nearly full, fill the balance of the space with charcoal, put on the cover and seal the edges with fire-clay. The reason for keeping the steel from coming into contact with the box is that the iron, especially

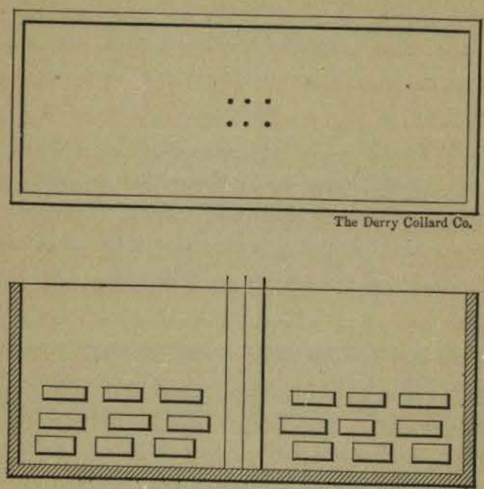

Figure 26. Iron box for annealing.

cast iron, has a great affinity for carbon, and will, when they are both red hot, extract it from the steel, leaving the latter somewhat decarbonized at the point of contact.

In order to be able to determine when the contents of the box are heated to the proper degree, several $\frac{1}{4}$ inch holes should be drilled through the center of the cover and a $\frac{3}{16}$ wire run down through each of these

to the bottom of the box, as shown in the sectional view, Fig. 26.

When the box has been in the fire long enough, according to the judgment of the operator, to heat through, draw one of these wires by means of a pair of long-handled tongs, or by a pair of ordinary length, slipping a piece of gas pipe on each leg to give the required length. If the wire drawn shows hot the entire length, the operator may rest assured that the steel is of the same temperature, because the wire was run down between the pieces at the center of the box. If the wire did not show red-hot, wait a while and draw another. When a wire is drawn that shows the proper degree of heat, the box should be left long enough to insure its being heated uniformily throughout, then the fire may be extinguished. If the walls of the furnace are much hotter than the boxes, the door may be left open until they are somewhat cool. If the furnace shows a disposition to heat the boxes too hot with the door open, they may be removed for a few minutes until the furnace is somewhat cooler, when the boxes may be returned to the furnace, the door closed and the work allowed to cool slowly.

A method that insures excellent results is to plan, if possible, to empty one furnace of work to be hardened some little time before the work being annealed is sufficiently heated. Keep the first furnace closed to retain the heat as much as possible, so that it will pass the stage where it is liable to overheat the articles, and it will commence to cool down somewhat. When the work being heated for annealing has been subjected to the heat a sufficient length of time, the boxes may be removed from the furnace they were heated in and placed in the first furnace. All danger of heating too hot from radiation is done away with. This method cannot, of course, be practiced if there is but one furnace.

While it is generally understood that the object of annealing steel is to make it soft enough to work to advantage, yet from the hardener's standpoint annealing has another and more important office than simply to make steel workable.

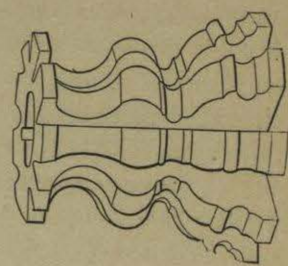

Figure 27. An irregular milling cutter.

A piece of steel as it comes from the steel mill or forge shop is very apt to show a difference of grain in various parts of the piece, due to uneven heating and an unequal closing of the pores in the process of rolling or hammering; consequently there exists in the piece internal strains. In order to overcome the effect of these internal strains, which must manifest themselves when the steel is hardened, the work should be blocked out somewhere near the shape and annealed. If the piece is a milling machine cutter, punch press die, or similar tool, having one or more holes through it, the holes should be made somewhat smaller than finish size before annealing to remove strains. If it is a milling machine cutter of irregular contour, as

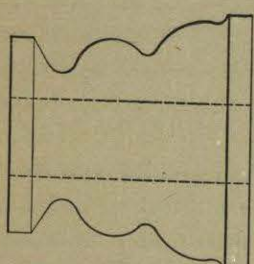

Figure 28. Irregular milling cutter blocked out for annealing.

shown in Fig. 27, it should be blocked out as represented in Fig. 28. The benefit gained in pursuing this course is that it is heated for annealing under as nearly as possible the same conditions, so far as shape is concerned, as when heated for hardening; consequently the tendency to change shape will be overcome in the annealing.

Long pieces of steel that are to be hardened will give much better results if roughed out—that is, all scale and outside surface removed by planing or turning—then thoroughly annealed. Should the piece spring when annealing do not straighten when cold, as it is almost sure to spring when hardened. If it is not sufficiently large to turn out without straightening, it should be heated red-hot and straightened. The hardener is blamed many times because a costly reamer or broach or similar tool is crooked in hardening, when in reality the blame rests with the man who turned or planed it to size.

After it was annealed he tested it in the lathe, and finding it running out somewhat he takes it to an iron block or an anvil, and commences to hammer. He finally gets it fairly straight, and feels quite proud of his job. He doesn't like to see a man machine a piece of steel that is crooked even if it will finish out, when a few strokes of a hammer will fix it all right.

He has, by means of hammering, set up a system of internal strains much more serious than the ones removed by the process of annealing. He commences to machine the piece. Every time he goes below the effects of a hammer mark, the particles of the piece of steel "goes" or moves in some direction at this point, and it is necessary to repeat the operation of hammer persuasion again, with the effect that by the time the article is ready to harden, it is in no condition to be hardened. It is either crooked in all directions, or it is only waiting for the fire to relieve it and allow it to go where it will. When the hardener gets through with it, it looks like a cow's horn, and of course the hardener is blamed.

If he happens to be a man without any machine shop experience, or does not understand the nature and peculiarities of steel, he does not know where to place the blame, and perhaps it wouldn't do any good if he did.

He, of course, isn't going to shoulder it, so the fault is laid to the steel, and, in consequence, if the trouble continues, another make of steel is bought because the man in charge does not know or cannot spend time to locate the trouble. It cannot be the fault of the man in the shop, they say; it must be the steel; or they decide it must be the hardener, because some other concern with whom they are acquainted use this same steel and have no trouble, so the hardener has to stand the blame.

A successful business man is quoted as saying: "If I were to drive a mule team, I would study the nature of mules." A man to be a successful hardener must study the nature of steel. He must know what steel is liable to do under certain conditions, and how to avoid undesirable results. No matter whether it relates to his department or some other department, he should know that it is possible for the tool maker to treat the steel in such a manner that results anything but satisfactory *must* follow when it is hardened. He should also understand that he may make the steel un-

fit for use by overheating when annealing, or he may not heat it uniformly throughout, and consequently does not remove the tendency to spring from internal strains. If a satisfactory steel is furnished, the hardener should never blame the steel for bad results which are caused by his ignorance or carelessness, because he may be furnished with an undesirable steel next time. And in time those over him in authority will tire of complaints about a steel that another concern is satisfied with.

A method of annealing steel which the writer has seen practiced in some shops, but which should never be used when annealing tool steel, is to pack the articles in a box with cast iron dust or chips. Now this method works nicely when annealing forgings or other pieces of *machinery* steel which were hard and show glassy spots and cannot be softened by the ordinary processes of annealing. The cast iron seems to have an affinity for the impurities liable to be present in the low grade steels, and the result is very soft and easily worked pieces. But if the method is applied to tool steel the carbon is extracted to an extent which is highly injurious to it. To be sure, tool steel can be annealed very *soft* if packed as described, but the result is anything but desirable.

The writer had charge at one time of a hardening plant where, among other things, many hundred pairs of bicycle cranks were hardened every week. A lot of ten thousand crank forgings were received and started through the regular routine necessary to get them in a condition for hardening. When the first batch reached the hardener it was found impossible to harden them by ordinary processes. And, by the way, samples had been forged and sent us ahead of the main batch which had been tested and found all right. They hardened and tempered in a satisfactory manner and stood the required tests.

The first test was made by placing each end of the crank on the two projections of an iron block, as shown in Fig. 29, and struck in the center a blow with a heavy hammer in the hands of an experienced inspector. They were then taken to a testing machine and given a very severe test, which consisted in holding the end which went on the axle in a fixed position. Pressure was applied to the other end until the crank was bent a certain amount. The pressure was removed and the crank was supposed to come back straight, but the cranks in the large batch would not harden.

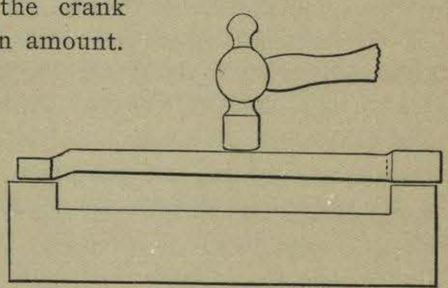

Figure 29. Testing a bicycle crank.

Investigation at the forge shop where we procured them, showed that through some mistake the cranks, after being forged, were packed in cast iron dust or chips in the annealing pot. Orders had been given to anneal some machine steel forgings in this manner and to anneal the cranks in charcoal, but someone got the orders mixed, and hence the trouble. The cranks were made of 40-point carbon open hearth steel. We remedied the defect by packing them in iron boxes with

wood charcoal, and submitting them to heat in the furnace for several hours after they were red-hot. In this way we got them in condition to harden.

Another method which works nicely when applied to annealing machinery steel, but which is entirely unfitted for tool steel, is to pack the pieces in annealing boxes in expended bone—i. e., bone that has been previously used in case hardening. As before stated, machinery steel packed in this manner, and heated, gives excellent results. It is also an excellent way of annealing cast iron (by this is meant small castings, as typewriter parts, etc., which must be very soft in order to machine nicely).

But tool steel should never be packed in any form of bone, as bone contains phosphorus, and this is the most injurious of any of the impurities which tool steel contains. The steel maker uses every effort possible to reduce the percentage of this impurity to the lowest possible point, for while it is a hardening agent, its presence makes tool steel brittle, so that it is folly to pay a good price for steel on which the manufacturer has spent much time and money to rid of undesirable impurities and consequently must charge a high price for, and then use some method whereby the steel is charged with these very impurities.

In concluding, it may not be amiss to emphasize a few facts that have already been mentioned. Do not overheat steel when annealing or it will be permanently injured. Do not subject it to heat for a longer period of time after it becomes uniformly heated throughout than is necessary to accomplish the desired result. For while it is necessary to heat the steel when annealing to as high a heat as will be needed in hardening, and while the steel must be subjected for a period of time to heat that insures its being of the same temperature in the middle of the piece as it is at the surface, yet we must be careful not to overdo it.

Steel kept at a red heat for a long period of time, even if it is not overheated, will betray the fact when the temper is drawn after hardening, if it does not at any other time. A piece of steel which is kept hot for too long a period when annealing, may apparently harden all right, but when the temper is drawn the hardness apparently runs out—i. e., when the piece is heated to a straw color it may be filed very readily, whereas a piece from the same bar not annealed, or which was *properly* annealed and then hardened and drawn to the same temper color, would show all right—i. e., a file would just catch it.

Uniform temperature when heating for annealing is as desirable as when heating for hardening. If a large block is unevenly heated, its corners and edges are hotter than the main part of the block. Violent strains are set up at these points, so it will be readily apparent that uniform heating during the various processes is one of the secrets of successful hardening of tool steel.

There are other methods of annealing steel, methods whereby the surface does not become oxidized by the process of heating, as when heating drill rods, etc., but as these methods are not likely to be used by mechanics in every day shops, their consideration would be entirely out of place at this time.

Lastly, remember that any process of annealing that takes from the steel any of its hardening properties should never be used, no matter how soft it will

make the steel. It is better to work a piece of steel which is hard, than to unfit it for doing its maximum amount of duty when finished; but *it is* possible to anneal most steel so that it will be workable and yet harden in a satisfactory manner; in fact, in a much more satisfactory manner than if not annealed.

When annealing high carbon steel, and it is desirable to retain the full amount of carbon in the steel, it is advisable to pack in the annealing box with charred leather, instead of wood charcoal.

When it is desirable to harden the surface of low carbon steel harder than it would naturally be, it may be machined nearly to size, packed in a box with charred leather and run for a length of time sufficient to give the desired results. After machining to shape, it may be hardened in the ordinary manner.

Hardening Baths.

When steel is heated to the proper hardening heat it is plunged into some cooling bath to harden. The rapidity with which the heat is absorbed by the bath determines the hardness of the steel. Knowing this, it is possible by the use of baths of various kinds to give steel the different degrees of hardness and toughness. A bath that will absorb the heat contained in a piece of steel the quickest, will make it the hardest, everything else being equal. A bath of mercury will cause a piece of steel plunged in it to be harder than if it were plunged in any of the liquids commonly used