of the piece, until a certain limit is reached. Now, if a change in temperature of a few degrees changes the size of a piece of steel, the reader is asked to imagine the change in size and structure which must take place when it is heated red hot. This means a change in temperature of about 1,000 degrees, and the effect of heat on steel is to expand it, while the opposite effect is accomplished when it is cooled. The more rapidly it is cooled the harder it will be. It is indeed wonderful that a piece of steel can undergo the changes which take place in its size and structure, and remain intact. When steel is cooled in the hardening bath, the outside of course chills and hardens first, while the inside is hot and consequently soft for some little time afterward. Now, the outside, being hardened, is practically inflexible, while the inside continues to change in structure until cold. This is especially true of pieces having teeth or projections on their surface.

Understanding the fact that heat causes steel to expand, it will readily be seen that it is absolutely necessary that it should expand *uniformly* throughout the piece. If the corners and edges are hotter than the balance of the piece, then it is unevenly expanded, and consequently will contract unevenly. Now, if one part of a piece of steel contracts more than another, or not uniformly with another part, it is liable to crack from the effects of the unequal contraction; if it is not cracked when taken from the hardening bath, it is liable to crack at some future time for no apparent reason. This applies especially to large pieces, and steel having a high percentage of carbon.

The Workman.

The writer's professional experience in the various methods of working steel, brings him in contact with men of all degrees of intelligence. Some men are really skillful in the particular line they are engaged in; that is, they are very careful when heating and dipping in the bath, and get excellent results. But they do not know the difference between a steel of ¾ per cent. carbon and one of 1½ per cent; in fact, they do not know anything about percentages of carbon, and don't care; they say so in as many words. The steel they use is always the same make and temper. They have never used anything else. If they should get hold of another make, that worked differently from that they had always used, they would condemn it, saying it was no good, because it didn't act just like the steel they were accustomed to handling.

Now, if anything should happen to the steel mill making their particular brand, they would be obliged to learn the art of hardening all over again, or go out of business. When it becomes necessary, or the concern who employs these men considers it advisable, to change the steel used; or if it is necessary to have the composition changed to get some desired result, this poor fellow is all at sea. He doesn't know what to do, and he doesn't want anyone to tell him what to do. His only cry is, "The steel isn't good for anything," when in reality it may be the best on the market. Such a man is to be pitied, but he is a very expensive man for those in whose employ he happens to be, and a very unpleasant fellow to attempt to teach anything.

Another example is the man who banks on his twenty or fifty years' experience, and considers that because he has been allowed to exist for that length of time and occupy a position as blacksmith, or hardener, that he must necessarily know it all. To him steel is steel; he treats it all alike. If there is some particular steel good-natured enough to stand his treatment, that is the only brand on the market fit to use—according to his way of thinking—and he generally has such an unpleasant and forcible personality, that he either has his say or goes where he can. He never investigates the merits of different makes of steel; simply condemns every make that will not stand his abuse.

If every man of the type under consideration advocated using the same steel, there might be a plausible excuse for looking into the merits of that particular brand, to the exclusion of every other, but you will hardly find two of them advocating the use of the same steel. I am happy to say this class of hardener is not in as great a majority as formerly; their number is gradually diminishing. It is impossible to teach him anything, because that long experience of his stands in the way; it is his only stock in trade, and he presents it every time anything is said on the subject.

Now, a long experience in any particular line of

work is a good thing for a man, provided it has been a real experience, rather than an existence, and in no line of business is it more valuable than in the working of steel, if the man has kept pace with the procession. If not, then he is no farther advanced than when he fell out of line, and as it is a law governing all our lives, that no man stands still, he must of necessity either advance or go backward. The man who has not kept pace with the progress of events, must necessarily go backwards.

Another class we meet with is the jolly, good-natured fellow, who wants to please everybody, but does not know how, and is too lazy to find out. He had rather tell a story than to keep his eyes and attention on the piece he is heating, consequently he has all kinds of luck. There is no remedy known for this chap. He is willing to be told how to do, but is too lazy to assimilate and put in practice what is told him.

A class of hardeners which are few in numbers, but who should get into some other business as soon as possible, consists of men who are practically color blind. They cannot distinguish between the various shades of red, neither can they discern the temper colors as closely as they should. Some of them are extremely intelligent, capable men, but they have missed their calling, and missed it most decidedly, because a man to be a successful blacksmith or hardener, must have good powers of distinguishing colors and shades.

There are many other classes that might be considered, but it would be a waste of time, so we will look in upon the successful hardener. There are various degrees of success, but we will consider the man who is a success according to the generally accepted idea.

The successful hardener is one who finds out what is wanted or expected of the article he is to harden; whether extreme hardness, toughness or elasticity, or a combination of two of these qualities. He also understands the nature and pecularities of the steel he is using; he considers the fire he is to use, and the bath in which the steel is to be quenched after it is heated.

His spare moments are not spent hanging around street corners, or saloons, but in reading and studying such books and mechanical journals as treat on subjects in his line. In this way he becomes familiar with the nature of steel and knows what to do when certain conditions which are out of the ordinary arise; he gets the experience of others and his knowledge makes it possible for him to discriminate between that which will be of value to him, and that which will not.

When a piece of work is given him he studies the shape of the piece, the best method of heating and quenching, in order to get the desired results. To him steel is not simply steel, which must be treated just like every other piece of the same metal, but it is a valuable tool or piece of machinery which he takes pride in hardening in the best possible manner. If he hears of a brand that is giving some one trouble, he is anxious to get a piece of it, and experiment and find out why they can not get good results from it.

If he hears of a brand that some one claims gives extra good results when using, he is anxious to get a sample and test it, and see for himself if the steel is all the makers claim it is.

He is not above learning, takes advantage of every

opportunity to get the ideas and experience of others, especially men who have had a wide experience. To him the articles he is called on to harden represent so much money entrusted to his care, and he takes every means possible to get it out in a satisfactory manner.

Does some one ask, where do you meet such men? The writer is happy to say such men are not the exception. To be sure they are not in the majority, but the number of men who are making a careful study of this subject is really encouraging.

Steel.

Although there are many makes of steel and, in most cases, several grades of the same make, yet to the average mechanic there are two kinds of steel, viz., machinery steel and tool steel.

Machinery steel is used in making such parts of machines, apparatus or tools as do not require hardening in order to accomplish the result for which they are intended. Or, if they require hardening at all, it is simply a surface hardening, the interior of the piece being soft with a view to obtaining greater strength. This class of steel is of a lower grade than tool steel. It is softer, works more easily, both in the operations of forging and machining, and can be safely heated to a higher temperature without harm to the steel. It resembles more closely wrought iron and is sometimes scarcely to be distinguished from it. Machinery steel is used whenever it will answer the purpose, not only on account of its being more easily machined, but its first cost is only ¼ to $\frac{1}{10}$ that of ordinary tool steel, and for most purposes where it is used, it answers the purpose as well or better.

Although it is considered advisable to group steel under two heads, as mentioned, namely, machinery steel and tool steel, yet on account of the different grades of the article under each head it will be necessary to distinguish them somewhat as they are considered under the various processes of hardening.

Tool steel is made with the idea in view that it is to be made into such tools, appliances or parts of machines as require hardening in order to accomplish the desired result. Although the term "tool steel" is applied to steel intended to be made into cutting tools, there are many makes of this article, each make differing in some respects from every other make. Not only is this so, but most makers put out tool steel of different tempers. Now, the word "temper," as used by steel makers, means the quantity or percentage of carbon the steel contains. It is low temper, medium, or high, or number or letter so and so, according to the understanding of the marks in each particular mill. The following are considered by steel makers as the most useful tempers of tool steel:

Razor temper (1½ per cent. carbon). This steel is so easily burnt by being overheated that it can only be placed in the hands of very skillful workmen. When properly treated it will do many times the work of ordinary tool steel when working hard metals, etc.

Saw file temper (1⅜ per cent. carbon). This steel requires careful treatment, and although it will stand more heat than steel of 1½ per cent. carbon, it should not be heated hotter than a low red.

Tool temper (1¼ per cent. carbon). A very useful temper for turning tools, drills and planer tools in the hands of ordinary workmen.

Spindle temper (1⅛ per cent. carbon). A very useful temper for mill picks, circular cutters, very large turning tools, screw thread dies, etc.

Chisel temper (1 per cent. carbon). An exceedingly useful temper, combining, as it does, great toughness in the unhardened state, with a capacity of hardening at a low heat. It is well adapted for tools where the head or unhardened end is required to stand the blow of a hammer without snipping off, and where a hard cutting edge is required, such as cold chisels, etc.

Set temper (⅞ per cent. carbon). This temper is adapted for tools where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, etc.

The following also gives the steel maker's meaning of the word "temper":

Very hard	150 carbon +
Hard	100—120 carbon
Medium	70—80 carbon

In order that the reader may understand something of the significance of the terms used to designate the amount of carbon a piece of steel contains, the following brief explanation is given. A point is one hundreth of one per cent. of any element. 100 points is one per cent. A 40 point carbon steel contains forty one-hundreths (.40) of one per cent. of carbon. The same explanation applies to any element that goes into the composition of steel. The steel is sometimes designated by the number of points of carbon it contains—as 20 carbon or 60 carbon steel. The amount of carbon the steel contains does not necessarily determine the *quality* of the steel, as the steel maker can give an ordinary low grade stock a very high percentage of carbon. This would harden under the ordinary conditions, but would be practically useless if made into cutting or similar tools.

It becomes necessary many times to procure a low grade steel having as low a percentage of carbon as possible. Then again it is advisable, where a greater amount of strength is required, to give the steel a higher percentage of carbon. This will be briefly alluded to from time to time under the various topics.

The reader will readily see from the foregoing that it is the presence of carbon in steel that causes it to harden. The amount of hardness and the degree of heat necessary when hardening depending on the quantity of carbon the steel contains. Tool steel is hardened by heating it red hot and plunging into some cooling bath. The more quickly the heat is extracted the harder the piece will be.

Tool steel has certain peculiarities which must be understood if one would be a successful hardener. The outside surface of a bar of steel, as it comes from the steel mill or forge shop, is decarbonized to a considerable depth. This is because the action of the oxygen in the air causes the carbon to be burned out of the steel at the surface during the various operations when the steel is red hot. In order that the decarbonized

portion may not give trouble, it is necessary to cut away enough of the surface to remove this portion before hardening. If a tool which is to finish $\frac{1}{2}$ inch diameter is to be made out of round steel, it is necessary to select stock at least $\frac{1}{16}$ inch diameter larger than the finished tool, or the outer surface will not harden sufficiently. For sizes from $\frac{1}{2}$ to 1 inch diameter, select stock $\frac{1}{16}$ to $\frac{1}{8}$ inch larger. For sizes from 1 to 2 inches diameter, select stock from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch. For sizes above 2 inches, about $\frac{1}{4}$ of an inch should be cut off.

It is necessary when centering round steel to have the center hole very near the center of the stock, as shown in Fig. 2, in order to take off an equal quantity

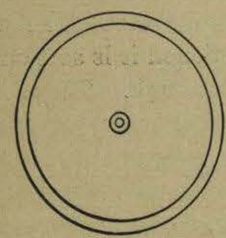

Figure 2.

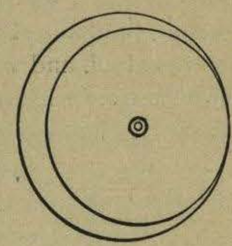

Figure 3.

Proper and improper centering.

of the decarbonizing surface all around. If a piece is centered, as shown in Fig. 3, the decarbonized surface will be entirely removed from one side of the piece and scarcely any of it taken from the opposite side; consequently, the side from which it was removed will be hard, while the opposite side will not harden, or at least will not be as hard as the other side.

So it will be very readily seen that this simple fact, which is often entirely overlooked in machine shops, is a cause of a great amount of trouble.

Tool makers, as a rule, understand this fact in regard to steel, but some one in authority, wishing to save money for the manufacturing concern, gives the job of centering to the "tool room kid," as he is termed many times. He fails to instruct him in the proper manner, the boy does not understand the nature of steel, and as a consequence, it is centered, as shown in Fig. 3.

Now, if the tool maker were given the job, he would readily see that it was centered wrong. But the spirit of economy still prevails, and the boy is allowed to rough out the piece. As a consequence, the outside surface is removed, and all traces of the eccentric centering are eliminated. The piece is made into a reamer or some other tool, and when hardened it is soft on one side, the other side being hard enough. There is no one that can be blamed but the hardener, so he, poor fellow, has to "catch it." It wouldn't be human nature to stand by and say nothing when blamed for something one didn't understand, so he, in turn, says the steel is no good.

As a consequence, the make of steel is often changed and another kind is procured, and as it is desirable to test the steel before making any quantity of it into costly tools, the tool maker is told to cut off a piece of the stock and make a reamer just like the one that wouldn't harden properly. He centers the piece, as shown in Fig. 2, turns it to size, cuts the teeth and gets it ready for hardening. It comes out all right. The steel is pronounced O. K. and a supply is

ordered. A large batch of reamers is made up and the same boy is given the job of centering and "roughing" them, and the results are the same or worse than when the former lot was hardened. Now, it is evident to every one that the hardener *must* be to blame. He hardened one reamer from this *same* steel and *it* was satisfactory. Well, the only conclusion is that he made a *mistake* when he did that *one*, and isn't on to his business, so he is nagged and found fault with until he can stand it no longer and gets out. The next man has the same results, and those in charge say, "You can't get a decent hardener now-a-days." All this trouble and expense because some one wanted the reputation of being a good manager.

Now, a boy *can* center and rough out stock and do it all right, but he must be told how and he must be watched. If a make of steel that gives satisfaction suddenly shows freaks, do not at first condemn the steel, but look for the cause. Many people have the idea that there are unaccountable mysteries connected with tool steel, and that hardening is a thing which must be attended with luck, or bad results follow. Now, as a matter of fact, if a good steel is used, the cause may be found for all troubles which occur when it is hardened, and many times they will be found to result from some penny wise and pound foolish notion.

Another peculiarity of steel is that if the position of any of its molecules is disturbed when the steel is cold, there is apt to be trouble when the piece is hardened. For instance, if a piece of steel that is to be hardened for any given purpose is cut from a bar of tool steel and it is found to be so bent that it would be impossible to turn and make straight and remove all the decarbonized surface, the piece should be heated red hot and straightened. If it were straightened cold, then finished to size and hardened, it would be almost sure to spring. The writer has seen men at work making blanking dies for punching press work who, when they made the openings too large at any point, would take a hammer and pene the stock into the opening without heating the die. They would plane the top of the die for shear and then finish it and swear about the hardener when the piece cracked in hardening directly under where they pened. Possibly, it would not show any bad results at that time, but when the die was used, the portion referred to would crack off. Or if the punch were a tight fit, it would lift a piece of steel from the face of the die the shape of the hammer pene or of the set used.

Steels of different makes vary in their composition. A successful hardener will experiment with a *new* steel and find out just what he can do with it. One make of steel will harden at an extremely *low* heat; another make will not harden in a satisfactory manner at that heat. It requires a higher heat in order to harden it. Now, if we were to heat the first steel as hot as we were obliged to heat the other, we should ruin it, or at least harm it. For this reason it is not advisable, generally speaking, to have a half a dozen different kinds or makes of steel around a shop, unless someone knowing the nature and peculiarities of each is to do the hardening. And even then trouble will follow unless a ticket accompanies each tool stating the kind of steel, and this in the ordinary machine shop would lead to endless confusion.

A steel which gives satisfactory results should be

selected and then used until convinced that something better is to be had. The judgment of an experienced hardener is not always to be relied upon as to the best brand of steel for a particular purpose. It may be that he has had excellent results with a certain brand because he has methods of hardening particularly fitted to that brand of steel; but it may be true that were he to change his methods to adapt them to another steel, much better results would follow.

The writer was at one time brought in contact with a hardener whose complaints in regard to the steel furnished had caused the superintendent of the shop to change the make of steel several times. Each time a new steel came into the shop the result was the same, until finally by the advice of one of the steel manufacturers several tools similar to those previously hardened with unsatisfactory results were made from each of the condemned steels and given to a man who was considered an expert hardener. When they were hardened and returned they were all found to be in a satisfactory condition, not a crack visible in any of them. They all gave good satisfaction, proving that the man rather than the steel was at fault.

Almost any of the *leading* makes of steel in the market will give good results if treated properly, but the same treatment will not answer for all makes. Some makes are more satisfactory than others for certain purposes, but better results may be obtained from most of them than is often the case.

Steel may be purchased in bars of various shapes. The more common shapes are round, square, flat and octagon. If steel is to be cut from the bar and machined to shape, it is advisable to purchase bars which allow of machining to the desired shape, at the least expense and with as little waste of material as possible. Always remember that it is necessary to remove the decarbonized portions previously mentioned.

If a tool which is to be cylindrical in shape is to be made, use a piece of round steel. If an article which is to be finished square, use a piece of square steel, etc.

Steel of the same quality and temper is furnished in all the common shapes on the market. It was formerly considered necessary, if best results were desired, to use octagon steel when making cylindrical pieces of work, but now all steel makers claim to make round steel of exactly the same quality as the corresponding sizes of octagonal shape, and the experience of every mechanic who has tested the two under similar circumstances substantiates the claim.

The steel maker puts on the market steel of different tempers, but he advocates the use of the particular temper which he considers best adapted to the work in the individual shop. As a rule he does not make any mention of any other temper, because he knows that if steel of several different tempers are kept in stock, that in all probability the labels will be removed in a short time and any distinguishing marks be thrown away. Then no one in the shop will know one temper from another, and when a piece of ⅞ per cent. carbon steel is made into a shank mill or similar tool, and a piece of 1½ per cent carbon steel is made into some tool that must resist the action of heavy blows, trouble will follow and the steel be condemned. For this reason it is considered advisable to advocate the use of a temper that will give satisfactory results when put to most uses. But the fact remains that

steel, in order to give best results, should contain the proper percentage of carbon for use on the particular job.

In shops where detail is followed very closely, the steel is kept in a stock-room, each different temper by itself, and so marked that there is no danger of it getting mixed. Much better results are then obtained, provided a competent man does the hardening, than if one temper was used for everything. But in a shop where there is only one rack, and sometimes no rack, the stock, machinery steel, tool steel, and everything else is kept on this one rack, or in a pile on the floor, it is not advisable to have steel of different tempers lying around, or results anything but satisfactory are sure to follow.

Percentage of Carbon Necessary to Produce Desired Results.

In the first part of this section is given a table of percentages of carbon present in steel for various purposes. This table is generally accepted as a guide to those desiring steel for any given purpose, and, generally speaking, it is safe to use stock of the tempers given, but modern competition has made it necessary to harden steel harder and yet have it able to stand more than was formerly the case. When these conditions prevail, it is necessary many times, especially in the case of cutting tools, to use steel having a higher percentage of carbon than is given in the table.

When steel containing a higher percentage of carbon is used, then extra care must be observed when heating. For the operations of forging, annealing, or hardening high carbon steels should not under any circumstances be given to a careless workman, or to one not thoroughly familiar with the effects of heat on steel of this character.

When high carbon steels are used and treated properly, they will do more work than steels containing a lower percentage, but unless they are to be handled by a competent man, they generally prove to be a very unsatisfactory investment.

When long articles which are to be hardened are made of tool steel, the writer has had excellent results by taking the steel as it came from the bar, or after it was roughed out for annealing, or even after it was forged in the smith's shop, by heating it to a forging heat. Then, standing it on end on the anvil, or on a block of iron on the floor—if it were long—and giving it one or more blows on the end with a hand hammer or sledge; the weight of the hammer depending on the size of the piece. This operation is sneered at by many expert steel workers, but the writer's experience convinces him that better results will follow when the piece is hardened, if this precaution is taken, the tendency to spring is apparently greatly reduced. Should the piece be bent by the operation, it should be straightened while red hot, because if straightened cold, it most surely will spring when hardened.

The writer has no intention of advertising any make of steel, as he does not believe any one make is best for *all* purposes, but experience has convinced him that some makes of steel give better results for certain purposes than others, also that some makes are better adapted for "all around" use than others.

If a party is using a steel with unsatisfactory

results, it is advisable to take measures to ascertain whether the trouble is in the steel, or in the method of working it. The writer has seen one of the best steels on the market condemned and its use discontinued, because the workman who did the hardening had been accustomed to a steel containing a lower percentage of carbon. The steel he recommended was adopted, the results so far as hardening were concerned were satisfactory, but the tools did not produce nearly the amount of work they should.

After a time, the services of an expert were sought. He advocated the use of the very steel they had discarded. A tool was made from it, the expert hardening the tool. When put to actual use, it proved itself capable of doing many times the amount of work between grindings that could be obtained from low carbon steel.

The hardener, like a sensible man, allowed the expert to instruct him in the proper methods to pursue, with the result that he became one of the best hardeners the writer has ever had the pleasure of meeting.

A steel should never be selected because it is *cheap*, because it often happens that the steels which sell for the least money are the dearest in the end. It is possible to put $100.00 worth of work on a piece of steel costing 25 cents. Now, if the tool was found useless when hardened, then $100.25 has been expended in vain. On the other hand, if steel adapted to the purpose had been used, and it had cost 50 cents, there would have been a clear saving in money of nearly $100.00. This is not an exaggerated comparison, as such cases are frequently met with by the writer.

On the other hand, it is folly to pay 75 cents a pound for steel, when 16 cents will buy one exactly suited to the job. Good steel is cheaper at any price it would be apt to bring in the open market, than steel not adapted for the purpose would be if it were a gift. A steel not adapted to the purpose is *dear at any price.*

The writer has had charge of tool rooms employing large numbers of tool makers, and experience has convinced him that it is a saving of money in every case to test every bar of tool steel received into the shop that is to be made into tools.

If the steel is kept in the stock-room, the stock keeper can—when the hack saw, or cutting off machine is not in use—cut a piece from the end of each bar, stamping the piece cut off and the bar alike. These pieces can be given to an experienced hardener, to heat them to the proper hardening heat, and quench them in a bath of water or brine. After they are thoroughly dry, break as near across the center as possible, examining the center of fracture for pipes. A pipe is a cavity which of course makes the bar unsound. It may run the entire length of the bar. If a bar having a pipe is discovered, the steel maker will gladly replace it with a sound bar. Any make of steel is liable to have cavities of this kind, although the inspector at the mill generally discovers it in the ingot, thus preventing it being made into bars; but it sometimes escapes even the most careful inspection.

If a tool costing $50.00 were made from a bar that was piped, it would in all probability go all to pieces in the bath when hardened, unless the tool were of a character that allowed the piped portion to be removed. It is safer, however, to inspect the bar before any costly tools are made from it. If the bar proves

sound, the grain should be examined; if this is fine, and of the proper appearance, it may be tested for hardness with a file.

If the piece proves to be all right, the bar may be stamped O. K. or given some distinguishing mark; should it prove otherwise, the manufacturer should be notified and the steel returned to the mill.

This system of inspection may seem like a needless waste of money, but the cost of one tool which is of no use when finished, would pay the necessary expense of testing all the steel used in a machine shop of the ordinary size in five years.

When a tool is required to do extra hard work, that is, cut hard stock, or run at a higher speed than is ordinarily employed in the shop, it is advisable to get a steel having a greater percentage of carbon than the steel used for tools for ordinary work. When high carbon steels are bought, they should be distinctly labeled or stamped, and kept by themselves away from the rest of the steel, because if the identity of the piece is lost, it is liable to be made into tools and hardened without the hardener knowing that it differs in composition from the steel ordinarily used. As a consequence he would heat it to the same temperature he was accustomed to give the steel regularly used, and it would in all probability be cracked from the heat which was higher than was necessary.