Introduction.

An experience which covers twenty-five years of actual practice, in the various branches of machine shop work, has taught the writer that much more depends on the condition of the various cutting tools used, than mechanics in general realize.

The various machines used in working iron and steel to shape have been improved, and made heavier in the parts subjected to strain, in order that heavier cuts and faster feeds might be taken to reduce the cost of production.

If a tool is doing the maximum amount of work possible for it to do, when it is used in a light machine, it would be folly to purchase a heavier, stronger machine and use the same tool in it. But it has been found in many cases that cutting tools could be made that would take heavier cuts and faster feeds than the older types of machines could carry. Consequently it has been necessary to re-design most types of machines used to remove stock, in order to bring them into shape to be used as tools, parts of machines, and other apparatus.

Competition has made it absolutely necessary that every possible means be taken to reduce the cost of an article without reducing the quality. Where possible the design is changed so the article may be made more cheaply. And as labor is, generally speaking, the principal factor to be considered, it is necessary to reduce as far as possible the number of operations, or simplify those necessary, and so reduce the cost of the manufactured article.

If by the use of machinery especially adapted to the work to be done, it is possible to do in one operation the work which formerly required four separate operations, then the amount paid for labor has been very materially reduced, without necessarily reducing the pay of the operator. In fact it is found possible in many cases to increase his compensation, and at the same time reduce the cost per piece of work very materially.

Now, in order that improved machinery may do its maximum amount of work per day, it is necessary to have the cutting tools, fixtures, etc., made in a manner that allows them to do *their* part of the work. If a milling machine were bought and set up in a shop, and it was found that the fixtures formerly used in holding the pieces of work were not strong enough to hold them when the new machine was taking the heaviest cut possible, heavier fixtures would be made at once in order that the investment of money made in purchasing the machine might not be considered as having been thrown away. Following out the same line of reasoning, it would be necessary to make cutting tools of a design that made it possible to take as heavy cuts, and use as coarse feeds, as the strength of the machine and fixtures would allow.

While manufacturers in general recognize the im-

portance of having machines especially fitted for their needs, many times the good work stops right at this point. They are not educated to a point that makes it possible for them to comprehend the importance of having the cutting tools hardened in a manner that insures their doing the amount of work possible.

While it is often necessary to re-design cutting tools to get added strength, many times this needed strength may be had by proper hardening.

A manufacturer of a high grade tool steel, in conversation with the writer, said, if he could have one per cent. of the value of steel in this country spoiled by improper hardening, he would not exchange his income for that of the President of the United States, By the value of steel, he meant its value at the time the article was hardened. A piece of steel which cost fifty cents in the bar, may be worth many dollars when ready for hardening, and represents to the manufacturer the total cost of steel and labor.

This line of reasoning might be carried a great deal further. If a tool which is made to do a certain job is ruined, the time the machine or machines stand idle waiting for another one to be made, many times represents a greater loss than the money value of the tool. This is especially true where the time given to complete the job is limited.

If a tool is hardened in a manner that makes it impossible for it to do as much or as good work as it ought, the loss may be greater than in either of the cases before cited, yet this loss is seldom taken into consideration.

The writer's experience has convinced him that few mechanics realize the vast waste of time in many shops, because tools are not capable of doing the amount of work possible were they properly hardened. Take for instance a milling machine cutter which runs at a periphery speed of thirty-six feet per minute, milling a mild grade of machinery steel. It is found necessary to stop this machine once in twenty working hours to sharpen the cutter, milling in the meantime five hundred pieces. A cutter is made from the same bar, and hardened by a process that makes it possible to run the tool at a periphery speed of eighty feet per minute, and it is then found necessary to grind but *once* in two hundred hours; milling in the meantime eight thousand pieces. Not only is the efficiency of this machine increased many fold, but the expense of grinding, and the necessary delay incident to stopping the machine, changing cutters and setting up, and the cost of tools per piece, is reduced very appreciably.

Does some one ask, How is this trouble to be remedied? The answer is, men must be educated to see the enormous waste going on all the time; the waste of steel, of time required to make the tools, of the time valuable equipment is laying idle, and the small percentage of work produced per machine, all go to reduce dividends, and this because so little attention is given a subject which should receive as much consideration as any one branch of machine shop work.

When the trouble is apparent, then it is necessary to find a remedy. The physician must necessarily understand the human body in order that he may diagnose diseases. If one would be a successful hardener of steel, he must understand the nature and peculiarities of steel. As a study of drugs alone would not fit one to practice medicine, neither will practice alone fit one

to harden steel, especially if new problems are constantly coming up.

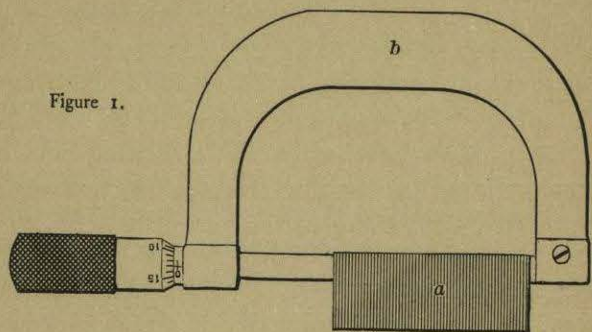
At the present time when libraries are accessible to nearly every one, and books and mechanical journals, treating on steel and the proper methods of its manipulation, are within the reach of all, there is no good reason why ignorance of a subject so interesting, and at the same time of such vital importance to both manufacturer and mechanic, should be so general.

A study of the nature of steel will convince one of the importance of extreme carefulness when heating either for forging, annealing or hardening. A man who understands the effect of heat on high carbon tool steel is often amazed at the careless manner which many old blacksmiths assume when heating a piece of steel. A difference of 100 to 200 degrees of heat after the steel is red hot, does not, according to their idea, injure the steel in the least, but in reality it makes a vast amount of difference in the strength of the piece.

In some shops a man is called a successful hardener if he is fortunate enough to avoid cracking the pieces he is called upon to harden. Apparently no account is taken of the capability of the tool to perform a satisfactory amount of work. A man who devotes his attention to hardening steel in a manner to avoid cracking, regardless of the utility of the tool, is not worthy of the title of a successful hardener; he should be styled, as an eminent mechanic calls this class, *a non-cracker*. Now, it is possible to harden steel in a manner that does away with the liability of cracking, yet gives it the amount of hardness necessary, in order that it may do the amount of work expected of it.

A study of the effects of expansion and contraction of steel in the fire and baths is necessary in order to select the proper forms of furnaces and bath, so that the best results may be obtained. Suppose a micrometer is left for some time in a room where the temperature is 40 degrees Fahr., a piece of work is placed between the contact surfaces, as shown in Fig. 1.

Figure 1.



Illustrating expansion of steel.

Now grasp the micrometer by the frame at the portion marked *b*, with a warm hand; in a few seconds the metal will have expanded to a degree that allows the work *a* to drop from the gauge, thus proving that but a very small amount of heat is needed to expand the steel sufficiently so the contact points no longer touch the piece between them.

Now, if a few degrees of heat will expand steel so it can be readily observed, it is apparent that a heat of 900 to 1,200 degrees Fahr. must cause the process of expansion to be carried to a much greater extent. The amount of heat necessary to give steel, in order that it may harden when plunged in some cooling bath, varies with the make of steel, the percentage of carbon it con-

tains, and also on the percentage of other hardening elements in the steel. Jarolinech places the critical temperature at 932 degrees Fahr. (500 Centigrade) as determined by him experimentally. The lowest heat at which a piece of steel will harden satisfactorily is termed the refining heat, because the effect of the operation of suddenly cooling steel heated to this temperature is to refine the grain, making it the finest possible.

The writer does not propose giving a scientific explanation of the changes which take place in a piece of steel when it is heated to the hardening heat, and quenched in the cooling bath, but the practical sides of the question will receive careful attention.

Every man and boy working in a machine shop knows that steel heated red hot and plunged in water, will harden, but it is necessary to know how hot it must be heated in order that satisfactory results may follow. We should thoroughly understand the action of too great an amount of heat on the structure of steel, in order that overheating may be avoided. It is also necessary to have a correct understanding of the effects of baths of various kinds on steel, if it is dipped in them when red hot.

It is an acknowledged fact that the lowest possible heat at which steel will harden, leaves it the strongest This is illustrated elsewhere. Knowing this, it will be seen that an article made of steel is very much less liable to crack when hardened at a low heat, than if it were heated to a temperature which caused it to be brittle.

Commencing with cold steel, every degree of heat applied changes in a measure the size and structure 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