PRICE 25 CENTS

HIGH-SPEED AND CARBON TOOL STEELS

THEIR CHARACTERISTICS AND TREATMENT

MACHINERY'S REFERENCE BOOK NO. 117
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HIGH-SPEED AND CARBON TOOL STEELS

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CHAPTER I

TOOL STEEL FOR THE UNITED STATES NAVY

Previous to 1909, each of the U. S. navy yards prepared requisitions for the purchase of tool steels for its own purposes. These requisitions either specified that proprietary material should be purchased or that the award of contract be based on information obtained by a test of some description on samples submitted by the bidders. By this method, there could be no uniformity in the specifications of the navy yards, and in order to centralize purchasing and to standardize the tool steels, a tool steel board recommended that the Philadelphia Navy Yard be made the purchasing station. This action was taken in 1909 and at that time specifications were drawn up for one high-speed steel and three grades of carbon steel.

The chemical composition required for the high-speed steel differed from that of any of the commercial brands, but the chemical composition of each grade of carbon steel corresponded to that of commercial tool steels. The three grades of carbon tool steel varied principally in their carbon content, in order to adapt them to the purposes for which such tool steels are generally used. The contracts were awarded to the lowest responsible bidder who was able to meet these specifications for tool steel of a chemical composition within the specified limits. The specifications required physical tests in addition to chemical analysis, as a part of the inspection, but these tests did not give decisive results and proved conclusively that it was advisable to revise the existing specifications. This step was taken because these specifications did not provide a means of ascertaining the relative merits of the tool steels offered by the different bidders, or of learning whether there were other tool steels that were superior to those within the specified limits of chemical composition.

In order to overcome these objections, a set of specifications was finally drawn up which are given in a later section of this chapter, as presented by Mr. L. H. Kenney in a paper before the Society of Naval Architects and Marine Engineers. These specifications require the bidders to submit samples of the tool steels which they offer for sale. The samples are manufactured into tools and subjected to physical tests devised to determine the relative merits of the different steels. The data obtained in this way constitute the basis for the award of contracts. In this set of specifications the chemical compositions are given the maximum and minimum limits, the purpose being to indicate to the bidder the kind of tool steel that is wanted, but the physical
te the real basis for the award of contracts. The object
n is to introduce competition as to the quality of tool
simply having competition in price, to provide a

means of learning something about the relative merits of the commercial tool steels, and to take advantage of the developments and progress made by the manufacturers in this industry. By this means, definite information can be obtained concerning the qualities of the different tool steels before the contracts are awarded for their purchase.

The study of tool steels which has been made possible by the adoption of this set of specifications is conducted under the direction of the engineer officer of the Philadelphia Navy Yard. The subject is divided into two general classes, one of which covers the high-speed or tungsten steels and the other the carbon tool steels.

Tungsten Steels

The limits of the chemical composition called for under the revised specifications were varied from those required by the original specifications in order to permit bidders to submit proposals on their commercial or standard tool steels, and the feature of a selective test was introduced. This selective test provides means for investigating the relative suitability of the different tool steels offered by bidders for the class of work for which the steel is required, and the recommendation for the award of contract is based on the information thus obtained. In order to obtain samples of tool steel for the selective test, the specifications require each bidder to furnish a sample bar of the steel which he offers. This bar is delivered to the engineer officer, under whose direction the selective tests are conducted. The heat-treatment of the tools, their chemical analysis, the condition of the physical test, and the computations necessary to determine the award of contract constitutes the selective test. A lathe tool selected for the physical test is kept cutting without lubricant until it fails by the sudden breaking down of the cutting edge, due to heating caused by friction of the chip. A record of the elapsed time of the run is made, which is the principal variable, other conditions being kept constant. After failure, each tool is reground, care being taken to remove the effect of the heat produced during the previous cut; the tool is then tested once more until it breaks down, as previously described. After the conclusion of this cut, the tool is reground and tested a third time.

During the test, a voltmeter and ammeter are used to determine the power supplied to the motor which drove the test lathe. This is done in order to obtain a measure of the work done by the nose of the tool. The ammeter readings vary for the different tools, due principally to slight variations in depth of cut and cutting speed, which indicates that the work done by the different tools is not the same. In order to allow for this difference in computing the selective factor, a quantity was introduced called the "work value," which is [illegible]
product of the mean elapsed time of r [illegible] of all [illegible]
and the mean watts required to
watts. The work value, theref
by the tool. The work value
given steel that were tested

least squares. The work value divided by the price per pound gives the "selective factor" for the test, the contract being awarded to the manufacturer of the steel having the highest selective factor.

In conducting the selective tests with tungsten tool steels, five tools made from the same sample bars are stamped with an index number which is assigned to each sample, and with consecutive numbers for the tools of each sample. The tools are hand-forged to the No. 30 lathe tool form of the Sellers system. The following day the tools are heat-treated. For this purpose, one oil furnace is maintained at a temperature of from 1600 to 1700 degrees F. and another furnace at from 2400 to 2450 degrees F. The cutting ends of the tools are preheated in the low temperature furnace and then transferred to the high temperature furnace. After the tools are removed from the heat-treating furnace, they are cooled by dipping the ends into oil. The oil is agitated by compressed air and is cooled to maintain it at as nearly an even temperature as possible. Oil is used for quenching because it is less noisy and less expensive than compressed air, and tests which have been made also appear to indicate that better results are obtained by using oil as a quenching medium. The tools are cooled in oil until they are black hot, when they are removed and placed on the cooling table. All the tools are tested on a single nickel-steel forging because the characteristics of nickel-steel forgings vary. The depth of cut, feed, and cutting speed are kept constant throughout the selective test, thus making the cutting time the principal variable. In regrinding it is found necessary to remove about 3/32 inch of the tool to get rid of the effects of heating.

Carbon Tool Steels

The information obtained from the selective tests conducted on samples of high-speed steel indicated that it was advisable to revise the requirements for carbon tool steels which were given by the original set of specifications, and a method of conducting selective tests, similar in character and purpose to those previously referred to, was adopted for use with this class of steels. Four classes of carbon tool steel were selected which varied principally in their carbon content. The specifications require the conditions of the selective test to be maintained as nearly constant as possible for each class of steel. The elapsed time of the run is the principal variable in the test, the tools being operated until they break down. Milling cutters are used for the tests on steels of Classes 1 and 2 (see table), and the duration of the run consists of the total time that the cutters are operating, but it does not include the time required to return the milling machine table to the starting point and to set it for the next cut.

A cape chisel is used for the selective test on carbon tool steels of Class 3. In some of the early tests, trouble was experienced through breaking the shank of the hammer end of the chisel. This trouble has
r as the selective tests are concerned—and also in
ating about ½ inch of the hammer end of the
enching the tool by dipping about ¾ inch

into brine for a few seconds and then the entire tool. The cutting end is treated at the same temperature as the hammer end, and the temper of both ends is drawn by submerging the chisel in a molten lead bath at the desired temperature. In making these tests, it has been found that the heat-treatment does not extend back far from the cutting edge and there is only a short distance on the tool where the maximum cutting life can be obtained. If the chisel shows poor results on the first test, indicating that the temper has not been drawn sufficiently, the second test usually gives more satisfactory results, while the third test may show that the chisel is too soft.

A button-head rivet set is used for testing Class 4 of carbon steel. The set is heated to the desired temperature and quenched in brine, after which the temper is drawn in a lead bath. Each set is used to drive a certain number of hot rivets and an observation of its condition is made after the test. This test is not carried to destruction, however, as in the preceding tests and consequently does not yield decisive results.

The results of the tests of carbon steels of Classes 1, 2 and 3 vary considerably. As a result, it has not been found advisable to adjust these results by principles of least squares. After the tests have been completed, the data are gone over and those results which vary widely from the average are rejected. The selective factor for the different steels is then calculated and the contract awarded to the manufacturer whose steel shows the highest selective factor.

Each sample of carbon tool steel submitted for selective test is tested to determine the decalescent point in order that it may be hardened at a suitable temperature. In heat-treating, the temperature of the tools is raised to a point slightly above the decalescent point and they are then quenched in brine. After quenching, the temper is drawn in a lead bath, after which the cutting tools are ground ready for the selective test. The milling cutters used for making the selective tests for carbon tool steel were of the newer coarse teeth type, recently introduced. The distinctive feature of these milling cutters is the large pitch of the teeth, thus providing a large clearance for the chips. The cutter is operated at a speed of 370 revolutions per minute with a feed of 20 inches per minute and a depth of cut of 0.080 inch through the full travel of the milling machine table. The table is run back to the starting point and reset as often as necessary until the failure of the cutter occurs. The cutter is run without lubricant, in order to make the tests as severe as possible.

Specifications for Tungsten Tool Steel

1. *Class* 1.—Lathe and planer tools, milling machine tools, and in general all tools for which high-speed steel is used.

Specifications for Carbon Steel

2. *Class* 1.—Lathe and planer tools, and tools requiring keen cutting edge combined with great hardness, for finishing shrinkage dimensions on nickel-steel gun forgings, drills, taps, reamers and screw-cutting dies.

3. *Class* 2.—Milling cutters, mandrels, trimmer dies, threading dies, and general machine-shop tools requiring a keen cutting edge combined with hardness.

4. *Class* 3.—Pneumatic chisels, punches, shear blades, etc., and in general tools requiring hard surface with considerable tenacity.

5. *Class* 4.—Rivet sets, hammers, cupping tools, smith tools, hot drop-forge dies, etc., and in general tools which require great toughness combined with the necessary hardness.

CHEMICAL COMPOSITION

Tungsten Tool Steel	Class 1, Per Cent Limit	
	Maximum	Minimum
Carbon	0.75	0.55
Chromium	5.00	2.50
Manganese	0.80	0.05
Phosphorus	0.015	....
Silicon	0.30	....
Sulphur	0.02	....
Tungsten	20.00	16.00
Vanadium	1.50	0.85
Iron	*	*

Machinery

*Remainder

Carbon Tool Steel	Class 1, Per Cent Limit		Class 2, Per Cent Limit		Class 3, Per Cent Limit		Class 4, Per Cent Limit	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Carbon	1.25	1.15	1.15	1.05	0.95	0.85	0.85	0.75
Chromium	†	†	†	†	†	†	†	†
Manganese	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.15
Phosphorus	0.015	....	0.015	....	0.02	....	0.02	....
Silicon	0.40	0.10	0.40	0.10	0.40	0.10	0.40	0.10
Sulphur	0.02	....	0.02	....	0.02	....	0.025	....
Vanadium	†	†	†	†	†	†	†	†
Iron	*	*	*	*	*	*	*	*

Machinery

*Remainder †Optional

Physical Tests of Tungsten Tool Steel

6. *Class* 1.—The sample bar will be forged into five tools, treated and ground to the No. 30 form of the Sellers system of lathe tool forms. Each tool will be tested on a nickel-steel forging of about 100,000 pounds tensile strength, with a cut ¼ inch deep, 1/16 inch feed, and a cutting speed of 50 feet per minute. Each tool will be twice reground and retested. A record will be made of the length of time each without a lubricant or cutting compound before it is ruined.

Physical Tests of Carbon Tool Steel

7. *Class* 1.—Five 7/16-inch diameter, 4-tooth facing mills will be made from the sample bar and tested on a piece of ⅝-inch ship's plate without lubricant. Each mill will be run until it is so dull that it breaks either in the teeth or in the shank. The depth of cut will be 0.08 inch, the revolutions per minute of the mill will be 370, and the feed of material 20 inches per minute. A record will be made of the length of time each mill operates.

8. *Class* 2.—Same tests as *Class* 1.

9. *Class* 3.—Five ½-inch pneumatic chisels will be made from the sample bar. Each chisel will be tested on a nickel-steel plate with a cut 1/16 inch deep.

A record will be made of the distance each chisel cuts with a lubricant before it is ruined.

10. *Class* 4.—Two ½-inch rivet sets will be made from the sample bar. A record will be made of the condition of the sets after a certain number of rivets have been driven.

11. *Modification of Tests.*—Any or all of the above tests may be modified at the discretion of the engineer officer.

12. *Method of Manufacture.*—The tool steels shall be made in either the electric or crucible furnace. The bars must be forged or rolled accurately to the dimensions specified, free from seams, checks, and other physical defects and of homogeneous compositions. The tungsten tool steels shall be delivered unannealed, unless otherwise specified, and the carbon tool steels shall be delivered annealed unless otherwise specified. The bars shall be delivered in commercial lengths and short pieces will not be accepted unless so specified.

13. *Stamps on Material.*—Each bar or piece of tool steel, whether sample bar for "selective test," "acceptance test," or material delivered under contract, shall be stamped with the manufacturer's name, his trade name and temper index, and in addition identification stamps of the kind and class of tool steel as given in these specifications. The tungsten tool steel, Class 1, shall be stamped T-1, and the carbon tool steels, Classes 1, 2, 3, and 4: C-1, C-2, C-3, and C-4; the letters to be about 3/16 inch high. If the bars are longer than about 4 feet, the above stamps should be placed at intervals of about 3 feet along the bar.

14. *Acceptance Test.*—Sample bars for "acceptance test" will be taken from the material delivered under contract to the general storekeeper, Navy Yard, Philadelphia, Pa., or if the material is inspected at the place of manufacture, the inspector will forward sample bars of the dimensions called for to the storekeeper, who will forward them to the engineer officer for him to arrange the tests indicated by these specifications and recommend the acceptance or rejection of the material. If the material does not prove to be equivalent to the sample bar furnished with proposal this will be considered sufficient cause for rejection. The contractor shall replace the shipment within two weeks, if practicable, after the receipt of notice of rejection. The

sample bars used for this test will be credited the contractor if the material under test is accepted.

15. *Defective Material.*—If material, when being manufactured into tools, develops physical defects which could not be detected by inspection, such as "cracks," "pipes," etc., the manufacturer of this steel shall replace, without cost to the government, such defective material.

16. *Reservation and Alternate Proposals.*—The right is reserved to reject any or all proposals.

Bidders may submit proposals on tool steel which differs from the composition and method of manufacture specified, provided this is clearly stated in their proposal, and provided they furnish the engineer officer with a statement of the exact chemical composition and method of manufacture of the tool steel. This information will be considered confidential by the engineer officer if the bidder requests it. The tool steel will be tested if, in the opinion of the engineer officer, it is considered suitable for the purpose intended.

17. The engineer officer will, after the prescribed tests have been made, recommend the award of contract for the steel or steels which, in his opinion, it is to the best interest of the government to purchase, due consideration being given to the cost of the material. The relation of the tests and the price of the material will be the basis for selection.

18. *Selective Test.*—Each bidder shall furnish with his proposal a sample bar of tool steel stamped as called for under heading "Stamps on Material" for the "selective test." The relation of the results obtained from the tests conducted as provided for under the heading "Physical Tests" and the price of the material determine the selective factor. The dimensions of the sample bars shall be as follows:

Tungsten Tool Steel

Class 1.—¾ by 1½ inch by 5 feet long.

Carbon Tool Steel

Class 1.—⅝-inch diameter rod, 2 feet long.
Class 2.—⅝-inch diameter rod, 2 feet long.
Class 3.—¾-inch octagon rod, 5 feet long.
Class 4.—2-inch diameter rod, 2 feet long.

19. *Treatment of Samples.*—Each bidder will state in his proposal, if he considers it necessary to do so, the treatment to which the material must be subjected in order to get, in his opinion, the best results.

20. *Delivery of Sample Bars.*—All sample bars stamped as called for under the heading "Stamps on Material" must be delivered to the general storekeeper, Building No. 4, Navy Yard, Philadelphia, Pa., prior to the time fixed for opening of proposals. Sample bars delivered late will not be received. Failure to comply with the above requirements will eliminate the proposal from consideration. All sample bars will be delivered by the general storekeeper to the engineer officer for the "selective tests."

CHAPTER II

RELATION OF PRICE OF TOOL STEEL TO MANUFACTURING COSTS

It often happens that steel manufacturers receive orders with an additional remark something like this: "This steel, which costs twice as much, must give at least double the production of our present steel in the operation in which it is to be used, otherwise it will be returned." This indicates that there are many who reason that if a tool steel costs, say, 50 or 100 per cent more per pound than another, then it must be able to do 50 or 100 per cent more work to justify the price. As a matter of fact, if one steel does five per cent more work than another it is well worth fifty per cent more per pound on all usual operations. There are many ways of proving this. One is to take any machine in the shop and learn the relation of tool cost to total costs. For illustration, we have selected a lathe using tools made from 1½- by ¾-inch steel. How much high-speed steel is used a day? Our observations, estimates and averages show that the daily consumption is one-twelfth pound of high-speed steel on the average lathe, doing fairly hard work at a good speed. This is based on work requiring the tool to be ground five or six times a day. If the tools cut all day on one grinding it indicates that they are cutting considerably below capacity, although this is sometimes necessary owing to local conditions. The one-twelfth pound daily consumption of steel is arrived at in the following way:

High-speed Steel used Daily on 20-inch Lathe

Size of tool: 1½ by ¾ inches. Average number of grindings: six per day.

Steel ground away each grinding	1/32 inch
Steel ground away each day (six grindings)	3/16 inch
Steel ground away each week (six days)	1 inch (approx.)

Then the tool needs redressing. In redressing and retempering, a small piece of steel is cut off. Making liberal allowance, this waste is about one-half inch of steel.

The waste of steel in redressing is	½ inch
The amount of steel ground away is (see above)	1 inch
The weekly consumption of steel	1½ inch

One and one-half lineal inch by 1½ by ¾ inch high-speed steel weighs one-half pound. The daily consumption, therefore, is one-sixth of one-half pound, or one-twelfth pound.

The Daily Cost of Tool Steel

On the basis of one-twelth pound steel consumption per day, if equal quantities were used:

High-grade high-speed steel at 71 cents per pound costs per day	$0.06
Cheap high-speed steel at 48 cents per pound costs, per day....	.04
Increased first cost of higher priced steel, per day.............	$0.02

The Cost of Operating

On a lathe such as we are using for illustration,

The machinist's hourly rate, about..............................	$0.36
The overhead (including power)............................	.24
The total hourly rate...	$0.60
The day rate (eight hours)..................................	$4.80

The Value of the Product

If the man operating the lathe which we are using for illustration turns out 100 units of work daily, each piece costs the manufacturer 1/100 of $4.80 or 4.8 cents, and just that much value is produced. If the higher priced steel enables the machinist to turn out one piece more daily, thus increasing the output only one per cent, we have the following results:

Value of one extra piece produced...........................	$0.048
Increased first cost of the steel..............................	.020
Net daily profit on one per cent increase.....................	$0.028

In this case a one per cent increase would warrant buying a good grade of steel costing fifty per cent more than cheap steel.

With high-grade tool steels, increases in production as high as fifty per cent or one hundred per cent are often secured, but the object of this article is to show that a five per cent increase in production justifies paying much more than a fifty per cent increase in first cost.

Taking the same illustration from another point of view: With the higher priced steel at 71 cents per pound,

The man's time per day..	$2.88
The "overhead" per day..	1.92
Steel per day...	0.06
Daily total..	$4.86

With cheap steel at 48 cents per pound,

The man's time per day..	2.88
The "overhead" per day..	1.92
Steel per day...	0.04
Daily total..	$4.84

The total daily cost has been increased less than one-half of one per cent; one-half of one per cent of $4.84=2.4 cents. Therefore, if the higher priced steel does one-half of one per cent more work, it is the cheapest, although the price per pound may be fifty per cent higher than the steel formerly used.

Saving in Grinding

There is another point of view from which the price of tool steel should be considered, and that is the saving in grinding. Some tool steel users think that if the steel costs twice as much, it must require grinding only one-half as many times, but in the foregoing illustration, if one grinding is saved in two days, it justifies paying fifty per cent more for the steel. We arrive at this conclusion through the following: We have found that sixty cents an hour is a conservative estimate of the cost of a man's time and the overhead expense. On this basis every grinding which requires about five minutes means a loss of time and production worth five cents. The excess first cost of steel at seventy-one cents, as compared with a forty-eight-cent steel on the machine we are using for illustration, amounts to two cents a day. Therefore, if tools made from the higher priced steel save one grinding in two days, they warrant an increase of fifty per cent in the price per pound.

In addition to the profit and saving resulting from increased production and fewer grindings, there are also secondary savings to be considered. For instance, tools made from the higher priced steel will require redressing and rehardening less frequently, and the cost department knows what this means in the way of economy. Another saving results through a reduction in the amount of steel used. This has not been brought into our figures, but it should be considered in discussing tool steel costs. Less of the high-priced steel will be required than is the case where cheap steels are used.

Another important saving that is often forgotten, and which cannot be computed, is the time saved on break-down or emergency jobs. There are times in many shops when the management would gladly pay as much as the monthly tool steel bill to save an hour on a repair part, the lack of which holds up a large shipment, or stops work throughout the shop.

A number of minor savings have not been mentioned, but they are not needed to prove the wisdom of paying fifty per cent more for a steel which does five per cent more work. In conclusion, it may be stated that this method of considering tool steel costs may be applied on any machine, regardless of the kind of steel used. In nearly every case the higher priced steel, whether in ordinary tool steel grades or in high-speed steel grades, will be found cheapest if it brings about even a slight increase in the efficiency of cutting tools.

The indirect relation of the cost of the tools of production to the cost of production set forth in the foregoing, applies all along the line. The first cost of a machine is of little importance in comparison with its productive capacity during its lifetime. A lathe costing $1000 may in the course of ten years earn $10,000 for the shop in which it is used, while another of the same nominal capacity but of superior design and workmanship, costing say $1100, might earn $12,500 in the same period, or sufficiently more than the other to wipe out the original cost and the interest on the investment.

CHAPTER III

THE INFLUENCE OF HEAT ON HARDENED TOOL STEELS

By testing various samples of carbon steel in the tool steel testing machine designed by Mr. E. G. Herbert, it was found by him that carbon tool steels have a very low durability at a low cutting speed; that there is an increase of durability as the cutting speed increases; and that a maximum durability of cutting speed is obtained at about 50 to 80 feet per minute. There is then a decline of durability to a very low value if the cutting speed is further increased. These general characteristics are common to all tool steels that have been tested, whether of the carbon or high-speed steel type (tungsten or tungsten-vanadium varieties). All of these give, when the durability is recorded in diagrammatic form, a single- or double-peaked curve, according to the heat-treatment they have received. All show a low durability at low cutting speed, this characteristic being especially marked in the case of some high-speed steels, which latter often retain their durability at very high speeds.

It has been pointed out that the observed changes in the durability of cutting tools are mainly caused by the changes in the temperature of the cutting edge, due to the heat generated at different cutting speeds. This heat theory has been confirmed by experiments showing that changes of durability corresponding to those which occur under varying cutting speeds can be produced by varying the temperature of the tool in other ways, while the cutting speed remains constant—for instance, by varying the temperature of the water with which the tool is flooded, or by varying the depth of the cut (a heavy cut generating more heat than a light one), or by dispensing entirely with the cooling water.

The various problems that were dealt with in the experiments were as follows:

1.—It has been found by experiments on the tool steel testing machine that all tool steels, without exception, have a very low durability, and are very quickly blunted when cutting under water at low speeds and fine cuts, that is, under conditions which preclude any considerable heating of the cutting edge; and it has been found that any alteration in the cutting conditions which tends to increase the temperature of the cutting edge results in an increased durability of the tool. What, if any, are then the correlative changes in the physical properties (strength, hardness, toughness, etc.) of hardened steel which occur when it is raised from a low to a higher temperature?

2.—All varieties of tool steel have been found to be capable, when suitably hardened, of producing double-peaked speed-durability curves (see Fig. 1), the characteristics of such steels being that at a certain speed they are less durable than at either a [illegible] lower speed. Is it possible to correlate this low durabili[illegible] ed with a particular physical condition at a certain t[illegible]

3.—All tool steels are found to lose their durability when the cutting speed is raised above a certain limit. Is there any corresponding change in their physical properties when they are heated above a certain temperature?

4.—Assuming that each cutting speed corresponds to a definite temperature of the cutting edge (the weight of cut and all other conditions remaining constant), what are the actual temperatures of the cutting edge corresponding to the various cutting speeds, and corresponding to the various changes in the durability and physical properties of the steel?

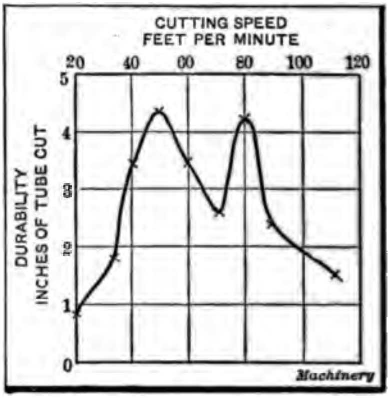

Fig. 1. Example of Double-peaked Durability Curve

Before dealing with these problems, it is necessary briefly to consider the nature of the actions tending to wear or blunt a cutting tool, and the correlative physical properties constituting durability, which the tool must possess in order to withstand these actions. The principal action to which a tool is subjected in cutting is one of friction under heavy pressure. This tends to rub away the surface of the steel, by causing the particles of steel to slide over one another. To resist blunting by this action a tool must possess hardness. But the stress on the tool point is not constant: as the chip is detached it breaks up into a series of short segments (more or less completely separated), and this process subjects the tool to a succession of changes of pressure, amounting almost to blows, and tending to chip off portions of the cutting edge. To withstand this action the tool must possess toughness.

If we make a tool of glass and another of copper, and use them to turn a cylinder of soft material, such as lead in the lathe, we shall find that both are very soon blunted, but from totally different causes. The glass tool, though extremely hard, is brittle, and is blunted by the chipping away of minute particles of the cutting edge. The copper tool, though very tough, is soft, and is blunted by the rubbing away of the cutting edge. If now we imagine that by some subtle alchemy we can gradually change the tool of glass into one of copper, it will probably pass through some intermediate stages where it will retain some of the hardness of glass without all its brittleness, and will have attained some of the toughness of copper without all its softness. The tool in this intermediate state will probably keep its sharp cutting edge much better than either the glass or the copper tool.

In order then to measure, throughout a range of temperatures, those physical properties of steel which constitute its durability, it is necessary to test it at each temperature for hardness and for toughness. Experiments with suitable apparatus were, therefore, carried out for measuring the hardness and toughness at various temperatures, taking into consideration such factors as different methods of grinding the tools, etc. The experiments made it possible to answer the questions propounded above, as follows:

1.—The low durability of all tool steels, cutting under water at low speeds and light cuts, seems to be completely explained by the low values of hardness and toughness which always occur at cutting temperatures of 50 to 100 degrees C. (122 to 212 degrees F.). The breaking tests have shown in every case the product, hardness times toughness, increases in value as the temperature is raised above 100 degrees C. The cutting tests have shown in every case that the durability increases when the cutting speed is raised above 20 feet per minute. These cutting tests have also shown that the durability always increases when a tool working at 20 feet per minute is allowed to cut dry instead of with water, or with hot water instead of cold. It is impossible to doubt that these are different manifestations of the same physical change in the steel.

A clear recognition of this phenomenon is of great practical importance. A great deal of the metal cutting in every machine shop consists in taking fine finishing cuts, often with water on the tool. If such cuts are taken at a slow speed, the temperature of the cutting edge may not rise above 100 degrees C., in which case the tool will be quickly blunted. Its durability can be increased by increasing the speed or by cutting dry. Many cases are known to have occurred in ordinary workshop practice, where an increase in cutting speed has actually resulted in increased durability of the tool. Low durability at low cutting temperatures (on, for example, finishing cuts) is a familiar characteristic of high-speed steels, and is most marked in tools which have been suitably hardened for very high temperature work. High-speed steel can be so hardened as to retain its durability at fairly low temperatures, and there are now on the market tungsten steels specially adapted for low temperature work, such as finishing very heavy forgings; but every description of steel known to the author loses its durability if the cutting temperature is low enough. It should be noted that a low cutting temperature can only occur when there is a combination of low speed with light cut. A heavy or moderate cut raises the temperature of the cutting edge above 100 degrees C., even at very slow speeds.

2.—The phenomenon of the double-peaked curve is not completely elucidated, though the evidence goes some way to explain it. The variations of hardness and toughness with temperature are of a complicated character, and the cleft between the two peaks of a durability curve appears to be caused by the conjunction of depressions in the hardness and toughness curves at a particular temperature. The relative heights of the two peaks are found to vary with the conditions of cutting, and this variation may be due to a change in the relative importance of the hardness and toughness factors, according to the quality of the material cut, or the shape of the tool.

3.—The decline in durability which takes [illegible] when a certain limiting speed is exceeded, is evidently caused by an actual softening of the cutting edge by the heat generated in cutting. This softening, which is extremely local, takes place even when the tool and the work are practically immersed in running water. The speeds and temperatures at which the softening occurs depend largely on the particular hardening process which has been applied to the tool, and are generally highest in high-speed steel.

4.—It is not yet possible to establish an exact scale of cutting temperatures corresponding to the scale of cutting speeds, but a comparison of the temperature-durability tests with the speed-durability tests enables us to make an approximation, as in Fig. 2.

To establish the relation between the speeds of cutting with and without water, a comparison was made between the various results obtained in the tests, from which it appears that the effect of using water is approximately to double the cutting speed; in other words, the edge of a tool flooded with water attains about the same temperature as the edge of a tool cutting dry at half the speed. This must not be taken as a general statement applicable to all cutting operations. The dry cutting temperature depends largely on the volume of metal operated upon. The tube used in the tool steel testing machine is small in diameter and light in section; it becomes considerably heated under a dry cut. In machining a large forging, the body of metal absorbs a great deal of heat, with only a slight rise in temperature, and the use of water has less effect on the cutting speed.

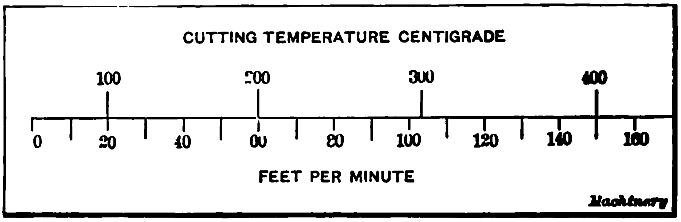

Fig. 2. Approximate Scale of Cutting Temperatures and Cutting Speeds when Testing in Tool Steel Testing Machine

Considerable interest attaches to a comparison of the durabilities of carbon and high-speed steels. It appears that the high-speed steel has two distinct features of superiority. The speeds at which it attains its maximum durability are not very different from those at which carbon steel is most durable, but the high-speed steel is several times as durable at these speeds. Quite distinct from its superior durability at moderate cutting temperatures is the property possessed by high-speed steel of retaining some durability at temperatures high enough to soften carbon steel, but its actual durability under such conditions is much less than under conditions which do not unduly heat it. In other words, its abrasive quality appears to be more important than its heat-resisting quality.

CHAPTER IV

DEVELOPMENT AND USE OF HIGH-SPEED STEEL

The following discussion on high-speed steel and tools made from this material is an abstract of a paper read by Mr. J. M. Gledhill before the Iron and Steel Institute of Great Britain. The high-speed steels of the present day are combinations of iron and carbon with: (1) Tungsten and chromium, (2) Molybdenum and chromium, (3) Tungsten, molybdenum and chromium.

Influence of Carbon

A number of tool steels were made by the Armstrong, Whitworth Co. with the carbon percentage varying from 0.4 per cent to 2.2 per cent, and the method of hardening was to heat the steel to the highest possible temperature without destroying the cutting edge, and then rapidly cooling in a strong air blast. By this simple method of hardening it was found that the greatest cutting efficiency is obtained where the carbon ranges from 0.4 per cent to 0.9 per cent, and such steels are comparatively tough. Higher percentages are not desirable because great difficulty is experienced in forging the steels, and the tools are inferior. With increasing carbon contents the steel is also very brittle, and has a tendency to break with unequal and intermittent cutting.

Influence of Chromium

Having thus found the best carbon content to range from 0.4 per cent to 0.9 per cent, the next experiments were made to ascertain the influence of chromium varying from 1.0 per cent to 6.0 per cent. Steels containing a low percentage are very tough, and perform excellent work on the softer varieties of steel and cast iron, but when tried on harder materials the results obtained were not so efficient. With an increased content of chromium the nature of the steel becomes much harder, and greater cutting efficiency is obtained on hard materials. It was observed that with an increase of chromium there must be a decrease in carbon to obtain the best results for such a percentage of chromium.

Mention may here be made of an interesting experiment to ascertain what effect would be produced in high-speed steel by substituting vanadium for chromium. The amount of vanadium present was 2.0 per cent. The steel readily forged, worked very tough, and was hardened by heating to a white heat and cooling in an air blast. This tool when tried on medium steel stood well, but not better than the steel with the much cheaper element of chromium in it.

Influence of Tungsten

This important element is contained in by far the greater number [illegible]ent high-speed steels in use. A number of experiments were made with the tungsten content ranging from 9.0 per cent to 27.0 per cent. From 9.0 per cent to 16.0 per cent the nature of the steel becomes very brittle, but at the same time the cutting efficiency is greatly increased, and about 16.0 per cent appeared to be the limit, as no better results were obtained by increasing the tungsten beyond this figure. Between 18.0 per cent and 27.0 per cent it was found that the nature of the steel altered somewhat, and instead of being brittle, it became softer and tougher, and while such tools have the property of cutting very cleanly, they do not stand up so well.

Influence of Molybdenum

The influence of this element at the present time is under investigation, and the experiments with it have so far produced excellent results; it has been found that where a large percentage of tungsten is necessary to make a high-speed steel, a considerably less percentage of molybdenum will suffice. A peculiarity of these molybdenum steels is that in order to obtain the greatest efficiency they do not require such a high temperature in hardening as do the tungsten steels, and if the temperature is increased above 1800 degrees F. the tools are inferior, and the life shortened.

Influence of Tungsten with Molybdenum

It was found that the presence of from 0.5 per cent to 3.0 per cent molybdenum in a high tungsten steel slightly increased the cutting efficiency, but the advantage gained is altogether out of proportion to the cost of the added molybdenum.

Influence of Silicon

A number of high-speed steels were made with silicon content varying from a trace up to 4.0 per cent. Silicon sensibly hardens such steels, and the cutting efficiency on hard materials is increased by additions up to 3.0 per cent. By increasing the silicon above 3.0 per cent, however, the cutting efficiency begins to decline. Various experiments were made with other metals as alloys, but the results obtained were not sufficiently good by comparison with the above to call for comment.

An analysis of one of the best qualities of high-speed steels produced by the author's firm (Armstrong, Whitworth Co.) is as follows: "A.W." Steel.—Carbon, 0.55 per cent; Chromium, 3.5 per cent; Tungsten, 13.5 per cent.

What may be said to determine a high-speed steel, as compared to an ordinary tool steel, is its capability of withstanding the higher temperatures produced by the greatly increased friction between the tool and the work due to the rapid cutting. An ordinary carbon steel containing, say, 1.20 per cent carbon, when heated slightly above the critical point and rapidly cooled by quenching in water, becomes intensely hard. Such a steel gradually loses this intense hardness as the temperature of friction reaches, say, 500 degrees F. The lower the temperature is maintained the longer will be so that the cutting speed is very limited. With rapid cutting steels the temperature of friction may be greatly extended, even up to 1100 degrees F. or 1200 degrees F., and it has been proved by experience that the higher the temperature for hardening is raised above the critical point and then rapidly cooled, the higher will be the temperature of friction that the tool can withstand before sensibly losing its hardness. The high degree of heating (almost to the melting point, in fact) which is necessary for hardening high-speed steel, forms an interesting study in thermal treatment and is indeed a curious paradox, quite inverting all theory and practice previously existing. In the case of hardening ordinary carbon steels very rapid cooling is absolutely necessary, but with high-speed steels the rate of cooling may take a considerably longer period, the intensity of hardness being increased with the quicker rate of cooling.

Annealing High-speed Steel

Turning now to some points in the heat-treatment of high-speed steel, one of the most important is the process of thoroughly annealing it after working into bars. Accurate annealing is of much value in bringing the steel to a state of molecular uniformity, thereby removing internal strains that may have arisen, due to casting and tilting, and at the same time annealing renders the steel sufficiently soft to enable it to be machined into any desired form for turning tools, milling cutters, drills, taps, threading dies, etc. Further advantage also results from careful annealing by minimizing risks of cracking when the steel has to be reheated for hardening. In cases of intricately-shaped milling tools having sharp square bottom recesses, fine edges, or delicate projections, and on which unequal expansion and contraction are liable to operate suddenly, annealing has a very beneficial effect toward reducing cracking to a minimum. Increased ductility is also imparted by annealing, and this is especially requisite in tools that have to encounter sudden shocks due to intermittent cutting, such as planing and slotting tools, or others suddenly meeting projections or irregularities on the work operated on. The annealing of high-speed steel is best carried out in muffle furnaces designed for heating by radiation only, a temperature of 1400 degrees F. being maintained from twelve to eighteen hours according to the section of the bars of steel dealt with.

A number of other methods are also used for annealing high-speed steel. The following method is recommended by one of the largest high-speed tool steel manufacturers in America. Particular attention is called to the temperatures to which the steel to be annealed is to be heated, the time necessary, and also, that powdered charcoal is given first, it having the preference over fine air-dried lime or powdered mica.

"In annealing high-speed steel, use an iron box or pipe of sufficient size to allow at least one-half inch of packing between the pieces of steel to be annealed and the sides of the box or pipe. (We call at- here to the fact that it is not necessary that each piece of steel to be annealed be kept separate from every other piece, but only that the steel be prevented from touching the sides of the annealing pipe or box.) Pack carefully with powdered charcoal, fine dry lime or mica. Cover with cap, which should be air-tight, but if it is not, then lute on with fireclay. Heat slowly to a full red heat, about 1475 or 1500 degrees F., and hold at this heat from two to eight hours, depending on the size of the pieces to be annealed. A piece of 2 by 1 by 8 inches requires about three hours time. Cool as slowly as possible, and do not expose to the air until cold. A good way is to allow the box or pipe to remain in the furnace until cold."

A series of experiments were recently made to determine the proper temperature to which to heat high-speed steel for annealing. It was found then when this steel was heated to below 1250 degrees F. and slowly cooled, as in annealing, it retained the original hardness and brittleness imparted to the steel in forging. When heated to between 1250 and 1450 degrees F., the Brinnell test indicated that the steel was soft, but impact tests proved that the steel still retained its original brittleness. However, when heated to between 1475 and 1525 degrees F. the steel became very soft, it had a beautiful fine-grained fracture, and all of the initial brittleness had entirely disappeared.

In carrying these tests further, to 1600, 1750, and 1850 degrees F., it was found that the steel became very soft, but there was a gradual increase in brittleness and in the size of the grain, until at 1850 degrees F. the steel became again as brittle as unannealed steel; the fracture at this temperature was dull, dry and lifeless, and showed marked decarbonization. Dried air-slaked lime was used as a packing medium in making these tests. The steel was packed in tubes sealed air-tight on both ends. The decarbonization that took place was probably due to the oxygen in the air that had filled the intervening spaces between each minute particle of lime, before it was packed in the tube, attacking the carbon of the steel; this decarbonization would not have taken place if powdered charcoal had been used. The latter would have supplied all the carbon necessary to combine with any oxygen present in the tubes.

An annealing chart, taken by a Bristol recording pyrometer, showing the temperature of one of the annealing furnaces in which a well-known grade of high-speed steel is annealed by the manufacturer, is shown in Fig. 3. The method, which is carried on by this manufacturer day after day, is to first pack the bars to be annealed in ten-inch diameter wrought-iron pipes, about fourteen feet long, the packing medium being pulverized charcoal. Then both ends of the pipes are sealed air-tight with fireclay. The annealing furnaces are fired with coal and are brought up to 1500 degrees F. at 7 A. M. At this time the large furnace doors are opened and from four to six of the ten-inch pipes, previously packed with steel and sealed, are rolled into the furnace. The doors are then closed and the furnace is continuously fired until 5.30 P. M., the temperature being kept as near to 1500 degrees F. as possible. The chart, which shows two days will indicate how well this temperature has been maintaine

5.30 P. M. firing is discontinued, all holes that might permit the influx of air are closed, and the pipes are permitted to cool down slowly with the furnace. It will be seen, by again referring to the chart, that there is a gradual drop in temperature from the time firing is discontinued until the pipes are taken from the furnace the following morning preparatory to beginning another day's work.

The chart also indicates that the temperature of the annealed steel, when taken from the furnace, is about 1000 degrees F. This temperature is several hundred degrees below the critical point, or recalescence point of high-speed steel, this point being at about 1350 degrees F., so that the annealed bars can be taken from the pipes and permitted to cool to normal temperature without further delay, because after cooling to 1000 degrees F. they would not again become hard without the application of more heat.

Fig. 3. Temperature Record obtained from an Annealing Furnace

The above method is excellent for annealing high-speed steel on a large scale. If it is desired to anneal only a few small pieces of this grade of steel rapidly, they can be "water annealed," by a method similar to that used for carbon steels; the temperature to which the steel is raised, however, is not as high as for carbon steel. In water annealing, the piece to be annealed is gradually and uniformly heated to 760 degrees F. It is then taken from the furnace and plunged into a bath of pure water, previously heated to a temperature of 150 degrees F., where it is permitted to cool until reduced to the temperature of the bath. Afterwards the steel can be drilled, filed, or machined into any form with little difficulty. The more care devoted to the heating, the better the results will be. To heat rapidly will induce internal strains and greatly increase the risk of breakage when the pieces are plunged into the water bath.

Another annealing method which differs considerably from those outlined on the preceding pages is used by a well-known tool manufacturer. While doubt has been expressed as to its practicability, it is claimed to give good results. There is only one objection; the pieces annealed will scale off somewhat, but as the surface is generally machined anyway, this objection is—for many classes of work—of no importance. The method is as follows:

Pack the tools to be annealed directly in the oven, one on top of the other, the furnace being entirely filled if necessary. Then heat the furnace to a temperature not exceeding 1700 or 1750 degrees F. It should not require more than three hours for the furnace to reach this heat, which is then maintained for about two hours more, or, until the temperature of all the tools has been raised to that of the furnace itself. (When smaller pieces are to be annealed, it is therefore, sufficient to maintain the heat for about one hour.) Then shut off the heat and at the same time close all holes, such as burner and draft holes, as carefully as possible, and let the tools cool off in the furnace. This cooling takes places very much quicker than when the first mentioned method is used, because the tools are not packed, and, hence, there is a saving in time not only in the heating but also in the cooling. The greater part of the expense of annealing is thus saved on account of the saving in fuel, and the elimination of the packing, packing materials and the boxes.

Forging and Hardening

In preparing high-speed steel ready for use the process may be divided principally into three stages: forging, hardening, and grinding. It is, of course, very desirable that high-speed steel should be capable of attaining its maximum efficiency and yet only require treatment of the simplest kind, so that an ordinarily skilled workman may easily deal with it, otherwise the preparation of tools becomes an expensive and costly matter, and materially reduces the advantages resulting from its use. Fortunately, the treatment of high-speed steel as produced by leading firms is of the simplest; simpler in fact than of ordinary carbon steels or of the old self-hardening steels. Great care has to be exercised in the heating of the latter steels, for if either are heated above a blood-red heat, say, 1600 degrees F., the danger of impairing their efficiency by burning is considerable; whereas with the high-speed steel, heating may be (and must be) carried to a much higher temperature, even to the melting point, it being practically impossible to injure it by burning. The steel may be raised to a yellow heat for forging, say, 1850 degrees F., at which temperature it is soft and easily worked into any desired form, the forging proceeding until the temperature lowers to a good red heat, say, 1500 degrees F., when work on it should cease and the steel be reheated.

In heating a bar of high-speed steel preparatory to forging (which heating is best done in a clear coke fire) it is essential that the bar be heated thoroughly and uniformly, so as to insure that the heat has penetrated to the center of the bar, for if the bar be not uniformly heated, leaving the center comparatively cold and stiff, while the outside is hot, the steel will not draw or spread out equally, and cracking will probably result. A wise rule in heating is to "hasten slowly."

It is not advisable to break pieces from the bar while cold, the effect of so doing tending to induce fine end cracks to develop which ultimately may extend and give trouble; but the pieces should be cut off while the bar is hot, then be reheated as before and forged to the shape required, after which the tool should be laid in a dry place until cold.

The temperature for hardening high-speed steel varies somewhat according to the class of tool being dealt with. When hardening turning, planing, or slotting tools, and others of similar class, only the point or nose of tool should be gradually raised to a white melting heat, though not necessarily melted; but no harm is done even if the point of the tool becomes to a greater or less extent fused or melted.

The tool should then be immediately placed in an air blast and cooled down, after which it only requires grinding and is then ready for use. Another method, which may be described, of preparing the tools is as follows: Forge the tools as before, and when quite cold grind to shape on a *dry* stone or *dry* emery wheel, an operation which may be done with the tool fixed in a rest and fed against the stone or emery wheel by a screw, no harm resulting from any heat developed at this stage. The tool then requires heating to a white heat, but just short of melting, and afterward complete cooling in the air blast. This method of first roughly grinding to shape also lends itself to cooling the tools in oil, which is specially efficient where the retention of a sharp edge is a desideratum, as in finishing tools, capstans and automatic lathe tools, brass-workers' tools, etc. In hardening where oil cooling is used, the tools should be first raised to a white heat, but without melting, and then cooled down either by air blast or in the open to a bright red heat, say, 1700 degrees F., when they should be instantly plunged into a bath of rape or whale oil, or a mixture of both.

Referring to the question of grinding tools, nothing has yet been found so good for high-speed steels as the wet sandstone, and the tools ground thereon by hand pressure, but where it is desired to use emery wheels it is better to roughly grind the tools to shape on a dry emery wheel or dry stone *before* hardening. By so doing the tools require but little grinding after hardening, and only slight frictional heating occurs, but not sufficient to draw the temper in any way, and thus the cutting efficiency is not impaired. When the tools are ground on a wet emery wheel and undue pressure is applied, the heat generated by the great friction between the tool and the emery wheel causes the steel to become hot, and water playing on the steel while in this heated condition tends to produce cracking.

With regard to the hardening and tempering of specially formed tools of high-speed steel, such as milling and gear cutters, twist drills, taps, threading dies, reamers, and other tools that do not permit of being ground to shape after hardening, and where any melting or fusing of the cutting edges must be prevented, the method of hardening is as follows:

A specially arranged muffle furnace heated either by gas or oil is employed, and consists of two chambers lined with fireclay, the gas and air entering through a series of burners at the back of the furnace, and so under control that a temperature up to 2200 degrees F. may be steadily maintained in the lower chamber, while the upper chamber is kept at a much lower temperature. Before placing the cutters in the furnace it is advisable to fill up the hole and keyways with common fireclay to protect them. The cutters are first placed upon the top of the furnace until they are warmed through, after which they are placed in the upper chamber, Fig. 4, and thoroughly and uniformly heated to a temperature of about 1500 degrees F., or, say, a medium red heat, when they are transferred into the lower chamber and allowed to remain therein until the cutter attains the same heat as the furnace itself, *viz.*, about 2200 degrees F., and the cutting edges reach a bright yellow heat, having an appearance of a glazed or greasy surface. The cutter should then be withdrawn while

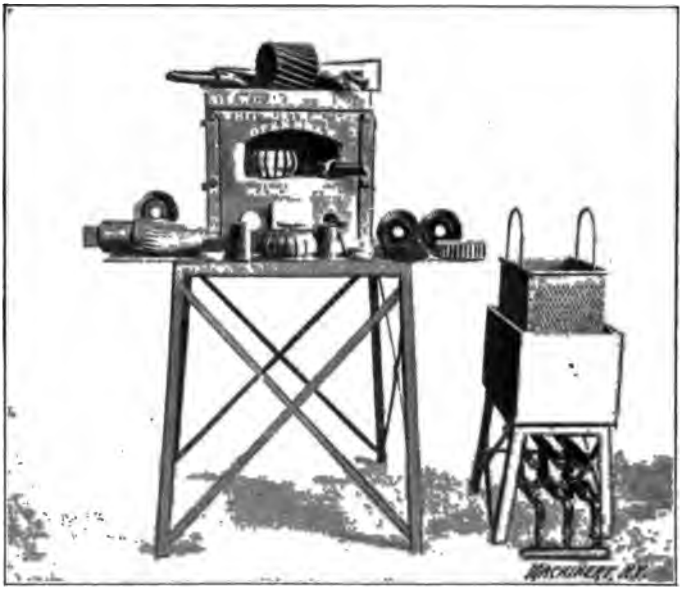

Fig. 4. Muffle Furnace for Hardening Milling Cutters made of High-speed Steel; also Tank and Dipping Cage for Tempering them in Oil

the edges are sharp and uninjured, and revolved before an air blast until the red heat has passed away, and then while the cutter is still warm—that is, *just* permitting of its being handled—it should be plunged into a bath of tallow at about 200 degrees F. and the temperature of the tallow bath then raised to about 520 degrees F., on the attainment of which the cutter should be immediately withdrawn and plunged in cold oil.

Of course there are various other ways of tempering, a good method being by means of a specially arranged gas-and-air stove into which the articles to be tempered are placed, and the stove then heated up to a temperature of from 500 degrees F. to 600 degrees F., when the gas is shut off and the furnace with its contents allowed to slowly cool down.

Very satisfactory results in hardening high-speed steel tools, such as cutters, drills, etc., have been obtained by the following method: First pre-heat in an oven-type gas furnace to from 1300 to 1500 degrees F.; then transfer the steel to another gas furnace having a temperature varying from about 2000 to 2200 degrees F.; when the steel has attained this temperature, quench in a metallic salt bath having a temperature varying from 600 to 1200 degrees F., depending upon the kind of high-speed steel used. The piece to be hardened should be stirred vigorously in the bath until it has obtained the temperature of the bath; then it is cooled, preferably in the air, and requires no further tempering; or it may be put directly into the tempering oil, which should be at a temperature anywhere between 100 and 600 degrees F. The tempering bath is then gradually raised to the heat required for tempering. The salt bath for quenching should consist of calcium chloride, sodium chloride and potassium ferro-cyanide, in proportions depending upon the required heat. Various kinds of steel require different temperatures for the metallic salt bath. After the temper of the tool has been drawn in the oil, the work is dipped in a tank of caustic soda, and then in hot water. This will remove all oil which might adhere to the tools, and is a method that applies to all tools after being tempered.

The Pyrometer and Time Study in Steel Treatment

The general experience of a maker of lathe and planer cutters for tool-holders, outlined briefly in the following, shows how necessary are exact scientific methods to insure the production of uniformly satisfactory high-speed steel tools:

"Investigations in machine shops and tool-rooms indicate that the fault of most importance to the managers is the lack of uniformity in results obtained from high-speed cutting tools. Many places were found where attempts were made to treat steel by faulty methods or with inadquate facilities. The lack of pyrometers, failure to use pyrometers when provided, hardening in charcoal furnaces insufficiently heated and treating without pre-heating, were a few of the practices noted that produced ununiform results—a few good pieces and many almost worthless.

"It seems to be the general opinion among those not getting results that pyrometers are not of much use, that they do not give correct readings, and that better results can be gotten by depending on a man's experience than on any mechanical device. Now in the treatment of cutters we have had failures with pyrometers, but at the same time have found the cure for it, and that is frequent calibration. There is no question but what a man's eye is a better judge of the heat in a furnace than an incorrectly calibrated pyrometer.

"In the treatment of our cutters, we have probably employed no more skilled men than are used in many large plants for treating high-speed steel, but the methods that they use and depend on are scientifically correct. Since the adoption of the improved Taylor-White treatment of high-speed steel we have sent out thousands of cutters and have received practically no complaints. Our experience has shown that a cutter treated today is the same as one treated six months ago and will be the same as one treated six months from now. We have tested all makes of high-speed steel, and have proved that with proper heat-treatment any one of four or five of the real high-grade high-speed steels is entirely satisfactory and, in fact, cutters made from all of them cannot be told apart in use.

"All our cutters are pre-heated in a low-heated furnace at a temperature of 1350 degrees F. This heating takes out all strains in the metal and puts it in the best possible condition for bringing quickly to the high heat necessary to get the best results from high-speed steel. Every cutter from the smallest to the largest is treated in accordance with its sectional area and size. It goes from the low-heat into the high-heat furnace and stays there for a time that has been determined for each size of tests. We use pyrometers constantly on both furnaces, which are tested twice a week, having found that this is as long as they can safely go without being checked. The heat-treating room is provided with a specially made clock which starts on the pull of a lever by the man running the furnace, who knowing the proper length of time required for the cutter being treated, sets the clock accordingly. At the end of the predetermined time the clock rings a bell and stops, and the operator takes out a cutter and puts it into the proper medium.

"Our experience shows that it is necessary to bring the high-heat furnace to a temperature above the melting point of high-speed steel to get satisfactory results. This, of course, requires positive accuracy of the time chart as a fraction of a minute too much in the furnace would ruin the cutter, and too short a time would not give sufficient heat. Another reason for this is that to get the best results from high-speed steel, it is necessary to quickly raise the heat from 1350 degrees F. to the highest heat required.

"We believe that the essentials for proper treatment of high-speed steel are: a first-class quality of high-speed steel, pre-heating, quickly raising the temperature of the steel to the proper
a high-heat furnace, the use of accurately calibrat
a correct time chart."

Hardness or Temper of High-speed Steel Tools

Of the elements involved in tool efficiency, hardness or temper formerly was considered the most important, the design and conditions of use being little regarded. At the present time, the intelligent making of high-speed tools involves a consideration of all these and other elements, relegating to hardness or temper its appropriate place. The extreme hardness of many of these tools has frequently led to the inference that a tool has been properly treated if it is very hard, so hard that a good file will not "touch" it. However, extreme hardness is not always an indication of the efficiency of a high-speed tool; although it is necessary in certain classes of work (cutting refractory stock, for instance), in others it not only is unnecessary, but perhaps even undesirable. As a matter of fact the largest users of the best makes of high-speed steel find that for many purposes tools do the best work and give the most efficient service when soft enough to be "touched" by a good file, and even when so soft that it will "take hold." However that may be, the file test for high-speed tools is quite valueless even in those cases where it is desirable that the degree of hardness be determined. Such tests, to be of value, would require that the files must be absolutely uniform in temper. Even the best of files, however, vary more or less in temper and hardness; and a tool passed as "hard enough," when tested by one file might easily fail to pass the test when tried by another, presumably of the same temper.

Disadvantages of High-speed Steel Tool-holders

The early method of economizing in steel by using tool-holder stock rather than making the entire tool of high-speed steel, in the case of those tools whose cutting edges or points work without intermission (as those used for turning, planing and similar operations) is open to criticism, and is not now so generally followed as formerly. A characteristic of the operation of high-speed tools is the rapid generation of heat in the cutting edge. In the case of milling cutters and kindred tools this is of small consequence, because the cutters are intimately attached to a relatively large mass of metal which conducts the heat away very efficiently. Furthermore, these cutters work intermittently, each for a very brief space of time, and for the remainder of the revolution are exposed to the air and cooled by it. The cutting edges are not allowed, therefore, to get exceedingly hot, as is the case with the edge of a turning tool run at the same speed. It is necessary that the body of such a turning (or similar) tool be large enough to conduct away a considerable portion of the heat generated at the cutting edge; and in order to do this effectively the tool must be continuous; that is, there must be no appreciable separation between the part of the tool which does the cutting and the body from which most of the heat radiates, as there is ordinarily when a small steel is held in a tool-holder. There are tool-holders which his difficulty, and which are satisfactory in smaller sizes.

Methods of Uniting High-speed Steel with the Tool Body

From the very first, methods were sought whereby high-speed steel cutting points could be intimately combined with tool bodies made of ordinary and much cheaper steels. For the most part the methods tried were ineffective and impracticable. The reasons are not well understood. The disinclination of the two steels to unite probably is due to a difference in their coefficients of expansion. There is, however, no trouble in brazing them together; and when this does not involve placing a great strain upon the brazed joint, this method does very well. Obviously the cutters are hardened before being brazed into place. A successful example of such a combination is a lathe or a planer tool made with practically no forging and with a relatively thin plate of high-speed steel brazed to the front and top to form the cutting edge. Rose and other forms of reamers and mills have been made in a similar way, the body of machinery steel being machined with recesses for high-speed blades, which are brazed into place. Such tools have been in use for several years, with satisfaction. The latter, especially, are as good as if of solid high-speed steel except when it is essential that they be re-annealed or re-hardened—which is seldom necessary.

Almost as soon as the new steels made their appearance, the feasibility of welding, electrically and autogenously, a high-speed cutting point and a machinery steel tool body was demonstrated. Such tools conform to the requirement of being perfectly continuous, and the weld is practically as strong as the rest of the tool. It is feasible to forge the end to any required shape as if the entire tool were of high-speed steel; and, since in hardening only the nose is heated to a high heat, the machinery or tool steel body is in nowise impaired. The method of electrical welding, as used in this connection, is exceedingly simple. The two pieces to be welded are attached to the terminals of a circuit of suitable voltage, and the edges brought together. The resistance to the passage of the current offered by the imperfect contact sets up enough heat to melt the metal and forms a perfectly homogeneous junction. The autogenous (oxygen and acetylene blowpipe) method is almost as simple; the flame is directed into the crevice where the two pieces are brought together, and melts the adjacent metal so as also to form a homogeneous joint.

Fig. 5 shows samples of electric welding which are of special interest to machine shop managers, foremen, and others interested in economical shop practice. They illustrate the economy in the use of high-speed steel, made possible by the electric welding process. The upper left-hand figures show a counterbore made with a carbon steel shank and high-speed cutting part electrically welded thereto. Below these views are views of a lathe center with carbon steel shank and high-speed steel tip, before and after finishing. In the same illustration are shown diamond point, side and turning lathe tools of high-speed steel welded onto carbon steel or machine steel shanks.

A twist drill broken in the shank can be repaired by welding on a new piece, and with high-speed twist drills, the saving in expense is considerable. The process is also advantageous in making extension drills. The ordinary practice is to weld on a wrought-iron shank or to insert a wrought-iron filling piece, because of the difficulty of making welds in steel. The electric welding process makes it possible to weld on carbon steel shanks which, of course, are stiffer and stronger than wrought iron. The figure directly below the lathe tools shows a twist drill with a repaired tang, the tang having been twisted off and replaced by another tang electrically welded.

A method for welding high-speed steel cutters to machine steel bodies or shanks has been patented by Mr. Paul A. Viallon, 102 Avenue Parmentier, Paris, France. The process is comparatively simple and inexpensive. The machine steel shank is indented about as shown at *A* in Fig. 6, and the high-speed steel cutter may have the appearance shown at *B*. The surfaces *C* and *D* are well finished, and the shank and the cutter are both heated to a cherry-red heat. Solder is applied on the surface *C*, the cutter is placed on it, and the two parts are forced together by heavy pressure. This operation has the effect of melting the soldering material and producing adherence between the cutter and the shank. The tool is now carefully put into the fire, from where it is withdrawn when it has reached a yellow heat (2200 to 2400 degrees F.). The weld is now completed by hammering at the top of the tool, first lightly, and then with heavier blows. The tool is permitted to cool slowly, and may then be ground and finished and reheated to the required hardening temperature for high-sp

Fig. 5. Samples of Tools Electrically Welded for Economy of High-speed Steel and to effect Repairs

steel, and hardened. When the welded-on part of high-speed steel is worn down so that it must be replaced by a new cutter, the old cutter may be detached without injuring the machine steel shank, by heating the cutter and the shank at the joint, and then removing the cutter by pressure applied on its side.

Another method (patented) recently brought forward, somewhat resembling brazing, is asserted to give a joint fully as strong as the rest of the tool. A thin film of copper is placed along the line of the joint, and the parts to be welded are surrounded by a reducing compound and then placed in a furnace raised to a temperature of about 1200 degrees C. (2200 degrees F.). The copper flows freely into the interstices and is said to produce actual cohesion between the adjacent molecules, making a perfect joint, so strong that a fracture will follow a new break rather than pass through the joint.

These methods are available for all classes of tools made partly of high-speed and partly of machinery steel or other materials. Reamer and mill blades, die faces, shear blades, jack knives, etc., all are readily welded to supporting forms or backs and make tools quite as efficient as if of solid high-speed steel—and generally much more so than if the cutters or faces were attached by screws, bolts, rivets, or similar methods. Long-shank and extension drills, reamers, etc., can readily be made with the cutting parts of high-speed steel and the shanks of cheaper steel. The processes mentioned, especially the electrical, are available also for the repair of broken tools, many of which can thus be saved for further use. The repairing may involve the welding of the broken parts or the replacing of an old part by a new, as may be most expedient.

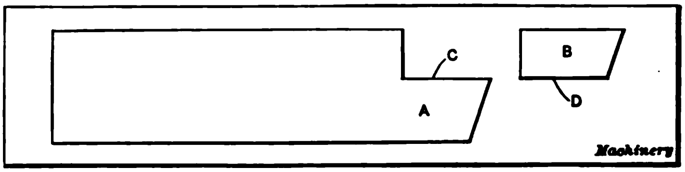

Fig. 6. High-speed Steel Cutter to be Welded to Shank of Machine Steel

Cutting High-speed Steel

Only an expert can nick and break high-speed steel from the bar without damage to the structure adjacent to the fracture—and even an expert cannot be sure of doing so with safety; the best way, where the end is to be used for working purposes, is to cut the bar. The circular saw most frequently used does very well, though a band saw works better and rather more rapidly. Small bars can readily be cut in bundles, if held very rigidly. The saws, obviously, should, themselves, be of high-speed steel. Complaints have been made that it is impossible to saw these steels. The complaints probably originated in the use of improperly hardened saws; for there is no difficulty whatever in cutting them with suitable saws. A singular but most effective method has been employed to some extent. It consists in the use of a highly-speeded disk of tough steel. When an unused disk is first forced against the high-speed steel, the disk does not take hold well; but after being run in contact with the high-speed steel for a time it cuts perfectly and rapidly, leaving a clean burrless kerf. The disk may be of any steel tough enough to withstand the tremendous centrifugal (and other) stresses set up by the pressure and the terrific speed required. Just why such a disk cuts is not exactly clear. The periphery is usually found studded with particles of the steel being cut, and the "sawdust" appears to be the result of true cutting.

Detecting Cracks in High-speed Steel Tools

Fine cracks in tools are most difficult to discover. Even the microscope often fails to disclose them. Generally they can be detected, if present, by the very simple expedient of moistening the suspected surface with petroleum, rubbing clean, and then wiping off with chalk. Some petroleum enters the cracks and afterwards sweats out, moistening the overlying chalk. The nature and extent of the cracks are thus rendered visible. This frequently is of great importance in testing lots of high-speed steel tools.

Re-forging of Worn-down Tools

Tools which have worn down so as to be useless can usually, when made of solid high-speed steel, be forged or machined down and worked into tools of smaller size, if care is exercised. It is necessary always to re-anneal prior to attempting to machine such old tools; and it is also expedient when forging them to smaller shapes. In passing, it might be mentioned that re-annealing is desirable after machining and before hardening all sorts of intricately-shaped tools, in order to relieve any possible machine-caused strains. In re-forging high-speed tools, whether for reduction in size or merely in re-fettling, it is desirable that they be heated rather slowly at first; they should not be thrust cold into a very hot fire.

Some Results of the Use of High-speed Steel

That great economy is effected by the use of high-speed steel is beyond all doubt, from whichever point of view the question is looked at; for it is not only rapidity of cutting that counts, but the output of machines is correspondingly increased, so that a greater production is obtained from a given installation than was possible when cutting at low speeds with the old tool steel, and the work is naturally produced at a correspondingly lower cost, and of course, it follows from this that in laying down new plant and machines the introduction and use of high-speed steel would have considerable influence in reducing expenditure on capital account. It has also been proved that high-speed cutting is economical from a mechanical standpoint and that a given horse-power will remove a greater quantity of metal at a high speed than at a low speed, for although more pow
ally required to take off metal at a high than at a l

reason of the increased work done) the increase of that power is by no means in proportion to the large extra amount of work done by the high-speed cutting, for the frictional and other losses do not increase in anything like the same ratio as a high-cutting speed is to a low-cutting speed. A brief example of this may be given in which the power absorbed in the lathe was accurately measured, electrically.

Cutting on hard steel, with 3/16 inch depth of cut, 1/16 inch feed, and speed of cutting 17 feet per minute, a power of 5.16 horsepower was absorbed, and increasing the cutting speed to 42 feet per minute, the depth of cut and feed being the same, there was a saving in power of 19 per cent for the work being done. Another experiment with depth of cut 3/8 inch and traverse 1/16 inch compared with 1/16 inch traverse and 3/16 inch depth of cut, showed a saving in power of as much as 28 per cent, and still proceeding with a view of increasing the weight of metal removed in a given time the feed was doubled (other conditions being the same) and a still further saving of power resulted. In a word, as in the majority of things, so it is with rapid cutting, the more quickly work can be produced the cheaper the cost of production will be.

Again, as regards economy, there is not only a saving effected in the actual machine work, but since the advent of high-speed cutting it is now possible, in many instances, to produce finished articles from plain rolled bars, instead of following the old practice of first making expensive forgings and afterward finishing them in the machine. By this practice not only is the entire cost of forging abolished, but the machining on the rolled bar can be carried out much quicker and cheaper in suitably arranged machines, quicker even that the machining of a forging can be done.

Example of Efficiency of High-speed Steel

A remarkable example of the gain resulting from the use of high-speed tools may be recorded; the articles in this case being securing-bolts, made by the author's firm, for armor plates. Formerly where forgings were first made and then machined with ordinary self-hardening steel, a production of eight bolts per day of ten hours was usual. With the introduction of high-speed steel, forty similar bolts from the rolled bar are now produced in the same time, thus giving an advantage of five to one in favor of quick cutting, and also in addition abolishing the cost of first rough-forging the bolt to form; in fact, the cost of forging one bolt alone amounted to more than the present cost of producing to required form twelve such bolts by high-speed machining. The cutting speed at which these bolts are turned is 160 feet per minute, the depth of cut and feed being respectively ¾ inch and 1/32 inch, the weight of metal removed from each bolt being 62 pounds, or 2480 pounds in a day of ten hours, the tool being only ground once during such period of work; from such an example as this it will be at once apparent what an enormous saving in plant and cost results.

Equally remarkable results are obtained with high-speed milling cutters, and one example among many may be cited. Hexagon nuts for 3⅜-inch diameter bolts are made from rolled bars, the cutting speed of milling being 150 feet per minute, giving a production of ninety nuts per day, against thirty formerly. More than ninety nuts could have been produced had the machine been more powerful.

The Newer High-speed Steels

After the metal cutting industries had taken breath, so to speak, following the advent of air-hardening or high-speed steels, and begun to adjust themselves to the new situation, the use of self-hardening or mushet steels rapidly decreased until very little call for it existed and most manufacturers ceased making it altogether, putting out instead a more or less excellent quality of the high-speed kind. This, however, was not for some little time after the Taylor-White discoveries became public. The self-hardening steels had come into rather general use in difficult jobs, and in progressively managed shops were used to a considerable extent on all sorts of jobs; and so, while the new steels with their wonderful possibilities were justifying themselves and establishing their place, very properly there was a disposition to hold fast to that which had already proved itself, rather than to take up something but little known or tried.

Recently there has again come to be some demand for steels which, while possessing the qualities of high-speed steel to a moderate degree, enough to adapt them to a class of work not requiring its high cutting powers and red-hardness, could be bought at a price considerably below that of high-grade air-hardening steel; and a number of manufacturers have brought forward steels to fill this gap. There doubtless are many kinds of work wherein a steel of less endurance than the best high-speed varieties would answer every requirement and yield results equally as good—jobs where extremely high speeds or heavy cuts are in the nature of the case impracticable, or as in certain wood-working operations, where a cutter of higher endurance than one of the best carbon steel would have an almost indefinite life anyway. In such cases, it would seem, the high cost of air-hardening steel imposes an unnecessary expense in tool equipment.

Most such "new" steels are nothing more nor less than mushet or self-hardening, though some seem to be manganese rather than tungsten steels. A typical example of such a "special," "intermediate," or "semi-high-speed" steel, of excellent sustaining power and not exceptionally hard to treat, has the composition:

Carbon	1.19	per cent.
Tungsten	7.56	per cent.
Chromium	3.34	per cent.
Manganese	0.46	per cent.
Phosphorus	0.024	per cent.
Sulphur	0.025	per cer
Silicon	0.20	per c

Another, corresponding still more closely in its composition to mushet steel, gave this analysis:

Carbon	0.94 per cent.
Tungsten	4.78 per cent.
Chromium	0.69 per cent.
Manganese	0.27 per cent.
Phosphorus	0.01 per cent.
Sulphur	0.01 per cent.
Silicon	0.11 per cent.

Both these steels, it will be observed, are rather lower in carbon than most mushet steels formerly were, and the first is rather higher in tungsten while the second is lower in chromium. A third, which scarcely falls within the mushet class, is thus composed:

Carbon	1.25 per cent.
Tungsten	2.25 per cent.
Chromium	0.28 per cent.
Manganese	0.85 per cent.
Silicon	0.21 per cent.

The latter is advertised and sold specifically as a "finishing" steel; and it unquestionably gives excellent results in this particular kind of work. There are, besides, a number of other steels on the market, sold for tool use, the tungsten contents (or molybdenum equivalent) of which ranges anywhere below that essential to a high-grade high-speed steel—say 17 per cent—and down to that indicated in the analysis above. Most of these are sold as high-speed steels, though usually at a lower price than is customary for those of highest grade, and to a greater or less extent are so, when the chromium content corresponds with the tungsten.

Still another steel very widely advertised as an "intermediate" steel, and certainly working exceedingly well in certain classes of work, including blanking and stamping as well as cutting wood and metals of moderate hardness, has this anomalous composition:

Carbon	1.03 per cent.
Tungsten	0.46 per cent.
Manganese	0.30 per cent.
Phosphorus	0.025 per cent.
Sulphur	0.009 per cent.
Silicon	0.008 per cent.

This is represented as a very dense steel requiring very slow and careful heating to a bright cherry-red (800 to 850 degrees C. or about 1500 to 1550 degrees F.) for cutting tools, and somewhat lower for tools intended to withstand pressure or blows. It is water hardening, as might be supposed from its composition, and requires the temper to be drawn, as in the case of carbon steel tools. It is claimed to be at least 50 per cent tougher than carbon tool steel—though that is about what it seems really to be except for being high in manganese. Several other steels sold for about the same purposes also have about the same amount of manganese, and some a certain amount higher.

CHAPTER V

HARDENING AND TEMPERING STEEL

While there have been many articles published regarding the hardening and tempering of steel and the furnaces used, there is but little detailed information available regarding the baths used for these operations. The time has long since passed when each hardener had his own carefully guarded secrets regarding the composition of quenching baths. On the other hand, the time has also passed when it was a common belief that to harden a piece of steel it was only necessary to cool it off more or less rapidly in almost any kind of cooling medium; it has been found that the cooling mediums for hardening and the heating mediums or baths for tempering do, after all, play quite an important part both as regards economy and the efficiency of the tools treated. It is the intention in this article to outline the methods which have proved most successful, and to give the compositions of baths which from long experience in connection with hardening operations have proved to give the best all around results and to be the most economical; in many cases they have not been the cheapest in initial cost, but nevertheless are most economical because of the better results obtained with the tools treated and the greater length of time that the baths could be used before deteriorating. A description of such receptacles—cooling tanks and tempering furnaces—for the treatment of steel as have proved to be the best for all around purposes has also been included.

For the sake of convenience the subject to be treated will be divided into four distinct parts as follows: (1) Baths used for cooling (quenching). (2) Baths used for tempering (drawing the temper after hardening). (3) Some tests and analysis of baths referred to under (1) and (2). (4) Receptacles and furnaces used in quenching and tempering.

Characteristics of Quenching Baths

No matter what the composition of a quenching bath, to insure uniform hardening the temperature of the bath must be kept constant, so that successive pieces of steel or tools quenched will be acted upon by baths of the same heat. The necessity of a uniform temperature for a quenching bath will be readily understood by reference to ordinary water for a cooling bath; everyone having any knowledge of the subject knows that a tool quenched in such a bath at room temperature will come out much harder than if quenched when the water is at the boiling point. In fact, it is well known that one way of partially annealing steel is by plunging it at a red heat into hot water. The same difference in hardness will result when using any quenching bath at different temperatures, and hence no actual and dependable data can be obtained unless means are taken for keeping these baths at a uniform heat.

When using quenching baths of different composition the tools quenched will vary in hardness. This is due mainly to the difference in heat-dissipating power of the different baths. Thus a tool hardened at the same temperature in water and brine will come out harder when quenched in brine; the greater the conductivity of the bath the quicker the cooling. The general opinion, today, is that the composition of a quenching bath is of small importance as long as the bath cools the pieces rapidly. Those who have made a study of the subject have found different opinions regarding the same quenching bath by different users, and a good many quenching fluids have been condemned owing to improper heating and in many cases to improperly built furnaces.. As an example may be cited an oven furnace with which the user once had trouble. Owing to faulty construction of this furnace, more air was let into the heating chamber of the furnace than could be taken care of by the fuel oil; after having condemned first the steel and then the quenching bath, and then trying one quenching bath after another with the same results, it was suggested that the "heating" did not look just right, and an expert was called in to find out what the trouble was. After much experimenting with the burners and the furnace itself good results were finally obtained. The difficulty seemed to be that the oxygen of the air attacked the steel and formed oxide of iron on the surface of the tools, which consequently had a soft scale on the outside.

Those who are skeptical as to there being any difference in the effect on steel of cooling baths of different composition will readily admit that it is advantageous to use baths free from oxygen and from ingredients that tend to oxidize. Quenching baths should be uniform; good tool steels of high carbon are very sensitive to differences in both water and oils. Water for hardening tool steel should be soft; entirely different and very unsatisfactory results will be obtained when using hard water. While different quenching oils show less difference in the results obtained, vegetable and animal oils will give somewhat different degrees of hardness depending upon the sources from which they are obtained. One cannot be too careful in the selection of water, as it is likely to contain many impurities. If it contains greasy matters, it may not harden steel at all, whereas if it contains certain acids, it will be likely to make the tools quenched in it brittle and even crack them.

List of Quenching Baths

(1) Water—soft—preferably distilled; good tool steel should require no mixture added to pure water. (2) Salt added to water; will produce a harder "scale" than if quenched in plain water. (3) Sea (salt) water—the keenest natural water for hardening. (4) Water as under (1), containing soap. (5) Sweet milk.* (6) Mercury.* (7) Carbonate of lime.* (8) Wax.* (9) Tallow.* (10) Air—mostly used for high-speed steel; mere exposure, however, is in many cases and on many steels not sufficient to produce hardness and an air blast is necessary, as this furnishes cool air in rapid motion. (11) Oils such

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* Generally used for special purposes only.

as cottonseed, linseed, whale, fish, lard, lard and paraffine mixed, special quenching oils, etc.

The following list of oils and names of firms supplying them is given for the sake of convenience. The firms mentioned are reliable and their oils have been thoroughly tried out in comparison with other makes and have proved to be superior; opinions may, of course, differ in this respect and no doubt there are many oils that have not been tried that may be as good.

Cottonseed oil—Union Oil Co., Providence, R. I.; Underhay Oil Co., Boston, Mass.

Linseed oil—Spencer Kellogg & Sons, Inc., Buffalo, N. Y.

Whale oil—no difference found between two different kinds.

Fish oil—only one kind tried.

Lard oil—W. B. Bleecker, Albany, N. Y.; E. F. Houghton & Co., Pittsburg, Pa.

Paraffine oil—Underhay Oil Co., Boston, Mass.

Special quenching oil—E. F. Houghton & Co., Pittsburg, Pa. Very good and cheap. While this may possibly deteriorate somewhat faster than some of the others mentioned it will prove very economical.

The order of the intensity with which various cooling baths will harden steel of about 0.90 to 1.00 per cent carbon is as follows: Mercury, carbonate of lime, pure water, water containing soap, sweet milk, different kinds of oils, tallow and wax. In all cases, except possibly the oils, tallow and wax, it must be remembered that the tools become harder as the temperature of the bath becomes lower.

Baths used for Tempering

The object of tempering is to reduce the hardness and to remove internal strains caused by sudden cooling in quenching. The composition of a tempering bath is of little importance compared with that of a quenching bath when considering the effect upon the pieces treated. Aside from the operator's convenience and possible bad effects upon his health, the different baths used for this operation must be considered with regard to initial cost, lasting quality, effects on finish, etc.

While oil is the most widely used medium for tempering tools in quantities, other means and methods are employed, especially by those who have tools in small quantities to temper, when the expense of installing and running an oil tempering furnace would not be warranted. Of these methods we first find the one used by the old-style tool hardener of only partly cooling the tool when quenching it, then quickly withdrawing it, polishing off the working surface, and then letting the heat which remains in the tool produce the required temper as judged by the color. If the tool has a shank, it is good practice to heat part of the shank also and quench the working part of the tool only, in which case this part can be cooled off thoroughly; the heat remaining in the body or shank of the tool will do the tempering, which also in this case must be judged by the color.

The sand bath is another frequently used medium for tempering, the sand being deposited on an iron plate and heated; by the use of this method a piece to be tempered can be given different tempers throughout its length, as, for example, rivet hole punches; these are placed endwise—bottom down—in the sand about two-thirds projecting outside the sand into the air (see Fig. 7). It is readily seen that the nearer the bottom of the sand bath, the higher the heat, and the punch so placed, when tempered right, will have the bottom soft—a deep dark blue—the neck a very dark straw, and the working part of the punch on top a light straw color; thus there is a gradual increase in hardness from the bottom up. Pieces so drawn must previously have been polished, and the temper is judged by the color. When the pieces have attained the right color they are, of course, cooled off, generally in water or oil. A plate without sand similarly heated can also be used, but it is not as satisfactory.

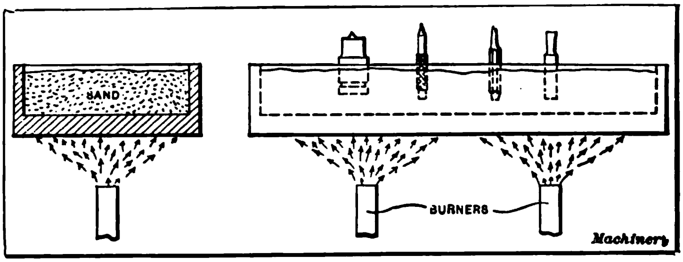

Fig. 7. Arrangement used for Sand Tempering

A plate arranged as shown in Fig. 8 will be found very convenient when drawing small, round pieces. The pieces are rolled on the inclined plate which is heated as indicated. The length of time the work is in contact with the plate can be regulated by adjusting the amount of the incline, as well as the location of the "stop." This arrangement can also be used for such work as punches, etc., in which case the plate, of course, should stand level and not in an inclined position.

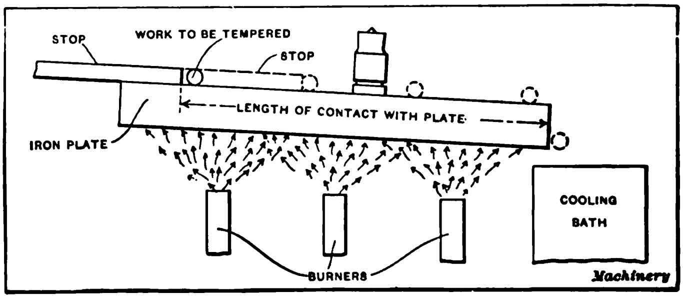

Fig. 8. Tempering Arrangement utilizing an Inclined Plate on which the Objects roll down

Another frequently used tempering medium is hot air, the temper in this case also being judged by the color. For this method of tempering special furnaces should be employed in order to get uniform results. This method is used more especially for small and light work in quantities and where the color has to be bright and clear. While all of these methods have the advantage of enabling one to actually see the temper given to tools treated, the oil tempering bath is the one mostly used owing to its economy.

The two main points to be considered when using an oil tempering furnace are: first, to have the heat uniform throughout (not hotter where the burners or flames are in contact with the walls of the furnace); and second, to leave the pieces to be tempered in the oil long enough to have attained the heat of the oil throughout when taken out. The first point can be taken care of, as far as possible, by proper construction of the furnace; the second can best be taken care of by immersing the pieces to be tempered in the oil before starting to heat, and letting the pieces remain in the oil and be heated with it to the temperature required. In such a case, one should, of course, have more than one furnace, or else after each operation take the hot oil out and refill the tank with cold. The method described is very much better than the one frequently used of immersing the pieces in a bath which already has the required temperature and then letting them remain long enough to attain the heat of the bath throughout, as a furnace yet has to be designed which will maintain a uniform heat for even as short a time as is required for this operation. Furthermore, it is not necessary that a piece to be tempered be held in the bath a certain length of time at the required temperature; the temperature desired need only be maintained long enough to insure that the piece has been evenly heated throughout.

When tempering to high heats, or, rather, when tempering to higher heats than the flash point of any tempering oils (650 to 700 degrees F.*) some other tempering fluid than oil must be used. Lead is the one usually employed. As it is impossible when using lead to let the pieces to be tempered be heated up with the lead, they must be immersed at the predetermined temperature and kept there until heated evenly throughout to the same temperature as the lead. It is claimed by many that it is easier to maintain a uniform heat in a lead bath than in an oil bath, but it has been found that, owing to the lead not circulating as readily, the temperature may vary considerably in different parts of the bath, and hence it is not very reliable.

Salt is another medium frequently employed for tempering heats between 575 and 875 degrees F. Salt fuses at 575 degrees F., but when immersing the pieces to be tempered the salt will immediately solidify around the cold pieces. When these are heated to 575 degrees, the salt will melt and the pieces should be withdrawn. This is not reliable, however, as the pieces, especially if large, will not have had time to be heated through before the salt melts. If a higher temper is required, it is, of course, only necessary to let the pieces remain in the bath and get the readings of the heat from a pyrometer. In all these

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* There are tempering oils on the market claimed to have a flash test of 750 degrees, but it is doubtful if they ever have been found to stand this test. Heavy black cylinder oil has been found to stand a flash test of 725 degrees.

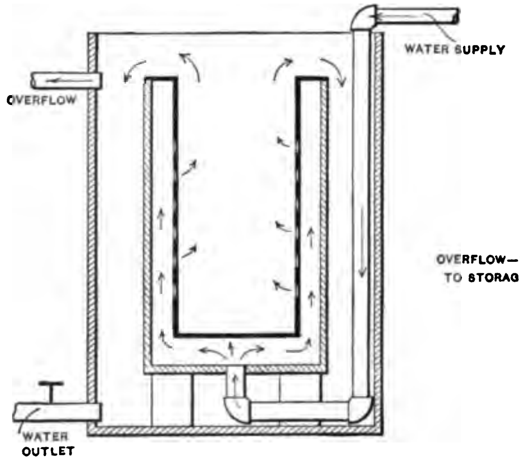

Fig. 9. Water or Brine Tank for Quenching Baths

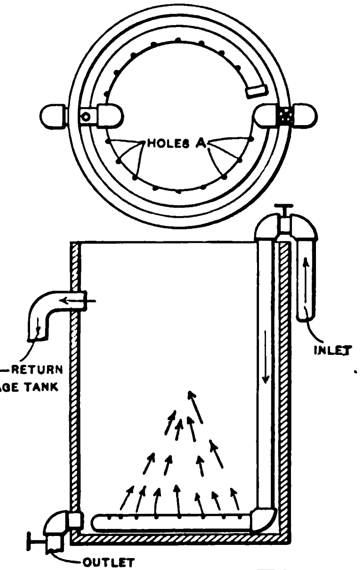

Fig. 10. Another Type of Water or Brine Tank

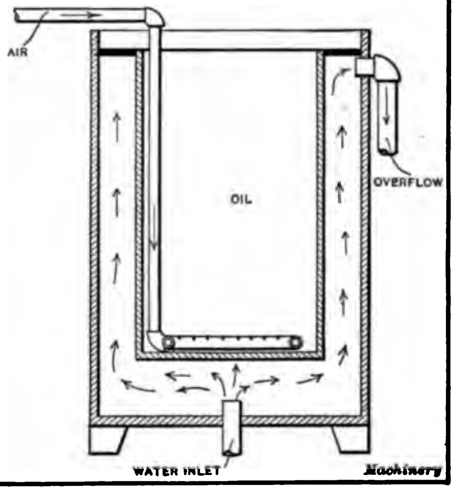

Fig. 11. Oil-quenching Tank with Water Circulated in an Outer Tank

methods, it is questionable if it is good practice to suddenly immerse cold pieces to be drawn into baths of such high temperatures. When a lower temper is required, and an oil tempering bath or furnace is not available, alloys of lead and tin can be used for as low heats as 400 degrees F. and of lead and antimony for 500 degrees F. However, this involves the inconvenience of keeping a large number of different alloys on hand, if it is desired to vary the temper heats. The following table for different alloys was compiled by Mr. O. M. Becker.

Melting Temperatures of Lead—Tin Alloys

Lead	Tin	Melting Temperature, Degrees F.	Lead	Tin	Melting Temperature, Degrees F.
14	8	420	24	8	480
15	8	430	28	8	490
16	8	440	38	8	510
17	8	450	60	8	530
18.5	8	460	96	8	550
20	8	470	200	8	560

The oils for tempering baths specified below are given for the sake of convenience only; the statements are based upon the findings of thorough experiments. There may, of course, be many other oils just as good that have not been tried.

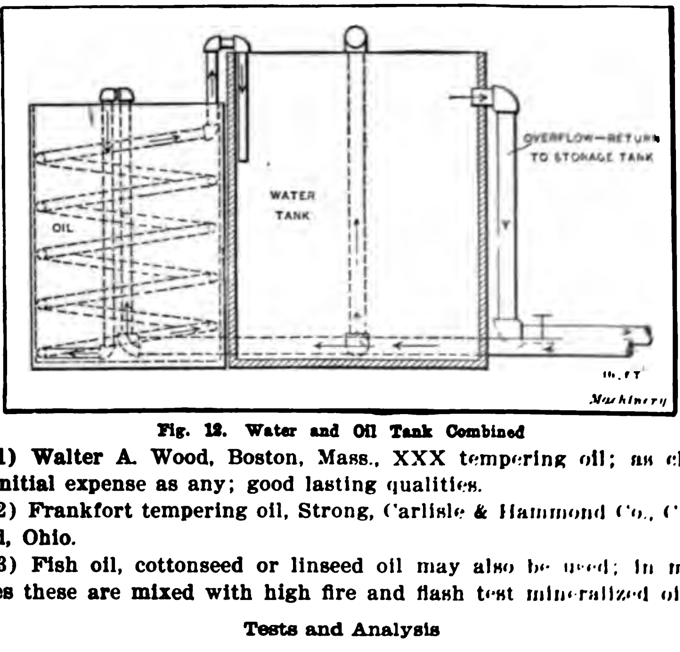

Fig. 12. Water and Oil Tank Combined

(1) Walter A. Wood, Boston, Mass., XXX tempering oil; as cheap in initial expense as any; good lasting qualities.

(2) Frankfort tempering oil, Strong, Carlisle & Hammond Co., Cleveland, Ohio.

(3) Fish oil, cottonseed or linseed oil may also be used; in many cases these are mixed with high fire and flash test mineralized oils

Tests and Analysis

The analysis and test results of oils when new (not used) as compared with those of oils which have been used such a length of time as to render them practically valueless will be found interesting.

	Tempering Oil W. A. Wood		Lard and paraffine oil mixed (half and half) used for quenching	
	New	Old (thick)	New	Old (thick)
Flash point	550	475	400	380
Fire test	625	550	475	450
Mineral oil, per cent	94	30	25	10
Saponifiable oil, per cent	6	70	75	90
Specific gravity	0.920	0.950	0.912	0.925

Houghton tempering oil: flash point, 595 degrees; fire test, 685 degrees; specific gravity, 0.900.

Frankfort tempering oil: fire test, 670 degrees.
Frankfort quenching oil: fire test, 500 degrees.
Paraffine oil (Underhay): fire test, 450; specific gravity, 0.912.
Lard oil (Bleecker): fire test, ——; specific gravity, 0.920.

The great difference in tests and analysis between new and used oils should be noted; oils used constantly at high heats will gradually lose the "mineral" part of the oil, the more so the higher the heat used. A tempering bath can therefore be prolonged in life by adding to it now and then new mineral oil. To lengthen the life of the bath high heats should be avoided as much as possible.

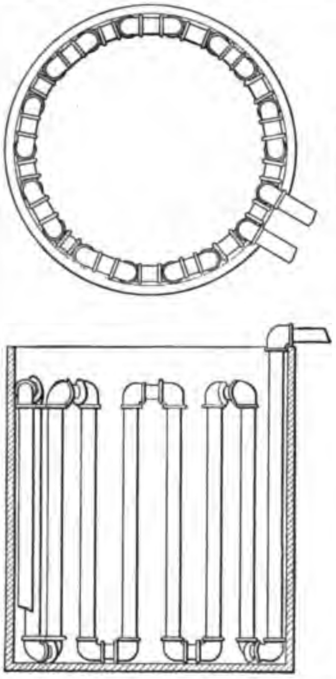

Fig. 13. Ordinary Type of Quenching Tank

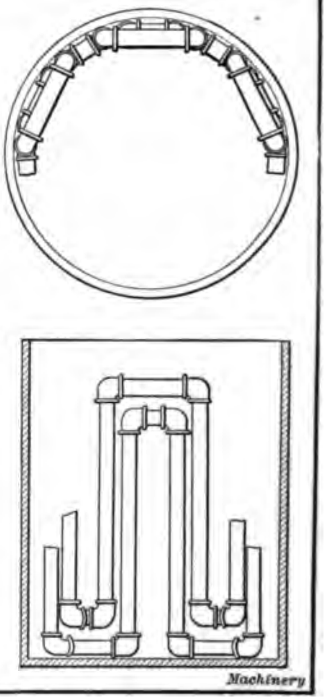

Fig. 14. Oil-quenching Tank with Water and Steam Coils

Receptacles and Furnaces used in Quenching and Tempering

The main point to be considered in a quenching bath is, as mentioned, to keep it at a uniform temperature so that successive pieces quenched will be subjected to the same heat. The next consideration is to keep the bath agitated, so that it will not be of different temperatures in different places; if thoroughly agitated and kept in motion, as is the case with the bath shown in Fig. 9, it is not even necessary to keep the pieces in motion in the bath, as steam will not be likely to form around the pieces quenched. Experience has proved that if a piece is held still in a thoroughly agitated bath it will come out much straighter than if it has been moved around in an unagitated bath. This is an important consideration, especially when hardening long pieces. It is, besides, no easy matter to keep heavy and long pieces in motion unless it be done by mechanical means.

In Fig. 9 is shown a water or brine tank for quenching baths. Water is forced by a pump or other means through the supply pipe into the intermediate space between the outer and inner tank. From the intermediate space it is forced into the inner tank through holes as indicated. The water returns to the storage tank by overflowing from the inner tank into the outer one and then through the over-

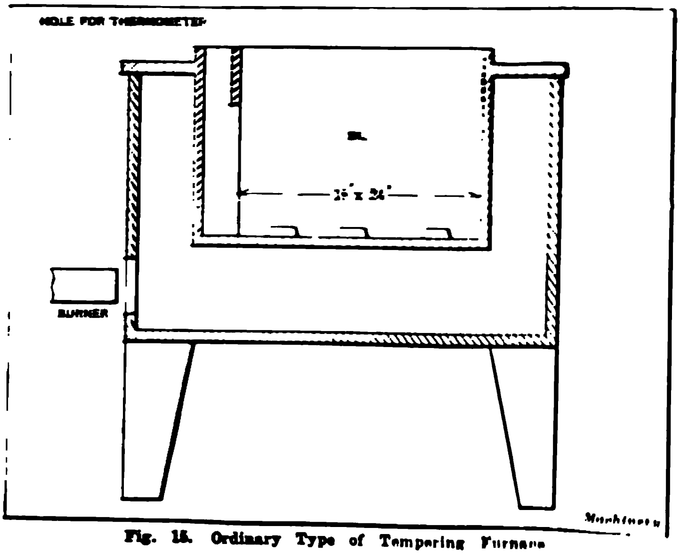

Fig. 15. Ordinary Type of Tempering Furnace

flow pipe as indicated. In Fig. 10 is shown another water or brine tank of a more common type. In this case the water or brine is pumped from the storage tank and continuously returned to it. If the storage tank contains a large volume of water, there is no need of a special means for cooling. Otherwise, arrangements must be made for cooling the water after it has passed through the tank. The bath is agitated by the force with which the water is pumped into it. The holes at *A* are drilled on an angle, so as to throw the water toward the center of the tank. In Fig. 11 is shown an oil quenching tank in which water is circulated in an outer surrounding tank for keeping the oil bath cool. Air is forced into the oil bath [illegible] agitated.

Fig. 12 shows a water and oil tank combined. The [illegible] by a coil passing through it in which water is circul[illegible] passes into the water tank. The water and oil bath [illegible] agitated.

Fig. 13 shows the ordinary type of quenching tank cooled by water forced through a coil of pipe. This can be used for either oil, water or brine. Fig. 14 shows a similar type of quenching tank, but with two coils of pipe. Water flows through one of these and steam through the other. By this means it is possible to keep the bath at a constant temperature.

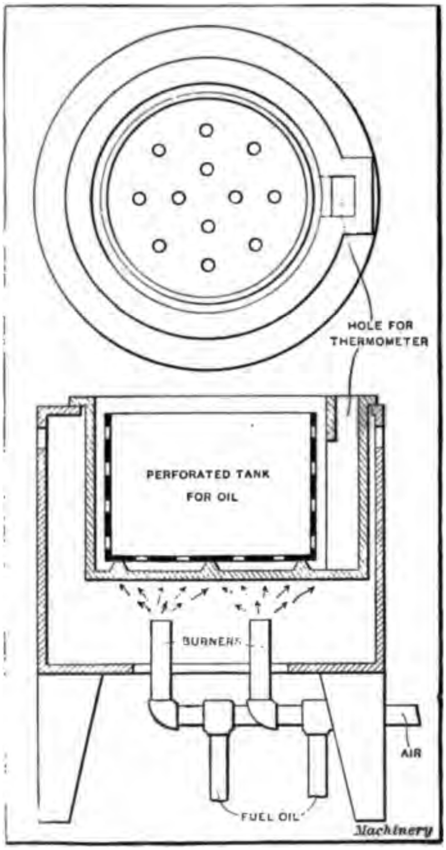

Fig. 16. Special Tempering Furnace with Perforated Oil Tank

In tempering furnaces the only really important consideration is to insure that the furnace is so built as to heat the bath uniformly throughout. It is doubtful if there can be found a tempering furnace on the market that will fill this requirement entirely, although many give good results in general. It is never safe, however, to let any tools being tempered rest against the bottom or sides of the tank, as no matter how scientifically the furnace may be built these parts are, in most cases, hotter than the fluid itself. It is, of course, just as important not to let the thermometer rest against any of these parts in order to insure correct readings. After the pieces tempered are taken out of the oil bath, they should immediately be dipped in a tank of caustic soda (not registering over 8 or 9), and after that in a tank of hot water. This will remove all oil which might adhere to the tools.

Fig. 15 shows an ordinary type of tempering furnace. In this the flame does not strike the walls of the tank directly. The tools to be tempered are laid in a basket which is immersed in the oil. In Fig. 16 is shown a tempering furnace in which means are provided for preventing the tools to be tempered from coming in contact with the walls or bottom of the furnace proper. The basket holding the tools is immersed in the inner perforated oil tank. This same arrangement can, of course, be applied to the furnace shown in Fig. 15.

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