job entry training program

SHOP THEORY

VOLUME ONE

national machine tool builders' association
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JOB ENTRY TRAINING PROGRAM

SHOP THEORY

In Two Volumes
Volume One

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FOREWORD

This text is the result of a need in industry for an updated explanation of machine shop operations and related topics ranging from use of hand files to an explanation of numerical control. The reader who will use this text in his effort to cover the area of knowledge referred to as "shop theory" will find a comprehensive body of material compiled to enable the reader to absorb as many fundamentals as possible in a short period of time. Because of the comprehensive treatment accorded to this text not all the material will be used in all training situations; the reader will determine which sections pertain to his area of interest and may pursue some topics lightly and others in depth. NMTBA's Training Committee is constantly searching for and developing new techniques and improved methods for skills training. This text is one result of this constant search. Machine shop trainers and trainees gratefully acknowledge the generosity of Professor Orville D. Lascoe's work in the development of this text. Professor Lascoe is internationally known and respected for his contributions to research and training and for his dedicated interest to the machine tool industry.

John Mandl

John Mandl
Director of Training
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SHOP THEORY

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CHAPTER I

INDUSTRIAL PROCESSES

In order to minimize waste in both time and materials, a number of industrial processes produce pre-worked shapes that are to be finished by machine tools. These pre-worked shapes are generally produced in the approximate size and form desired by one of the following processes:

(1) Castings
(2) Forgings
(3) Mill shapes

Typical piece part shapes preworked by castings are automotive cylindrical block, pistons, and fly wheels. By forging processes --crankshafts, valves, connecting rods and cam shafts. Steel mills produce the mill shapes in the forms of sheet, plate, bar stock, and structural shapes.

CASTING PROCESS

Castings are the products of foundries and are used in many lines of manufacturing. Castings are grouped into six general classes known commercially as common:

(1) gray cast iron
(2) alloy gray cast iron
(3) malleable cast iron
(4) steel
(5) alloy steel

(6) non-ferrous metal castings

In order to produce castings made from different metals, several types of melting furnaces are employed. The cupola furnace is normally used for melting gray iron. Electric furnaces are used for producing malleable iron castings. For melting steel, the open-hearth, crucible or electric furnace is used. The non-ferrous metals are generally melted in a crucible by gas-fired or electric furnaces.

The casting process may be defined as pouring molten metal into a mold containing a cavity of the desired shape of the piece part desired. Molds are made of sand which are destroyed upon solidification of the metal. If the mold is of the permanent type, it is separated to remove the casting. Castings range in weight from a few ounces to many tons. In order to make different sizes of castings, a variety of materials are employed to construct molds. Molding operations are classified under five classifications, according to the material used and the techniques of working the mold:

(1) Green sand molding --the most economical method of making a casting.

(2) Skin-dried molds --a green sand mold mixed with wheat flour and dried with a torch flame before pouring.

(3) Dry-sand molds --are made of green molding sand mixed with a binder consisting of wheat flour, resin and linseed oil; the entire mold is baked in an oven before pouring.

(4) Loam molds --are forms built of bricks and plastered over with loam mortar rich in clay. These molds are used in the production of large castings.

(5) Iron molds --as the name implies are made of iron. Their advantage is that many castings can be made before a replacement is necessary.

Cast metals are generally classified in two groups: Ferrous and non-ferrous. Each of the classifications is furthur subdivided according to its compositions. The following diagram illustrates the principle classifications (Figure 1).

ADVANTAGES OF CASTING PROCESSES:

(1) Casting process is the most economical method for producing complicated shapes in quantity production.

(2) Metal can be placed where it will do the most good and can be better distributed for fatigue strength. Recesses and undercuts can be cast to reduce or eliminate machining. Properly designed castings often result in weight saving over other methods of fabrication.

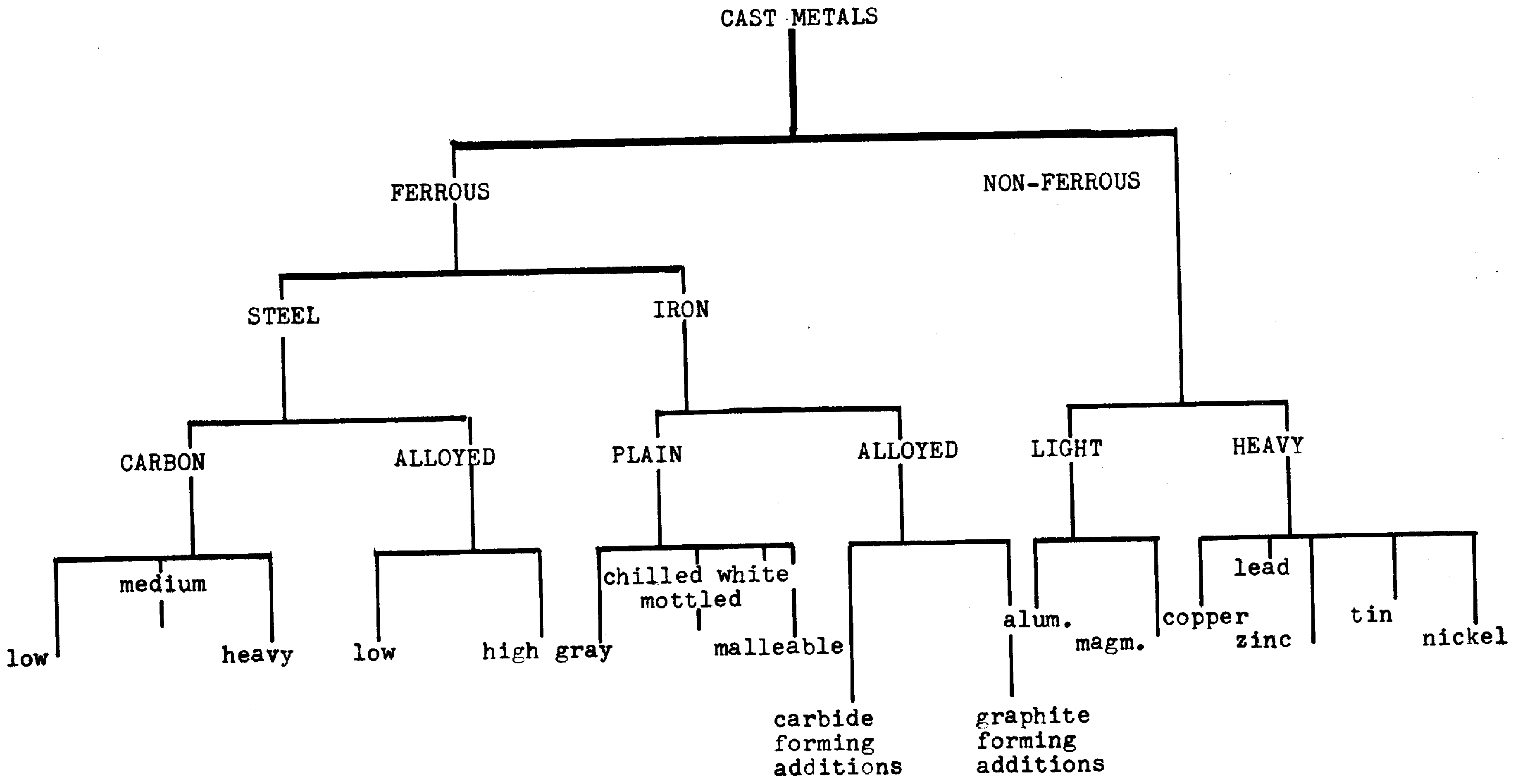
(3) Precision castings have reduced machining time.

(4) Cast structures have higher resistance to creep and better dampening characteristics.

FORGING PROCESS

The shaping of metal in either the hot or cold state by some mechanical means defines forging and cold forming of metals. When a piece of hot metal is hammered or pressed into a steel die a preworked shape is formed to the desired form and size.

In most cases, the metal to be forged is heated to



(Figure 1) Cast Metals Classifications

its correct forging temperature. Cold forging is accomplished in the range from room temperature up to the critical temperature of the metal. The properties of the metal are actually improved by mechanical working, since grain refinement is caused by the process. Both hot and cold working produce a structure elongated in the same direction as that of rolling, drawing or other forms of mechanical working.

FORGING OPERATIONS

There are basically three forging operations performed by mechanical forming:

(1) Drawing out --this increases length and decreases cross-sectional area of a piece part.

(2) Upsetting --this increases cross-sectional area and decreases length.

(3) Squeezing --this compresses the material in a closed impression die.

Forgings are generally superior in mechanical properties to castings of the same chemical analysis; therefore, parts which must withstand severe stresses are preferably made by forging.

Forgings have better mechanical properties than castings because:

(1) the fiber flow lines when properly controlled and directed tend to provide greater strength;

(2) hammering or pressing operations produce a

dense structure free from voids, blow holes, or porosities;

(3) the working of the metal breaks up coarse grains by producing a slip along crystallographic planes.

The forging processes are generally grouped under four principal methods:

(1) Smith Forging
(2) Drop Forging
(3) Press Forging
(4) Upset Forging

Smith Forging --is performed in a pair of dies with flat surfaces . The shaping of the part depends upon the skill of the smith who moves the metal and directs the operation. Smith forgings are made to approximate dimensions; therefore, machining is necessary for surfaces requiring close tolerances. This method is used for production of small quantities. The size of the forgings range from one pound to over 200 tons. Machine tools used to perform these operations are steam hammers, large hydraulic presses and air hammers.

Drop Forgings --operations are accomplished with closed impression dies. Closed impression dies consist of two halves. The upper die is fastened to the ram of the press and the lower die to the anvil cap of the machine. The impact of the hammer on the heated metal forces it into every part of the mating dies. The Drop forging method is used producing forgings weighing from less than an ounce to several hundred pounds.

Press forging --is similar to drop forging since closed impression dies are employed; the difference is that metal is squeezed into the die cavities using a sustained pressure. The operations are performed in large mechanical or hydraulic presses. Press forging is faster than drop forging since only one blow is needed for the metal at each die cavity and ejector pins remove the part on the return stroke.

Upset Forging --is the operation of upsetting or gathering of metal to form heads on bolts. The forging machine used to perform such operations is essentially a double action press with its motions in a horizontal plane instead of vertical as in the hammers and presses used for drop forging operations. Dies used to perform upsetting operations are closed impression dies consisting of two die blocks and a set of heading tools.

ADVANTAGES OF THE FORGING PROCESSES

The main advantage of forgings is their greater strengths possible with the process compared with castings. Close dimensional tolerances are possible and assembly operations can be performed by welding.

ROLLING PROCESSES

The rolling of metal into sheet, plate and bar forms by the steel mill operations produce the greatest tonnage of steel used in all manufacturing operations. The products produced are generally referred to as mill shapes.

Mill shapes of all sizes and forms are used extensively in machine shop operations along with castings and forging.

Ferrous and non-ferrous sheet and plate metal is for press operations, weldments, and flamed cut shapes for machining. Bar stock in rounds, squares, hexagon and flat shapes of various sizes are the most essential materials used in machining operations consisting of low, medium, and carbon compositions and alloyed steels.

Rolling process is accomplished by passing a hot ingot of steel between two large rolls made of chilled white cast iron. A rolling mill may consist of one or more stands permitting the ingot to be roughed to shape by the first stands and passed on to the finishing stands for final drawing to size and shape.

Rolling refines the grain structure of the metal and develops fiber flow lines in the direction of the rolling.

In order to produce desired shapes such as bars, plates or sheets, the rolling is done in two or more rolling operations with repeating operations when necessary. Products produced by the hot rolling processes are generally referred to as hot-rolled products. In order to improve and size these products to closer dimensional tolerances, they are re-rolled by cold drawing, the main advantages being:

(1) Shapes can be finished to close tolerances. Dimensions can be held to within 0.002" to 0.004";

(2) Surface improvements by removing oxidations;

(3) Tensile strength is increased;

(4) Hardness is increased.

Mill supply houses provide a complete stock list of steel and aluminum shapes available as standard shapes and sizes with complete data on chemical compositions and heat-treatment. Skilled machinists frequently use these catalogs for selecting materials and determining the workability characteristics of each metal.

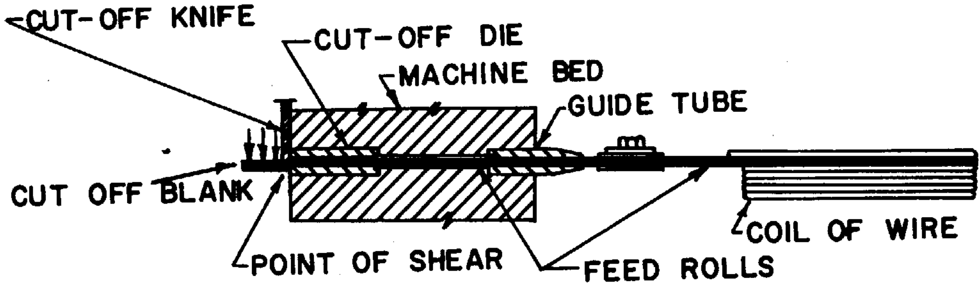
COLD FORMING

Cold forming, frequently referred to as cold heading, cold upsetting, or cold forging, is an automatic process in which sections of wire are sheared to length and then formed cold by pressing between two dies. The shapes of the die cavities determine the resulting form (Figure 2)

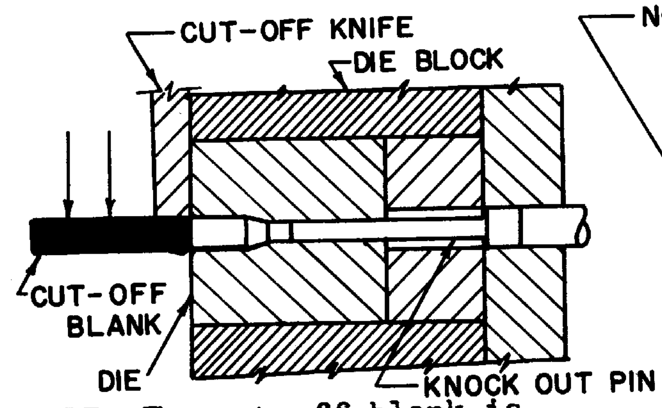
Ordinary bolt and screw blanks, rivets and nails are made by this process as are many special shapes for particular applications. It is primarily with these special items that this series will be concerned.

Cold forming machines run at speeds varying from 2,000 pieces per hour to 30,000 pieces per hour. Pressures

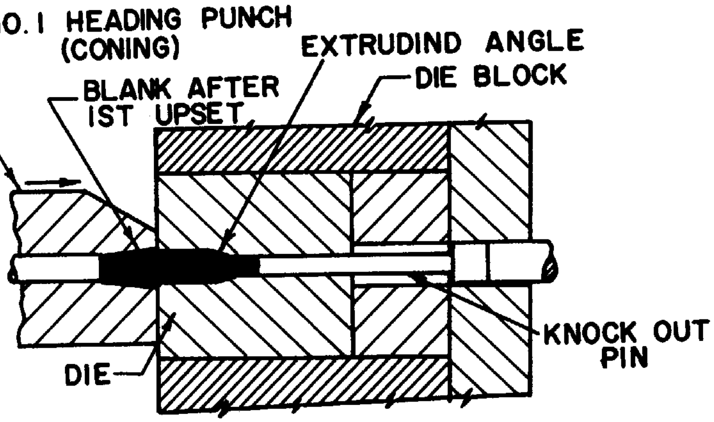
THE COLD FORMING (COLD HEADING) OPERATION



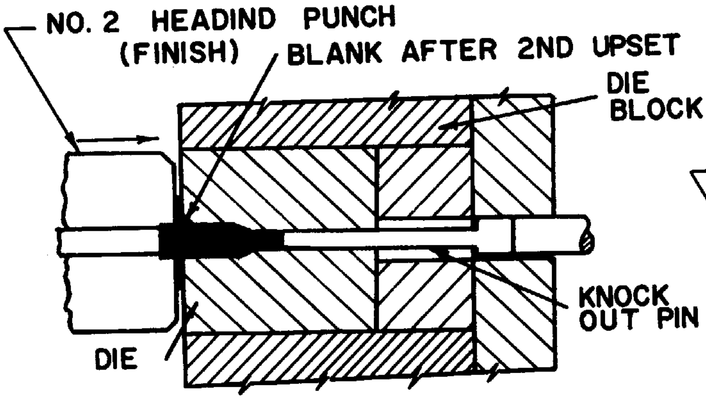
I The wire is fed automatically from a coil and sheared to length with a lateral motion of the cut-off knife.



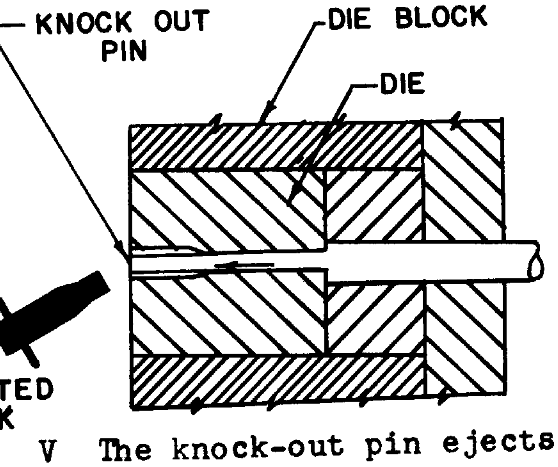
II The cut-off blank is positioned in front of a cylindrical die.



III The first punch travels forward forcing the blank into the die thereby extruding one end (reducing diameter) and making the first upset on the other end of the blank.



IV The second punch moves forward to complete the forming of the washer and hexagon head.



V The knock-out pin ejects the finished part.

(Figure 2)

developed in this operation vary from 2 tons in the small machines to over 100 tons in the large machines.

A cold header or cold former is in many respects similar to an automatic press operating in a horizontal rather than a vertical position (Figure 2 and 3).

Parts produced on headers are frequently subjected to secondary automatic operations such as thread rolling, knurling, extruding, flattening, piercing, drilling, broaching, bending, etc.

THREAD ROLLING BY COLD FORMING

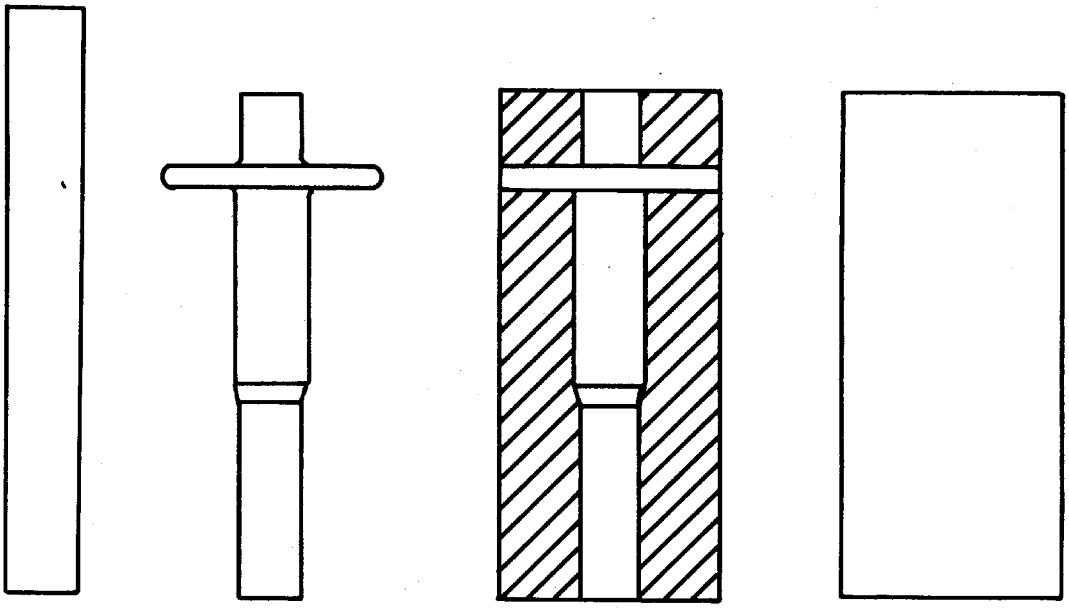
Thread rolling is a cold forming process which forms the thread by displacement of metal rather than by removal of metal.

This operation is performed by rolling and squeezing a metal blank between two dies which have been machined in a pattern similar to the finished thread (Figure 4 and 5).

Rolled threads are usually superior to those produced by other methods for the following reasons:

(1) Cold working increases the tensile strength. Tests on straight tension loads indicate rolled threads are 10 to 25 percent stronger than cut or ground threads of similar size and material. In tests under fatigue loads an increase as great as 50 percent is sometimes recorded.

(2) In rolling, the fibers are elongated and rearranged in unbroken flow lines following the thread contours; when a thread is cut or ground, these lines are severed since they



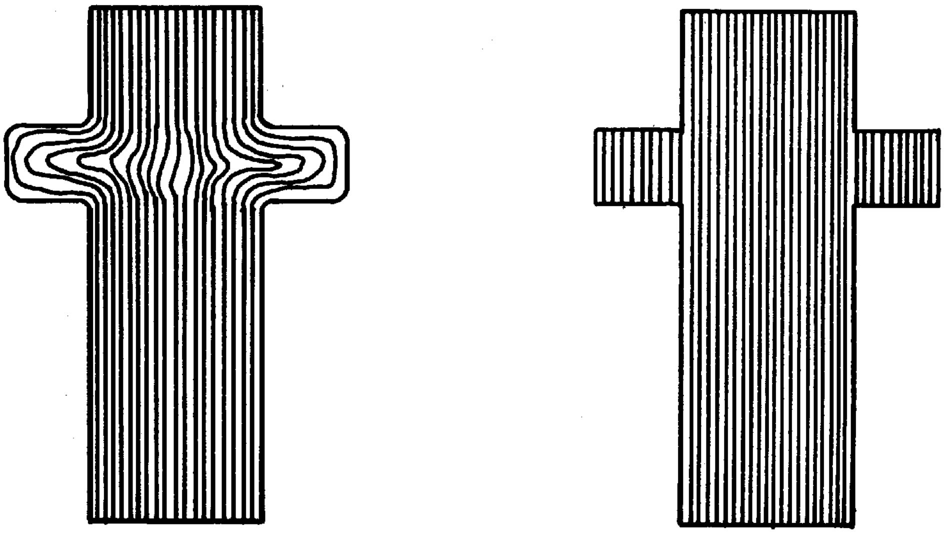
COLD HEADING STOCK

COLD HEADED PART

SCREW MACHINE PART

SCREW MACHINE STOCK

▨ = 85% SCRAP



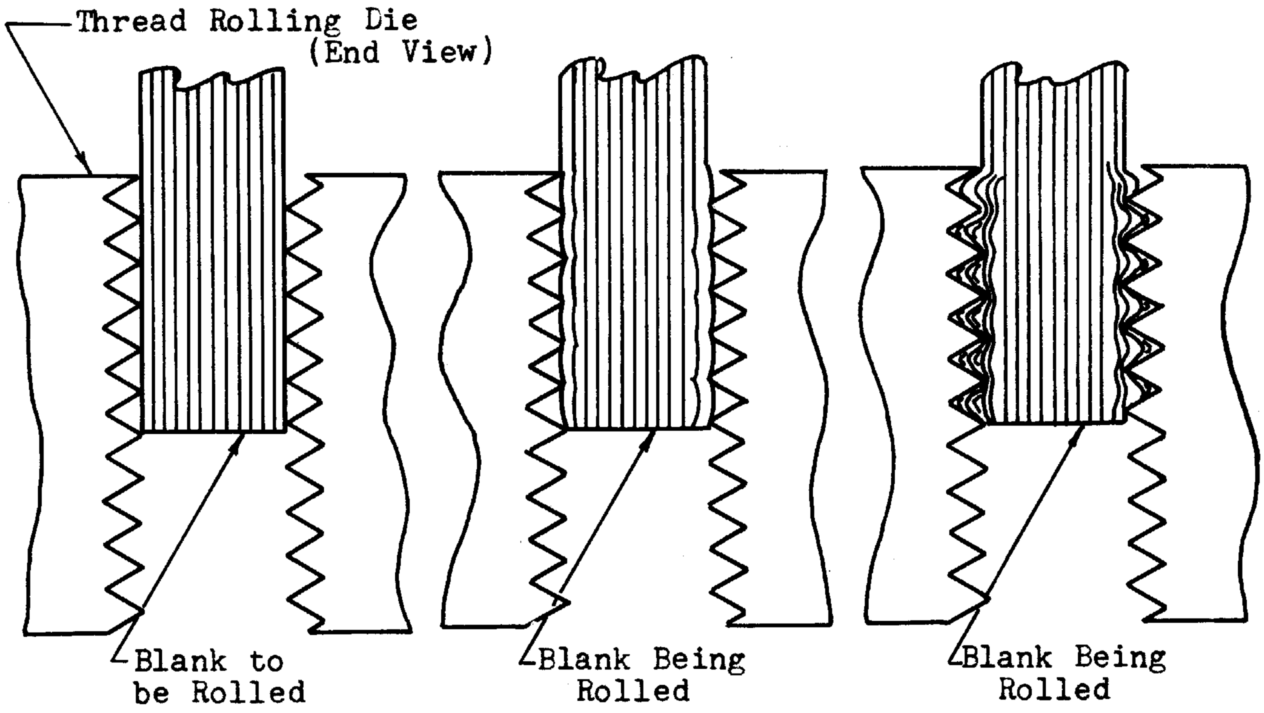
COLD HEADED PART

Flow lines follow contour of upset section, imparting strength.

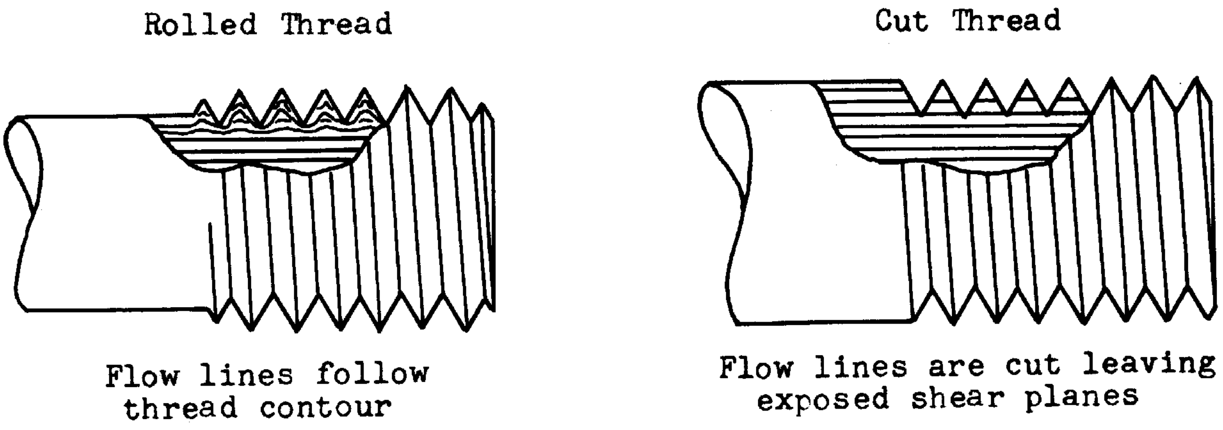
SCREW MACHINE PART

Flow lines are parallel to axis.

(Figure 3)



Lines show how fibers are rearranged to follow thread contours. This cold working increases tensile strength.


Rolled Thread

Cut Thread

Flow lines follow thread contour

Flow lines are cut leaving exposed shear planes

Rolled threads have greater resistance to shear or stripping failure.

(Figure 4)

remain parallel to the axis. This leaves exposed shear planes which decrease the resistance to stripping and other shear failures (Figure 5).

(3) Because of precision manufacture of rolling dies, very accurate threads can be produced by this method.

(4) Rolling tends to harden and burnish the surface making it non-porous and free from tears thus providing some protection against surface corrosion and also improving the appearance.

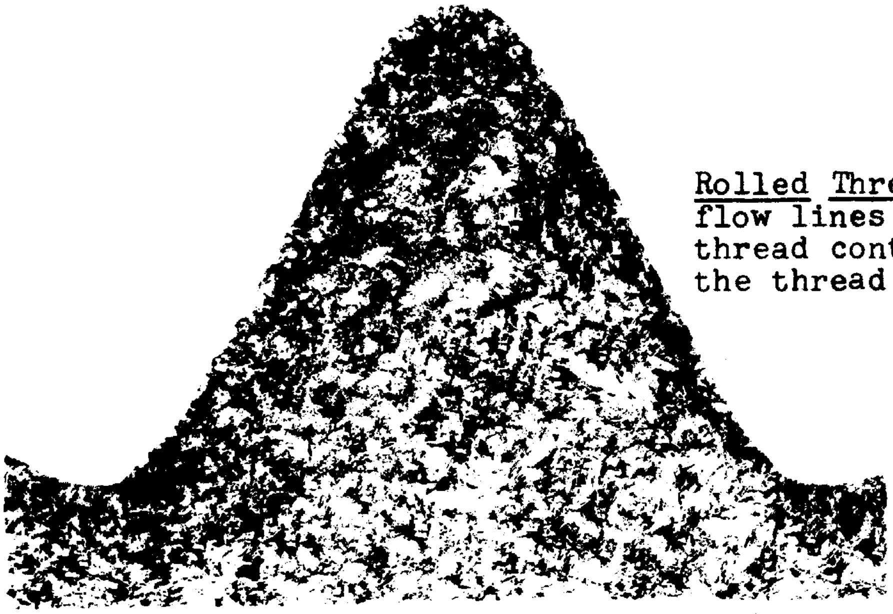
(5) Rolling can be performed effectively on a wider variety of materials than can cutting.

(6) Pointing is usually unnecessary on rolled threads because the elongating effect of rolling will provide undersize starting threads.

(7) There is considerable material saving because the rolling blank is smaller than the finished thread and no material is removed. Material savings range from 13 to 27 percent depending on thread size.

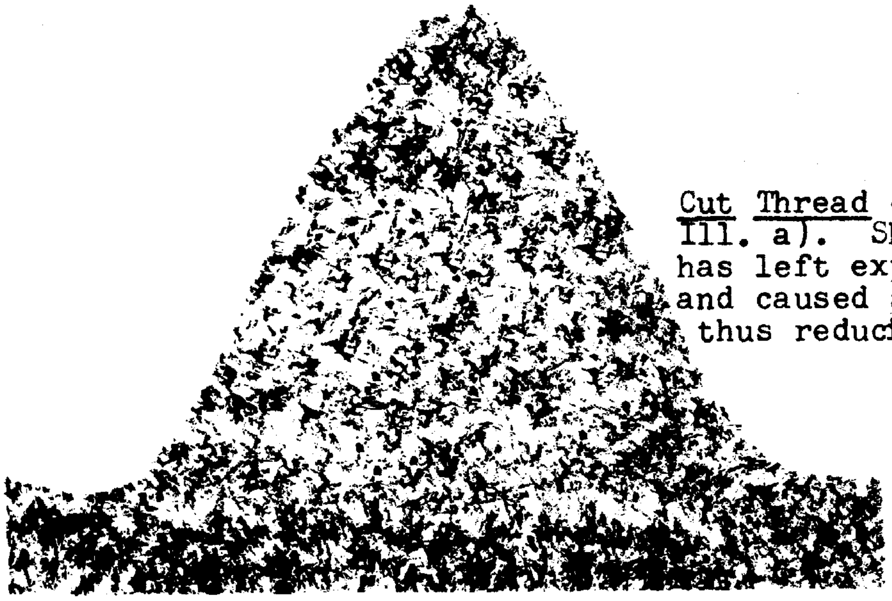
(8) Rolling is fast and therefore economical.

PHOTOMICROGRAPH OF ROLLED THREAD & CUT THREAD



Rolled Thread - Shows how flow lines follow the thread contour thus making the thread stronger.

Illustration (a)



Cut Thread - (Same steel as Ill. a). Shows how cutting has left exposed shear planes and caused surface irregularities thus reducing thread strength.

Illustration (b)

Thread in Illustration (a) in straight tension load is about 15% stronger than thread in Illustration (b). Under fatigue loads, the disparity is even greater.

(Figure 5)

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CHAPTER II

MATERIALS, PROPERTIES & HEAT-TREATMENT

The engineer and toolmaker has at his disposal many types of metals of widely differing properties. One must consider the several physical properties of metals and then the ways and means of obtaining the most desirable properties. For a given metal, there are several conditions under which it may exist and each of these conditions has a definite bearing upon its usefulness for a particular application. Once this has been established, the various uses and properties of several metals can be applied to fabrications of machines and structures by casting, forging, welding and machining.

PHYSICAL PROPERTIES

In order to understand some of the terms used defining physical properties of metals, it will be necessary to define some of the common terms which are applied in describing metals.

A load applied to a part causes a stress to be set up in that part which resists the action of the load. There are three kinds of elementary stress:

1. Tension, which may be illustrated as the stress in a rope which is holding up a load;
2. Compression, which may be illustrated as the stress in a column or pedestal which is holding

up a load;

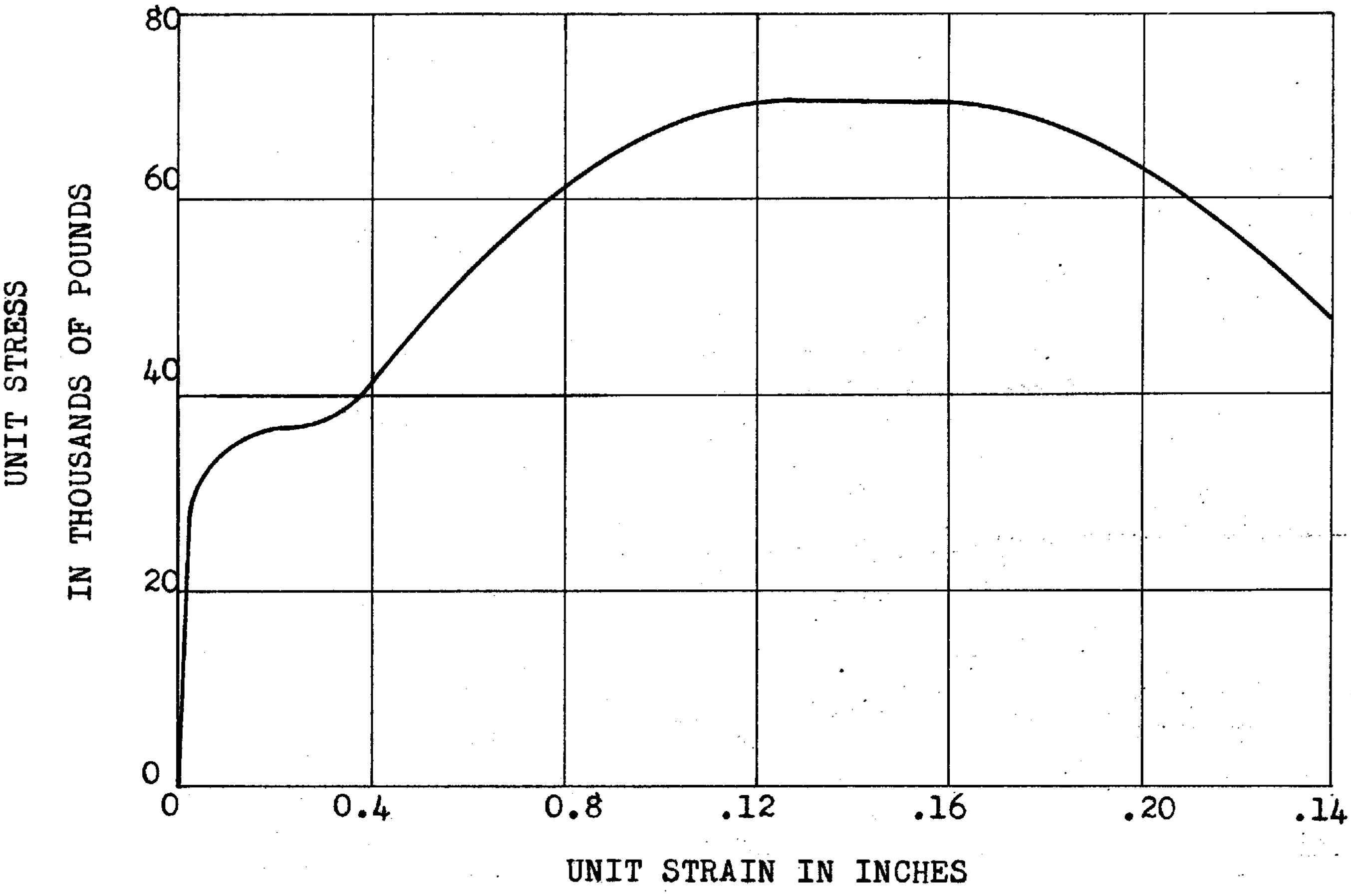
3. Shear, which may be illustrated as the stress in a rivet which holds two plates in tension.

Strain is the deformation of a material when stressed.

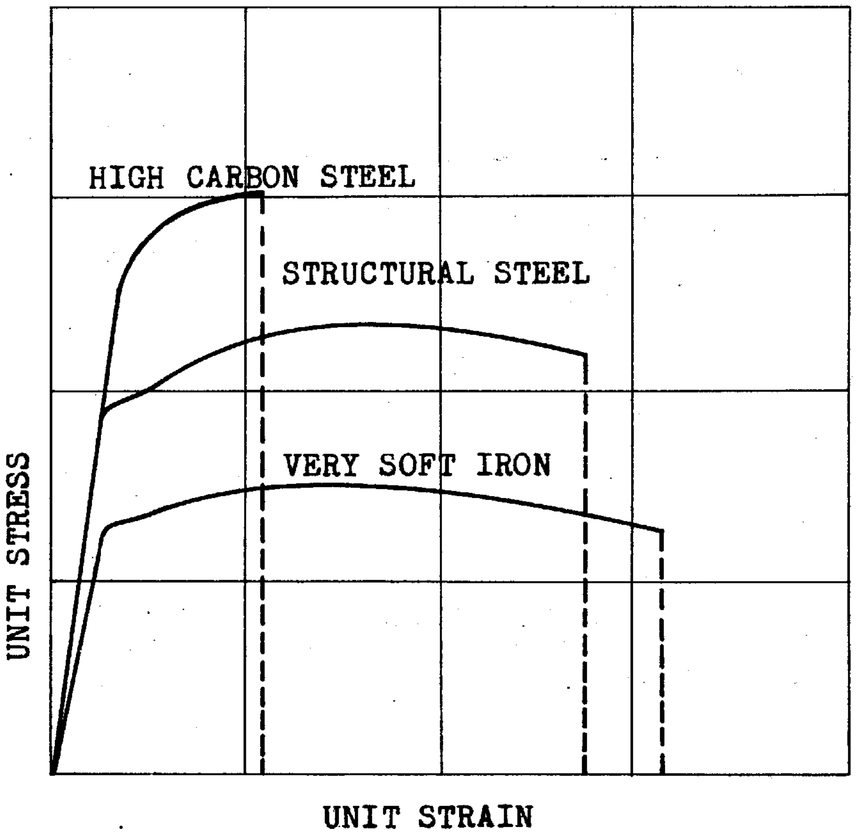
Metals are well known to be elastic in varying degrees; that is, when a load is applied, the metal deforms, and then, when the load is removed, the metal returns to its original shape. Now if a curve is plotted, having unit stress on the vertical axis and unit strain or deformation on the horizontal axis, it is seen that when a metal such as mild steel is stressed, the strain is small and of uniform degree up to a stress of about 35,000 pounds per square inch. The additional strain is noted without a corresponding increase in stress. This first indication of an increase in the rate of strain without a corresponding increase in stress is called the yield point of the metal.

As the study of the accompanying stress-strain curve indicates, the limiting strength of the metal has not yet been reached at the yield point, but the load continues to increase until what is called the ultimate strength is reached. After reaching the ultimate strength, the metal gradually stretches, weakens and ruptures at a stress less than that at the ultimate. A metal which is stressed below its yield point is still elastic and will return to its original form.

Toughness is the ability of a metal to stand great



STRESS-STRAIN CURVE FOR MACH. STEEL



COMPARATIVE STRESS-STRAIN DIAGRAM

deformation at high stress without rupture. The opposite of this characteristic is brittleness, shown in a type of material which ruptures with little warning deformation. Structural steel and rubber are examples of materials which possess great toughness, and on the other hand, glass and cast iron are both very brittle materials. The amount of toughness possessed by a material is indicated quantitively by the total area under the stress-strain curve up to a point of rupture as indicated by the accompanying curves for high carbon steel, structural steel, and soft iron. It is evident that structural steel is the toughest of those depicted; i.e., it has the greatest deformation at the highest stress. The high carbon steel exhibits the highest tensile strength of the three, and soft iron is the most ductile.

Ductility, as was noticed in the soft iron, is the property which allows a metal to deform a great amount, regardless of the stress which is necessary to cause the deformation. The definition of toughness which requires that a material stand great deformation at high stress points to the essential difference between toughness and ductility, for ductility requires only large deformation of the metal.

Hardness is a term which may be exactly defined only in terms of the tests which are used to determine it. Hardness includes resistance to abrasion, to cutting, or to wear.

The Brinell Hardness Tester operates on the principle of forcing a 10 mm. hardened steel ball into the surface of the piece being tested by applying a load of 3000 kilograms (6614 lbs.). The diameter of the indentation is then measured with the aid of a microscope, having a transparent millimeter scale in the optical system. Brinell hardness numbers are calculated from the load applied, diameter of ball, and the diameter of the ball impression. The diameter of impressions used is the average of two measurements at right angles to each other. The reading error of the instrument should not be more than 0.02 mm. A table of Brinell hardness numbers corresponding to different diameters of impressions is used in computing results of tests instead of the basic formula. Since no grinding is necessary, the Brinell Hardness Tester is suitable for rough material such as castings and drop forging, and it yields accurate results on nearly all types of ferrous and non-ferrous metals. The Brinell machine, like all indentation machines, allows an accurate record to be kept of testing. The large indentation which the machine leaves, and the length of time necessary to make Brinell Tests are principal disadvantages of the Brinell Tester. In addition, the size of the specimen is limited, this method cannot test thin stock and is not particularly accurate for very hard metals.

The Rockwell Hardness Tester measures the depth of residual penetration by a steel ball 1/16" in diameter or a diamond cone under certain fixed conditions of load. A minor load of 10 Kg. is first applied, which seats the penetrator in the surface of the specimen and holds it in position. The dial is then turned to the point marked "set" and the major load applied. After the pointer comes to rest, the major load is removed, leaving the minor load still on. Rockwell hardness numbers are based on the difference between the depth of the penetrator at major and minor loads. This difference is automatically registered when the major load is released (the minor load still being applied) by a reversed scale on the indicator dial which thus reads directly Rockwell hardness numbers. Every report is used, or else its interpretation becomes a matter of guess work. The scales are indicated by letter and are necessary because of the several combinations of major load and penetrator. Accurate testing can be done more quickly with the Rockwell machine than with the Brinell tester, the direct hardness reading on the scale being the principal reason for the lessened testing time. The Rockwell machine is good for all types of metal, ferrous and non-ferrous, both soft and hard, and records can be kept of the testing. The Rockwell machine is also limited as to the size of specimen and it makes a small indentation which may be objectionable.

The principle employed by the scleroscope is the drop and rebound of a diamond tipped hammer. This hammer drops by the force of its own weight from a fixed height to the surface of the test specimen. The readings of the resulting rebound in the Model D instrument are recorded on a dial after the strike and rebound of the hammer. The dial remains fixed until it is released for another test. The reading is made from the height of the first rebound noted on the scale at the top of the hammer. The scale consists of units which are determined by dividing the average rebound from quenched high carbon steel into 100 equal parts. The scleroscope should always be set level when making a test. The scleroscope test is a rapid, fairly accurate means of testing metal and is very good for smooth surfaces and if the specimen is not finished originally, a great deal of preparation is required. The scleroscope is limited by the size of stock and is not useful for non-ferrous metals.

The file test is used to determine whether a steel is as hard as a file. There are no degrees of file hardness, --either it is or is not as hard as the file being used. To make a file test, the handle of the file is grasped in the hand with the index finger extended along the file, and the surface to be tested is rubbed slowly but firmly with the sharp teeth. Just as soon as it is apparent whether or not the file will bite into the piece being tested, it is removed. The simplicity and the rapidity of this method of hardness testing are strongly in its favor for the control of hard surfaces in production. In the period of a few seconds, the tester can determine the hardness of each tooth in a gear, various surfaces of a ball or bearing, or other hardened parts such as tool without injury to the surface. Comparisons of file hardness are dependent on the size, shape, and hardness of the files; the speed, pressure, and angle of the file while moving across the hardened part; and the composition and heat treatment of the steel being tested. The file test is a rapid, inexpensive test which requires no preparation of the specimen and is suitable for testing knife edge cutting tools without being limited as to the size of stock. The file test is inaccurate, no record can be made of the test, and testing requires a great measure of skill and experience.

REVIEW QUESTIONS

T F Unit stress may be correctly expressed as follows: 6000 pounds.

T F Total stress is expressed in units which involve weight and area.

T F Steel is more elastic than lead.

T F Lead is more elastic than steel because it will stretch out further under a load.

T F The elastic curve is plotted with unit stress on one axis and unit strain on the other.

T F There is a straight line relationship between unit stress and unit strain below the yield point.

T F The yield point is that point on an elastic curve where an increase in stress is noted without a corresponding increase in strain.

T F All metals exhibit a marked yield point.

T F The yield point is the maximum amount of stress which a ductile metal will stand without rupture.

T F The ultimate strength is the greatest unit stress which a metal will withstand.

T F A metal which is stressed above the yield point will have a permanent deformation.

T F Stressing a metal above the yield point will cause a raising of yield point for the metal.

T F Toughness is the ability of a metal to stand great deformation at high stress.

T F Copper is a good example of a very tough metal.

T F Toughness of metals increases only as the hardness of the metal increases.

T F The higher the carbon content, the tougher the metal.

T F Toughness is indicated by the area under the stress-strain curve.

T F Toughness and ductility are identical in meaning.

T F Hardness may be defined as resistance to abrasion.

T F Resistance to indentation is a frequently used measure of hardness.

T F The Brinell Tester measures the width of indentation of a ball under a standard load.

T F Brinell hardness may be determined in one operation.

T F The Rockwell Tester measures the depth of indentation of a ball under a standard load.

T F The Rockwell machine is a direct reading machine.

T F The scale used is an important part of a Rockwell hardness reading.

T F The principle of the scleroscope is resistance to abrasion.

T F The file test is of little practical value.

T F A piece tested with a file is too badly marked to be of use.

STEEL

In order to understand how the properties of steel are controlled, it is necessary to have a conception of what steel is. Steel is defined as an alloy of iron and carbon in which the amount of carbon is less than two per cent. When the amount of carbon exceeds this value, it is cast iron. Wrought Iron, although containing up to .30% carbon, differs from steel mainly in the process of manufacture. Wrought iron contains slag, whereas steel is entirely free from it.

In practice, a steel consisting of iron and carbon alone never occurs. Other elements are present in various quantities. These quantities in ordinary carbon steels are too small to have an appreciable effect on the properties of the steel. The elements that occur in steel may be divided into two groups, one of which is detrimental, the other beneficial. The detrimental elements are sulfur, oxygen, arsenic, phosphorus, and nitrogen. These elements decrease the strength, ductility, and toughness under various conditions. The group of elements that are beneficial to steel may be further divided into those that are added to steel for purification and those that are added to make alloy steel. The elements added for purification are silicone, manganese, and occasionally aluminum. Titanium and vanadium may also be used, but they are too expensive for ordinary use. The effect of these elements is to cause oxidation of the impurities which are then removed with the slag.

CARBON STEELS AND THEIR PROPERTIES

Iron and carbon alloys, when cooling, undergo definite changes, depending upon the percentage of carbon and the rate of cooling.

From the time steel begins to solidify until it reaches its final condition it passes through several crystalline stages which have varying characteristics. Pure iron is made up of crystals called ferrite. When carbon is added, it combines with the iron to form the chemical compound of iron carbide, known as cementite. The amount of carbon in cementite is 6.677% by weight. Where the carbon content of the steel is .9%, called the eutectoid mixture, ferrite and cementite form crystals at the same time which mutually tend to interfere with each other's growth. As a result, a peculiar mixture is formed consisting of alternate layers of ferrite and cementite; this is called pearlite. For carbon values below the eutectoid, a mixture of ferrite and pearlite will result; above 0.90% carbon, the mixture will consist of pearlite and cementite. Steels then, may have a structure consisting of ferrite and pearlite, pearlite and cementite, or pearlite alone. The proportion in which these occur is fixed by the carbon content.

The crystalline structures have different properties. Ferrite is soft, very ductile, weak, strongly magnetic, and has a low yield point and low shearing strength, the maximum engineering tensile strength being about 40,000 lbs. per square inch. Cementite is harder than glass, brittle, of very high breaking strength in shear (about 300,000 lbs. per sq. in.) but of low tensile strength. Pearlite is a fine crystalline structure and has an engineering strength from 120,000 to 160,000 lbs. per square inch. The hardness is much greater than that of ferrite but less than cementite. In the same way the ductility is less than that of ferrite but greater than that of cementite.

Since the crystalline formations are in direct proportions to the carbon content, the properties of steel depend on the amount of carbon present.

CONTROL OF PROPERTIES OF STEEL

The properties of steel may be changed by cold working, but in general, this method is insufficient to give the properties required in special steels such as tool steels. The greatest control of properties can be obtained by heat treating. As an example, a .34 carbon steel in the normal condition has a maximum tensile strength of 85,000 pounds, after heat treatment, it was found to have a tensile strength of 200,000 pounds. The strength after heat treatment, however, will depend largely on the manner in which the steel is heat treated.

The principles of heat treating are based on three facts:

1. Steels have different internal structures at high and low temperatures;
2. An appreciable time is required for change in structure at any temperature;
3. The time required for a change in structure is very short at high temperatures and approaches infinity at low temperatures.

Certain changes take place in the structure and the properties of the metal as it cools. These changes are considered allotropic according to most authorities. Allotropy is the variation in physical properties, such as crystalline structure, without change of chemical composition. The temperatures at which these changes take place are called critical temperatures and are more or less definite for a given carbon content.

Allotropic changes in steels up to about .9% C, or the eutectoid mixture, affect only the pure iron and are considered as the allotropic forms of iron. Steels up to about .9% C, as indicated by the point O (Figure 6), undergo two distinct transformations, and eutectoid steel changes directly from the eutectoid austenite to pearlite.

In cooling from the molten state, steel first appears as a solid in the austenitic formation. Carbon and the carbide of iron are in solid solution with the iron. Austenite is the only formation which can hold the carbon or its compound in solid solution. This solid solution can be pictured as salt dissolved in ice. A frozen solution of salt and water, however, is impossible, as salt is thrown out of solution with water when low enough temperatures are reached. Steels which cross the temperature line K-O when cooling, liberate part of the iron in the Alpha allotropic formation. When the temperatures drop to the line L-N-O, steels become magnetic. At temperatures M-O, only the eutectoid mixture remains as austenite, which changes to pearlite on furthur cooling.

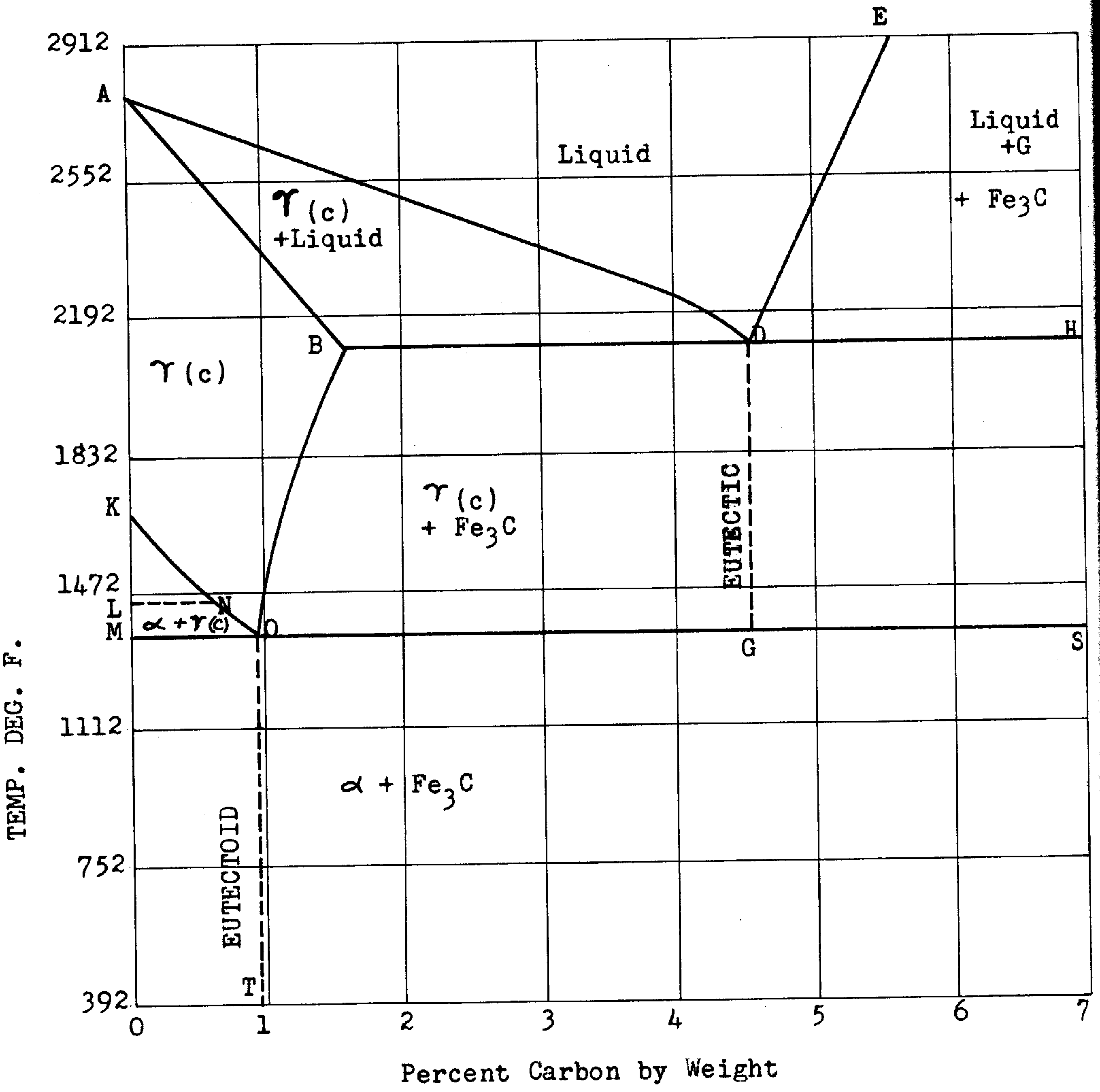
Steels with a higher carbon content than the eutectoid mixture liberate the carbide of iron (Fe_3C) when cooling, until only the eutectoid mixture is left in solid solution.

So far, changes occurring while cooling the steel have been discussed. When steel is heated, these changes take place in reverse order with a perceptible lag. Thus, the critical temperatures when heating the steel are somewhat higher than when cooling it. This may be explained by the assumption that a certain length of time is required for any change to go to completion. The time of the transformation at red heat is estimated at ten to thirty seconds.

SIMPLIFIED EQUILIBRIUM DIAGRAM OF IRON-CARBON ALLOYS

(C) - Austenite; (γ) -Ferrite; Fe_3C-Cementite; (G)-Graphite

Critical Temperature Line--L-N-O-S



(Figure 6)

If a high carbon steel is quenched at a sufficiently rapid rate, such as secured with liquid air or iced brine, the transformation is entirely prevented and the quenched steel consists of austenite. If, on the other hand, the quenching is done in the common bath of either water or oil, the structure obtained is principally martensite. With a somewhat slower rate of cooling, which may be obtained by quenching in certain oils or in a heated lead bath, other structures called troostite or sorbite may be obtained. These structures may also be obtained by reheating when tempering as mentioned later.

The different structures may be explained by describing their properties.

Austenite is soft, ductile, and tough. Martensite is the hardest stage and is responsible for the hardness of cutting tools. Troostite is intermediate between martensite and pearlite (see carbon steel) in its physical properties. It has a finer crystalline structure, however, than pearlite. When a piece of steel is quenched, large internal stresses are set up which reduce the strength of the steel. Thus the available strength of the quenched steel is the difference between the natural strength and the cooling stresses. The internal stresses may be removed by tempering but not without a certain amount of softening of the steel. For these reasons, the natural strength of hard steel is never fully available.

If the rate of the transformation could be appreciably reduced at the higher temperatures, it would not be necessary to quench steel at such a rapid rate and most of the internal stresses could be avoided. The heat treated steels would not only be extremely hard but would have their full natural strength available for use.

Although the heat treatment of steel is still in a state of development, it is known that all elements that go into solid solution in steel retard the rate of the reactions.

It is known that the higher carbon steels when heat treated are harder and better adapted for cutting tools than the low carbon steels. The effect of the carbon is to retard the rate of the transformation, and the more carbon there is in the steel, the slower is the rate of the transformation, and therefore, better results are obtained with high carbon steels. There is, however, a limit to the amount of carbon that steel may contain, as above 2%, carbon tends to crystallize in the form of graphite and produces structures different from those of steel. These structures are characteristic of cast iron. Carbon, fortunately, is not the only element that will go into solid solution in the iron, but it is the cheapest and most effective for a given amount used.

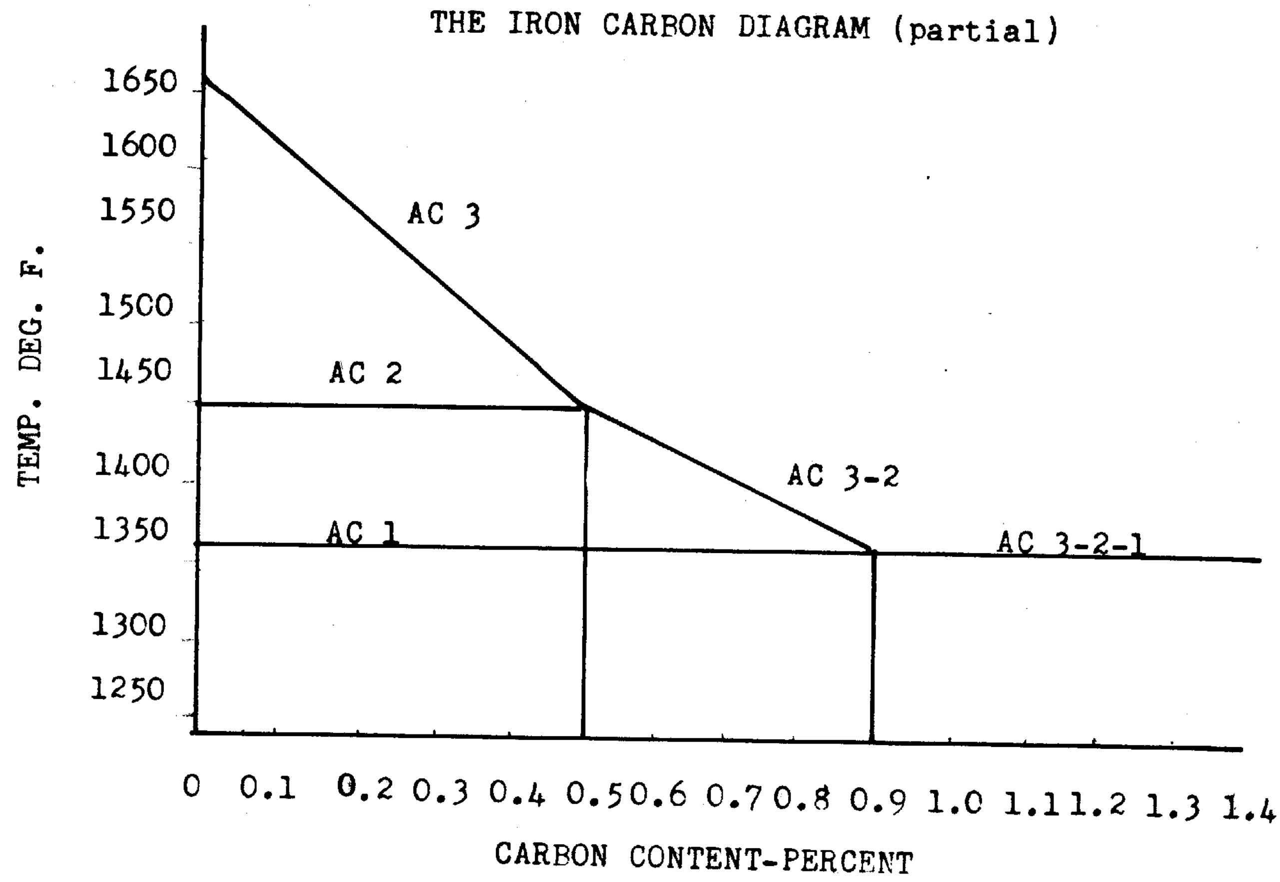
The accompanying partial Iron-Carbon Diagram represents that portion of Figure 7 as indicated by KLMON. This gives a clearer graphic picture of that section of the Iron-Carbon diagram up to the eutectoid point.

The Critical Points. The phase changes liberate heat when they take place on cooling, and absorb heat on heating. These evolutions and absorptions of heat are shown by halts or arrests in cooling curves and heating curves, which indicate the temperatures at which the changes take place, and these are usually called thermal critical points or critical temperatures.

The "Critical Range" as used in the definitions is the temperature range between the lines AC_1 and AC_3 as illustrated by the diagram given on the following page.

How the Diagram is Plotted. The temperature is plotted vertically and the carbon content horizontally. Any point on the diagram represents a definite alloy or carbon content. The carbon content is shown on the lower horizontal line, while the temperature is shown on the vertical line at the left of the diagram.

In order to know at just what temperature the end of the AC_3 critical range (which must always be exceeded for annealing, normalizing or quenching for hardening) comes for a given steel, we must either (a) make a thermal analysis on that particular steel, (b) have a complete and


THE IRON CARBON DIAGRAM (partial)

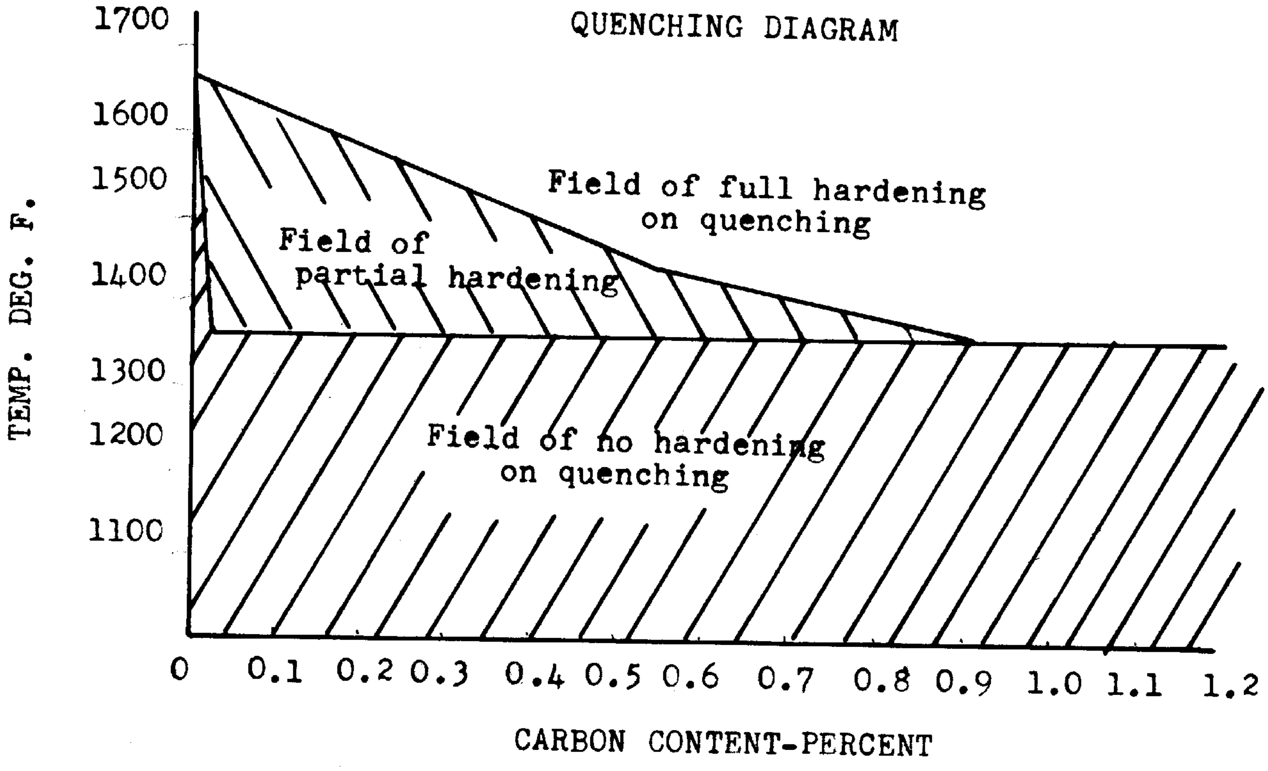

QUENCHING DIAGRAM

CHART SHOWING TEMPERATURE REQUIRED TO PRODUCE HARDENING ON QUENCHING OF STEELS OF DIFFERENT CARBON CONTENTS

(Figure 7)

accurate chemical analysis and compare the analysis with known AC_3 end temperatures for steels of varying composition, or (c) heat a number of specimens of the steel, take out specimens at different temperatures and quench them. The hardness will, except in extremely low carbon steels show a sudden jump as AC_1 is passed and increasing hardness as the temperature rises to the end of AC_3. The fracture will show the smallest grain size at about the best temperature for annealing, normalizing or quenching. As the temperature rises above the end of AC_3 the grain size increases. Examination under the microscope will show the grain size more certainly than will the fracture. After the critical temperature has been found it then remains to determine the proper time at the chosen temperature, which will be a little above the end of AC_3.

PROPERTIES AND USES OF HIGH CARBON STEELS

High carbon steel has a carbon content of .6% to 1.6%, and is used mostly for cutting tools and other articles requiring hardness. For this reason, it is often referred to as "tool steel". As will be later shown, it has the desired hardness not merely because its carbon content gives greater hardness and strength, but because by proper heat treatment it is possible to increase the hardness to a much greater degree. Unfortunately, increased hardness is always accompanied by increased brittleness. The tool steel is useless as a cutting tool until it has been

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hardened, and if in service it becomes heated to 600 F or more, it rapidly loses its hardness and must be hardened again to be useful. This property of "losing its temper" has led to the development of the newer cutting tool materials, and explains why high carbon steel is limited to uses where high temperatures are not involved. Common tools made of this steel are: cold chisels, punches, screw drivers, wood chisels, plane bits, and other wood working tools, and drills for light service. For drills and tools for cutting metal under high speed production methods, however, the ordinary tool steel is unsatisfactory, and in its place is used one of the newer materials.

HIGH SPEED STEEL

High speed steel is an alloy steel used chiefly for cutting and forming tools. It has displaced carbon steel for machine tool work, because, as its name indicates, it can be used for cutting at higher speeds. Most of the various compositions contain: carbon, tungsten, chromium and vanadium. A typical composition is as follows: carbon, 0.60 - 0.75%; tungsten, chief element, 13-19%; chromium, 3-4%; and vanadium, 1%.

This steel is air-hardening or self-hardening; that is, if overheated in service, even at a red heat, it will recover its hardness on cooling in air. It is not easily forged at ordinary forging temperatures, but is usually purchased from the manufacturer in bars of the desired size, which need only to be ground to shape, having been hardened at the mill. Annealed bars may be obtained; these may be machined to shape and then hardened. This steel will hold its hardness at a temperature of approximately 1200 F, about twice that of carbon steel.

COBALT-CHROMIUM-TUNGSTEN ALLOYS

Alloys of this group, of which Stellite is a representative example, are not steels at all, but are non-ferrous alloys chiefly of cobalt, chromium, and tungsten. Usually carbon is present, in amounts up to slightly over 2%. The tool grade of stellite can not be rolled or forged; tools made of it must be cast and ground to shape. It requires no heat treatment, but is used as cast. It is not affected by heat up to a temperature of 1800 F, and is tougher at red heat than when cold. The tool grade is used principally for cutting tools and for hard surfacing softer materials. For hard surfacing, it is applied from a welding rod by a welding process. It fuses at 2600-2800 F, and has a UTS as high as 92,000 psi., and an ultimate compressive strength as high as 280,000 psi. This high compressive strength in any material is an important factor in its effectiveness as a cutting tool material.

CEMENTED CARBIDES

Cemented tungsten carbides and tantalum carbides are used for cutting tools. Cemented tungsten carbide, which is sold under trade names such as: Carboloy, Diamondite, etc., consists of very small particles of tungsten carbide held together in a matrix of cobalt. The density of tungsten carbide is almost that of tungsten, which is 2½ times that of iron. It cuts glass, porcelain, hardened steel, chilled cast iron, concrete, bakelite, and hard rubber. Its hardness is exceeded only by that of silicon carbide and the diamond, both of which are used in grinding wheels for grinding the carbide tools. It was originally produced in Germany as early as 1926, as "Widia", and "Hartmetall", and has been commercially produced in the United States since 1929. Its use has revolutionized machine tool design because of the enormously increased speeds and cuts it has made possible.

It has a UTS as high as 300,000 psi. and an ultimate compressive strength as high as 540,000 psi. Its hardness is between that of the sapphire and the diamond; its red hardness is probably higher than that of any other known cutting tool material; the upper limit of its working temperature is uncertain.

HIGH CARBON TOOL STEELS AND THEIR USES

Carbon Per Cent	Uses
0.60 - 0.70	Dies for drop forging or bolt-heading: plate punches.
0.70 - 0.80	Cold chisels, pick axes, wrenches, vise-jaws, shear blades, band saws.
0.80 - 0.90	Rock drills, circular saws, machine chisels, punches and dies, shear blades, hot and cold sets, set hammers, swages, flatteners, smiths' tools.
0.90 - 1.00	Punches and dies, machinists' hammers, small cold chisels, hot sets, small shear blades, large pincers, large taps, granite drills, trimming dies, mill picks, circular cutters.
1.00 - 1.10	Cutting tools for lathes, planers, shapers, and slotters, mandrels, lathe centers, taps, small cold chisels, hot sets, small shear blades, large pincers, large taps, granite drills, trimming dies, mill picks, circular cutters.
1.10 - 1.20	Taps, thread and metal-cutting dies, milling cutters, twist drills, reamers, knives for woodworking machinery, carpenters' tools, wood cutting tools.
1.20 - 1.30	Files, taps, milling cutters.
1.30 - 1.50	Engravers' tools, knives for cutting paper, tools for turning chilled iron rolls, dies for wire drawing.
1.50 - 1.60	Saws for cutting steel, dies for wire drawing.

REVIEW QUESTIONS

T F Wrought iron and steel differ principally in carbon content.

T F A steel consisting of iron and carbon alone is not obtainable commercially.

T F Oxygen, arsenic, and nitrogen are particularly beneficial in steel.

T F Vanadium may be used in small amounts for purifying steel and in larger amounts as an alloying element.

T F Carbon has a greater effect on the physical properties of steel than any other element.

A steel is observed as being very soft, ductile, magnetic, and has a low yield point. What type of structure would it be expected to show: Ferrite, Pearlite, Cementite, Austenite, Troostite, Sorbite?

T F Steels have different structures at high and low temperatures.

T F Pure iron is composed of crystals of ferrite.

T F The eutectoid point is at 1.12% carbon.

T F A steel composed of ferrite and pearlite is weaker than a steel composed of all pearlite.

T F Cementite weakens a steel and causes it to have a lower yield point.

T F The ductility of pearlite is less than that of ferrite.

T F Tempering steel means hardening steel.

T F Changes in the structure of steel at high temperature are instantaneous.

T F A steel heated to 1800 F would be expected to have a ferritic structure.

T F Time for structural changes in steel at low temperature approaches infinity.

T F The temperatures at which changes in structure of steels occurs are called critical temperatures.

T F A different iron-carbon diagram is necessary for each steel of varying carbon content.

T F In cooling from the molten state, steel first occurs as a solid in the austenitic formation.

T F Martensite is very hard and brittle.

T F Troostite is weaker and more ductile than pearlite.

T F As steel is being heated it absorbs heat as it passes through its critical temperatures.

T F The behavior of practically any steel of any carbon content may be predicted by the use of one drawn-carbon diagram.

ALLOY STEEL

Even though the carbon content of steel is limited to 2%, greater and more accurate control of the properties of the steel can be obtained by adding other elements. Other elements are not as effective as carbon, but their quantity is not limited as carbon is. By adding a sufficient amount of some of the elements, it has been possible to slow down the rate of the transformation to a point where the steel consisted of the first structure austenite when cooled slowly in air. Steels which contain elements other than carbon and iron in quantities sufficient to affect the control of the properties are called alloy steels.

Alloying elements may be divided into four groups according to the way in which they function.

The elements of the first group form exactly the same kind of structures, in combination with carbon, that iron does. The main effect produced by the elements of this group is to depress the critical temperature and that way decrease the necessary reduction in temperature for stopping the reaction or transformation. The principal elements of this group are nickel and manganese.

The second group is represented by the element chromium. Its effect on the critical temperature is similar to that of the first group. However, the carbide of chromium does not act like that of iron, and the effect of this group in reducing the critical temperature is not as great as that of the first.

The elements of the third group form structures only partially similar to the iron and the iron carbide structures of the first two groups with the result that the critical temperatures are only slightly depressed. In this group belong such elements as tungsten, molybdenum, vanadium, and probably copper, titanium, and aluminum.

In the first three groups the alloying elements act with the carbon in much the same way that iron does. In other words, the alloying elements to a certain extent take the place of iron in the various crystalline structures.

There is a fourth group of elements, however, which take the place of carbon in the steel. The critical temperatures are affected very little. The structures of these steels are similar to those of the straight carbon steels. If the percent of the alloying element reaches a quantity where it forces the free crystallization of carbon into the form of graphits, the steel becomes too brittle for use. The elements of this group are silicon and boron. Silicon steel has the special property of having an unusually low magnetic resistance and is used in making laminated cores for transformers.

The heat treatment of alloy steels follows the same general principles as that of carbon steels. The greatest difference is in the time element. In the alloy steels the rate of the transformation has been slowed down to a point where accurate control of the properties can be obtained. In special steels, such as the high speed steels, the rate of the transformation is so slow that cooling in air gives a quenching rate fast enough to produce the desired hardness. Such a steel may be subjected to high temperatures for a considerable length of time without having its properties affected. Properly heat treated carbon steel, however, can be made harder than high speed steel and is better suited for some finishing operations.

HEAT TREATMENT

Heat treating of steel usually consists of heating, quenching, tempering (drawing), and normalizing.

HEATING

The heating of steel may be accomplished in several ways, the most common of which is in furnaces especially designed for the work. The furnaces are usually heated with gas, oil or electricity. Provisions are made for accurate measurement and control of the temperatures within the furnace. Baffles are sometimes constructed in the furnace to keep the steel out of direct contact with the flames. The furnace is usually kept at a constant temperature and the piece of steel allowed to come up to the temperature of the furnace. The temperature to which the steel is heated depends upon the chemical composition and the size, and should be from 50 to 150 F above the critical temperature so as to assure a uniform structure. The range of critical temperatures of carbon steels is shown on the equilibrium diagram Figure 6. Alloy steels usually have lower critical temperatures, depending upon their composition.

In heating steel up to the critical temperature, the crystals making up the structure do not change in size. At the critical temperature, where the carbon or carbide goes into a solid solution in the iron, a decrease in size of the crystals is affected due to the change in the structure. Above the upper critical temperature, the growth of the crystals proceeds at a fairly rapid rate. The higher the temperature the faster is the rate. The growth of the crystals will continue up to a point where oxidation or burning of the metal takes place. The coarser crystalline structures are weaker and more brittle and care must be taken not to heat the steel unnecessarily. Many failures in steel are due to improper heat treatment. Failures due to unnecessary heating show a very coarse crystalline structure at the break which is entirely different from the structure when the piece fails from fatigue.

Steel which has been heated too long or too high above the critical temperature, providing it has not been burned, can have its properties restored and the crystalline structure refined by special heat treatment. The treatment consists in heating the steel just above the critical temperature where maximum grain refining takes place, and then quenching or cooling it.

Besides heating the steel in furnaces, in preparation to quenching, small pieces are sometimes heated in molten lead or salt baths.

When the steel has been properly heated it is ready for the quenching bath.

QUENCHING

The rate of the reactions and the desired properties in the finished steel will determine the rate of quenching. Since the rate of the transformation is fastest in the low carbon steels and slowest in alloy steel, the low carbon steels will require the fastest quenching medium. Besides the quenching rate, other properties of the quenching medium such as odor, corrosiveness, stability and flash point must be given due consideration.

The factors that determine the quenching rate of a medium are the specific heat, viscosity and the temperature of vaporization. The medium with the higher specific heat will absorb a greater amount of heat and its cooling action will be more effective. Viscosity, being a measure of fluidity, will indicate the ability of the medium to carry away heat by natural or forced circulation. Thus, a quenching medium with a high viscosity will be more sluggish and a less effective carrier of heat. The formation of vapor around the object prevents proper contact between the quenching medium and the object, producing an insulating effect. The medium with the lower temperature of vaporization will give off vapor sooner and will be less effective as a cooling medium. Furthermore, it is apt to cause unequal cooling of various parts of the object, due to local insulation by the vapors.

The quenching mediums employed in general practice are air, water, brine, mineral oils, compounded oils, animal oils, fish oils, vegetable oils and special liquids.

With but a few exceptions, air is not used as a quenching medium. Formerly high speed tools were air quenched but more recent practice is to use oil. Very small objects are unavoidably air quenched due to their size. The desired physical properties in such cases are obtained by very careful tempering.

Water quenching is one of the most rapid methods of cooling. It has several disadvantages, however, in the way it affects the properties of the steel. The quenching rate, especially in small objects is usually so rapid that undue stresses are set up in the piece. These stresses may cause distortion or even exceed the natural strength of the steel, thereby rupturing it. Water, furthermore, has the disadvantage that it loses its cooling efficiency more rapidly than oil with increases in the temperature. If uniform results are required, precautions must be taken to keep the bath at a nearly constant temperature. The vaporization temperature of water under normal conditions is 212 F which is comparitively low and vapor formation will affect the rate as well as the uniformity of cooling.

Oils are coming more and more into use as quenching mediums. The oils available for quenching purposes are numerous, some being less desirable than others. Fish oils have the disadvantage of giving off offensive odors, especially when heated by the steel, and like the vegetable oils, they oxidize readily and become gummy. This increases their viscosity and reduces their quenching speed. Animal oils gradually become rancid, which is undesirable. The mineral oils are best suited for quenching purposes as they are comparatively stable and do not give off bad odors. Some metallurgists claim that better results can be obtained with mineral oils which have been compounded with some animal or vegetable oil, but there are no data available to support this claim.

Oils have a slower cooling rate than water or brine but for that reason the cooling stresses set up in the piece are much smaller and the available strength of the steel is greater. Alloy steels, furthermore, do not require such a rapid quenching rate as is obtained with water or brine. As a result, oils are used almost exclusively. Oils vaporize at a much higher temperature than water or brine and their cooling effect is only slightly reduced by a considerable increase in the temperature of the bath. For uniform results it is sufficient to keep the temperature of the bath within a range of 50 F. For this temperature range, the quenching rate varies only 2 to 3 per cent.

There are several ways in which the quenching bath may be cooled, all of which are useful depending upon the particular conditions. The most simple method is to rely on the natural dissipation of the heat from the tank to the air. This method may be used where the quantity of the quenching liquid is large in comparison to the amount of steel quenched.

Where quenching is done on a quantity production basis, some means must be employed for cooling the quenching bath. There are three general methods by which this can be done. One is to circulate the oil in a radiator or coil which may be air, water, or brine cooled. Another method is to circulate water or brine through a coil which is immersed in the bath. The third method is to use compressed air.

The extent to which any of the above methods is employed depends on the individual requirements of the work under consideration.

Best results in keeping down the temperature of the oil bath are undoubtedly obtained when the oil in the tank itself is circulated. By circulating the oil through external cooling coils or radiators, cooled oil is continually brought into the vicinity of the hot metal and the heated oil is carried away. It is possible by this method to maintain more constant temperatures in the bath.

The most efficient of the methods in which the oil is circulated is the one which employs brine cooling of the coils or radiator. The brine is cooled in a regular refrigerating plant and is circulated around the coils carrying the oil. The oil can be cooled very quickly and to almost any desired temperature by regulating the flow of the oil through the coils and the temperature of the brine. Where the size of the plant does not warrant such an expensive installation, the coils may be cooled by submerging them in a tank of running water, or by spraying them with water. The method of circulating the oil through air-cooled radiators is the least efficient of these methods, but is serviceable where the amount of work handled is small in comparison to the quantity of oil carried in the circulating system.

Systems which rely on convection for the circulation of the oil to carry the heat from the steel to water-cooled coils immersed in the tank are not so efficient as the systems in which the oil is mechanically circulated. This is due to the fact that very little of the heat is dissipated by conduction through the oil, and the natural circulation of the oil is comparatively slow.

In systems where the oil is not circulated, air is sometimes used for agitating purposes. However, care must be observed in its use. It must come in direct contact with the steel as soft spots would result. It should not be used in animal or vegetable oil baths, and is undesirable where compounded oils are used because of the rapid oxidation it causes. If properly used, it will assist considerably in cooling the bath.

The volume of the quenching medium to be used, and hence the size of the tank, depends upon the size and the number of pieces to be quenched per hour and the method of cooling the bath. Where means are provided for cooling the bath, good practice is to use 15 lbs. of oil for each pound of steel quenched per hour; a ratio of less than 10 to 1 should not be used. For uncooled baths, the ratio of oil to steel quenched per hour should be higher. A tank should be of sufficient size to handle with ease the largest pieces to be treated and leave a generous allowance for the circulation of the quenching medium. The tank, of course, must be designed to handle the full working capacity of the plant, and it is much more desirable to have the tank too large than too small.

TEMPERING

The rate of the transformation, especially in carbon steels, is so rapid at red heat that it is almost impossible to cool or quench the steel at the instant that the desired structures are present. Tempering is therefore sometimes used for agitating purposes. However, care must be observed in its use. It must come in direct contact with the steel as soft spots would result. It should not be used in animal or vegetable oil baths, and is undesirable where compounded oils are used because of the rapid oxidation it causes. If properly used, it will assist considerably in cooling the bath.

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TEMPERING

The rate of the transformation, especially in carbon steels, is so rapid at red heat that it is almost impossible to cool or quench the steel at the instant that the desired structures are present. Tempering is therefore resorted to.

Although the time of the complete transformation at red heat is from ten to thirty seconds, the rate drops off very rapidly with a decrease in temperature, thus at 1300 F approximately one minute would be required; at 750 F, two hours, and at 400 F it would take about a hundred days.

Tempering consists in raising the temperature of the steel, after it has been quenched to give a structure slightly harder than necessary, to a point where the transformation proceeds at a controllable rate. When the steel has reached the desired structure, it is again rapidly cooled.

As stated before, quenching leaves the steel hard but brittle and subjected to severe internal stresses. Tempering reduces these stresses, making the steel stronger and tougher but softer, and the only way to obtain a hard and strong steel is by using alloying elements which decrease the necessary quenching rate, thereby eliminating to a large extent the internal stresses.

Tempering Control

The amount of tempering may be closely estimated by the color of the oxide film which forms on a polished surface of the steel when heated in the open fire, or open furnace. The corresponding colors and temperatures of steel during tempering are given in the following chart:

Temperature		Color
Deg. C.	Deg. F.	
225	440	Light Straw
240	466	Dark Straw
255	493	Yellowish Brown
265	511	Reddish Brown
275	530	Purple
285	547	Violet
305	585	Blue
330	627	Gray

The above table may be used as a comparison, only when the steel is heated at a moderately rapid rate, as the time element has a decided effect. Thus the steel, when heated at a given temperature for a period of time, will also change color in the order indicated in the chart. Of course, the higher the tempering temperature the faster will be the rate of tempering. The fact that the tempering color includes both the time and temperature elements makes it a fairly reliable means for controlling the tempering effect. For best results, especially in quantity production, it is advisable to control the amount of tempering by standardizing the time and the temperature at which the tempering is done. For these reasons steel is usually tempered by heating it for a definite time in ovens or baths which are kept at a certain temperature. Constant temperature oil baths are most desirable in heating steel to temperatures below 525 F, as with these it is possible to obtain more uniform heating with less trouble than by other means. Above 525 F fused salts or lead must be used for the heating bath.

APPLICATION OF ALLOY STEELS

In order to select the proper type of steel for a particular application, something of the characteristics of the steel must be known. Since these characteristics vary, not only with the analysis of the steel, but also with the heat treatment to which it may be subjected, it is advisable to know something about the heat treatment required to bring out the characteristics required.

Heat Treatment

When steel is heated beyond a certain temperature, certain internal structural changes take place in the metal. The temperature at which these changes take place is known as the critical temperature. These changes do not take place instantaneously. There is a time element present, and by taking advantage of this time element, the process of heat treating is made possible in that the steel is heated above the critical temperature and cooled more rapidly than a reversal of internal changes can take place.

At normal or room temperature, steel can exist in four states:

(1) "as rolled" condition, either hot or cold rolled
(2) Annealed condition and/or normalized
(3) Fully hardened
(4) Drawn or tempered after hardening

The "as rolled" steel is most common in industry today. Cold rolled or cold drawn steel is hot rolled steel which has either been rolled or drawn through dies while cold. The bars are sized by this process and are given a smooth bright finish.

Annealing

Annealing is defined as "a uniform heating above the critical temperature followed by slow cooling". Annealing produces three results:

(1) Softens steel for better machining
(2) Relieves stresses due to rolling or forging
(3) Refines the grain

Normalizing

Normalizing consists in heating the steel to approximately 100 F above the critical temperature and cooling in still air at ordinary temperature. Normalizing relieves strains due to machining, rolling, etc., and prevents distortion in subsequent heat treatment.

Hardening

A hard surface can be produced in a steel in two ways:

(1) By heating a high carbon alloy above the critical temperature and quenching.
(2) Case hardening a low carbon alloy by carburizing and hardening.

All carbon steel can be hardened to a degree depending upon the carbon content. The maximum hardness is obtained at about .85% carbon. Alloying other materials with the iron and carbon does not change this fundamental law. With alloys, however, the critical temperature will vary with the kind of alloy.

REVIEW QUESTIONS

T F In heating steel up to the critical temperature, the crystals making up the structure do not change in size.

T F As the steel is heated above the lower critical temperature an increase in size of grain will be expected.

T F Above the upper critical temperature, the growth of crystals proceeds at a fairly rapid rate.

T F Burned metal can have its properties restored and crystalline structure refined by special heat treatment.

T F Alloy steels have critical temperatures which are determined only by their carbon content.

T F The rate of transformation of grain structure is fastest in alloy steel.

T F Low carbon steels require the fastest quenching medium.

T F Water is a faster quenching agent than oil.

T F Tempering reduces the hardness of steel.

T F Tempering reduces the ductility of steel.

T F Tempering makes steel tougher.

T F Tempering reduces internal stresses set up in quenching.

T F Tempering is resorted to because of the slow rate of transformation of structure above the critical temperature.

T F The temperature is the only essential item in satisfactory tempering.

T F Alloying elements which go into solid solution decrease the necessary quenching rate.

T F Alloy steels are usually subjected to higher internal stresses on quenching than are plain carbon steels.

DIFFERENCE BETWEEN TEMPERING AND QUENCHING OILS

The difference between quenching and tempering oils lies not only in their use but also in their properties.

Quenching oils, as previously explained, are used for removing heat from steel. They are kept cool so that they would be more effective in removing the heat from the steel. The temperatures of the quenching baths seldom exceed 150 F. This permits the use of comparatively light oils which circulate readily and carry away the heat more rapidly. These oils have a low flash point corresponding to their viscosity.

Tempering oils, on the other hand, are used for heating the steel for drawing. The temperatures of oil heating baths run as high as 525 F. The baths are held at constant temperatures and the oil must be of such consistency as to withstand these high temperatures over long periods of time. These oils must be heavy in body so that minimum vaporization takes place and must have a high flash point in order to reduce the fire hazards.

The fallacy of the improper use of these oils cannot be stressed too much, and before making any recommendation, the problem on hand should be carefully considered.

ANNEALING

Annealing is a heat treating process used for three purposes in general:

(1) To soften the steel, thereby making it more machinable;

(2) To relieve internal stresses;

(3) To refine the grain.

Annealing consists in heating the steel uniformly above the upper critical temperature, and then cooling it slowly as desired.

Not only shrinkage stresses caused by unequal cooling of complicated sections, but also fatigue stresses due to alternate loading and unloading, such as occur in moving parts of machinery, can be removed by annealing.

CASE HARDENING

Case hardening is used where it is desirable to have a tough and resilient piece of steel with a very hard surface to resist wear.

Carburizing consists in heating a piece of low carbon steel (.15 to .22% C) usually above the critical temperature in the presence of some carburizing material, such as charcoal. Carbon monoxide gas is given off by the carburizing material and acts as a carrier of carbon to the surface of the steel. The oxygen which is released when the carbon is absorbed forms more carbon monoxide gas with the carburizing material and in that way the process of carburization is carried on. It is necessary to heat the steel at a temperature corresponding to at least the lower critical temperature (M-O, Figure 6), as a part of the steel is then in the austenitic formation and capable of absorbing the carbon in a solid solution. A greater degree of carburization is possible with the higher temperatures, as the amount of steel in the austenitic state increases with the temperature, reaching a maximum at the upper critical temperature.

Care must be taken to exclude excess air, as oxidation instead of carburization of the steel would take place. In practice, the piece of steel is packed with the carburizing material inside of a cast steel or cast iron box, which is then sealed. The time of heating will depend upon the desired depth of penetration of the carbon into the surface of the steel and the temperature of heating. The higher temperatures up to a certian point give a higher rate of carburization. The rate of diffusion of the carbon into the interior of the steel must be considered, as it is possible to carburize at a rate slow enough to give the piece of steel a uniform structure thoughout. On the other hand, if the rate of carburization is too high, the surface of the steel may become oversaturated with carbon, leaving an uneven structure. The proper rate is best determined by experiment. All indications are that steel which has been carburized at a lower temperature and longer period of time shows the best properties.

After the steel is carburized, it must be heat treated in order to bring out the properties of case hardened steel. The heat treatment of carburized steel will vary according to the temperature and time of heating. The piece of carburized steel may be considered as being made up of two or more steels having different carbon contents. The low and the high carbon parts have different critical temperatures. When the steel has not been heated too high above the upper critical temperature of the original piece, the core part usually does not require a special treatment for the refining of the grain. The case, however, being of higher carbon content and heated for a considerable length of time has a coarse grain structure. Therefore, the carburized piece after it has cooled is reheated to the upper critical temperature of the case portion and is then quenched. The second heating does not affect the core and gives the case the proper treatment. When the steel has been heated above the upper critical temperature of the core (1800 F), the grain throughout the piece requires refining. The carburized piece is first heated just slightly above the upper critical temperature of the core, giving that part the maximum grain refining. It is then quenched or cooled slowly and reheated to the upper critical temperature of the case. After quenching again, the case is left very hard, but the core comparatively soft. Any internal stresses produced in the core by the first quenching are relieved by the second heating.

CYANIDING

Cyaniding is used where a skin hardness is desired. The steel is immersed in a bath of molten potassium cyanide (1560 F) which produces a quick but superficial case. Although the case is hard, it is very thin and will not stand the wear or abuse that a carburized type of case will.

NITRIDING

Nitriding is a more recently developed form of case hardening in which the heated steel is subjected to ammonia gas, from which it absorbs nitrogen. The nitrides thus formed give the steel a hard surface with need of furthur heat treatment. The steel used generally contains at least 1.00% aluminum, but even cast iron has been successfully nitrided.

HEAT TREATING DEFINITIONS (Especially as Related to Ferrous Metals)

Steel. An alloy of iron and carbon with a carbon content less than two percent, initially cast and malleable in some range of temperature.

Carbon Steel. Steel which owes its properties chiefly to various percentages of carbon without substantial amounts of other alloying elements. Also known as ordinary steel or straight carbon steel.

Alloy Steel. A steel made by incorporating with the iron some element in addition to carbon, in sufficient quantity to confer special properties on the steel.

Alloy Elements. Elements other than carbon added for the purpose of improving properties.

High Speed Steel. An alloy steel used for tools. It owes its properties chiefly to the alloying elements, which are tungsten and chromium in addition to carbon.

Cast Steel. Any object made by pouring molten steel into molds.

Heat Treatment. An operation or combination of operations involving the heating and cooling of a metal or alloy in the solid state for the purpose only of obtaining certain desirable conditions or properties.

Quenching. Rapid cooling by immersion in liquids such as brine water and oil solutions.

Hardening. The heating and quenching of certain iron base alloys from a temperature either within or above the critical range.

Tempering. The reheating, after hardening, to some temperature below the critical range, followed by any desired rate of cooling. NOTE: Annealing is a comprehensive term. The purpose of such a heat treatment may be:

- a. To remove stresses;
- b. To induce softness;
- c. To refine the crystalline structure;
- d. To alter the ductility, toughness, electrical, magnetic, or other physical properties;
- e. To produce a definite microstructure.

Normalizing. Heating iron base alloys to approximately 100 F above the critical temperature range followed by cooling to below that range in still air at ordinary temperature.

Spheroidizing. Prolonged heating of iron base alloys at a temperature in the neighborhood of, but generally slightly below, the critical range, usually followed by slow cooling.

Carburizing. The adding of carbon to iron base alloys by heating the metal below its melting point in contact with a carbonaceous material.

Case Hardening. The carburizing and subsequent hardening by suitable heat treatment, of all or part of the surface of an iron base alloy.

The Case of a carburized or case hardened iron base alloy article is that portion in which the carbon content has been substantially increased.

The Core. That part wherein the carbon content has not been substantially increased.

Cyaniding. The surface hardening of an iron base alloy article by heating at a suitable temperature in contact with a cyanide salt, followed by quenching.

Nitriding. Adding nitrogen to iron base alloys by heating the metal in contact with ammonia gas or other suitable nitrogenous material. NOTE: Nitriding is conducted at a temperature below the iron-carbon critical range and produces surface hardening of the metal without quenching.

Decarburization. The removal of carbon usually refers to the surface of solid steel.

Decalescence. The absorption of heat which occurs when steel is heated through the AC_1 point shown on the iron-carbon diagram.

Recalescence. The liberation of heat when steel is cooled through the AR_1 point.

Fracture. The irregular surface produced when a piece of metal is ruptured or broken.

Fracture Test. Breaking a piece of metal for the purpose of examining the fractured surface.

Grains. Groups of crystals in metals. Each grain consists of crystals oriented in one direction.

Grain Growth. An increase in the grain size of metals.

Overheating. Heating to such high temperatures that the grains have become coarse, thus impairing the properties of the metal.

Burning. The heating of a metal to temperatures sufficiently close to the melting point to cause permanent injury.

MACHINING HINTS

Metals vary greatly in cutting characteristics, and must be machined with suitable techniques. The following hints on machining the more common of them are intended as an aid in setting up jobs initially. On long runs or repetitive jobs, adjustments may be made by analysis of tool wear.

STEEL

Carbon and Alloy Steels

These have much the same cutting characteristics. Both cut with a continuous chip and form a built-up edge on the tool if run at low speeds. As speed increases, a "Critical" point is reached above which the built-up edge is swept away and cutting is more efficient, tool life greatly extended, and finish improved. This critical speed is affected by hardness of the steel, chip thickness, and to a lesser degree by the depth of cut. Good cutting practice is usually 50% to 100% above critical speed. Soft "gummy" steels, such as boiler plate or SAE 1010, require very high machining speeds to remain safely above the critical speed and thus cut efficiently, whereas steel hardened to 300 Brinell cuts efficiently at less than 1/2 the speed. Similarly, light cuts (chip thickness and depth) require more speed than heavy cuts.

Because of the strong, continuous chip, steel tends to crater or erode the top face of the tool. A flat chip will curl away from the top face of the tool with comparatively light force, whereas the same amount of steel in a channel shaped chip has greater structural rigidity and requires more force to deflect. When the tool has a large nose radius, a curved or channel cross section is produced in the chip thus requiring higher tool pressure and power.

When the tool has a small nose radius, a flat ribbonlike chip is produced, tool life is better, and less power is required.

Stainless Steels

From the standpoint of machining characteristics, these steels divide into two groups: the hardenable (magnetic), and the austenitic (non-magnetic). Hardenable stainless steels machine much the same as alloy steels of equal hardness, and the foregoing recommendations will apply. Austenitic stainless steels such as 18-8, type 300, etc., are work hardening, yet soft and gummy in their tendency to tear and to build up on the cutting edge. The build-up tendency calls for high speed, whereas the work-hardened chip and machined surface call for speeds in the lower ranges to prevent excessive tool wear. The best condition is therefore a compromise, with a feed rate heavy enough to get under the work-hardened surface of the previous cut, recognizing that tool life will be shorter than with equivalent jobs on other steels.

High Manganese Steels

For applications involving severe impact and wear, steels with 12 - 14% of manganese are frequently used because of their extreme work-hardening properties. Cutting speeds of 35 to 100 feet per minute and feeds not less than .020", and preferably 1/16", stock should be allowed so that the finishing tool can get under the work-hardened surface.

Gray Iron

This machines with a crumbling chip and has very little tendency to build up along the cutting edge. Machining techniques are therefore quite different than for steel. Because of freedom from a built-up edge, there is no lower limit or critical speed to be considered, and tool wear is almost directly proportional to speed of cutting. Speeds up to 400 ft. per min., depending upon feed rate and depth of cut, are common. For normal cutting, such as .025" feed and .200" depth of cut, speeds of 275 ft. per min. where cutting speed is more important than tool life, are common.

The low strength chip breaks into a crumbly powder, so a large nose radius has no disadvantages, and does permit better finish, faster feed, and longer tool life.

High Tensile Cast Iron

Addition of alloys such as nickel, or use of steel scrap in cast irons to obtain higher strength cast irons, has become almost universal. These additions have little effect on the machining characteristics except that the chip is mechanically stronger and has some tendency to crater the top surface of the tool.

Chilled Iron

Surfaces of cast-iron parts deliberately chilled to high hardnesses, such as rolling mill rolls, are very abrasive on the cutting tools. Tool life is extended to a practical range by use of lower cutting speeds and stretching the chip out over a long cutting edge to finish the job with a minimum of footage passing under the cutting edge. Use of large diameter rounds or extreme lead angles on longitudinal feeds, or broad tools on cross feeds, accomplish this purpose.

NON-FERROUS MATERIALS

Copper Alloys

The alloys of copper machine with a low strength chip and can be run 500 to 1000 ft. per min. with good tool life. The aluminum bronze alloys have some tendency to build up on the cutting edge, but a speed of 250 to 500 feet per minute, depending upon hardness, will prevent this build-up.

Aluminum and Magnesium Alloys

These light-weight alloys machine readily at speeds over 500 ft. per min. The low tensile chip exerts little pressure on the tool. Rakes and clearances may therefore be increased to as much as 15° for greater life and freer cutting.

Plastics

None of the common types present great machining problems but when they are combined with fillers or fibers such as clay, asbestos, cotton, paper, glass, etc., they may become quite abrasive. The more abrasive the filler, the lower the practical machining speed and shorter the tool life.

TYPES AND IDENTIFICATION OF METALS

There are three general tests which may be used to help tell ferrous metals (iron base) from non-ferrous metals (non-iron base). However, these three tests will not always give a final identity of ferrous or non-ferrous. They will, however, separate all metals into three groups making it possible to know what furthur tests should be made. These three tests are: weight test, spark test, and magnet test.

(1) Weight Test: All light weight metals are non-ferrous. Heavy metals will usually be ferrous metals, However, there are a few heavy non-ferrous metals such as nickel alloys, lead, etc. Steel, stainless steel, and cast iron are heavy ferrous metals.

(2) Spark Test: Touch a piece of metal to a grinding wheel and watch for sparks. Each type of ferrous metal will give off a distinctive spark stream. Non-ferrous metals will usually give off no sparks. The exceptions to this are: titanium, nickel and tungsten. They will give a very small spark stream which differs from the sparks made by steel.

CAUTION: DO NOT TOUCH LIGHT WEIGHT OR SOFT NON-FERROUS METALS TO AN ORDINARY GRINDING WHEEL. THEY MAY CLOG UP THE WHEEL AND CAUSE IT TO BREAK.

(3) Magnet Test: Most ferrous metals will be attracted by a magnet. Most non-ferrous metals will not be attracted by a magnet. The "300" type stainless steel used in the Air Force are ferrous metals which are non-magnetic. Nickel-chromium-iron alloy (Inconel)

is a non-ferrous alloy that is very similar to stainless steel. It is also heavy and non-magnetic. Nickel-copper alloy (Monel) is a nickel alloy that is heavy and slightly magnetic.

These three tests will separate the metals into three groups so that you will know what furthur tests should be made for final identification.

(1) Light Weight, Non-magnetic Metals: These metals are non-ferrous. The main alloys in this group will be aluminum and magnesium alloys.

(2) Heavy, Non-magnetic Metals: These metals may be either ferrous or non-ferrous. Stainless steel and Inconel will both fall in this group.

(3) Heavy, Magnetic Metals: Steel and cast iron are the main metals in this group.

RESISTANCE TO SHAPING

PLAIN CARBON ALLOYS

Material	TOOLABILITY			WORKABILITY			
				By Hammer		Pressure Rolls, etc.	
	Hand Tools	Machine Tools	Special Tools	Cold	Hot	Cold	Hot
				Excellent	Excellent	Excellent	Excellent
Wrought Iron	Good	V. Fair	--	Good	V. Good	Good	V. Good
Mild Steel	V. Good	V. Good	--	V. Fair	Good	Only Fair	Fair
Medium Carbon Steel	Good	Good	Good	Poor	Only Fair	Unsuitable	Unsuitable
High Carbon Steel	V. Fair	V. Fair	Good	Poor	Only Fair	Unsuitable	Unsuitable
Cast Steel (Skin removed)	V. Fair	V. Fair	Good	Fractures	Crumples	Unsuitable	Unsuitable
Cast Iron (Skin removed)	Good	Good	V. Good				

OTHER CARBON ALLOYS

Material	Hand Tools	Machine Tools	Special Tools	Cold	Hot	Cold	Hot
				Tough	Good	Tough	Good
Chromium Steel	V. Fair	Difficult	V. Fair	Good	Good	Good	Good
Nickel Steel	Good	Good	Good	Cracks	Fair	Cracks	Fair
High Speed Steel	Good	Good	Good	Fractures	Crumples	Unsuitable	Unsuitable
Nickel Cast Iron	Good	Good	Good				

NON FERROUS ALLOYS

ALLOY	TOOLABILITY AND WORKABILITY
The Alpha Brasses	File readily with new files. Unpleasant to machine. Chip comes away in long ribbons with sharp jagged edges leaving surface torn and rough. Will stand large amount of Cold Work (draws readily)

NON FERROUS ALLOYS (continued)

ALLOY	TOOLABILITY AND WORKABILITY
The Alpha Beta Brasses	File readily. Readily machinable particularly if Brass is "Leaded." Small 'grain' chips. Poor Cold Working qualities but Hot Works very well.
The Bronzes	In general all these have fair to good cutting properties.
The Cupro Nickels	Machinable and readily Hot Worked.
The Aluminums	All readily machinable. Some Die Castings tend to be very short.

WHICH METAL IS IT - A REFERENCE CHART

Material	Appearance (a) Surface	 (b) Fracture	Sound
Wrought Iron	Red or black and scaly	Fine fibrous fracture	Dull note
Black Mild Steel Bright	Grey, black and rough. Polished bright grey	Light grey. Medium crystalline structure	Dull clang
0.4% Carbon Steel	Grey-black	Light grey. Medium crystalline	Dull clang
1.0% Carbon Steel	Blue-black patches of smooth scale	Very light grey Fine crystalline	Medium to high ring
(As Cast) Grey Cast Iron (Machined)	Dull grey, rough, pitted, sandy Light grey, dirty Fairly smooth	Dark grey, coarsely crystalline. Dark blobs.	Very dull note
High Speed Steel	Fine blue-black sheen, or "Bright ground"	Fine sparkling crystals	Very high ring
Brasses	Bright yellow. May be due to oxides	Coarsely crystalline	Sonorous
Aluminum (pure)	Very light or silvery grey	White crystalline	Dull note
Copper	Reddish-brown to green due to oxides	Bright fine crystals	Sonorous

WHICH METAL IS IT - A REFERENCE CHART
(continued)

Material	Spark Type	Toolability	Heated Red Hot and Quenched	
		Held in Vice and filed	(a) File Test	(b) Work on Anvil Under Hammer
Wrought Iron	Medium forked sparklers, Yellowish-red	File drags. Slag threads damage tool.	No change	No change
Black Mild Steel Bright	Many white sparks with few forked sparklers	Cuts very readily	No change	No change
0.4% Carbon Steel	Many white sparks with few forked sparklers	Cuts quite readily	Hardening just noticeable	No appreciable difference
1.0% Carbon Steel	Many small repeating whitish-red sparklers	Marked resistance to cutting	Will not file Glass hard	Very brittle Splinters
(As Cast) Grey Cast Iron (Machined)	Short stream of small repeating sparklers. Red to yellow	Hard skin damages tool edges - remove this, files well	No appreciable difference	No appreciable difference
High Speed Steel	A few dull red sparklers	Resists strongly Work hardens badly	Will not file	Shatters
Brasses	No spark	Files well (use new file)	No appreciable change	Varying effects
Aluminum (pure)	No spark	Cuts very easily File clogs	No appreciable change	No change
Copper	No spark	Cuts easily File clogs	Cuts very easily	Increased ductility

WHICH METAL IS IT - A REFERENCE CHART
(continued)

Material	Spark Type	Toolability	Heated Red Hot and Quenched	
		Held in Vice and filed	(a) File Test	(b) Work on Anvil Under Hammer
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(As Cast) Grey Cast Iron (Machined)	Short stream of small repeating sparklers. Red to yellow	Hard skin damages tool edges - remove this, files well	No appreciable difference	No appreciable difference
High Speed Steel	A few dull red sparklers	Resists strongly Work hardens badly	Will not file	Shatters
Brasses	No spark	Files well (use new file)	No appreciable change	Varying effects
Aluminum (pure)	No spark	Cuts very easily File clogs	No appreciable change	No change
Copper	No spark	Cuts easily File clogs	Cuts very easily	Increased ductility

WHICH METAL IS IT - A REFERENCE CHART
(continued)

Material	Workability Tests			
	Hammered Cold		Hammered Hot	
	(a) On Anvil	(b) In Vice	(a) On Anvil	(b) In Vice
Wrought Iron	Flattens well before cracking	Bends repeatedly before cracking	Works easily Hand welds readily	Bends freely
Black Mild Steel Bright	Flattens reasonably before cracking	Bends well before fracture	Works and welds well	Bends well
0.4% Carbon Steel	More resistance to flattening	Bends. Slight spring	Works well between bright and dull red	Bends well
1.0% Carbon Steel	Resists strongly Finally fractures	Resists-bends a little-then snaps	Works reasonably but only between bright and cherry red	Bends quite well
(As Cast) Grey Cast Iron (Machined)	Shatters	Snaps short Brittle	Collapses (is "hot short")	Snaps easily Hot short
High Speed Steel	Great resistance Finally shatters	Snaps without bending	Can be worked	Bends - some resistance
Brasses	Considerable variations Ductile to brittle		Considerable variations Ductile to brittle to "Hot Short"	
Aluminum (pure)	Flattens readily	Bends well	Collapses (Hot Short)	Collapses
Copper	Flattens easily Work hardens	Bends very easily	Works easily	Bends easily

CHAPTER III

HAND TOOLS

A machinist must be skillful in the use of a number of hand tools that are used in bench work operations. He may be assembling a piece of equipment or fitting metal parts. Such work commonly includes small pieces which are finished by hand or must be fitted together after they have been machined.

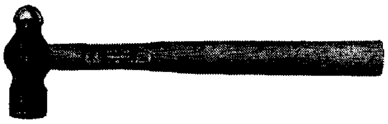
Bench and assembly work require skillful use of hand tools; therefore a machinist must develop manual skills through constant use and practice. The condition of hand tools relates the efficiency of a mechanic's work. All tools should be kept clean and in first class condition.

The most common hand tools used by machinists are hammers, files, hack saws, chisels, punches and wrenches. These tools are frequently used for metal fitting and assembly work, along with a number of basic layout tools, such as scribes, steel rules, dividers, prick and center punches, combination squares, and layout plates. The following descriptions identify some of the most used hand tools.

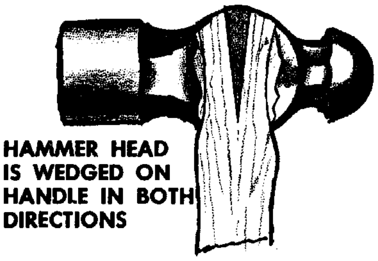
IMPACT TOOLS

Ball Peen Hammers

The typical hammer used by machinist is the ball peen hammer. The flat face of the hammer is used for general work and the ball end for peening or riveting. Peening or swaging may be defined as the stretching or spreading of metal by hammering. Ball peen hammers are classed according to the weight of the head ranging from 4, 6, 8, 12 oz. and 1, 1 1/2, and 2 lbs. (Figure 8)

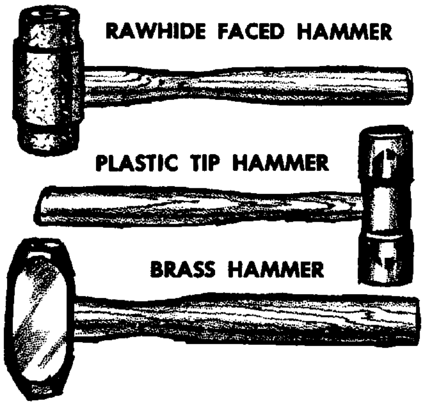


(Figure 8)



Soft Head Hammers

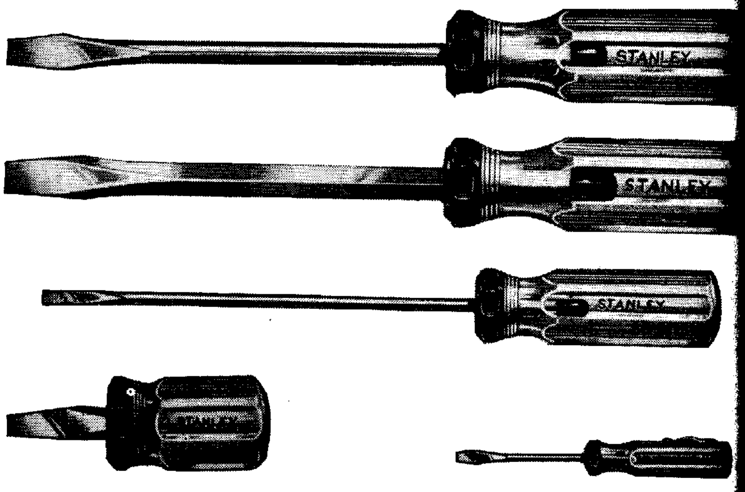
There are several types of hammers that are required for general machine work that will not mar or upset metal parts when hammering. These hammers are made of lead, plastic, rawhide or brass.



(Figure 9)

Screw Drivers

For loosening and tightening screws, and bolts, the screw driver is the most frequently used tool in the shop. It is also one of the hand tools quite frequently misused (Figure 10)



(Figure 10)

Slots and grooves on screws and bolts will vary in width; therefore the selection of the correct size screw driver is very important. The use of the screw driver for prying or as a chisel should be avoided.

Phillips type screw drivers have become very popular in recent years because of the many Phillips head screws used by automobile and truck manufacturers, especially on mouldings and other trim. The heads of these screws have two slots which cross at the center. Their advantage over screws with standard slots is that the screw driver can't slide sideways out of the slot and mar the finish. However, more downward pressure must be exerted on the Phillips screw driver to keep it in the cross slot than to keep a correctly ground standard screw driver in a standard screw slot.

An offset screw driver is frequently used where there isn't sufficient space to work a standard screw driver. The offset screw driver has one blade forged in line with the shank or handle and the other blade at right angles to the shank. With such an arrangement, when the swinging space for the screw driver is limited, the mechanic can change ends after each swing and thus work the screw in or out of the threaded hole.

If a screw driver blade becomes damaged through misuse or if a corner chips off because the blade is too hard, the screw driver can be made serviceable again by grinding it on an emery wheel.

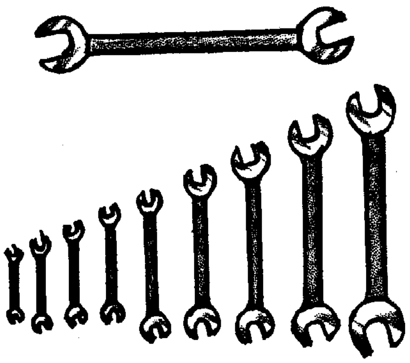
WRENCHES

Open-end Wrenches

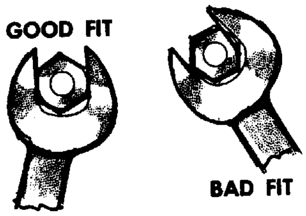
Solid, non-adjustable wrenches with openings in each end are called open-end wrenches. The average set in a good tool kit numbers about 10 wrenches with openings that range from 5/16 to 1 inch in width. This combination of sizes will fit most of the nuts, cap-screws and bolts (Figure 11)

The size of the openings between the jaws determines the size of the wrench. The smallest wrench in the ordinary set has a 5/16 inch opening in one end and a 3/8 inch opening in the other. Consequently, it would be called a 5/16 by 3/8 open-end wrench.

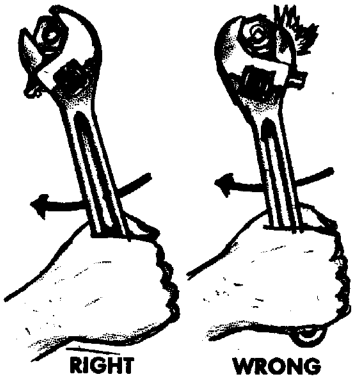
There are a few simple rules for the correct use of open-end wrenches: Be sure that the wrench fits the nut or bolt head. When you have to put a hard pull on a wrench, such as when loosening a tight nut or tightening a loose nut, make sure the wrench seats squarely on



Open-end



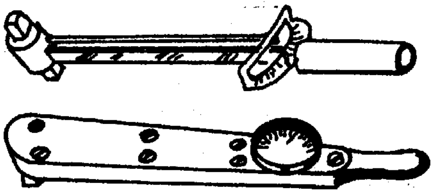
(Figure 11)



Adjustable
(Figure 12)

Box
(Figure 13)

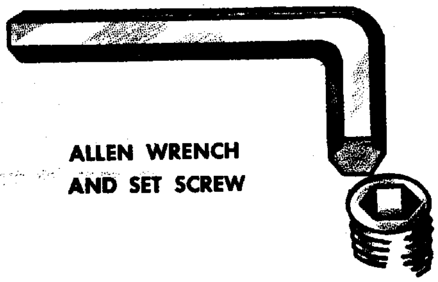
the sides of the nut. Always pull on a wrench - don't push: Pushing on a wrench is dangerous. When you push on a wrench to loosen a tight nut and the nut breaks loose unexpectedly, you will invariably strike your knuckles against some part you overlooked (Figure 11).



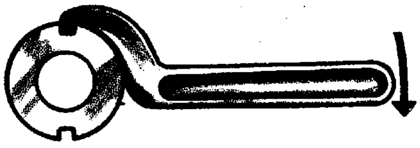
(Figure 14)

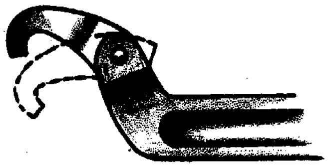
Adjustable Wrenches

Adjustable wrenches are shaped somewhat similar to open-end wrenches but have one jaw adjustable. The name is somewhat confusing because the ordinary monkey wrench is also adjustable. However, whenever the term "adjustable wrench" is mentioned, it refers only to a wrench which is somewhat like an open-end wrench but has an adjustable jaw. The angle of the opening to the handle on an adjustable wrench is 22-1/2 degrees. The usual set of adjustable wrenches consists of a 4, 6, 8, 10 and 12-inch wrench, but they also are made in 15 and 18-inch. A large 18-inch adjustable wrench is very useful for maintenance work on tanks. Some wrench manufacturers make double-end adjustable



(Figure 15)





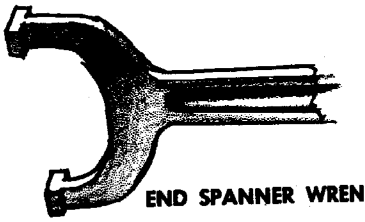
(Figure 16)

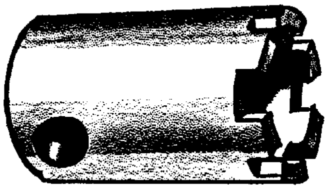
wrenches with an adjustable opening on each end.

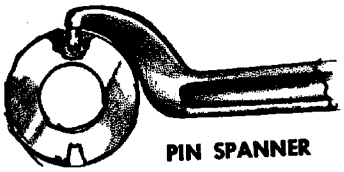
Adjustable wrenches aren't intended for hard service - treat them gently. Whenever you have to exert any amount of force on an adjustable wrench to "break loose" a tight nut or "snug down" a nut which is being tightened - there are two important points to remember. First, always place the wrench on the nut so that the pulling force is applied to the stationary jaw side of the handle. Adjustable wrenches can withstand the greatest force when used in this manner. Second, after placing the wrench on the nut, tighten the adjusting knurl so the wrench fits the nut snugly. If these two precautions are not observed, the life of an adjustable wrench will be short (Figure 12).

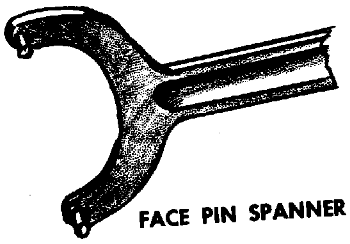
Box Wrenches

Box wrenches are very popular among mechanics. One reason for this is that they can be operated in very close quarters. They are called "box" wrenches because they box or completely surround the nut or bolt head. In place of a


END SPANNER WRENCH


END SPANNER WRENCH


PIN SPANNER


FACE PIN SPANNER

(Figure 17)

hexagon or six-sided opening, there are 12 notches arranged in a circle. A wrench with this type opening is called a 12-point wrench. A 12-point wrench can be used to continuously loosen or tighten a nut with a minimum swing of the handle of only 15 degrees compared to a 60-degree swing of the standard open-end wrench, or to a 30-degree swing with the open-end wrench if it is flopped after every swing. A 60-degree swing is one-sixth of a full circle. Another advantage of the box wrench is that there is no chance of the wrench slipping off the nut and it can't spread on the nut. Because the sides of the opening in a box wrench are so thin, it is ideally suited for nuts which are hard to get at with an open-end wrench.

Torque Wrenches

Another accessory for the socket wrench set is a handle which measures the amount of pull you put on the wrench. This is called a "torque wrench." Torque is the amount of turning or twisting force applied on the nut. On some makes of torque wrenches a pointer indicates on a scale the amount of force being applied. On others you set the dial for the amount of torque or twisting effort you wish to apply. Then, when you pull on the wrench, a light flashes the instant that amount of force is applied.

The accuracy of torque-measuring depends a lot on how accurately the threads are cut, the amount of lubrication applied to the threads and the type of lubrication. Readings shown by the wrench are much more accurate when the threads are lubricated (Figure 14).

Set-screw Wrenches

The most common type is hexagonal to fit the hexagon socket in the set screw. The trade name for this type is an Allen wrench. The other two types are made from round bar stock and each end is fluted to fit the flutes or little splines in that type set screw (Figure 15)

Spanner Wrenches

Spanner wrenches are special wrenches for special jobs. They are supplied as special wrenches in the tool equipment furnished to service certain units (Figures 16 & 17)

There are a number of types. The "hook spanner" is for a round nut which has a series of notches cut in the outer edge. The hook or lug is placed in one of the notches with the handle pointing toward the direction in which the nut is to be turned. Some hook spanner wrenches are adjustable and will fit nuts of various diameters.

U-shaped hook spanners have two lugs on the face of the wrench to fit notches cut in the face of the nut or screw plug.

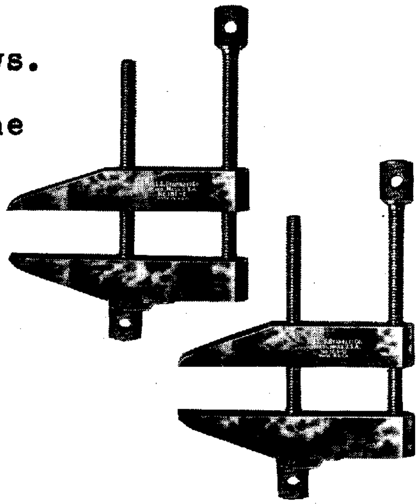
End spanners resemble a socket wrench but have a series of lugs on the end that fit into corresponding notches in the nut or plug.

Pin spanners have a pin in place of a lug and the pin fits into a round hole in the edge of the nut.

Face pin spanners are similar to the U-shaped hook spanners except that they have pins instead of lugs.

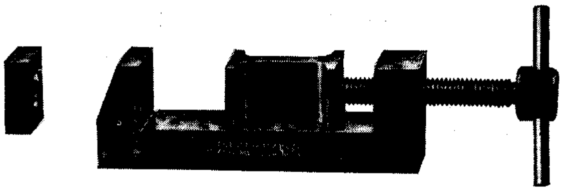
CLAMPS AND VICES

TOOLMAKERS' PARALLEL CLAMP



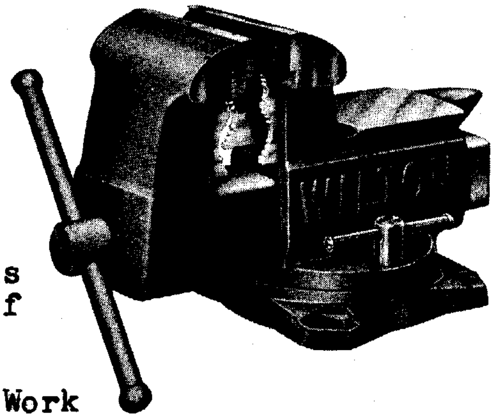
The parallel clamp has two knurled screws. The screws on the outside push the jaw apart. The resulting leverage clamps the work when the jaws are parallel. The jaws must be parallel so that the full surface of the jaws covers the work. If the jaws do not clamp the work evenly, the work will slip. Parallel clamps are extremely useful for holding work together in tapping and drilling small parts.

TOOLMAKERS' HAND VISE



The toolmakers' hand vise is a small hand vise with two interchangeable blocks. The choice of block to be used depends on the size of the work to be held by the vise. The vise is used for drilling and tapping small parts.

MACHINIST VISE



The bench vise is the most useful work holding device for clamping work for most bench work operations. On many vises, the immovable jaw is fixed to a swivel base that may be rotated on its axis to secure a better position for the work if it is at an angle to the normal position of the vise.

The vise jaws are hardened and serrated to grip the work rigidly. Work that must not be marred can be protected by using soft removable jaws made of copper.

CHISELS

Cold chisels are made from tough steel containing 70-point to 90-point carbon (meaning .7 per cent to .9 per cent carbon). Chisel steel is usually octagonal in shape, though it may be hexagonal or rectangular. The size of the chisel is determined by the width of the cutting edge, which should not be more than the size of the cross section of the steel used.

The ground surface of a chisel is called the "facet." Flat and cape chisels have two facets, while the diamond point, the round nose, and the gauges have only one facet. The flat and cape chisel to be used for chipping should be ground so that the facets form an angle of 70° for cast iron; about 60° for steel; about 50° for brass; and about 40° for babbit, copper, and other soft metals. Each facet should be uniform, making an equal angle to the axis of the chisel. When using the chisel, too deep a chip should be avoided. About 1/8" is deep enough. The last chip should be about 1/32".

Whenever it becomes necessary to file or work cast iron by hand, the original cast surface (scale) should be removed by chipping since this surface is very hard and would quickly dull a file.

As chipping is done below the scale, the chisel should not be injured. Chipping also saves time, for metal may be removed faster with the use of a hammer and a chisel than with the use of a file.

A flat cold chisel is used for chipping flat surfaces, cutting thin metals, cutting off rivet heads, and splitting nuts that have become rusted on bolts. A cape chisel is used to cut keyways or narrow grooves in metal. A round nose is used for cutting oil grooves in bearings or for making small fillets. A diamond point is used to draw drills back when they start working away from the line they are supposed to drill to; also, to cut square corners. No matter what kind of chisel you are using, keep it sharp.

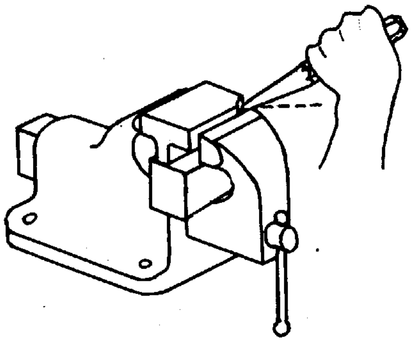
When chipping metal, the depth of the cut is controlled by the angle at which you hold the chisel. Don't try to take too deep a cut. For rough cuts, one-sixteenth of an inch is enough, with half that much or less for finishing cuts.

Keep your eyes on the cutting edge of the chisel. Swing the hammer in the same plane as the body of the chisel. Strike one or two light blows to check your "swing," then increase the force as required.

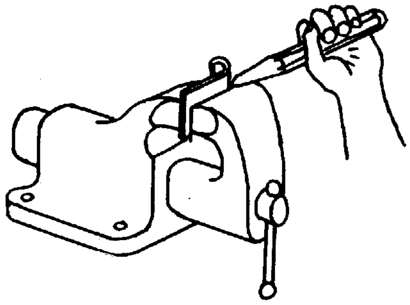
When using a chisel for chipping, always wear goggles to protect your eyes. If there are other men close by, see that they wear goggles or are protected from flying chips, or else put up a screen or shield to keep the chips from hitting anyone. These two precautions can save many a man from losing the sight of an eye.

METAL FITTING

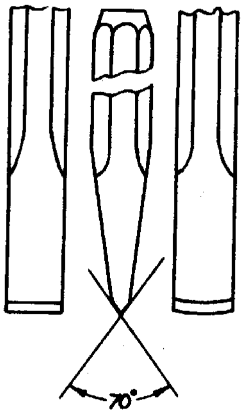
How To Use Cold Chisels



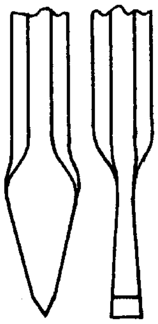
Chipping. Note how the chisel is held.



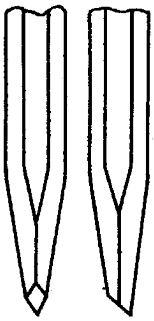
Shearing cut in a vise. Note another method of holding a chisel.



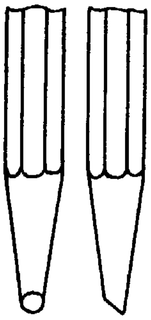
Flat Chisel



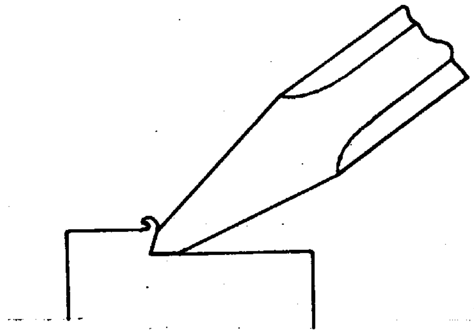
Cape Chisel



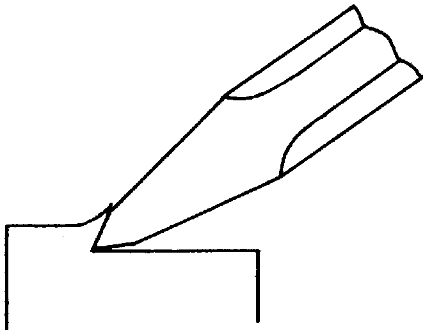
Diamond Point



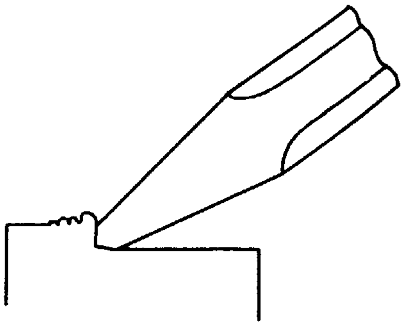
Round Point



Correctly Ground Chisel



Ground Too Sharp



Too Blunt

HAND SCRAPING

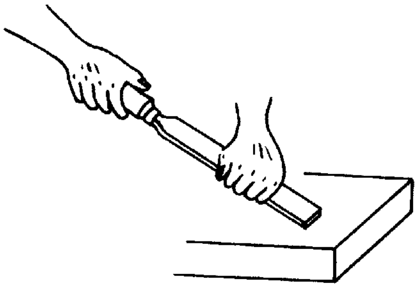
Parts of tools and machines which require contact with each other must have very accurate surfaces in order to work together with the right degree of accuracy. Producing these surfaces is an important problem in the manufacturing of modern machinery.

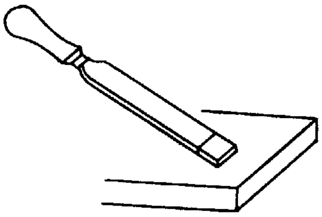
Until recently, craftsmen made true surfaces exclusively by hand methods, as there were no machines in existence that could make such surfaces. Hand fitting is still one of the most accurate of fitting methods and is still used to a great extent. The usual hand methods employed in accurate fitting work consists of hand scraping and lapping.

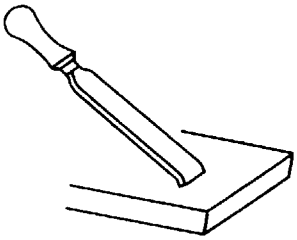
No surface is absolutely true, but by scraping, a surface may be obtained that for all practical purposes may be considered true. In the operation of scraping, we remove the high spots until we get a surface which is fairly true. By an additional scraping operation we can obtain a beautiful "flaky" surface. This operation is done only on flat surfaces which have been scraped. The process of making a surface "flaky" is known as "flaking." Flaking is a hand-scraping process in which the scraper cuts are very light; each cut is made in such a way that some attractive pattern is formed on the surface. By flaking, we get a surface beautiful in appearance. Skilled mechanics recognize that any scraped or flaked surface must be very carefully protected. Any blows or scratches may destroy completely an otherwise perfect surface.

How scrapers are made. Scrapers are made of high-carbon steel and are hardened. They are then ground to the right shape and honed on an oilstone, being made as sharp as possible. Excellent scrapers may be made from old files. The scraper end should be ground at 90° with the sides and edges. Since scrapers are very hard, care should be taken in honing them; otherwise grooves may be worn in the oilstone. This will make accurate honing impossible.

Types of scrapers. The two most commonly used scrapers for flat work are illustrated in Figures 17 a & b. The flat scraper as illustrated in Figure 17a is used for general scraping. It is usually the size of a 10" or 12" hand file. The cutting is done on the forward (push) stroke. The hook scraper, Figure 17b is used for flaking or frosting the work.







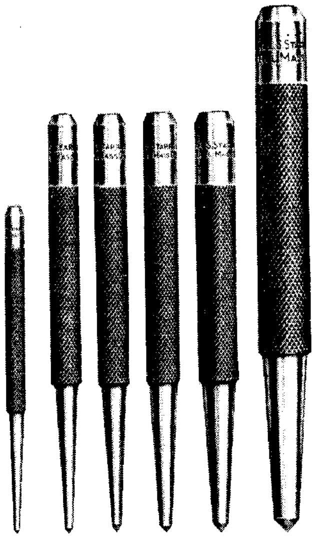
(Figure 17a)

(Figure 17b)

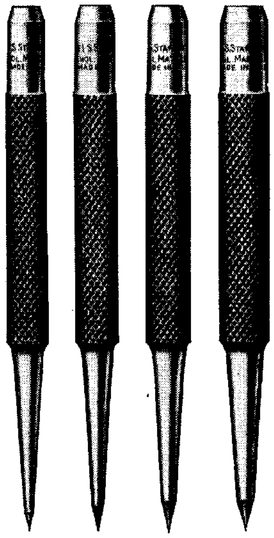
Hints on scraping. Do not get oil on the surface that is being scraped. In order to accomplish anything, scrape hard. If too much metal is to be removed by scraping, file a little until the surface is about true. Not more than two or three thousandths of an inch of metal should be removed by scraping. Dip the scraper in water or turpentine to make it cut better and more easily. When roughing, especially try to keep the cuts about square in shape and cross them in succeeding courses. This will help to make the marking easier to see. Place a very thin coat of Prussian blue on the master surface plate. Place the work being scraped face down on the master plate and move it over the surface using a figure 8 motion. This will spot the work and indicate where to scrape. The best way to apply the Prussian blue is with a rag. Be extremely careful that no grit or dirt gets on the master surface plate. Use the whole master plate - not one spot.

PUNCHES AND SCRIBES

In transferring information from a working drawing to a metal surface, marking scribes and dividers are used to mark layout lines. In order to retain the location of these lines small indentations are made by prick and center punches. The scribe is a piece of hardened steel 6" to 10" long pointed on one or both ends to a needle point. It is used as a pencil to scratch or scribe lines on metal. The prick punch is then used to punch small marks (Figure 19). The point of the prick punch is usually a sharp point of 30°.

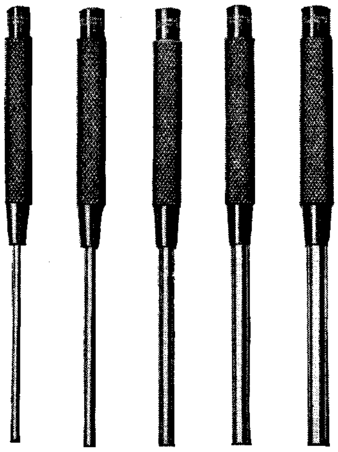


(Figure 18)



(Figure 19)

Another punch that is very valuable to the mechanic is the center punch. The center punch looks like the prick punch: the difference is in the point angle which is 60° to 90°. This punch is used to enlarge prick punch marks for centers of holes that are to be drilled (Figure 18). Starting or drift punches are used to knock out taper pins or rivets. These punches are available in a variety of sizes. They are blunt on the end and are made to stand heavy shock blows (Figure 20).



(Figure 20)

LAYOUT TOOLS

SURFACE GAGE

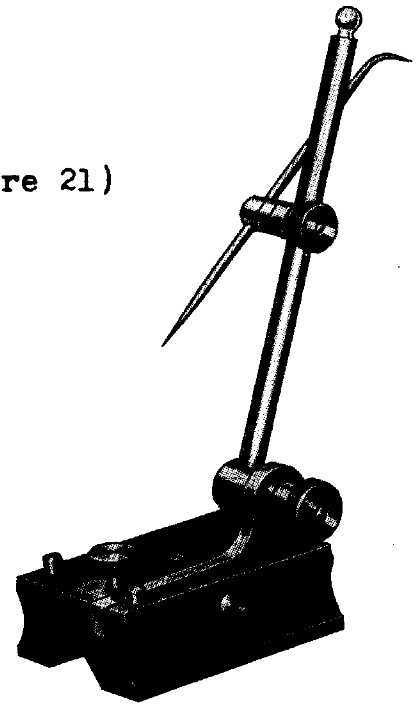
A surface gage is used for scribing lines on layout work and for checking parallel surfaces. The square or rule holder of the combination set is frequently used in conjuction with a layout plate to set the scribe of the surface gage to a desired height (Figure 21).

HERMAPHRODITE CALIPER

A hermaphrodite caliper is similar to a divider except one leg is bent like a caliper. Its principle use is to scribe arcs or as a marking gage in layout work (Figure 22).

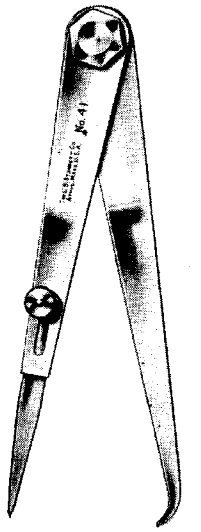
COMBINATION SET

One of the most useful layout tools is the combination set, which consists of a steel rule, a square, a center head and protractor. This tool is used as a rule for making measurements, marking miters, locating centers on ends of round stock or measuring angles and as a depth gage (Figure 23).



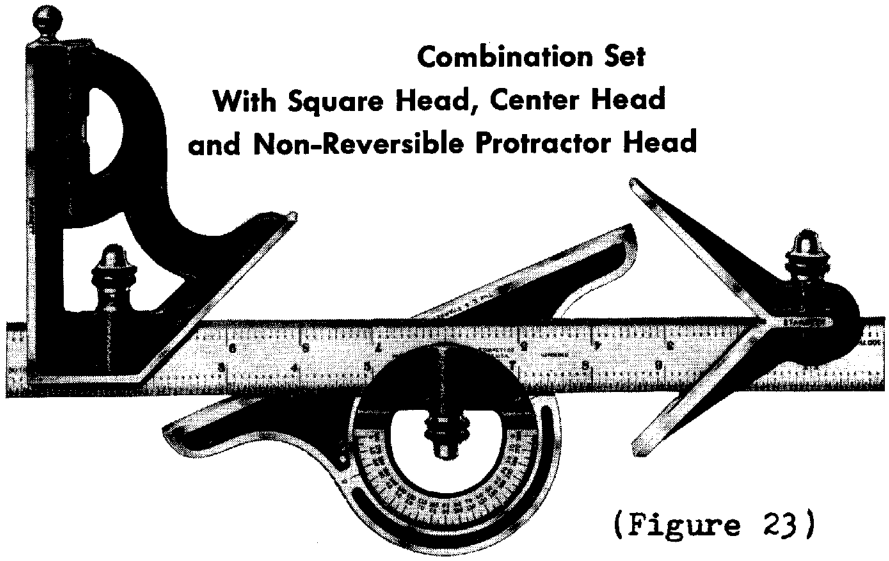
(Figure 21)

SURFACE GAGE



(Figure 22)

HERMAPHRODITE CALIPER



(Figure 23)

COMBINATION SET

FILES AND FILING

To know how to select and use files is one of the important qualifications of a good mechanic. High grade tool steel is used, and great care in heat treatment is important. If the file is too hard, the teeth will be brittle and break; if too soft, the tool is worthless.

Size, shape, cut. A file is usually designated by:

(1) its length in inches, not including the tang which fits into the handle;

(2) its shape or cross section, whether hand, mill, flat, round, square, half-round, three-square (triangular), or any other shape;

(3) its cut (coarseness or number of teeth per inch).

Single cut and double cut. A single-cut file has single rows of parallel teeth, or cuts, extending diagonally the length of the file; the double-cut has two series of parallel teeth, or cuts, crossing each other diagonally, and the second cut is usually finer than the first. The teeth of a double cut file are sharp points, and for this reason they cut faster.

How files are named. The coarseness of files is designated by the following terms: rough, coarse, bastard, second cut, smooth, and dead smooth. The dead-smooth file is double cut. The cut of a file (degree of coarseness or the number of teeth per inch) varies with the length of the file itself and the kind. A rough cut in a short file may be as fine as a second cut of a longer size. In other words, the shorter the file the finer the pitch, or more teeth per inch.

The mill file is flat, tapering in width, and slight in thickness for about one-third of its length. It is used in lathe work because chip clearance is provided by the curvature of the work. It is also used for draw filing and finishing, as well as for sharpening mill saws.

The flat file tapers in both width and thickness and is cut on both edges as well as on the sides. It is in common use by machinists and repair men. This file is usually made double cut.

The hand file is parallel in width and tapered in thickness. Teeth are cut on both sides and on one edge only. This feature permits filing into corners and other work where a "safe" or uncut edge is required. This file is usually made double cut.

A blunt file is the same size its entire length, and has a uniform cross section. Files are more adaptable for a variety of work if they taper to a small cross section at the point. It is necessary to give three details when asking for or ordering a file: (1) shape, (2) cut, (3) length; for example: (a) hand file, (b) bastard, (c) 10 inch.

Hints on filing. The position of the filer should be easy and natural. The file should be provided with a handle suitable to the size of the file and the nature of the job (Figure 24).

The height of the work to be filed when held in the vise should not be above the level of the worker's elbow as he stands erect. Never tap the file on the vise to clean it. Also, the file should never touch the vise jaws while filing.

The work should be held securely so that it does not chatter. The file must be guided by arms and hands, with regular, even, and controlled strokes. Long, slow strokes accomplish more and are less tiring than fast, short strokes. Crossing the cut or filing from different directions will assist in indicating where the file is cutting.

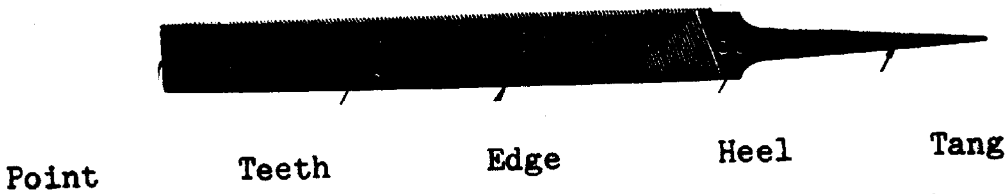
The file does its work on the forward stroke with a shearing cut. The downward pressure should be relieved on the backward or return stroke without lifting the file from the work. If faster cutting is desired, it is better to select a coarser file than to "ride" the one being used.

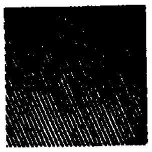
Oil should not be used when filing cast-iron surfaces; neither should chips be removed from cast iron by hand, as grease or moisture will cause the file to slip and dull quickly. When filing wrought iron or steel, oil or grease does no harm. Oil is sometimes used to protect the points of a new file, and also to produce a smooth finish.

Oil may be removed from a file by rubbing chalk across the teeth and then brushing it out. The chips, filings, or "pins" may be removed by tapping the edge of the file on a wooden block, using a file card or by pushing the chips from the gullets (the space between the teeth) with a piece of soft metal.

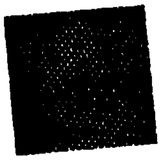
METAL FITTING

Files and Filing

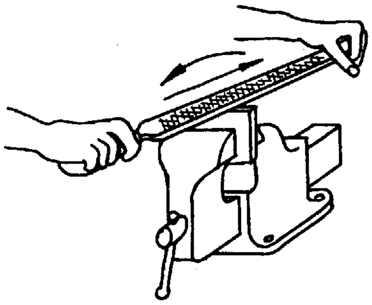




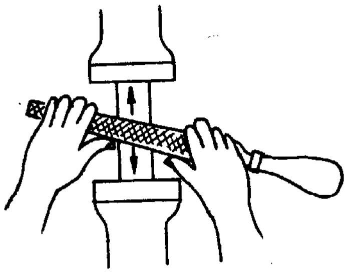
Single - Cut



Double - Cut



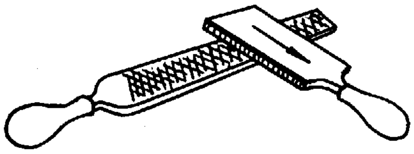
Proper Method of Using the File



Draw Filing

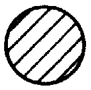
Flat

Half Round

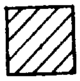


Cleaning
the file

Three Square



Round



Square

(Figure 24)

Finished surfaces should be protected in the vise by the use of copper or soft metal jaws. If the work to be filed is cast iron, the scale should be removed by machining or by chipping with a cold chisel before an attempt is made to file the surface. A few strokes on cast-iron scale or any hardened surface will ruin a file.

When it is desired to have a more finely finished surface (flat or round), the work should be "draw filed" as the grain or lay produced by draw filing will be in the direction of the stroke. Only the finer files should be used for drawing filing.

To file brass, solder, lead, and aluminum with an ordinary double-cut file is very unsatisfactory, because the teeth quickly become clogged with chips which are difficult to remove. A curved-cut file is very efficient for filing soft metals.

HACK SAWING

The hand hack saw is a metal-cutting saw. It is used for cutting metal that has not been hardened. The blades used for hand hack sawing are usually about 1/2" wide, .038" to .065" thick, and 8" to 24" long.

Hack-saw blades are made from tool steel, high-speed steel, or tungsten-alloy steel. The manner in which they are hardened and tempered gives the blades their toughness, flexibility, and strength. Some manufacturers harden the teeth only, leaving a flexible blade.

The set in a hack-saw blade is generally regular alternate; that is, one tooth is slightly bent or turned to the right and the next to the left. The teeth are turned just enough to insure free, smooth, rapid cutting in a slot a little wider than the blade itself, removing no more stock than is necessary. In certain fine-toothed saws, a pair of teeth is set alternately right and left, a style of setting known as"double alternate." A wave set is often used on fine-pitch saws. It is to be preferred for copper tube cutting. The number of teeth per inch and kind of material to be cut must be considered to get the best results. The following saw blades are recommended by manufacturers for the purposes noted:

Use a 14-tooth-per-inch hack-saw blade on machine steel, cold-rolled steel, and structural steel, because the coarse pitch (the number of teeth per inch) is free and fast cutting.

Use an 18-tooth-per-inch hack-saw blade on a solid stock, aluminum, babbitt, tool steel, high-speed steel, cast iron, and the like. An 18-tooth blade is recommended for general use.

Use a 24-tooth-per-inch blade on tubing, tin, brass, copper, channel iron, and sheet metal over 18 guage. If a coarser pitch is used, the thin stock will tend to strip the teeth out of the saw blade. Two or more teeth should be in contact with the work.

Use a 32-tooth-per-inch blade on small tubing, conduit, and sheet metal less than 18 guage. Two blades with teeth placed in opposite directions are sometimes used on very thin material.

Hand hack-saw frames are made in fixed or adjustable lengths to take from 6" to 12" blades. The length of the blades under 14" is measured from center to center of holes. The 10" blade is most common for hand hack saws.

<u>How to use a saw</u>. The blade should usually be put in the frame with the teeth pitching forward so that the saw will cut on the forward stroke. The blade should be tensioned in the frame so that when it is thumbed with the finger nail it will give a clear note, indicating that it is drawn tight. If the blade is left too loose in the frame, there is danger of kinking the blade, and a kink will ruin the blade. The work should be held firmly in the vise in such a manner that it cannot vibrate or move, and some attention should be given to the angle in which irregular work is held, in order that there will not be danger of the teeth becoming caught and consequently broken on sharp corners.

The frame should be held firmly with both hands. A right-handed person will grip the handle of the frame with the right hand and guide the saw with the left by taking hold of the forward end of the frame. Pressure should be applied on the saw only in the forward stroke. Pressure

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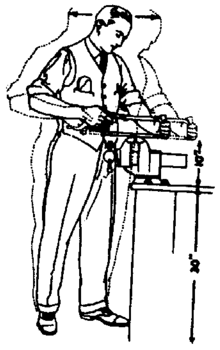
The frame should be held firmly with both hands. A right-handed person will grip the handle of the frame with the right hand and guide the saw with the left by taking hold of the forward end of the frame. Pressure should be applied on the saw only in the forward stroke. Pressure should be entirely relieved on the back stroke; otherwise, there is danger of dulling the blade. The saw should move at a steady even rate not to exceed forty strokes per minute. The strokes should be so made that the entire length of the blade will be used in each cutting stroke; otherwise, the teeth will be dulled at the center of the blade and the end teeth will not be used. The workman should stand so that the body sways with the stroke in order that the arms will not become tired.

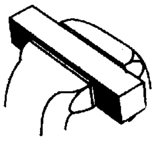
Safety Precautions. The chief danger in the use of hacksaws is in injuring the hand when a blade breaks. Breaking is caused by one of two things - either the operator is bearing down too hard on the blade or else is not pushing the saw straight, thereby twisting the blade which causes it to break. When this latter happens, the hand will sometimes come against the work and a disagreeable and sometimes serious bruise will result.

HAND HACK SAWING

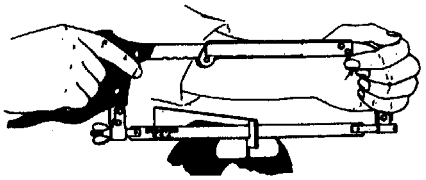
The proper position for the workman to stand in when hand hack-sawing.



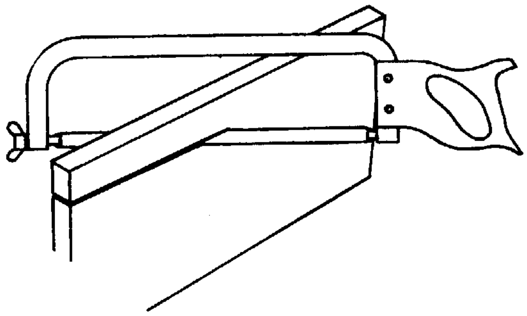
Work to be hand hack-sawed should be first notched with a file.



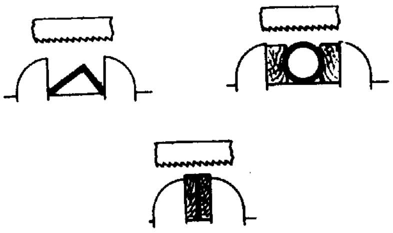
Illustrating the correct manner of holding a hand hack-saw. Note that the saw is guided by both hands.



Illustrating how a hand hack-saw blade may be turned in the frame in order to cut a narrow strip from a large sheet of metal.

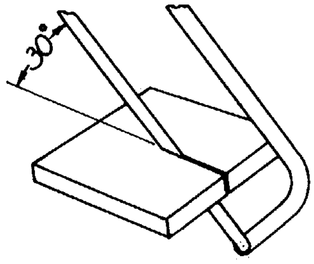


Illustrating how odd-shaped pieces of material should be held in the vise for sawing. Note that the saw goes through the material in such a manner that the blade is not likely to catch on sharp corners.

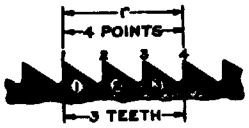


HAND HACK SAWING (cont.)

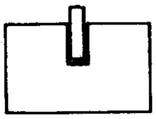
Thin, flat stock should be held horizontally and the saw should make an angle of about 30° with the work.



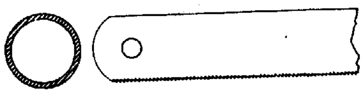
There is always ONE more POINT per INCH than there are TEETH per INCH. This should be kept in mind when specifying.



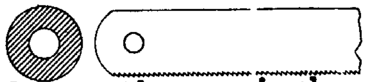
Illustrating how the set of a saw provides clearance for the blade.



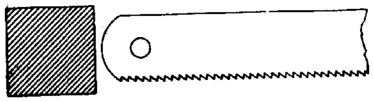
For safely cutting thin tubing such as aircraft tubing, copper refrigerating tubing, copper water pipe BX and electrical conduit use a pitch of 32 teeth per inch wave set.



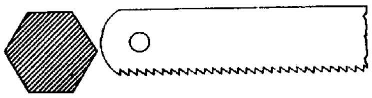
For pipe, angles, channels, heavy tubing and usual structural forms use a pitch of 24 teeth per inch.



For cast iron, machine steel, tool steel, and other solid materials use a pitch of 18 teeth per inch.



For fast cutting on large sections of bronze, aluminum, low-carbon steel, or other solid sections, use a pitch of 14 teeth per inch.



TAPS AND DIES

Taps and dies. Taps are used for cutting internal threads; for example, those in nuts. Threading dies are used for cutting external threads or those on round rods, bolts, and screws. Taps and dies may be had for all standard screw threads. Machine threads must be cut on the engine lathe. The lathe is capable of cutting either internal or external threads. The holder for holding a tap is called a "tap wrench," and the holder for a die is called a "die holder" or "die stock."

Work to be threaded is generally held in a vise or in a lathe chuck mounted on the spindle of the lathe. When held in a vise, the work is stationary, and the tap or die is turned by hand. When held in a lathe chuck, the tap or die is held stationary, and the chuck holding the part to be threaded is revolved slowly by hand.

Taps. The tap is designated by three things: (1) the outside diameter, (2) the number of threads per inch, and (3) the form of the thread. Example: "1/4 - 20 tap, N.C." would mean that the outside diameter of the tap is 1/4", the number of threads per inch are 20 and the form of the thread is of the National Coarse Thread. The parts of a tap consist of the groove or flute, the land, and the shank. The extreme end of the shank is squared to receive the tap wrench.

Threading die. Dies are unlike taps in that those most used are adjustable. Hand dies may be divided into three general classes: the solid die, the split die, and the two, three, or more piece die. A set containing taps, dies, tap wrenches, and die holders is called a "screw plate."

Left-hand taps and dies. Some of the more common sizes of taps and dies may be had in either right-hand or left-hand threads. Left-hand taps and dies, however, are special and are always higher priced than right-hand. Left-hand taps and dies are also marked with the letters L. or L.H. which means left-hand threads.

Hints on tapping and threading. In the actual operation of using taps and dies, the tools must be kept from binding. Metals, such as cast iron and brass, thread easily; thus the tap or die may be continuously turned in a clockwise direction until the operation is completed.

On such metals as machine steel, wrought iron, and alloy steel, taps and dies have a tendency to stick or catch in the work; therefore, it is often necessary to make from one-third to one-half a revolution in a clockwise direction, and then counter-clockwise, thus freeing the tap. This movement back and forth is continued until the job is completed.

If the job to be threaded has thin walls, care must be taken in gripping such a piece in the vise to prevent distortion.

Taps, especially those above 1/2" in diameter, are generally used in sets of three, and are called "taper tap," "plug tap," and "bottoming tap." When using taps it is best to use them in their proper order: first, the taper tap; second, the plug tap; and third, the bottoming tap. The use of a bottoming tap may be left out if the hole to be tapped is of such a nature that the tap may pass through the work. If a full thread is required to the bottom of a blind hole, the bottoming tap must be used.

When using an adjustable die, do not try to finish the thread in one cut of the tool unless the part being threaded is 1/2" in diameter or under. It can be done, but it is certainly poor practice and very hard on the die. Plan on taking at least two cuts and possibly three.

Lubricant or cutting compound should be used when cutting threads on steel such as nuts and bolts. Cast iron should be cut dry; in other words, do not use oil on cast iron when cutting threads.

CHAPTER IV

METAL CUTTING FUNDAMENTALS

METAL CUTTING CONCEPTS

The machining of metals requires an understanding of the theory involved in metal cutting. To design a cutting tool to remove metal with care when machining a given material requires an understanding of the variables involved in the process. There are four major factors that influence the cutting performance:

(1) The metallurgical composition of the cutting tool material and the work material.

(2) The tool geometry and life factors.

(3) The use and effect cutting fluids have on tool life performances.

(4) The physics and mechanics of the actual cutting performances; such factors as forces on tools, speeds and feeds, depth of cuts, chip formation, etc.

Other factors that must be considered are:

(1) The power that is required for the removal of a given amount of metal.

(2) The rate at which the cutting tool is worn away by the machining operation.

MACHINABILITY VARIABLES

Two variables that serve as a simple criterion for evaluating the machinability of a metal are the chip formation and the cutting fluid used. The chip formation will determine the degree of finish, the workpiece will reveal the efficiency of the machining operation, while the cutting fluid contributes to better tool performance and finish.

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CHIP TYPES AND THEIR FORMATION

In metal cutting, the unwanted metal is removed in the form of chips. Turning operations produce three basic chip types.

Type 1. The discontinuous or segmented chip produced when machining cast irons or other brittle metals. Conditions that favor this type of chip are large chip thickness, small rake angles, and low cutting speeds (Figure 25).

Type 2. The continuous chip without a built-up edge. Conditions favoring its formation are when machining ductile materials, small chip thickness, large rake angles and high cutting speeds (Figure 26).

Type 3. The continuous chip with a built-up edge. This type of chip is produced from very ductile materials having high work-hardening properties and machining under heavy cuts (Figure 27).

FACTORS GOVERNING LATHE CUTTING TOOL DESIGN

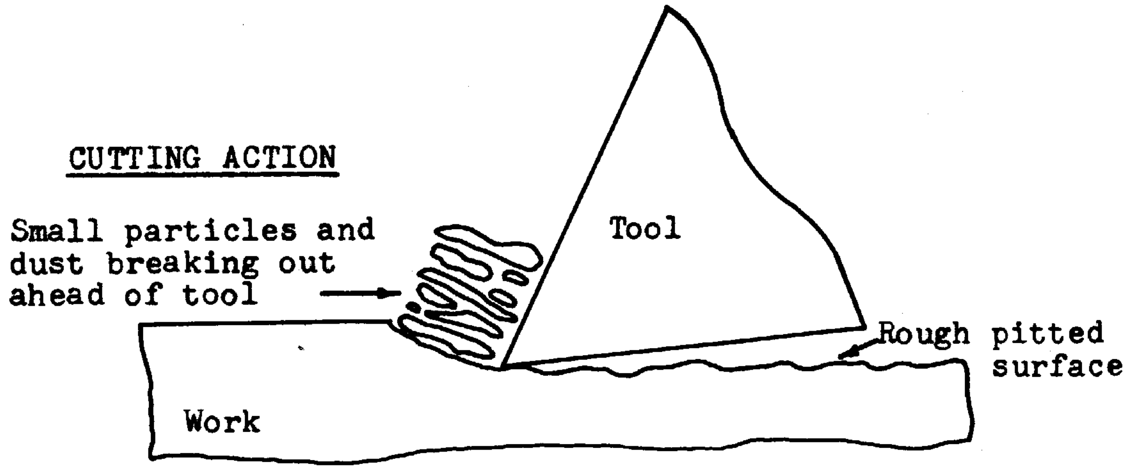
Single point cutting tools play an important part in machining metals, and the tool geometry must be understood in order to grind the correct cutting angles on the tool for efficient metal removal. The forces exerted on the cutting tool occur in three different directions in ordinary metal turning operations:

(1) The forces exerted against the top or face of the tool in a downward direction due to the rotation of the workpiece;

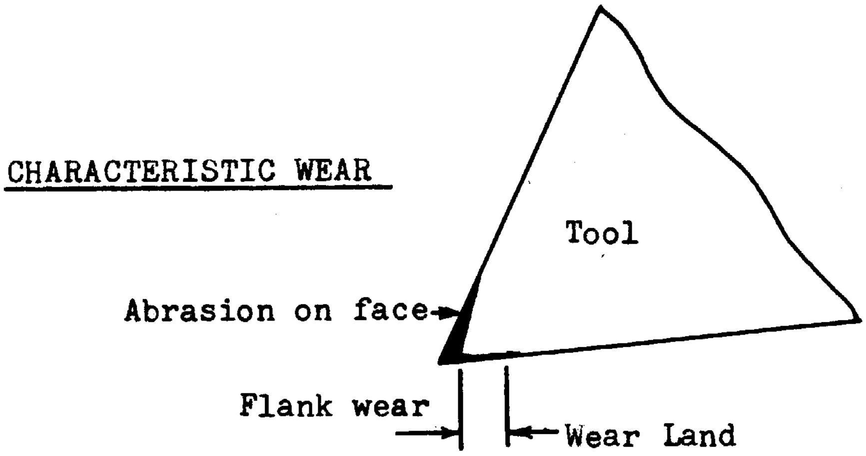
(2) The force exerted against the flank or side of the tool due to the lateral motion or feed of the tool;

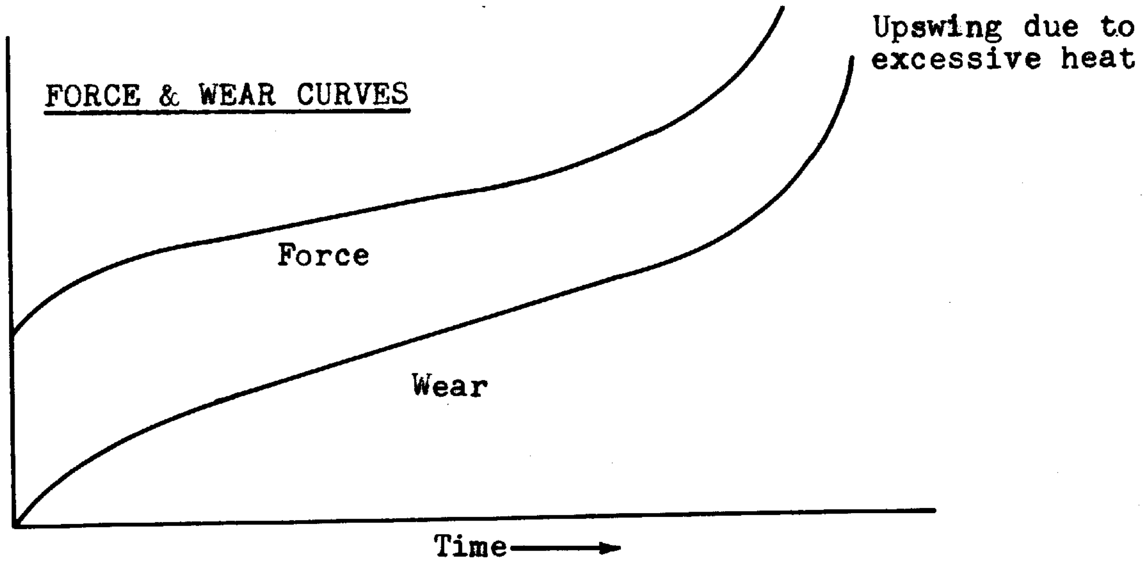
(3) The force exerted against the end or nose of

TYPE 1 -- DISCONTINUOUS OR SEGMENTAL CHIP



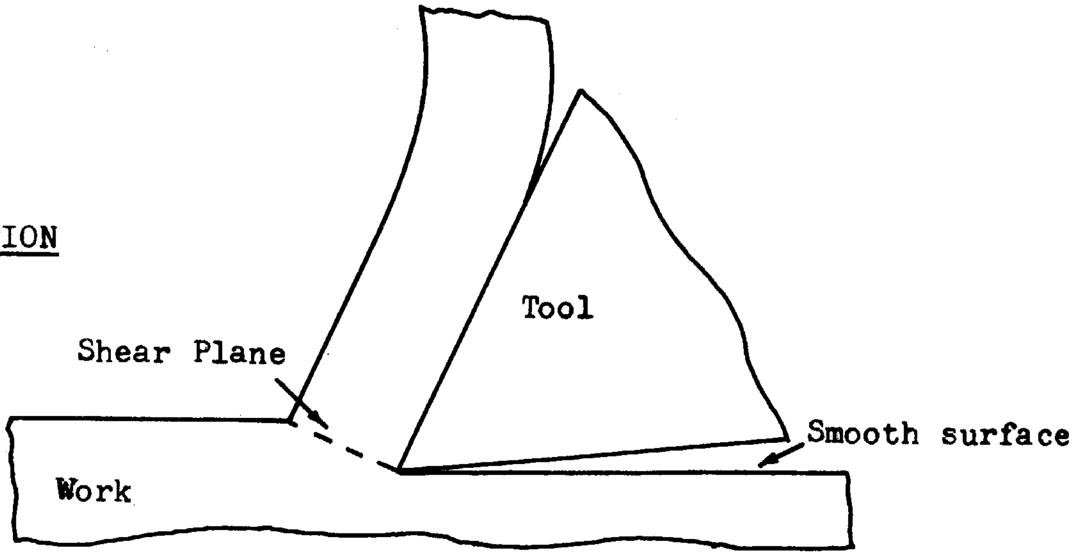
(Figure 25)





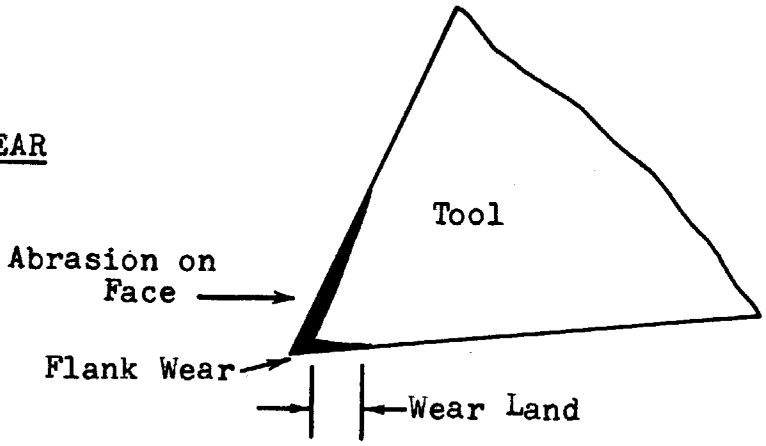
TYPE 2 -- CONTINUOUS CHIP WITHOUT BUILT UP EDGE

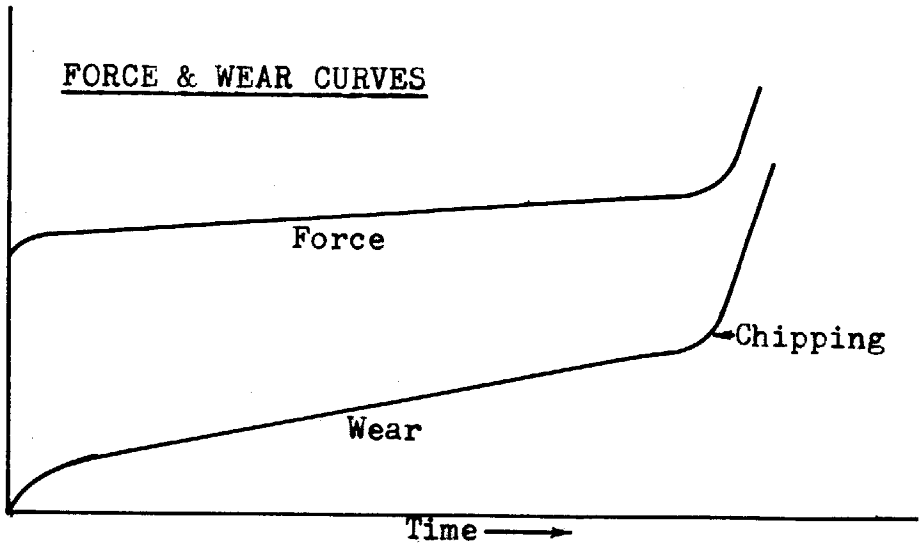
CUTTING ACTION



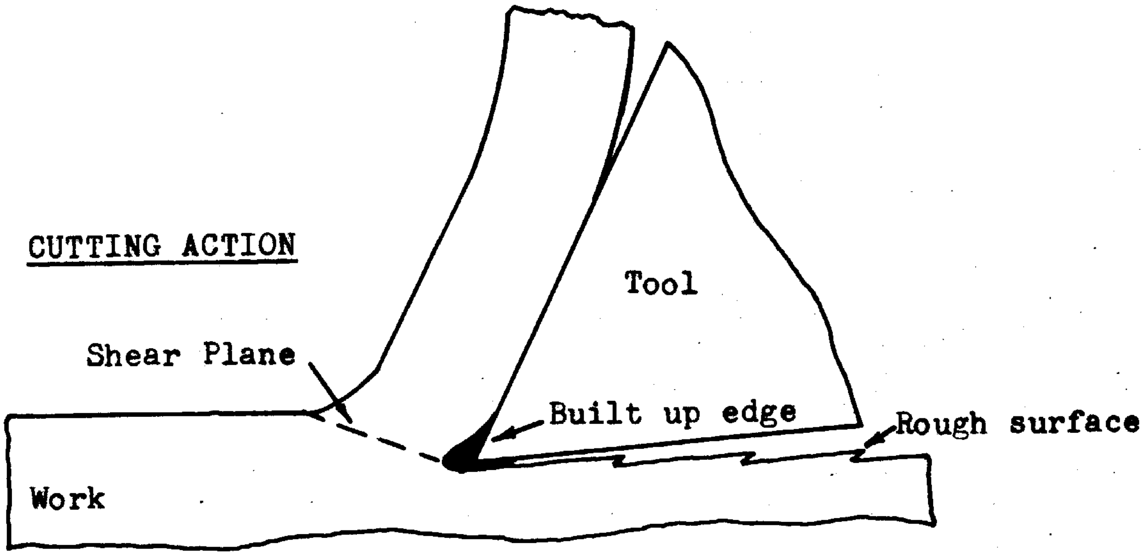
(Figure 26)

CHARACTERISTIC WEAR

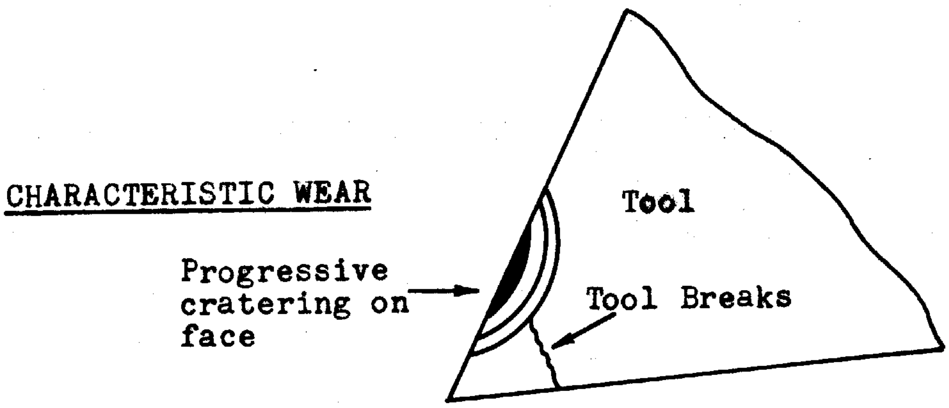


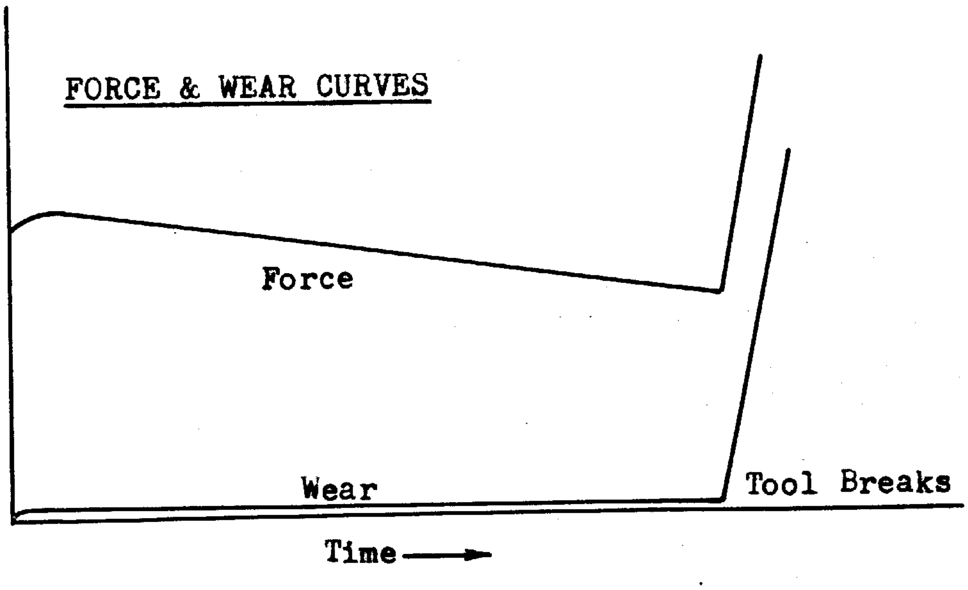

FORCE & WEAR CURVES

TYPE 3 -- CONTINUOUS CHIP WITH BUILT UP EDGE



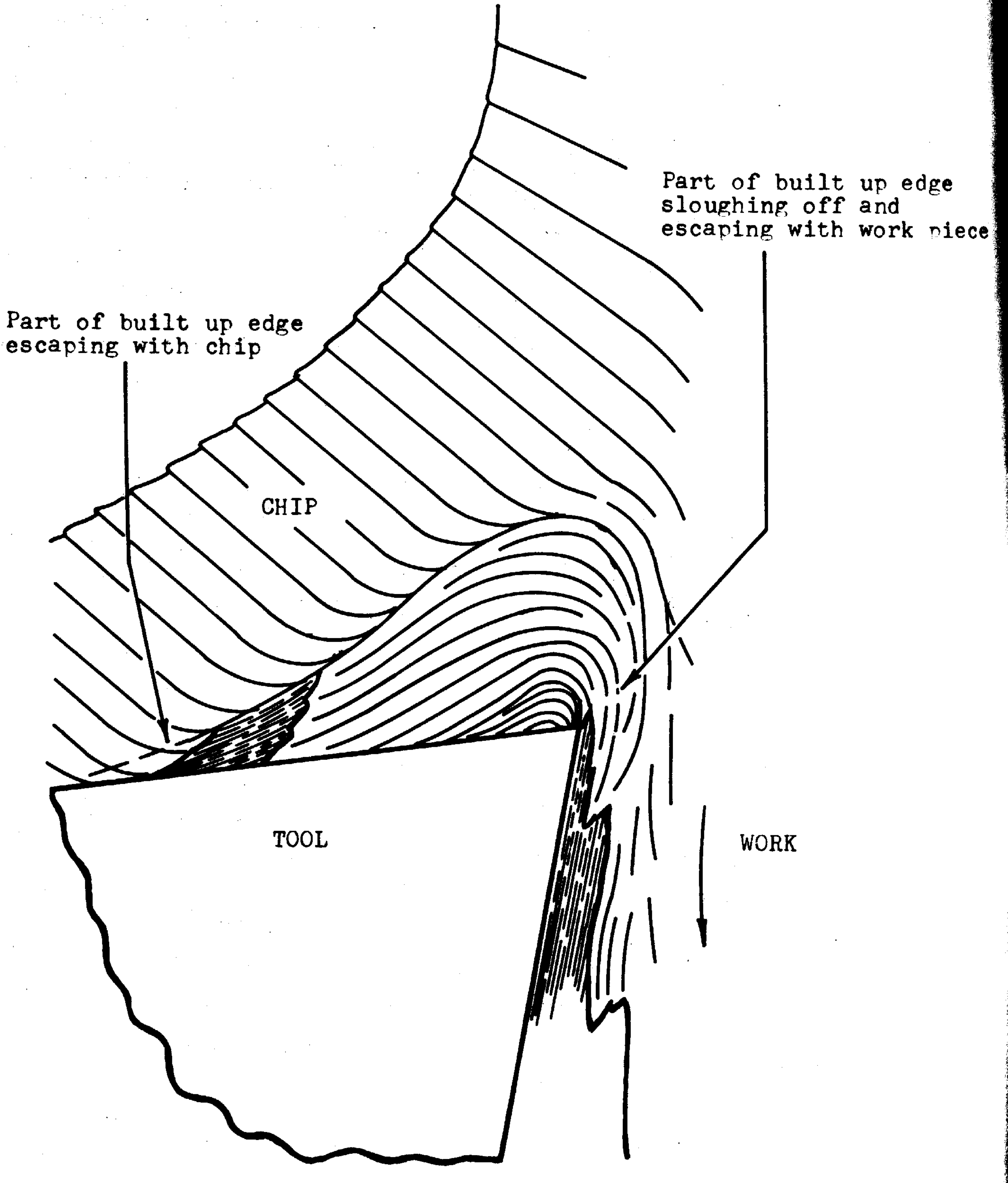
(Figure 27)





UNSTABLE BUILT UP EDGE SLOUGHING OFF

CAUSING ROUGH SURFACE FINISH



(Figure 27a)

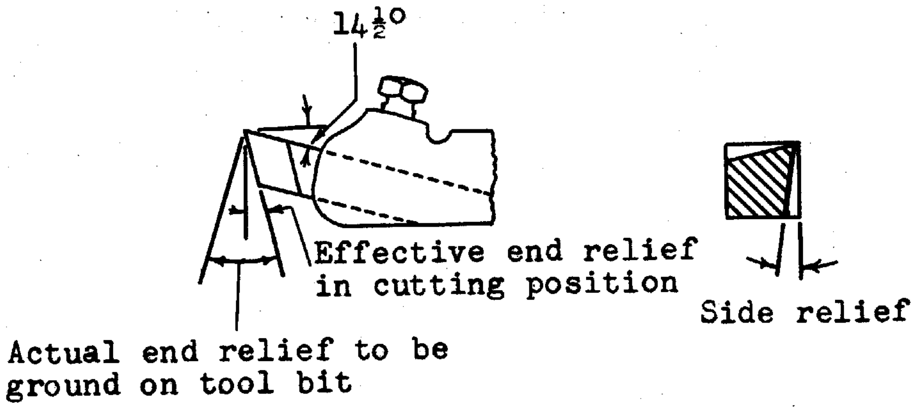
the tool due to the fact that the tool is forced into the material.

These three forces exerted on the tool from three different directions are essential because this makes the cutting action possible. The thrust force exerted on the flank and nose of the turning tool is concentrated on a small area adjacent to the side and end cutting edges.

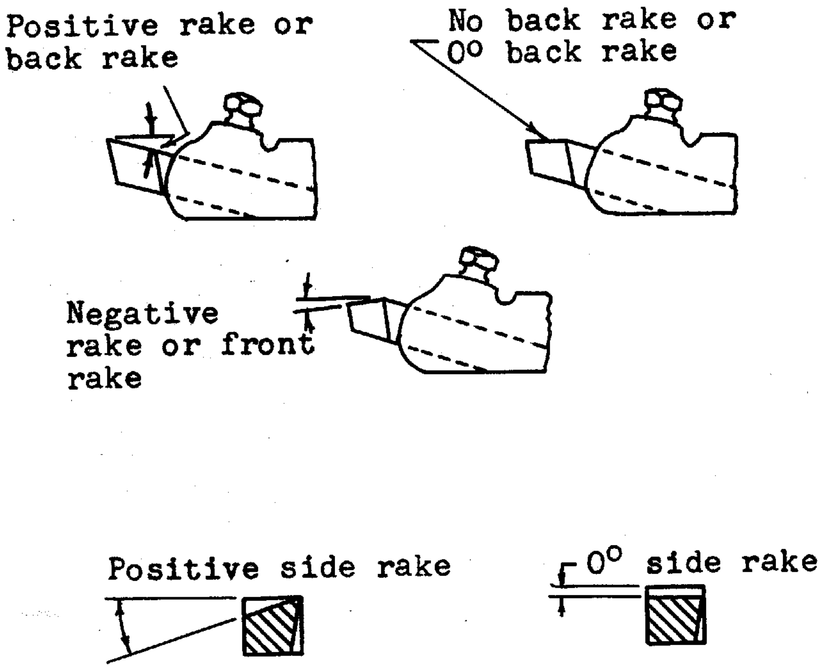
By grinding the flank back at an angle sloping from the side cutting edge, it will improve the tool's cutting efficiency by increasing the effectiveness of the thrust force exerted on the side and end cutting edge angles (Figure 28). The greatest amount of thrust force exerted on the face of a turning tool is concentrated on an area adjacent to the side and end cutting edge angles, (a) by grinding the face back at an angle sloping from the side cutting edge and (b) by holding the tool at an angle sloping from the cutting edge, it will improve the tool's efficiency in cutting tough or ductile metals.

TERMINOLOGY USED TO DESIGNATE SINGLE POINT TOOL GEOMETRY

Tool Grinding. A tool is ground to a given form and shape for two reasons: (a) to produce a cutting edge with the best cutting tool angles that will give the most efficient cutting performance; (b) to grind the most efficient cutting angles for the material that is to be machined,



Relief Angles



Rake Angles

(Figure 28)

TOOL ANGLES AND THEIR FUNCTIONS

Side Rake. Side rake angles may be defined as a plane that forms the face or top of a tool that has been ground back at an angle sloping from the side cutting angle. The extent of side rake influences the angle to which the chip leaves the workpiece as it is directed away from the side cutting angles (Figure 29).

Back Rake. Back rake indicates that the plane that forms the face or top has been ground back at an angle sloping from the nose. When a tool bite is held by a tool holder, the holder establishes the back rake angle. The extent of back rake influences the angle at which the chip leaves the workpiece as it directed against the nose of the tool (Figure 30).

Side Relief. The term side relief indicates that the plane that forms the flank and side of the tool has been ground at an angle sloping down from the side cutting edge. Side relief angles concentrate the thrust forces exerted on the flank of a tool in a small area adjacent to the side cutting edge (Figure 31).

End Relief. The end relief angle indicates that the nose or end of the tool has been ground back at an angle sloping down from the end cutting edge. End relief concentrates the thrust force exerted on the nose of the tool in a small area adjacent to the end cutting edge (Figure 32).

Side Cutting Angle. The side cutting edge angle indicates that the plane that forms the flank or side of a tool has been ground back at an angle to the side of the shank, establishing the angle of the tool's side cutting edge in relation to the shank (Figure 33).

End Cutting Edge Angle. The end cutting edge angle indicates that the plane that forms the end of a tool has been ground back at an angle sloping from the nose to the side of the shank (Figure 34).

Nose Radius. The nose radius is formed by rounding the point of the tool to blend with the tool's cutting edge angles. The nose radius influences the surface finish performed during a cutting operation.

CUTTING TOOL FORMS FOR VARIOUS LATHE OPERATIONS

The following are typical examples of tool forms that are used in various turning operations:

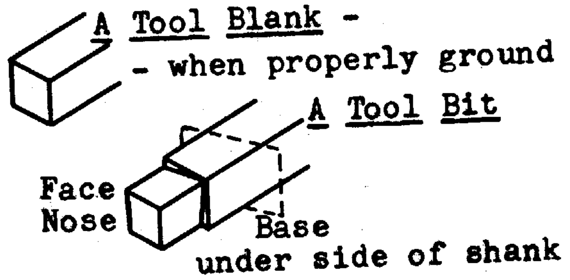
Thread Cutting Tool Forms. The following are important factors that must be adhered to when grinding cutting tools for cutting various national standard thread forms:

(1) V-Type Threads. The V-type thread cutting tool is the most widely used in cutting threads. It is always ground so that its cutting edges converge at 60° cutting angles.

(2) Acme Thread. The 29° worm and the acme thread cutting tools are both ground so that the side cutting edges are at a 29° angle.

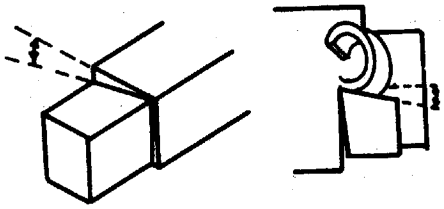
(3) Square Threads. These tools are ground with a straight cutting edge on its end which is at right angles to the shank. It is ground back of both sides for a depth slightly more than twice the distance of the lap. The purpose is to prevent the flanks from rubbing

A Tool Blank - - when properly ground is A Tool Bit



Side Rake

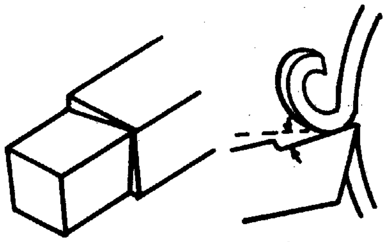
"Side rake" indicates the plane that forms the "face," or top of tool.



(Figure 29)

Back Rake

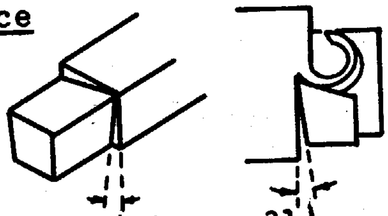
"Back rake" indicates the plane that forms the "face," or top of tool.



(Figure 30)

Side Clearance

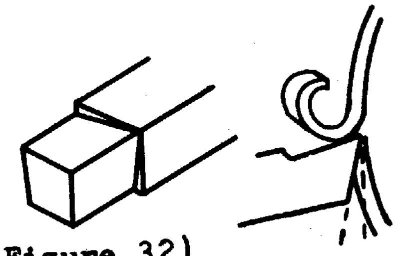
"Side clearance" (or side relief) indicates the plane that forms the "flank," or side, of a tool.



(Figure 31)

End Clearance

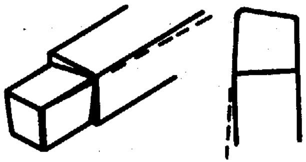
"End clearance" (or end relief) indicates the end of a tool has been ground back.



(Figure 32)

Side Cutting-Edge Angle

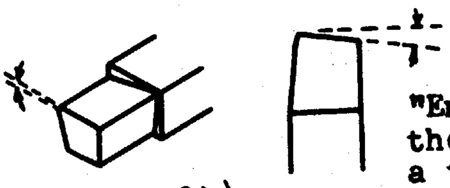
"Side cutting-edge angle" indicates the plane that forms the flank, or side, of a tool.



(Figure 33)

End Cutting-Edge Angle

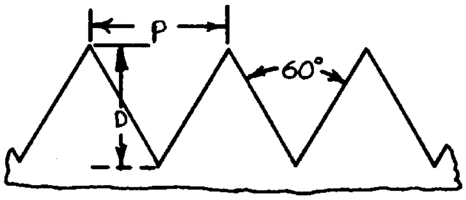
"End cutting-edge angle" indicates the plane that forms the end of a tool.



(Figure 34)

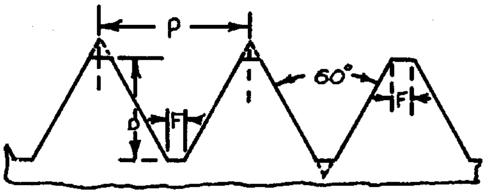
SHARP V-THREAD

Depth D = 0.866 x pitch
Angle = 60 degrees in plane of axis



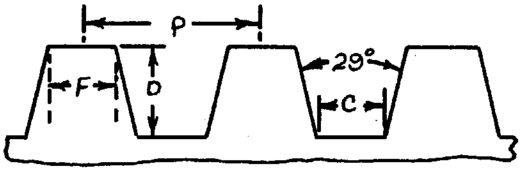
AMERICAN STANDARD THREAD

Depth D = 0.6495 x pitch
Width of flat F = 0.125 x pitch
Angle = 60 degrees in plane of axis



AMERICAN NATIONAL ACME THREAD

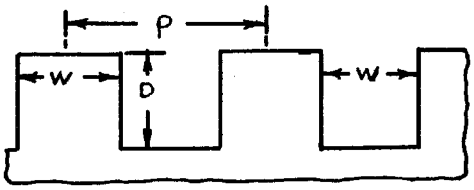
Min,depth D = 0.5 x pitch
Max. depth D = 0.5 x pitch + 0.010 inch
Width F = 0.3707 x pitch
Width C = width F for min. depth
Width C = width F - 0.0052 inch for max. depth
Angle = 29 degrees in plane of axis



(Figure 35)

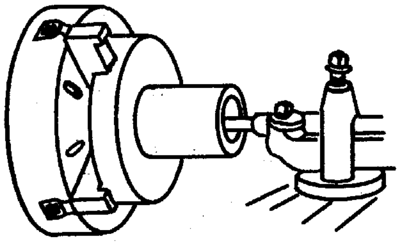
SQUARE THREAD

Depth D = 0.5 x pitch
Width W for screw = 0.5 x pitch
Width thread groove in nut = 0.5 x pitch + 0.001 to 0.002 inch clearance

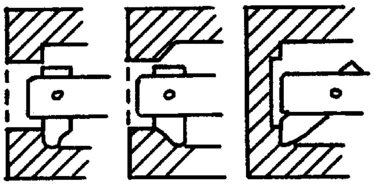


(Figure 36)

BORING SET-UP



(Figure 37)



TOOL BIT POSITIONING
FOR BORING BARS

as the tools penetrate the workpiece (Figure 36).

(4) Boring Tools. Single point tools are also ground to be used in boring bars and are used for internal machining of cored or drilled holes. These tools may be inserted in boring bars at different angles and are also ground for the operation desired (Figure 37).

VARIOUS TOOL SETTINGS AND THE EFFECTING RESULTS

The following tool settings indicate the results when tools with different cutting edge angles are set to cut the same depth and are fed at the same rate; the amount of metal removed per unit of time will be the same, but the dimensions of the chip will vary with the angle of the tool's cutting edge. When a tool ground to a given back rake and end relief angles is mounted on center, above and below center, the cutting tool's efficiency is impaired. When the back rake and end clearance angles on a tool are changed by tilting the tool shank at an angle even though the nose is on center position, the tool's cutting efficiency is impaired. The shape of a chip indicates the extent of chip friction to which the tool is subjected. If the tool is tilted down, chip friction is created. A tool bit when mounted on a tool holder should have the minimum projection. The shorter the bit, the more rigid the tool will be held while cutting. The tool holder should also be mounted in a tool post with minimum overhang to provide rigid setting while machining. Boring tools should be carefully set so that the cutting nose of the tool is on the center line of the workpiece and ground with a little more back rake than a turning tool. Incorrect tool grinding and tool setting for boring will greatly affect the performance of a boring operation. When turning sharp tapers, the tool must be set on center. If not, the end section of the taper will remain untapered. If a workpiece mounted between centers is to be faced or squared, it must be held parallel to the length of the bed, and the tailstock center must be perfectly aligned with headstock center; if not the end surface will be cut to a concave or convex form. The shape of a shoulder depends upon the contour of the tool cutting edge, the angle of setting, and the direction of tool feed. These settings produce shoulders having different contours by varying the angle to which the tool is set. When a thread is cut on taper surface, the tools should be set so that the center line of the tool shank is at the center line of the workpiece.

SCREW THREAD FORMS

V-type thread forms may be produced by advancing the tool at a 29½o angle. This method causes the tool to take a light finishing cut on the thread form that carries the thread when in use. Tools used to cut square, acme, and

29° worm threads are advanced straight into the workpiece for successive cuts. To cut a 60° type thread on an exterior surface, the compound is set at $29\frac{1}{2}^{\circ}$ angle to the right, while when cutting a right hand thread in a bored hole, it is set to the left. To cut a 60° right thread on taper exterior surfaces, the tool is set at an angle of 90° through the center line of the workpiece, regardless of whether a taper attachment is used or the offset tailstock method.

TOOL LIFE

Tool life is the type of tool failure caused by abrasive wear on the flank or face of the cutting tool resulting in excessive tool forces. Whenever the cutting forces exceed a critical value for a given tool, small portions of the cutting edge begin to chip off or the entire edge may break away. The high forces could also be caused by excessive vibration (chatter), or the tool could undergo a complete temperature failure. The hardness (and Strength) of a tool varies with temperature and when the tip of a tool becomes very hot, the tool gets too soft to function properly and failure results. This type of failure occurs quite rapidly and is easily observed.

Standard tool life - cutting speed tests have been developed to determine the effect of speed, feed, depth of cut, tool material, tool shape, work material, cutting fluids, etc., on tool life. During these tests, the cutting tools are run to complete failure, or as in the case of carbides to some predetermined amount of wear. The results of these tests when plotted on logarithmic coordinates usually show up as straight lines having the equation $VT^n=C$. The slope of the line, n, is a measure of the abrasive wear on the tool. A 45° line, $n=1$, indicates that abrasive action caused failure, while a horizontal line, $n=0$, indicates that abrasion had no effect and the tool failed by heat. Experimental tests must fall within the limits of the heat or abrasive type of failure as shown in Figure 38.

The height of the curve is designated by "C" and is a measure of the allowable cutting speed. In the equation $VT^n=C$, the value of "C" is the cutting speed for a one-minute tool life. Standard machinability ratings are usually given as $V_{60}=X$, where "X" is the cutting speed for a 60-minute tool life. To compare the machinability ratings of different materials, the A.S.M.E. "Manual On Cutting of Metals" used standard conditions in lathe turning tests of:

Tool life = 60 min. cutting fluid = dry
feed = 0.010 ipr cutting tool = 18-4-1 H.S.S.
depth = 0.100 inch tool shape = 8, 14, 6, 6, 6, 15, 3/64

Similar tool life curves may be obtained for milling and drilling.

EFFECT OF CUTTING SPEET ON TOOL LIFE

When the cutting speed is decreased, the tool life will increase if the tools fail in a normal manner. Figure 39 shows typical results when testing high-speed steel and sintered carbide tools. The equation $VT^{.12} = 92$ for high-speed-steel tools shows that the cutting speed must be reduced 8 percent to double the tool life. For carbide tools, having the equation $VT^{.25} = 460$, the cutting speed must be reduced 13.7 percent to double the tool life.

A chipping type of failure will cause unpredictable tool life. The tool life cutting speed curve for a carbide milling cutter, Figure 40, shows that when the cutting speed was reduced below 300 fpm, chipping of the cutting edge caused early failure. This failure may have been caused by the presence of an unstable built-up-edge or by the strain of the interrupted cut.

EFFECT OF FEED

Increasing the feed will reduce the tool life (in minutes) but is an effective way to increase the rate of metal removal. The highest possible feed should be used and is only limited by acceptable surface finish, excessive tool forces, or tool breakage.

The cutting-speed tool-life lines for three feeds are shown in Figure 41. When the feed was doubled from 0.025 to 0.050 ipr, the cutting speed for a 60-minute tool life was reduced from 45 to 28 fpm (reduced 38%). However, the rate of metal removal was increased from 2.17 to 3.36 cubic inches per minute as shown in Figure 42.

To represent the effect of feed, the feed rate is plotted vs. the cutting speed for a 60 minute tool life. The equation for this curve is: $V_{60}\ (f)^x = C_1$

where: V_{60} = Cutting speed for a 60 minute tool life

f = Feed rate ipr or ipt

x = Slope of the line = $\frac{A}{B}$

C = Constant for these conditions

The following conclusions can be drawn from this curve:

(1) The metal removal rate increases as the feed increases despite the drop in cutting speed as can be seen in Figure 42.

(2) The cutting speed has to be decreased if the feed is increased and the tool life is desired to remain the same.

EFFECT OF DEPTH

Increasing the depth of cut requires only a slight decrease in cutting speed to maintain the same tool life as shown in Figure 43. To show the benefit of increasing the depth in terms of metal removal, the depth of cut was doubled from 0.025 to 0.050 inch and the cutting speed, V_{60}, was only reduced from 71 to 62 fpm, but the rate of metal removal was increased from 0.53 to 0.93 cubic inch per minute. The equation for this curve is:

$$V_{60}(d)^y = C_2$$

where: d = depth in inches

y = slope $\frac{A}{B}$

C_2= constant for the given conditions

The following conclusions can be drawn from these graphs:

(1) The metal removal rate increases as the depth increases despite the drop in cutting speed;

(2) The cutting speed has to be decreased if the depth is increased and the tool life is desired to remain the same.

EFFECT OF METAL CUT

Metals vary greatly in properties and in ease of machining. Some grades of aluminum can be cut at 10,000 feet a minute whereas some steels must be cut at 100 feet a minute for a 60-minute tool life. The physical and metallurgical properties of the material cut have a definite effect on tool life.

EFFECT OF TOOL MATERIAL

There are so many different compositions of tool materials and so many different ways in which they can be used that only a few broad generalizations can be made as a basis for comparison. One of the most significant facts of modern metal cutting in regard to the selection of cutting tool material, is that the latitude of performance between the many grades of sintered carbide is far greater than that offered by different compositions of high speed steel.

Thus an unsatisfactory cutting performance may be rectified simply by using a different grade of carbide whereas a corresponding change in the composition of a high speed steel is rarely sufficient for this purpose.

A rough comparison of four general types of cutting tool materials is given in the following table where the cutting speeds are expressed in percent based on 18-4-1 high speed steel at 100%. Note that ranges are given for sintered carbides in recognition of the considerable latitude represented in different grades.

Relative Cutting Speed - Percent

Tool material	Cutting Steel	Cutting Cast Iron
Carbon Tool Steel	30	25
High Speed Steel	100	100
Cast Non-ferrous	125	200
Sintered Carbides	250-1000	400
Ceramics	1000-1500	

EFFECT OF TOOL SHAPE

Unfortunately, variations in tool shape do not lend themselves to simple correlations as in the case of cutting speed and size of cut. The effect of tool shape is shown qualitatively by curves in Figure 44.

Separate curves are given for high-speed steel and sintered carbide tools in the rake, relief and side cutting edge angle correlations because of the significant differences in their behavior. The location of the optimum rake angle for high-speed steel tools is largely a function of the rigidity of the entire machining setup. At larger rake angles, say, around 35 degrees, the tools begin to chip, but if greater rigidity can be achieved, larger rake angles can be used. Thus, for HSS tools it can be said that greater rigidity will allow the use of larger rake angles, resulting in longer tool life.

The effect of rake angle on tool life is not so simple for carbide tools as shown in Figure 40. The optimum "b" appears to be similar in nature to the optimum for HSS, in that it is a function of rigidity. Carbides are susceptible to increased spalling with increased rake, and hence the optimum occurs at smaller rake angles than for HSS; rigidity is even more important than it is for HSS tools.

The second optimum "a" for carbide tools may not occur at all under certain cutting conditions. If it does occur, it may be higher or lower than the other optimum. However, some recent tests on carbide turning of titanium with higher feeds and speeds did produce this optimum in the region of small negative rakes.

The curves in Figure 40 show the effect of relief angle on tool life for both HSS and carbide tools. For HSS tools, the increase in relief angles after about 13° brings about a decrease in tool life. This is true only if a built-up-edge is present on the tool. For carbide tools, the relief angle can be increased furthur to obtain greater tool life. It is a common mistake to assume that carbide tools require exceptionally small relief angles to prevent spalling. Carbide milling cutters have performed very well with relief angles between 12 and 16 degrees. Good rigidity is, however, essential to achieve this result.

Figure 44 illuatrates the effect on tool life when the side cutting edge angle is increased. In this case, the tool life for both HSS and Carbide increases up to a certain point. Beyond this point, the direction of the resulting force causes chatter (see Figure 44).

EFFECT OF CUTTING FLUIDS

Cutting fluids influence tool wear and surface finish. In general, those cutting fluids which are good coolants will increase tool life by reducing temperatures, thus delaying 'temperature failure'; good lubricants will reduce or eliminate the built-up edge, thereby improving surface finish and extending the tool life. At low speeds, the cutting fluids are far more effective in extending tool life in the form of better finish than they are in delaying 'temperature failure.'

The good lubricants are generally effective through chemical action. In order for a fluid to be effective, it must first penetrate to the point of the tool.

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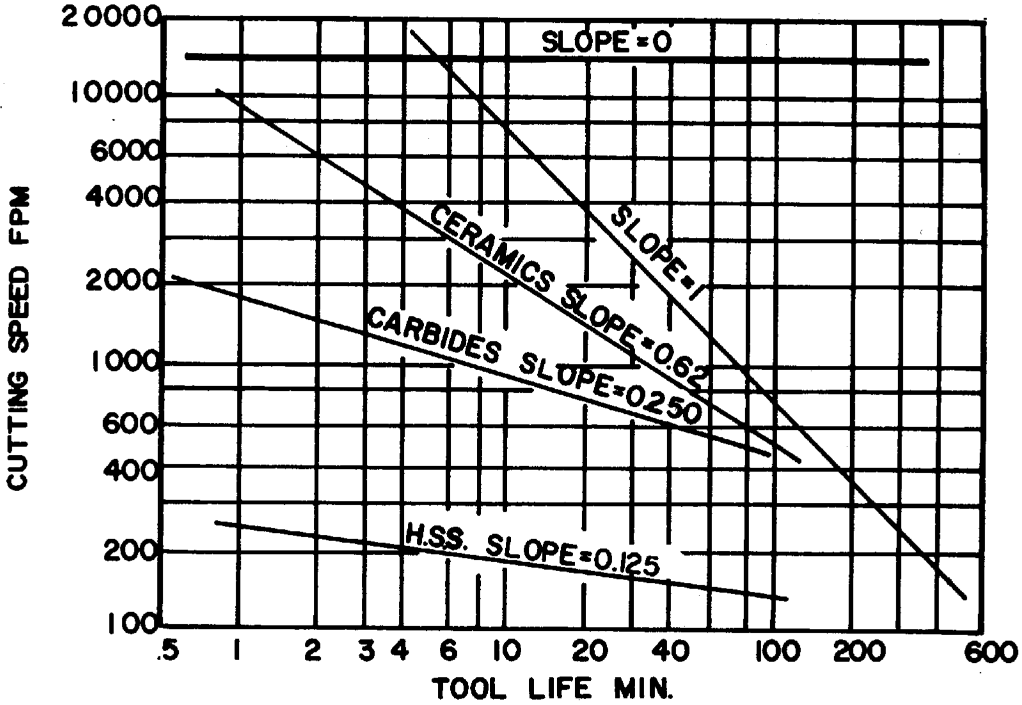
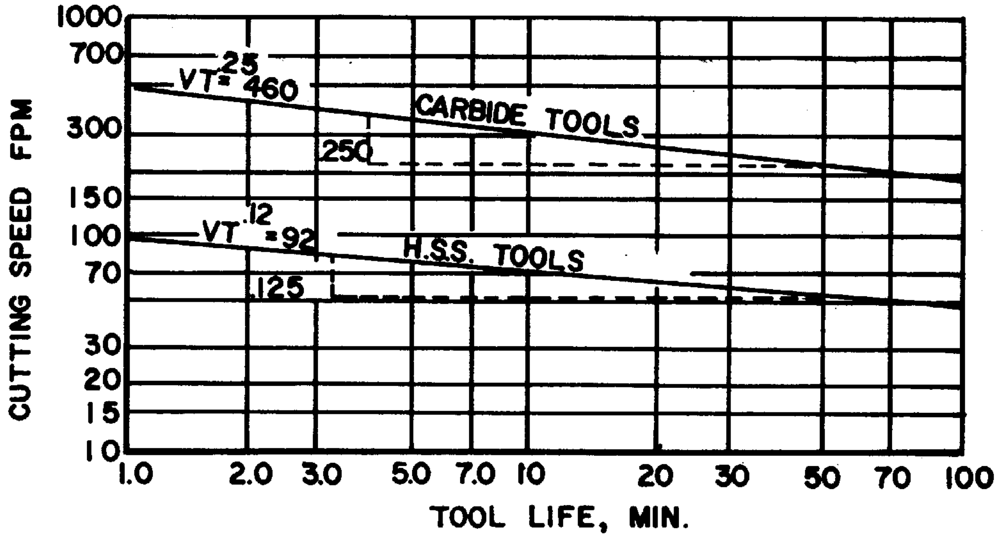


Actual and Theoretical Slopes of Tool Life Lines.

(Figure 38)

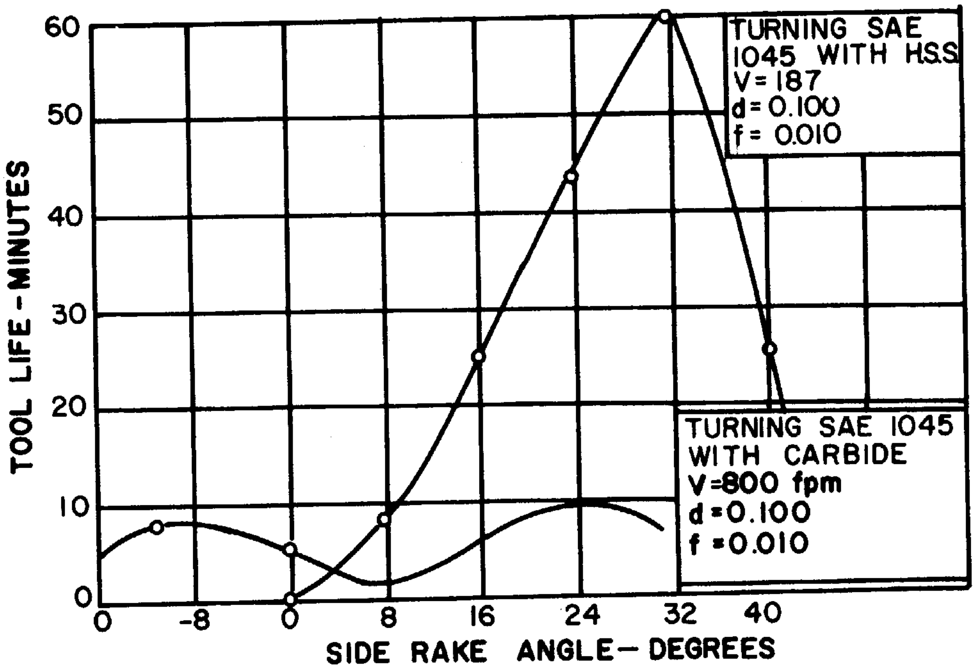
Cutting Conditions: Feed-.0125 ipr, Depth-.100 in.

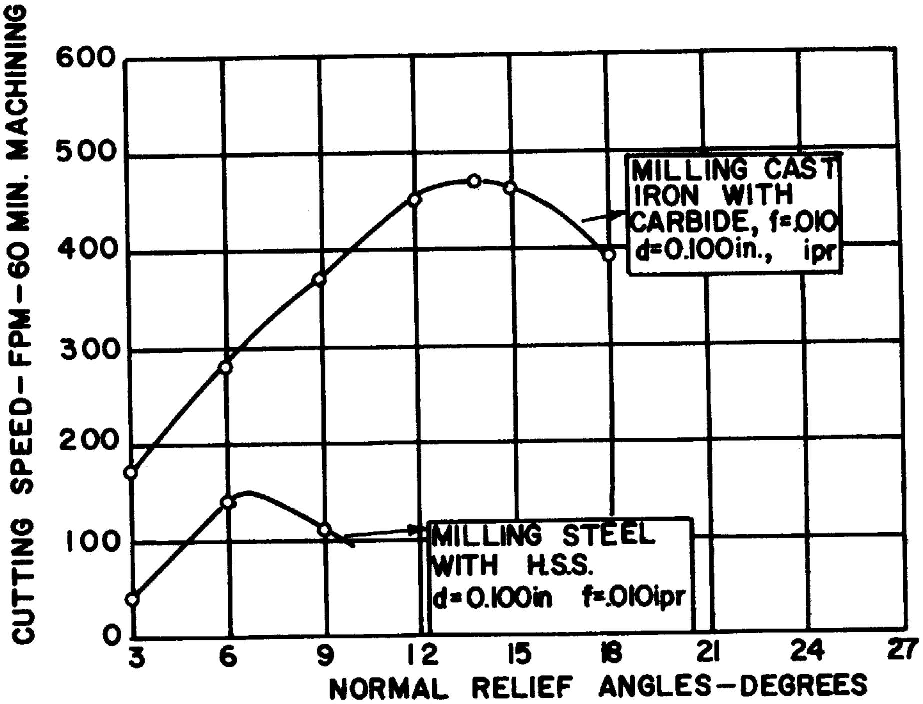


Typical Curves of Cutting Speed vs Tool Life (for steels-350 BHN)

(Figure 39)

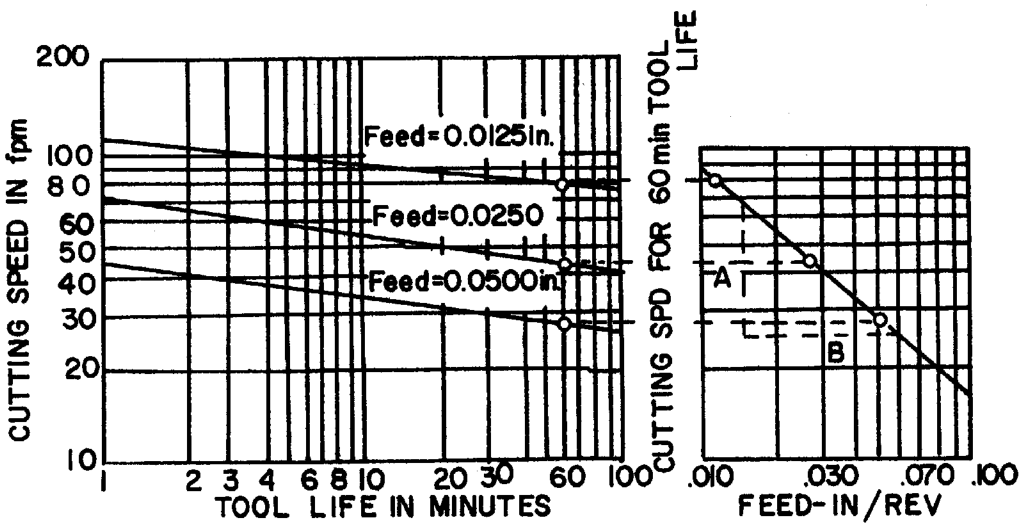
Effect of Side Rake Angle





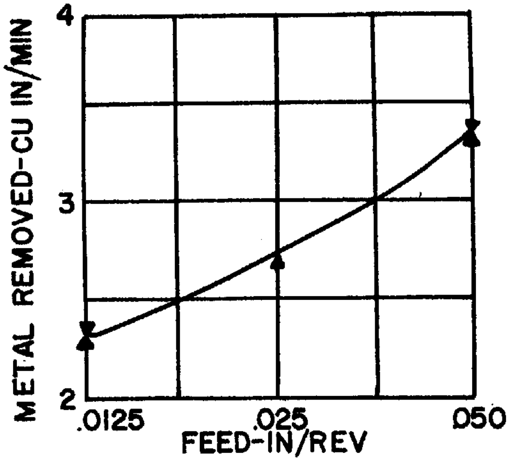
(Figure 40) Effect of Relief Angle

(Figure 41) Effect of Feed on Cutting Speed



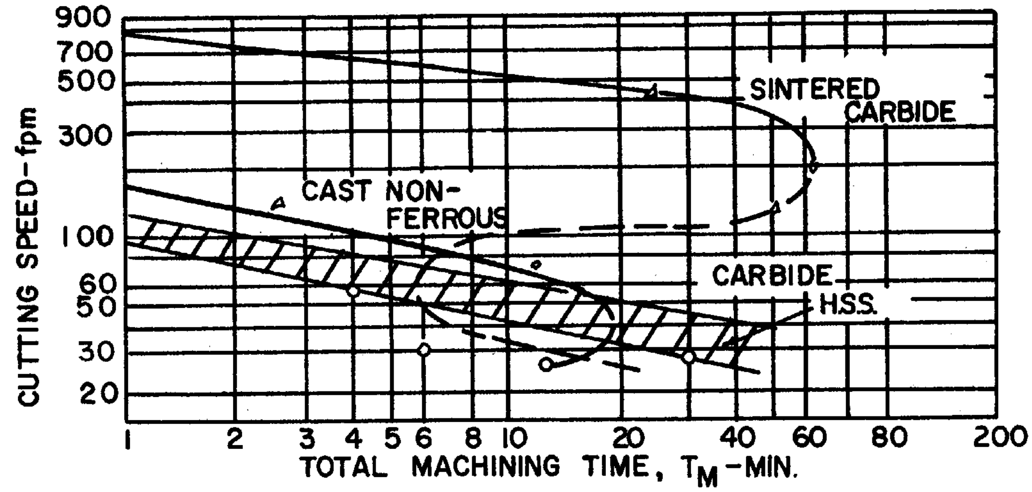
Cutting Conditions:
Material Cut-2340 Steel, Tool-High Speed Steel,
Depth-.200 in., Cutting Dry

(Figure 42) Metal Removal Rate vs Feed

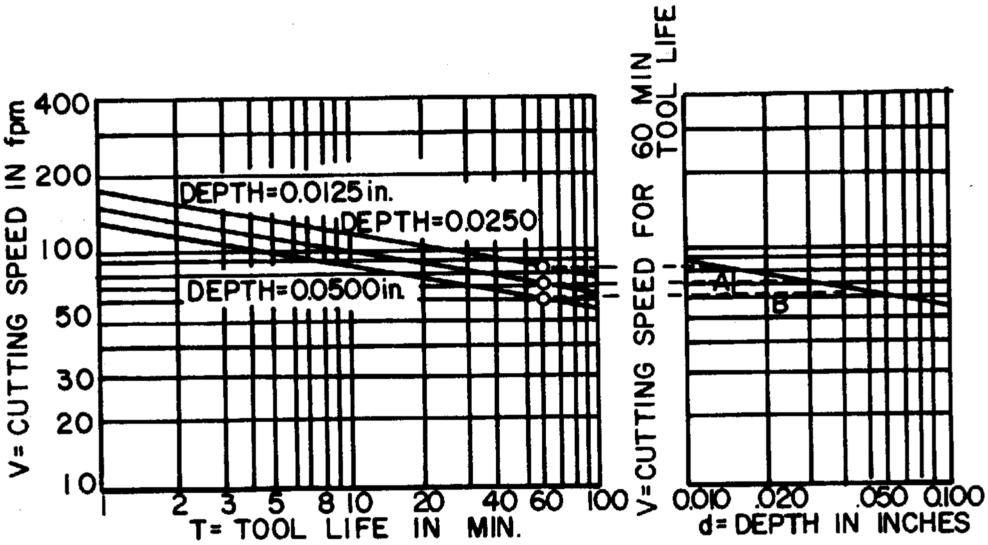


Cutting Conditions:

Milling-4130 Cast Steel, Feed-.0125 ipr, Depth-.100 in.

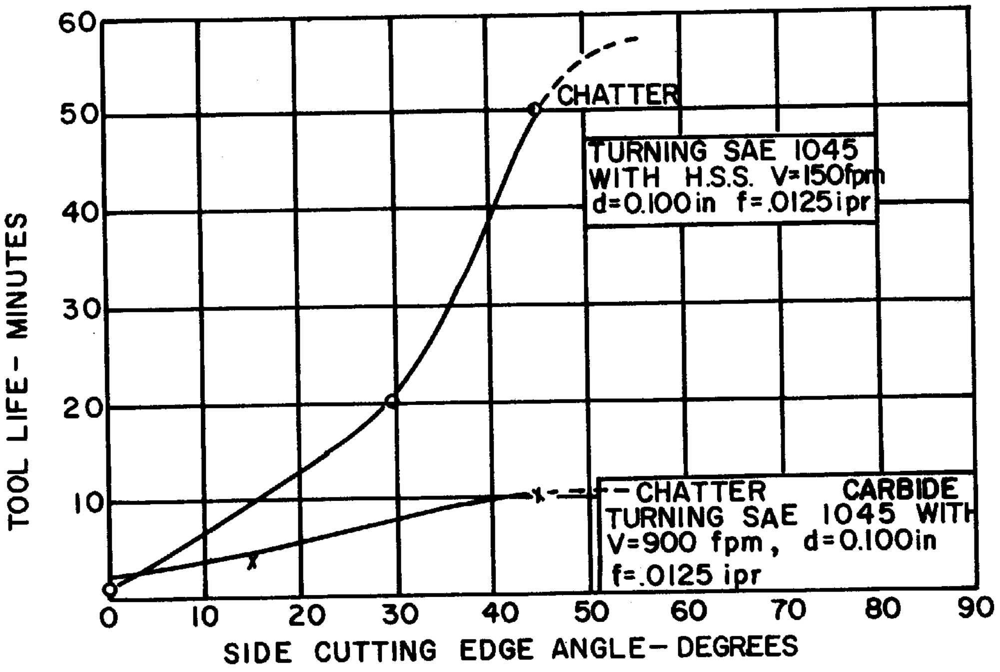


Effect of Different Tool Materials on Cutting Speed



Cutting Conditions:
Material Cut-3240 Annealed Steel, Tool-High Speed Steel, Feed-.025 ipr, Cutting Dry

(Figure 43) Effect of Depth of Cut on Cutting Speed



(Figure 44) Effect of Side Cutting Edge Angle

TOOL LIFE IN GRINDING

Mention should be made of the evaluation of wear of the grinding wheel. The amount that a grinding wheel wears during an operation is conveniently expressed in terms of the grinding factor G.

$$G = \frac{\text{Volume of Metal Removed}}{\text{Volume of grinding wheel consumed}}$$

This ratio is easily determined and can be then used to evaluate grinding variables such as wheel hardness, cutting fluid, cutting speed, cross feed, etc.

The volume of grinding wheel consumed is determined from the change in wheel diameter (D_1-D_2) as measured with a micrometer. The volume is then taken to be:

$$D_1 - D_2 \text{ x width of wheel x } \pi D_1$$

where:

D_1 = initial diameter

D_2 = final diameter

MACHINABILITY SYMBOLS

V - Cutting speed in feet per minute

V_{60} - Cutting speed for a 60 minute tool life

T - Tool life in minutes

T - Torque in ft. lbs.

n - Slope of the tool life line as in $VT^n - C$

n - Number of teeth on a milling cutter

C - Constant

N - R.P.M.

F_T - Cutting force in lbs.

F_L - Feeding force in lbs.

F_R - Radial force in lbs.

f - Feed in inches per revolution or feed in inches per tooth

d - Depth in inches

w - Width

D - Diameter of work or cutter

fpm - Surface speed feet per minute

hp_c - Cutting HP

hp_g - Motor HP

uph - Unit hp or hp per cubic inch per minute

METAL CUTTING RELATIONSHIPS

$$\text{fpm} = \frac{\pi \ D \ N}{12} \quad ; \qquad N = \text{rpm} = \frac{\text{fpm} \times 12}{\pi \ D}$$

$$hp_g = \frac{hp_c}{\text{machine eff.}}$$

$$hp_c = \frac{Fc \times V}{33000}$$

$$hp_c \text{ drilling} = \frac{2\pi \ T \ N}{33000}$$

$$\text{Unit hp} = \frac{F_T \times V}{33000 \times 12 \ V \ fd} = \frac{F_T}{360000 \ fd}$$

Approximate metal removal rate in turning $in^3/min = 12 \ Vfd$.

Exact metal removal rate in turning

$$in^3/min = \frac{\pi}{4} (D_1^2 - D_2^2) \ N \ f$$

Metal removal rate in face milling:

$$in^3/min = N \times n \times f \times w \times d.$$

Metal removal rate in drilling:

$$in^3/min = N \times f \times \frac{\pi}{4} D^2$$

Velocity tool life relationship: $VT^n = C$

Area of a circle = $\frac{\pi D^2}{4}$

Circumference of a circle = πD

CHIP CONTROL

Unbroken or straight chips are hazardous and troublesome. They pile up in the work area, endanger the operator, and are difficult to remove.

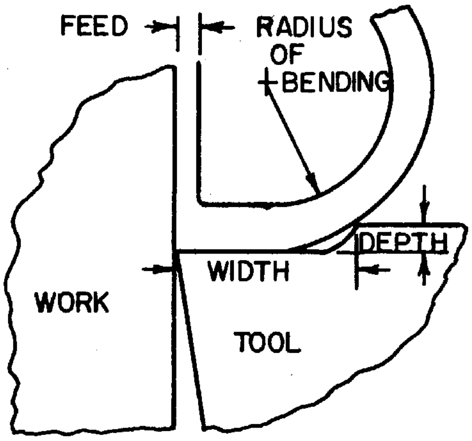
Well broken chips take up less space, make machines easier to keep clean and are much safer to handle.

The first approach to breaking chips is to increase the feed rate. Heavy feeds will generally produce well broken chips without the use of chip breakers. However, if heavy feeds do not produce the desired results, chip breakers will have to be incorporated into the tools.

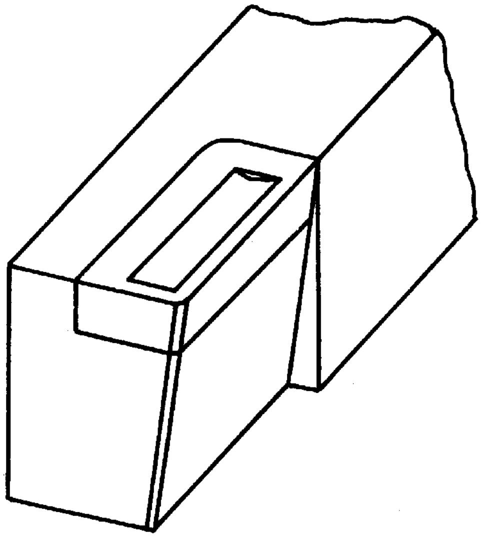
HOW CHIP BREAKERS WORK

Chip breakers are obstructions put in the direction of chip flow causing the chip to curve into a circular path and break. The back rake angle of the tool will direct the chip to break against the tool or the work. The width and depth of the chip breaker will determine the size of the broken chips.

Action of the Chip Breaker in bending a chip.



CHIP BREAKER TYPES

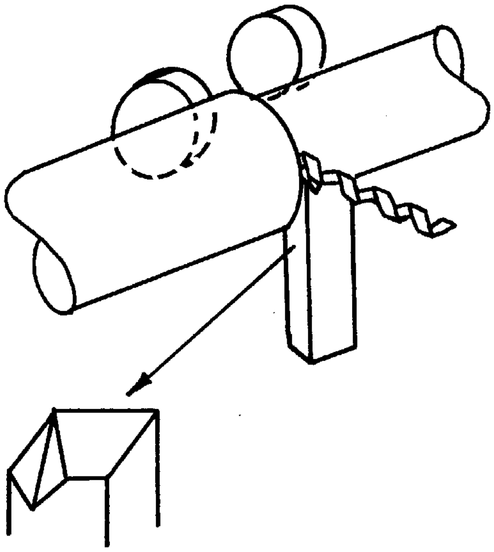


Groove Type

This style is used for both High Speed Steel and Carbide tools. The high rake angle produced has the advantage of lower power consumption and good tool life.

EXAMPLE:

Roller-turner tool; this groove curls the chip and removes it from the roller supports.

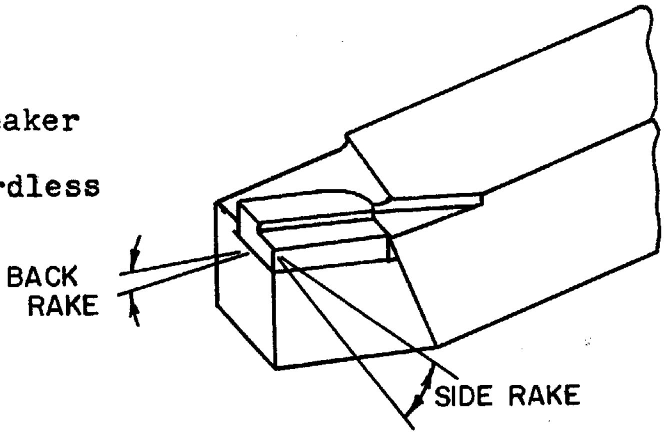


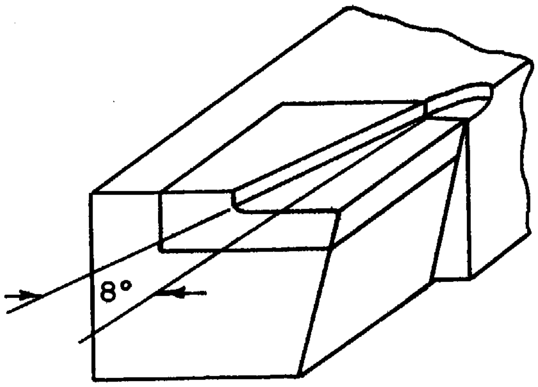
Shelf Type

This is the most common chip breaker for Carbide tools because of the ease of grinding.

Parallel Type

Used for deep cuts. The breaker width remains the same regardless of depth cut.



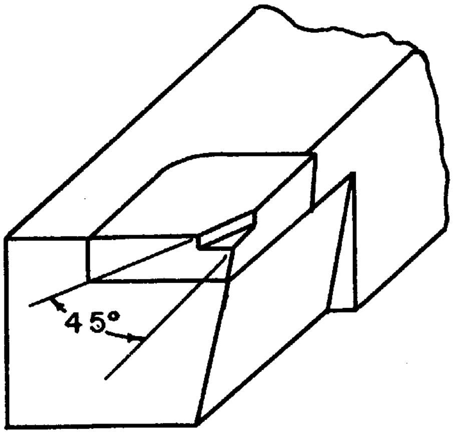


8° Angular Type

Used for most operations.

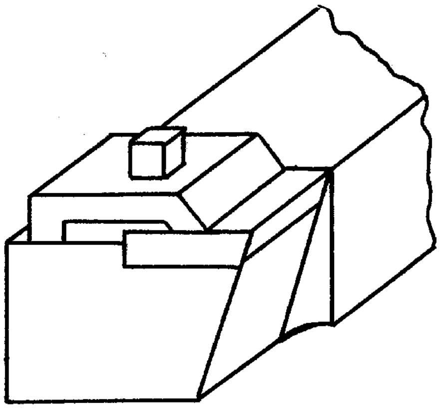
45° Angular Type

Used for light finishing cuts.



Mechanical Type

The mechanically held block is used for large tools, it is adjustable and avoids the necessity of grinding a groove or shelf. This method is used to advantage with clamped on tips.

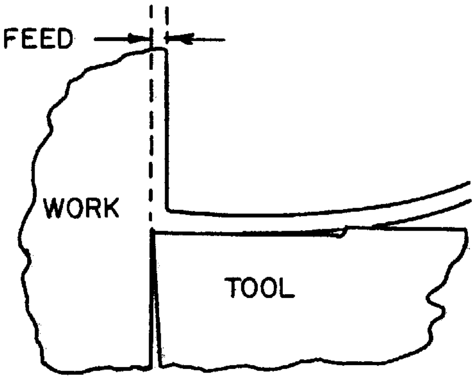


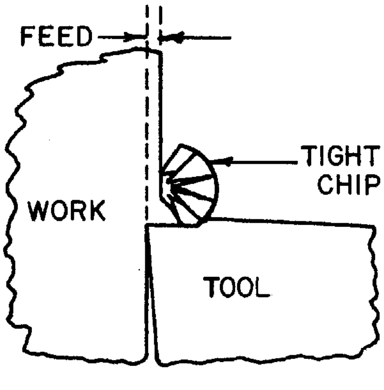
CHIP BREAKER DIMENSIONS ARE CRITICAL

A chip breaker bends the chip so it will break when striking the tool or work. If the radius of bending is too large the chip will not break. If the radius of bending is too small the tool life will be reduced. The factors effecting the radius of bending are feed, breaker width and breaker depth.

Breaker Width

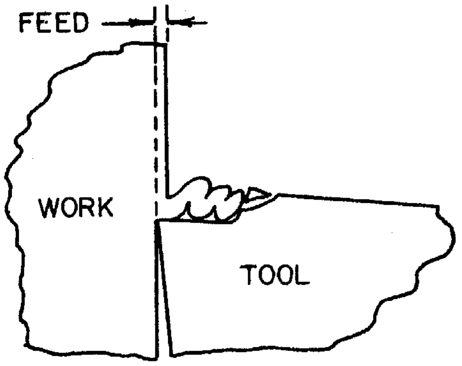
A breaker that is too wide will not break the chip.





Breaker Width A breaker that is too narrow will crowd the chip, heat the tool, and reduce the tool life.

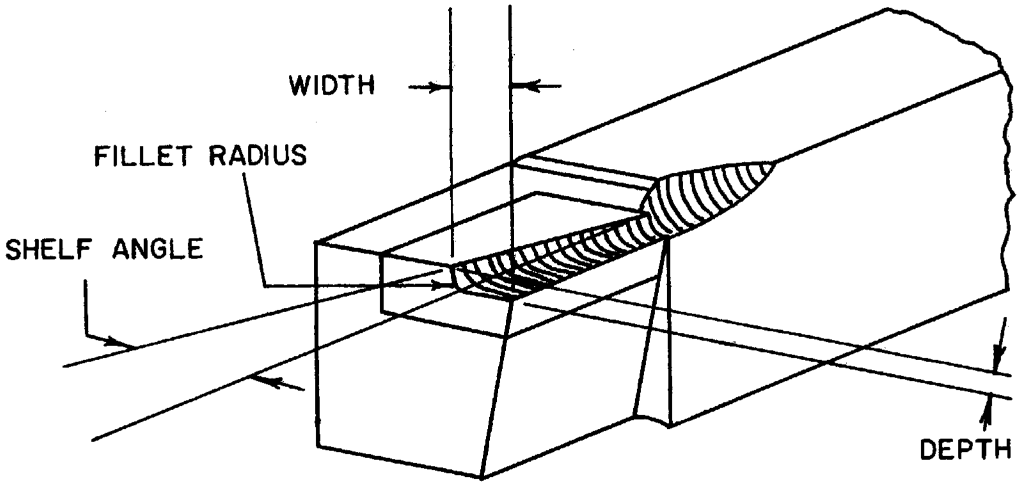
Breaker Depth



A breaker ground too deep and with a sharp fillet radius will catch the chip on the shelf causing chipping, high forces and poor tool life.

DESIGN OF CHIP BREAKERS

A. Design of the Shelf Type Chip Breaker



Important Dimensions for Shelf Type Chip Breaker

1. Determining Shelf Depth

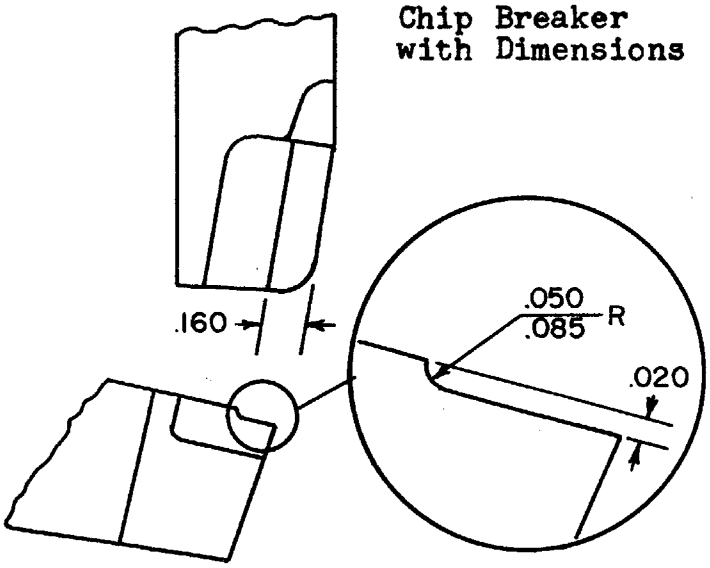
The depth should be proportional to the size of cut and tool size.

Tool Shank Size	Shelf Depth
Less than 3/4"	.015 to .020 inch
From 3/4" to 1"	.020 to .025 inch
Above 1"	.025 to .030 inch

A standardized depth of .020 is recommended

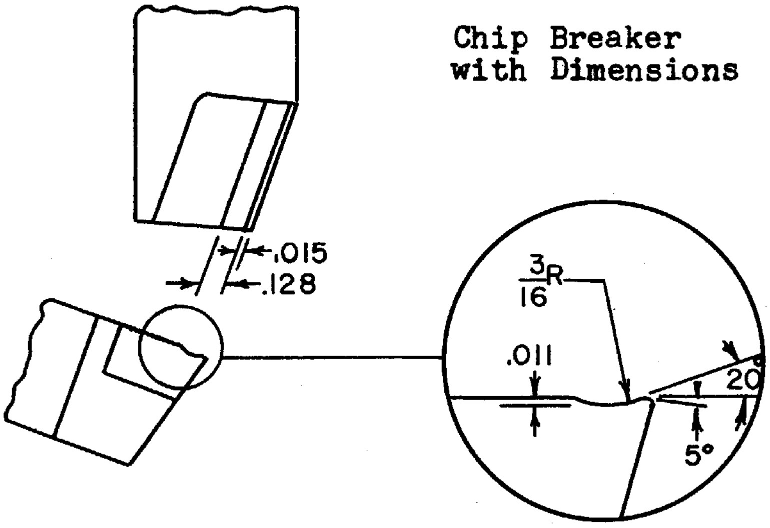
SHELF TYPE

Chip Breaker
with Dimensions

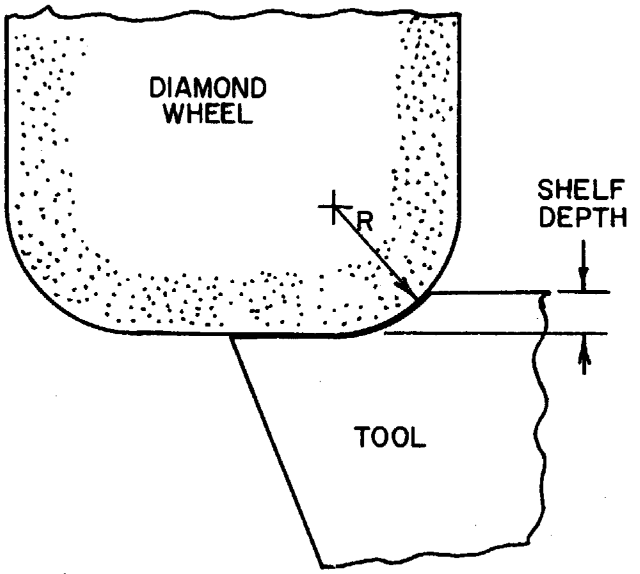


GROOVE TYPE

Chip Breaker
with Dimensions



B. Determining Fillet Radius



Fillet Radii are determined by shelf depth and Diamond wheel corner radius.

Shelf Depth	Fillet Radii in Inches	
	Minimum	Maximum
.015 inch	.035	.065
.020	.050	.085
.025	.060	.100
.030	.070	.125

C. Determining Breaker Width

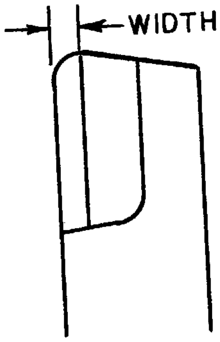
The breaker width is influenced by:

1. Material cut
2. Feed rate
3. Tool side cutting edge angle
4. Depth of cut

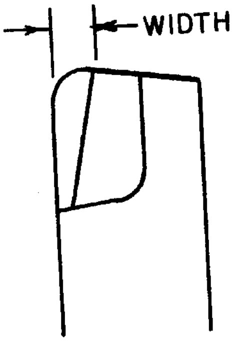
The true chip thickness is a function of the actual feed, side cutting edge angle and depth of cut.

Approximate Chip Breaker Width for a 0.020 Groove Depth

Modified Feed = Chip Thickness	Breaker Width
.005 - .0075	.050
.009 - .012	.076
.015 - .022	.125
.025 - .040	.187



Parallel Type



Angular Type

Recommended Rake Angles

Material Cut	Tool Material	
	Carbides	High Speed Steel
Ductile, Low Hardness, Below 200 BHN	20°-30°	30°
Med. " , 200 - 300 BHN	10°-20°	20° - 25°
Alloy, Heat Treated 300 - 400 BHN	0°-10°	5° - 10°

SURFACE FINISH

If you can machine a good enough surface finish, a grinding operation can be eliminated. Most product engineers, process planners, time study men, and machine operators know this, but the big question always has been, "How can I predict the setup conditions which will give this good surface finish? What materials, feeds, speeds, and tool shapes must be used? Present surface finish charts give a range of values but no way to obtain them."

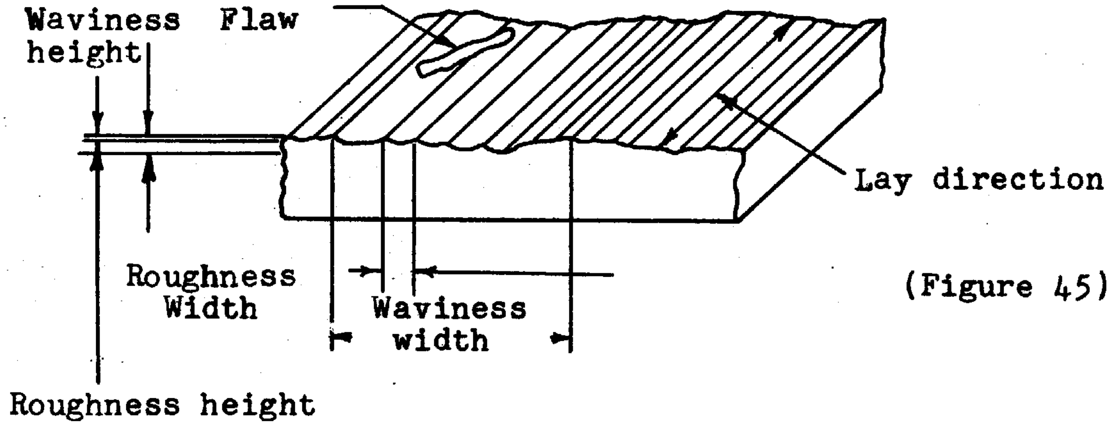
The following will help to eliminate the guesswork from the surface finish problem by illustrating, for single point cutting tools, the effect of the major variables on surface roughness. Easy to use charts have been developed which present the relations between these variables and make it possible to predict the surface roughness.

LIMITATIONS

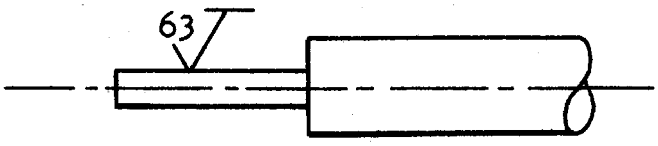
Of course, there are many other factors which affect the surface finish, such as rigidity, cutting fluids, rake angles, and smoothness of the cutting tool, but these will be considered later. It is assumed in this article that dry cutting is used and that there is sufficient rigidity to prevent chatter. The depth of cut is assumed to be uniform and typical of finishing cuts.

WHAT IS SURFACE ROUGHNESS?

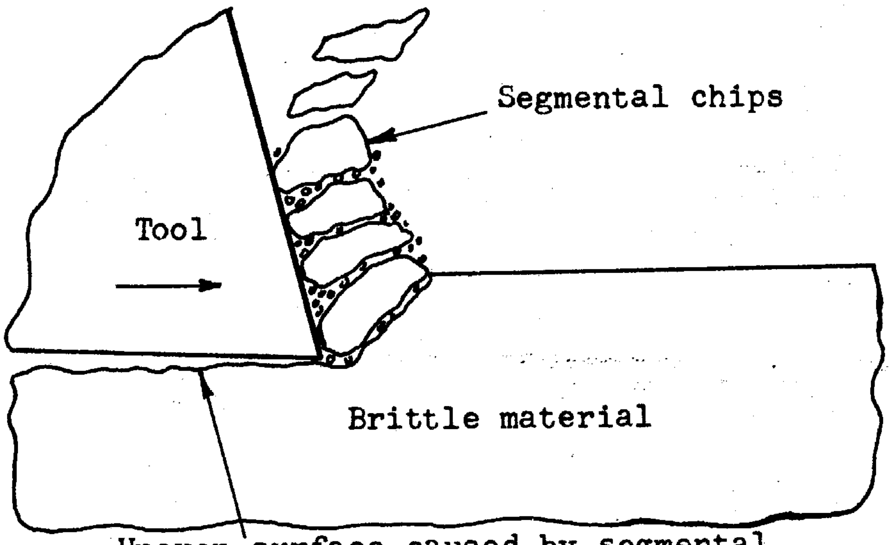
Since we are limiting this discussion to the roughness factor of surface finish, it should be mentioned that no attempt is being made to discuss waviness, flaws, or pattern of the roughness which is called lay. These factors are shown in Figure 45 and described in the ASA standard B46.1 "Surface Roughness, Waviness and Lay." In this standard a symbol is given representing all characteristics of surface finish. However, in most cases a simplified symbol, as shown in Figure 46, is used to indicate the maximum allowable roughness.



(Figure 45)

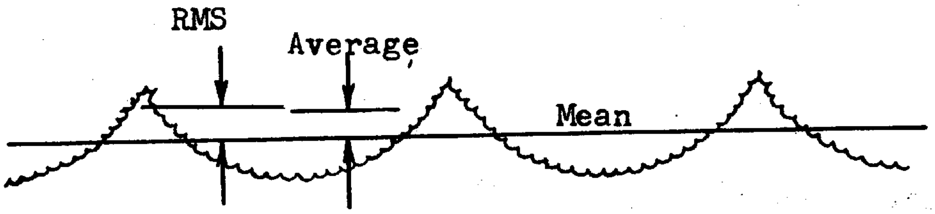


(Figure 46)



SEGMENTAL CHIPPING

Surface roughness is measured in microinches (millionth of an inch, 0.000001) and is the deviation from the mean line, as shown in Figure 47. In the past, the root mean square method (rms) has been used for averaging. This gives a value of approximately 30% of the peak-to-valley height. Recently the arithmetical average height has become more popular, and it gives a value of approximately 25% of the peak-to-valley height, as shown in Figure 47.



(Figure 47)

WHAT FACTORS INFLUENCE SURFACE ROUGHNESS?

The most important factors affecting surface qualities are:

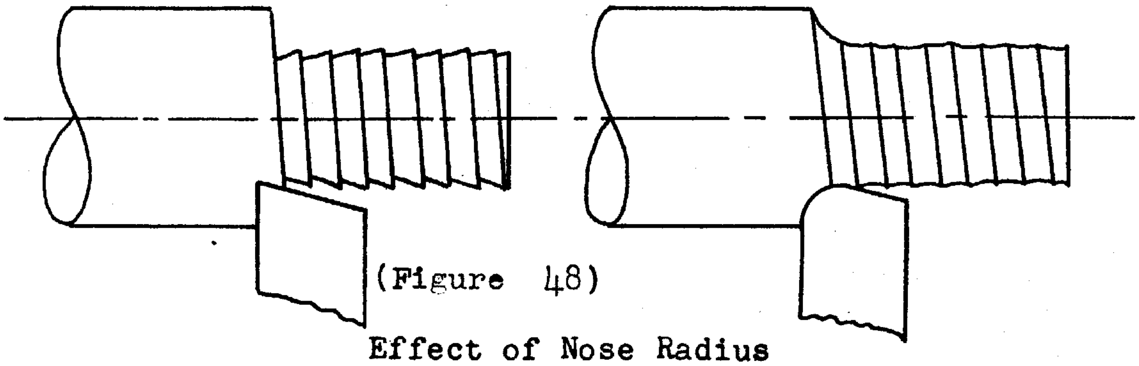
(1) Materials cut - high ductility of the material cut produces rough surfaces at low cutting speeds. Low carbon steels should be normalized, or quenched and drawn to reduce the ductility and improve the finish. Mechanical cold working will also reduce the ductility with beneficial results. Free cutting materials which include lead or sulphur have thinner chips and a minimum of "build up" on the point of the tool, so that the cutting condition is stable and the finish approaches the contour of the cutting edge of the tool. Brittle materials will break out below the surface, creating more roughness.

(2) Cutting speed - At slow cutting speeds a large unstable built-up edge causes high roughness. As the cutting speed is increased the built-up-edge becomes smaller and more stable, and the finish improves.

(3) Nose radius - The profile of the cutting tool is reproduced on the surface of the workpiece under ideal conditions. A larger radius will create a rough surface (Figure 48).

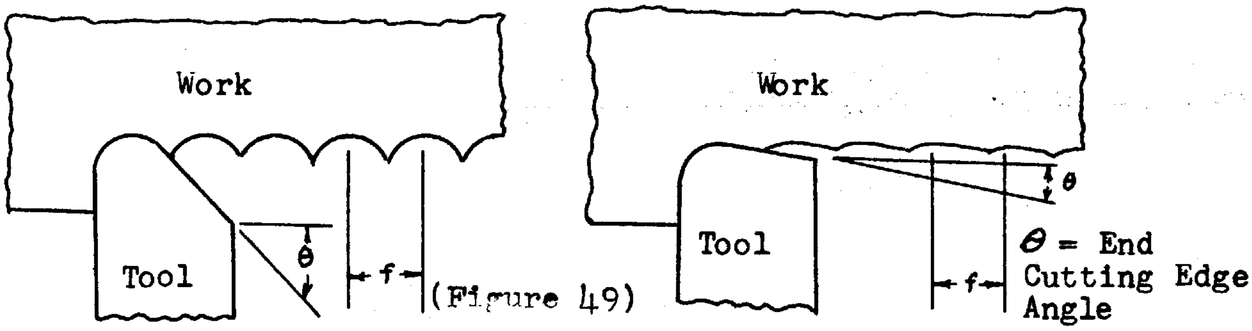
(4) **Feed** - is the spacing of the tool profile marks. Smaller feeds improve the surface finish.

(5) Smaller end-cutting-edge angles improve the surface finish, as shown in Figure 49, particularly at higher feed rates. Figure 49 is for a 6 degree end-cutting-edge angle.



(Figure 48)

Effect of Nose Radius



(Figure 49)

GRINDING SINGLE POINT TOOL

To grind tool bits to be used on an engine lathe for various turning operations, a bench or pedestal grinder is used for this purpose. The grinder should be equipped with two different grade grinding wheels so that one wheel may be used for roughing the tool angles and the other for finishing grinding to final shape. The pedestal grinder should have proper safety glass shields and the operators should wear safety goggles.

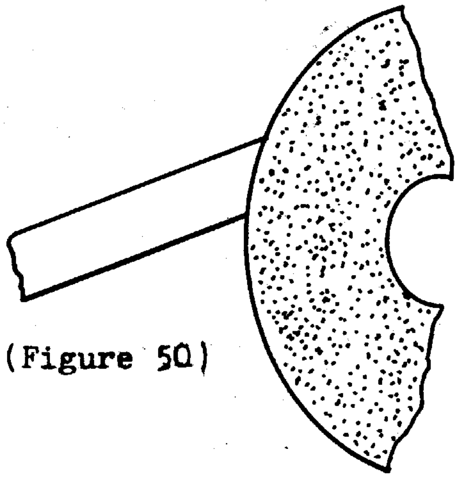
The grinding wheel face should be dressed if needed before the operation is started. The tool bit, depending on the size, may be held between the thumb and index fingers of both hands, and positioned against the grinding wheel face illustrated in Figure 50.

The first angle to be rough ground should be the end cutting edge angle by positioning the tool bit, as illustrated; the relief angle can also be ground at the same time. Tilt the tool bit until the bottom of the tool strikes the face of the wheel face and apply slight pressure on the bit and move the tool bit across the face of the grinding wheel. This prevents glazing of the wheel. (Note Figures 50 and 51). After the end cutting edge and relief angle have been rough ground, reposition the tool bit to grind the side cutting edge angle and the side relief angle at the same time by holding the tool bit parallel with the wheel face and tilting the tool until the bottom of the tool strikes the wheel face (Figure 52). To form the nose radius on a tool bit, position the sharp point of the tool on the face of the wheel, tilting the tool slightly so that the bottom of the tool makes contact with the wheel first and pivot the wheel on a radius to form the round nose (Figure 53). To grind the side rake angles, position the tool bit in front of the grinding wheel face by holding the side cutting edge angle horizontal and parallel with the face of the wheel and tilt the tool until the bottom edge strikes the wheel face first (Figure 54).

This will grind the positive side rake angle, and by pivoting the tool so that the wheel will grind a little more depth towards the body of the tool bit, the back rake angle can be ground while the tool is in this same position (Figure 54).

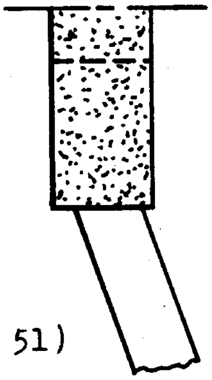
To grind the nose radius, pivit the tool bit slightly upwards and swing to right and left. Large tool bits that are used for heavy depth of cuts quite frequently require a chip breaker. This may be done by grinding a small groove on the top face of the tool close to the cutting edge. For finish turning all tool bits should be stoned with an abrasive stone; this will provide a keen cutting edge. The same practice should be done between several cuts when turning. This will save removing a tool bit for complete grinding.

GRINDING RELIEF AND RAKE ANGLES ON A TOOL BIT



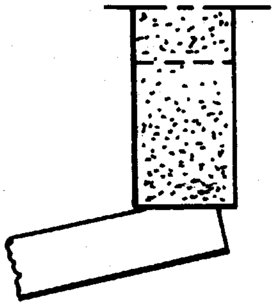
(Figure 50)

A. End Relief Angle



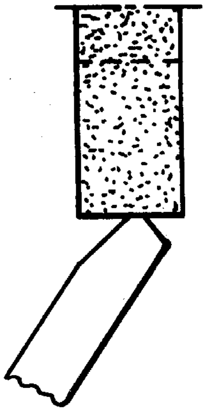
(Figure 51)

B. End Cutting Edge Angle



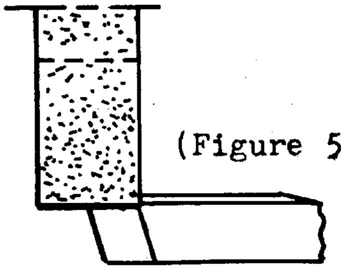
(Figure 52)

C. Side Cutting Edge Angle



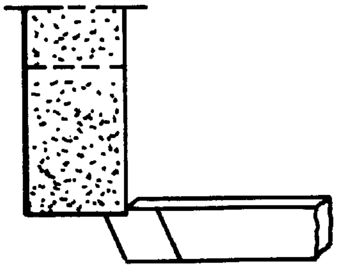
(Figure 53)

D. Nose Radius

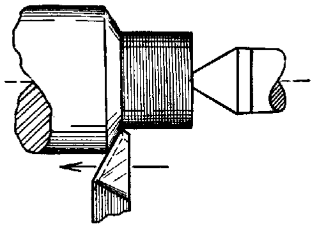


(Figure 54)

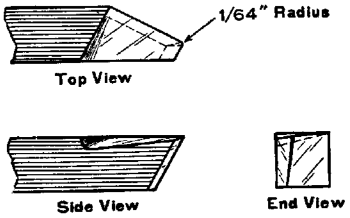
E. Side Rake



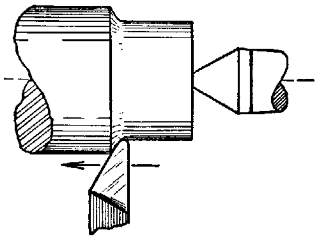
F. Chip Breaker



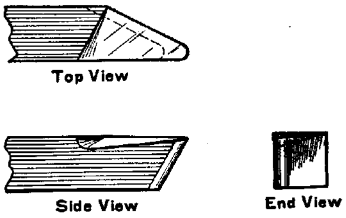
Application of Roughing Tool



Detail of Roughing Tool



Application of Finishing Tool



Detail of Finishing Tool

SPEED AND FEED CALCULATIONS FOR TURNING

In order to machine materials economically and efficiently on a lathe, it is necessary to have a knowledge of feeds and speeds for certain machining conditions. Cutting speed, feed, and depth of cut are terms which apply to all machining operations.

Speed may be defined as the peripheral speed at the cutting edge and is always given in fpm (surface feet per minute) since work diameters vary and the rpm on a spindle of a machine is meaningless without knowing the peripheral speed of the work material. The factors which govern the selection of cutting speeds are:

(1) Metals Being Machined - hard metals require slower cutting speeds than soft or ductile metals.

(2) Cutting Tool Materials Used - high speed steel cutting tools are normally used at slower cutting speeds than tungsten carbide materials or ceramics.

(3) The Tool Geometry and the Operation Being Performed - some machining operations require slower cutting speeds because of greater tool and work surface contact. For example, form turning or cutting off operations should be done at slower speeds than straight turning operations.

(4) Speed and Depth of Cut - when performing heavy roughing cuts, a much slower cutting speed should be employed than when taking light depths of cuts for finish turning operations.

(5) Coolants or Cutting Compounds - Ferrous materials when machined dry require slower cutting speeds than when a coolant or a cutting compound is employed. The coolant will reduce the heat, thereby permitting the speeding up of the cutting operation and increasing the tool life.

(6) Horse Power and Machine Capacity - Machines with higher horse power and speeds are more rigidly

> constructed and, if in good condition, would have the capabilities to use cutting tool materials designed for machining at higher speeds. This is essential for tungsten carbide and ceramics cutting tools in order to use these tools at the optimum cutting speeds and feeds.

The cutting speeds given in Table I are considered safe speeds for turning with high speed cutting bits. These are only averages and machine conditions, capacities and setups employed can increase these cutting speeds considerably. To calculate the surface feet per minute of a given workpiece that is being machined when the work diameter and the rpm are given, the following formula will compute fpm:

$$\text{fpm} = \frac{3.1416 \text{ x work diameter x rpm}}{12"}$$

For example, assume that it is desired to calculate he surface feet of a piece of work material that is 3 nches in diameter and it revolves at a speed of 250 rpm:

$$\text{fpm} = \frac{3.1416 \text{ x } 3 \text{ x } 250 \text{ rpm}}{12"}$$

To convert surface feet per minute to rpm, the following ormula can be used:

$$\text{rpm} = \frac{12" \text{ x fpm}}{3.1416 \text{ x work dia.}}$$

For example, assume that it is desired to calculate e rpm for a piece of low carbide steel that is 2 inches diameter having a surface feet per minute of 100 feet;

$$\text{rpm} = \frac{12" \text{ x } 100}{3.1416 \text{ x } 2"}$$

Feed is expressed as ipr (inches per revolution) or the distance that the tool advances for each revolution of the work. Factors governing the selection of feed are:

(1) Rigidity of the Work and the Setup Employed - a coarse feed is used for large rigid work which is held securely in a four-jaw chuck or between centers, while a fine feed would be required for long cylindrical work that may be held in a collet chuck or between centers.

(2) Finish Desired - to acquire a fine finish, a fine feed would be selected while a coarse feed would produce a rough surface.

(3) Depth of Cut - the feed used for heavy cuts cannot be as great as that used for light cuts due to the pressure asserted on the cutting tool when taking heavy cuts. The depth of cut determines how much the work diameter is reduced. Therefore, the workpiece diameter is reduced twice the depth of cut.

SPEED AND FEED CALCULATIONS FOR SHAPERS

To calculate speed and feed for shapers, the ram which moves with a reciprocating motion carries the tool head and the cutting tool over the work surface. The cutting speed on a shaper is determined by the speed at which the tool cuts over the work in feet per minute. Cutting speed for shapers is given in the number of strokes per minute. The shapers ram is adjustable for various settings to acquire the correct number of strokes per minute. The setting is dependent on the length of stroke. To calculate the required strokes per minute, multiply the cutting speed by 7 and divide the product by the number of strokes per minute.

$$N = \frac{CFS \times 7}{L}$$

N = number of strokes per minute
cfs = cutting speed
L = length of stroke in inches which is the length of the work on the machine, plus 1 inch.

This allows the overtravel of the tool to clear the work. For example, to determine the number of strokes per minute for roughing a piece of metal 10 inches long, the length of stroke required would be 10 + 1", giving a stroke of 11". For example, $n = \frac{20 \times 7}{11} = 12.7$. The following table gives recommended cutting speeds for various metals.

Materials To Be Machined	Carbon Steel Tools Cutting Speed (feet per minute)		High Speed Steel Tools	
	Roughing	Finishing	Roughing	Finishing
Cast Iron	30	20	60	40
Mild Steel	25	40	50	80
Tool Steel	20	30	40	60
Brass and Bronze	75	100	150	200
Aluminum	75	100	150	200

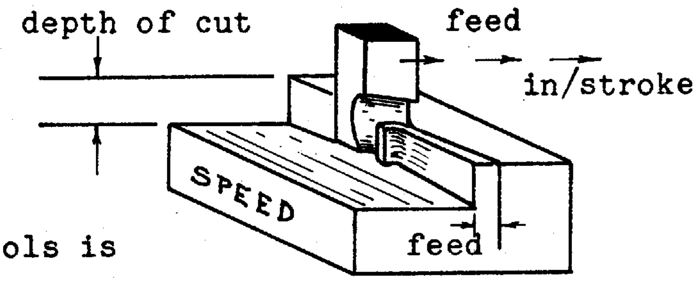
Table I. Recommended Cutting Speeds for Various Metals.

Feed - refers to the distances the tool advances for each stroke of the shaper ram. Shaper feeds ranging from .010" per stroke up to approximately .180" per stroke may be obtained with more shapers.

Finish Desired - a fine feed is used on work desiring fine finish, while a coarse feed should be employed for rough cuts. Depth of cut will vary with fine finishes. Depth of cut for fine finishes with sharp tools should not exceed .005 inches depending on type of cut. When considerable material is to be removed by the feed, the cut should be held to a maximum.

Work-Tool Motion

Speed is relative motion between tool and work expressed in surface feet per minute (FPM).



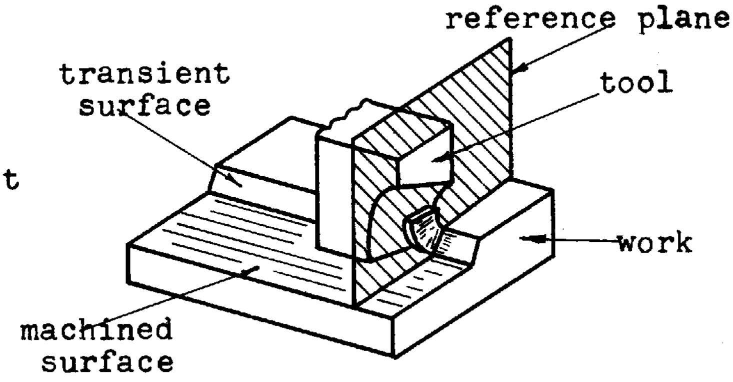
Linear

Feed with single-point tools is the amount the tool or work table is indexed and is measured parallel to the machined surface and perpendicular to tool path.

Depth of cut is the perpendicular height of the transient surface.

Imaginary Reference Plane

Note from illustration that this plane is perpendicular to tool work relative motion and contains the tool point needed in defining all tool lines.

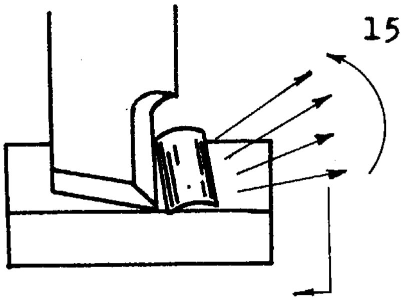


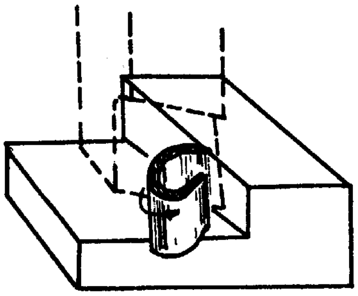
CHIP ACTION IN SHAPING AND PLANING

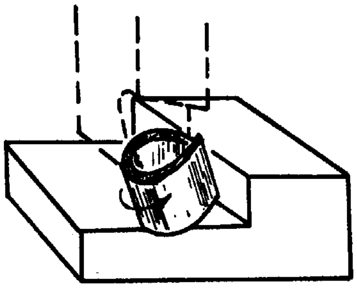
Cutting edge angles - These angles are measured on a reference plane from the machine surface to the end cutting edge and from a normal to the side cutting edge. The tool point is the apex.

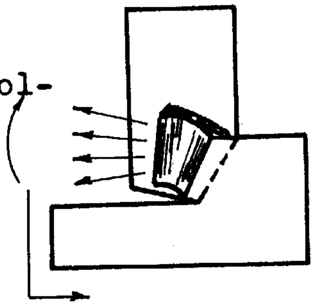
Tool face slope - This is usually given by the four angles, all normal to the reference plane. Back and side rakes are normal to and on machine surfaces. The resultant rake equals rake and inclination are normal to and on transient surface.

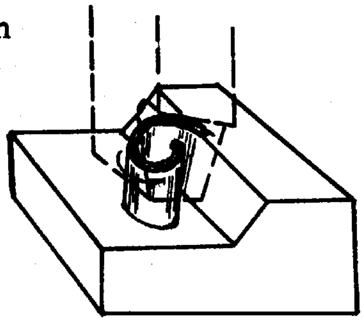
Chip Flow Controlled by Tool Angles - The chip disposal surface finish and tool life are influenced by the direction of chip flow. The following illustrations show the effect of changing inclination and cutting edge angles. Note that as the inclination increases, the cutting edge becomes more inclined in a direction similar to the back rake. This tilts the chip plane to a spiral upward direction directing the chip away from the machine surface. As the side cutting edge angle increases, the transient surface slopes even more, lifting the resulting rake plane and chip spiral, thereby causing the chip to flow away from the surface.

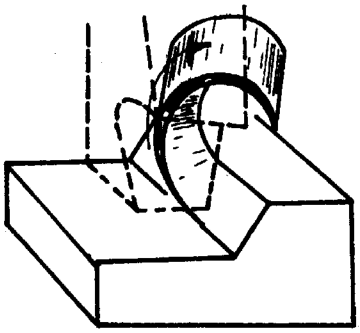


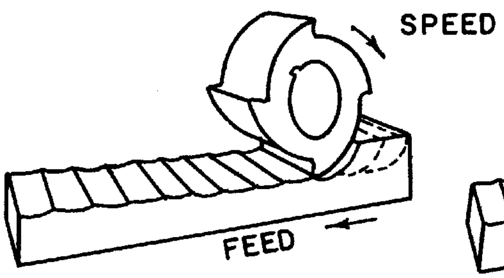




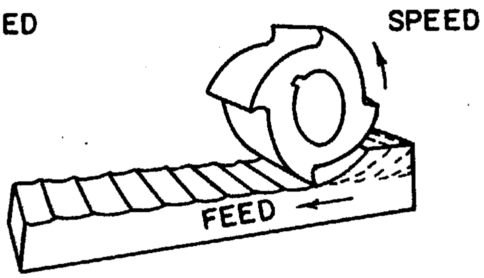








DOWN MILLING



UP MILLING

SPEED AND FEED CALCULATIONS FOR MILLING

The proper selection of speeds and feeds is fundamental for the best performance of all milling cutters. Climb cutting and rigid machines with sufficient power are highly recommended for milling with high-speed-steel cutters.

Speeds - exact speed and feed recommendations for milling are difficult because of the number of variables. In general, surface speed of milling cutters should vary inversely with the hardness of the material to be milled. Soft materials can be milled at high speeds; hard materials call for low speeds.

Finish and accuracy improve with higher speed, lower feed and shallow depth of cut.

Where maximum stock removal is the prime objective, milling speeds should be held to the lower limit of the ranges indicated in Table II. If the available horsepower permits faster rates of stock removal, then an increase in the rate of feed or depth of cut should be considered rather than an increase in speed. In every instance, speed will depend upon the condition of the milling machine and the rigidity of the workpiece and fixtures.

Where their application is recommended, Cast-Alloy cutters should be run at approximately twice the speed of High-Speed-Steel cutters. Carbide cutters should be run at approximately five times the speed of High-Speed-Steel cutters. Machine rigidity and climb milling are prerequisites for best results with both Cast-Alloy and Carbide milling.

Feeds - the highest production rate is obtained when each tooth in the cutter takes the largest possible cut. The heat generated in a heavy chip is proportionately less than in a light chip. Cutter life, as expressed in cubic inches of metal removal between grinds, increases with higher feed rates.

All feed rates should be calculated on the basis of feed per tooth. Feed rates expressed in inches per minute of table travel can be misleading because of variations in numbers of teeth in cutters of the same diameter.

Normal feed per tooth can be increased without detrimental effect on cutter life, provided the following conditions exist:

(1) Milling machine is in good condition, with ample power available.

(2) Fixture is rigid and designed to bring cut close to the milling table.

(3) Proper milling cutter selected for the material being machined.

Rigid setups, soft materials, and shallow cuts permit heavier feeds. Frail setups, thin cutters, deep slots, stringy material and high finish requirements call for lower feeds per tooth.

As a guide in setting up an initial job, the following table of suggested feeds should prove of value: TABLE II

Type of Cut	Starting feed per tooth
Face Milling	.008
Straddle Milling	.008
Channel or Slot Milling	.008
Slab Milling	.007
End Milling or Profiling	.004*
Sawing	.002

* For end mills smaller than ½ inch diameter, feeds per tooth must be much lower than the figure given.

Horsepower Comsumption in Milling - With the higher speeds and feeds that are possible with present-day cutters, especially carbide cutters, horsepower requirements are correspondingly higher. It is important, therefore, to ascertain that sufficient power is available to handle the desired cuts with these higher speeds and feeds.

By introducing a constant, C, corresponding to the machinability of the material to be cut, it is possible to calculate the horsepower required for a given cut as follows:

hp = Motor horsepower

d = Depth of cut in inches

w = Width of cut in inches

F = Feed (inches per minute)

f = Feed per tooth in inches

T = Number of teeth in cutter

rpm = Revolutions per minute of cutter

C = Machinability constant

$$\text{Then hp} = \frac{d \times w \times F}{C}$$

$$\text{or hp} = \frac{d \times w \times T \times f \times rpm}{C}$$

Values of C for various materials, based on 60% machine efficiency and a 25% allowance for dulling, are:

Work Material	C (constant)
Aluminum, Magnesium	4.0 plus
Brass	2.5
Bronze, Copper	2.0
Cast Iron	1.5
Steel, up to 150 Brinell	.75
Steel, 300 Brinell	.6
Steel, 400 Brinell	.5

Coolants or Lubricants - On many milling operations, it is important that careful consideration be given selection and application of a coolant. Coolants are used on milling operations for three principal reasons:

> Control of tool temperature. It is important that tool temperature be kept below the point of damage to the tool. Coolant is seldom used on carbide milling applications. Coolant flow on any job should be steady and in sufficient

volume to maintain the desired cooling effects.

Control of work temperature. Close size control of workpieces is possible only if reasonable control of expansion from heating is exercised. Coolant is applied to carry away the full heat generated by machining.

Reduced friction during chip formation. Careful investigation has shown that the action of a coolant on a chip forms a film coating with lubricating properties. The heat generated in chip formation is radically reduced through this lubricating action. Reduction of heat from chip formation automatically reduces the total heat to be absorbed by the tool and the work material. This explains why small amounts of coolant which are effective film formers are often more efficient than copious quantities of coolant which act merely as a refrigerant.

POWER CALCULATIONS

The power requirement for metal cutting under average conditions is calculated from the following formula:

$$HP_{motor} = \frac{A \times B}{0.7}$$

Where:

A = Unit HP factor (hp/in^3/min) from Table III

B = The metal removal rate calculated from Table III

.7 = Average assumed machine efficiency factor

When more than one tool is cutting at the same time, calculate the HP requirements for the individual tools and add for total HP.

If extremely light or extra heavy cuts are taken, a fourth factor, the feed correction factor, should also be used. The formula will then read:

$$HP_{motor} = \frac{A \times B \times C}{0.7}$$

Where: C = feed correction factor from Table IV.

TABLE III

AVERAGE UNIT HORSEPOWER FACTORS

Ferrous Materials:

Work Matl.	Brinell Hardness Numbers Up to 175	Up to 275	Up to 400
Plain Carbon Steel	0.5	0.9	1.1
Free Cutting Steel	0.4	0.5	-
Alloy Steel	0.6	0.8	1.3
Cast Iron	0.3	1.0	-

Non Ferrous Materials:

	Soft	Medium	Hard
Brass	.33	.50	.83
Leaded Brass	-	.25	-
Bronze	.33	.50	.83
Copper (pure)	-	.91	-
luminum	.25	.25	.33
onel	-	.69	1.4
inc Alloy (die cast)	-	.25	-
agnesium Alloy	-	.10	-

TABLE IV

FEED CORRECTION FACTORS

ght Cuts:

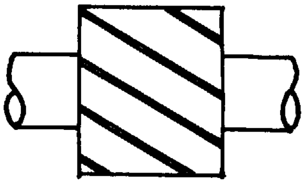
ed ipr or ipt	.001	.0015	.002	.0025	.003	.004
factor	1.55	1.45	1.4	1.33	1.3	1.22

avy Cuts:

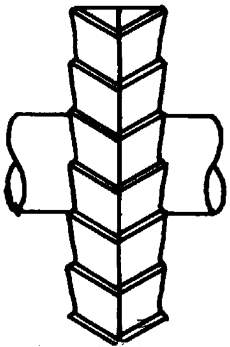
ed ipr or ipt	.030	.040	.050	.060	.070	.080
factor	0.86	0.82	.79	.76	.74	.73

GUIDE TO CORRECT FEED SELECTION

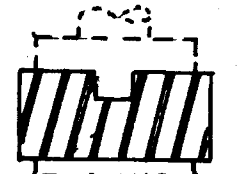
Feed Per Tooth per Revolution = Chip Load



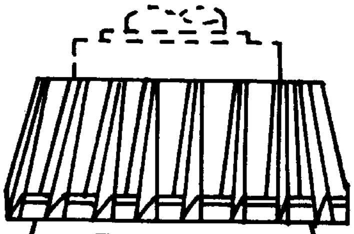
Plain Slab



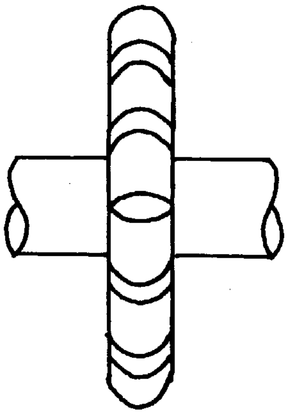
Side



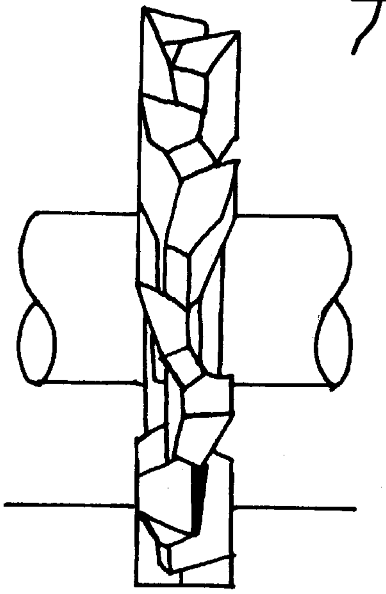
End Mill



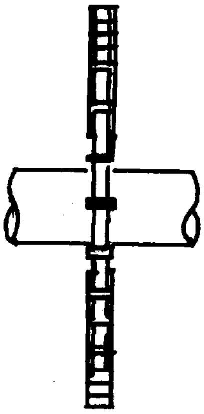
Face Mill



Form



Staggered Tooth



Saw

RECOMMENDED CHIP LOAD TABLES

Type of Cutter	In Cast Iron	In Steel	In Brass, Bronze Aluminum
Face Mill, H.S.	.020 to .025	Less 40%	Plus 50%
Slab Mill, H.S.	.010 to .015	Less 40%	Plus 50%
Slotting Cutter, H.S.	.006 to .012	Less 40%	Plus 50%
Form Mill, H.S.	.004 to .006	Less 40%	Plus 50%
End Mill, H.S.	.002 to .010	Less 40%	Plus 50%
Saw, H.S.	.001 to .003	Less 40%	Plus 50%
Cemented Carbide Face Mill	.008 to .012	.004 to .008	.010 to .016

TABLE V

In general, select the proper SPEED for work material and cutter; and then determine the feed, within the above limits, according to the cut and the power available or the finish required.

RECOMMENDED CONDITIONS FOR MACHINING HIGH STRENGTH THERMAL RESISTANT ALLOYS

by

METCUT RESEARCH ASSOCIATES INC.
CINCINNATI 9, OHIO

RECOMMENDED CUTTING CONDITIONS FOR MACHINING AISI 4340 STEEL QUENCHED AND TEMPERED TO 49-52 R_c

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
Turning 52 R_c	C-8 Carbide	SR: -5° SCEA: 15° BR: -5° ECEA: 15° Relief: 5°	1/2" Sq. Throwaway holder with mech. chip breaker	.100"	-	.009"/rev.	150 ft./min.	47 min.	.016"	None
Turning 52 R_c	T-15 HSS	SR: 15° SCEA: 0° BR: 0° ECEA: 5° Relief: 5°	5/8" Sq. Tool Bit	.060"	-	.009"/rev.	25 ft./min.	65 min.	.060"	Soluble Oil (20:1)
Face Milling 52 R_c	C-6 Carbide	AR: 0° ECEA: 5° RR: -15° Cl: 8° CA: 45°	5" Dia., 5 Tooth Inserted Tooth Face Mill	.100"	2"	.005"/tooth	150 ft./min.	65"/tooth	.016"	None
Side Milling 52 R_c Up Milling Setup	C-6 Carbide	AR: -5° ECEA: 5° RR: -10° Cl: 8° CA: 45°	7" Dia., 6 Tooth Inserted Tooth Face Mill	.100"	1-3/4"	.0075"/tooth	150 ft./min.	65"/tooth	.016"	None
Slot Milling 52 R_c Down Milling Setup	C-2 Carbide	AR: 5° bi-negative RR: -10° ECEA: 1° CA: 45° x .030" Cl: 8°	6" Dia., 6 Tooth Brazed Tooth Slotting Cutter	.250"	1"	.005"/tooth	190 ft./min.	38"/tooth	.016"	None
End Milling 52 R_c	C-2 Carbide	AR: 0° ECEA: 3° RR: 0° Cl: 15° CA: 45° x .030"	1-1/4" Dia., 4 Flute Heavy Duty Brazed Tip End Mill	.250"	1-1/4"	.0015"/tooth	50 ft./min.	78"	.016"	(1) Soluble Oil (20:1)

(1) Applied as spray mist through axis of cutter.

(continued)

RECOMMENDED CUTTING CONDITIONS FOR MACHINING AISI 4340 STEEL QUENCHED AND TEMPERED TO 49-52 R_C

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
End Milling 49 R_c	T-15 HSS	35° RH Helix CA: 45° x .060" Per. Cl: 6°	3/4" Dia., 4 Flute End Mill	.250"	3/4"	.001"/tooth	55 ft./min.	70"	.016"	Soluble Oil Flood (20:1)
Drilling 50 R_c	T-15 HSS	2 Flute, 118° Crankshaft Point 7° Clearance	1/4" Dia. Drill 2-1/2" Long	.500" Thru Hole	-	.001"/rev.	30 ft./min.	100 + Holes	*	Highly Sulphurized Oil + Light Machine Oil (1:1)
Drilling 52 R_c	Same	Same	Same	Same	-	Same	20 ft./min.	34 Holes	.016"	Same
Tapping 50 R_c	M-10 HSS	4 Flute Taper Tap 60% Thread	5/16-18 NC Taper Tap	.500" Thru Hole	-	-	5 ft./min.	146 Holes	Tap Breakage	Highly Chlorinated Oil + Inhibited Trichloroethane (3:1)
Tapping 50 R_c	(1) Same	4 Flute Taper Tap 75% Thread	Same	Same	-	-	Same	13 Holes	Tap Breakage	Same
Tapping 52 R_c	M-10 HSS Cyanided	4 Flute Taper Tap 60% Thread	Same	Same	-	-	Same	65 Holes	Tap Breakage	Same

* Test discontinued before .016" wearland was obtained.

(1) Higher tap life can be obtained using cyanided taps.

RECOMMENDED CUTTING CONDITIONS FOR MACHINING VASCO JET 1000 QUENCHED AND TEMPERED TO 50-52 R_c

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
Turning 52 R_c	C-8 Carbide	SR: -5° SCEA: 15° BR: -5° ECEA: 15° Relief: 5°	1/2" Sq. Throwaway holder with mech. chip breaker	.100"	-	.009"/rev.	100 ft./min.	50 min.	.016"	None
Turning 52 R_c	T-15 HSS	SR: 15° SCEA: 0° BR: 0° ECEA: 5° Relief: 5°	5/8" Sq. Tool Bit	.060"	-	.009"/rev.	20 ft./min.	55 min.	.060"	Highly Sulphurized Oil
Face Milling 52 R_c	C-2 Carbide	AR: 0° ECEA: 5° RR: -15° Cl: 8° CA: 45°	5" Dia., 5 Tooth Inserted Tooth Face Mill	.100"	2"	.005"/tooth	125 ft./min.	80"/tooth	.016"	None
Side Milling 52 R_c Down Milling Setup	C-2 Carbide	AR: 0° ECEA: 5° RR: -15° Cl: 8° CA: 45°	7" Dia., 6 Tooth Inserted Tooth Face Mill	.100"	1-3/4"	.0075"/tooth	150 ft./min.	65"/tooth	.012"	None
Slot Milling 52 R_c Down Milling Setup	C-2 Carbide	AR: 5° bi-negative RR: 10° ECEA: 1° CA: 45° x .030" Cl: 8°	6" Dia., 6 Tooth Brazed Tooth Slotting Cutter	.250"	1"	.005"/tooth	190 ft./min.	50"/tooth	.012"	None
End Milling 52 R_c	C-2 Carbide	AR: 0° ECEA: 3° RR: 0° Cl: 15° CA: 45° x .030"	1-1/4" Dia., 4 Flute Heavy Duty Brazed Tip End Mill	.250"	1-1/4"	.0015"/tooth	60 ft./min.	105"	.016"	(1) Soluble Oil (20:1)

(1) Applied as spray mist through axis of cutter.

(continued)

RECOMMENDED CUTTING CONDITIONS FOR MACHINING VASCO JET 1000 QUENCHED AND TEMPERED TO 50-52 R_c

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
Drilling 50 R_c	M-33 HSS	2 Flute, 118° Crankshaft Point 7° Clearance	1/4" Dia. Drill 2-1/2" Long	.500" Thru Hole	-	.001"/rev.	40 ft./min.	105 Holes	.016"	Highly Sulphurized Oil + Light Machine Oil (1:1)
Drilling 52 R_c	Same	Same	Same	Same	-	Same	Same	68 Holes	.016"	Same
Tapping 50 R_c	M-10 HSS Cyanided	4 Flute Taper Tap 60% Thread	5/16-18 NC Taper Tap	.500" Thru Hole	-	-	5 ft./min.	75 + Holes	*	Highly Chlorinated Oil + Inhibited Trichloroethane (3:1)
Tapping 50 R_c	(1) M-10 HSS	4 Flute Taper Tap 75% Thread	Same	Same	-	-	Same	8 Holes	Tap Breakage	Same
Tapping 52 R_c	M-10 HSS Cyanided	4 Flute Taper Tap 60% Thread	Same	Same	-	-	Same	40 + Holes	*	Same
Tapping 52 R_c	Same	4 Flute Taper Tap 75% Thread	Same	Same	-	-	Same	7 Holes	Tap Breakage	Same

* Test discontinued; tap still cutting.

(1) Tap life can be improved by using cyanided taps.

RECOMMENDED CUTTING CONDITIONS FOR MACHINING D6AC STEEL QUENCHED AND TEMPERED TO 56 R_c AND 58 R_c

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut inches	Width of Cut inches	Feed	Cutting Speed ft./min.	Tool Life	Wear-land inches	Cutting Fluid
Turning 56 R_c	C-4 Carbide	BR: -5° SCEA: 15° SR: -5° ECEA: 15° Relief: 5° NR: 1/32"	1/2" square throwaway holder with mech. chip breaker	.062	-	.005" per rev.	75	38 min.	.016	None
Turning 56 R_c	030 Ceramic	BR: -5° SCEA: 15° SR: -5° ECEA: 15° Relief: 5° NR: 1/32"	1/2" square throwaway holder with mech. chip breaker	.062	-	.005" per rev.	175	26 min.	.016	None
Face Milling 56 R_c Down Milling Setup	C-2 Carbide	AR: 0° ECEA: 6° RR: -15° Clearance: 10° CA: 45°	4" diameter face mill	.060	2	.010" per tooth	65	65" per tooth	.016	None
Face Milling 58 R_c Down Milling Setup	C-2 Carbide	AR: 0° ECEA: 6° RR: -15° Clearance: 10° CA: 45°	4" diameter face mill	.060	2	.008" per tooth	65	25" per tooth	.016	None
Slot Milling 56 R_c Down Milling Setup	C-2 Carbide	AR: -5° bi neg. RR: 0° ECEA: 1° CA: 45° x .030" Clearance: 10°	6" dia. x 1" wide inserted tooth slotting cutter	.125	1	.003" per tooth	230	40" per tooth	.020	None
Slot Milling 58 R_c Down Milling Setup	C-2 Carbide	AR: -5° bi-neg. RR: 0° ECEA: 1° CA: 45° x .030" Clearance: 10°	6" dia. x 1" wide inserted tooth slotting cutter	.125	1	.002" per tooth	125	48" per tooth	.020	None

RECOMMENDED CUTTING CONDITIONS FOR MACHINING D6AC STEEL QUENCHED AND TEMPERED TO 56 R_c AND 58 R_c

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut inches	Width of Cut inches	Feed	Cutting Speed ft./min.	Tool Life	Wear-land inches	Cutting Fluid
End Mill Slotting 56 R_c	C-2 Carbide	AR: 0° ECEA: 5° RR: 0° Clearance: 15° CA: 45° x .030"	1-1/4" dia., 4 flute heavy duty, brazed tip end mill	.125	1-1/4	.003" per tooth	40	54 inches	.016	(1) Soluble Oil (1:20)
Drilling 56 R_c	C-2 Carbide	Point Angle: 118° Helix Angle: 0° Clearance: 10° Notched Point	.250" dia. carbide tipped die drill	1/2" thru hole	-	.001" per rev.	115	70 holes	.016	Highly Chlorinated Oil
Drilling 58 R_c	C-2 Carbide	Point Angle: 118° Helix Angle: 0° Clearance: 10° Notched Point	.250" dia. carbide tipped die drill	1/2" thru hole	-	.001" per rev.	115	40 holes	.016	Highly Chlorinated Oil
Reaming 56 R_c	C-2 Carbide	Helix Angle: 0° (2) Corner Angle: 45° Clearance: 10°	Standard .272" dia. 4 flute carbide tipped chucking reamer	1/2" thru hole	-	.002" per rev.	65	60 holes	.012	Highly Chlorinated Oil

SURFACE GRINDING

Wheel Grade	Grinding Fluid	Wheel Speed feet/minute	Table Speed feet/minute	Down Feed inches/pass	Cross Feed inches/pass	G Ratio
32A46H8VBE	Highly Sulphurized Oil	6000	40	.001	.050	75

(1) Applied as spray mist through axis of cutter

(2) 5° negative rake land honed on tooth corners approximately .010" wide

RECOMMENDED CUTTING CONDITIONS FOR MACHINING
RENE 41 SOLUTION TREATED AND AGED TO 365 BHN

Operation	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut inches	Width of Cut inches	Feed	Cutting Speed ft./min.	Tool Life	Wear-land inches	Cutting Fluid
Turning	C-2 Carbide	BR: 0° ECEA: 15° SR: 5° Relief: 5° SCEA: 15° NR: 1/32"	1/2" square throwaway holder with mech. chip breaker	.062	-	.009 in/rev	70	28 min.	.016	Soluble Oil (1:20)
Turning	T-15 HSS	BR: 0° ECEA: 5° SR: 15° Relief: 5° SCEA: 0° NR: 1/32"	5/8" square tool bit	.062	-	.009 in/rev	12	81 min.	.030	Highly Chlorinated Oil
Face Milling	C-2 Carbide	AR: 0° TR: 5° RR: 7° Incl: -5° CA: 45° ECEA: 5° Clearance: 10°	4" diameter face mill	.060	2	.0065 in/tooth	63	29 in/tooth work travel	.030	Highly Chlorinated Oil
Face Milling	T-15 HSS	AR: 0° TR: 22° RR: 30° Incl: -22° CA: 45° ECEA: 5° Clearance: 10°	4" diameter face mill	.060	2	.011 in/tooth	22	75 in/tooth work travel	.030	Highly Chlorinated Oil
End Mill Slotting	T-15 HSS	30° RH Helix RR: 10° CA: 45° Peripheral Cl: 10° ECEA: 3°	3/4" diameter 4 tooth end mill 1" flute length	.250	3/4	.002 in/tooth	18	69 inches work travel	.020	Soluble Oil (1:20)
Slot Milling Down Milling	C-2 Carbide	AR: -5° bi-negative RR: 5° ECEA: 1° CA: 45° x .030" Clearance: 10°	6" diameter single tooth inserted tooth cutter	.125	1	.003 in/tooth	61	80 in/tooth work travel	.016	Highly Chlorinated Oil
Drilling	T-15 HSS	$118^{\circ}/90^{\circ}$ point angle, 3° clearance 29° helix angle split point	1/4" dia., heavy web type drill 2-1/2" O. L. 1-1/2" flute length	1/2" thru hole	-	.002 in/rev	17	95 holes	.020	Highly Chlorinated Oil

RECOMMENDED CUTTING CONDITIONS FOR MACHINING
RENE 41 SOLUTION TREATED AND AGED TO 365 BHN

Operation	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed ft./min.	Tool Life	Wear-land inches	Cutting Fluid
Tapping	M-10 HSS	2 flute plug tap spiral point 75% thread	5/16-24 NF plug tap	1/2" thru hole	-	-	5	140 holes	Tap Breakage	Highly Chlorinated Oil
Reaming	M-2 HSS	6 flute straight chucking reamer CA: 45° Clearance: 10°	.272" diameter reamer	1/2" thru hole	-	.005 in/rev	20	96 holes	.016	Highly Chlorinated Oil

SURFACE GRINDING

Wheel Grade	Grinding Fluid	Wheel Speed feet/minute	Table Speed feet/minute	Down Feed inches/pass	Cross Feed inches/pass	G Ratio
32A46J8VBE	Highly Sulphurized Oil	4000	40	.001	.050	10

RECOMMENDED CUTTING CONDITIONS FOR MACHINING
6Al-4V TITANIUM (1)

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
Turning 312 BHN	C-1/C-2 Carbide	SR: 6° SCEA: 6° BR: 0° ECEA: 6° Relief: 6°	5/8" Sq. Tool Bit	.050"	-	.009"/rev.	165 ft./min.	65 min.	.015"	Soluble Oil (10:1)
Turning 365 BHN	Same	Same	Same	Same	-	Same	150 ft./min.	70 min.	.015"	Same
Turning 312 BHN	M-3 HSS	SR: 5° SCEA: 0° BR: 0° ECEA: 5° Relief: 5°	5/8" Sq. Tool Bit	.050"	-	.005"/rev.	65 ft./min.	65 min.	.060"	Soluble Oil (10:1)
Turning 365 BHN	Same	Same	Same	Same	-	Same	55 ft./min.	70 min.	.060"	Same
Face Milling 312 BHN	C-1/C-2 Carbide	AR: 0° ECEA: 6° RR: -10° Cl: 12° CA: 30°	4" Dia., Single Tooth Face Mill	.050"	2"	.006"/tooth	97 ft./min.	42"/tooth	.015"	Soluble Oil (20:1)
Face Milling 365 BHN	Same	Same	Same	Same	Same	Same	Same	62"/tooth	.015"	Same

(1) For two heat treated conditions:
Annealed to 312 BHN
Solution Treated and Aged to 365 BHN

(continued)

RECOMMENDED CUTTING CONDITIONS FOR MACHINING
6Al-4V TITANIUM

Operation & Workpiece Hardness	Tool Material	Tool Geometry	Tool Used for Tests	Depth of Cut	Width of Cut	Feed	Cutting Speed	Tool Life	Wear-land	Cutting Fluid
Face Milling 312 BHN	T-15 HSS	AR: 0° ECEA: 6° RR: 0° Cl: 12° CA: 30°	4" Dia. Single Tooth Face Mill	.050"	2"	.005"/tooth	78 ft./min.	50"/tooth	.060"	Soluble Oil (20:1)
Face Milling 365 BHN	Same	Same	Same	Same	Same	Same	Same	45"/tooth	.060"	Same
Drilling 312 BHN	M-10 HSS	2 Flute, 118° Standard Point 7° Clearance	13/64" Dia. Drill 2-3/4" Long	.250" Thru Hole	-	.005"/rev.	32 ft./min.	175 Holes	.015"	Highly Sulphurized Oil
Drilling 365 BHN	Same	Same	Same	Same	-	Same	25 ft./min.	59 Holes	.015"	Same
Tapping 312 BHN	M-10 HSS	3 Flute Taper Spiral Point Tap 70% Thread	1/4-20 NC Spiral Point Tap	.250" Thru Hole	-	-	14 ft./min.	150 Holes	Tap Breakage	Highly Sulphurized Oil
Tapping 365 BHN	Same	Same	Same	Same	-	-	Same	30 Holes	Tap Breakage	Same

SPEED AND FEED CALCULATIONS

For Turning Tools, Milling Cutters, and Other Rotating Tools

To Find	Having	Formula
Revolutions per Minute = R.P.M.	Cutting Speed in Feet per Minute = C.S., & Diameter of Tool in Inches (or Diameter of Piece Being Turned) = D	$\text{R.P.M.} = \frac{\text{C.S.x12}}{\text{Dx3.1416}}$
Cutting (surface cutting) Speed in Feet per Minute = C.S.	Diameter of Tool in Inches (or Diameter of Piece Being Turned) = D, & Revolutions per Minute = R.P.M.	$\text{C.S.} = \frac{\text{Dx3.1416xR.P.M.}}{12}$
Feed per Minute in Inches = Fd.M.	Feed per Revolution in Inches = Fd.R, & Revolutions per Minute - R.P.M.	$\text{Fd.M.} = \text{Fd.R.xR.P.M.}$
Feed per Revolution in Inches = Fd.R.	Feed per Minute in Inches = Fd.M, & Revolutions per Minute = R.P.M.	$\text{Fd.R.} = \frac{\text{Fd.M.}}{\text{R.P.M.}}$
Feed per Tooth = Fd.T.	Number of Teeth in Tool = T, & Feed per Revolution in Inches = Fd.R.	$\text{Fd.T.} = \frac{\text{Fd.R.}}{\text{T}}$
Feed per Tooth = Fd.T.	Number of Teeth in Tool = T, Feed in Inches per Minute = Fd.M, & Speed in Revolutions per Minute = R.P.M.	$\text{Fd.T.} = \frac{\text{Fd.M.}}{\text{TxR.P.M.}}$
Number of Cutting Teeth per Minute = T.M.	Number of Teeth in Tool = T, & Revolutions per Minute = R.P.M.	$\text{T.M.} = \text{TxR.P.M.}$

SURFACE SPEED TABLE *and* TOOL SELECTOR CHART

TABLE OF SURFACE SPEEDS PER MINUTE

General H.S. Steel Cutting Range — GENERAL TANTUNG CUTTING RANGE — General Carbide Cutting Range

ACE PER UTE	40	50	60	70	80	90	100	110	120	140	160	180	200	250	300	350	400	450	500	600	SURFACE FEET PER MINUTE
N.	REVOLUTIONS PER MINUTE																				DIA. IN.
¼	611	764	917	1070	1222	1375	1528	1681	1833	2140	2444	2750	3056	3820	4584	5348	6112	6882	7640	9168	¼
⅜	408	509	611	713	815	916	1018	1120	1222	1426	1630	1832	2037	2546	3056	3563	4074	4584	5092	6112	⅜
½	306	382	458	535	611	688	764	840	916	1070	1222	1376	1528	1910	2292	2674	3056	3438	3820	4584	½
⅝	244	306	367	428	489	550	611	672	733	856	978	1100	1222	1530	1833	2139	2445	2750	3056	3666	⅝
¾	204	254	306	357	407	458	509	560	611	714	814	916	1018	1273	1528	1783	2037	2292	2546	3056	¾
⅞	175	218	262	306	349	393	436	480	523	612	698	786	872	1090	1310	1528	1746	1964	2183	2620	⅞
	153	191	229	267	306	344	382	420	458	534	612	688	764	955	1146	1337	1528	1719	1910	2292	1
⅛	136	170	204	238	272	305	339	374	407	476	544	610	678	850	1019	1188	1358	1528	1698	2038	1⅛
¼	122	153	183	214	244	275	305	336	366	428	488	550	611	764	917	1070	1222	1375	1528	1834	1¼
⅜	111	139	166	194	222	249	277	305	332	388	444	498	554	695	833	972	1111	1250	1389	1666	1⅜
½	102	127	153	178	204	229	254	280	305	356	408	458	509	637	764	891	1019	1146	1273	1528	1½
¾	87	109	131	153	175	196	218	240	262	306	350	392	436	545	655	764	873	982	1091	1310	1¾
	76	95	114	133	153	172	191	210	229	266	306	344	382	477	573	668	764	859	955	1146	2
¼	68	85	102	119	136	153	170	187	204	238	272	306	340	425	509	594	679	764	849	1018	2¼
½	61	76	92	107	122	137	153	168	183	214	244	274	305	382	458	535	611	688	764	916	2½
¾	55	69	83	97	111	125	139	152	166	194	222	250	278	345	417	486	556	625	690	834	2¾
	51	64	76	89	102	115	127	140	153	178	204	230	255	318	382	446	509	573	637	764	3
¼	47	59	70	82	94	106	117	129	141	164	188	212	234	295	353	411	470	529	590	706	3¼
½	44	54	65	76	87	98	109	120	131	152	174	196	218	270	327	382	437	491	540	654	3½
¾	41	51	61	71	81	92	102	112	122	142	162	184	204	255	306	357	407	458	509	612	3¾
	38	48	57	67	76	86	95	105	114	134	152	172	191	239	286	334	382	430	477	572	4
½	34	42	51	59	68	76	85	93	102	118	136	152	170	210	270	297	340	382	420	540	4½
	30	38	46	53	61	69	76	84	92	106	122	138	153	191	229	267	306	344	382	458	5
½	28	35	42	49	55	62	69	76	83	98	110	124	138	175	208	243	278	313	350	416	5½
	25	32	38	44	51	57	64	70	76	88	102	114	128	160	191	223	255	286	318	382	6
½	23	29	35	41	47	53	59	65	70	82	94	106	118	145	176	206	235	264	290	352	6½
	22	27	33	38	44	49	54	60	65	76	88	98	109	136	164	191	218	246	273	328	7
½	20.4	25	31	36	41	46	51	56	61	72	82	92	102	125	153	178	204	229	250	306	7½
	19.1	24	29	33	38	43	48	52	57	66.9	76	86	96	120	143	167	191	215	239	286	8
½	18	22	27	31	36	40	45	49	54	62	72	80	90	110	135	157	180	202	220	270	8½
	17	21.2	25	30	34	38	42	47	51	60.1	68	76	85	106	127	149	170	191	212	254	9
½	16.1	20.1	24	28	32	36	40	44	48	56	64	72	80	100.5	121	141	161	181	201	242	9½
	15.3	19.1	23	27	31	34	38	42	46	54	62	68	76	95.5	115	130	153	172	191	230	10
	13.9	17.4	20.8	24	28	31	35	38	41	48	56	62	70	87	104	122	139	156	174	208	11
	12.7	15.9	19.1	22	25	29	32	35	38	44	50	58	64	79	95	111	127	143	159	190	12

|←HIGH SPEED STEEL→|←—— TANTUNG ——→|←—— CEMENTED CARBIDE ——→|

TO USE THIS CHART find the proper surface speed and refer to the work diameter columns at extreme right or left. The correct R.P.M. is shown opposite the work diameter to be turned.

The colored areas in the above chart show the general cutting range for high-speed steel, Tantung and cemented carbide cutting tools. These speeds are for broad, general use and are subject to change because of the variables occurring in tools and material. A good rule to observe—start your Tantung at double the speed and carbides at two to three times the speed as used for high-speed steel tools on the same machine and work.

FEED AND SPEEDS FOR DRILLS OF HI-SPEED STEEL

Size of Drill Inches	Feed per Rev. Inches	Cast Steel	Alloy Steel	Tool and Carbon Steel	Hard Cast Iron	Malleable Iron	Mild Steel	Cast Iron	Bronze Brass
		Feet per Minute							
		40	50	60	80	90	100	110	200
		Revolutions per Minute							
1/16	.003	2445	3056	3667	4889	5500	6112	6724	12224
3/32	.0035	1628	2038	2442	3258	3666	4584	5043	9168
1/8	.004	1222	1528	1833	2445	2750	3056	3362	6112
5/32	.0045	976	1221	1465	1954	2198	2546	2802	5092
3/16	.005	815	1019	1222	1630	1833	2036	2242	4072
7/32	.0055	698	872	1047	1396	1570	1781	1962	3564
1/4	.006	611	764	917	1222	1375	1528	1681	3056
9/32	.0065	542	678	814	1084	1222	1375	1513	2750
5/16	.007	489	611	733	978	1100	1222	1344	2444
11/32	.0075	444	555	666	888	1000	1120	1233	2290
3/8	.008	407	509	611	815	917	1018	1121	2036
13/32	.0085	376	469	563	752	846	946	971	1892
7/16	.009	349	437	524	698	786	874	921	1748
15/32	.0095	326	407	488	652	732	819	881	1638
1/2	.010	306	382	458	611	688	764	840	1528
9/16	.0105	271	339	407	543	611	679	747	1358
5/8	.011	244	306	367	489	550	612	673	1224
11/16	.0115	222	277	333	444	500	555	611	1110
3/4	.012	204	255	306	407	458	508	559	1016
13/16	.0125	188	234	281	376	423	474	521	948
7/8	.013	175	218	262	349	393	438	482	876
15/16	.0135	163	203	244	326	366	407	448	814
1	.014	153	191	229	306	344	382	420	764