CHAPTER 11

Cutting Tools and Cutting Speeds

In the beginning of a discussion of lathe tools, it is necessary to call attention to the work done by a committee under the sponsorship of the American Standards Association. The committee consisted of members of the National Machine Tool Builders' Association, the Society of Automotive Engineers, the Metal Cutting Tool Institute, and the American Society of Mechanical Engineers.

This committee set up standard terms and definitions for tools used in machine-shop practice. All such terms and definitions are used in this chapter with the permission of the American Standards Association. These terms and definitions are discussed and illustrated and it will be to the benefit of the apprentice to learn them just as soon as possible. Get to use the correct terminology at the very beginning of your trade apprenticeship.

KINDS AND CARE OF CUTTING TOOLS

Cutting-tool Efficiency.[1] A machine tool is no more efficient than its cutting tool. Plants that machine widely different types of material on a production basis find it economical to use tools especially designed for each material, rather than to use one design of tools for all jobs. Magnesium alloys call for tools of somewhat different design from those used on iron or copper alloys, while cast iron calls for tools of different design from those used on alloy steel.

Cutting tools must combine sufficient strength to maintain a sharp cutting edge, sufficient wear resistance to prevent wearing of the cutting edge, sufficient toughness to prevent chipping of the cutting edge, and sufficient hardness to prevent picking up of the chips.

However, if a cutting tool is to give maximum production with the least amount of trouble and maintenance, it is necessary that the following five points be observed:

1. The right kind of tool material for the purpose of the tool must be selected.
2. The tool must be given the correct hardening heat-treatment.
3. The tool must be correctly designed.
4. The tool must be accurately made by the toolmaker.
5. The tool must be properly applied in the machining operation with the proper coolant and lubricant.

It is very necessary for the student in machine-shop practice to realize in the *beginning* that the cutting tool is a most important factor. There is nothing in shop work that should be given more thoughtful consideration than cutting tools. If one understands the principles underlying the successful action of the cutting tool, he has gone a long way in becoming expert in its use.

Time is always wasted if an improperly shaped tool is used. A dull tool is dangerous to use. It is fairly difficult for the beginner to hold a lathe tool against the grinding wheel and grind it just how and where it should be ground. He must first learn how it should be ground, and he must acquire by practice the knack of grinding it.

The action of a cutting tool depends primarily on three things: (1) the rigidity of the work, that is, of the piece itself, and the manner in which it is held in the machine; (2) the rigidity of the tool—its size and the way in which it is held; and (3) the shape of the cutting tool as it is ground, and as it is presented to the work.

The machine-tool builder takes care of the design of the machine to give the necessary strength and stability. The cutting action of the tool, however, depends on its shape and its adjustment in the holding device. This is especially interesting to the machinist because most of the cutting tools he uses in the shop must be shaped—or at least sharpened— and adjusted (set) by himself. The experienced workman will never use a dull tool, a poorly shaped tool, or a tool improperly set or insecurely held if he can help it.

---

[1] N. E. Woldman and R. C. Gibbons, *Machinability and Machining of Metals*, New York, McGraw-Hill Book Company, Inc., 1951.

Simple Fundamental Factors Governing Lathe Cutting-tool Design. If you look up the meaning of the word *cut* in a standard dictionary, you will find that it may mean any of the following: cleave, gash, incise, divide, carve, hew, trim, pare, remove, etc. Because one of the simplest words in the English language can be correctly used to convey so many different thoughts, each of a dozen different people might have his own particular impression of the meaning of the word *cut*. Little wonder then that so many people, including trained mechanics, find it difficult to describe clearly their own ideas of just how a cutting tool behaves, and why it behaves in a certain manner under certain conditions.

Perhaps our childhood experiences and our fear of being cut cause us to think of cutting as being primarily a "slicing" action, which can be brought about with little effort other than the effort of moving the cutting tool. Because of this, we seldom stop to think that when an instrument or tool cuts, *pressure*, as well as motion, is necessary. Broadly speaking, the thinner and the sharper the edge of the cutting tool, the less pressure is required to cut a piece of material.

In cutting metal with a machine-driven cutting tool, pressure is perhaps the most important factor in the cutting action. It is true that motion is also necessary, but the effect of motion is more noticeable and, therefore, more easily understood. Pressure, on the other hand—what causes it, how is it exerted on the tool, and how it affects both the tool and material—is not so easily understood without considerable study. However, it is largely because of the effect of pressure on the cutting action, that a machine tool is designed in a specific manner.

To begin with, it should be recognized that a metal-cutting tool actually "pushes" the metal apart. As a result, the pressures exerted on the cutting edge of a machine-driven cutting tool are very high, particularly as the rate of feed and depth of cut increases. This pressure force occurs in three different directions in the ordinary metal-turning operation: (1) the force 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; and (3) the force exerted against the end or nose of 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 necessary because they make the cutting action possible. At the same time, as they increase, they increase the friction between the tool and the workpiece with its attendant heat and tool wear.

Primarily, the location of the cutting edge is determined largely by the direction in which cutting pressure is to be applied. That is, the tool blank is ground so as to create a cutting edge so located that the cutting pressure will force it into the material being cut. The objective is to produce a cutting edge that will require a minimum of pressure to force it through the metal, yet will withstand the application of cutting pressure without breaking, and will resist wear.

Simple Fundamentals Governing the Form and Application of Lathe Tools. Fundamentally, all cutting tools are provided with a cutting edge or edges which are adaptations of three basic forms, namely, the *point*, the *straight edge*, and the *shaped edge* (Fig. 11-1). A *pointed* cutting edge (Fig. 11-1*a*) is the part of a tool where three or more surfaces come to form a point. A *straight* cutting edge (Fig. 11-1*b*) is the part of a tool where two flat surfaces intersect to form a straight line. A *shaped* cutting edge (Fig. 11-1*c*) is the part of a tool where two surfaces, one of which must be curved, intersect to form a curved line.

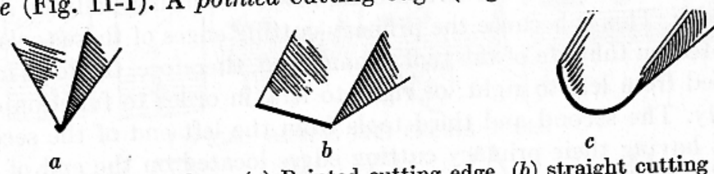


Fig. 11-1. Cutting edges: (*a*) Pointed cutting edge, (*b*) straight cutting edge, (*c*) shaped cutting edge. (*The Shell Oil Company*)

Examples of these basic forms as applied to cutting tools follow:

Tools with pointed *edges:* Scriber, handsaw, circular saw, rasp, grinding wheel, emery cloth.

Tools with straight *edges:* Cold chisels, wood chisels, mill file, keyway cutter, drill, countersink, tapered reamer with straight flutes.

Tools with shaped *edges:* Cape chisel, milling cutters (concave and convex), milling cutters with spiral cutting edges.

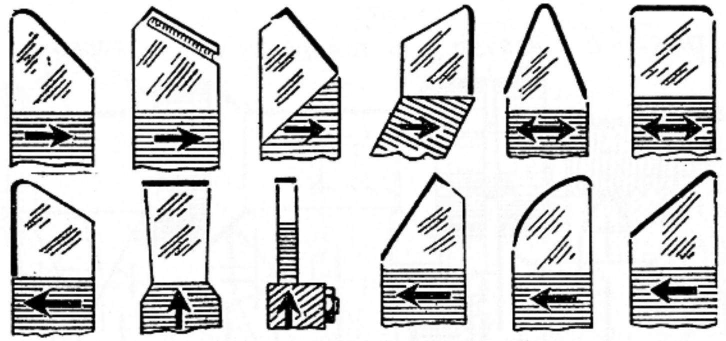
The cutting edge of a lathe tool is important for several reasons. In the first place, it is, strictly speaking, the only portion of the tool that actually cuts. The rest of the tool bit serves as a support for the cutting edge, carries away the heat generated by the cutting action, and aids in the removal of the chip. Thus, the cutting efficiency of any tool depends, to a great extent, upon the proper design and location of the cutting edge or edges. In addition, the location and shape of the cutting edges determine how the tool must be applied and what shape and surface finish it will produce.

Because the cutting edge of a lathe tool must always be advanced *into* the work, it is relatively easy to determine which lathe tool is intended for a certain type of operation by studying the shape and location of the cutting edge in relation to the tool's shank.

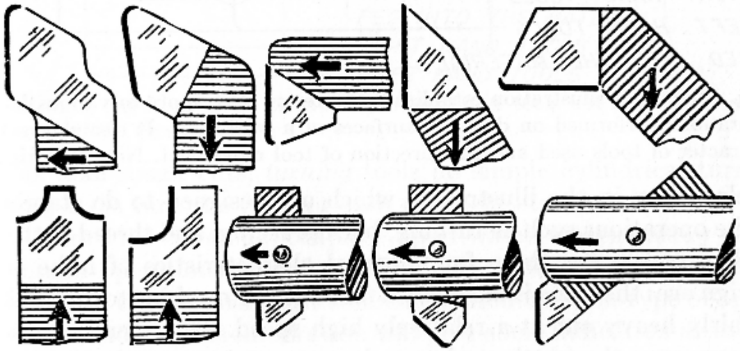
For instance, if you were seeking a tool suitable for use in a simple outside turning operation, wherein the cut is advanced by moving the tool either to the right or left, any tool having a cutting edge shaped like those in the two top rows in Fig. 11-2 (except second and third tool from the left, second row), would normally be satisfactory. This is because the primary cutting edges of these tools are located on the side of the tool's shank and, therefore, the tools must be fed from left to right, or right to left, in order to function correctly. The second and third tools from the left end of the second row, having their primary cutting edges located on the end of the tool's shank, would obviously be effective only when used for operations where they would be advanced into the work by feeding them "nose" first.

The shape and contour of the cutting edge also tell a story, if you study them very carefully. For instance, it is sometimes much simpler to grind the cutting edge of a tool convex or concave than it is to control the motion of a tool to make it produce concave or convex contours on the workpiece. Thus, lathe tools having cutting edges of such special shapes are designed primarily for special forming operations and are called *forming tools.*

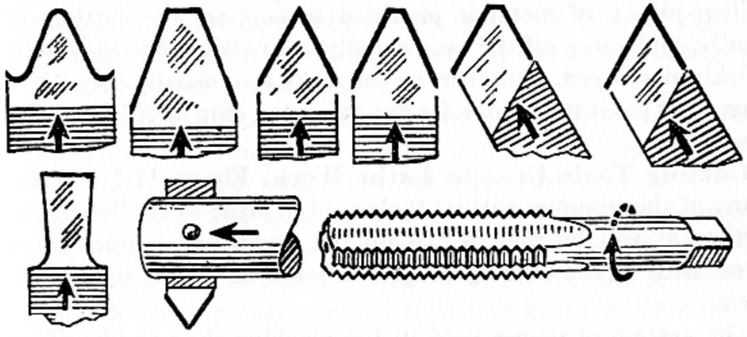
If you examine the typical lathe tools illustrated in Fig. 11-2, you will notice that they have two characteristics in common. They are relatively sturdy tools, that is, they contain a considerable amount of metal in proportion to the size of the cutting edge; and they are fairly simple in design. This is especially true of all the



TYPICAL OUTSIDE TURNING TOOLS

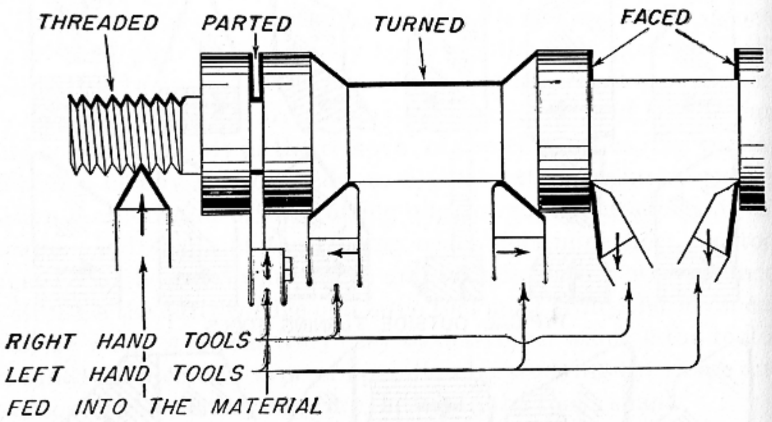


TYPICAL BORING AND FACING TOOLS



TYPICAL THREAD CUTTING TOOLS

Fig. 11-2. Typical lathe tools. Arrows indicate the direction in which the tools are fed. (*The Shell Oil Company*)



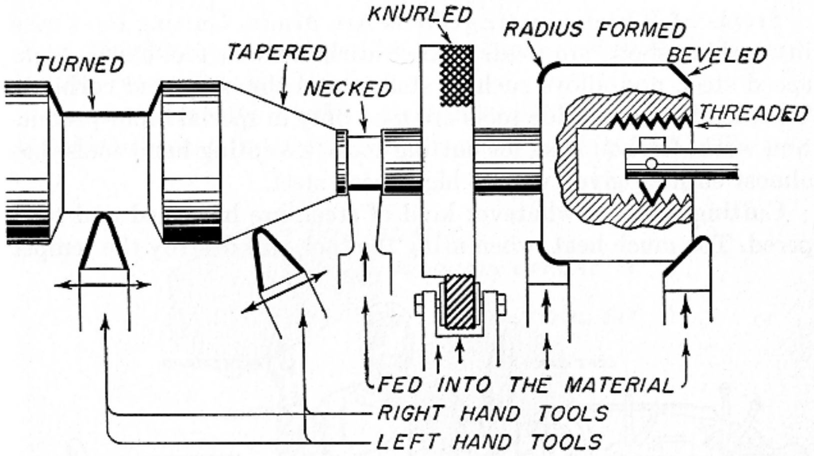


Fig. 11-3. This illustration establishes the terms that apply to various lathe operations performed on different surfaces of a workpiece. It also shows the character of tools used and the direction of tool movement. Note that right-hand tools cut from right to left, while left-hand tools cut from left to right. (*The Shell Oil Company*)

tools shown in the illustration which are designed to do standard lathe operations such as turning, boring, facing, and thread cutting.

The reason for these fundamental characteristics of lathe tool design are: the lathe is normally a fast-cutting machine tool. It takes a fairly heavy cut at a relatively high speed. This exerts a heavy pressure on the cutting edge and generates a great deal of heat. Unless plenty of metal is provided to support the cutting edge rigidly, and carry off the heat rapidly, its cutting efficiency will be quickly destroyed. However, as the lathe tool usually cuts "in the open," no great provisions for removing the chip as it is cut off are needed.

Cutting Tools Used in Lathe Work. Figure 11-2 illustrates many of the common cutting tools used in lathe work. Before going further, it will be well to explain the origin and reasons for the terms used in the naming of specific lathe tools and their various parts.

The system of names used in the machine shop to identify the various kinds of cutting tools is not too hard for the apprentice to grasp, providing the reasons why these names have been selected is clearly understood. Most lathe tool names are derived from the *operations each type of tool is designed to do;* for example, *roughing* tools take rough cuts, *turning* tools do simple cylindrical turning, *facing* tools turn the faces or ends of stock, etc.

Figure 11-3 shows a workpiece upon which a great many of the common operations have been done. In addition, the illustration shows the type of tool most commonly used for each type of operation. A study of this illustration will give some indication as to why different tools are used for threading, parting, turning, facing, etc. For example, a parting tool obviously could not be used efficiently to do a turning operation, chiefly because it has a cutting edge only on the end or nose of the tool.

Tool names are more specifically designated by prefixing those names with the terms *right-* or *left-hand.* For instance, right- (or left-) hand roughing tool, right (or left) turning tool, etc. The designation of a tool as a right-hand or left-hand is determined basically by the location of the tool side-cutting edges, but not in the manner that you would expect. A left-hand tool is one which has its side cutting edges on the *right* and *moves to the right.* The right-hand tool is one which has its cutting edges on the *left* and *moves to the left.* Thus a tool that began cutting on the operator's left was called a left-hand tool even though it moved to the right and had its side cutting edges on the right, and vice versa. Study Fig. 11-4 very carefully.

Steels of Which Cutting Tools Are Made. Cutting tools used in machine shops are made of high-carbon steel (tool steel), high-speed steel, and alloys such as stellite and the cemented carbides. The stellite and carbide tools are used only in special rapid-production work. Carbon steel for cutting tools, excepting hand tools, has almost entirely given way to high-speed steel.

Cutting tools, of whatever kind of steel, are hardened and tempered. Too much heat, when using the tool, will destroy the temper and make the cutting edge soft. In lathe work, or drilling, or milling—any machine operation where metal is cut—heat is generated. The chip is heated instantaneously, the work itself soon warms noticeably, and the tool point becomes very hot. In many machines a liquid coolant is used to carry away part of the heat, but in any case, if a *carbon-steel* tool is used and the speed of the cut is so high that enough heat is generated to blue the cutting edge, the temper is lost. The great value of *high-speed steel* lies in the fact that it will stand about three times as much heat as carbon steel and still retain its temper. A limit speed for carbon steel may be at least doubled when using high-speed steel; that is why *high-speed* steel is so named, and the reason for its success.

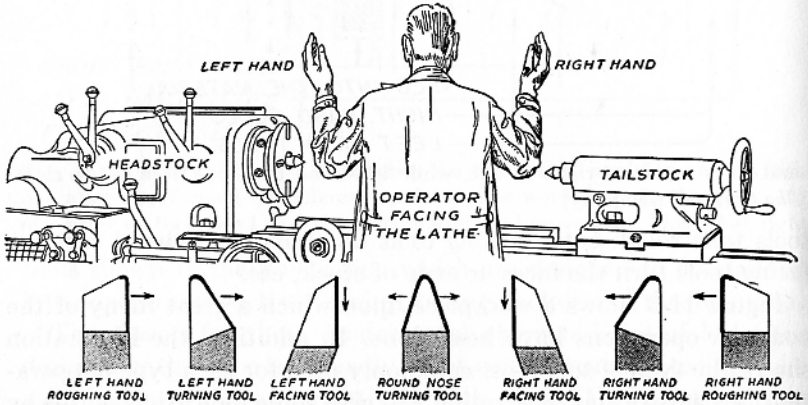


Fig. 11-4. How to distinguish between right- and left-hand tools. When the tool is held face up with the nose pointing away from the operator and the *cutting edge* is on the *right* side, it is considered a left-hand tool because it is used to make a cut that begins on the operator's left, even though it moves to his right; and vice versa, if the cutting edge of the tool is on the left side, it is called a right-hand tool. (*The Shell Oil Company*)

Terms Generally Used to Designate Different Lathe Tools. A *tool blank* when properly ground is a *tool bit* (Fig. 11-5). The tool bit consists of a *face*, a *nose*, and a *shank*. The under side of the shank forms the *base*. The *cutting edge* is formed by the meeting of two surfaces, or *faces*, two planes, or one plane and one curved face, or two curved faces. In Fig. 11-5, the *heavy black line* indicates the cutting edge. The same holds true for all heavy black lines in the illustrations for tool bits.

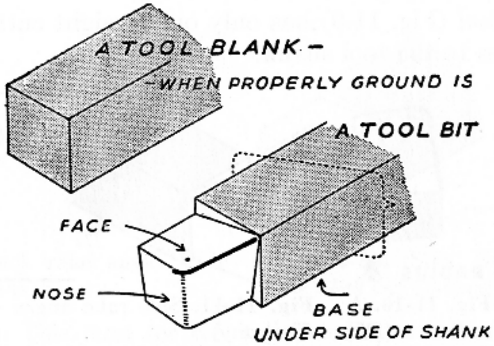


Fig. 11-5. Tool blank and ground tool. (*The Shell Oil Company*)

Fig. 11-6. A round-nose tool. (*The Shell Oil Company*)

Fig. 11-7. A *V-threading tool*. (*The Shell Oil Company*)

Fig. 11-8. An American National form-threading tool. (*The Shell Oil Company*)

The cutting edge or edges of a tool may be visualized as being in the form of a straight line, or a curved line, or a combination of both. When this is done, a round-nosed turning tool may be viewed as being made up of two straight cutting edges, set at angles to the center line of the shank, and one curved cutting edge (Fig. 11-6).

A *V-threading tool*, on the other hand, may be visualized as being made up of two straight cutting edges that meet at a point, the angle with the center line of the shank being 30 deg. or 60 deg. between the two cutting edges (Fig. 11-7).

An American National threading tool (Fig. 11-8) may be visualized as being made up of three straight lines or cutting edges, two of which are set at angles to the one at the end.

A *necking tool* (Fig. 11-9) has only one straight cutting edge, set at right angles to the tool shank.

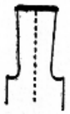


Fig. 11-9. A necking tool. (*The Shell Oil Company*)

Fig. 11-10. A radius. (*The Shell Oil Company*)

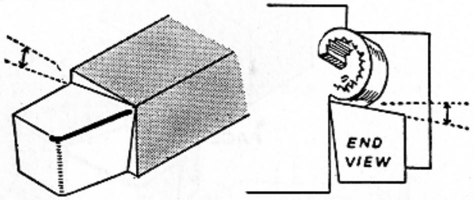


Fig. 11-11. Side rake angle. (*The Shell Oil Company*)

The term *radius* (Fig. 11-10) applies to the radius of a circle that would be formed if the part of the cutting edge of a tool that is rounded were completed. This arc of a circle is generally on the nose of a tool and may be ground to any radius required to do the given job.

A tool is ground to a given form for two reasons: (1) to produce a cutting edge of a given shape in a given position in relation to the shank of the tool; and (2) to produce a form that will permit the cutting edge to be fed into the workpiece so it can cut efficiently. The difference in form among tools is brought about by variations in the size of the angle to which the various planes involved are ground and in the radius to which portions of the cutting edge may be rounded.

DEFINITIONS: CUTTING-EDGE TERMS:

Side Rake. This term indicates that the plane that forms the face or top of a tool has been ground back at an angle sloping from the side cutting edge (Fig. 11-11). The extent of side rake influences the angle at which the chip leaves the workpiece as it is directed away from the side cutting edge.

Back Rake. This term indicates that the plane which forms the face or top of a tool has been ground back at an angle sloping from the nose. However, when a tool bit is held by a toolholder, the holder establishes the back-rake angle which normally is 16½ deg. The extent of back rake influences the angle at which the chip leaves the workpiece as it is directed away from the nose of the tool (Fig. 11-12).

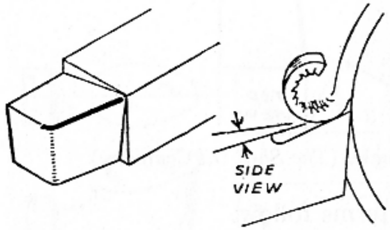


Fig. 11-12. Back rake angle. (*The Shell Oil Company*)

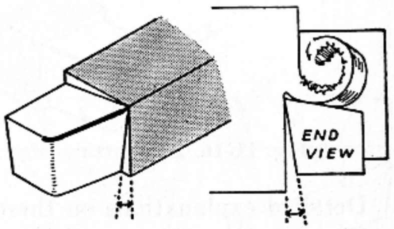


Fig. 11-13. Side clearance angle. (*The Shell Oil Company*)

Side Clearance. This term (or *side relief*) indicates that the plane that forms the flank or side of a tool has been ground back at an angle sloping down from the side cutting edge. Side clearance concentrates the thrust force exerted on the flank of a tool in a small area adjacent to the side cutting edge (Fig. 11-13).

End Clearance. This term (or *end relief*) indicates that the nose or end of a tool has been ground back at an angle sloping down from the end cutting edge (Fig. 11-14). End clearance concentrates the thrust force exerted on the nose of the tool in a small area adjacent to the end cutting edge.

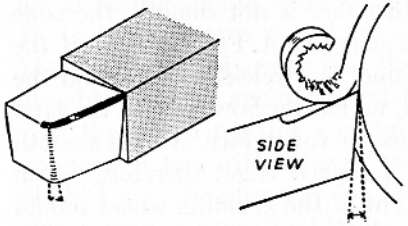


Fig. 11-14. End clearance angle. (*The Shell Oil Company*)

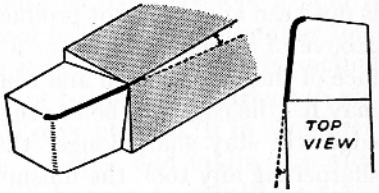


Fig. 11-15. Side cutting-edge angle. (*The Shell Oil Company*)

Side Cutting-edge Angle. This term indicates that the plane which forms the flank or side of a tool has been ground back at an angle to the side of the shank (Fig. 11-15), thereby establishing the angle of the side cutting edge in relation to the shank.

End Cutting-edge Angle. This term indicates that the plane which forms the end of a tool has been ground back at an angle sloping from the nose to the side of the shank, establishing the angle of the end of the tool in relation to the shank (Fig. 11-16).

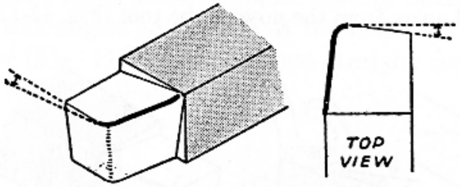


Fig. 11-16. End cutting-edge angle. (*The Shell Oil Company*)

Detailed explanations on these terms follow.

The Cutting Edge and the Faces That Form It. A cutting tool may have a single cutting edge, as a chisel or a lathe tool; two cutting edges as a twist drill; or several, as a reamer or a milling cutter. Any cutting edge is formed by the meeting of two surfaces, or *faces:* two plane surfaces, as for example, a flat chisel; or one plane and one curved; or both curved. Sometimes these faces are called merely the *front*, or *side*, or *top*, as in tools for lathe, shaper, and planer. Occasionally, a face is called the *lip* when referring to a lathe tool or a drill. The front of a tooth of a reamer or a milling cutter is called the *face* of the tooth, while the other cutting-edge surface is called the *land.*

In any tool, both surfaces that form the edge must be smooth to produce a keenness of edge. If either face is not smooth, the edge is not keen and it cannot produce a smooth cut. For example, if the groove of a milling cutter or a reamer is carelessly made, and the face of the tooth is torn and rough, no matter how smooth the land may be, the edge will be as rough as the rough face. Also, a smooth edge will stay sharp longer than a ragged edge; therefore, when sharpening any tool, the finishing cut of the grinding wheel should be light. The intelligent use of an oilstone is recommended.

When the cutting edge is broken or rounded it is dull and, to sharpen it, one of the faces (in some tools, both faces) must be ground. The grinding of a lathe tool is done, usually, by hand, moving the tool skillfully against the revolving abrasive wheel. To sharpen it skillfully means, first, to know the positions in which it must be held against the wheel to meet the requirements, and second, to gain the knack of holding it in these positions.

Contour of Turning Tool. For generations past the *roughing tool* was forged and ground to have a top face substantially as shown in Fig. 11-17*a*. That is, the top face was "egg shaped" with the cutting edge presented to the work at an angle of 20 to 30 deg. and the nose rounded in proportion to the size of the tool. Taylor proved that such a shape, with the round nose modified to meet conditions, will answer in most cases for roughing and finishing cuts in either steel or cast iron in the run of shop jobs in a 14- or 16-in. lathe, and for roughing cuts in the shaper, planer, and larger lathes.

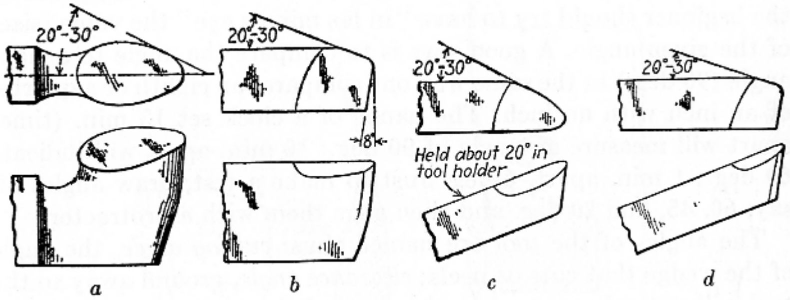


Fig. 11-17. Contours of turning tools.

In Fig. 11-17*b*, is shown a shape of tool ground on a bar, which, as far as the cutting edge is concerned, is the same as the tool *A*. In 11-17*c* is shown a tool bit ground to resemble tool *a*, and in 11-17*d* the tool bit resembles the tool *b*. Practically, the four tools are alike in the shape of the cutting edges and in the cutting action.

If the round nose of a certain tool leaves feed marks too pronounced, a tool with a larger radius may be used. If in a different kind of job, the nose has too large a radius, and taking the wider chip seems to cause a chatter, it will be easy to substitute a tool with a narrower nose. Various other shapes of tools will be described from time to time.

Tool Angles. To grind the tool properly the edge must keep its shape—flat or curved as the case may be. Also, to cut well, the surfaces that form the edge must be "ground to certain angles." These tool angles are measured in degrees and are often described as so many degrees "with the horizontal" or "with the vertical." (In this case, *horizontal* means in a plane parallel to the base surface of the tool, and *vertical* means at right angles to the base surface. Lathe tools are held in the tool post practically in a horizontal position and no doubt this is the reason for these terms.)

When reading about the tool angles and when practicing grinding, the beginner should try to have "in his mind's eye" the value (size) of the given angle. A good way is to compare the angle to a right angle (90 deg.) in the same way one compares an eighth or a quarter of an inch with an inch. The hands of a clock set 15 min. (time) apart will measure an angle of 90 deg.; 10 min. apart will indicate 60 deg.; 1 min. apart, 6 deg. Just to make a test, draw angles of, say, 60, 45, and 20 deg. and then gage them with a protractor.

The angles of the tool are named thus: *cutting angle*, the angle of the wedge that cuts or peels; *clearance angle*, ground away so the tool will not rub; *rake angle*, the slope of the tool so it will peel instead of push off the chip. Discussions of these angles follow.

Cutting Angle. The action of any cutting tool in any material is that of a wedge prying apart or separating the substance of the material. The angle of the wedge is the *cutting angle of the tool* (see Fig. 11-18).

The harder the material to be cut, the more the cutting edge must be supported, that is, the cutting angle must be greater. The cutting angle that is correct for wood is not substantial enough to stand up under the strain of cutting iron or steel; the cutting edge, not being sufficiently supported against such a severe crushing force, would soon crumble and the value of the tool would be lost. The proper cutting angle for a metal-cutting cutting tool is 60 to 80 deg. depending largely upon the hardness of the metal to be cut.

A cutting tool must be correctly shaped and sharpened, and properly set in the machine, in order to have its cutting angle effective. Many tools, such as drills, milling cutters, and some lathe tools, are already shaped when the machinist gets them, but he must know how to sharpen them. The tool bits, so much used for turning, boring, and planing, must be shaped, as well as sharpened and set, by the man on the machine.

Metal is ground away from the forged lathe tool—and from the tool bit—to sharpen it, and to give it after it has been sharpened

the shape it ought to have and (when set in the machine) the correct cutting angle. It is not enough to know that the cutting angle for a certain tool must be 70 deg.; the machinist must know how to grind and how to set the tool to get that angle. That is, when the tool is held against the grinding wheel to get the shape of a turning tool, for example, and a cutting angle of, say, about 70 deg., it i

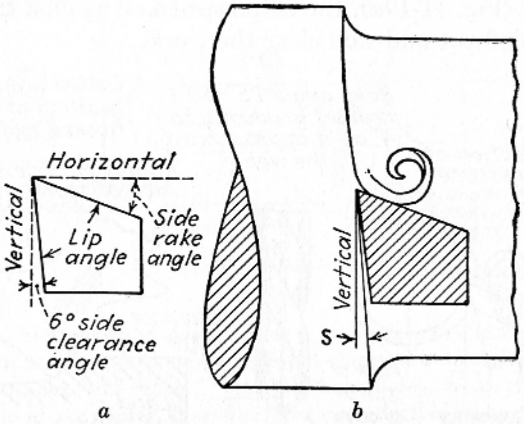


Fig. 11-18. In (*a*) are illustrated the side clearance angle of 6 deg. from the vertical, the cutting angle or lip angle of 60 to 80 deg. (depending on the material mainly, sometimes on the nature of the cut) and the side rake angle of average 12 deg. from the horizontal. In (*b*) is the *action* of the tool. Note the chip being peeled off because the tool has rake. Note also the separation of the material just ahead of the cutting edge. Attention is called to the slant of the cut as indicated by the angle *S*, which shows that since the tool feeds (to the left in this case) it must have clearance or it will rub. The coarser the feed and the smaller the diameter for a given feed, the greater the slant, but 6-deg. side clearance is usually enough.

ground on the side and on the front so that it will not rub on the work. This is grinding the *clearance*, side clearance and front clearance. It is also ground (or held in the toolholder) so that the top of the tool slopes, toward the back or toward the side, or both, and this angle of slope is called *rake*. Slope from the front to the back is called *front* rake (or, in some shops, back rake) and the slope to the side is called *side* rake.

Clearance Angles. When whittling with a jackknife, the back of the blade is raised a trifle, otherwise it will merely rub instead of cut. If it is raised 10 deg. the *clearance angle* is 10 deg. In most machine-shop cutting operations the action is similar; the cutting edge digs in, splitting or parting the metal ahead of itself, *one face* of the tool pries or peels off the chip, the *edge* tends to smooth the torn surface, and *the other face clears the work altogether.*

Three examples will illustrate the action:

1. The work in a lathe as it revolves is forced down against the cutting tool (Fig. 11-19*a*), the chip is pried off against the top of the tool, and the front and side clear the work.

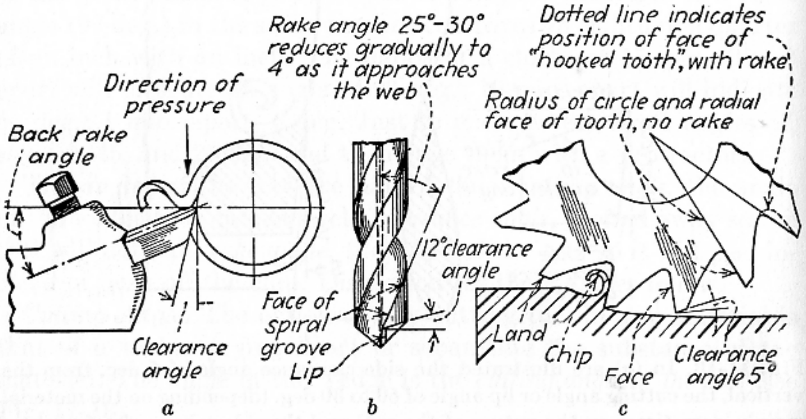


Fig. 11-19. Shows clearance and rake on three much-used machine-shop cutting tools: (*a*) lathe tool, (*b*) twist drill, and (*c*) milling cutter.

2. A twist drill, pressed (fed) into the work, cuts as it revolves. The cutting edges dig into the metal, the faces (of the spiral grooves) pry or peel off the chips, and the *lips* clear the work because they have been backed off, that is, given clearance (Fig. 11-19*b*).

3. In the case of a milling cutter the face of the tooth peels off the chip while the land just clears (Fig. 11-19*c*).

In all three of the above examples one face pries or peels off the chip and the other is ground at an angle, or as the machinist says, "backed off" or "given clearance" or "relieved," so it will not rub.

In general, the angle of *side clearance* on a lathe tool should not be more than 6 deg. (Fig. 11-20*a*), because the greater the amount of metal a cutting edge has under it, or the more it is backed up, the longer it will stay sharp.

The direction of the force which is exerted against the turning tool is along a line tangent to the circumference of the work at the cutting point (see Fig. 11-20). As the usual practice is to set the turning tool on center or a little above, it is necessary to have clearance at the front of the tool, so that it will not rub. This *front clearance* is usually about 10 deg. The design of the tool post (ring and rocker) permits of using tools of various heights. Since 10 deg. is practically a standard clearance, the height of the tool will determine the amount to set the tool above center to resist the tangential force of the cut and still have sufficient clearance. This is illustrated in Fig. 11-21. That is, a tool may be *ground* with 10 deg. front clear-

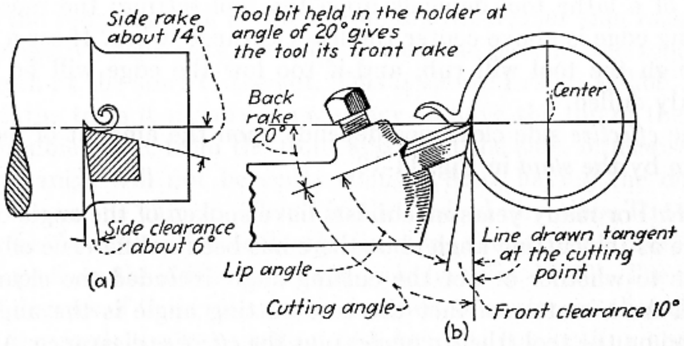


Fig. 11-20. (*a*) Side rake and side clearance; (*b*) back rake and front clearance. The line drawn tangent at the cutting point shows the direction of the force against the tool. Set "on center," this tool has 10-deg. front clearance. If it were set a little above center, it would have less effective front clearance, less cutting angle, and more rake.

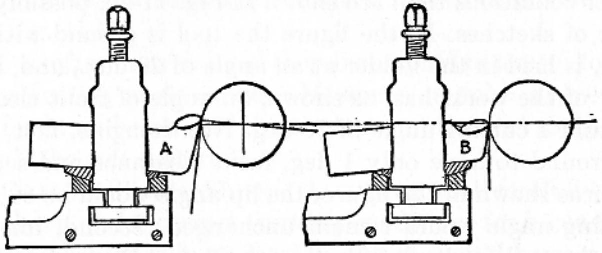


Fig. 11-21. Setting a lathe tool to get the proper clearance angle. A front clearance of 10 or 12 deg. is usually ground on a forged tool. Note the position above the center of the new tool *A* so as not to give excessive front clearance. Note *B*, which represents the position of the same tool after being sharpened several times, set on center to give correct clearance.

ance, yet when set above center have, in effect, much less than 10 deg. The amount it really has when in action in the lathe is known as *effective* clearance.

From the above it will be understood that the *effective* front clearance of a lathe tool depends upon the tool setting; the more the cutting edge is above center the less clearance it has. If set a little too high the tool will rub, and if too low the edge will be more quickly dulled.

The *effective* side clearance depends upon the amount of feed as shown by the *slant* in Fig. 11-18.

NOTE: For many years machinists have spoken of the angle of the wedge as the cutting angle, but there has been a difference of opinion as to whether or not the cutting angle included the clearance angle. As a matter of fact the true cutting angle is the angle as ground on the tool (the *lip angle*) plus the *effective* clearance. Also it should be noted that on a tool having a curved cutting edge such as the usual turning tool, the true cutting angle is the composite of the side and end angles and is measured on the line of the chip flow.

It may help in understanding the effective clearance to imagine two other conditions than are shown in Fig. 11-20, possibly making a couple of sketches. In the figure the tool is ground with 60-*deg. lip angle*, is held in the holder at an angle of 20 deg., and, being set *on center* of the work, has, as shown, an angle of front clearance of 10 deg. and a cutting angle of 70 deg. Now imagine, first, that the tool is ground to have only 1 deg. front clearance and set exactly on center as shown in the figure; the lip angle would be 69 deg. and the cutting angle would remain unchanged. Second, imagine the front of the tool (as in the figure with 60-deg. lip angle) tipped up until the cutting point is just high enough to bring the tangent line to indicate 1 deg. front clearance instead of 10 deg. (Fig. 11-21*b*). In this case the lip angle would remain 60 deg., but the cutting angle would be 61 deg. instead of 70 deg. as before.

Rake Angles. A definition of rake is *an inclination from the vertical or horizontal.* If a turning tool is set in a lathe so the top is flat and horizontal, it will have no rake, or if a drill has straight grooves it has no rake. Note in Fig. 11-19 that both the lathe tool and the twist drill have rake, while the milling cutter, having a radial tooth, has no rake. A milling cutter with a "hooked tooth" has rake (shown in one tooth in Fig. 11-19). When a tool has no rake it pushes off the metal, while if it has rake it tends to peel off the chip. Most tools have rake.

Sometimes a tool is given *negative* rake. For example, in planer work the roughing tool is often ground with regular side rake but with negative back rake, in order to ease the blow as the tool hits the work at the start of the cut. This is shown in Fig. 11-26*b*.

In lathe tools it usually is necessary to have the top of the tool on a double slope, from the front and from the side, otherwise the cutting angle will not be acute enough. Also, having the double slope causes the chip to "flow" in the desired direction. The slope from the front is called *back rake* (in some shops, front rake) and the slope from the side is called *side rake* (see Fig. 11-20). The number of degrees of these rake angles depends, of course, on the cutting angle required; the more rake a tool has, the less cutting angle it has, that is, the sharper the wedge is. A cutting angle of 70 deg. is average for cast iron and tool steel, and 60 deg. is average for machine steel. In a toolholder the back rake is taken care of, usually, by the position of the bit at an angle in the holder (Fig. 11-23). The side rake may be nicked in the bit or it may be ground as illustrated in Fig. 11-22.

Brass is a softer material and therefore would not seem to require so heavy a cutting angle as steel. However, no rake is given a cutting tool for brass because of the tendency of the tool to "hook in" or "dig in" the soft material.

Keep Cutting Tools Sharp. A cutting tool carefully ground will stay sharp under correct working conditions for a considerable time, but as soon as it is noticeably dull it should be reground or the tool and possibly the work will be ruined. A dull tool tears rather than cuts the material; it springs the work and does not make a smooth cut. To *keep cutting tools sharp* is a most important factor in efficient machine work.

It is an acknowledged fact that lack of judgment in the grinding of tools costs thousands of dollars every year in the wastage of materials alone. To sharpen a dull tool shall it be ground on the top, on the front, or on the side, or a little here and there? No rule can be given. Each tool grinding calls for judgment. Examine the particular tool; how many times may it be ground on the top before it is worn out? How much may it be ground on the side before it is too thin? How much of the life of the tool is lost by grinding it on the front? Keep these things in mind when sharpening a tool.

In this connection refer again to Fig. 11-22; regular tool bits for the lathe, shaper, and planer are sharpened by grinding on the end only, when previously beveled as shown. The tool bit is ground in a surface grinder for a side rake of 12 to 14 deg. its whole length. It is an improvement for the usual facing, shouldering, and turning tool and for standard thread tools. (For shaper and planer bits the bevel is from the opposite edge.) Side rake is thus provided once and for all. All sharpening is done on the end and the bits do not have the usual ugly nicked points. The economy in grinding time and the saving of the tools are notable.

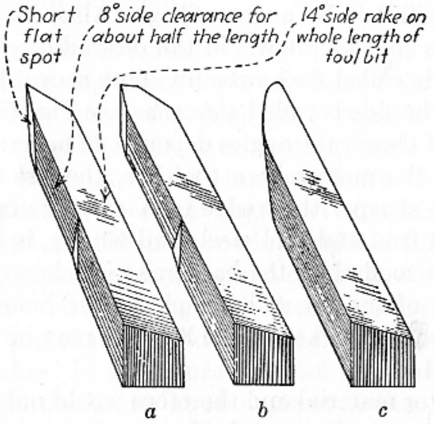


Fig. 11-22. Tool bits beveled on the top for side-rake angle. Sharpened by grinding on the end only. (*a*) Facing, (*b*) shoulder, and (*c*) turning.

Grinding Cutting Tools. The beginner should grind a practice piece of machine steel (preferably a little larger than the tool bit so as not to get them mixed) and acquire the knack before attempting to grind an expensive tool bit. It may be fairly difficult at the start to grind the proper front clearance because the bit when in use is held at an angle in the holder. Until the eye is trained, use a gage. The 60-deg. center gage is suitable, if 10-deg. front clearance is wanted, because in most of the holders the tool bit is set at an angle of 16½ deg. with the horizontal (Fig. 11-23). For any other than 60-deg. cutting angle it is easy to cut out a small sheet-metal gage of the angle desired.

When grinding carbon steel, care must be taken not to bear on too hard or the edge will become blue and the temper lost. A wet grinder should be used if one is available. It is not so easy to burn the temper out of a high-speed cutter but it is easy to cause surface cracks by not having water enough. Have plenty of water and do not bear on too hard; give the wheel a chance.

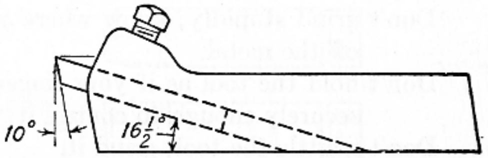


Fig. 11-23. Tool bit is held in the holder at an angle of 16½ deg. to give the back rake.

A tool bit should *not* be ground in a holder, first, because the method is clumsy and inefficient, and second, because one is liable to grind the holder. If occasionally the holder is ground a little, soon it is ruined. Figure 11-24 shows the correct way to hold the turning-tool bit. Hold it securely but not rigidly. As it is swung from *a* through *b* around to *c* (Fig. 11-25), it pivots slowly between the left thumb and forefinger, with the pressure mostly with the right forefinger. Grind one continuous cut, keeping in mind the front and side clearance. Tip it a little to the right, as at *a*, to grind the side

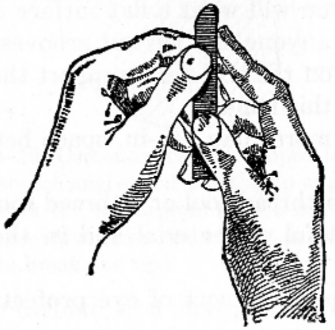


Fig. 11-24.

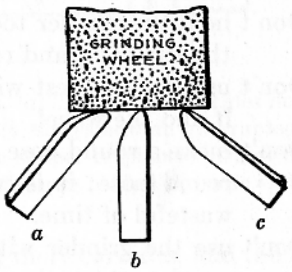


Fig. 11-25.

clearance, and to the left as it reaches *c* in order to finish the round nose.

Oilstoning the edge serves to produce a better finish on the work, and prolongs the life of the tool.

DONT'S IN TOOL GRINDING

Don't grind stupidly; know where and why and how to take off the metal.

Don't hold the tool as if your fingers were paralyzed; hold it securely enough to control it.

Don't whittle the tool; grind it.

Don't hold the tool left-handed or otherwise awkwardly; hold it properly—it's the easiest way.

Don't be afraid to use plenty of water.

Don't hold the tool in one place or you will cut a groove in the wheel.

Don't use a wheel that is grooved or out of round if you can help it.

Don't grind on the side of a wheel except when necessary. When it is necessary you will want a flat surface and it won't be flat if you or anyone else has cut grooves in it.

Don't hold the smaller tools on the tool rest; support them in the left hand and rest this hand.

Don't use the tool rest with more than 1/16-in. space between it and the wheel.

Don't make a round nose of a thread tool or a thread tool of a round nose; it is wasteful of material and in the end wasteful of time.

Don't use the grinder without some sort of eye protection—goggles or guard.

Cemented Carbide Tools. A word should be said here about the cemented carbides, the wonderful superspeed cutting materials. First, what they are: Pure tungsten, carburized to form tungsten carbide, was produced about the end of the last century by Henri Moissan. It is one of the hardest known substances, but is brittle and porous. It was not commercially valuable until a method of *cementing* it (holding tiny particles together with a suitable binder) was developed (about 1927). Since then it has been found that carbides of tantalum, titanium, molybdenum, and several others are valuable, and mixtures of different carbides that will give various *grades* of product, each superior for its particular class of work, have been developed.

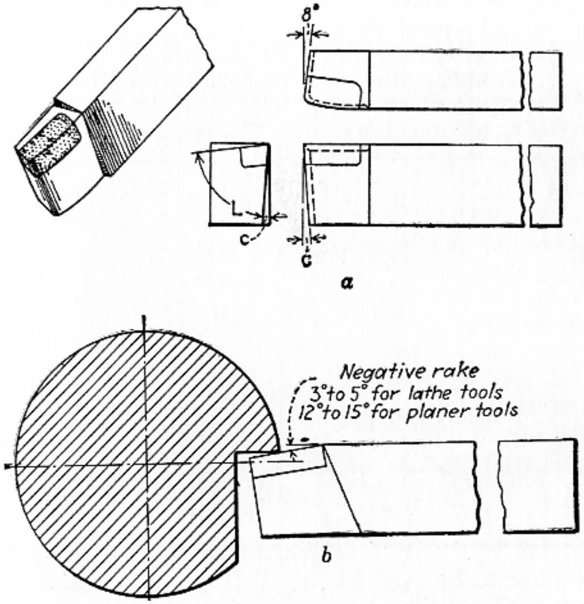


Fig. 11-26. Cemented carbide-tipped tools. (*a*) Turning tool, angles marked *c* are clearance angles and *L* is the lip angle; (*b*) shows how an interrupted cut in lathe work (or the beginning of a cut in a shaper or planer) strikes the tool having negative rake; the impact is some distance behind the nose and is less likely to break the tip.

The carbide, or a mixture of two or more carbides, and the binder (cobalt is much used) are powdered and mixed in the most thorough way, and then molded under hydraulic pressure into the shapes desired. These ingots or rough shapes are next pre-sintered at about 1500°F. and have then the consistency of the graphite in a pencil. In this condition they may be further shaped by turning, drilling, filing, etc., somewhat oversize to allow for later shrinkage. The pieces are final-sintered in special furnaces at temperatures ranging from 2500° to 2900°F., depending upon the grade. During this process the binder coalesces and cements the carbide particles together, forming a structure of extremely hard carbide crystals in a tough binder.

The cemented carbide thus produced has extraordinary hardness, high compression strength, low heat conductivity, but is quite brittle. Due to its brittleness, it cannot be used as a tool bit in a holder, like a high-speed-steel bit for example, but is fitted into and brazed in place to be used as the cutting point in the end of a bar of steel (Fig. 11-26) or a reamer, drill, or other cutting tool. Because of its low conductivity of heat it never becomes hot enough to melt the brazing material.

Table of Angles for Carbide-tipped Tools

Material to be machined	Clearance angle, C	Lip angle, L
Soft gray cast iron	5°	74°–80°
Hard gray cast iron	4°	74°–80°
Chilled cast iron (65–90 scleroscope)	3°	82°–86°
Soft steel	6°	60°–65°
Hard steel	5°	65°–74°
12% manganese steel	4°	80°–84°
Stainless steel	5°	65°–74°
Soft steel castings	5°	68°–73°
Hard steel castings	5°	73°–78°
Bronze, brass, etc.	6°	65°–75°
Aluminum alloys	8°	50°–55°
Planer tools	As above but with negative back rake 12 to 15°	

Cemented carbides have qualities that make possible cutting speeds several times as fast as high-speed steel. Also they will freely cut hard substances that steel will not cut at all. Their first cost is high, but there is no doubt of their value in production work, not only as cutting tools, but also for parts that must be wear-resisting such as guides, gages, and wire dies. It should be emphasized, however, that particular *grades* are made for given purposes, and *cemented-carbide tools cannot be used indiscriminately on various materials.* Nor can cemented-carbide cutting tools give satisfactory results unless the greatest care is taken to eliminate all vibration in work holder and toolholder. Further, safety demands protection against the tendency of the red-hot chips to fly. Note the substantial toolholder illustrated in Fig. 11-27.

Catalogues furnished by the manufacturers give details of selection, grinding, and use, and are interesting and instructive, but expert advice in the selection of the suitable grade is always recommended. When necessary to sharpen the tool, knowledge, care, and skill are needed. Carbides cannot be ground on ordinary wheels. Diamond wheels are needed for grinding.

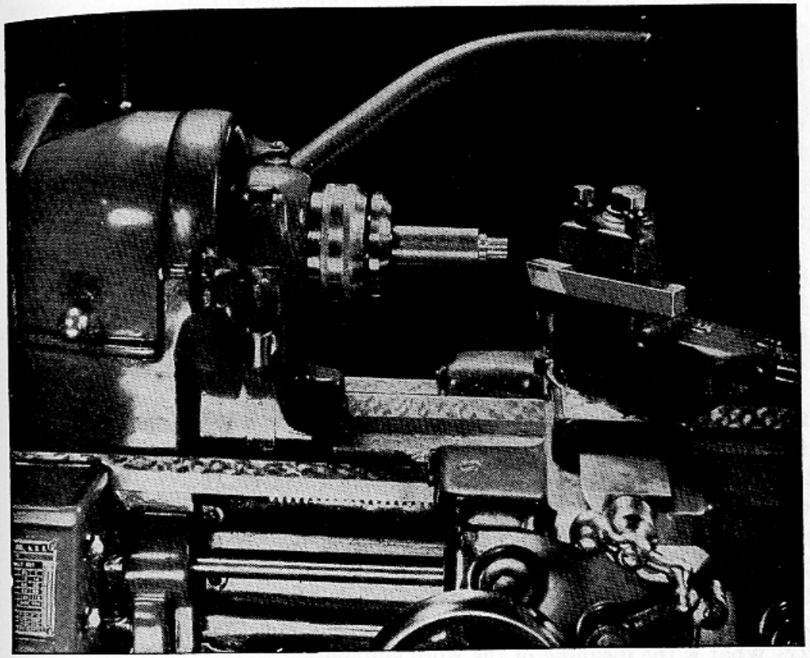


Fig. 11-27. Carbide-tipped tool ready for use. (*The South Bend Lathe Works*)

QUESTIONS ON CUTTING TOOLS

1. What is the general shape of the cutting edge of a turning tool for lathe work? What are the disadvantages of a sharp point on a turning tool?
2. What is meant by cutting angle? How many degrees are included in the cutting angle of an average turning tool? Why not 90 deg.? Why not 30 deg.?

3. What is meant by clearance angle? How much side clearance has a lathe turning tool? How much front clearance? What is the disadvantage of too great a clearance angle?
4. What is meant by front rake? Side rake? What is the object in giving rake to a tool?
5. Other things being equal, will a tool with side rake cut equally well if fed in either direction?
6. What is meant by negative rake?
7. What is a right-hand turning tool?
8. What is a bent tool?
9. It may be stated that a cutting-off tool has five clearance angles; where are they?
10. It may be stated that a side tool has four clearance angles; where are they?
11. When it is necessary to sharpen a side tool, is it ground on the top, on the side, or on the front? Why must judgment be exercised?
12. What are the advantages of a tool that has been oilstoned?
13. If a tool rubs on the work, what faults may be found?
14. What is the chief advantage of a tool holder and bit?
15. Should the bit be ground in the holder or should it be removed before grinding? Give reasons.
16. Name three things on which the action of a cutting tool depends.
17. What is meant by the contour of a tool face?
18. What is meant by effective clearance?
19. What is the difference between the corner-rounding tool and the crowning tool?
20. What is the purpose of beveling the top surface of a tool bit?
21. What is meant by the term cemented in referring to carbide tools?
22. What is the difference between a tool bit and a tipped-tool?
23. What is the meaning of the word sintered?
24. What do you understand by the words tungsten, tantalum, and molybdenum?
25. How is the carbide tip fastened in place?

SPEED, FEED, AND DEPTH OF CUT

Roughing and Finishing Cuts. There are two kinds of cuts in machine-shop work called, respectively, the *roughing cut* and the *finishing cut*. When a piece is *roughed out*, it is fairly near the shape and size required, but enough metal has been left on the surface to finish smooth and to exact size.

Bars of steel, forgings, castings, etc., are obtained, if possible, of the shape and size that will machine to the greatest advantage, that is, usually with one roughing and one finishing cut. Sometimes, however, certain portions of a piece may require more than one roughing cut. Also, in some jobs, for example, when great accuracy is not needed, or when a comparatively small amount of metal must be removed, a finishing cut may be all that is required.

The *roughing cut*, to remove the greater part of the excess material, should be reasonably heavy, that is, all the machine, or cutting tool, or work, or all three, will stand. One need not worry much about the machine being overworked, and it will soon be quite easy to judge the capabilities of the given tool. The machinist's purpose is to remove the excess stock as fast as he can without leaving a surface too torn and rough, without bending the piece if it is slender, and without spoiling the centers.

The *finishing cut*, to make the work smooth and accurate, is a finer cut. The emphasis here is refinement—very sharp tool, comparatively little metal removed, and a higher degree of accuracy in measurement.

Whether roughing or finishing, the machinist must set the lathe for the given job. He must consider the size and shape of the work and the kind of material, also the kind of tool used and the nature of the cut to be made; then he proceeds to set the lathe for the correct speed and feed and to set the tool to take the depth of cut desired.

Definitions. *Cutting speed* in any machine-shop operation is expressed in *feet per minute*. In lathe work it is the number of feet measured on the circumference of the work that passes the cutting edge of the tool in 1 min. If it were possible to measure the exact length of the chip removed in 1 min., it would measure the cutting speed in feet per minute.

The *feed* in lathe work is the amount the tool advances for each revolution of the work. For example, in turning a cylinder with 1/32-in. feed it will require 32 revolutions of the work to move the carriage 1 in. The machinist speaks of "coarse feed" and "fine feed." These terms mean nothing except when applied to lathes of practically the same size. What might be regarded as fine feed on a large lathe would be a coarse feed on a small lathe.

By the term *cut* in lathe work is meant the *depth of cut.* Suppose a cylinder of machine steel 2 in. in diameter is put in a lathe and a cut made reducing the diameter to $1\frac{7}{8}$ in. Regardless of the speed or feed, the depth of the cut is $\frac{1}{16}$ in. It should now be clear what the foreman means when he says "Give it a higher speed," "Try a coarser feed," or "Take a deeper cut."

The Time Element. One of the most important problems entering into machine-shop work is the time element. The time it takes to produce a finished piece of work depends largely on the rate at which the metal is removed from the original stock. The rate at which the metal is cut off depends on three things, namely, the depth of cut, the feed, and the cutting speed. Take for example the turning operation.

1. It is obvious that the cutting edge of the tool takes a deeper cut if it reduces the diameter $\frac{1}{4}$ in. than if it reduces it only $\frac{1}{8}$ in. It will be folly to take two cuts if $\frac{1}{4}$-in. reduction in roughing size is necessary. One factor then is the depth of cut.

2. If every time the work revolves the tool is fed $\frac{1}{64}$ in., it will remove a chip only half as thick as if it were fed $\frac{1}{32}$ in. If practicable to set the feed for $\frac{1}{32}$ in., why not get the piece turned in half the time? Another factor then is the amount of feed.

3. If this work is 2 in. in diameter and revolves 70 times in 1 min. a point on the circumference will travel about 30 ft. in 1 min. If the cutting tool will stand 60 ft. per minute cutting speed it will not be efficient to turn at half this speed. The third factor then is the cutting speed.

There is a new problem of cutting speed, feed, and depth of cut for every job on every machine in the shop. After awhile the workman becomes expert enough to attend to these things automatically. At the start, however, these problems require close attention and certain calculations.

Cutting Feeds and Speeds. There are so many conditions that determine the proper depth of cut and feed that it is impossible to give any set rule for either. The shape of the tool, the way in which it is held, the kind of steel from which it is made are factors; also the kind of material being cut, whether machine steel or tool steel, brass or cast iron; the shape of the piece being cut, whether it is rigid or inclined to spring; the nature of the cut, whether it is roughing or finishing, are all factors which must be taken into consideration when obtaining an efficient depth of cut or amount of feed.

Conditions also govern the rate at which the tool will cut, and no table can be given that will apply in all cases. Fortunately however, there are certain well-established *average* cutting speeds for various metals.

Average Cutting Speeds with Tools of High-speed Steel*

Stainless steel and Monel metal	50 ft. per min.
Annealed tool steel	60 ft. per min.
Machine steel, wrought iron, and cast iron	80 ft. per min.
Brass	200 ft. per min.
Aluminum	300 ft. per min.

* Average cutting speed with tools of carbon steel is about half the above.

Cutting speeds must not be confused with revolutions per minute (r.p.m.). A piece 2 in. in diameter will have to make five times as many r.p.m. as a piece 10 in. in diameter to give the same cutting speed. In other words, each different diameter must have a different number of r.p.m. to give the same cutting speed. If the beginner will calculate for the first few jobs the r.p.m. necessary to give the required cutting speeds, after awhile he will become so accustomed to seeing the machine work properly that he will be able to set up without calculations and almost without thought.

Cutting-speed Calculations. Cutting speed (excepting the shaper and planer) is the rate at which a point on the *circumference* travels. In the case of a lathe it is the circumference of the work; in the case of a milling machine or drill press it is the circumference of the milling cutter or of the drill. And remember, in machine-shop practice, when speaking of sizes, the *diameter* is expressed, not the circumference. Also these diameters are given in *inches,* while cutting speed is expressed in feet. To find the circumference of a piece of work (or of a drill or milling cutter) multiply the diameter by 3.14 and, to reduce to feet, divide by 12. However, instead of multiplying the diameter by 3.14 and dividing by 12 in every problem it is much quicker to multiply the diameter by 0.26. The diameter multiplied by 3.14 and this divided by 12 is equal to 0.26 times the diameter.

$$\frac{\text{diameter} \times 3.14}{12} = 0.26 \times \text{diameter}$$

That is, the circumference in feet is always equal to 0.26 times the diameter in inches.

Further, if one had a job that figured 2 ft. in circumference it would take 20 r.p.m. to give a cutting speed of 40 ft. per min.; if the job figured ½ ft. in circumference it would take 80 r.p.m. to give a cutting speed of 40 ft. In both cases the number of r.p.m. is equal to the cutting speed divided by the circumference in feet. From these examples the following may be deduced: To obtain the r.p.m. necessary to give any required cutting speed, multiply the diameter (in inches) by 0.26 and divide the cutting speed by this product.

Since 0.26 is so nearly ¼, it may be stated that for all practical purposes the number of r.p.m. may be calculated by the following:

RULE: To obtain the number of r.p.m. necessary to give any required cutting speed, divide ¼ of the diameter into the cutting speed; OR multiply the cutting speed by 4 and divide by the diameter.

EXAMPLE: A piece of steel 2½ in. in diameter is to be turned in a lathe. What number of r.p.m. is necessary to give a cutting speed of 80 ft. per min.?

SOLUTION: $$\text{R.p.m.} = \frac{CS}{\frac{1}{4}D} = \frac{80}{\frac{1}{4} \times 2\frac{1}{2}} = \frac{80}{\frac{5}{8}} = 128 \textit{ Ans.}$$

or $$= \frac{4CS}{D} = \frac{4 \times 80}{2.5} = 128 \textit{ Ans.}$$

Value of High Speed. In a previous paragraph it was stated that the edge of the tool parted the metal "ahead of itself," and it might have been said further that the metal has a tendency to "pile up" on the nose of the tool, tearing the turned surface similarly as with a dull tool.

Every machinist knows that this tendency is less at the faster speeds, but the cemented-carbide cutting tools have made it possible to prove that above a "critical speed" (over 250 ft. per min. for most steels) this piled-up edge does not form, nor is there a parting ahead of the metal, and the chip and turned surface are not torn.

It is under the same principle that a bullet from a rifle will pierce a pane of glass, and thrown by hand will shatter the glass.

During a recent test, using a multiproduction lathe (The American Tool Works Company, Cincinnati, Ohio) with a cemented-carbide cutting tool, bars of steel were successfully turned at 350 ft. per min. The chip breaker curled and disposed of a ⅜-in.-wide chip which was "as smooth as glass," and the turned surface was clean cut. The same kind of steel was being turned with a high-speed steel tool in a nearby lathe at 80 ft. per min., with much inferior results.

Of course cemented-carbide tools are expensive. The modern lathe is fast, accurate, and rigid in construction and therefore is able to use these cutting tools. The machinists now employed have been trained in the use of these cutting tools, and it can be clearly seen that, with all the above factors, the trend today is toward almost universal use of cemented-carbide cutting tools. They definitely save time in production and thereby save money for the manufacturer and the consumer.

QUESTIONS ON CUTTING FEEDS AND SPEEDS

1. What do you understand by time element in machining a piece of work?
2. Name four things that may determine the proper feed for turning.
3. What is the difference between cutting speed and revolutions per minute?
4. How many r.p.m. are necessary to turn a piece of work 1½ in. in diameter at a speed of 30 ft. per min?
5. What number of r.p.m. is necessary to give a cutting speed of 40 ft. per minute on work 2¼ in. in diameter?
6. What rule is used to find the r.p.m. of a drill to give a required cutting speed?
7. Is this same rule used to obtain the r.p.m. of work in a lathe to give the required cutting speed?
8. In turning a cast-iron pulley 12 in. in diameter, how many r.p.m. will be necessary to give a cutting speed of 40 ft. per minute?
9. Why is it that machine steel can be turned at a higher speed than tool steel?
10. If the r.p.m. and the diameter of the work are known, how may the cutting speed be found?
11. What is the property that gives high-speed steel its value?
12. Name three things to emphasize in considering the finishing cut.

What Happens When Metals Are Cut. Maybe, when you were a kid, one spring afternoon when the gang switched from marbles to baseball, you made the mistake of sliding into second base on a hip pocket full of marbles. If you had been a winner that day, there might have been several layers of marbles between you and the ground, but those next to you were pressed into you as firmly as though they were in contact with the ground. The explanation, of course, was merely that the pressure of the ground on the outer layer of marbles was transmitted from marble to marble until it finally got to you. If you keep the behavior of those marbles in mind throughout the next few pages, it will help you to understand what "goes on" in a piece of metal while it is being cut.

Another point that should be understood clearly is that metals, for all their density and apparent solidity, are not as solid or uniform in their physical structure as you might think. They are much like a piece of concrete—a mixture of grains held together by cement. As a result, when pressure is applied to the grains in a limited area, as happens when a cutting tool bites into the metal, the pressure is passed along from one grain to another in areas next to the point where the cutting pressure is applied, just as was the case with the marbles.

There is another characteristic feature of the structure of metals that is even more important in its influence on the behavior of metals under the effect of the cutting action. Without getting too deep into the science of metallurgy, we can explain briefly that the grains which make up all metals have a characteristic structure that science describes as crystalline. This merely means that the atoms which make up the grains are all arranged in a definite order and orderly pattern. In metals, this pattern takes the form of a series of interlocked cubes. So, in a given metal, all the grains have the same characteristic cubical internal structure, although the lines of the cubical pattern in no two adjacent grains line up or are parallel. The material that binds the grains together, however, does not have this orderly arrangement of the atoms which compose it. Its atoms are thrown together in a random pattern giving it a structure that is called *amorphous*, meaning having no regular form or structure.

As a result of the grains of metal having this crystalline structure, every grain has certain cross-sectional planes which the atoms do not hold together as strongly as in other parts of the grain. These

planes are described generally as *planes of weakness*. When pressure is applied to a grain, sections of it begin to "slip" along these planes. Up to a certain point, this slipping merely causes the grain to be deformed. Beyond that point the grain will be sheared apart. The extent to which a grain can slip without breaking varies in different types of metals. If it can slip considerably, the metal is said to be *ductile*. If it fractures without slipping far, the metal is called *brittle*. So long as grain sections merely slip along these planes of weakness, it is usual to refer to the planes along which they slip as *slip planes*. However, if the movement is sufficient to fracture the grain, they are usually called *cleavage planes*. This is apt to be confusing, for the same planes of weakness are involved in either case. What these planes are called is simply a matter of whether the grains are only deformed or actually broken by the pressure. Since we are interested in this discussion on the actual breaking apart of the grains of metal, we will consider the planes in question to be *cleavage* planes.

The importance of the presence of these cleavage planes in metals will become more apparent after the fundamentals of cutting have been made clear. Cutting requires pressure and motion of the cutting edge or the material being cut. The value or intensity of the cutting action depends upon the keenness of the cutting edge, the velocity of motion, and the degree of pressure involved. For instance, you can squeeze a knife blade quite hard without cutting your hand, yet if you attempt to withdraw it without loosening your grasp, your hand will be instantly cut. But you can move your hand fairly rapidly over the same cutting edge without being cut, if you touch it lightly enough.

As you will see in Fig. 11-28, there are three basic methods by which material can be cut, and they are distinguished primarily by the amount of pressure, that is, the force per unit area, and speed of motion applied. In Fig. 11-28*a*, the motion of the cutting edge is along the line of cut. The cutting edge travels at a relatively high speed, and under relatively light pressure. In Fig. 11-28*b*, the cutting edge moves towards the line of cut. It may travel at a relatively low rate of speed but necessitates a relatively high pressure to cut. In Fig. 11-28*c*, the cutting edge travels toward the line of cut, but it moves at a high rate of speed and also under high pressure.

The first type of cutting motion produces what we can call a *slicing action*, the familiar cutting motion used in carving a roast or slicing bread. The cutting is accomplished almost entirely by the relatively rapid movement of the cutting edge. Just enough pressure is required to cause the sides of the tool to "spread" the material slightly so that the edge can reach the area to be cut as the cut progresses. Because the pressure is low, the edge requires little support, so the tool is "thin," and the sides forming the cutting edge are very nearly parallel.

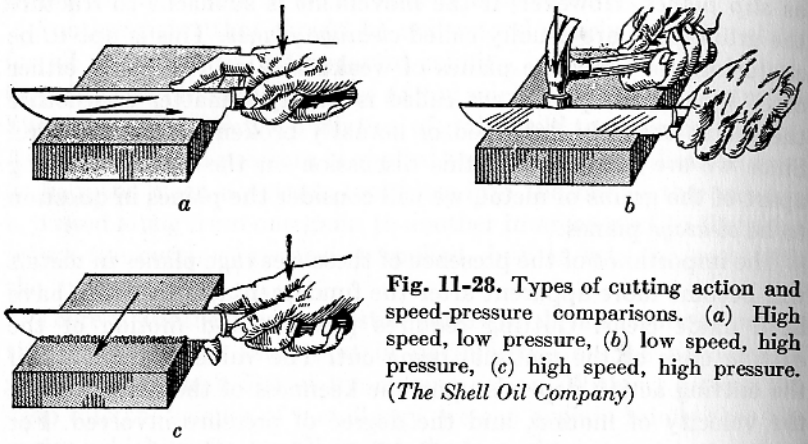


Fig. 11-28. Types of cutting action and speed-pressure comparisons. (*a*) High speed, low pressure, (*b*) low speed, high pressure, (*c*) high speed, high pressure. (*The Shell Oil Company*)

The second cutting motion might be described as a *wedging action*. The action of a cold chisel and that of an ax used to cut a log are typical examples. Great pressure, usually applied suddenly, accounts for most of the cutting action. Thus the cutting edge must be supported by a much greater amount of material. As a result, a wedging tool is fairly thick, that is, the sides forming the cutting edge meet at a wider angle than those of a slicing tool.

The final cutting motion, and the one that concerns us most in lathe operations can be described as a *scraping action*. The pressure applied to the cutting edge and the speed of the cutting motion are both relatively high. For this reason, the cutting edge of a scraping tool requires maximum support to "hold up," so it is designed with the sides forming the cutting edge meeting at a wider angle than either the slicing or wedging tool. See Fig. 11-29 for the comparisons of these angles. It should also be noted that the tool is designed to enter the material at such an angle that most of the pressure is concentrated on one side of the cutting edge.

While it is commonly considered that to cut, the cutting tool must be much harder than the material being cut, you may recall such phenomena as a straw being driven into solid wood by a tornado, your foot punching a clean hole in a sheet of hard but thin ice, and a baseball neatly penetrating a pane of glass. In other words, a softer material can cut, providing the energy it exerts on the material cut (as determined by the velocity and the weight of, or the pressure behind, the cutting object) is great enough. In the case of the straw, though its weight was light, its velocity was high. In the case of your foot, its velocity was low but the weight great. In the case of the baseball, its weight and velocity, while only moderate, combined to produce relatively great energy.

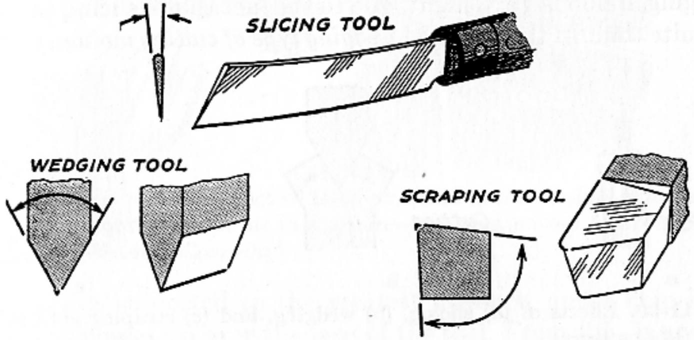


Fig. 11-29. Difference in amount of metal that supports the cutting edge. (*The Shell Oil Company*)

Thus we find that the slicing action, which involves a relatively high velocity but little pressure, only permits the cutting of material considerably softer than the tool. The wedging action, with relatively high pressure applied—often with considerable speed for a brief period, as when the cold chisel is struck with a hammer—permits cutting of a material much more nearly equal the hardness of the cutting tool; while the scraping action, which combines relatively high pressure and high speed of cutting movement, makes possible, under proper conditions, the cutting of materials almost as hard as the cutting tool.

The fact still remains, however, that for practical purposes, to cut a piece of material we use a cutting tool considerably harder than the material being cut, because it is ordinarily impractical to achieve sufficient velocity and pressure simultaneously. However, as we shall see, the cutting of the harder metals would be an almost impossible job were it not for the crystalline structure of metal and the cleavage planes which this structure introduces.

If you will study Figs. 11-28 to 11-32, you will notice that even the thinnest cutting edge applies some wedging action to the material after the edge has entered. In the case of a slicing motion, this wedging action is very slight, due to the fact that a slicing tool must be quite thin. In the so-called *wedging type of cutting motion*, material on both sides of the tool is subjected to a still greater degree of wedging pressure. Yet, the actual displacement of the material is only moderate, because the wedging action takes place equally on both sides of the cutting edge of the tool that is only moderately "thick." Under the influence of scraping action, however, as shown in Fig. 11-30*c*, the extreme wedging pressure, resulting from the wide angle between the sides of the tool forming the cutting edge, is concentrated on one side of the cutting edge. The deformation, or displacement, of the material in such cases is relatively great.

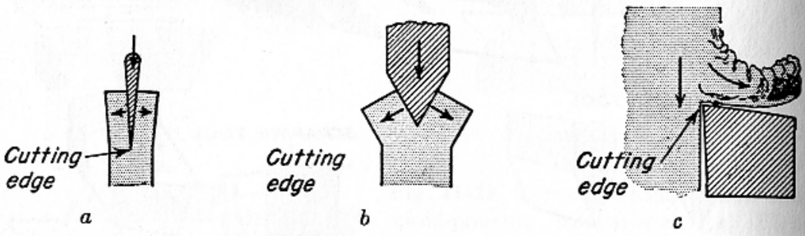


Fig. 11-30. Effects of (*a*) slicing, (*b*) wedging, and (*c*) scraping actions. (*The Shell Oil Company*)

As we will recall, metal is made up of many grains. Pressure applied to one grain or layer of grains passes on to other individual grains or layers of grains. Pressure of the wedging action of the cutting tool, therefore, passes from grain to grain of the metal. Since it is not applied uniformly to all surfaces of the grains, it subjects them to a sort of shearing action. This shearing action causes the grains to slip and finally break along their cleavage planes. When enough grains are thus fractured, a piece of metal is separated from the workpiece. What happens when a piece of metal is being cut on a lathe, therefore, is simply that by applying a wedging action behind a cutting edge, the metal is "split" along the lines of cleavage of the grains subjected to the greatest pressure, and a chip is released and passes up over the face of the tool. From this, it may be seen that it is the wedging action of the face of the tool that does most of the work; the cutting edge itself does little actual cutting. It serves merely to start the wedging action and perhaps smooth off small parts left behind as the chip separates from the workpiece. However, the sharper the cutting edge, the more the wedging action tends to be concentrated on a relatively few grains of the workpiece

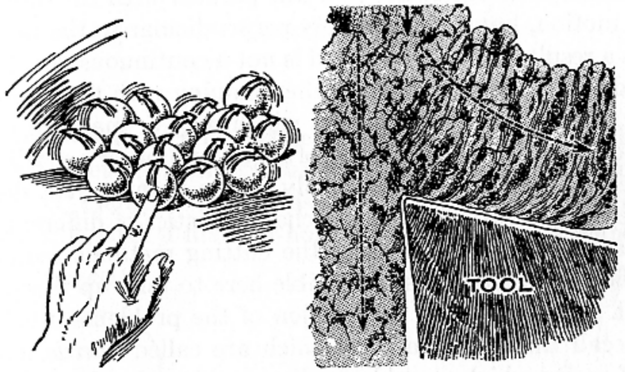


Fig. 11-31. The pressure effect of tools on metal grains is similar to that of pressure applied to one marble in a group—it is transmitted from marble to marble. (*The Shell Oil Company*)

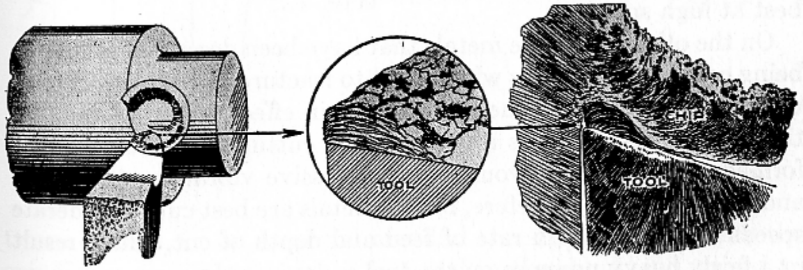


Fig. 11-32. The false cutting edge. (*The Shell Oil Company*)

material. As a result, a cleaner separation of chip and workpiece occurs, and hence a smoother finish.

Since the tool meets the workpiece at an angle that concentrates the wedging action on the face of the tool, the greatest pressure and the resultant cleavage is not in a line parallel with the direction of cutting motion, but approximately perpendicular to the face of the tool. As a result, the chip removed is not a continuous one, like that removed by a carpenter's plane when planing with the grain, but a number of chip parts or segments which may or may not cling together, depending upon the type of metal and other conditions.

While all metals behave basically in the manner just described when being cut, variations in the characteristics of different metals necessitate certain variations in the cutting methods required for most efficient results. It is impossible here to take up these factors in detail. However, as an illustration of the problems involved we might recall that some metals, which are called *ductile*, are composed of grains which are able to slip considerably along their lines of cleavage before breaking. Such grains tend to be deformed, rather than fractured, when subjected to the cutting pressure. This causes part of them, in effect, to "flow" up over the face of the tool, before the actual separation takes place. This produces a continuous chip and a smoother cutting action. In such cases, a high speed of workpiece motion at a moderate feed and depth of cut, which results in moderate pressure, is desirable. That is why such metals are cut best at high speeds.

On the other hand, the metals that have been described as brittle, being composed of grains which tend to fracture rather than deform under pressure, are inclined to "split," in effect, ahead of the cutting edge. This produces a rough, jerky cutting action and if performed at high speeds would cause excessive vibration, tool wear, and uneven finish. Therefore, brittle metals are best cut at moderate speeds with fairly high rate of feed and depth of cut, which result in a fairly heavy pressure on the tool.

As a final word, study the figures in this section very carefully. Follow the text and you should be able to understand just what happens when metals are cut.

CHAPTER 12

Centering

Holding Work in the Lathe. Work to be turned in the lathe may be held between centers, fastened in a chuck, clamped to the faceplate, or clamped to the saddle. Work that is to be faced or turned true with a finished hole is held either on a mandrel between centers, or on a special mandrel the shank of which fits the spindle, or on a plug which is fastened in the chuck and turned to fit the hole.

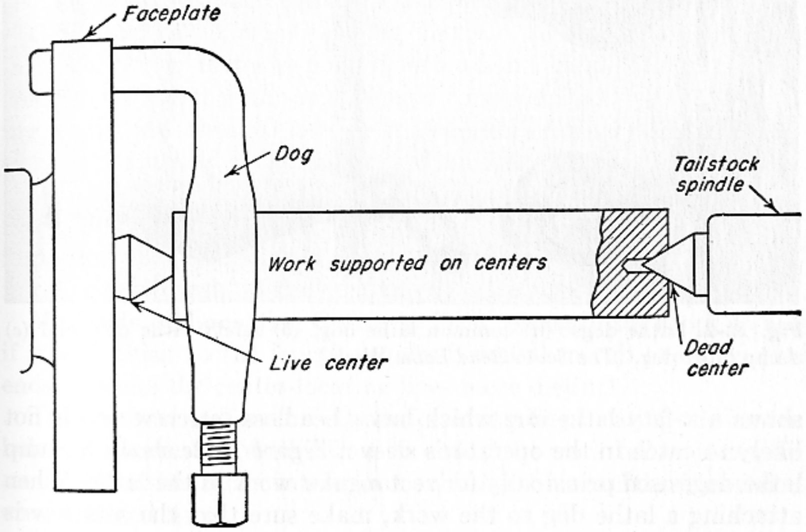


Fig. 12-1.

A large proportion of lathe work is mounted on centers. Sixty-degree countersunk holes, called *centers*, are drilled and reamed in both ends of the piece to be turned. These holes fit the 60-deg. lathe centers and the work is thus supported (Fig. 12-1).