VIRAM SERIES

PRODUCTION TECHNOLOGY

As per AICTE Curriculum for Diploma

R.K. Jain

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Production Technology

(for Diploma Course)

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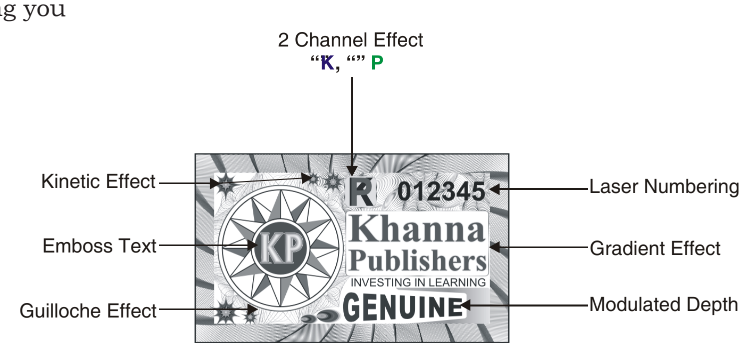

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Preface

The book "Production Technology" has been brought up to date to cover the complete latest syllabus of diploma. The purpose of this text book is to provide a comprehensive knowledge and insight into various aspects of engineering materials, their treatment and fabrication, casting and foundry, hot and cold working of metals, welding and other joining techniques. Manufacturing processes, machining and tooling techniques, non-conventional methods of machining cutting tools, tooling equipment and machine tools, dies, jigs and fixtures, presses etc.

It is hoped that students will find this book useful, serving their purpose of scoring high marks with thorough understanding of subject matter.

Author is thankful to Mr. Kratu Khanna and Ms. Akshita Khanna (children of Mr. Vineet Khanna and grand children of Mr. Romesh Chander Khanna) for their keen interest in bringing out full series of books for diploma engineers.

Any suggestion for improvement of the book shall be welcome.

—R.K. Jain

Contents

Chapter 1

Elementary Theory of Metal Cutting

1.1. INTRODUCTION

Machining of metal involves forcing of cutting tool through the excess material of the workpiece. In the form of chips, this excess material is progressively separated from the workpiece, thereby rendering workpiece to a desired shape and size. It may be emphasised here that the cutting tool never peels off chips or the excess-material from the workpiece, but the chips are generated because of plastic deformation of metal just ahead of the cutting edge of the tool.

Although the workpiece can be effectively shaped by a large number of other manufacturing processes, yet the process of machining plays an important role, being one of the most versatile processes of manufacturing. Its versatility can be attributed to so many factors, some of which are:

1. Machine tools do not require elaborate tooling.
2. The process of machining can be employed to all engineering materials.
3. The wear of tools is not costly, if it is kept within limits.
4. A large number of parameters which come into play during machining can be suitably controlled in order to overcome technological and economical difficulties.

1.1.1. Elements of Cutting Process (Mechanics of Metal Cutting)

Any cutting process involves workpiece, tool (including holding devices), chips and cutting fluid. For removing the metal, wedge shaped tool is constrained to move relative to the workpiece so that it removes the metal in the form of chips. Referring in Fig. 1.1 (which shows the position of cutting tool in relation to work in order to cut metal with less effort), it will be seen that there are three basic angles of importance, *viz.*, rake angle, clearance angle and setting angle.

First we shall consider the geometry involved in the cutting process assuming it to be a two dimensional process, *i.e.* we sha1l concentrate on one representative plane. This is with a view to simplify the treatment. This is also known as orthogonal cutting. In it the cutting edge of the tool is at right angles to the direction of relative motion between the tool and the workpiece. Examples of orthogonal cutting are: turning at the open end of a tube or planing of a rib with the tool wider than the rib width. Actual cutting processes involve tools and processes which are three dimensional. (Oblique cutting). In orthogonal cutting, the cutting edge of tool is located at 900 to the motion of work piece. In oblique cutting, the cutting edge of the tool is inclined and not perpendicular to motion of workpiece. It may be mentioned that principles developed for orthogonal cutting generally also apply to oblique cutting.

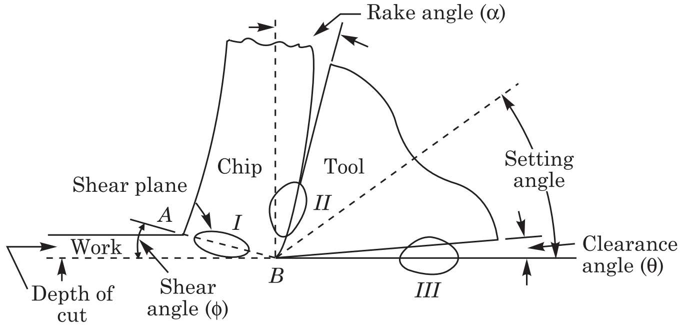

Fig. 1.1. Position of tool in relation to work

In any cutting operation, following observations can be made:

(*a*) Metal is cut by removal of chips which may be in the form of continuous ribbon or discontinuous chips composed of individual segments, which depends on the work material and cutting conditions. The chip is thicker than the actual depth of cut and it is correspondingly shortened. The hardness of the chip is usually much greater than the hardness of the parent material.

(*b*) There is no flow of metal at right angles to the direction of chip flow.

(*c*) Flow lines are evident on the side and back of a chip, which suggests that cutting involves a shearing mechanism. On observing the flow lines on the surface of a chip it will be obvious that chips are formed by blockwise slip of metal. However, the front surface is usually smooth due to a burnishing action. It is important to note that chips are formed due to process of deformation or plastic flow of material, which takes place by means of phenomenon called slip.

(*d*) A lot of heat is generated in the process of cutting due to friction between the chip and tool. The friction can be reduced by having sharp cutting edge and better tool finish, increased sliding speed, improved tool geometry, use of low friction work or tool materials, and use of a cutting fluid. The temperature of the cutting tool reaches a high value when taking a heavy cut at high speed.

(*e*) In Fig. 1.1, line *AB* is the dividing line between the work and the chip. The material above this line is deformed by an internal shearing process and comes out in the form of chip. The rate at which metal is deformed is high. The material below this line is underformed. Shear plane is the plane along line *AB* and perpendicular to the plane of paper.

(*f*) In front of the cutting tool point, generally no crack is observed. Due to strain hardening, the hardness of metal in chip. the built-up edge and near the finished surface is usually greater than that for the metal.

(*g*) Sometimes a built-up edge is formed at the tip of the tool and it significantly alters the cutting process. It deteriorates the surface finish and rate of tool weal' is increased.

(*h*) The inclination of plane AB with respect to surface of work is known as shear angle. This angle increases when the tool friction is decreased ; and increase of shear angle means that shear plane will be of smaller length and the thickness of chip will also be less. If the shear stress on the shear plane be assumed to remain constant, then the force along the shear plane will also vary as the area of the shear plane. Further the amount of plastic deformation to which the chip is subjected also decreases as the shear angle increases.

(*i*) In the metal cutting process, three areas of interest requiring due consideration are shown in Fig. 1.1 by circles I, II, and III. The first one is along the shear plane, second is the interface between the chip and the tool face, and the third is the finished or machined surface and the material of tool adjacent to that surface.

(*j*) The steady state conditions on which the cutting theories are based often get changed by the formation of discontinuous chips. The tool geometry is also altered by the presence of bui;t-up edge.

1.1.2. Geometry Of Single Point Tool

Tool geometry concerns with the basic tool angles, i.e. angles ground on tool to make it efficient in cutting. A single point tool has only one cutting edge and is most widely used ill industries. It is designed with sharp edges to minimise rubbing contact between tool and workpiece. Factors like cutting tool life, surface finish on workpiece, force required to shear a chip are affected by variations in shape of cutting tool. Such a tool is available in two forms. In one form it is solid tool and in the other form it is a tipped tool. The tip is either brazed or' mechanically held on an alloy steel shank.

Shank. It is the body of the tool or that part on which cutting edge is formed. If the tool is of insertion type, then shank is that part in which cutter is inserted.

Nose. Sometimes, it designates the cutting edge but particularly it relates to the top of cutting edge which is usually given a radius and seldom it is like a sharp point.

Face. It is that part against which chips are beared.

Base. It is the support of tool shank.

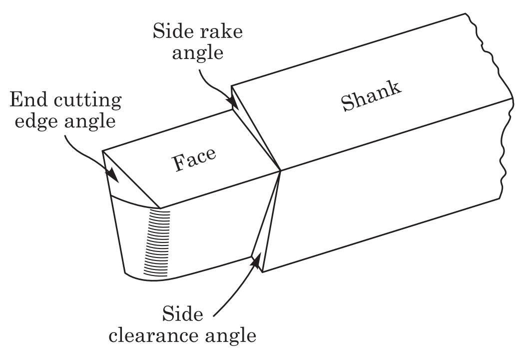

Fig. 1.2. Single point tool.

Flank. It is the end surface, *i.e.* adjacent to the cutting edge and below it, when the tool is in horizontal position.

Nominal size of tool. It is expressed by width and height of the shank and the tool length.

1.1.3. Tool-Angles

In a single point tool, there are various angles; each . of them has a definite purpose. They are listed below in the order of importance.

1. Rake angle
2. Clearance angle.
3. Cutting angle
4. Lip-angle (Metal cutting-angle).

(*i*) *Rake-angle*. It is the most important angle of the tool. The nominal rake-angle is the angle made by the face of tool and the plane parallel to the base of cutting tool. If the rake angle is measured in the direction of tool shank, it is called back *rack-angle* and if measured in a direction at right angles to it, then it is called *side rake-angle*. The effective rake angle depends upon the position of tool relative to the job axis. The purpose of this angle is to allow the chips to flow plastically over the tool face, so that smoother action can take place. Rake angle is the only angle on which the strength of the tool depends. Rake angle controls the chip formation, and is in turn governed by the mechanical properties of the material being cut. The force on the tool is reduced by increasing the rake angle but tool is weakened. Thus a compromise between the two factors has to be obtained. Here is a table of back and side rake angles for some of commonly used materials in production engineering.

S. no.	*Material*	*Back rake*	*Side rake*
1.	Brass	0°	0°
2.	C.I.	10°	12°
3.	Aluminium	14°	14°
4.	Hard steel	5°	9°
5.	Roughing cuts on medium and soft steel	8°	14°–20°
6.	Monel metal	6°–8°	15°–18°

Negative rake angle. In brittle materials like brass, zero rake angle is provided, but in tougher materials like copper, negative rake angles are also used, because of tougher characteristics of the materials. The tougher characteristic has a tendency to cause the cutting edge of the tool to dig into the material and spoil the job surface. Carbide tipped tools usually have negative rake angles. The main purpose of using negative rakes is (1) to increase the strength of cutting tool point, (2) to give better finish, (3) to decrease the temperature rise at the tool-tip because more heat flows to chips from tool.

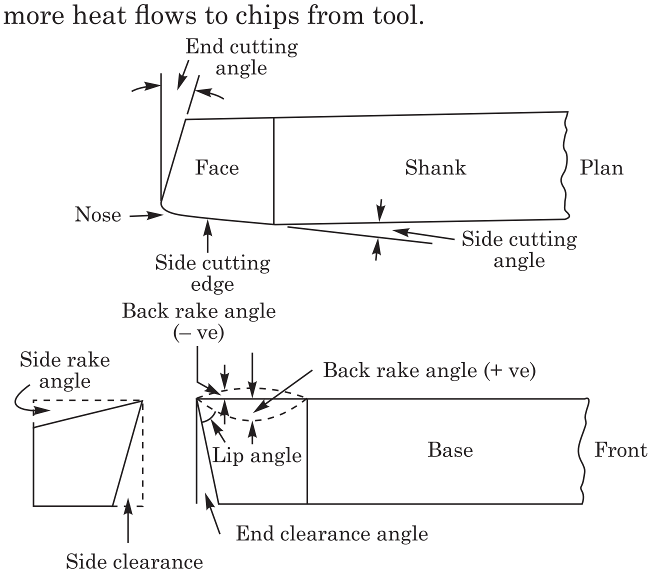

Fig. 1.3. Cutting angles of single point tool.

(*ii*) *Clearance angle*. It is the angle of the end of side surfaces which are below the cutting edge. When the tool is in horizontal position, the normal clearance angle is measured from the plane perpendicular to the base of tool shank. The effective clearance depends upon the position of tool relative to the job. The purpose of this angle is to avoid any frictional drage of the tool on the job and prevent the tool from rubbing on the surface already cut. Its magnitude depends upon the shape of the surface being cut, and is kept as small as possible to avoid weakening of the tool.

(*iii*) *Cutting angle*. The true cutting angle is the angle between the face of tool, and the line tangent to the machined surface at the cutting point.

(*iv*) *Lip angle*. It is the angle between the tool face and the ground end surface of flank. It is usually between 60° to 80°.

Nose radius. Side and end cutting edges can be joined to form a point but that is not desirable as it leads to high heat concentration at a sharp point. Joining side and end cutting edges by an arc (nose radius) is the common practice. Provision of nose radius improves tool life, surface finish and reduces cutting force. However, large nose radius results in chatter and that too is not desirable. Therefore, nose radius should be selected properly.

Tool Signature. It is numerical method of identification of tool standardised by the American Standards Association (ASA) according to which the seven elements comprising signature of a single point. tool are always stated in the following order: back rake angle, side rake angle, end clearance (relief angle), side clearance (relief angle), end cutting edge angle, side cutting edge angle, and nose radius. Symbols of degrees for angles and units for nose radius are omitted and only numerical values of those components are indicated.

1.2. CHIP-FORMATION

In any machining operation, the material is removed from the workpiece in the form of chips, the nature of which differs from operation to operation. As the form and dimensions of a chip from any process can reveal lot of information about the nature and loyalty of process, the analysis of chip formation is very important. Chips are formed due to tearing and shearing.

In the process of chip formation by tear, the workpiece material adjacent to tool face is compressed and a crack runs ahead of cutting tool and towards the body of the workpiece. The chip is highly deformed and workpiece material is relatively underformed. Cutting takes place intermittently and there is no movement of the workpiece material over the tool face. In chip formation by shear, there is general movement of the chip over tool face.

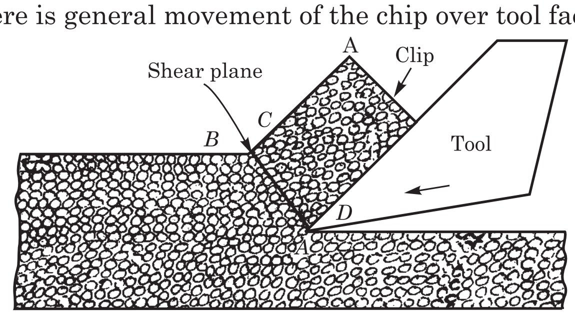

Fig. 1.4. Shear plane/shear zone in cutting zone.

As the tool advances into the workpiece, the metal ahead of the tool is severely stressed. The cutting tool causes internal shearing action in the metal such that the metal below the cutting edge yields and flows plastically in the form of chip. Firstly compression of the metal under the tool edge takes place and then follows separation of metal, when compression limit of that metal has been exceeded. Plastic flow takes place in a localised region called *shear plane*, which extends from the cutting edge obliquely upto the uncut surface ahead of the tool. When the metal is sheared the crystals are elongated, the direction of elongation being different than from that of the shear.

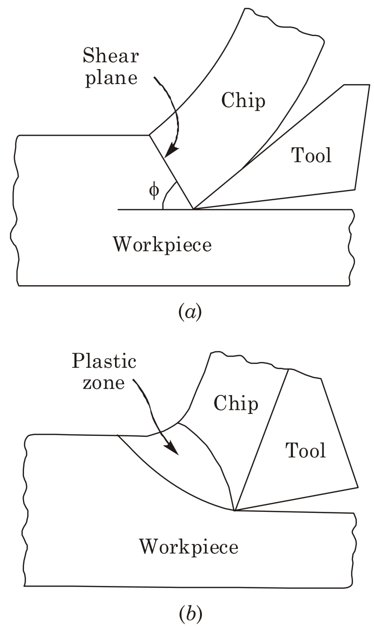

Fig 1.5. Shear plane/near zone in cutting action

It may be mentioned that the deformation of metal in the process of separation of chip, does not occur sharply across the shear-plane. The grains of the metal ahead of cutting edge of tool start elongating along the line *AB* and continue to do so until they are completely deformed along the line *CD*. The region between the lines *AB* and *CD* is called shear zone. After passing out the shear-zone, the deformed metal slides along the tool face due to the velocity of the cutting tool, For all mathematical analysis this shear zone is treated as a plane and is called a shear-plane.

The angle made by plane of shear with the direction of tool travel is known as shear angle (*f*), Its value depends on the material being cut and the cutting conditions. If (*f*) is small, path of shear will be long, chips will he thick, and the force required to remove the layer of metal of given thickness will be high and vice versa.

1.3. TYPES OF CHIPS

Every machining operation involves the formation of chips, the nature of which differs from operation to operation, properties of workpiece material and the cutting condition. Chips are formed due to cutting tool which is harder and more wear resistant than workpiece material, interference between tool and workpiece, relative motion between tool and workpiece sufficient force and power to overcome resistance of work material. The chip is formed by deformation of the metal lying ahead of the cutting edge by a process of shear. Basically, there are four types of chips:

1.3.1. Discontinuous Chip

These chips are small segments which adhere loosely to each other and form slightly larger-length. Discontinuous chips are formed when the amount of deformation which the chips undergo is limited by repeated fracturing.

It has been found that segments are regularly formed due to rupture of the metal ahead of the tool. Due to rupture taking place when the material directly above the tool face is compressed to such an extent that the deformed metal starts sliding along the face and the magnitude of compression force reaches the fracture limit of the metal.

This type of chip is obtained by machining hard and brittle metals like bronze, brass and cast-iron. Sometimes, cutting of ductile metals at very low feeds with small rake angle of the cutting tool and high speeds and high friction forces at the chip tool interface also result in the production of discontinuous chips. Discontinuous chips in ductile materials are formed when the hydrostatic pressure near the cutting edge is tensile or the shear energy reaches a critical value. The formation of this type of chip in brittle materials imparts good finish, increases tool life and consumes less power. Presence of discontinuous chips in ductile-materials results in poor-finish and excessive tool-wear. Smaller chips are easier to dispose off.

If discontinuous chips are produced from the brittle materials, then surface finish is fair, power consumption is low and tool life is reasonable. However when these are produced with ductile materials, then finish is poor and tool wear is excessive.

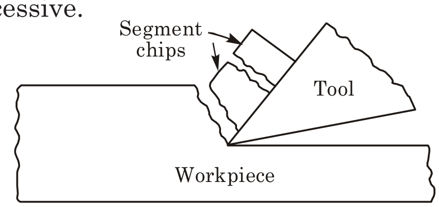

Fig. 1.6. Discontinuous chips

1.3.2. Continuous Chip

In continuous chip formation, the pressure of the workpiece builds until the material fails by slip along the slip plane. The inside of the chip displays steps produced by the intermittent slip, but outside of the chip is burnished smooth by chip rubbing on tool surface. It has its elements bonded together in the form of long coils and is formed by the continuous plastic deformation of metal without fracture ahead of the cutting edge of tool and is followed by the smooth now of chip up the tool face. The chips so obtained have same thickness throughout. This type of chip is obtained by machining ductile materials at very high cutting speed. Mild-steel and copper are considered to be most desirable for obtaining continuous chips.

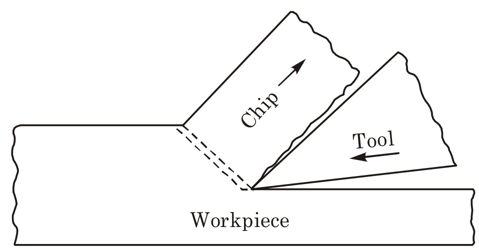

Fig. 1.7. Continuous chips.

Sometimes, continuous chips are produced at low cutting speed if effective cutting fluid is used because this type of chip is associated with low friction between the chip and the tool. Since finish is best, power consumption is low and tool life high with this type of chip, this is most preferred type. The only problem is of chip disposal which to some extent can be tackled by the use of chip breakers on the cutting tools.

1.3.3. Continuous Chip with Built up Edge

This type of chip is very similar to that of continuous type, with the difference that it is not as smooth as the previous one. It has a built up edge, adhering on the nose of tool. The built up edge changes the effective geometry of cutting. It is obtained by machining ductile metals with high speed tools at ordinary cutting speeds, thus introducing high friction between the chip and tool face. The form and size of such an edge depends largely on the cutting speed, being

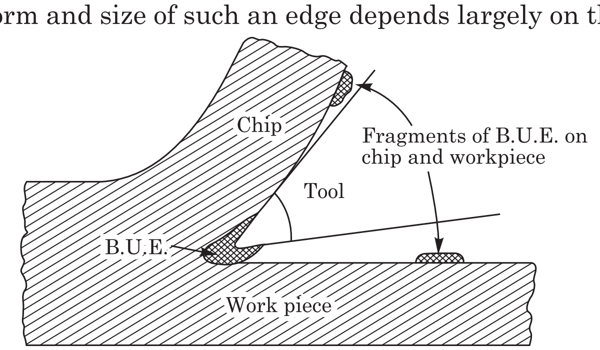

Fig. 1.8. Continuous chip with built up edge (B.U.E).

absent at very low and very high cutting speeds. This type of the chip is associated with poor surface finish, but protects the cutting edge from weal' due to moving of chips and the action of heat, causing an increase in tool life.

The main factors that are responsible for the formation of built up edge are cutting speed, rake-angle of tool, condition of cutting edge, coarse feed, insufficient cutting fluid, etc. The formation of built up edge can be reduced by machining metals at higher cutting speeds, because it slows down the formation of built up edge due to low friction at the tool chip interface. The formation of built up edge can also be reduced by making the tool face smooth, by using a material with a low coefficient of friction with the workpiece material, and by using an efficient cutting fluid. Tendency of welding can be reduced by using non-metallic tool material. The back of the chip (which is in contact with the tool face) gives a fairly good indication of the built up edge condition. If no built up edge is there, then back of chip should be clean. smooth and highly burnished.

Following points may be noted regarding built up edge:

(*i*) Built up edge may be formed initially by high friction forces existing on the rake face which may cause adhesion to occur. These friction forces cause the material to reach its shear flow stress along a line inclined to the rake face; a velocity discontinuity occurs and wedge shaped particles are left on the rake surface. Built up edge may also be formed by bluntness of the tool edge, *i.e.*, wear at point of the tool which may result in the formation of a dead metal zone. The subsequent growth of built up edge at a given speed depends on the work hardening properties of the metal.

(*ii*) Adhesion can be inhibited by using a polished tool, or under certain conditions by the application of a cutting lubricant.

(*iii*) The shape of built up edge is a function of temperature and hence cutting speed.

(*iv*) Positive rake angles on tools decrease built up edge at low cutting speeds and negative rake angles decrease built up edge at high cutting speeds.

(*v*) At low cutting speeds, dimensions of build up edge increase with increase in feed. At higher speeds. build up edge first increases with increase in feed but after a particular value it decreases.

1.3.4. Inhomogeneous Strain-Chip

This type of chip is produced by machining hard alloys like titanium which suffer a marked decrease in yield strength with increase in temperature.

Chip breaker. It is small step or groove ground into face of tool and sometimes separate piece is also fastened to the tool or tool- holder to act as chip breaker. These devices cause the chip to curl and break into pieces of short sections. Continuous chip is not desirable.

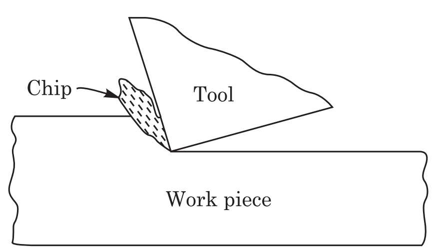

Fig. 1.9. Chip with inhomogeneous strain.

1.4. MECHANISM OF CHIP FORMATION

For metal cutting to be effective, it is necessary that tool takes the form of a large angled wedge. This tool must be driven asymmetrically into the work material, to remove a thin layer from a thicker body. The layer removed must be thin so that imposed stress on tool and work is within limits. Further a clearance angle must be provided on the tool to ensure that the clearance face does not make contact with the newly formed work surface. The included angle of tool edge can vary from 55° to 90° to enable chip to divert by an angle of at least 60° as it moves away from the work, across the rake face of the tool. The whole volume of the removed layer from the work (chip) gets plastically deformed and a large amount of energy is needed for its formation and to make it move across the tool face. The knowledge of the process of chip formation is thus essential.

The formation of chip involves shearing of the work material in the region *OA* (plane extending from the tool edge to the position where the upper surface of the chip leaves the work surface).

A very large amount of strain takes place in the region *OA* in very short interval of time, which result in fracture of the metal.

The cross-section of chip is not rectangular because the metal is free to move in all directions (except at rake face of tool where it is constrained) as it is formed into the chip. The chip tends to spread side-ways and as a result the maximum width t_2 is greater than the original depth of cut t_1. The chip spread is small with harder alloy, but with soft metals when cutting with a small rake angle tool, $t_2/t_1 > 1.5$ can be observed. Usually the chip thickness is greatest near the middle and' it tapers off somewhat towards the sides. The upper surface of the chip is always rough, usually with minute corrugations or steps. Even with a strong, continuous chip, periodic cracks are often observed, breaking up the outer edge into a series of segments.

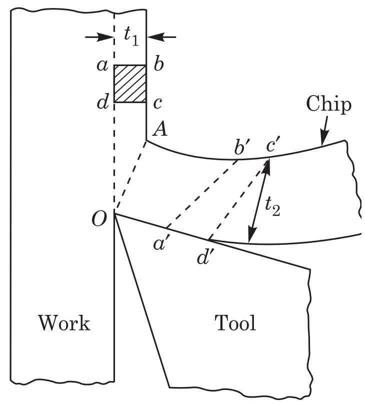

Fig. 1.10

As any volume of metal like *abed* (in Fig. 1.11) passes through the shear zone, it is plastically deformed to a new shape *a′ b′ c′ d′*.

The amount of plastic deformation or shear straing is related to the shear plane angle and the rake angle as shown in Fig. 1.11. It may be noted that shear strain = *b*/*a* in Fig. 1.11.

From Fig. 1.11, it will be noted that for each rake angle, there is a minimum strain when the mean chip thickness is equal to the feed ($t_2 = t_1$). For zero rake angle it occurs at shear plane angle of 45°. Also at zero rake angle the minimum shear strain-in 2 and becomes less as the rake angle is increased. Fig. 1.12 shows how the change of shape of a unit cube after passing through the shear plane occurs for different values of the shear plane angle.

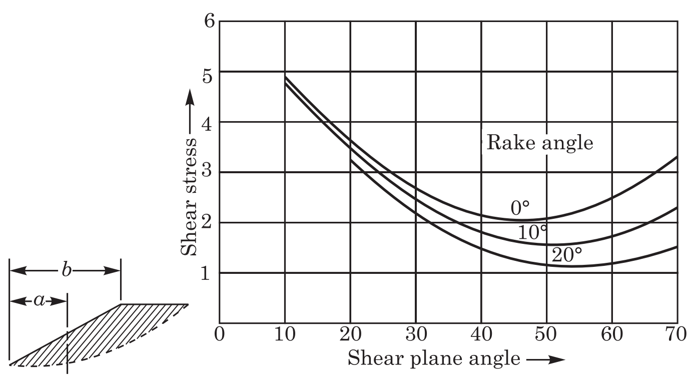

Fig. 1.11

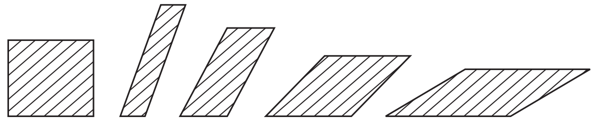

Fig. 1.12

1.4.1. Effect of Various Factors on Metal Cutting Characteristics

(*i*) *Velocity*. It directly affects the temperature at tool point. If velocity is so low that the temperature at tool point is below the recrystallisation temperature of the material, then work hardening in the chip will be retained and the built-up edge will be formed, On ductile materials, high velocity can lead to formation of less distorted and longer chips, and the use of artificial chip breaker is must. It has been found that direction of chip flow is not affected by velocity.

(*ii*) *Size of cut*. Increasing of depth of cut has not that much effect on chip as the feed. Increasing of feed widens the area of contact and changes the force per unit length, resulting in great distortion of chip. In case of ductile materials, it is possible to form segmented chips by increasing feed and depth of cut, but increasing them too much may lead to chatter, poor surface quality if the machine is not rigid enough. Deep turning cuts on small diameters have a greater percentage change in velocity along the length of cutting edge and this may lead to erratic built up edge behaviour with poorer surface quality. It is noted that direction of chip flow changes with change in size of cut.

(*iii*) *Tool geometry*. This changes the shear angle and ultimately the chip thickness. The smaller the rake angle, lesser the shear angle and greater the chip distortion and more the resistance to chip flow. At low rake angles, the built up edge is bigger in size and produces rough and more work hardened surfaces, but the chip being highly distorted breaks up into short lengths. The side rake angle is found to have much more effect than the back rake angle. Increasing of side cutting edge and nose radius reduces the chip thickness, thereby reducing the chip contact width to thin out the built up edge. Too much nose radius, however, may lead to chatter in non-rigid setups.

(*iv*) *Tool material*. It should be able to sustain high cutting velocities and the coefficient of friction between chip and tool material must not change.

(*v*) *Cutting fluids*.

(*vi*) Ductile materials produce continuous chips (normally with built-up edge) whereas brittle materials produce segmented or discontinuous chips. In latter case the cutting forces are also lower. Low friction, high cutting velocities and materials of low work-hardening capacity are desirable features for getting less distorted chip. Additions of lead, sulphur and phosphorous to low carbon steels help to break up chips, reduce built-up edge and improve surface quality.

(*vii*) Inspite of large theories put forward, it is still not possible to predict precisely the forces involved in metal cutting, because of the extreme complexity and the lack of geometrical constraint which is the characteristic of metal cutting.

1.5. GEOMETRY OF CHIP FORMATION

When a wedge shaped tool is pressed against the workpiece, chip is produced by deformation of material ahead of cutting edge because of shearing action taking place in a zone (treated as single plane) known as shear plane. Shear plane separates the deformed and undeformed material.

PRODUCTION TECHNOLOGY

As per AICTE Curriculum for Diploma

About the Book:

The purpose of this book is to provide the comprehensive knowledge and insight into various aspects of engineering materials, their heat treatment and fabrication, manufacturing processes, machining and tooling techniques, non-conventional methods of machining, the cutting tools, tooling equipment and machine tools, dies, jigs and fixtures, special attention has been given for their full coverage, modern practices and recent trends being followed in manufacturing have been covered in each chapter.

Numericals play an important role in clarifying the text and accordingly a large number of solved numericals have been added.

About the Author:

R.K. Jain, author of this book on 'Production Technology' has been associated with Mechanical Engineering for more than 40 years. He started his career as Lecturer in Mechanical Engineering Department in REC, Kurukshetra. Then he joined Central Electricity Authority where he rose to highest level of chairperson of the organisation. Presently he is consultant with World Bank. He has experience in all the aspects of Electricity Industry. He was actively involved in design of thermal power plants, supercritical technology in the country, selection of suitable sites and developing compact layouts of thermal power plants. He has long experience in writing a number of books on Mechanical Engineering subjects. He also authored books like 'The Art of Happy Living' and 'Lifestyle for Total Development'.

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