1 CUTTING TOOLS AND CUTTING MATERIALS

1.1 INTRODUCTION

A cutting tool is subjected to static and dynamic forces, high temperature, wear and abrasion. To get a reasonable tool life, the tool materials should meet the following requirements:

1. Hot hardness so that the tool does not loose its hardness and strength at the high temperature developed during machining.
2. Wear and abrasion resistance.
3. Impact toughness so that the fine cutting edge of the tool does not break or chip when the tool is suddenly loaded.

The selection of a proper tool material depends upon a number of factors such as type of cutting operation, material of the work piece, machine tool to be used and surface finish required. Usually, a compromise has to be made in the selection of tool material since the requirements to be met by tool material are often contradictory in nature. Over the years, a wide variety of cutting tool materials have been developed to meet the ever increasing demand of machining harder and harder materials.

1.2 CUTTING TOOL AND ITS TYPES

- *The tools which are used for the purpose of cutting the metals in the desired shape and size are called cutting tools.* During the process, such types of cutting tools always produce waste material in the form of chips or cuttings. Cutting tools are broadly classified into two major groups :

1. **Single Point Cutting Tool :** *The cutting tools terminating in a single point are termed as a single point cutting tools.* These tools are used on lathes, shapers, planers etc.

2. **Multi Point Cutting Tool :** *The cutting tools being composed of more than one single point are termed as multi-point cutting tools.* e.g. milling cutters, drills, broaches, grinding wheels etc.

The cutting tools may also be classified according to the motion as follow :

1. **Linear Motion Tools :** Lathe, boring, broaching, planing, shaping tools etc.
2. **Rotary Motion Tools :** Milling cutters, grinding wheels etc.
3. **Linear and Rotary Motion Tools :** Drills, honing tools, boring heads etc.

1.3 VARIOUS TYPES OF SINGLE POINT CUTTING TOOLS AND THEIR USES

Various types of single point cutting tools are used with different types of machines such a lathe, shaper, planer, slotter etc. Single point cutting tools of common use are given below :

A. Tools For Lathe Machines: On a lathe machine, different operations can b performed. For different operations, different tools are required :

1. **Turning Tool :** *These tools are used for turning*. These may be of two types :

   (*i*) Left hand turning tool,

   (*ii*) Right hand turning tool.

   Both types of turning tools are shown in fig. 1.1. Turning is done to reduce diameter and improve surface finish.

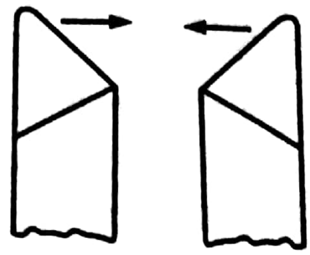


Fig. 1.1 : Left Hand and Right Hand Turning Tools

2. **Facing Tool :** *These tools are used for facing operation*. These may be of two types :

   (*i*) Left hand facing tool ,

   (*ii*) Right hand facing tool.

   Both types of facing tools are shown in fig. 1.2. Facing is done to reduce length and improve the surface of side ends.

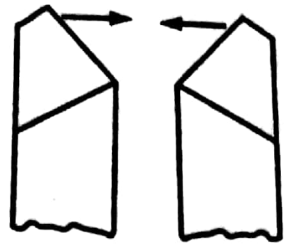


Fig. 1.2 : Left Hand and Right Hand Facing Tools

3. **Chamfering Tool :** *These tools are used for bevelling the corners of the workpiece for small lengths*. These may be of two types :

   (*i*) Left hand chamfering tool,

   (*ii*) Right hand chamfering tool.

   Both the types are shown in fig. 1.3.

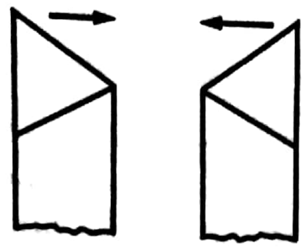


Fig. 1.3 : Left Hand and Right Hand Chamfering Tools

4. **External Threading Tool :** *It is a form tool and is used to cut threads of a particular shape and size*. The shape of the tool is determined by the inclined angle at the nose of the tool which should correspond to the angle of the thread. It may be 60° for metric threads or 55° for B.S.W. threads. The size or cross-section of the cutting edges of the tool depends upon the pitch of the thread. The external thre cutting tool is usually straight in length. An external thread cutting tool is shown in fig. 1.4.

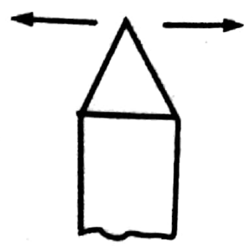


Fig. 1.4 : External Threading Tool

5. **Internal Threading Tool :** *It is used to cut threads in holes. e.g.* nuts. The cutting edge is exactly similar to an external threading tool, but the front clearance angle is sufficiently increased in a boring tool. The tool portion is usually at right angle to the shank or holder. An internal threading tool is shown in fig. 1.5.

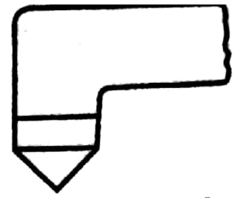


Fig. 1.5 :Internal Threading Tool

6. **Boring Tool :** *A boring tool is used to enlarge an already existing hole in the work-piece.* The cutting edge of the tool is similar to a left hand external turning tool, but front clearance angle is sufficiently increased to avoid rubbing with the work-piece. A boring tool is shown in fig. 1.6.

Fig. 1.6 : Boring Tool

B. **Tools For Planers :** Mostly the planer tools are made of high speed steel. Cemented carbide tipped tools are also used on planers. The shape of the planer tool depends upon the type of operation to be performed. Some different single point cutting tools are described below :

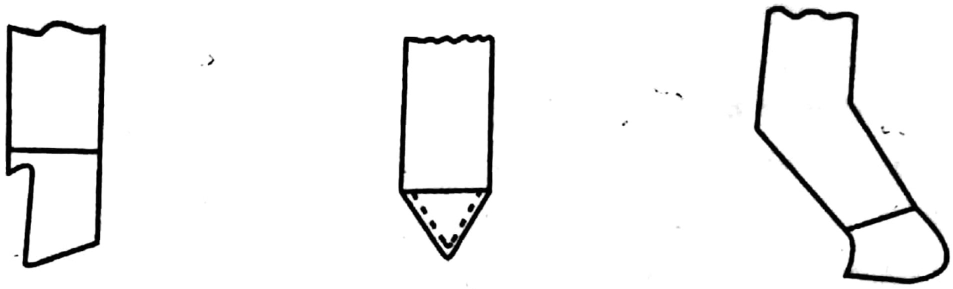
1. **Straight and Bent Roughing Tools :** Fig 1.7 shows various roughing tools for planing flat surfaces. *They are supposed to cut the material as far as possible within a short time.* The large cross section of the chips of the metal removed by them requires cutting edge of this category of tools to be quite sturdy.

(i) Right Hand (ii) Left Hand
(a) Straight Roughing Tools

(i) Right Hand (ii) Left Hand
(b) Bent Roughing Tools

Fig. 1.7

2. **Straight Neck, Round Nose and Goose Neck Tools :** *These tools are used for finishing operation for producing flat surfaces by planing.* These tools must produce a smooth surface on the workpiece. A goose neck tool is useful when hard spots are encountered during planing a metallic surface (See fig. 1.8).



(i) Straight Neck Tool **(ii) Round Nose Tool** **(iii) Goose Neck Tool**

Fig. 1.8

C. Tools For Shapers

The general shape of the tools for shaping is same as for turning, but their shanks should be a little more strong to withstand the shock which arises each time a cutting stroke occurs. Some cutting tools for shaper are shown below :

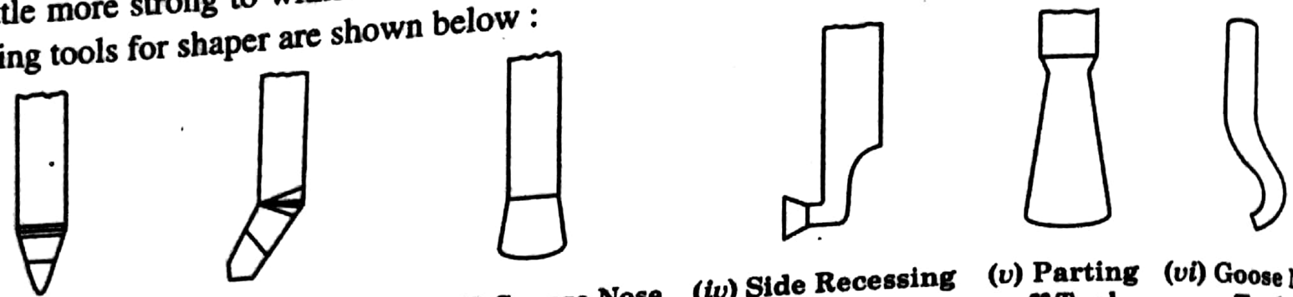


Fig. 1.9 : Shaping Tools

1.4 IMPORTANT TERMS RELATING TO SINGLE POINT CUTTING TOOL

Fig. 1.10 shows the different parts of a single-point cutting tool. These are as follow :

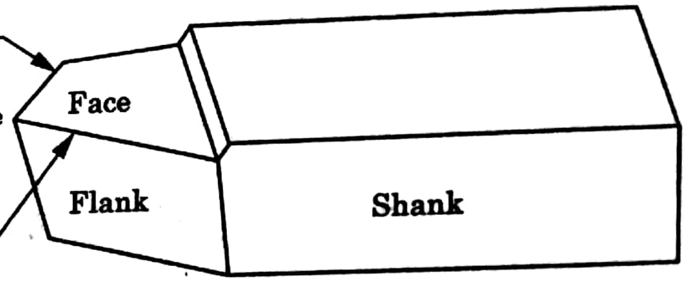


Fig. 1.10 : Single Point Cutting Tool

1. **Shank :** *It forms the main body of a tool and it is that part of the tool which is gripped in the tool holder.*

2. **Flank:** *The surface below and adjacent to the cutting edge is called flank of the tool.*

3. **Face :** *It is the top surface of the tool between the shank and cutting edge of the tool.* The chips flow along this surface only during cutting action.

4. **Heel :** *It is the curved portion at the bottom of the tool where the base and flank of the tool meet.*

5. **Nose:** *It is the point where the side cutting edge and end cutting edge intersect.*

6. **Neck :** *The portion which is reduced in section to form necessary cutting edges and angles is called neck.*

7. **Cutting edge :** *It is the edge on the face of the tool which removes material from the workpiece.* It consists of partially by the end cutting edge and largely by the side cutting edge.

1.5 IMPORTANT ANGLES OF A SINGLE POINT CUTTING TOOL

The different angles provided on single point cutting tool play a significant role in successful and efficient machining of different metals. Important angles of a single point cutting tool are as follow :

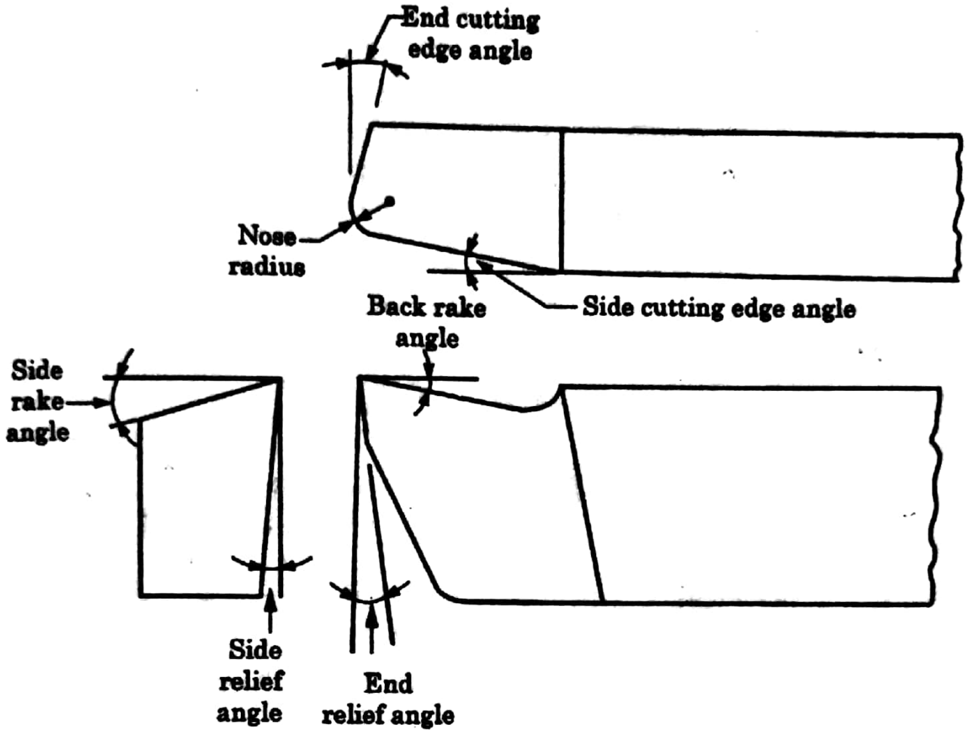


Fig. 1.11 : Principal Angles of a Single Point Cutting Tool

1. **Back Rake Angle :** *It measures the downward slope of the top surface of the tool from nose to the rear along the longitudinal axis.* Its purpose is to guide the direction of chip flow. Rake angle may be positive, negative or zero.

(*i*) **Positive Rake Angle :**

(*a*) Removes chips from machined surface.

(*b*) Produces better surface finish.

(*c*) Sharpens the cutting edge and hence less cutting force is required.

(*d*) Increases tool life and decreases power consumption.

(*ii*) **Negative Rake Angle :**

(*a*) Directs the chips to the machined surface.

(*b*) Causes more chatter.

(*c*) Strengthens the tool.

(*d*) Increases pressure between job and cutting tool.

(*iii*) **Zero Rake Angle :**

(*a*) More cutting forces and chatter.

(*b*) Rare use.

(*c*) Difficult to penetrate into the job.

(*d*) Poor surface finish.

2. **Side Rake Angle:** *It is the angle at which the top surface of the tool point slopes ba from the side cutting edge (primary cutting edge).*

The extent of the side rake determines the angle at which the chip leaves the work-piece as is directed from the primary cutting edge.

Positive side rake is used to direct the flow of chips and makes the side cutting ang smaller. The higher the rake angle, the lesser cutting force is required. However, the cutting ed becomes fragile.

3. **End Relief/Clearance Angle :** *It is the angle at which the surface joining the end front of the tool slopes down from the nose of the tool.* It prevents the end or front of the tool fro rubbing the work. It concentrates the thrust exerted on the end surface of the tool in the small an about the nose or the end cutting edge.

4. **Side Relief/Clearance Angle :** *It is the angle made by flank of the tool and a pla perpendicular to the base just under the side cutting edge.* This angle permits the tool to sideways into the job, so that it can be cut without rubbing.

5. **End Cutting Edge Angle :** *It is the angle at which the end or front of a tool point ha been ground back to the side of the shank.* It serves to reduce the amount of surface contact of th end with the workpiece. This angle may vary from 8° to 13°.

6. **Side Cutting Edge Angle :** *It is the angle at which the side of a tool point has bee ground to the side of the shank.* This angle serves two purposes :

(*i*) It protects the tool point from taking the initial shock of the cut.

(*ii*) It serves to thin out the chip. For a given depth of cut, the material will be spread over longer cutting edge. This angle may vary from 5 to 20°.

7. **Nose Radius :** *It is the curve formed by joining the side cutting edge and end cuttin edge. The angle so formed is called nose angle and the radius of the curve is called nose radius.*

1.6 SINGLE POINT CUTTING TOOL GEOMETRY

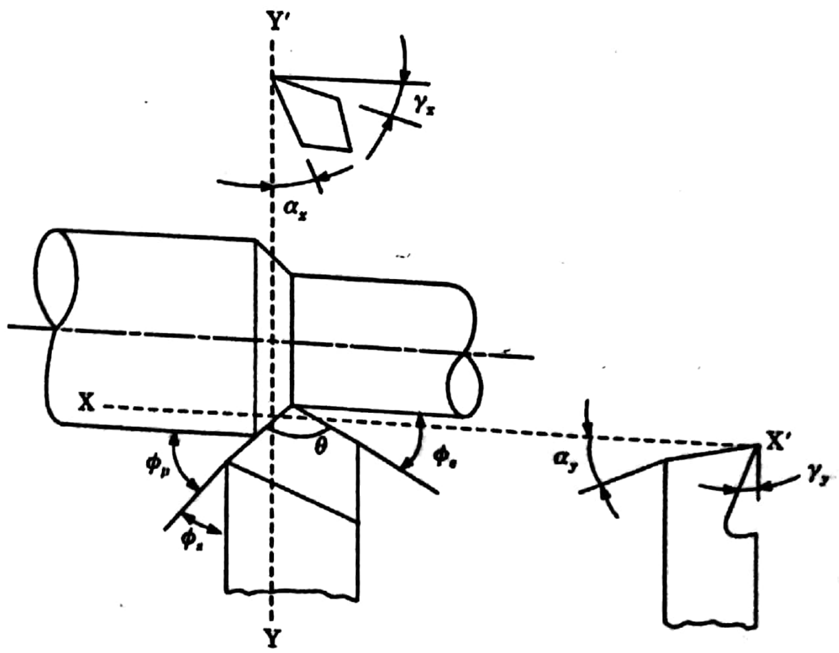
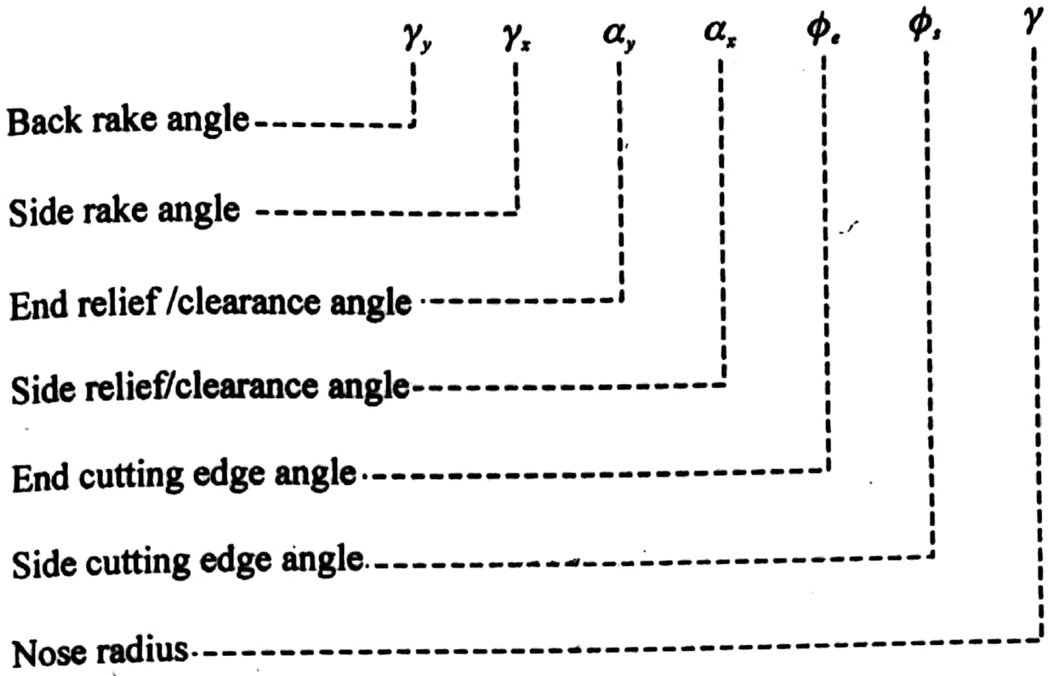


Fig. 1.12 : Tool Geometry



1.7 TOOL SIGNATURE

The term 'tool signature' or 'tool designation' is used to denote a standardised system of specifying the principal tool angles of a single point cutting tool which is as follow :

Back rake angle (γ_y)

Side rake angle (γ_x)

End relief /clearance angle (α_y)

Side relief/clearance angle (α_x)

End cutting edge angle (ϕ_e)

Side cutting edge angle (ϕ_s)

Nose radius

1.8 EFFECTS OF TOOL SIGNATURE

The followings are the effects of tool signature :

1. It reduces the cutting force required to shear the metal which increases tool life and reduces power consumption.
2. It improves the surface finish.
3. It allows the chips to flow in a convenient direction.

Problem 1.1. Describe a tool with 8, 10, 5, 5, 6, 6, 1 signature.

Solution :

Back rake angle (γ_y) = 8°

Side rake angle (γ_x) = 10°

End relief angle (α_y) = 5°

Side relief angle (α_x) = 5°

End cutting edge angle (ϕ_e) = 6°

Side cutting edge angle (ϕ_s) = 6°

Nose radius = 1 mm

1.9 HEAT PRODUCED DURING METAL CUTTING

During metal cutting, heat is produced from the following sources :

1. **Friction :** During machining operation, a lot of friction takes place between (*i*) the tool and work piece and (*ii*) the tool and the chip. The passing of the chips over the tool contributes the maximum friction. The heat so generated is known as the heat of friction. The total quantity of heat generated depends upon many factors such as cutting speed, material of the tool and workpiece, depth of cut and feed of tool.

2. **Plastic Deformation of Metal :** Due to sufficiently high pressure exerted by the tool on adjacent grains of the work-piece, a slip in the weak planes takes place producing deformation in the grains. The slipping action between the grains causes friction leading to generation of heat called the heat of deformation. The quantity of heat generated in this case also depends upon the cutting speed, material of the tool and work piece, depth of cut and feed of tool. The deeper the cut and heavier the feed, the greater is the amount of heat produced since the amount of slip is greater.

3. **Chip Distortion :** In machining operation, as the cut proceeds, the chip curls out and tensile and compressive stresses are generated in the chip. The outer surface is in tension, whereas inner surface is in compression. This results in distortion of grains and consequent generation of heat. Heat so produced is known as heat of chip distortion.

1.10 EFFECTS OF HEAT PRODUCED DURING METAL CUTTING

The followings are the effects of heat produced during metal cutting :

1. It reduces the tool life.
2. It reduces the surface finish.
3. Repeated replacement of tools occurs which increases the cost.
4. It causes the welding of chips with the face of tool.

1.11 CUTTING SPEED

Cutting speed of a cutting tool may be defined as *the speed at which the cutting edge passes over the material.* It is expressed in m/min. It affects the tool life. Tool life decreases as the cutting speed increases.

1.12 FEED

Feed of a cutting tool may be defined as *the distance through which the tool advances into or along the workpiece each time the tool point passes a certain position in its travel over the surface.*

It is expressed in mm in case of turning on lathe, mm/stroke in shaper and mm/tooth in milling machine.

1.13 DEPTH OF CUT

Depth of cut may be defined as *the perpendicular distance measured from the machined surface to the un-cut surface of the workpiece.*

1.14 PROPERTIES OF THE CUTTING TOOL MATERIALS

To be effective, the material from which a cutting tool is made must passes certain properties. The most important properties are as follow :

1. It should be harder than the material of work piece.
2. It should have the ability to retain its hardness at high cutting temperatures known as red hardness.
3. It should be tough *i.e.* it should have the ability to resist shock.
4. It should be able to be fabricated and shaped easily.
5. It should be high resistant to wear to ensure longer tool life.
6. It should be capable of withstanding the sudden cooling effect of the cutting fluid/coolant during cutting process.
7. It should have low coefficient of friction at the chip-tool interface, so that the surface finish is good and wear is minimum.
8. It should be cheap.

1.15 CUTTING TOOL MATERIALS

The important tool materials are as follow :

1. **High Speed Steel :** This tool material is basically high carbon steel, to which the various alloying elements (tungsten, molybdenum, chromium, vanadium and cobalt) are added in larger amounts (upto 25%) as compared to alloy tool steels to improve hardness, toughness and wear resistant properties. These materials are deep hardened and can be quenched in oil, air or salt. These are capable of retaining their hardness upto 600°C and so can be operated at much higher cutting speeds as compared to alloy tool steels, hence the name 'high speed steel'. These can safely operate at 2-3 times higher speeds than those possible with high-carbon steel tools. Three important types are described as follow :

(*i*) **18 – 4 – 1 High Speed Steel:** It contains

Tungsten =18%

Chromium = 4%

Vanadium = 1%

Carbon content is about 0.75%.

These elements form hard carbides which resist tempering, thus improving the hardness at red heat. It is considered as one of the best all purpose tool steels.

(*ii*) **Molybdenum High Speed Steel :** It contains

Molybdenum = 6%

Tungsten = 6%

Chromium = 4%

Vanadium = 1%

It has excellent toughness and cutting ability and is cheaper than other types of steels.

(*iii*) **Super High Speed Steel :** It contains

Tungsten = 20%

Chromium = 4%

Vanadium = 2%

Cobalt = 12%

These steels are also called cobalt high speed steels.

2. **High Carbon Steel :** High carbon steels were used entirely for all cutting tools before the development of high speed steels. High carbon steel has a carbon content of 0.7% to 1.5%. It has a maximum strength of 1400 N/mm^2 when carbon content is 0.8%. Thereafter, its hardness increases, but strength decreases with increase of carbon. It is hard, less ductile and is almost always fully heat treated (hardened and tempered) before being used. Its properties vary with the carbon content and method of heat treatment, but, in general, the lower the carbon content, the tougher the steel and the higher the carbon content, the harder and less shock-resistant the steel. The high carbon steels are not suitable for high speeds and heavy duty work because they loose their hardness at about 320°C. High carbon steel with carbon content of 1% to 1.5% is called tool steel. It is used for hand tools, press tools, machine parts, cutting saws, twist drills etc.

3. **Tungsten Carbide :** It is a very hard material. The fine crystals of tungsten carbide are difficult to join into tool bits by sintering because the temperature required is very high. The crystals of tungsten carbide when mixed with the powder of cobalt can be sintered at a temperature of about 1980°C to provide a strong material for use in certain machining operations. Tungsten carbide is of two types :

(*i*) Plain tungsten carbide,

(*ii*) Steel grade tungsten carbide.

(*i*) **Plain Tungsten Carbide :** It contains tungsten carbide and cobalt.

(*ii*) **Steel Grade Tungsten Carbide :** It contains titanium in addition to tungsten carbide and cobalt.

The followings are the properties of tungsten carbide :

(*i*) It is very hard and brittle.

(*ii*) It gives better surface finish.

(*iii*) It can withstand high temperature of about 1000 °C.

(*iv*) Its cutting speed is three times to that of high speed steel.

(*v*) It is good in compression.

4. **Cemented Carbides :** Cemented carbides are produced by a powder-metallurgy technique *i.e.* by using metals in their powder form. The final mixture of powders consists of various amounts of hard particles and a binding metal. The hard particles give the material hardness and abrasion resistance, while the binding metal provides the toughness.

The most common hard particles used is tungsten carbide, but titanium carbide and tantalum carbide are often added in varying amounts. The binding metal used is cobalt and various grades of cemented carbide are obtained for cutting different groups of materials by mixing in different proportions.

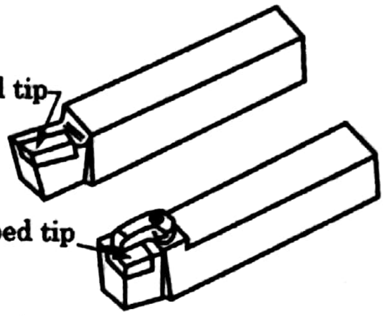


Fig. 1.13 : Tipped Lathe Tools

Cemented carbides normally contain 70 – 90% of hard particles together with 10 – 30% cobalt binding metal. In general, the more the cobalt, the tougher the cemented carbide. However, this increase in toughness obtained by increasing the cobalt content results in decreased hardness and abrasion resistance.

Cemented carbides are used as cutting tools for turning, milling, drilling, boring etc. in the form of tips or inserts which are brazed or clamped to a suitable tool shank as shown in fig. 1.13. The blanks are produced by mixing the metal powders in the correct proportions, pressing them into the required shape and finally heating at temperature as high as 1600°C. This process is known as sintering. This sintering stage results in the cobalt binding metal melting and fusing with the hard particles or cementing to form a solid mass, hence the name cemented carbides.

Cemented carbides are classified into three main groups :

(*i*) Those used for machining steel, designated by the letter 'P' and coloured blue.

(*ii*) Those used for machining cast iron and non-ferrous metals, designated by the letter 'K' and coloured red.

(*iii*) Multipurpose grades designated by the letter 'M' and coloured yellow.

These letters are followed by a number which, when increases, denotes increasing toughness with a resultant decrease in hardness.

Cemented carbides have red hardness higher than both high-speed steel and stellite and will retain their hardness at temperatures well in excess of 700°C.

Cemented-carbide tips are available in which a thin layer of titanium nitride is bonded over all the surfaces. This coating is extremely hard and has a low coefficient of friction, leading to an increase in abrasion resistance and a longer lasting cutting edge. It is claimed that speeds can be increased by 50% above those used with conventional cemented carbides with the cutting edge lasting the same time or alternatively, the cutting edge will last twice as long as that of the conventional tip is run at the same speed.

Owing to their extreme hardness, cemented carbides cannot be reground using the same wheels used to regrind high-speed steel and stellite. Silicon-carbide wheels (usually green in colour) must be used. To finish the cutting edge, it is necessary to use a diamond wheel which laps the surfaces to produce a keen edge. Great care must be taken to avoid overheating which leads to surface cracking of the tip and subsequent breakdown of the cutting edge.

Brazed tip tools are expensive and have disadvantages that they have to be removed from the machine to be reground and must then be reset in the machine and after each regrind, the tip becomes smaller and smaller. Tips, which are clamped in a suitable holder known as throw-away tips or inserts, do not suffer from these disadvantages. When one cutting edge is worn, the insert is merely unclamped, turned to the next keen cutting edge and reclamped. This is repeated until all cutting edges are used (there may be as many as eight) and the insert is then thrown away. The holder is not removed from the machine and no resetting is necessary. Both types do, however, have their applications in industries.

5. Stellite : Stellite is a cobalt-chromium-tungsten alloy containing no iron. It cannot be rolled or forged and is shaped by casting, from which it derives its cutting properties and hardness. No other form of heat treatment is required. Stellite is as hard as high speed steel and has a higher red hardness, retaining its hardness at temperature of 700°C. Being cast, it is also brittle and care must be taken to avoid chipping the cutting edge. It is more expensive than high-speed steel and supplied as solid cast tool bits of round, square and rectangular section and as tipped tools where the tip is brazed to a toughened steel shank.

Stellite can be reground using standard grinding wheels, but care must be taken to avoid overheating which leads to surface cracking and subsequent breakdown of the cutting edge.

6. Ceramic Cutting Materials : Two types of ceramic cutting materials are available : (*i*) A material made from pure aluminium oxide and (*ii*) A mixed ceramic of titanium carbide and aluminium oxide. The latter is used to cut the higher strength steels and chilled cast iron. The ceramic powder are mixed, pressed into required shape and finally sintered resulting in a solid dense blank which is subsequently ground to the correct size.

The tip blanks are used by clamping to a suitable tool holder. Ceramic cutting materials have a high abrasion resistance and high red hardness. They show no deformation even at temperatures upto 1000°C, remaining hard at temperatures which would affect cemented carbides. They can be used to cut grey cast iron, spheroidal – graphite cast iron, malleable iron and alloy steels at cutting speeds from 100 to 600 m/min. at cutting depths of upto 6 mm in cast iron.

Use of a cutting fluid is not recommended because of the danger of thermal shock. Pure aluminium oxide will be destroyed by a sudden temperature change of more than 200°C.

7. Diamond : Diamond is the hardest material known. For this reason, single crystal natural diamond tools have been used in industries for a great number of years to dress grinding wheels and as cutting tools to finish machined non-ferrous and non-metallic materials.