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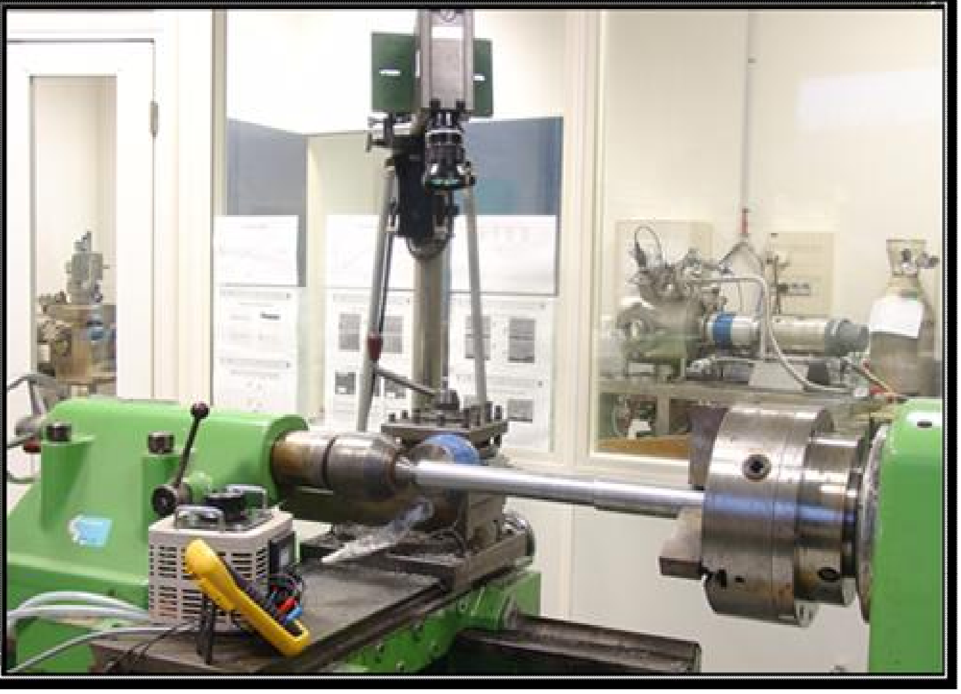
METAL CUTTING

Cours E-Learning

Educational manual designed for first-year students of the Master's program in Mechanical Engineering, with a specialization in Mechanical Manufacturing.



Enseignant : NECIB Djilani

2023/2024

To

all my students

PREFACE

This guide offers Mechanical Engineering Master's students a set of essential knowledge to understand the metal cutting process in the manufacture and shaping of mechanical parts. It addresses the introduction of machining processes, the interaction between the tool and the part, as well as the phenomena of decohesion and chip flow. In addition, it deals with friction between the tool, the part and the chip, exploring the various theories of wear. Conventional methods for calculating the mechanical effects during machining are presented, making it possible in particular to estimate the cutting power required for a given machine tool. Thanks to this knowledge, students can adjust and define new cutting parameters to minimize the impact of mechanical actions on machined surfaces, thus improving efficiency and productivity. This document is divided into five chapters:

- Chip formation analysis
- Geometry of cutting tools
- Wear of cutting tools
- Mechanical actions of the cut (cutting powers and forces) and choice of cutting conditions.
- Choice of cutting conditions.

SUMMARY

CHAPTER I : ANALYSIS OF CHIP FORMATION

CHAPTER II : GEOMETRY OF CUTTING TOOLS

CHAPTER III : WEAR OF CUTTING TOOLS

CHAPTER IV: MECHANICAL ACTIONS OF THE CUT (CUTTING POWERS AND FORCES)

CHAPTER V: CHOICE OF CUTTING CONDITIONS

CHAPTER I : ANALYSIS OF CHIP FORMATION

I.1. GENERAL INFORMATION ON MACHINING BY MATERIAL REMOVAL

I.1.1. The needs related to machining

Since their appearance, machining techniques have undergone multiple improvements. The processes of shaping materials by removing material have constantly been questioned in order to stay in step with industrial requirements, whether economic or ecological. Today, the manufacturing engineer must therefore be able to answer a multitude of questions in order to quickly produce parts with the required quality and at a lower cost.

For example, in the case of machining:

- What type of machine should be used and will it be enough in terms of power and accuracy?
- What are the cutting conditions to be used to minimize the damage to the tools or the machined material?
- What are the solutions to be adopted when designing the tools and in which materials should they be manufactured to improve their service life and / or the quality of the surface finishes of the machined parts?
- What are the mechanical properties of the part after machining?
- Is it possible to machine without adding lubricant? …

There would still be a considerable number of questions, of which it is difficult to establish an exhaustive list. The state of progress of knowledge on the fundamental level cannot provide an answer to all these questions. On the other hand, technology and machining techniques have made it possible to evolve and optimize production.

I.2. MACHINING

I.2.1.Definition

Machining is a general term describing a group of processes that consist of the removal of material and modification of the surfaces of a workpiece after it has been produced by various methods. Thus, machining involves secondary and finishing operations [1].

Machining operations are is also among the most versatile and accurate manufacturing processes in terms of its capability to produce diverse and complex geometric features utilizing sharp cutting tools to remove materials from the workpiece by shear deformation.

The main principle of these processes is providing the relative motions between the cutting tool and the workpiece, which is accomplished through machine tools. The machine tools are discussed and categorized based on the employed (Fig.I.1) [2].

I.2.2. Material Removal Processes

- Machining is the broad term used to describe removal of material from a workpiece
- Includes Cutting, Abrasive Processes (grinding), Advanced Machining Processes (electrical, chemical, thermal, hydrodynamic, lasers)
- Automation began when lathes were introduced in 1700s.
- Now have computer numerical control (CNC) machines.
- Machining operations are a system consisting of: workpiece, material, properties, design, temperature, Cutting tool shape, material, coatings, condition, Machine tool , design, stiffness & damping, structure, Fixture , workpiece holding devices.
- Cutting parameters: speed, feed, depth of cut [3].

Material removal processes are often required after casting or forming to:

- Improve dimensional accuracy
- Produce external and internal geometric features, sharp corners, or flatness not possible with forming or shaping.
- Obtain final dimensions and surfaces with finishing operations - Obtain special surface characteristics or textures
- Provide the most economical means of producing a particular part [4].

I.2.3.Types of Machining Process

- Single Cutting Edge
- (Point) Processes.
- Multi-Cutting Edge (Point) Processes.
- Random Point Cutting Processes – Abrasive Machining.
- Within each category the basic motions (kinematics) differentiate one process from another.

I.2.4.Classification of machining processes

Table.I.1.Classification of machining processes [5].

<table>
<tr><th colspan="4">Machining processes</th></tr>
<tr><th>Conventional machining</th><th>Abrasive machiining</th><th>Nontraditional machining</th><th>Microprecision machining and UPM</th></tr>
<tr><td rowspan="5">- Turning
- Drilling
- Milling
- Shaping/Planing
- Broaching
- Sawing
- Etc</td><td>Grinding</td><td>Mechanical energy mach. processses</td><td rowspan="3">Microprecision machining</td></tr>
<tr><td rowspan="2">- Surface grinding
- Cylinderical
- Centerless grinding</td><td>Thermal energy machining processses</td></tr>
<tr><td>Electrochemical machining processses</td></tr>
<tr><td>Abrasive finish machining</td><td rowspan="2">Chemical machining</td><td rowspan="2">Ultra-precision machining</td></tr>
<tr><td>- Honing
- Lapping
- Superfinishing
- Polishing</td></tr>
</table>

I.1.2. Introduction

Machining consists of removing material from a part using a tool. due to the different types of tools used, there are different machining processes :

- grinding, where the material is removed by the abrasive grains of a grinding wheel ;
- electro-erosion where the material is disintegrated by an electrode ;
- machining by cutting tool, the only method dealt with in the remainder of this file among the three. the tool is animated by a movement adapted to the desired shape. in contact with the workpiece and the tool, depending on the movement speeds, the chosen trajectories and the hardnesses of the materials, a chip is created coming from the machined part.

Machining is a process for generating surfaces. it consists of creating a new surface by removing material (chip formation) using a cutting tool. the characteristics of this surface depend on the tool-material torque, that is to say the parameters put into play during the cutting (cutting speed, feed speed, pass depth ......). any machining by a cutting tool is characterized by :

- A relative movement between the part and the tool, resulting from the composition of a cutting movement (mc) and a feed movement (Mf). the latter are translations and rotations, independent or conjugated (helical movement) for example ;
- The shape of the active part of the tool (point, line) ;
- The cutting conditions making it possible to optimize the productivity of the machine-tool-workpiece assembly.

In machining, there are several configurations that can be used depending on the cutting process (milling, planing, turning .....). During turning (Fig. I.1), the cutting movement (Mc) is applied to the workpiece with a circular trajectory and a rotation frequency defining the cutting speed (Vc). the feed movement (mf) is applied to the tool with a coplanar trajectory and a defined feed speed (Vf). There are two principles for generating a machined surface, shaped machining and envelope machining, sometimes used in a mixed way [7-8]..

I.3. TURNING

I.3.1. Definition

Turning is a mechanical cutting (material removal) process involving single-edged tools. The part is driven by a rotational movement (cutting movement), which is the main movement of the process, the tool is driven by a complementary translational movement (rectilinear or not) called advance movement, allowing to define the profile of the part (Fig.I.2).

The combination of these two movements, as well as the shape of the active part of the tool, makes it possible to obtain machining of rotational shapes (cylinders, planes, cones or complex rotational shapes) [9].

The material removal procedure produces the desired surface known as the produced surface (or machined surface) (a cutting tool during machining). A cut surface, or intermediate produced surface, created by a cutting-edge during machining, connects the two surfaces.

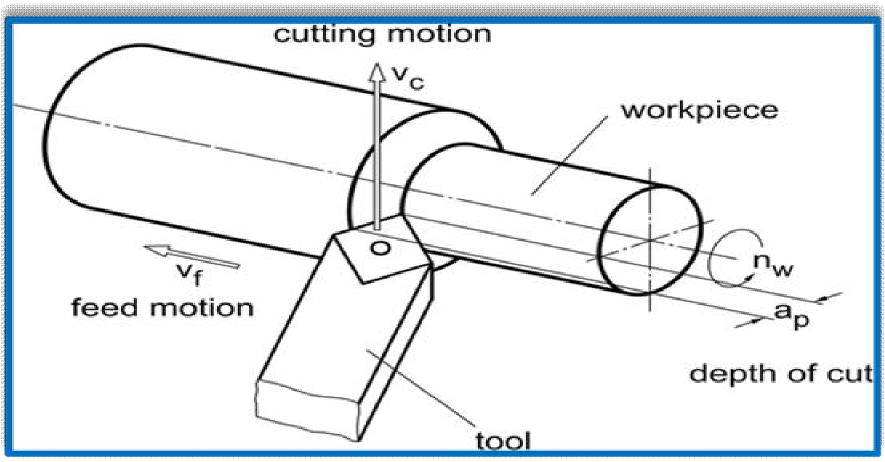


Fig. I.1. Turning procedure [9]

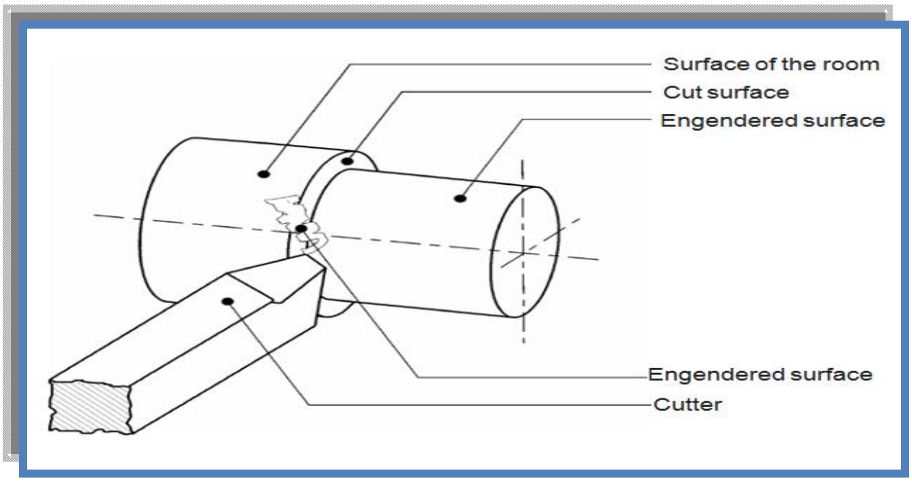


Fig.I.2. workpiece surfaces [9]

I.3.2. Turning principle

The piece is animated by a uniform circular movement that is the cutting movement Mc. The tool is driven by a translational movement parallel or oblique with respect to the axis of rotation, that is the forward movement Mf (Fig.I.3).

In its movement, the tip of the tool describes a line called a generatrix which transforms the part into a solid of revolution, by varying the displacement of the tool (radial movement) it will be possible to obtain all the solid of revolution such as cylinder, cone, sphere, etc.

Turning also allows the shaping of the internal shapes by drilling, boring, tapping [10].

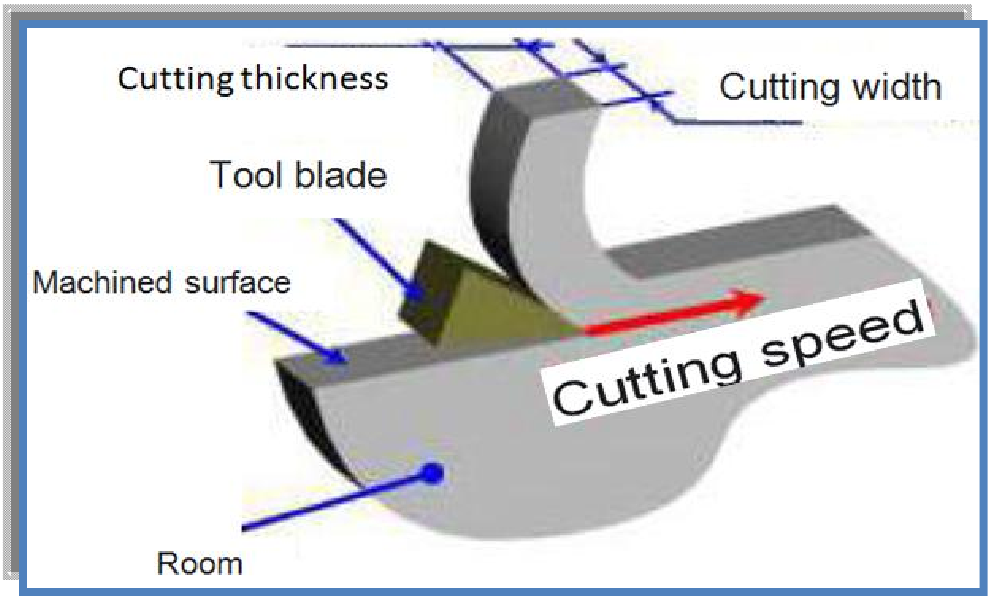


Fig. I.3. Turning principle [10]

CHAPTER II : GEOMETRY OF CUTTING TOOLS

II.1. THE CUTTING TOOLS

II.1.1. Cutting tool elements

A cutting tool consists of a body and a tail. A body is the part of the tool carrying cutting elements or inserts. Sometimes the edges can be cut directly into the body. On the other hand, the tail of the tool is the part by which it is held (Fig.II.1).

The part of the tool that is directly involved in the cutting operation (the edges, the cutting face and the draft face) is called the active part [11].

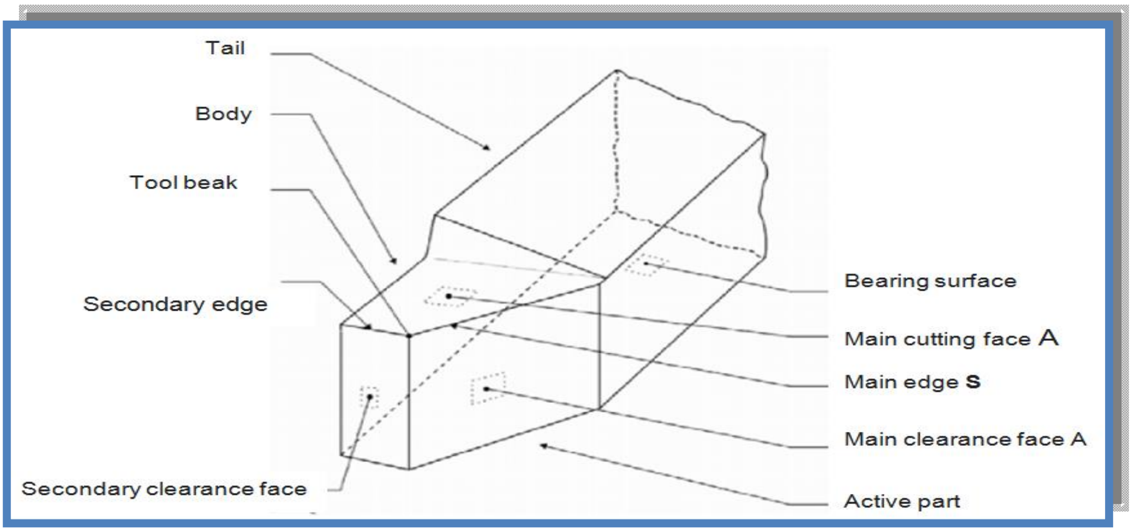


Fig.II.1. Tool element [11-14].

II.1.2. The geometry of the cutting tool

The cutting tool is the element that removes the material. There is a wide variety of cutting tools, different types of geometries, materials and coatings. A turning cutting tool may be characterized by edge geometry and spatial orientation defined by standardized cutting angles [12].

II.1.3. Classification of cutting tools:

Tools can be grouped into three groups:

1- Single-edged simple tools: turning and planing tool turning and planing tool.
2- Associated tools or tools with multiple edges: tools cutter, forest, reamer, saw, file etc.
3- Grinding tools: these are multi-edge tools with a slightly different mode of action than the tools in the 2nd group [13-14].

II.4.4. Tool faces and edges

A shank and an active component composed of tool material called the body make up a cutting tool. A cutting tool is made up of a tool body, which may also have one or more active components ($A_{\alpha 1}$, $A_{\beta 1}$ Fig.II.2). One-piece tools (made of carbides and high-speed steels) are those in which the active component is composed of a distinct material from the body (inserts or inserts for carbides, cermet's, ceramics, polycrystalline boron or diamond). The vocabulary for the various active elements of a turning tool is described in (Fig.II.2).) [17].

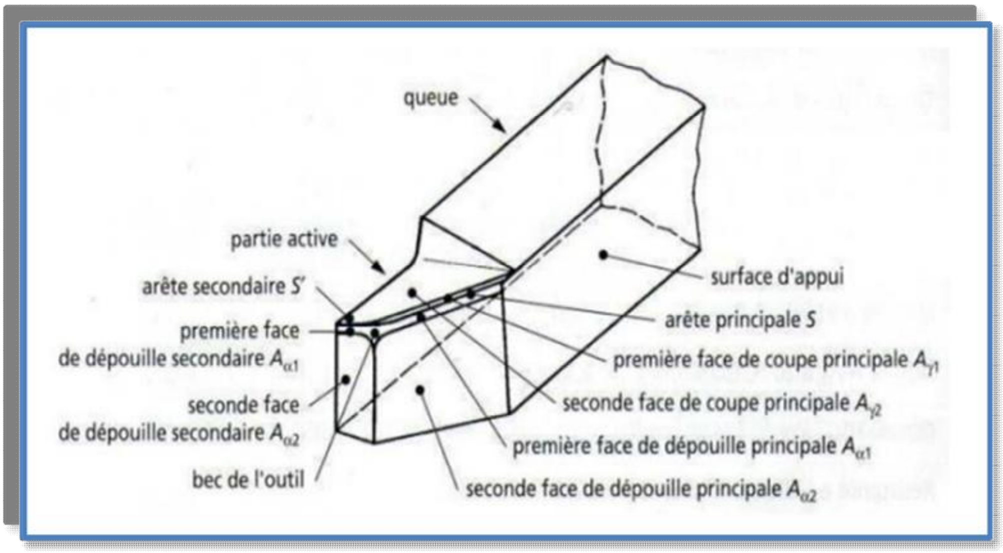


Fig.II.2. Tool faces and edges [17].

II.1.5. Tool elements

Cutting tools come in a huge range of varieties. The essential components of the various tools, however, are comparable. So, we will focus our discussion on a cutting tool used in cinematography in order to make the knowledge of the many components that define any tool simpler. Then, definitions for any other kind of tool can be subtracted [8].

II.1.5.1.Tool angels

It is important to identify the angles that have the biggest impact on the phenomenon of the cut in order to make it easier to explain.

The tool-in-hand reference system's three primary angles, clearance angle α, rake angle β, and rake angle cut, are shown in (Fig.II.3).

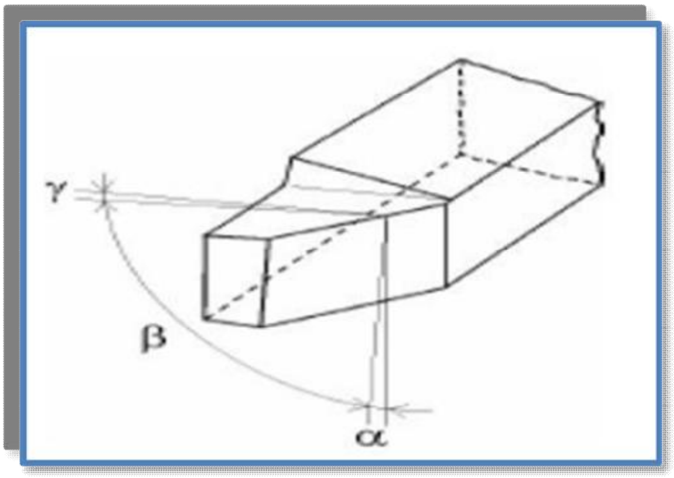


Fig.II.3. Cutter angles (tool in hand) [6].

The tool reference systems in use (Fig.II.4) show these angles in the same ways: end trimming tool (left) and side or side trimming tool (right).

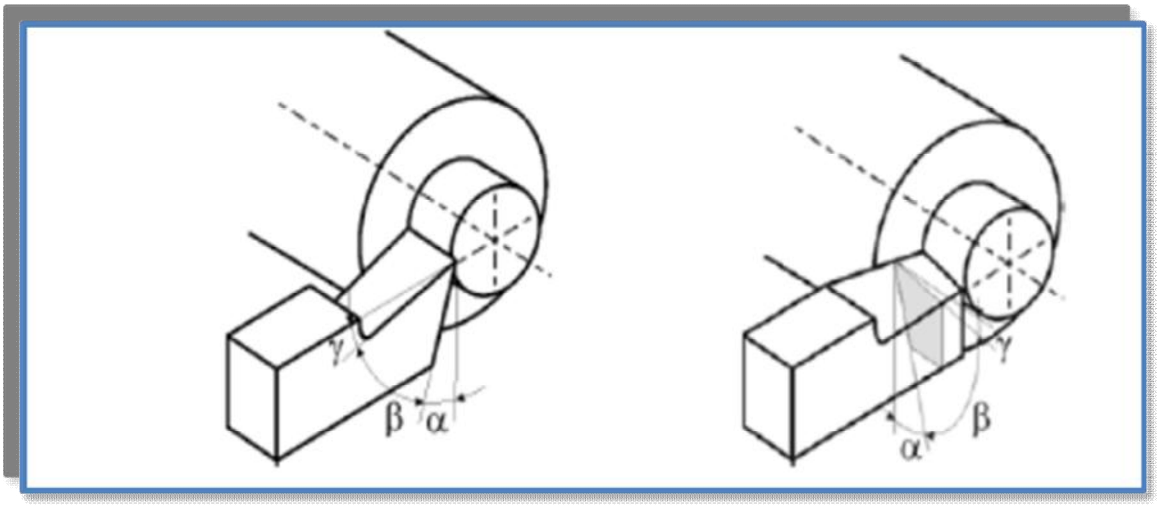


Fig.II.4. Bit angles (tool in work) [6].

Overall, the clearance angle α has an impact on the tool's usable life by affecting the friction between the tool and the component. The chip flow on the rake face and subsequent cutting forces, power consumption, heat generation, etc. are all impacted by the rake angle ɣ.

The breaking strength of the bit is influenced by bit angle β. These three angles add up to a constant 90o angle.

$$\alpha+\beta+\gamma=90°\ldots\ldots\ldots\ldots(I.1)$$

If the sum is greater than 90°, it is called a negative cut (negative γ) [6].

II.1.6. Tool materials

II.1.6.1. High speed steel

A high alloy steel known as high-speed steel, or HSS, is frequently used to produce cutting tools. Its hardness of about 65 is one of its intriguing qualities, HRc has a good lifespan because to its tenacity [18].

II.1.6.2. Carbides of metal

This group of alloys includes those made mostly of tungsten (60–90%), titanium and tantalum (1–35%), cobalt or nickel (5–15%), and alloys containing lower amounts of molybdenum or vanadium. Hard metal is produced by sintering, and it is often fashioned into plates that are fastened to the tool's body using screws, clamps, or brazing. Some little tools are totally constructed of hard metal.

▪ There are two types of carbide tools on the market, namely

- Instruments with brazed carbide inserts that are brazed with a prate brochure.
- The door plate is one of three blocks that make up tools with detachable carbide inserts. Pad and spacer pad together. After its lifespan has expired, it must be disposed of. Its primary measurements and forms are standardized.

II.1.6.3. Ceramic

Tools with detachable ceramic inserts are more stable at high temperatures and have higher hardness, which results in lower tenacity. They enable a significant material flow. nevertheless, necessitate a high degree of machine stability and rigorous attention to the cutting conditions. Typically, they are employed in finishing tasks.

II.1.6.4. Cermet

These are instruments with replaceable cemented inserts. As titanium carbonitride or titanium nitrides are carbides that include titanium particles, the name "cermet" is derived from the word "ceramic." Common uses include polishing ferritic steels, cast irons, low carbon steels, and stainless steels.

II.1.6.5. Diamond

The coefficient of friction in diamond is minimal. Aluminum alloys, copper alloys, magnesium alloys, thermosets, and other non-ferrous materials that are machined at low temperatures are appropriate; however ferrous materials cannot be machined using this method.

- **Note**

The material that has to be machined and the operation that needs to be done directly affect the cutting tool selection [18].

II.2. LATHE OPERATIONS

The engine lathe is an accurate and versatile machine on which many operations can be performed. These operations are:

II.2.1.Turning

In which the workpiece is rotated and a cutting tool removes a layer of material as the tool moves to the left.To produce straight, conical, curved, or grooved workpieces, such as shafts, spindles, and pins (Fig.II.5) [15].

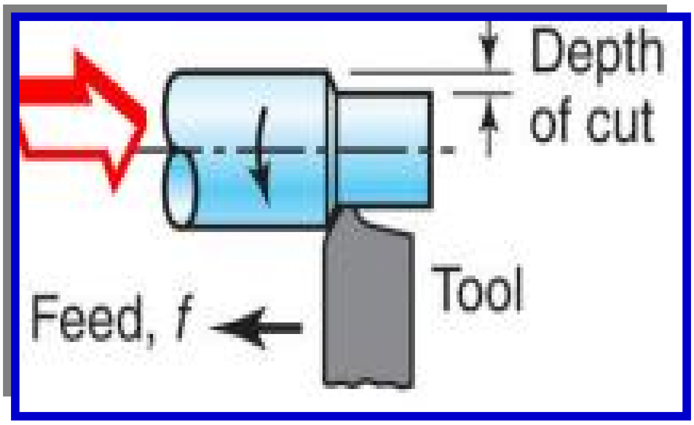


Fig.II.5.Turning process [15].

II.2.2.Facing

The facing is a machining operation by which the end surface of the workpiece is made flat by removing metal from it (Fig.II.6) [15].

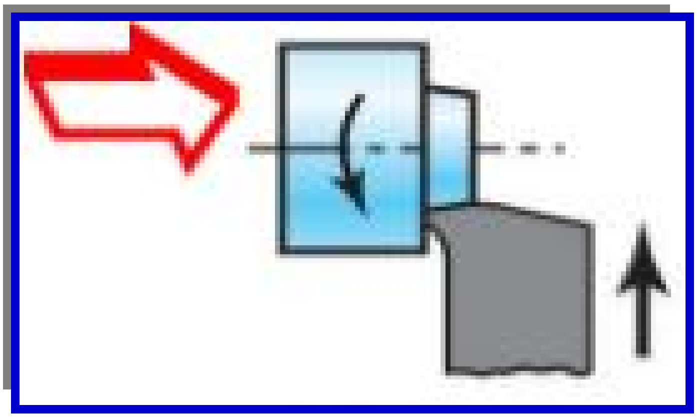


Fig.II.6.Facing process [15].

II.2.3. Boring

To enlarge a hole or cylindrical cavity made by a previousprocess or to produce circular internal grooves (Fig.II.7) [15].

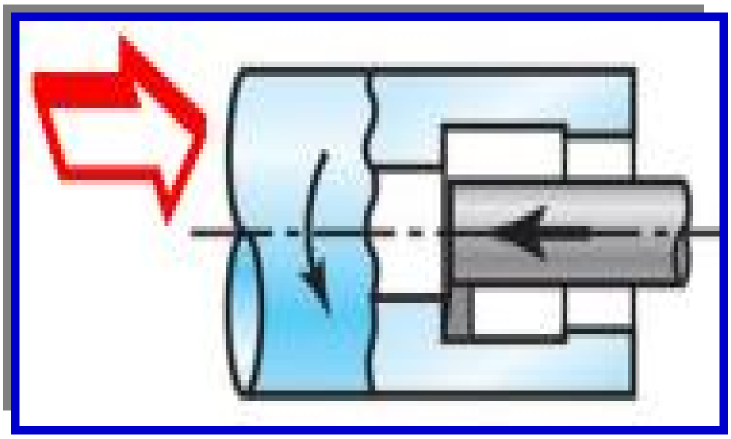


Fig.II.8. Boring process [15].

II.2.4. Drilling

Drilling is the operation of producing a cylindrical hole in the workpiece (Fig.II.9) [15].

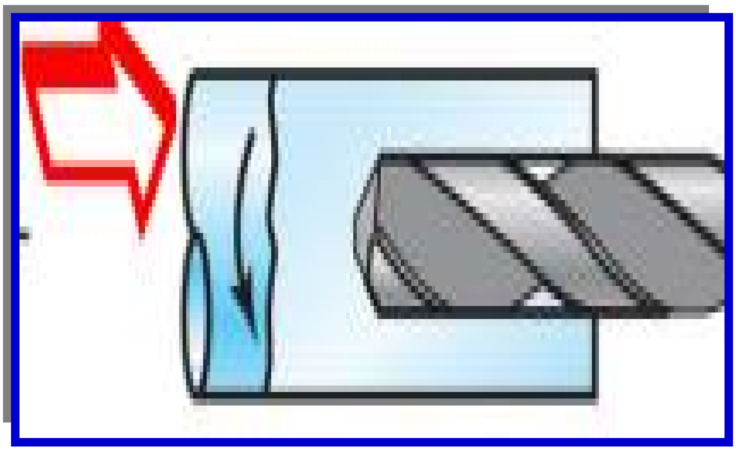


Fig.II.9.Drilling process [15].

II.2.5. Reaming

The holes that are produced by drilling are rarely straight and cylindrical in form. The reaming operation finishes and sizes the hole already drilled into the workpiece (Fig.II.10) [15].

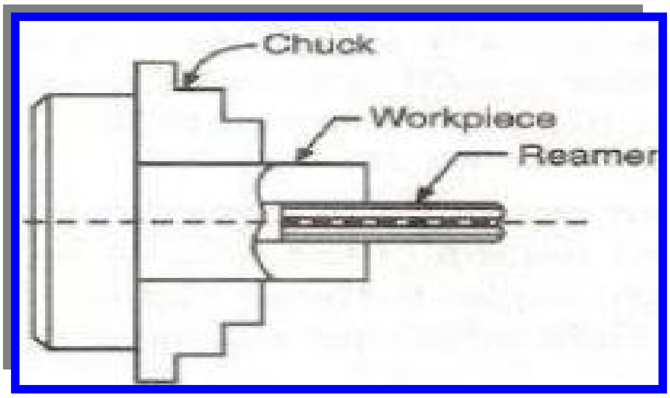


Fig.II.10. Reaming process [15].

II.2.6. Threading

Threading is the act of cutting of the required form of threads on the internal or external cylindrical surfaces (Fig.II.11) [15].

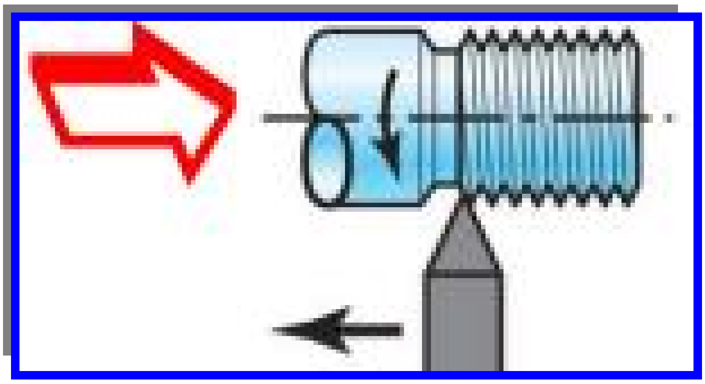


Fig.II.11.Threading process [15].

II.2.7.Knurling

To produce a regularly shaped roughness on cylindrical surfaces, as in making knobs and handles (Fig.II.12) [15].

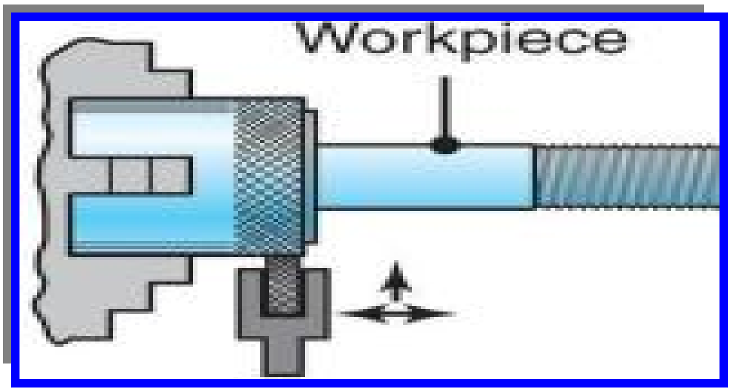


Fig.II.14.Knurling process [15].

II.2.8.Grooving

Grooving is the act of making grooves of reduced diameter in the workpiece (Fig.II.13) [15].

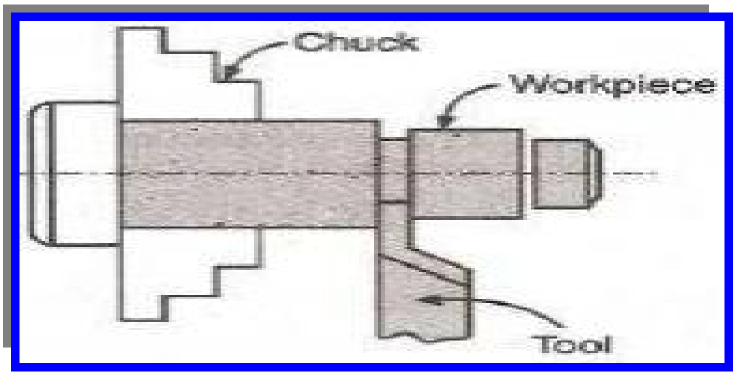


Fig.II.13.Grooving process [15].

II.2.9.Cutting off

In which the cutting tool moves radiallyinward and separates the right piece from the bulk of the blank (Fig.II.14) [15].

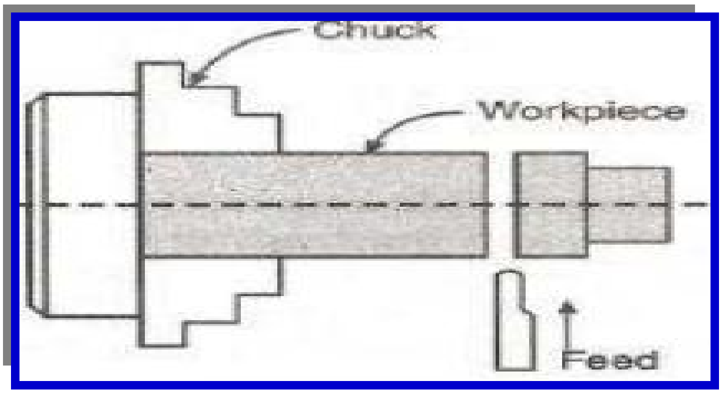


Fig.II.14. Cutting off process [15].

II.2.10.Forming

The forming is an operation that produces a convex, concave or any irregular profile on the workpiece (Fig.II.15) [15].

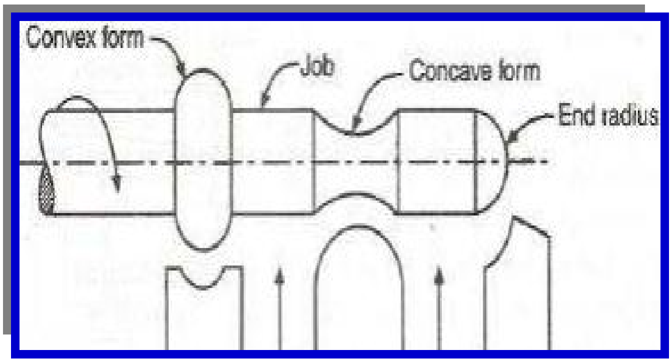


Fig.II.15.Forming process [15].

II.3.TYPES OF CUTTING

II.3.1. Orthogonal Cutting (2-D Cutting)

In Orthogonal Cutting, Cutting edge is (Fig.II.16) :

- Straight,
- Parallel to the original plane surface on the work-piece and
- Perpendicular to the direction of cutting.

For example: Operations: Lathe cut-off operation, Straight milling, etc [19].

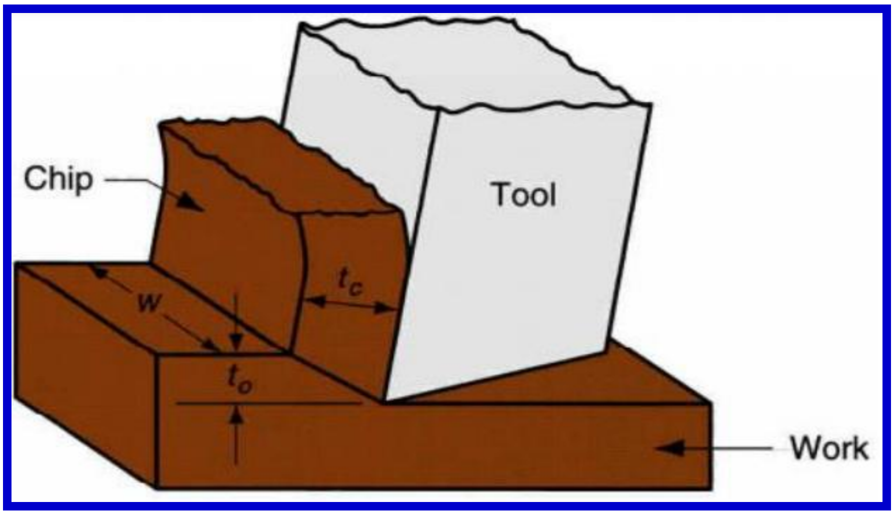


Fig.II.16. Orthogonal Cutting (2-D Cutting) [19].

II.3.2.Oblique Cutting (3-D Cutting)

– Cutting edge of the tool is inclined to the line normal to the cutting direction (Fig.II.17). In actual machining, Turning, Milling etc….
– Cutting operations are oblique cutting (3-D) [19].

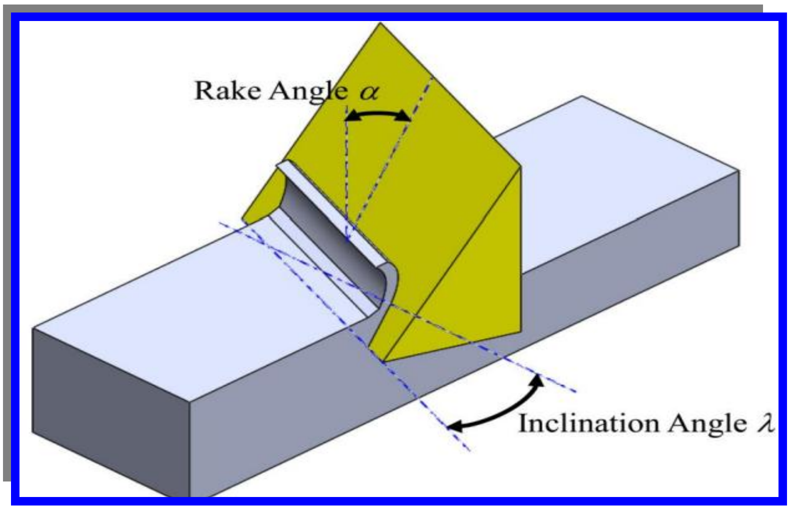


Fig.II.17. Oblique Cutting (3-D Cutting) [19].

II.4. TYPES OF CHIPS

The shapes of the chip vary according to the machining conditions.

The machining of plastic metals (steels) results in three types of chips: continuous, sheared and discontinuous.

II.4.1. The continuous chip

It occurs when steel is machined at a high speed. It then flows in the form of a long strip (Fig.II.18).

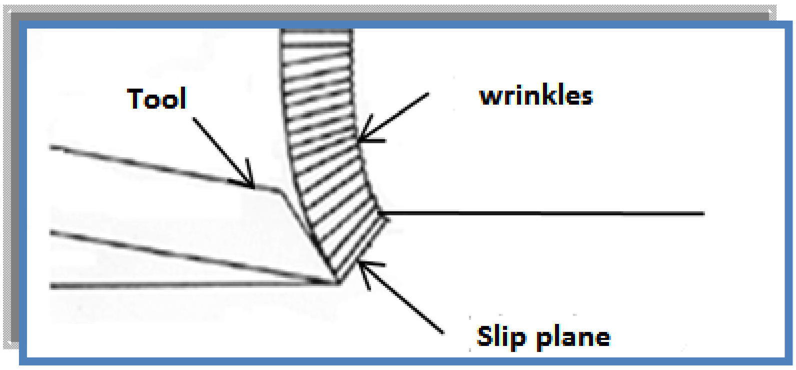


Fig.II.18. Continuous chip [20].

II.4.2. The sheared chip

It is obtained when the steel is machined at medium speed. The face of the chip facing the tool is smooth, while its opposite face bears notches that define the well-marked direction of the isolated elements strongly linked to each other (Fig.II.19).

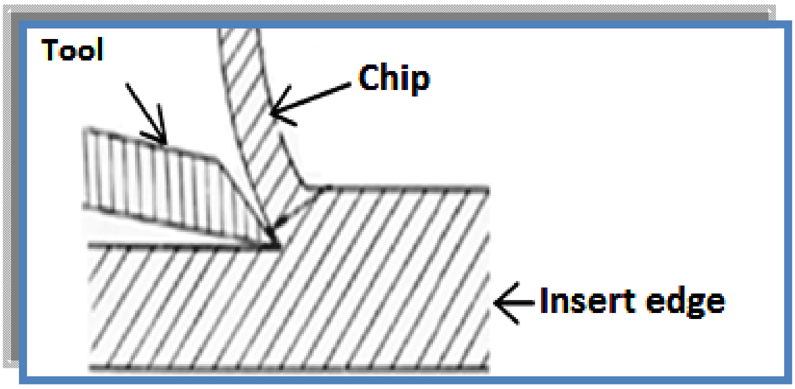


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Fig.II.19. Sheared Chip [20].

II.4.3.The discontinuous chip

It is obtained during the machining of hard and not very ductile metals, at low cutting speed. It is composed of separate, plastically deformed elements that are not bonded or not bonded at all (Fig.II.20).

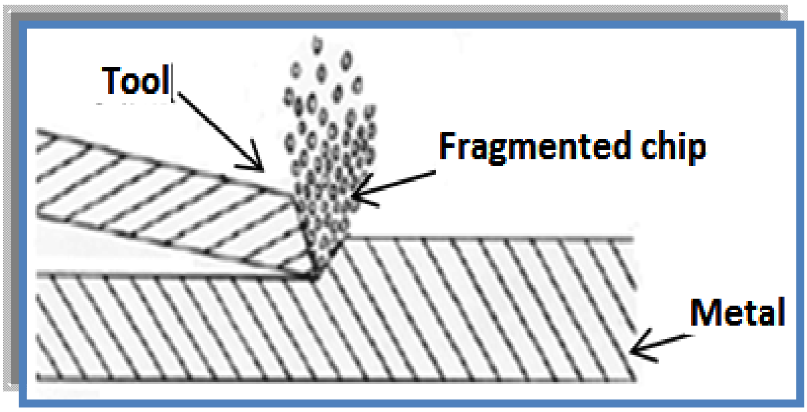


Fig.II.20. Discontinuous chip [20].

CHAPTER III: WEAR OF CUTTING TOOLS

III.1. INTRODUCTION

Material removal machining involves gradually reducing the dimensions of the workpiece by cold metal removal without deformation using a tool. The amount of material removed is called chips and the instrument with which the material is removed is called a cutting tool. The operator uses machine tools to machine a part [21].

III.2.DEFINITION OF WEAR

Wear is a complex set of phenomena that are difficult to interpret, leading to the emission of debris with loss of mass, dimension, shape, and accompanied by physical and chemical transformations of the surfaces.

Wear involves a significant amount of chemical reactions; chemically inert surface layers can sometimes be more resistant to friction than hard layers, especially in the presence of aggressive media.

It is generally combated because of its negative effects but it also has favorable aspects such as sharpening tools, finishing a surface by grinding [21].

III.2.1. The wear of cutting tools in terms of time

Tool wear (flank wear) as a function of cutting time (Fig.III.1) [21].

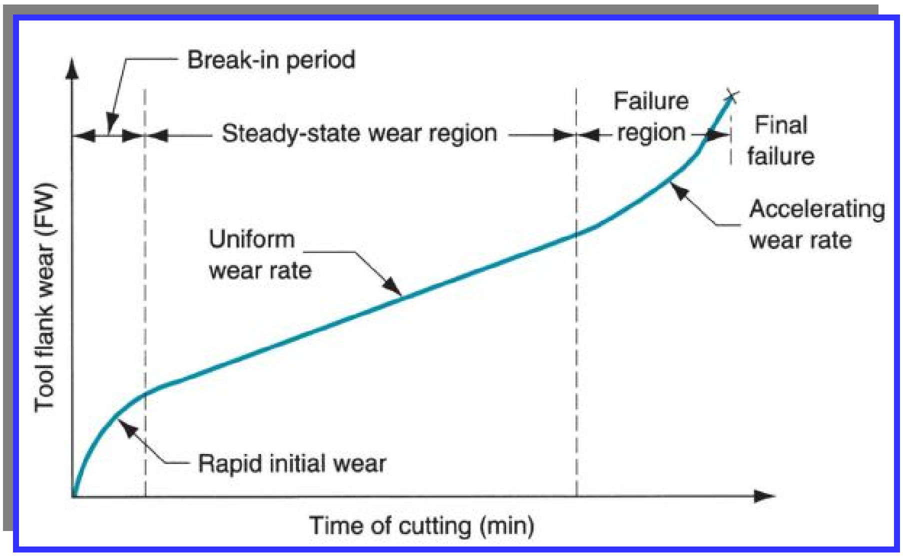


Fig.III.1.Represents tool flank wear in terms of .time of cutting [21].

– Features of tool wear in a turning operation. VB: indicates average flank wear (Fig.III.2) [22].

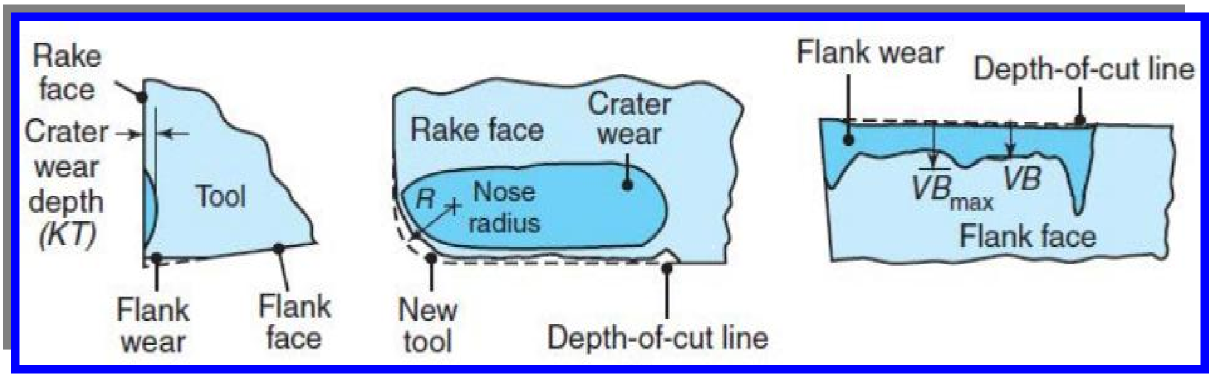
– 

Fig.III.2. Features of tool wear in a turning operation [22].

III.3. DIFFERENT FORMS OF WEAR

III.3.1.Taper Wear

It characterizes the lifespan. When it is too large, the cutting forces increase and the surface condition is less good (Fig.III.3). This is a general criterion for tool holding, characterized by a permissible wear value VB.

VB Critical = 0.6 mm in rough and 0.3 mm in finish (II.1)

This is due to excessive cutting speed or incorrect angular position of the tool (cutting face/piece).

Causes

- Blow speed too high
- Overly tenacious shade
- Insufficient wear resistance

Solutions

- ✓ Reduce cutting speed
- ✓ Choose a shade that is better suited to the needs of toughness or wear resistance

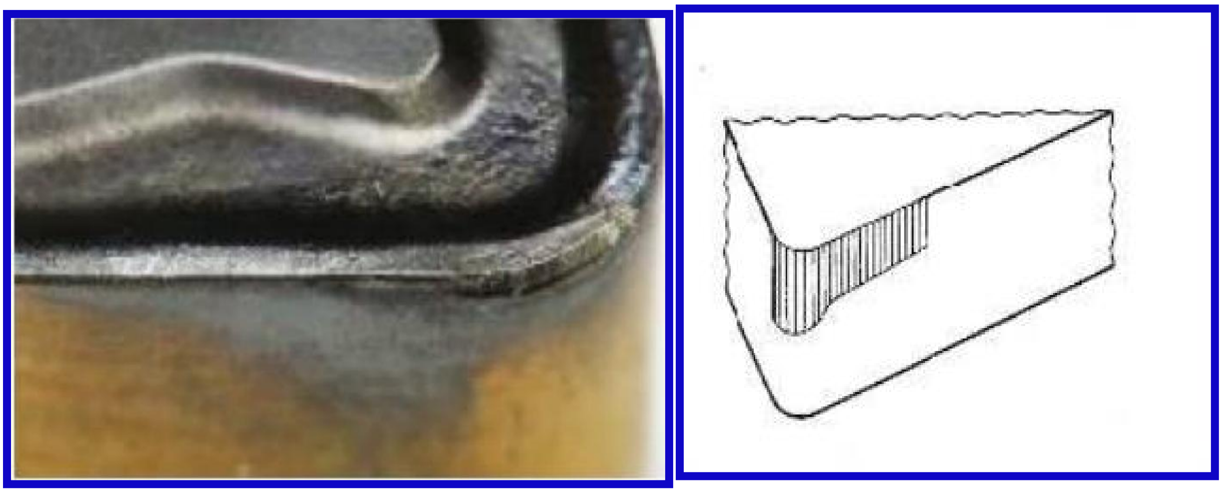


Fig III.3. Draft Wear [14-23].

III.3.2. Wear by flaking

Thin edge particle flaking and thermal cracking (common in interrupted machining) are important for tools made of fragile materials. The extent of flaking and thermal cracking is assessed to some extent by the maximum draft wear width VB max (Fig.III.4) [15].

Causes

- Unstable Conditions
- Shade too strong or too friable

Solutions

- ✓ Improve machine stability
- ✓ Choose a more tenacious shade
- ✓ Choose stronger geometry

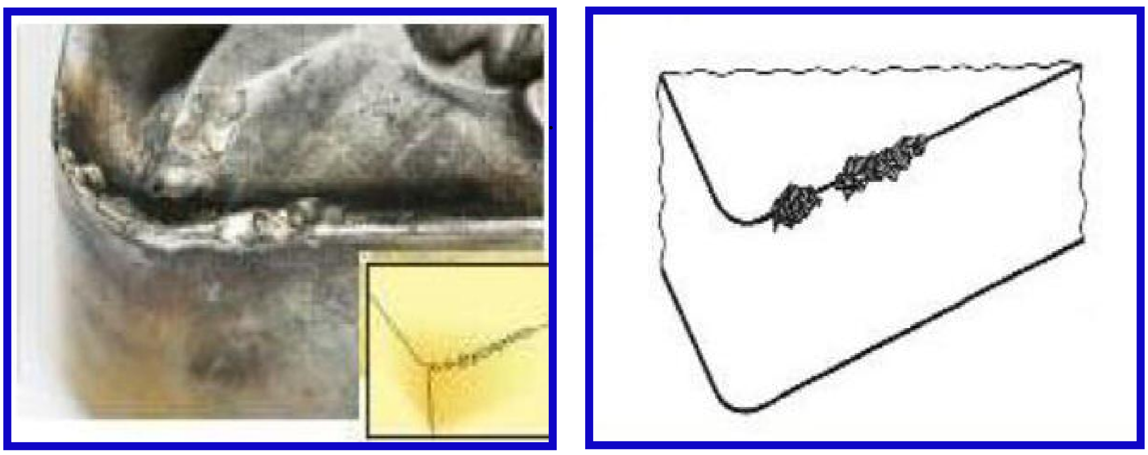


Fig III.4. Wear by flaking [14-23].

III.3.3. Wear by added edge or adherent chip

This type of wear is due to a temperature that is too low in the cutting zone, which causes the chip to flow badly and it solders at the edge. This adherent chip leads to an increase in the power required for cutting, and a rapid deterioration of the surface condition of the part (Fig.I II.5) [14-23].

Causes

- Cutting temperature too low
- Wafer chip welding
- Sticky material
- Geometry too negative

Solutions

- ✓ Increase the cutting temperature by increasing the cutting speed or feed
- ✓ Select a coating swatch
- ✓ Select more positive geometry

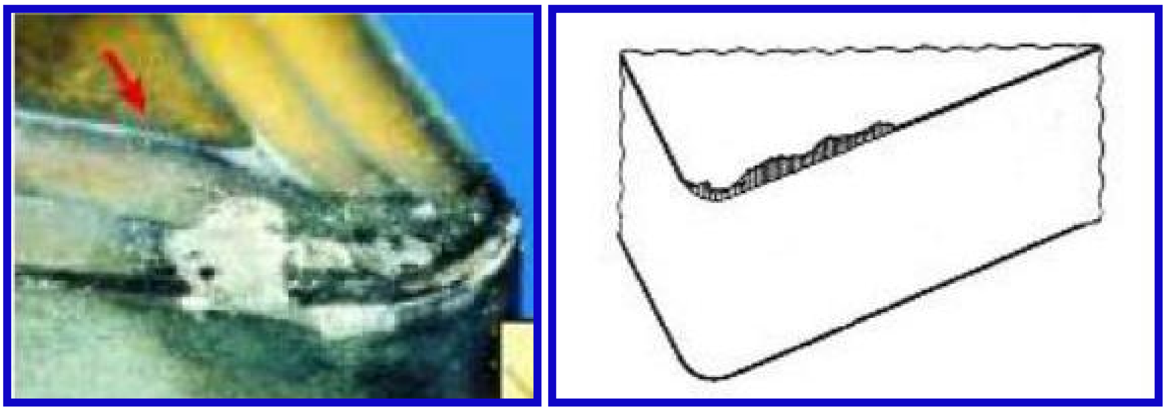


Fig. III.5. Wear forms of the cutting tool according to NFE 66 505 [14-23]..

III.3.4. Crater wear

Crater wear is the most common form of wear on the cutting face (face on which the chip slides); it is due to the contact with the chip. The depth of the KT crater can be used as a tool wear measure and a predetermined value of KT can be chosen as a tool life criterion. Crater wear is greater for metal carbide tools than for quick steel or ceramic tools. The position of the crater relative to the edge is also important. A wide and Deep crater away from the ridge may be less dangerous to the tool than a narrow and less Deep crater near the ridge

Figure III.6 [14-23]..

$$\text{Limit value: KT Critical} = 0.06 + 0.3\ f\ 2 \qquad (II.2)$$

The critical value is the value at which the tool is considered to be out of use with a significant risk of tool rupture (f: advance).

Causes

- Cutting speed and/or feed too high
- Overly tenacious shade
- Chip breaker too narrow

Solutions

- ✓ Reduce cutting speed and/or feed
- ✓ Select a shade that is more wear resistant
- ✓ Choose more open / positive geometry

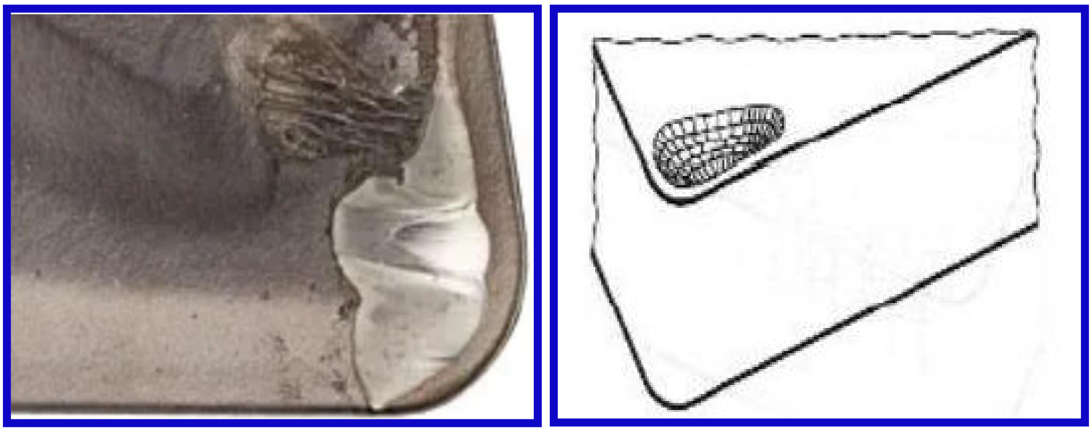


Fig. III.6. Crater wear [14-23]..

III.3.5. Wear by plastic deformation of the edge

This type of wear is characterized by the collapse of the cutting edge. If the temperature on the edge becomes too high. The latter can deform under the effect of mechanical stress (Fig.I II.7).

Causes

- Cutting temperature and pressure too high
- Very tenacious shade / tender
- Insufficient watering

Solutions

- ✓ Reduce temperature and pressure by reducing cutting speed and/or feed
- ✓ In case of wear in depression of the edge, first reduce the advance
- ✓ In case of wear in low pressure, first reduce the cutting speed

- ✓ Use a shade that is more resistant to wear and/or heat
- ✓ Choose more open / positive geometry
- ✓ Increase watering flow

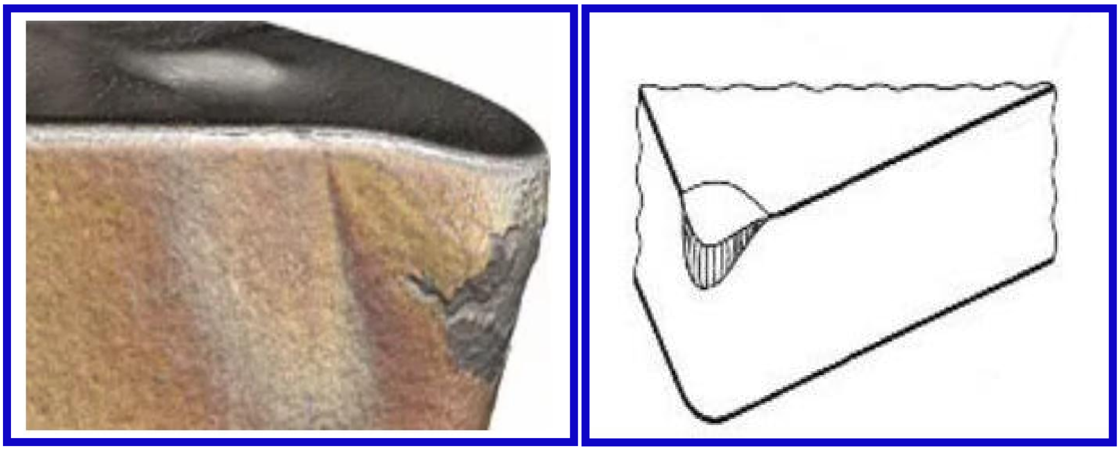


Fig. III.7. Wear by plastic deformation of the edge [14-23]..

III.4. WEAR CRITERIA

The criteria commonly used for carbide tools and, in particular, those recommended by the current standard concerning the wear of cutting tools in the standard, NFE66 505, fall into two categories

III.4.1. Direct criteria

They are based on the evolution of wear:

- Front wear criterion, characterized by a limit width VB of the wear strip on the undercut side of the tool;

- Craterization criterion, defined by the limit value of the depth of the limit crater KT, or by the limit value of the craterization ratio KT/KM, or by a limit value of the craterization angle αc;

- Tool death criterion, used mainly for high-speed steel tools;

- Volumetric or mass wear criterion characterized by the weight loss of the tool, measured by weighing or using radioactive tracers;

- Criterion based on variations in the dimensions of machined surfaces, currently used for determining the machinability of steels.

III.4.2. Indirect criteria

They are based on the variation of certain physical dimensions of the cut as a function of the wear of the cutting tool. For example:

- The forces and specific cutting work,
- The roughness of the machined surface,
- The temperature at the tip of the tool [24].

CHAPTER IV: MECHANICAL ACTIONS OF THE CUT (CUTTING POWERS AND FORCES)

IV.1. CUTTING FORCES

IV.1.1. Approximate value of the cutting force during turning

The cutting force Fc depends on the specific resistance to compression fracture Rr of the material being worked and its machinability, the dimensions of the chip, the tool used as well as the working mode. For the convenience of the calculations, the following relationship is assumed for the cutting force (Fig. IV.1) :

$$Fc = K \times S \times Rr \qquad \text{(IV.1)}$$

With :

Rr: the specific resistance to compression failure ;

S: Section of the chip defined by the advance f and the pass depth a, i.e.: S = a×f ;

K: Coefficient which takes into account the machinability of the material, the thickness of the chip, (it is stronger in finishing than in roughing) and the geometry of the cutting tool.

The following values K = 2.5 to 4 are generally adopted for steels and K = 4 to 5 for cast irons.

For the advance and penetration forces they are given by the following equations :

Fa = (0.2 to 0.3) Fc

Fp = (0.4 to 0.5) Fc

Since the three forces form a trirectangular trihedron then :

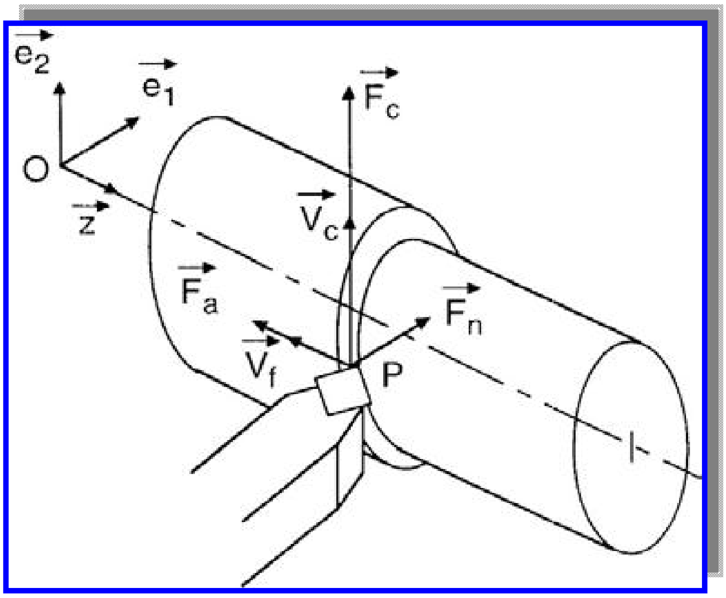


Fig. IV.1. Cutting force during turning [25]

$$F = \sqrt{(0.25.Fc)^2 + (0.45.Fc)^2 + Fc^2} \cong 1.12Fc$$

We usually take: F ≈ Fc

IV.4.2. Cutting forces during drilling

The drill has two cutting edges and to each and in its middle a tangential cutting force Fc is applied. The two forces form a torque pair (Fig. IV.2) :

***Mc = Fc* × *D/2*…………………………………(IV.2)**

The resistance of the cutting forces exerted on an edge admits three components :

* Fc: tangential cutting force ;
* Ff: advance effort ;
* Fp: penetration effort.

If the drill is perfectly sharpened and if the material of the part is homogeneous, we have :

Fc = Fc' ; Ff = Ff' ; Fp = Fp'

The equal and practically opposite components Fp , Fp' cancel each other out.

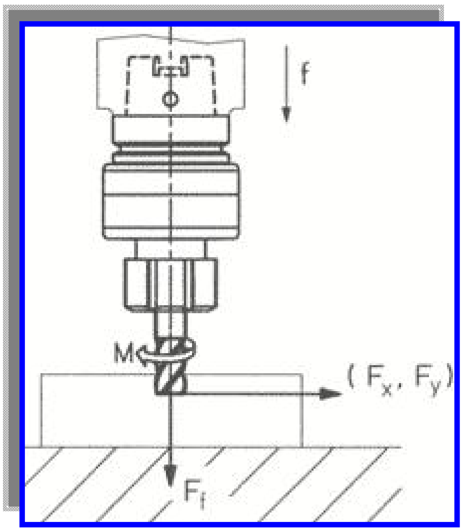


Fig. IV.2. Cutting forces during drilling [26]

The resultant of the feed forces is carried by the axis of the drill:

$$Fa = 2 \times Ff = K \times ftr \times D \quad \text{(IV.3)}$$

With :

- K: Experimentally determined coefficient ;
- ftr: Advance per turn ;
- D: diameter of the drill bit in mm.

IV.1.3. Cutting force during milling

The removal of metal is carried out by two conjugate movements; a cutting movement (Mc) of the milling tool, driven by the spindle of the machine and an advance movement (Ma) of the workpiece fixed on the table. The direction of the forces which stress the teeth of the milling cutter is linked to the mode of milling adopted :

- In opposition or in the opposite direction of the advance when the cutting movement of the tool is in the opposite direction to that of the advance of the part.

- By swallowing or matching when the cutting movement of the tool is in the same direction as that of the advance of the part.

The forces which are applied successively to each tooth of the tool are :

* the tangential cutting force Fc normal to the radius which leads to the cutting edge ;
* the forward force Ff, parallel to the direction of advance ;
* the penetration force Fp, perpendicular to the previous one.

Since the milling cutter is carried by its axis O, the forces Ff and Fp admit the resultant F which necessarily passes through O.

The cutting force that applies to each tooth has the value :

$$Fc = K \times S \times Rr \quad \text{(IV.4)}$$

With :

S: Section of the chip being the product of its thickness e by the cutting width C,

Rr: Specific resistance to compression failure,

K: Coefficient which takes into account the machinability of the material.

IV.1.4. Working power [Pe]

The power P [watts] is equal to the product of the force F [newtons] by the speed V [m/sec]

$$Pe = Fc \times Vc \text{ [watts]} \quad \text{(IV.5)}$$

$$Pe = \frac{Fc * VC}{60 * \eta} = \frac{Rr * K * S * Vc}{60 * \eta}$$

With :

* Rr: Breaking strength [N/mm2] ;
* k: Coefficient depending on the composition of the material ;
* S: Cross-section of the chip [mm2] ;
* Vc: Cutting speed [m/min] ;
* η: Efficiency of the machine.

CHAPTER V : CHOICE OF CUTTING CONDITIONS

V.1. INTRODUCTION

The formation of a chip is the result of complicated mechanical processes. The cutting edge (where the cutting face and the clearance face meet) pierces the material and creates the chip. The chip can melt locally due to friction between the workpiece on the cutting face and the workpiece on the clearance face, resulting in a sharp rise in interface temperature. This behavior can cause the chip to adhere to the cutting face [16].

V.2. CUTTING PARAMETERS

The primary elements affecting chip formation are (Fig.V.1):

- Cutting motion
- The cutting speed $\mathbf{Vc}$ [m/min]
- The depth of cut $\mathbf{a}$ [mm]
- The federate $\mathbf{V_f}$ [mm/revolution] or [mm/tooth/revolution]
- Tool geometry
- Tool material type and piece
- The type of operation
- Cutting time t_c
- Lubrication.

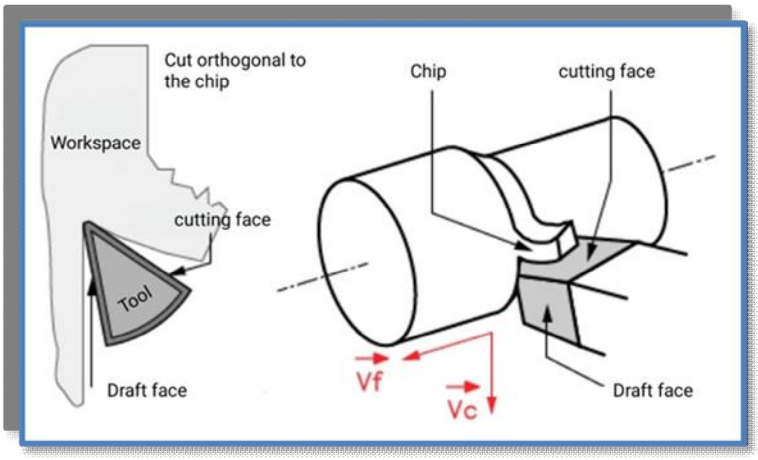


Fig.V.1. The cutting mechanism [18].

▪ **Note** When the penetration and/or feed are too low, the tool no longer cuts. The metal compresses superficially and the tool-part contact pressure causes premature erosion of the tool as well as the obtaining of a poor surface finish. It is necessary to choose minimum values for these data (values given by the tool manufacturer).

a. The tool's teeth cutting speed in minutes, **Vc** [m/min]. This element:

- In relation to the material of the tool and the type of material to be machined
- According to the operation's nature (roughing or finishing)
- The sensitive nature of the machining in respect to the type of operation)
- Based on the lubricating circumstances (dry or lubricated working).

Charts provide the typical cutting speed values dependent on the material to be machined and the material of the tool.

b. The following formula is used to get the rotation frequency **N** [rpm]:

$$Vc = \pi \times D \times N \quad \text{(V.1)}$$

where **D** [mm] represents the diameter of the workpiece (in turning) or the diameter of the cutter/drill (in milling/drilling).

c. The feedrate ***f*** [mm/rev] is expressed by the movement of the tool part in turning

- The feed mostly affects how rough the surface is. It is taken more in roughing than in finishing, and charts are also used to display the feed values.

d. The feed rate determines how quickly the tool or component will translate to be shown on the machine. The formula used to determine this parameter is as follows:

$$Vf = f \times Z \times N \quad \text{(V.2)}$$

With N the rate of rotation and Z the cutter's number of teeth.

e. The stock allowance of the material to be machined and the kind of operation both affect the step depth parameter **a** (roughing or finishing).

f. The chip's portion. The amount of chip removed by each tooth is determined by the feed rate f multiplied by the depth of cut a; this figure in turn affects the power required by the machine tool [16].

g. cutting time If L is the pass's length in millimeters, then the relation follows to calculate the pass's cutting time t_c :

$$tc = L/Vf \quad \text{(V.3)}$$

V.3. SOLUTIONS TO IMPROVE THE AGE OF THE CUTTING TOOL

- The cutting speed is dependent on the material being machined under stable cutting circumstances for the same cutting time.
- The size of the tool relies on the angle of the edge Kr, and erosion happens more quickly as the chip thickness E rises (knife tool). When the angle Kr rises, less power is absorbed for the same chip section
- To prevent the tool from overheating, it may occasionally be required to set a speed limit on the cutting motion. A method for supplying an abundance of refrigerant fluid to the active portion and resulting in efficient cooling is lubrication at high pressure.
- Use of a lubricant suited for the material being machined and the nature of the job is required to improve cutting performance.

- Changes in cutting speed are detrimental to effective tool holding [27].

V.4. VISIBLE WEAR ON THE TOOL

V.4.1. Edge plastic deformation when in use

This form of corrosion is distinguished by a more recent breakdown. If the tip's temperature rises too high. Mechanical stress can alter this [12].

Corrective measures:

- Choose a more powerful part,
- Use a stronger pad with a larger beak radius,
- Choose a larger cross-section chip geometry,
- Reduce the advance and possibly also the depth of passage.

V.4.2. Corrosion by cutting edge

Is constant when the predicted shadow is too flimsy in proportion to the task at hand, or when the tool is subjected to heat shocks. Perfendicular cracks occur at the cutting edge, and carbide particles are eventually pulled off this edge [12].

Corrective measures :

- Choose a more powerful part,
- Use a chip made of more stable edge materials,
- Reduce the lead at the start of the cut, in case of impact shredding of the chips.,
- Choose a different chip breaker geometry,
- Alter the angle of the tool's edge direction,
- Prepare the cut edge (e.g., 0.04 mm edge lapping).

V.4.3. Erosion by an embedded edge or adherent chip

This form of wear is caused by a low temperature in the cutting region, which causes the chip to flow poorly and weld to the edge. This adhering chip causes an increase in cutting power and a quick degradation of the part's surface condition [12].

Corrective measures:

- Increase cutting speed,
- Use coated hard metals or cermets,
- Select a positive edge geometry,
- Work with watering.

V.4.4. Erosion by stripping

The lifespan is characterized by it. When it is excessively big, the surface smoothness suffers and cutting forces rise (Fig. III.4). It is a generic standard for measuring tool life and is defined by an acceptable wear value (VB). The tool life given by the values is normally 15 minutes [12].

$$VB_{\text{Critical}} = 0.6 \text{ mm in roughing and } 0.3 \text{ mm in finishing}$$

This is caused by excessive cutting speed or incorrect angular position of the tool (cutting face / part)

Corrective Measures:

- Select a grade that offers greater wear resistance,
- Reduce cutting speed.

V.4.5. Hole eroding

It is a hollow wear on the cutting face, and it is caused by the chip rubbing against the tool's cutting face. During machining, the material is significantly diffused from the tool to the chip via adhesion process due to the high temperature at the chip-tool interface and the contact pressures between the chip and the tool. Additionally, it causes the tool's tip to flex plastically, exhibiting the SVP process and a bulge in the body face. Metal carbide tools frequently show wear, which typically results in the tool's tip breaking [12].

The critical value is the point at which the tool is regarded unusable, with a high danger of tool breakage (f: feed per revolution).

Corrective Measures:

- Make use of coated strong metal grades
- Select a positive sheets geometry
- Decrease the cutting speed or increase the advance

V.5. THE CRITERIA FOR CHOOSING

V.5.1.Introduction

The efficiency of the machining depends on the way in which the cutting parameters are adjusted. These parameters, whether they are constant or variable, work together to achieve the best possible result. The cutting speed and feed are essential, as they affect the speed of production and quality coins.

Choosing the right cutting speed depends on the material to be worked with, the grade of the cutting tool, and other factors. The increase in temperature with the cutting speed affects the wear of the tools. The recommended cutting conditions are tips, but must be adjusted according to the machine used. For successful machining, it is crucial to precisely adjust the parameters, based on specific criteria The optimization of the cutting conditions can be done according to different criteria.

- Minimize the cost of machining;
- Minimize the production time ;
- Minimize the number of tools needed [28].

V.5.2.The Criteria For Choosing

Several criteria make it possible to define the parameters of the cut [29]:

the type of machine (lathe, milling machine, drilling machine) and its power,

the machined material (steel, aluminum, etc.),

the material of the tool (ARS, metal carbide,...),

the type of operation (turning, straightening, roughing, finishing, surfacing, drilling, etc...).

The final objective is to obtain a machined part in good conditions. For this it is necessary to determine certain specific parameters, in particular:

the cutting speed ,

the feed speed , and the passing depth .

V.5.3.The type and power of the machine

Depending on the operation to be performed, it is necessary to choose the machining method, and therefore make the choice of the machine to be used (lathe, milling machine, drilling machine, etc...).

Naturally, there are often several possibilities for carrying out the same type of machining.

The power of the machine influences its performance. For machining by material removal, there are two main scenarios:

Rough machining, where we try to remove a maximum of material in a minimum of time. The objective in this case is to increase the chip flow rate as much as possible.

But the machine must be powerful enough, as well as the workpiece/workpiece holder attachment, otherwise the machine may "stall", or the workpiece may fly.

Finishing machining. For this type of operation it is the quality of realization that is important: the surface must be smooth, the dimensions must be correct. As the forces involved are lower than for a blank, the power of the machine is no longer a primary criterion.

V.5.3.The material of the piece

The cutting forces are different, depending on the material of which the part is made. The material therefore has an important influence on the choices relating to the machine power.

V.5.4.The material of the tool

Considering the fact that it is the tool that must machine the part (and not vice versa) it is important to choose tools with less wear and with the longest possible service life.

V.5.5. The type of operation and the shape of the tool

Taking into account the type of surfaces to be obtained, it is necessary to choose the operation and the appropriate tool. In a large majority of situations, several possibilities exist for carrying out the same type of machining, the choice being influenced in this situation by the parameters previously stated [29].

Abstract:

This guide provides Mechanical Engineering Masters students with the knowledge they need to understand the metal-cutting process in the manufacture and shaping of mechanical parts. It covers machining processes, the interaction between the tool and the workpiece, and the phenomena of decohesion and chip flow. It also deals with friction between the tool, the workpiece and the chip, exploring the various theories of wear. Conventional methods for calculating the mechanical effects of machining are presented, enabling the cutting power required for a given machine tool to be estimated. With this knowledge, students can adjust and define new cutting parameters to minimise the impact of mechanical actions on machined surfaces, thus improving efficiency and productivity. This document is divided into five chapters:

- Analysis of chip formation
- Cutting tool geometry
- Cutting tool wear
- Mechanical cutting actions (cutting forces and powers)
- Choice of cutting conditions.

Key words: Manufacturing, Chip formation analysis, Cutting tool, Wear, Cutting conditions.

Résumé:

Ce guide offre aux étudiants en Master de Génie Mécanique les connaissances essentielles pour comprendre le processus de coupe des métaux dans la fabrication et la mise en forme des pièces mécaniques. Il aborde les procédés d'usinage, l'interaction entre l'outil et la pièce, ainsi que les phénomènes de décohésion et d'écoulement des copeaux. Il traite également de la friction entre l'outil, la pièce et les copeaux, en explorant les différentes théories de l'usure. Les étudiants peuvent ajuster et définir de nouveaux paramètres de coupe pour minimiser l'impact des actions mécaniques sur les surfaces usinées, améliorant ainsi l'efficacité et la productivité. Ce document est divisé en cinq chapitres :

- Analyse de la formation des copeaux
- Géométrie des outils de coupe

- Usure des outils de coupe
- Actions mécaniques de la coupe (puissances et forces de coupe)
- Choix des conditions de coupe.

Mots clés : Usinage, Analyse de la formation de copeaux, Outil de coupe, Usure, Conditions de coupe.

BIBLIOGRAPHY

[1] Manufacturing Techniques Fall 2016/17 WEEK 10. Machining Processes and Machining Tools https://akademik.adu.edu.tr.

[2] Irving Paul Girsang and Jaspreet Singh Dhupia. Machine Tools for Machining.September2015.https://www.researchgate.net/publication/28684230.

[3] Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters https://www.ijeat.org/wp-content/uploads/papers/v2i1/A0726092112.pdf.

[4] machining processes IME 240. . https://personal.egr.uri.edu.

[5] Introduction to Machine Tools &Machines https://www.researchgate.net/publication/275344115.

[6] MAAMRI Deyaeddine, NECIBAbderrahmane. Optimisation des Paramètres de Coupe pour Minimiser la Consommation d'Energie Pendant le Tournage, Mémoire MASTER ACADEMIQUE Université. KasdiMerbah Ouargla. Faculté des Sciences Appliquées Département de Génie Mécanique.07/06/2015

[7] REMADNA. M, le comportement du système usinant en tournage dur. application du cas d'un acier trempe usine avec des plaquettes CBN (nitrure de bore cubique (2001). thèse de doctorat en Génie Mécanique, Institut National des Sciences Appliquées de Lyon.

[8] GERMAIN.G, Contribution à l'optimisation du procédé d'usinage assiste laser (2006), thèse de doctorat en Mécanique, Matériaux et Procédés, Ecole National Supérieure d'Arts et Métiers d'Angers.

[9] REMLI, F, L'effet d'usinage par tournage sur un acier XC18. 2016, Master Académique, Département de Génie Mécanique. Université Mohamed Khider-Biskra.

[10] Jean-Pierre corde bois et coll, « Fabrication Par Usinage », DUNOD, Paris 2003.

[11] BELLOUFI, Cours procédés de fabrication – Master / Maintenance industrielle, Université Kasdi MERBAH Ouargla – Algérie, 2010.

[12] NECIB. D, Contribution à l'optimisation de la durée de vie d'un outil de coupe par l'application d'un champ magnétique. Thèse de doctorat en Mécanique, 2012.

[13] Coupe des métaux ‹Pierozak-Jean Pierre. Edition OPU Alger 1988

[14] HAMAITI Youcef, NESRAT Abdelghani, « Impacts of the magnetic field on the turning wear behavior of XC38 steel », Master Académique, Département de Génie Mécanique, Université d' El-Oued, 2022.

[15] ROUABAH Chouaib, GUESSOUM Mohammed Laid, ROUIHA Tarek, « Influence of the magnetic field on the surface morphology of the cutting edge with lubrication », Master Académique, Département de Génie Mécanique, Université d' El-Oued, 2022.

[16] CHEMSA Mohammed Seghir, YAKOUB Rahaim, YOUCEF Mokeddem, «Study of the impact of the material removal rate on the tribological interactions of P-C-O contacts during the machining of C 48 steel», Master Académique, Département de Génie Mécanique, Université d' El-Oued, 2023.

[17] TILBI Hamza, « Influence de L'usure des Outils de Coupe sur la Qualité D'usinage Discontinue», Master Académique, Département de Génie Mécanique, Université Badji Mokhtar Annaba, 2020.

[18] https://fr.wikipedia.org/wiki/Rectifieuse.

[19] J. Ram Kumar. Department of Mechanical Engineering IIT Kanpur. TA202A: Introduction to Manufacturing Processes. Lectures 2-5 Conventional Machining Processes.

[20] CHAKIR Sara et LAIDI Karima, «Modélisation et Simulation des Mécanismes Aux Interfaces Pièce-Outil-Copeaux de L'acier Xc48», Master Académique, Département de Génie Mécanique, Université BLIDA 1, 2016.

[21] Cutting Tool Technology .https://www.mse.ncsu.edu.

[22] Tool Life: Wear and Failure https://fac.ksu.edu.sa.

[23] Usure des outils, Université de Lille 2017, https://analyse-fabrication.univ-lille.fr/co/000_module_MOG_30.html.

[24] M.REMADNA, le comportement du système usinant en tournage dur. application du cas d'un acier trempe usine avec des plaquettes CBN (nitrure de bore cubique (2001). thèse de doctorat en Génie Mécanique, Institut National des Sciences Appliquées de Lyon.

[25] https://fac.umc.edu.dz/ista/pdf/cours/Cours%206%20Efforts%20et%20puissance%20de%20coupe.pdf

[26] https://pdfcoffee.com/chapitre-4-efforts-de-coupe-puissance-pdf-free.html

[27] Les paramètres de coupe, www.https_fabrication.lille.fr.

[28] https://elearning.univ-msila.dz/moodle/pluginfile.php/714945/mod_resource/content/1/CH-V.

[29] https://analyse-fabrication.univ-lille.fr/co/chapitre_2_3_2.html.