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Manufacturing Technologies

Theory and Experiments of Machining

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Abstract:

The publication analyzes and develops theoretical knowledge about metal machining. Formulated postulates lead in practical conditions to a rational choice of machining conditions with the aim of minimizing the consumption of human labor, the consumption of types of energy and tool material. The intensification and optimization of the machining process requires a set of knowledge about the behavior of the material in the machining process, the phenomena of mutual interaction between the tool and the workpiece, and the changes in the material's properties during the machining process.

The development of theoretical knowledge about metalworking is largely based on the requirements of development and practice in the production process.
Practice is required to solve machining problems in interaction with other technology problems.

The subsequent understanding of machining also works in the direction that the parts are produced in such a way that it is not necessary to adapt them additionally during assembly.

The publication explains some problems of machining theory that are taught in technical universities. Analyzes are supplemented by conducting experiments, where theoretical knowledge is verified.

Keywords:

Technology, Machining, Cuttimg Tool, Tool Life, Machining Theory, Experiments.

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Manufacturing Technologies

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Manufacturing Technologies. Theory and Experiments of Machining.

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Contents

INTRODUCTION

Machining (metal cutting) is the process of shaping and sizing materials to a specific form and size. Typically, machining relates to metalworking, although it can also refer to the manufacture of wood, plastic, ceramic, stone, and other materials. If you have raw materials that you wish to mold into a certain shape for a specific purpose, you'll employ machining procedures to do it. Nuts and bolts, vehicle parts, flanges, drill bits, plaques, and a range of other equipment and things used in a variety of industries are examples of machined products.

Machining can also be seen as a crucial finishing technique in which tasks are created to the appropriate dimensions and surface polish by gradually eliminating surplus material from the prepared blank in the form of chips using a cutting tool(s) that are pushed through the work surface (s). A machine tool is power-driven equipment that removes extra material in the form of chips to size, shape, and process a product to the desired accuracy. Lathe Machines, Drilling Machines, Shaping Machines, Planer Machines, and so on. These are examples of machine tools. Finally, to remove the material of the workpiece's surface, a cutting tool is employed. To carry out the operation, it must be harder than the workpiece. Cutting tools are divided into two categories; single-point and multi-point.

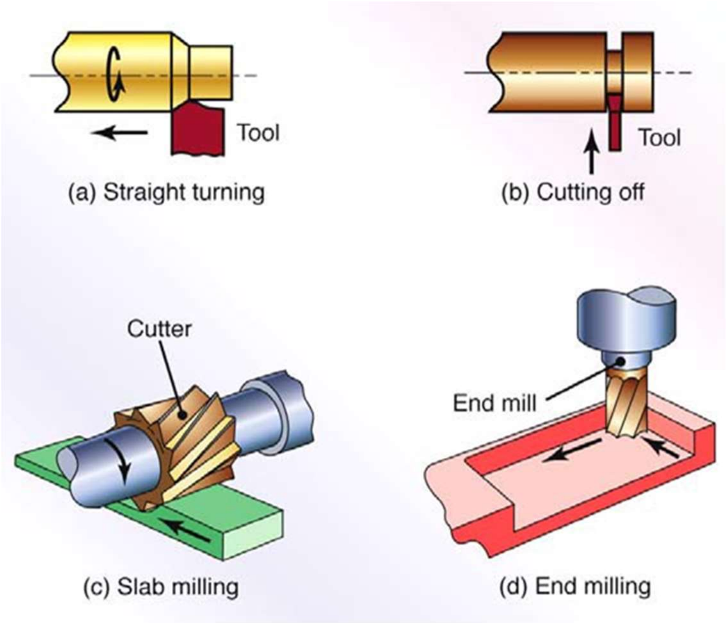
Most technical components, such as gears, bearings, clutches, tools, screws, and nuts, require dimensions and form correctness as well as a good surface polish to function properly. Performing techniques such as casting and forging, for example, are unable to achieve the required accuracy and polish. Such prepared parts, known as blanks, require semi-finishing and finishing, which is accomplished through machining and grinding. Grinding is essentially the same as machining. Machining to a high degree of accuracy and polish allows a product to meet its functional requirements, increase its performance, and extend its service life.

Some chapters are supplemented with protocols from experiments that can be carried out in laboratories. The template is an aid in processing the results of the experiments.

1. Principles of Metal Cutting

Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process.

Cutting processes remove material from the surface of workpiece by producing chips. Some of the more common cutting processes are illustrated in the Fig. 1.1.



(a) Straight turning
(b) Cutting off
(c) Slab milling
(d) End milling

Fig. 1.1 *Common cutting processes [2]*

- **Turning**, in which the workpiece is rotated and a cutting tool removes a layer of material as it moves to the left.
- **Cutting-off operation**, where the cutting tool moves radially inward and separates the right piece from the bulk of blank.
- **Slab-milling operation**, in which a rotating cutting tool removes a layer of material from the surface of workpiece.
- **End-milling operation**, in which a rotating cutter travels along a certain depth in the workpiece and produces a cavity.

1.1 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

Independent variables

The three principal machining processes are classified as **turning**, **drilling** and **milling**. Other operations falling into miscellaneous categories include shaping, planing, boring, broaching and sawing.

Turning operations are operations that rotate the workpiece as the primary method of moving metal against the cutting tool. Lathes are the principal machine tool used in turning.

Milling operations are operations in which the cutting tool rotates to bring cutting edges to bear against the workpiece. Milling machines are the principal machine tool used in milling.

Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the workpiece. Drilling operations are done primarily in drill presses but sometimes on lathes or mills.

1.2 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

1.3 Material Removal Processes

- 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
- Limitations, because material removal processes:
    - Inevitably waste material
    - Generally, require more energy, capital, and labor than forming or shaping operations
    - Can have adverse effects on the surface quality and properties, unless carried out properly,
    - Generally, take longer than shaping a product with other processes

1.4 Machine Tool Motions

- Primary motion that causes cutting to take place.
- Feed motion that causes more of the part surface to be machined
- Rotations and/or translations of the workpiece or cutting tool (Fig. 1.2)

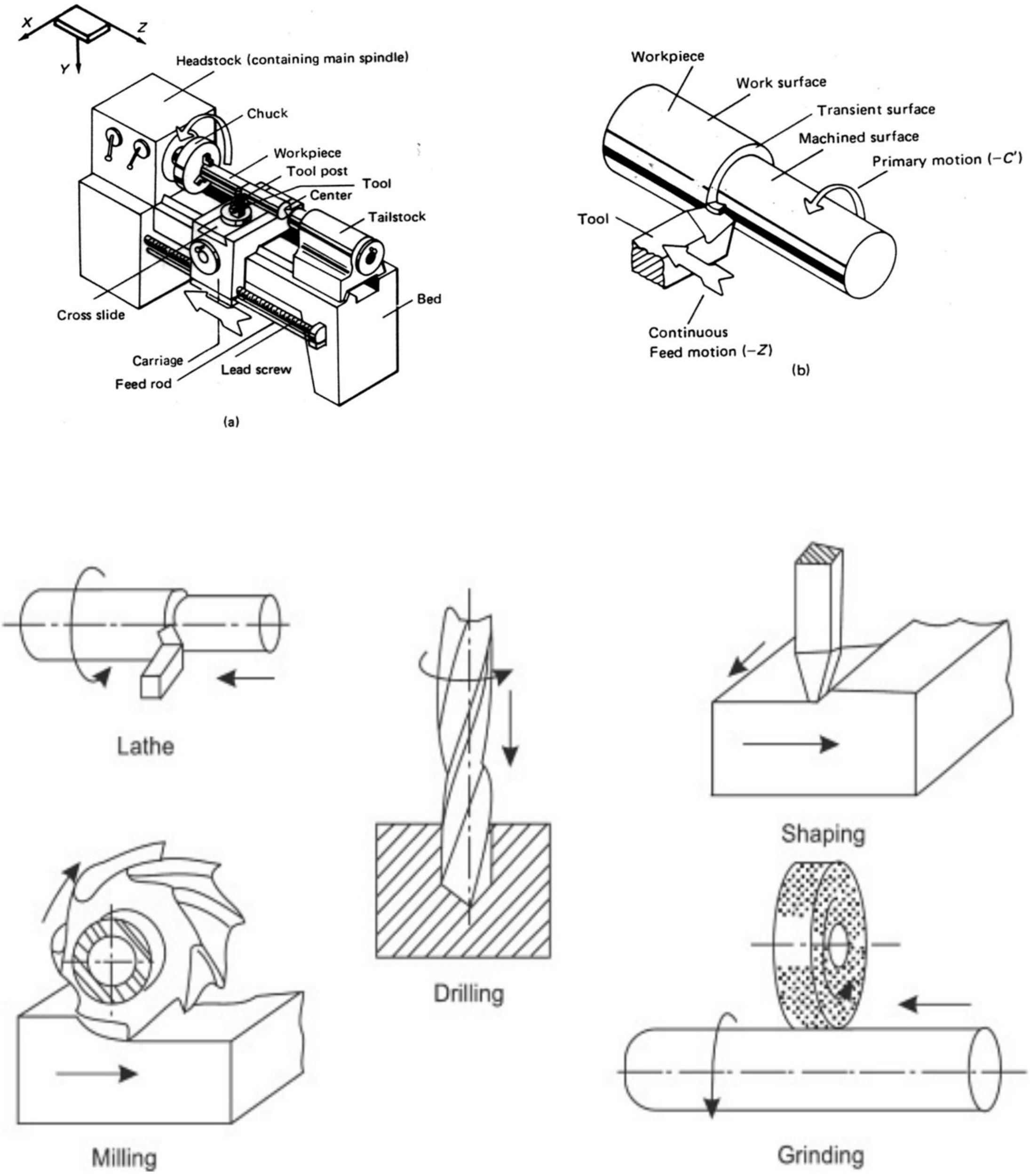


Fig. 1.2 *Working motions for some machine tools*

2. Geometry of the Cutting Tools

2.1Type of cutting tools

Cutting tools may be classified according to the number of major cutting edges (points) involved as follows:

- Single point: e.g., turning tools, shaping, planning and slotting tools and boring tools.
- Double (two) point: e.g., drills.
- Multipoint (more than two): e.g., milling cutters, broaching tools, hobs, gear shaping cutters etc.

2.2 Geometry of single point cutting (turning) tools

Both material and geometry of the cutting tools play very important roles on their performances in achieving effectiveness, efficiency and overall economy of machining.

2.3 Concept of rake and clearance angles of cutting tools

The word tool geometry is basically referred to some specific angles or slope of the salient faces and edges of the tools at their cutting point. Rake angle and clearance angle are the most significant for all the cutting tools. The concept of rake angle and clearance angle will be clear from some simple operations shown in Fig. 2.1.

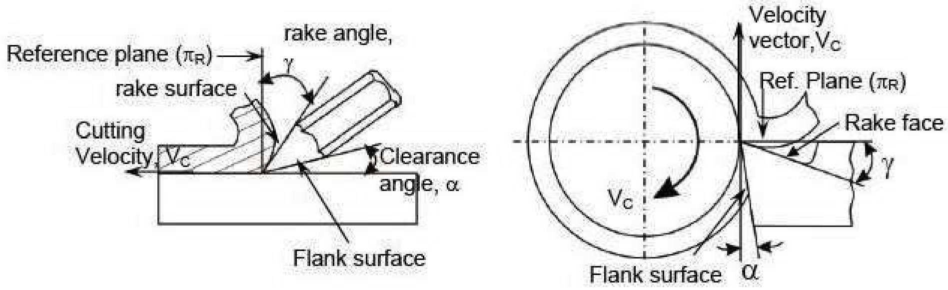


Fig. 2.1 *Rake and clearance angles of cutting tools [3]*

Definition

- Rake angle (γ): Angle of inclination of rake surface from reference plane.
- Clearance angle (α): Angle of inclination of clearance or flank surface from the finished surface. Rake angle is provided for ease of chip flow and overall machining. Rake angle may be positive, or negative or even zero as shown in Fig. 2.2 (a, b and c).

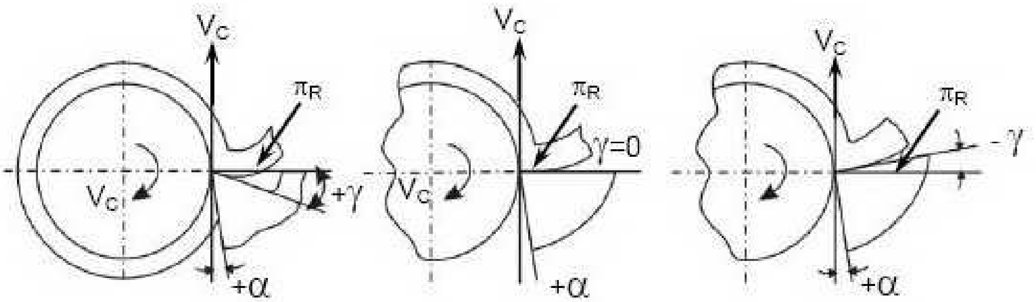


Fig. 2.2 *Three possible types of rake angles (a) Positive rake, (b) Zero rake, (c) Negative rake Fig.*

Relative advantages of such rake angles are:

- Positive rake - helps reduce cutting force and thus cutting power requirement.
- Zero rake - to simplify design and manufacture of the form tools.
- Negative rake - to increase edge-strength and life of the tool.

Clearance angle is essentially provided to avoid rubbing of the tool (flank) with the machined surface, which causes loss of energy and damages of both the tool, and the job surface. Hence, clearance angle is necessary and must be positive (30 ~ 150) depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.

The simplest form of cutting tool is the single-point tool such as is used in lathe and shaper work. Multiple-point cutting tools are merely two or more single-point tools arranged together as a unit. The milling cutter and broaching tool are good examples of this type.

Tool geometry for HSS

Here is important to provide maximum support for the cutting edges of the tools by keeping the clearance angles at a minimum. Large nose radii provide longer tool life, but care is necessary to prevent chatter. One recommendation is to use a radius equal to one-half to one-third the depth of cut.

Tool geometry for cemented tungsten carbides

To minimize the possibility of breakage, carbide tools with sharp cutting edges should not be used for roughing cuts. Chamfers and/or rounded comers are widely used for such applications. Nose radii should be as large as the workpiece and operations conditions permit because they result in stronger tool

Single point cutting tool geometry nomenclature

Cutting tool geometry nomenclature is based on standard. The turning tool and its main items are diagrammatically shown in Fig. 2.3.

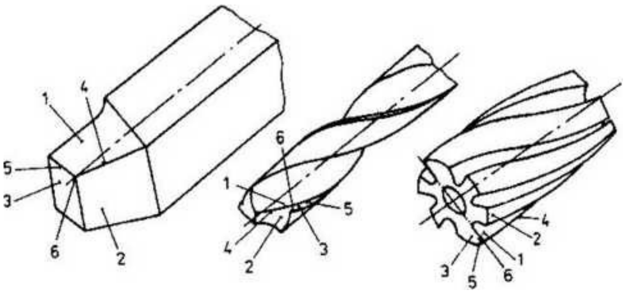


Fig. 2.3 *Important surfaces and edges of turning tool, spiral drill and mill [4]*

1 - (A_γ) rake surface, 2 - (A_α) – flank (back) surface, main 3 - (A_α ')- back surface - second. 4 - (S) primary cutting edge 5 - (S')- secondary cutting edge, 6 - point of the tool

2.4Systems of description of tool geometry

- Tool-in-Hand System - where only the salient features of the cutting tool point are identified or visualized as shown in Fig. 2.4 (a). There is no quantitative information, i.e., value of the angles.
- Machine Reference System - ASA system.
- Tool Reference System - Orthogonal Rake System- ORS.- Normal Rake System - NRS.
- Work Reference System - WRS.

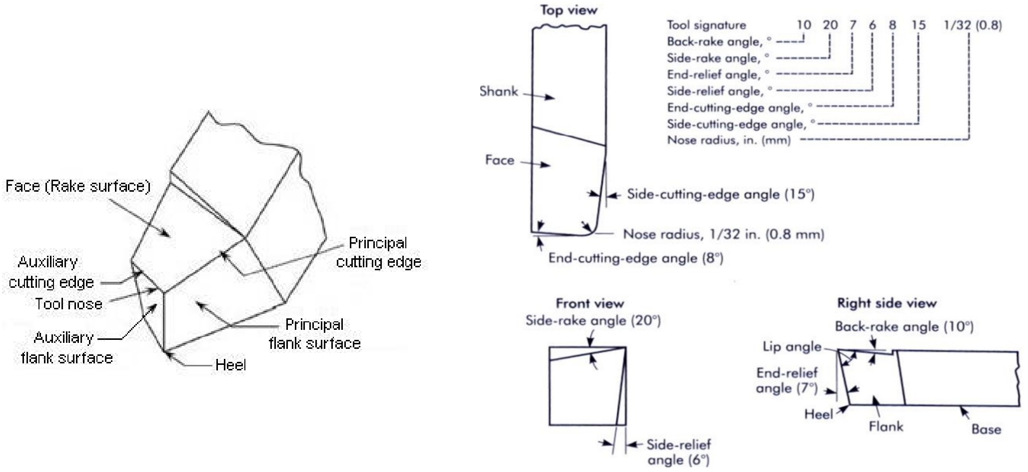


Fig. 2.4 *Basics features of single point cutting (turning) tool and the surfaces and angles on the tool*

Cutting tool surfaces and elements are shank, flank face, rake face, cutting edge, cutting wedge, etc. Shank is the main body of the tool. If the tool is an inserted cutter type, the shank supports the cutter or bit. Cutting wedge is the tool body enclosed between the rake and the flank faces. Rake face is the surface over which the chip formed in the cutting process slides. Flank face is the surface(s) over which the surface produced on the work-part passes. These terms will be explained very deeply to have better understanding cutting tool surfaces and elements. The geometry of a cutting element is defined by certain basic tool angles and thus precise definitions of these angles are essential. A system of tool angles is shown in figure below and is known as the tool-in-hand system. Rake, wedge and flank angles are specified by γ, β and α, respectively, and these are identified by the subscript of the plane of intersection. The definitions of basic tool angles in the tool angles-in-hand system are as follows in Fig. 2.5 and Fig. 2.6. [6]:

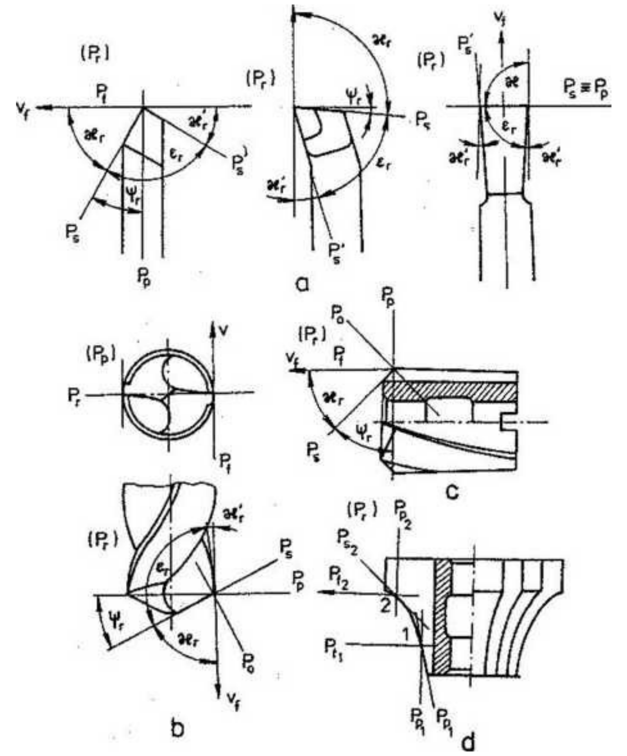


Fig. 2.5 *Tools in P_r plane: a) turning tool; b) spiral drill; c) end mill; d) tooth- formed mill*

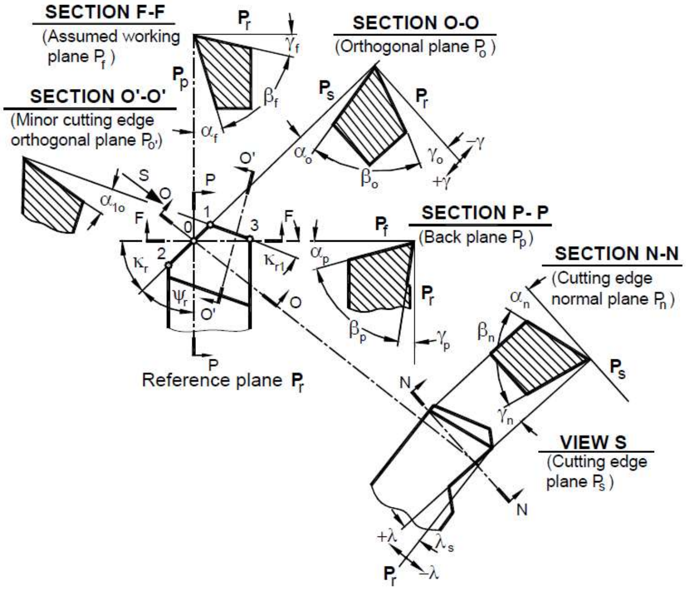


Fig 2.6 *The tool angles-in-hand system*

Captions for the Fig. 2.6
A_α – flank (back surface), A_γ- face (rake surface), P_r – tool reference plane, P_f - assumed working plane, P_s – tool cutting edge plane, P_n – cutting edge normal plane, P_o – tool orthogonal plane, S - major cutting edge, S' - minor cutting edge, corner, selected point of the cutting edge

α_o –tool orthogonal clearance angle, γ_o – tool orthogonal rake angle, χ_r – tool cutting edge angle, χ'_r – tool approach angle, ε_r - tool included angle, β_o – tool orthogonal wedge angle, λ_s - tool cutting edge inclination, r_ε – corner radius (radius nose), r_n - rounded cutting edge radius

2.5 Summary of turning parameters and formulas

The following formulas can be used to calculate machining parameters:

n - rotational speed of the workpiece, revolutions of the workpiece [rpm]

$$n = \frac{v_c}{\pi D_0}$$

f – feed [mm/rev]

v_f - feed rate, velocity of the feed or linear speed of the tool along workpiece length [mm/min]

$$v_f = n * f$$

v_c – cutting speed, velocity of cutting, surface speed of workpiece [m/min or m/s]

a_p – depth of cut [mm]

$$a_p = \frac{(D_0 - D_f)}{2}$$

l – length of the cut [mm]

T_m – time of machining [min]

$$T_m = \frac{l}{v_f}$$

D_o – original diameter of workpiece [mm]

D_f – final diameter of workpiece [mm]

D_a - average diameter of workpiece [mm]

$$D_a = \frac{(D_o + D_f)}{2}$$

MRR - material removal rate [mm^3/min]

$$MRR = \pi * D_a * a_p * n * f$$

t – cutting time [min]

$$t = \frac{l}{n * f}$$

3. Mechanics of Cutting

The factors that influence the cutting process are outlined in table 1:

Table. 1
The factors that influence the cutting process

Parameter	**Influence and interrelationship**
Cutting speed, depth of cut. feed, cutting fluids	Forces, power, temperature rise, tool life, type of chip, surface finish and integrity
Tool angles	As above; influence on chip flow direction; resistance to tool wear and chipping
Continuous chip	Good surface finish; steady cutting forces; undesirable, especially in automated machinery
Built-up edge chip (BUE)	Poor surface finish and integrity; if thin and stable, edge can protect tool surfaces
Discontinuous chip	Desirable for case of chip disposal; fluctuating cutting forces; can affect surface finish and cause vibration and chatter
Temperature rise	Influences tool life, particularly crater wear and dimensional accuracy of workpiece; may cause thermal damage to workpiece surface
Tool wear	Influences surface finish and integrity, dimensional accuracy, temperature rise, forces and power
Machinability	Related to tool life, surface finish, forces and power, and type of chip

- To understand this table, let us identify the **major independent variables** in the cutting process:
    a) Tool material and coatings;
    b) Tool shape, surface finish, and sharpness;
    c) Workpiece material and condition;
    d) Cutting speed, feed, and depth of cut;
    e) Cutting fluids;
    f) Characteristics of the machine tool (such as its stiffness and damping); and
    g) Workholding and fixturing.

- **Dependent variables** in cutting are those that are influenced by changes in the independent variables listed above, and include:
    a) Type of chip produced,
    b) Force and energy dissipated during cutting,
    c) Temperature rise in the workpiece, the tool, and chip,
    d) Tool wear and failure, and
    e) Surface finish of the workpiece after machining.

- When machining operations yield unacceptable results, a typical question posed is ***which of the independent variables should be changed first and to what extent***, if:
    a) The surface finish of the workpiece being cut is poor and unacceptable,
    b) The cutting tool wears rapidly and becomes dull,
    c) The workpiece becomes very hot, and
    d) The tool begins to vibrate and chatter [2].

3.1 The Mechanics of Chip Formation:

When a scale of metal cutting process reduces to micrometer range, mechanics of material

removal are affected by various factors such as workpiece material, cutting tool geometry and cutting conditions. A suitable model of constitutive behavior of the material is needed to represent properties of the work material at the conditions existing during chip formation Fig. 3.1. a)
shows the simple model (referred as the M.E. Merchant model) is sufficient for our purpose. It is called ***orthogonal cutting*** (forces involved are perpendicular to each other).

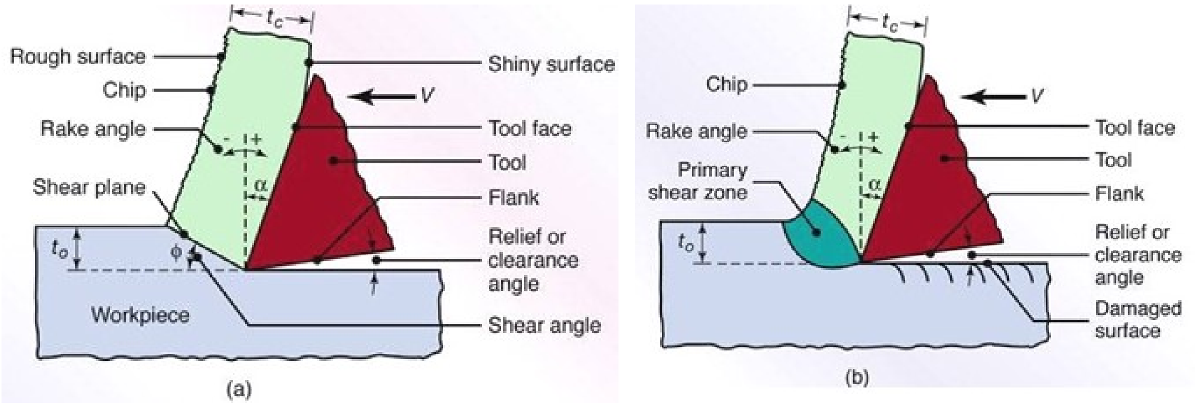


Fig. 3.1 *Schematic illustration of a two dimensional cutting process [18]*

Schematic illustration of a two dimensional cutting process (Fig. 3.1), also called orthogonal cutting: (a) Orthogonal cutting with a well-defined shear plane, also known as the Merchant Model. Note that the tool shape, depth of cut, to, and the cutting speed, *v*, are all independent variables, (b) Orthogonal cutting without a well-defined shear plane.

3.2 Types of chips produced in metal cutting

Types of metal chips are commonly observed in practice and their photomicrographs shown in Fig. 3.2. The four main types are:
a) Continuous,
b) Built-up edge,
c) Serrated or segmented, and
d) Discontinuous.

A chip has two surfaces: one that is in contact with the rake face of the tool and has shiny and burnished appearance caused by rubbing as the chip moves up the tool face. The other surface is from the original surface of the workpiece, it has a jagged, rough appearance, which is caused by the shearing mechanism shown in Fig. 3.1a).

Continuous Chips.

Built Up Edge (BUE) is the accumulation of workpiece material onto the rake face of the tool. This material welds under pressure, and is separate from the chip. Because BUE changes the effective geometry of the tool, it can have either positive or negative effects.

- Formed with ductile materials at high cutting speeds and/or high rake angles (Fig. 3.2a). The deformation of the material takes place along a narrow shear zone, the primary shear zone.
- Continuous chips may develop a secondary shear zone (Fig. 3.2b) because of high friction at tool-chip interface, this zone becomes thicker as tool –chip friction increases.
- In continuous chips, deformation may also take place along a wide primary shear zone with

curved boundaries (see Fig. 3.2) unlike that shown in Fig. 3.2a.

- Note that the lower boundary is below the machined surface, subjecting the machined surface to distortion, as depicted by the distorted vertical lines in the machines subsurfaces. This situation occurs particularly in machining soft metals at low speeds and low rake angles. It can produce poor surface finish and induce residual surface stresses.
- Although they generally produce good surface finish, continuous chips are not always desirable, particularly with the computer-controlled machine tools widely used today, as they tend to be tangled around the tool holder, the fixturing, the workpiece, as well as the chip-disposal system. This problem can be eliminated by chip breakers, or by changing parameters such as cutting speed or depth of cut [2].

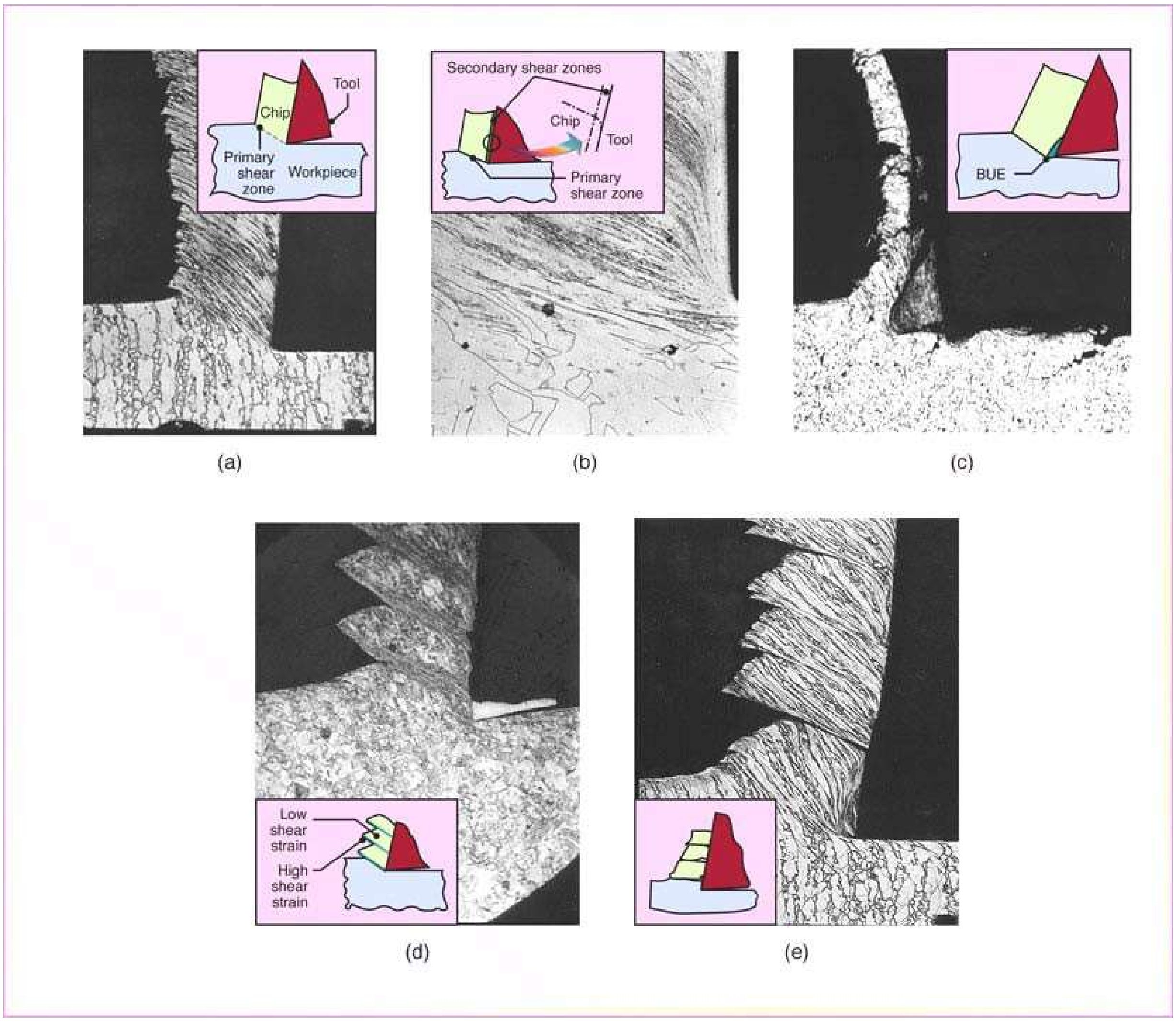


Fig. 3.2: *Basic types of chips produced in orthogonal metal cutting, their schematic representation, and photomicrographs of the cutting zone: (a) continuous chip with narrow, straight, and primary shear zone; (b) continuous chip with secondary shear zone at the chip- tool interface; (c) built-up edge (BUE); (d) segmented or nonhomogeneous chip; and (e) discontinuous chip [18].*

Built-up edge Chips

- A built-up edge (BUE) consists of layers of material from the workpiece that are gradually are deposited on the tool tip, Fig. 3.2c).
- As it becomes larger, the BUE becomes unstable and eventually breaks apart.

- Part of the BUE material is carried away by the tool-side of the chip; the rest is deposited randomly on the workpiece surface.
- The process of BUE formation and destruction is repeated continuously during the cutting operation, unless measures are taken to eliminate it. In fact, build-up edge changes the geometry of the cutting edge and dulls it (Fig. 3.2a).
- Although BUE adversely affects the surface finish (Fig. 3.2a and b and c), a thin, stable BUE is usually regarded as desirable because it reduces tool wear by protecting its rake face.
- Cold-worked metals generally have less tendency to form BUE than in their annealed conditions.
- Because of work hardening and deposition of successive layers of material, the BUE hardness increases significantly (Fig. 3.2 a).
- As the cutting speed increases the size of the BUE decreases, in fact it may not form at all.

The tendency for a BUE to form is also reduced by any of the following practices:

- Increase the cutting speeds,
- Decrease the depth of cut,
- Increase the rake angle,
- Use a sharp tool,
- Using an effective cutting fluid, and
- Use a cutting tool that has lower chemical affinity (tendency to form bond) for the workpiece material.

Causes of formation

In machining ductile metals like steels with long chip-tool contact length, lot of stress and temperature develops in the secondary deformation zone at the chip-tool interface. Under such high stress and temperature in between two clean surfaces of metals, strong bonding may locally take place due to adhesion similar to welding. Such bonding will be encouraged and accelerated if the chip tool materials have mutual affinity or solubility.

The weldment starts forming as an embryo at the most favorable location and thus gradually grows as schematically shown in Fig. 3.5 and Fig. 3.6, 3.7 [19].

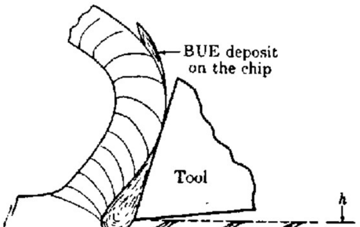


Fig. 3.3 *Scheme of built-up-edge formation*

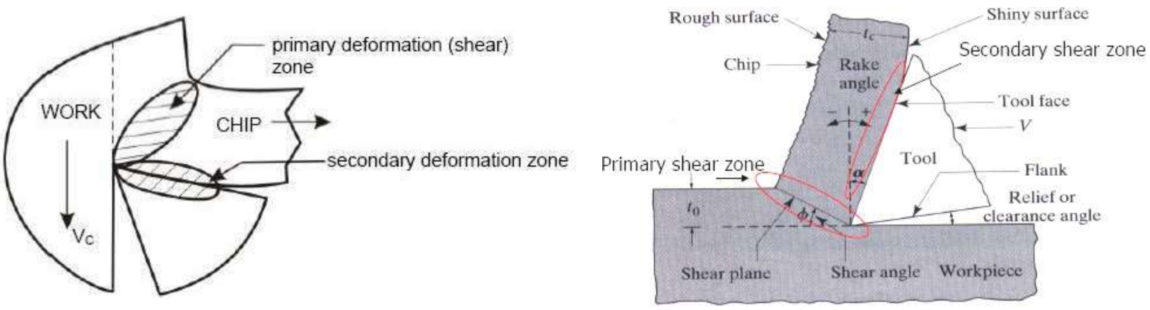


Fig. 3.4 *Primary and secondary deformation zones in the chip*

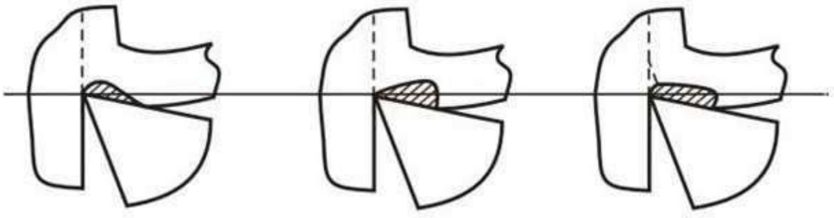


Fig. 3.6 *Different forms of built-up-edge*
(a) Positive wedge (b) Negative wedge
(c) Flat type

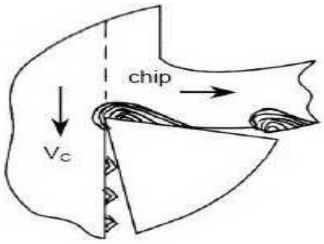


Fig. 3.7 *Overgrowing and overflowing of BUE causing surface roughness*

3.3 Chip formation

The chip form is greatly influenced by the materials being cut. Various continuous forms to crumbling material. The deformed chip is, in different segmental forms, usually held together in the ductile materials.

Continuous chip

Continuous chips are often produced when ductile materials such as steel or aluminum are machined. Continuous deformation of material without fracture creates a ribbon of metal. A chipbreaker or chip groove is normally built into the tool to control or otherwise minimize the length of continuous chip.

Serrated (segmented) chips

- Serrated chips (also called segmented or nonhomogeneous chips) are semicontinuous chips with large zones of low shear strain and small zones with high shear strain (Fig. 3.2 d).
- Metals with low thermal conductivity and strength that decreases sharply with temperature (thermal softness) exhibit this behavior such as titanium.
- The chips have a saw tooth-like appearance.

Discontinuous chips

- Discontinuous chips consist of segments that may be firmly or loosely attached to each other (Fig. 3.2 e).
- Discontinuous chips usually form under the following conditions:
    - Brittle workpiece materials.
    - Workpiece materials that contain hard inclusions and impurities, or have structures

  such as the graphite flakes in gray cast iron.
  - Very low or very high cutting speeds.
  - Large depths of cut.
  - Low rake angles.
  - Lack of an effective cutting fluid.
  - Low stiffness of the tool holder of the machine tool, thus allowing vibration and chatter to occur.
- Because of the discontinuous nature of chip formation, forces continually vary during cutting.
- Consequently, the stiffness or rigidity of the cutting-tool holder, the workholding devices, and the machine tool are important in cutting with both discontinuous chips and serrated chips.

The pattern and extent of total deformation of the chips due to the primary and the secondary shear deformations of the chips ahead and along the tool face, as indicated in Fig. 3.8, depend upon:

- Work material.
- Tool; material and geometry.
- The machining speed (v_C) and feed (f).
- Cutting fluid application.

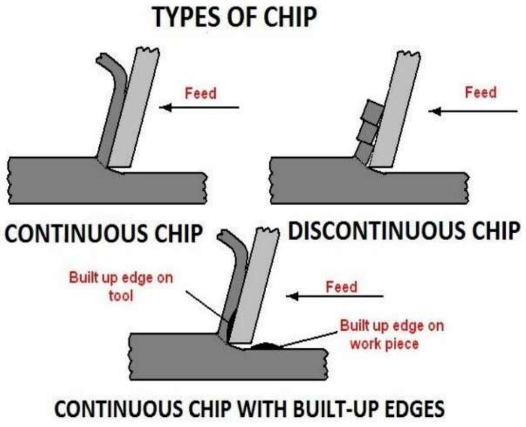


Fig. 3.8 *Types of chip*

The handling of wide and long chips often becomes difficult particularly while drilling large diameter and deep holes. Grooves, either on the rake faces or on the flanks as shown in Fig. 3.9 help to break the chips both along the length and breadth in drilling ductile metals. The locations of the grooves are offset in the two cutting edges.

Plain milling and end milling inherently produces discontinuous ‘coma’ shaped chips of favorably shorter length. But the chips become very wide while milling wide surfaces and may offer problem of chip disposal. To reduce this problem, the milling cutters are provided with small peripheral grooves on the cutting edges as shown in Fig. 3.9. Such in-built type of chip breakers breaks the wide chips into a number of chips of much shorter width. Similar groove type chip-breakers are also often provided along the teeth of broaches, for breaking the chips to shorter width and ease of disposal.

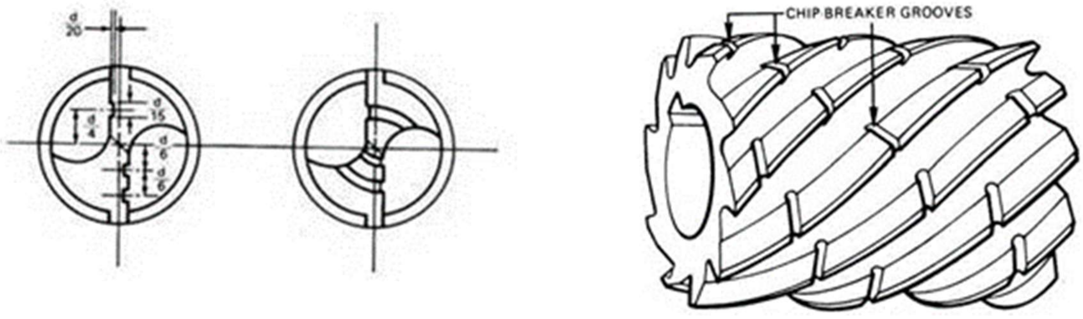


Fig. 3.9 *Chip breaking grooves for drilling and chip breaking grooves on a plain helical milling cutter*

4. Classification Tool Materials

Since the development of carbide cutting tools. industry has continued to research and develop better cutting tools capable of operating at greater speeds, feeds, and depth of cut. Although no tool has been found that will perform all jobs perfectly, great strides have been made in the development of cutting tools [7].

1. Carbon-Tool Steels:

- 0.6-1.5% carbon + little amount of Mn, Si, Cr, V to increase hardness.
- Low carbon varieties possess good toughness & shock resistance.
- High carbon varieties possess good abrasion resistance.

2. High Speed Steels (HSS):

- High carbon + little amount Tungsten, Molybdenum, Cr, V & cobalt to increase hardness, toughness and wear resistance.
- High operating temperatures up to 600ºC
- Two types of HSS i.e, is T-type and M-Type
- Vanadium increases abrasion resistance, but higher percentage will decrease grind ability.
- Chromium increases hardenability.
- Cobalt is added to HSS to increase red hardness.

3. Cast Cobalt Base Alloys:

- It is a combination of W, Cr, carbon, and Cobalt which form an alloy with red hardness, wear resistance and toughness. It is preparing by casting.
- Used for machining Cast iron, alloy steels, non-ferrous metals and super alloys

4. Cemented Carbides:

- These are carbides of W, Titanium, and tantalum with small amount of cobalt produced by means of powder metallurgy route.
- Two types i.e, Straight Tungsten Carbide Cobalt Grade and Alloyed Tungsten Carbide Grade, Straight Tungsten Carbide Cobalt Grade: Cast iron, non-ferrous alloys, plastics, wood, glass etc.
- Alloyed Tungsten Carbide Grade: All grades of steel at 3 to 4 times more speeds than HSS

Carbides are now so popular that ISO has developed an application chart. The chart is divided into three main areas: ISO - P, M and K. ISO P: is for the machining of long chip formation materials. ISO M: is for the machining of difficult to machine materials such as austenitic stainless steel. ISO K: is for the machining of short chip formation materials such as cast iron, hardened steel.

Detail grouping of cemented carbide tools is in the table.

5. Ceramic Tools:

- Aluminum Oxide, Silicon Carbide, Boron Carbide, Titanium Carbide, Titanium Boride
- High speed, longer tool life, superior surface finish, no coolant is required.

6. Diamond Tools:

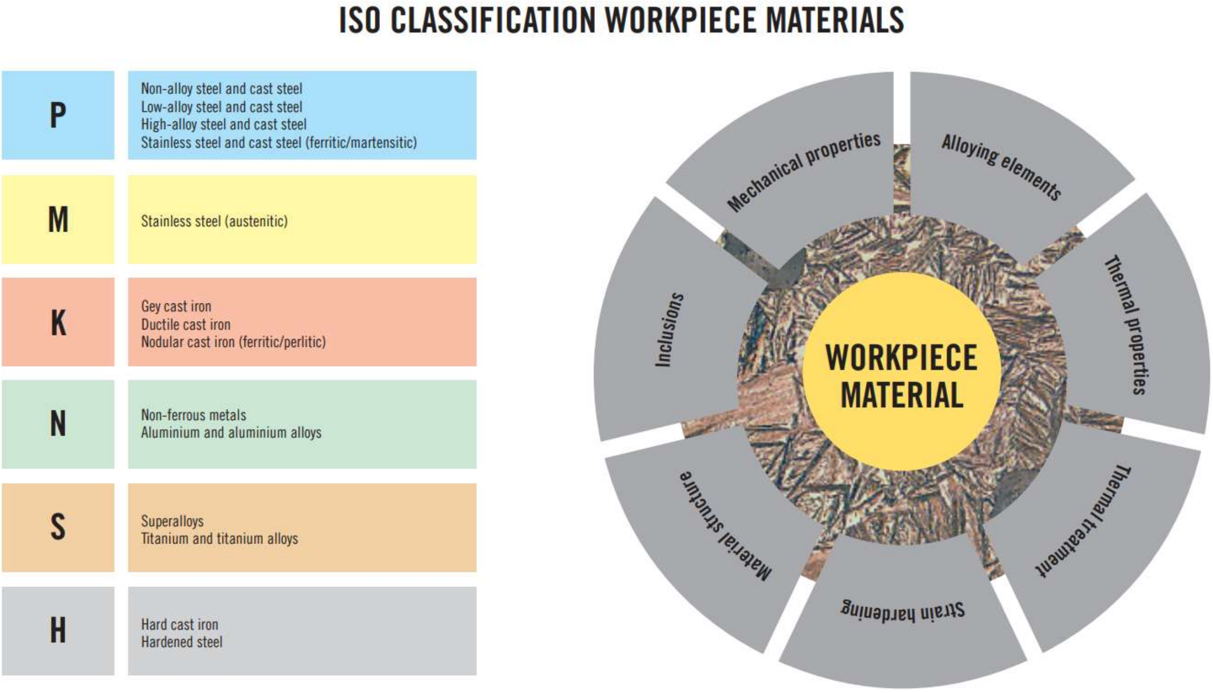
- More abrasion resistance.
- Used for turning grinding wheels.
- Used to produce mirror surface finish.
- Diamond abrasive belts are used to produce TV screens.
- Poly crystalline diamond inserts are brazed into cutting edges of circular saws for cutting construction materials like concrete, refractories, stone etc.

Table 2:
Detail grouping of cemented carbide tools

ISO App. group	**Material**	**Process**
P01	Steel, Steel castings	Precision and finish machining, high speed
P10	Steel, steel castings	Turning, threading and milling high speed, small chips
P20	Steel, steel castings, malleable cast iron	Turning, milling, medium speed with small chip section
P30	Steel, steel castings, malleable cast iron forming long chips	Turning, milling, low cutting speed, large chip section
P40	Steel and steel casting with sand inclusions	Turning, planning, low cutting speed, large chip section
P50	Steel and steel castings of medium or low tensile strength	Operations requiring high toughness turning, planning, shaping at low cutting speeds
K01	Hard grey C.I., chilled casting, Al. alloys with high silicon	Turning, precision turning and boring, milling, scraping
K10	Grey C.I. hardness > 220 HB. Malleable C.I., Al. alloys containing Si	Turning, milling, boring, reaming, broaching, scraping
K20	Grey C.I. hardness up to 220 HB	Turning, milling, broaching, requiring high toughness
K30	Soft grey C.I. Low tensile strength steel	Turning, reaming under favorable conditions
K40	Soft non-ferrous metals	Turning milling etc.
M10	Steel, steel castings, manganese steel, grey C.I.	Turning at medium or high cutting speed, medium chip section
M20	Steel casting, austenitic steel, manganese steel, sherardized C.I., Malleable C.I.	Turning, milling, medium cutting speed and medium chip section
M30	Steel, austenitic steel, sherardized C.I. heat resisting alloys	Turning, milling, planning, medium cutting speed, medium or large chip section
M40	Free cutting steel, low tensile strength steel, brass and light alloy	Turning, profile turning, especially in automatic machines.

In the machining industry, workpiece materials are divided into groups. Classifying the workpiece material correctly into the right group gives a good starting point for choosing the correct Carbide Grade, Cutting Edge geometry, and initial Cutting Speed.

his classification is the primary consideration for choosing the correct Carbide Grade and Cutting Edge geometry. The major carbide suppliers usually display their grades in the catalogs according to the above colors and letters code, with the addition of the Application Range code.



ISO CLASSIFICATION WORKPIECE MATERIALS

P	Non-alloy steel and cast steel Low-alloy steel and cast steel High-alloy steel and cast steel Stainless steel and cast steel (ferritic/martensitic)
M	Stainless steel (austenitic)
K	Gey cast iron Ductile cast iron Nodular cast iron (ferritic/perlitic)
N	Non-ferrous metals Aluminium and aluminium alloys
S	Superalloys Titanium and titanium alloys
H	Hard cast iron Hardened steel

Fig. 4.1 *Workpiece material clasification chart into groups [8]*

To adjoining graph lists most of the cutting tool materials for metal cutting (Fig. 4.2)

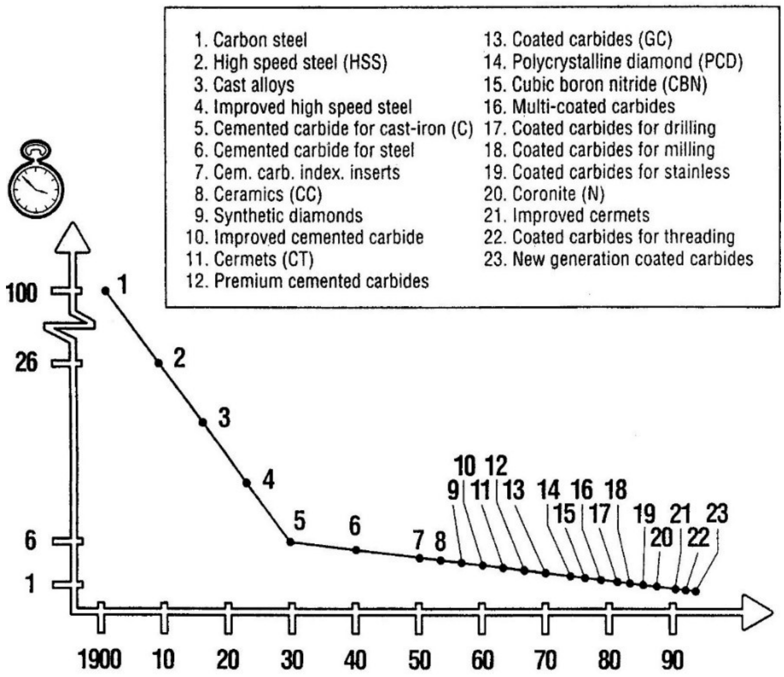


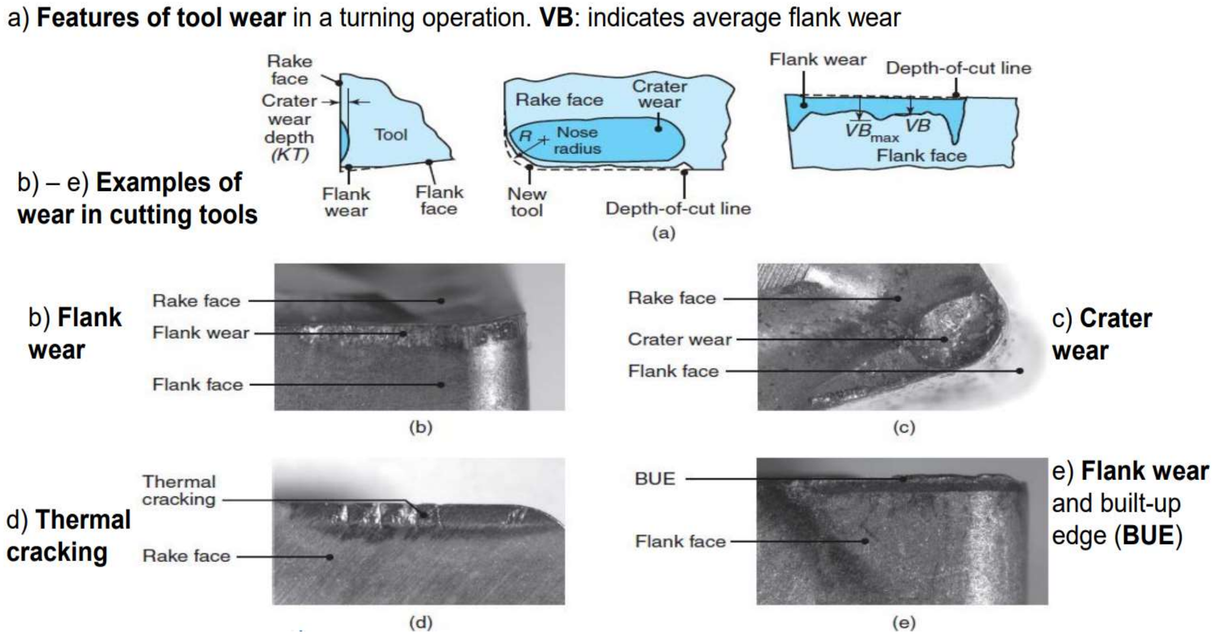
Fig. 4.2 *The development of the cutting tool materials with years of developing and ratio time of machining the same surface [4]*

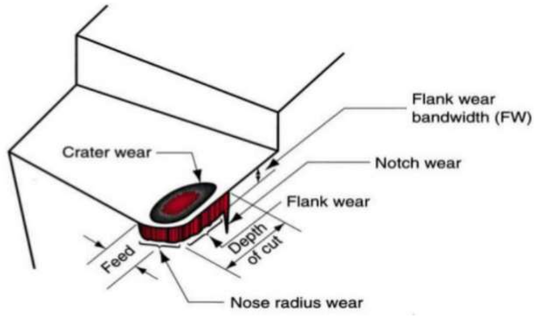
5. Tool Wear and Tool Life

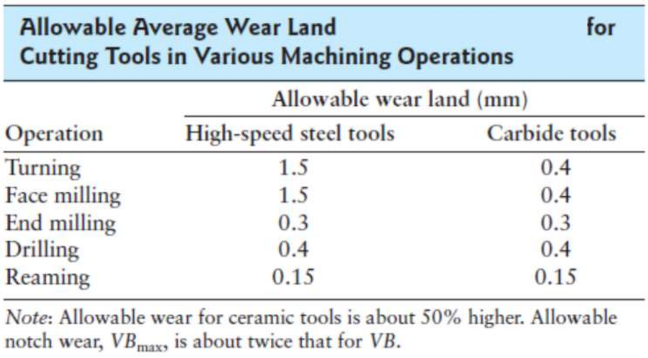
The tool life is one of the most important economic considerations in a machining operations and a comparison of alternatives (tools, work materials or cutting fluids) is justifiable on economic grounds.

Tool failure can be monitored by observing the following (Fig. 5.1):

1. Flank wear-abrasion or wear on the flank below the cutting edge.
2. Cratering-caused by the flowing chip which wears, a cup in the tool ' face behind the cutting edge which gradually grows larger and finally causes the cutting edge to crumble.
3. Built-up-edge thermal cracking or deformation.
4. Various combinations of the above.







Allowable Average Wear Land for Cutting Tools in Various Machining Operations

	Allowable wear land (mm)	
Operation	High-speed steel tools	Carbide tools
Turning	1.5	0.4
Face milling	1.5	0.4
End milling	0.3	0.3
Drilling	0.4	0.4
Reaming	0.15	0.15

Note: Allowable wear for ceramic tools is about 50% higher. Allowable notch wear, VB_{max}, is about twice that for VB.

Fig. 5.1 *Types of tool wear and allowable values of flank wear VB for high speed steel tools (HSS) and carbide tools [20]*

The important consideration is, that the tools are used until they are worn to a condition just short of that at which extensive regrinding would be necessary, they should be run only to the point at which regrinding is still economical with respect to time and tool material.

It has been found that, for high-speed steel tools preliminary failure is sufficient enough criterion of the tool failure for shop use. The appearance of the burnished band on the workpiece indicates that regrinding of the tool is necessary.

Since it is uneconomical to run cast-alloy, sintered-carbide, or ceramic tools, to complete breakdowns, it has been found that flank failure is a very good criterion of tool failure for shop use.

The growth of flank wear width in time is showed on Fig. 5.2 [21]. The curve has three typical parts.
1. *Initial wear*- the surface layer properties after regrinding can result in residual stresses, structural alterations. The contact area is small, pressure is high, the width increment in the beginning is larger than later.
2. *Normal wear*- both interaction surfaces and temperature rise, these influences are in equilibrium
3. *Accelerated wear*- structural changes, hardness falls, bearing properties are exhausted, the wear is in quick progress.

Cutting tools need to be replaced when:
1. Surface finish of the machined workpiece begins to deteriorate
2. Cutting forces increase significantly
3. Temperature rises significantly

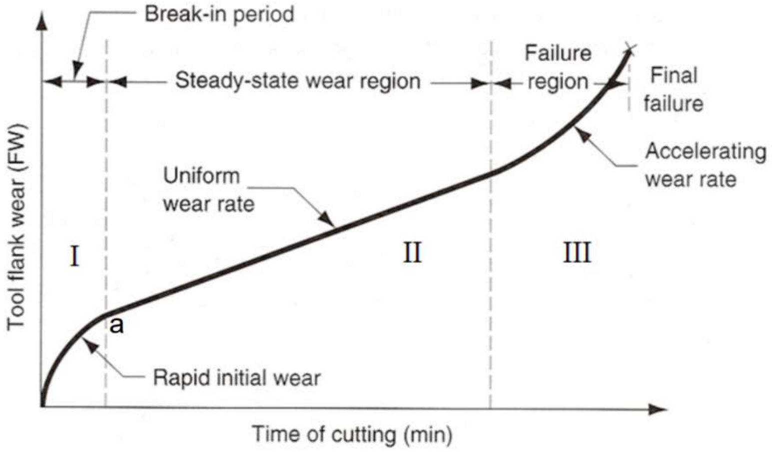


Fig. 5.2 *Tool wear as a function of cutting time, flank wear is used here as the measure of tool wear*

Tool life and its relation to practical variables. Tool life is related to cutting speed, dimensions of the cut, tool angles, tool shape, cutting fluid used, rigidity of the setup, chatter, dimensions of the workpiece and other variables.

The most important factor affecting the tool life is the cutting speed. Therefore, its effect will be discussed in detail (Fig. 5.3).

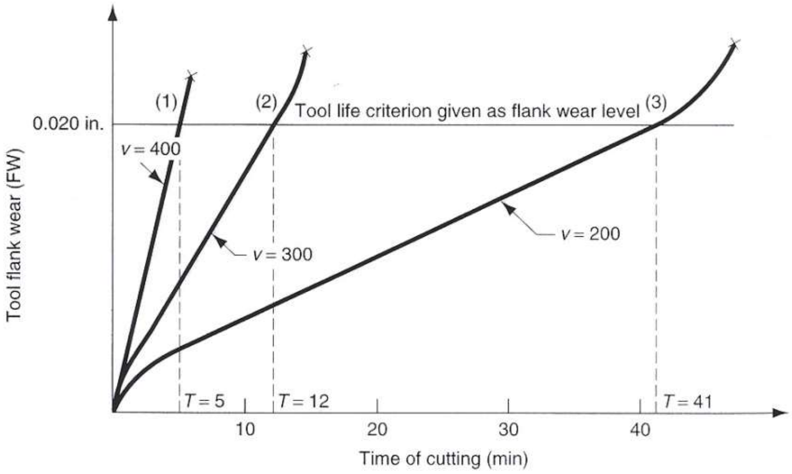


Fig. 5.3 *Effect of cutting speed on tool flank wear for three cutting speeds. Hypothetical values of speed and tool life are shown for a tool life criterion of 0.020 inch (0,4 mm) flank wear [21].*

Taylor tool life equation:

If the tool life values for the three wear curves are plotted on a natural log – log graph, cutting speed versus tool life.

Cutting speed is the variable having by far the greatest influence on tool life. The discovery of this relation around 1900 is credited to **F.W. Taylor**. It can be expressed in equation form and it is called Taylor tool life equation. **Taylor** showed that the relation between tool life and cutting speed ordinarily could be represented approximately by the empirical equation:

$$T = \frac{C_T}{{v_c}^m}$$

T - actual cutting time between resharpenings (min); v_c - cutting speed (m/min);
m- exponent whose value depends on tool material and other variables (3-11)
C_T- constant whose value depends on other machine variables and the work material variables.

This equation defines a straight line on log-log graph paper (Fig. 5.4, 5.5):

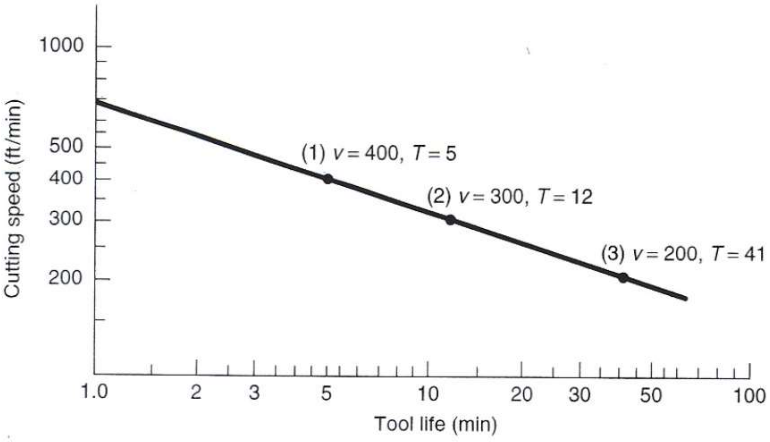
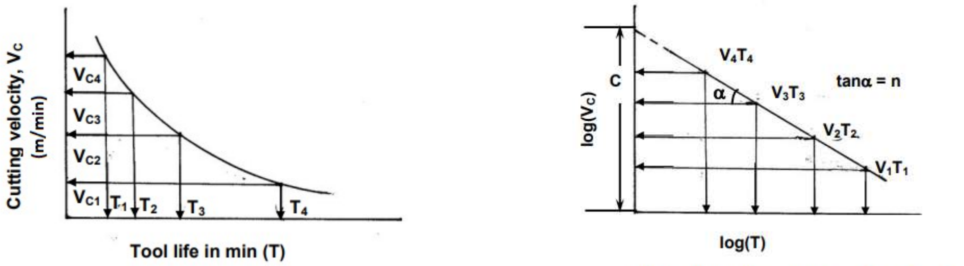


Fig. 5.4 *Natural log – log plot of cutting speed versus tool life [21].*



Cutting velocity - tool life relationship

Cutting velocity vs tool life on a log-log scale

Fig.5.5 *Cutting Velocity v_c and tool life T -relationship*

The tool life obtained at a given cutting speed is, of course influenced by the dimensions of the cut. There are two important general facts about the machining of metals.

1. As feed or depth of cut is increased, the cutting speed must be decreased to keep the tool life constant.
2. However, when this is done, the amount of metal removed by the tool during the same given life is considerably increased (this is especially true of an increase in the depth of cut, because of its very low exponent).

The general relationship between life and cutting variables as follows

$$T = \frac{C_T}{{v_c}^{(2{,}5-12)} * f^{0{,}9} * a_p^{0{,}3}}$$

where

T -actual cutting time between resharpening
C_T - constant depends prior on the work material
v_c - cutting speed
f - feed
a_p - depth of cut

Thus, a general rule may be stated:

The combination of a large depth of cut, and a high rate of feed with a low - cutting speed will allow a large amount of metal to be removed during a given life of the tool.

Machining economic:

In machining a certain part, we want to determine the parameters that will give us either the minimum cost per part or the maximum production rate (Fig. 5.6, 5.7) [21].

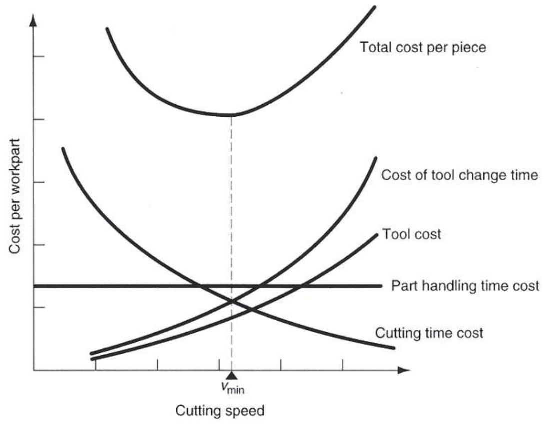


Fig. 5.6 *Cost per unit for a machining process versus cutting speed*

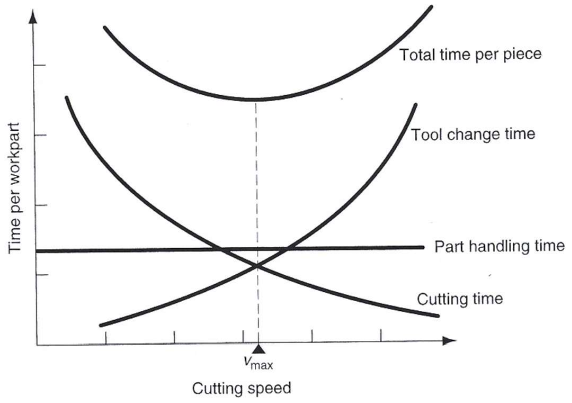


Fig. 5.7 *Production time versus cutting speed*

Tool life criterion in production:
The criterion of Taylor equation is not practical in a factory environment, the following are some alternates that are more convenient to use in production:
1. Changes in the sound emitting from operation.
2. Degradation of the surface finish on work.
3. Complete failure of cutting edge.
4. Workpiece count.
5. Chips become ribbon form or string

$$T_p = T_l + T_m + \frac{T_g}{N_p}$$

The time needed to produce a part is:
T_l -time involved in loading and unloading the part, changing speed and feed rates.
T_m - machining time per part.
T_g - time required to grind the tool.
N_p - number of parts machined per tool ground.

Factors affecting tool life

The life of the cutting tool is affected by the following factors:

- Cutting speed.
- Feed and depth of cut.
- Tool geometry.
- Tool material.
- Cutting fluid.
- Work piece material.
- Rigidity of work, tool, and machine.

For the purpose of controlling tool wear, one must understand the various mechanisms of wear that the cutting tool undergoes under different conditions.

The common **mechanisms of cutting tool wear** are:

(a) ***Mechanical wear***

- Thermally insensitive type; like abrasion, chipping, and de-lamination.
- Thermally sensitive type; like adhesion, fracturing, flaking etc.

Flank wear is a flat portion worn behind the cutting edge which eliminates some clearance or relief. It takes place when machining brittle materials. Wear at the tool-chip interface occurs in the form of a depression or crater. It is caused by the pressure of the chip as it slides up the face of the cutting tool. Both flank and crater wear take place when feed is greater than 0.15 mm/rev at low or moderate speeds.

(b) ***Thermo chemical wear***

- Macro-diffusion by mass dissolution.
- Micro-diffusion by atomic migration.

In diffusion wear the material from the tool at its rubbing surfaces, particularly at the rake surface gradually diffuses into the flowing chips either in bulk or atom by atom when the tool material has chemical affinity or solid solubility towards the work material. The rate of such tool wears increases with the increase in temperature at the cutting zone. This wear becomes predominant when the cutting temperature becomes very high due to high cutting velocity and high strength of the work material.

(c) ***Chemical wear***

Chemical wear, leading to damages like grooving wear may occur if the tool material is not enough chemically stable against the work material and/or the atmospheric gases.

(d) ***Galvanic wear***

Galvanic wear, based on electrochemical dissolution, seldom occurs when the work and tool materials are electrically conductive, cutting zone temperature is high and the cutting fluid acts as an electrolyte.

6. Machinability

The term; ‘Machinability’ has been introduced for gradation of work materials with respect to machining characteristics.

Machinability is the property of the material by which it can be machined easily and quickly.

But truly speaking, there is no unique or clear meaning of the term machinability. People tried to describe “Machinability” in several ways such as:

- It is generally applied to the machining properties of work material.
- It refers to material (work) response to machining.
- It is the ability of the work material to be machined.
- It indicates how easily and fast a material can be machined (Fig.6.1).

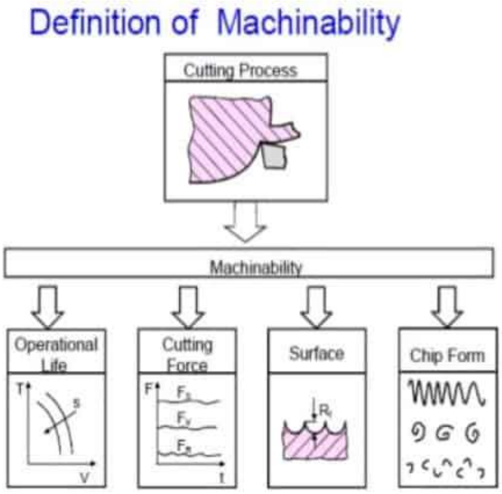


Fig. 6.1 *Different approaches to the definition of machinability [22]*

But it has been agreed, in general, that it is difficult to clearly define and quantify Machinability. For instance, saying ‘*material A is more machinable than material B’* may mean that compared to ‘B’:

‘A’ causes lesser tool wear or longer tool life.

‘A’ requires lesser cutting forces and power.

‘A’ provides better surface finish.

Attempts were made to measure or quantify machinability and it was done mostly in terms of:

- Tool life which substantially influences productivity and economy in machining.
- Magnitude of cutting forces which affects power consumption and dimensional accuracy.
- Surface finish which plays role on performance and service life of the product.

Often cutting temperature and chip form are also considered for assessing machinability.

Machinability rating (MR)

The machinability index KM is defined by:

$$KM = \frac{v_{c60}}{v_{c60R}}$$

where,

v_{c60} is the cutting speed for the target material that ensures tool life of 60 min,

v_{c60R} - the same for the reference material. Reference materials are selected for each group of work materials (ferrous and non-ferrous) among the most popular and widely used brands (Fig. 6.2, 6.3.).

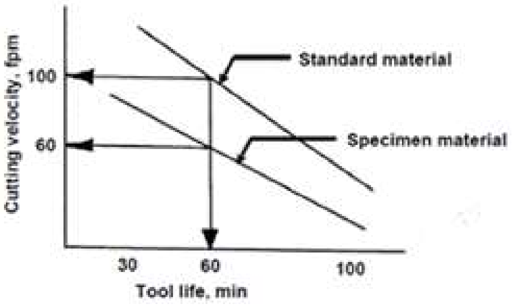


Fig. 6.2 *Machinability rating in terms of cutting velocity giving 60 min tool life*

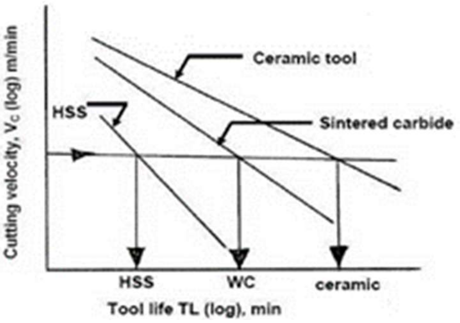


Fig. 6.3 *Role of cutting tool material on machinability (tool life)*

Example: Machinability rating

The reference material for steels, AISI 1112 steel has an index of 1 (cutting velocity 0,5 m/s, 30 m/min), VB = 0,5 mm.

For a tool life of 60 min, the AISI 1045 steel should be machined at 0.36 m/s (21,6 m/min).

Hence, the machinability index for this steel is,

$$KM = 0.36/0.5 = 0.72.$$

This index is smaller than 1, therefore, AISI 1045 steel has a worse workability than AISI 1112.

If KM greater than 1, the machinability of the target material is better that this of the reference material, and vice versa. Note that this system can be misleading because the index is different for different machining processes.

Machinability can be tentatively defined as "ability of being machined" and more reasonably as "ease of machining".

Such ease of machining or machinability characteristics of any tool-work pair is to be judged by:

- Magnitude of the cutting forces.
- Tool wear or tool life.
- Surface finish.
- Magnitude of cutting temperature.
- Chip forms.

Machinability will be considered desirably high when cutting forces, temperature, surface roughness and tool wear are less, tool life is long, and chips are ideally uniform and short enabling short chip-tool contact length and less friction.

7. Surface Roughness

Surface topography is of great importance in specifying the function of a surface. A significant proportion of component failure starts at the surface due to either an isolated manufacturing discontinuity or gradual deterioration of the surface quality. Typical of the former is the laps and folds which cause fatigue failures and of the latter is the grinding damage due to the use of a worn wheel resulting in stress corrosion and fatigue failure. The most important parameter describing surface integrity is surface roughness. In the manufacturing industry, surface must be within certain limits of roughness. Therefore, measuring surface roughness is vital to quality control of machining work piece. Below are the definition of surface roughness and its main measurement methods.

Description of Surface Roughness

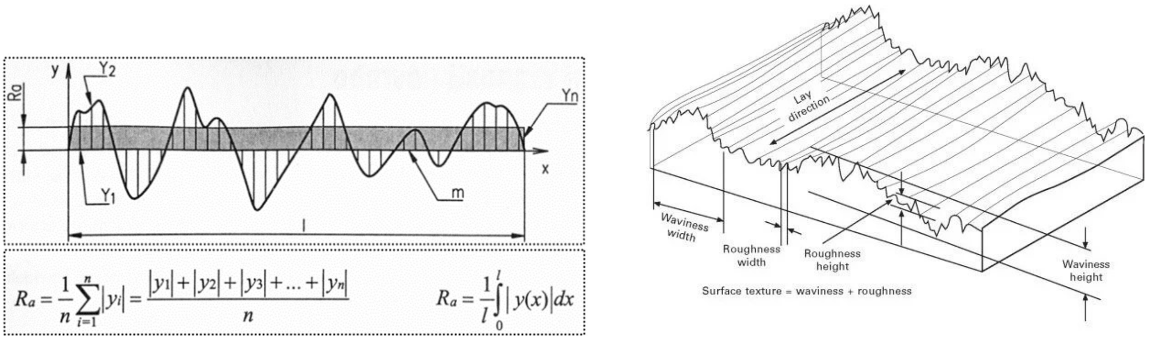
The roughness of a surface can be measured in different ways which are classified into three basic categories:

Statistical descriptors that give average behavior of the surface height. For example, average roughness Ra; the root mean square roughness *Rq*; the skewness *Sk* and the kurtosis *K*.

Extreme value descriptors that depend on isolated events. Examples are the maximum peak height *Rp*, the maximum valley height *Rv*, and the maximum peak to valley height *Rmax*.

Texture descriptors that describe variations of the surface based on multiple events. An example for this descriptor is the correlation length.

Among these descriptors, the *Ra* measure is one of the most effective surface roughness measures commonly adopted in general engineering practice. It gives a good general description of the height variations in the surface. The following figure shows a cross section through the surface, a mean line is first found that is parallel to the general surface direction and divides the surface in such a way that the sum of the areas formed above the line is equal to the sum of the areas formed below the line. The surface roughness *Ra* is now given by the sum of the absolute values of all the areas above and below the mean line divided by the sampling length. Therefore, the surface roughness value *Ra* is given by Fig. 7.1.



$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i| = \frac{|y_1|+|y_2|+|y_3|+\dots+|y_n|}{n} \qquad R_a = \frac{1}{l}\int_0^l |y(x)|dx$$

***Fig. 7.1** Surface roughness value Ra and elements of surface roughness [23]*

There are several ways to measure surface roughness. The main types of measurement techniques are direct measurement, comparison measurement, non-contact measurement, and in-process measurement.

Surface roughness terminology

Ra - The numerical average of all the peaks and valleys across the length of the test.

Rz - The average of consecutive highest peaks and lowest valleys. Distance between the highest peak and lowest valley, the distance of the second highest peak and the second-lowest valley, etc. This is usually done for the five biggest deviations, and then an average is calculated.

Rp - The calculated distance between the profile's tallest peak and the mean line within the evaluation length.

Rv - The calculated distance between the profile's lowest valley and the mean line within the evaluation length.

Rmax - The biggest successive deviation between the highest peak and the lowest valley, calculated within the evaluation length.

RMS - Calculated within the evaluation length, this is the root mean square average of profile height variation from the mean line.

Direct Measurement Methods

Direct methods assess surface finish by means of stylus type devices. Measurements are obtained using a stylus drawn along the surface to be measured: the stylus motion perpendicular to the surface is registered. This registered profile is then used to calculate the roughness parameters. This method requires interruption of the machine process, and the sharp diamond stylus may make micro-scratches on surfaces.

Comparison Based Techniques

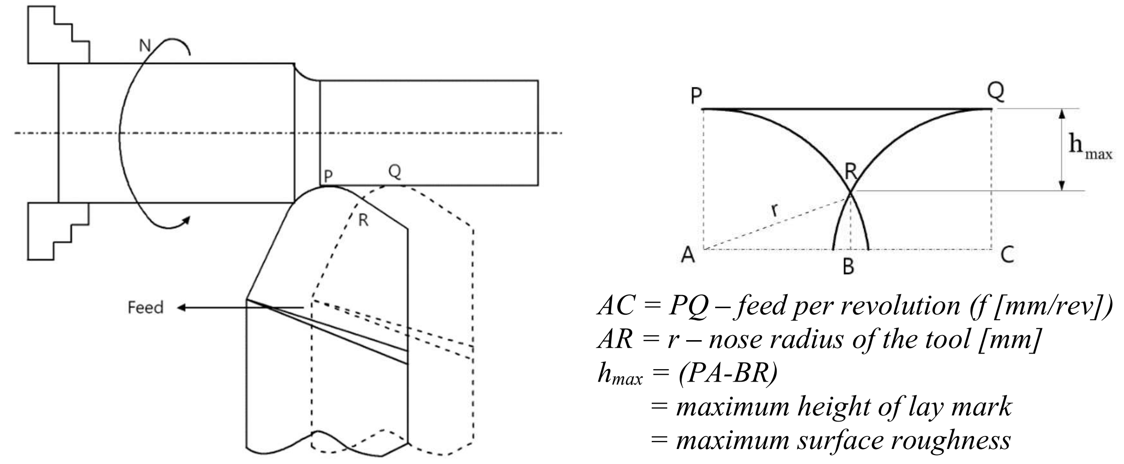
Comparison techniques use specimens of surface roughness produced by the same process, material and machining parameters as the surface to be compared. Visual and tactile senses are used to compare a specimen with a surface of known surface finish. Because of the subjective judgment involved, this method is useful for surface roughness Rq>1.6 micron.

Non-Contact Methods

There has been some work done to attempt to measure surface roughness using non-contact technique. Here is an electronic speckle correlation method given as an example.

When coherent light illuminates a rough surface, the diffracted waves from each point of the surface mutually interfere to form a pattern which appears as a grain pattern of bright and dark regions. The spatial statistical properties of this speckle image can be related to the surface characteristics. The degree of correlation of two speckle patterns produced from the same surface by two different illumination beams can be used as a roughness parameter.

A magnified view of the area PQR is depicted below. Note that nose radius (or QC or AP) does not necessarily equal to depth of cut (a_p); in fact, a_p is usually larger than AP (to avoid high chip deviation from orthogonal plane via restricted cutting effect). In practice, surface roughness parameter (h_{max}) is very small as compared to feed rate or nose radius of the tool. The following passages elaborate steps to determine h_{max} (Fig. 7.2).



AC = PQ – feed per revolution (f [mm/rev])
AR = r – nose radius of the tool [mm]
h_{max} *= (PA-BR)*
= maximum height of lay mark
= maximum surface roughness

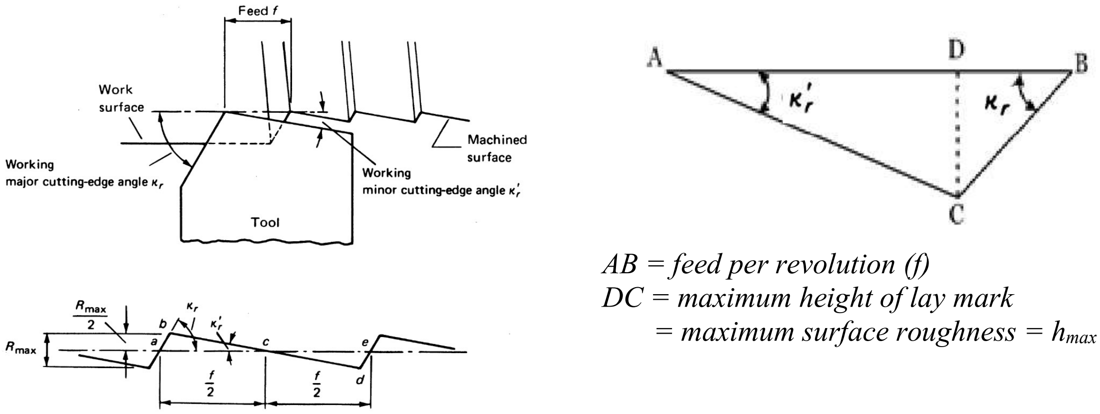
Fig. 7.2 *Estimation of surface roughness in turning using a rounded tool [11]*

We can calculate the maximum surface roughness:

$$h_{max} = \frac{f^2}{8 * r_\varepsilon}$$

Fig. 7.3 *Influence of nose radius on surface roughness*

The cylindrical workpiece is mounted in a three-jaw chuck, and it is rotated at a constant speed of *N* rpm (revolution per minute). A sharp single point right-handed cutting tool is used to remove excess layer of material. The tool has principal cutting edge angle (PCEA) of *æ* and auxiliary cutting-edge angle *æ*$_1$. Positions of the tool in two successive rotations are portrayed in the Fig. 7.4. So, the distance AB is equal to feed rate per revolution (*f*) [13].



AB = feed per revolution (f)
DC = maximum height of lay mark
= maximum surface roughness = h_{max}

Fig. 7.4 *Influence of principal cutting edge angle and auxiliary cutting edge angle on surface roughness*

So let us magnify the triangle ABC and redraw it as shown below. Mention the angles carefully. Angle A is equal to auxiliary cutting-edge angle ($æ_1$) while angle B is equal to principal cutting-edge angle ($æ$) of the cutting tool. So, DC is the maximum height of the lay marks, which is required to determine. It is quite simple, just consider two triangles (ADC and BDC) separately and apply trigonometric formula to incorporate feed rate.

$$h_{\max} = \frac{f}{cotgæ + cotgæ_1}$$

Generally, surface finish of any product depends on the following factors:

- Cutting speed.
- Feed.
- Depth of cut.

Cutting speed
Better surface finish can be obtained at higher cutting speeds. Rough cutting takes place at lower cutting speeds.

Feed
Surface finish will not be good when coarse feed is applied. But better finish can be obtained in fine feeds.
Turning operations are usually divided into coarse and fine turning, where the purpose of coarse turning is maximum cutting speed, while the fine turning performs the final machining to achieve the desired surface finish and dimensional tolerance.
In optimum conditions, the original dimension of the workpiece is so close to the final shape, also called near-net shape, that only fine turning is required to complete the detail.

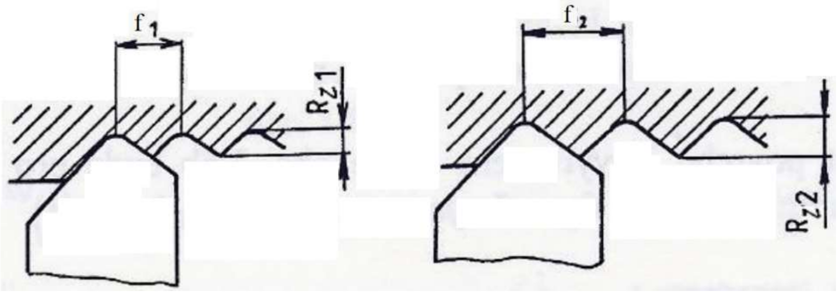


***Fig. 7.5** Effect of feed on surface roughness during turning*

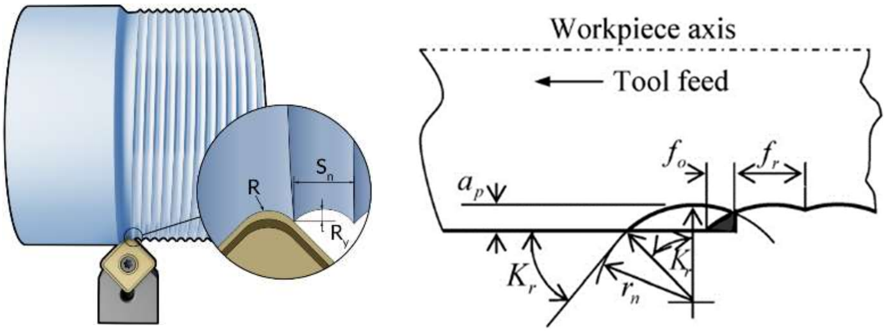


***Fig. 7.6** Influence of the nose radius on surface roughness [12]*

From the tool's nose radius and feed speed, theoretical surface roughness can be exactly calculated (Fig. 7.6).
However, vibrations in the tool or machine, tool wear, *built-up edges (BUE)* and chip types can affect the final surface finish.

Depth of cut
Lighter cuts provide good surface finish to the work piece. If depth of cut increases during machining, the quality of surface finish will reduce.
Therefore, higher cutting speeds, fine feeds and low depth of cuts or applied to ensure good surface finish. Usually, it is done in finishing cuts. But lower cutting speeds, coarse feeds and heavier depth of cuts are applied in rough cutting operations.

We will present typical courses of experimentally obtained dependences of surface roughness on parameters of the machining process and compare them with theoretical roughness (thin line in Fig. 7.7). To determine the probable roughness of the surface, a sufficient number of experiments must be carried out, especially if there is a built-up edge or the material is not homogeneous enough.

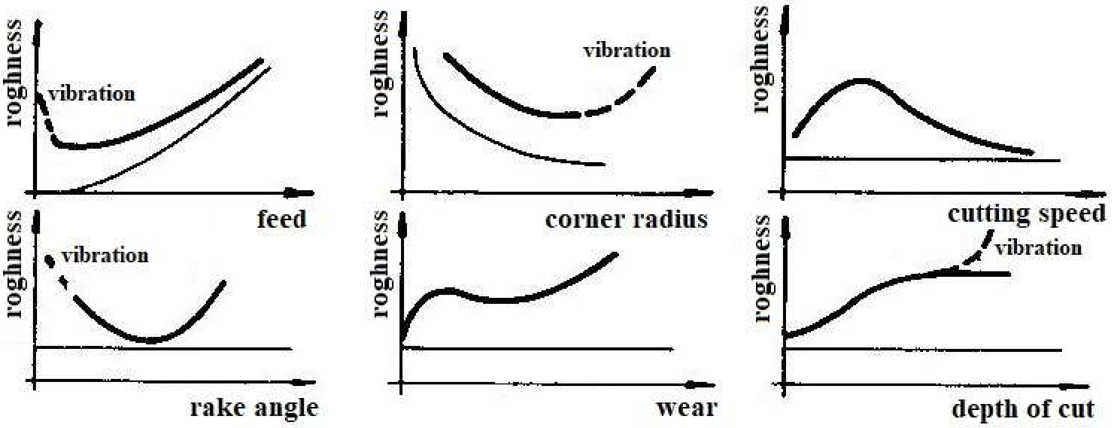


Fig. *7.7 Dependence of surface roughness on selected machining process parameters*

Exercise 1:
Experimental verification of the dependence f –Ra and r_ε – Ra

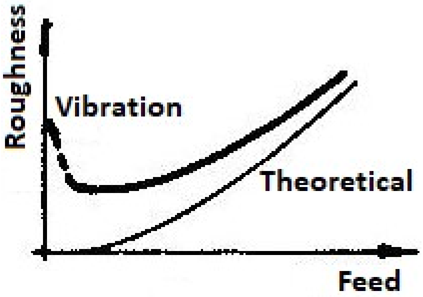
Production technologies II	Title of exercise: **Experimental verification of *the* dependence *f- Ra and* r_ε *- Ra***	
Name:	Study group:	Note:

Dependence f -Ra

For a given turning tool, experimentally verify the dependence of the roughness of the surface of the machined area on the selected feed *f*.

Description of the experiment:

Presumed theoretical dependence:



Cutting tool
Characteristics: **Material of the cutting part of the tool:**

Constant parameters of the experiment:

workpiece material	**workpiece diameter *d*** [mm]
rpm *n* [1/min]	**cutting speed *in*** [m/min]
depth of cut a_p [mm]	

Measured values:

feed *f* [mm/rpm]			
roughness R_a [µm]			

Graphical representation of the measured dependence:

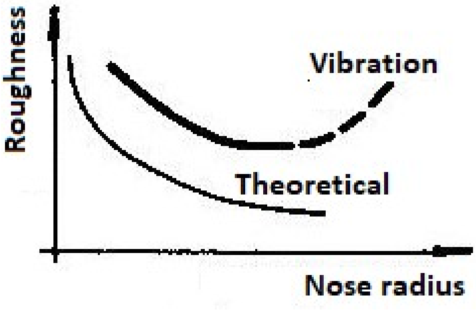
Evaluation of measurement results:

Dependence r_ε - R_a

For given turning tool, experimentally verify the dependence of the roughness of the surface of the machined area with the radius of the tool tip.

Description of the experiment:

Presumed theoretical dependence:



Tool
Characteristics: **Material of the cutting part of the tool:**

Constant parameters of the experiment:

workpiece material	**workpiece diameter *d*** [mm]
rpm *n* [1/min]	**cutting speed *in*** [m/min]
depth of cut a_p [mm]	**feed *f*** [mm/rpm]

Measured values:

Tool r_ε [m m]			
roughness R_a [µm]			

Graphical representation of the measured dependence:

Evaluation of measurement results:

8. Drilling, Reaming

The drilling processes.

Drilling is a term that covers all methods of making cylindrical holes in a workpiece with chip cutting tools (Fig. 8.1). Usually also covers subsequent machining such as broaching, reaming, counter-boring and various forms of finishing such as skiving and roller burnishing.
Common to all these processes is a *rotating main movement* combined with a *linear feed movement*. The cutting tool, the workpiece, or both may rotate, with the tool generally being fed (Fig. 8.2). Several different methods of drilling exist, including conventional, deep-hole, and a small hole drilling.

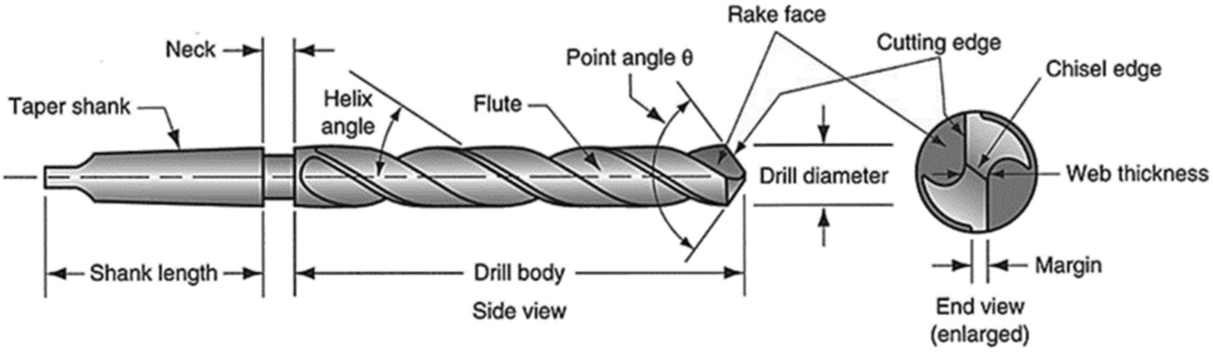


***Fig. 8.1** Detailed geometry of the twist drill [25]*

Irrespective of whether a solid drill or a drill with replaceable indexable inserts is used, the basic definitions for the drill's working conditions are the same.

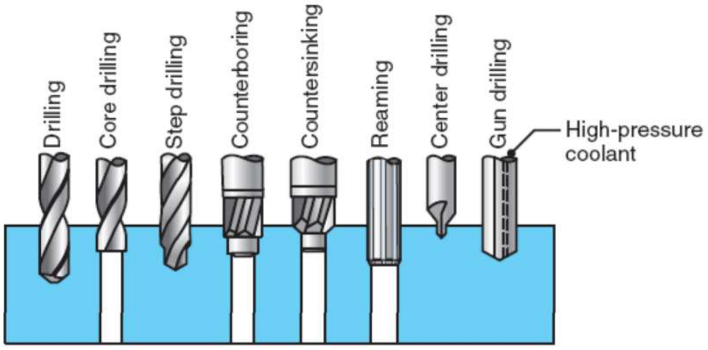


***Fig. 8.2** Other types of drills*

In drilling, the main movement is rotation, which can be done by either tool or workpiece. The spindle speed is expressed in the number of revolutions per minute. The cutting speed (v_c - in m/min) is determined for drilling by the periphery speed and can be simply calculated when the number of revolutions per minute is known from the spindle speed. During one revolution the periphery of the drill will describe a circle with a circumference of $n * D$, where *D* is equal to the tool diameter. If the diameter is expressed in mm, the result must be divided by 1000 to obtain the cutting speed in meters per minute.

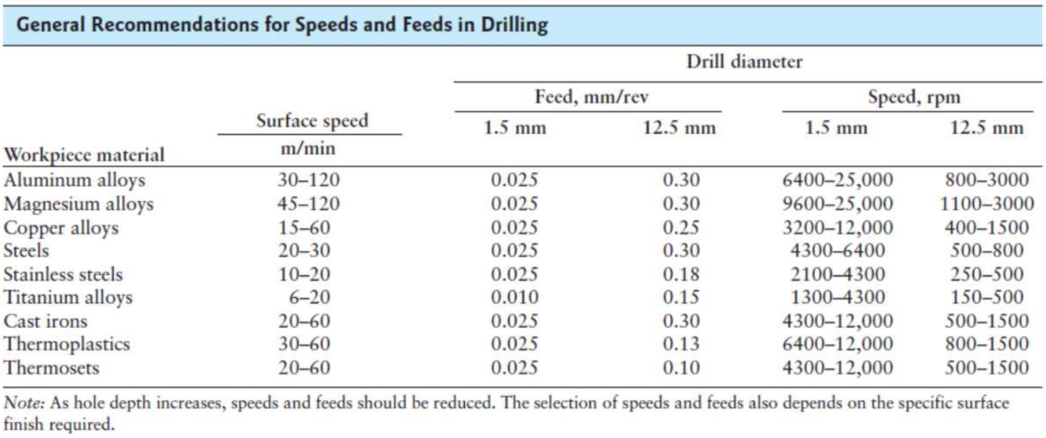
$$v_c = \frac{\pi * D * n}{1000} \quad \text{[m/min]} \qquad v_f = f * n \quad \text{[mm/min]}$$

The feed speed or penetration rate (v_f *- in mm/min*) is the feed of the tool in relation to the workpiece or, alternatively, the feed of the workpiece in relation to the tool, expressed in length per unit of time. Feed per revolution (f - *in mm/rev*) expresses the movement of the tool or workpiece during one revolution and is used to calculate feed.

The cutting width or radial cutting depth (a_p - *in mm*) is that part of the workpiece surface which the tool covers and is measured $a_p = (D - d) / 2$ *[mm]*.

Since the drilling tool is equipped with several cutting edges (z-number of edges), the feed per edge (f_z - *in mm/edge*) is used to define the chip area of the material removed in one cut, i.e. the radial cutting depth times the feed per edge.

The working conditions of the cutting wedge are like turning. While drilling is fast and economical, its cutting action is difficult and inefficient. Cutting speed varies from a maximum at the periphery of the tool to zero at the center of the tool, thus varying the load on the cutting edges. Both chip ejection and flow of the cutting fluid are restricted in drilling.



General Recommendations for Speeds and Feeds in Drilling

Workpiece material	Surface speed m/min	Drill diameter Feed, mm/rev 1.5 mm	Feed, mm/rev 12.5 mm	Speed, rpm 1.5 mm	Speed, rpm 12.5 mm
Aluminum alloys	30–120	0.025	0.30	6400–25,000	800–3000
Magnesium alloys	45–120	0.025	0.30	9600–25,000	1100–3000
Copper alloys	15–60	0.025	0.25	3200–12,000	400–1500
Steels	20–30	0.025	0.30	4300–6400	500–800
Stainless steels	10–20	0.025	0.18	2100–4300	250–500
Titanium alloys	6–20	0.010	0.15	1300–4300	150–500
Cast irons	20–60	0.025	0.30	4300–12,000	500–1500
Thermoplastics	30–60	0.025	0.13	6400–12,000	800–1500
Thermosets	20–60	0.025	0.10	4300–12,000	500–1500

Note: As hole depth increases, speeds and feeds should be reduced. The selection of speeds and feeds also depends on the specific surface finish required.

Fig. 8.3 *Working conditions for the drilling*

Twist (helix) drill

The rake angle γ, which is the angle between the chip surface (rake surface) and a line at right angles to the direction of cutting will, however, be changed on engagement (Fig. 8.4). When machining is in process the insert edge moves along a spiral path which inclines the effective rake angle on engagement γ_{ef} will increase.

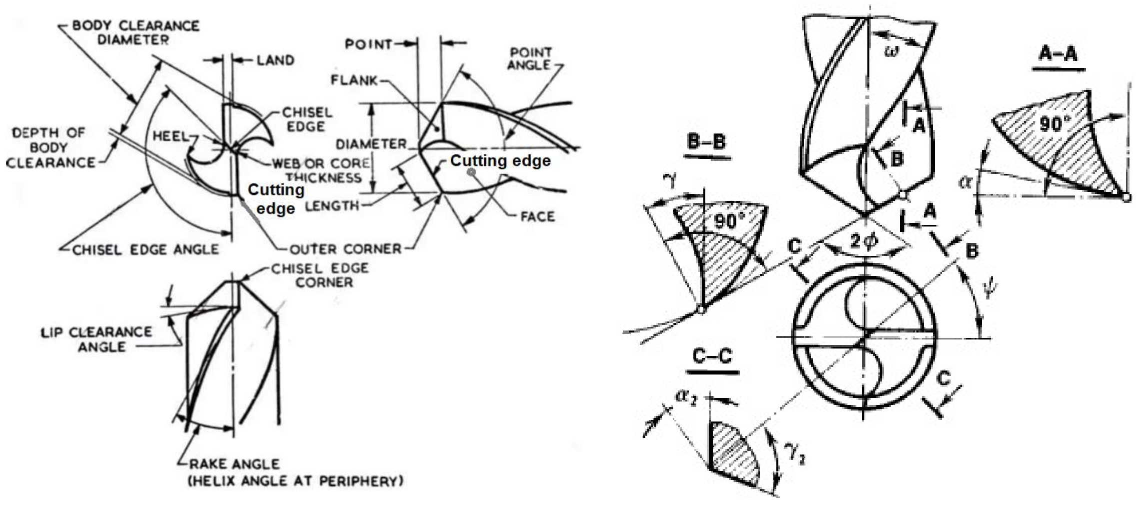


Fig. 8.4 *Angles for twist drills used in metal cutting*

The most employed drilling tool is the twist drill, which is available in diameters ranging from 0.25 to 80 mm. A standard twist drill (Fig. 8.5) [14] is characterized by a geometry in which the normal rake and the velocity of the cutting edge are a function of their distance from the center of the drill. Referring to the terminology of twist drill shown in Fig. 8.5, the helix angle of the twist drill is the equivalent of the rake angle of other cutting tools. The standard helix is 30°, which, together with a point angle of 118°, is suitable for drilling steel and cast iron (Fig. 8.5 a). Drills with a helix angle of 20°, known as slow-helix drills, are available with a point of 118° for cutting brass and bronze (Fig. 8.5 b), and with a point of 90° for cutting plastics. Quick helix drills, with a helix angle of 40° and a point of 100°, are suitable for drilling softer materials such as aluminum alloys and copper (Fig. 8.5 c). Figure visualizes the basic machining parameters in drilling and enlarging holes.

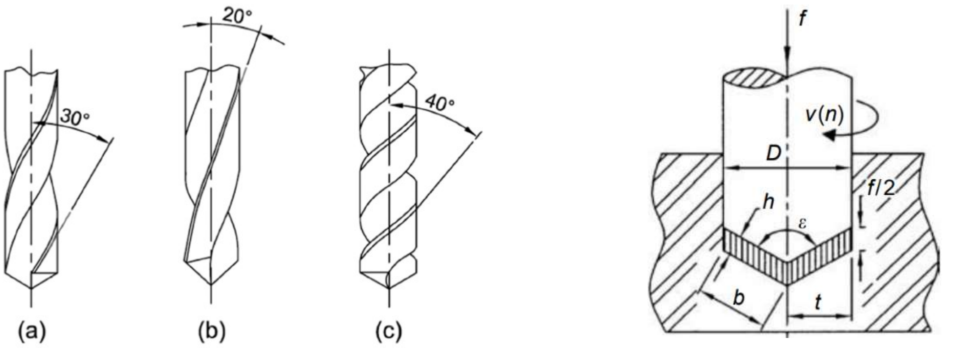


Fig. 8.5 *Helix drills of different helix angles: (a) standard, (b) slow, (c) quick and basic machining parameters in drilling [14]*

If high accuracy and high-quality finish are required, drilling must be followed by some other operations such as reaming, boring, or internal grinding (Fig. 8.6).

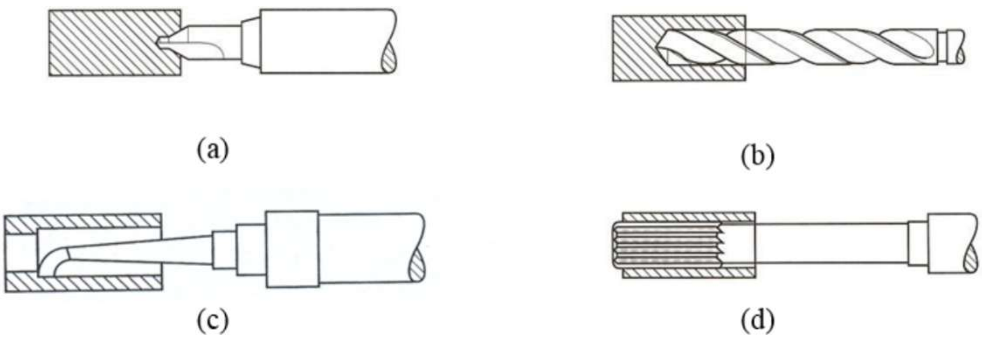


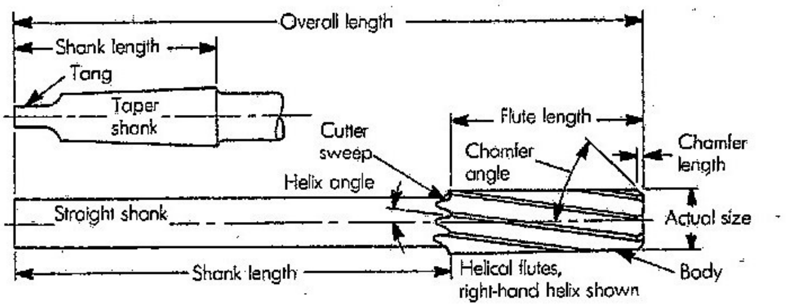
Fig. 8.6 *Sequence of operation required to obtain an accurate size hole: (a) centering and countersinking, (b) drilling, (c) boring, and (d) reaming.*

Reaming

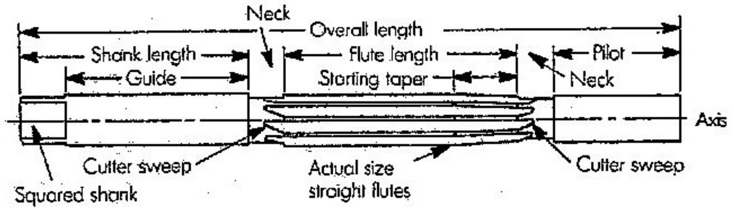
Reaming is a machining process for enlarging, smoothing, and/or accurately sizing existing holes by means of multiedge fluted cutting tools - reamers. As the reamer and/or workpiece are rotated and advanced relative to each other, chips are produced to remove relatively small amounts of material from the hole wall. Reaming may be performed on the same type of machines used for drilling.

Since stock removal is small and must be uniform in reaming, the starting holes (drilled or otherwise produced) must have relatively good roundness, straightness, and finish. Reamers tend to follow the existing centerline of the hole being reamed.

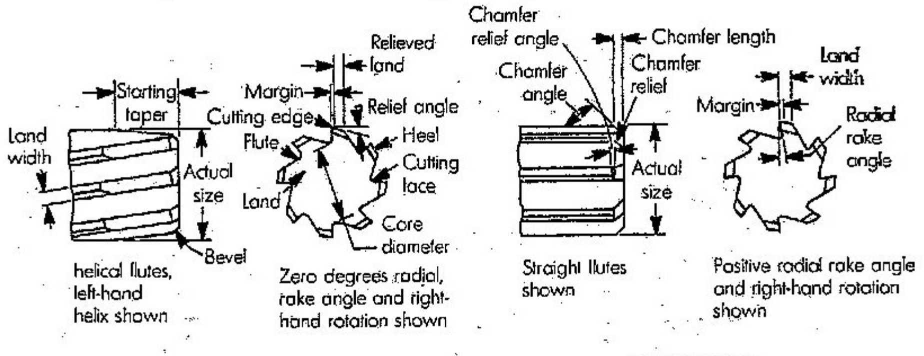
A reamer is a rotary cutting tool, generally of cylindrical or conical shape, intended for enlarging and finishing holes to accurate dimensions. It is usually equipped with two or more peripheral channels or flutes, either parallel to its axis or in a right or left-hand helix as required. Terms applying at reamers are in Fig. 8.7.



Chucking reamer, straight and taper shank



Hand reamer, pilot and guide



Hand reamer Machine reamer

Fig. 8.7 *Terms and parameters applying to reamers [4]*

Coolant-fed twist drills having means for directing coolant (fluid, gas or mist)) to the cutting edges offer many advantages for certain drilling application.

Flat, half round and straight-fluted drills have definite advantages for certain applications (Fig. 8.8).

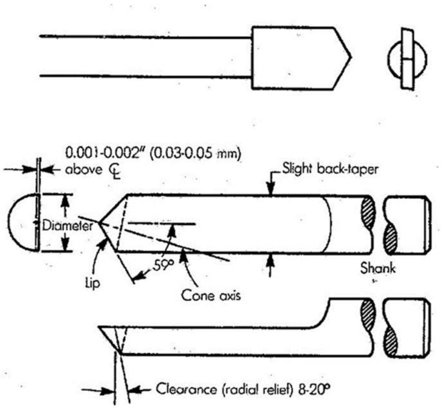


Fig. 8.8 Flat drill used to produce holes in hardened steel, glass, and tile and half-round drill

Drilling machines

Drilling machines (Fig. 8.9) are used for drilling holes, tapping (screw cutting), reaming and small-diameter boring operations.

The types of drilling machines range from simple bench type drills to large radial drills.

- The drill head of universal drilling machines can be swiveled to drill holes at an angle.
- Numerically controlled three-axis drilling machines are automating in the desired sequence using turret.
- Drilling machines with multiple spindles (gang drilling) are used for high-production-rate operations.

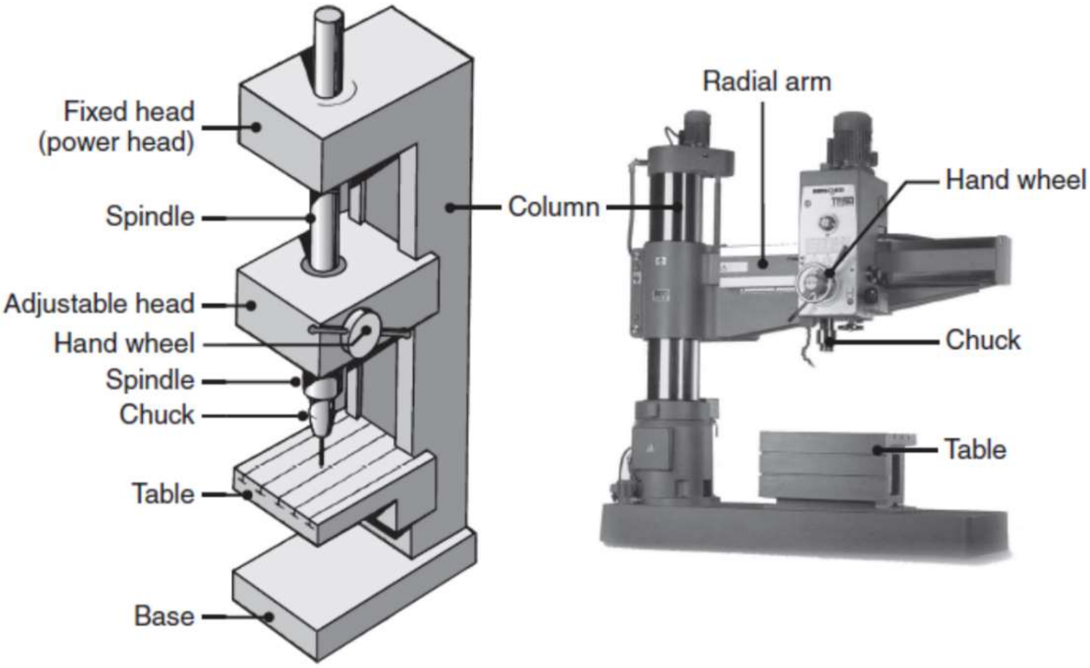


Fig. 8.9 *The main structural parts of machine tools for drilling*

Exercise 2:
Creating of a precise short hole

Production technologies II	Title of exercise: **Creating of a precise short hole**	
Name:	Study group:	Note:

Design a process for producing a through-hole precision short hole Ø16 H8 of length 20 mm in 12060 steel on a VR4 radial drilling machine tool. At the end of the operation, check the hole made with a caliber.

The production process will consist of the production

- of a centering hole with a centering drill Ø4 mm,
- pre-drilling with a drill with a diameter of Ø8 mm,
- drilling with a screw drill Ø15mm,
- roughing with a shell drill with 4 cutting edges Ø15,8 mm,
- reaming with a reamer with 8 cutting edges and checking with a caliper.

The tools will be made of high-speed steel. For each section, design a tool, theoretical cutting conditions.

Section number	Description of the section of the operation	Cutting tool	Cutting conditions - theory				Cutting conditions – in praxis			
			v_c	n	f	f_{teeth}	v_c	n	f	f_{teeth}
1	centering	Drill 4	20	1592	0,06	0,03				
2	drilling	Drill 9	20	708	0,12	0,06				
3	drilling	Drill 15	20	424	0,18	0,09				
4	Shell drilling	Shell drill 15,8	20	403	0,18	0,045				
5	reaming	Reamer 16	8	160	0,53	0,066				
6	checking	caliber	Caliber 16 H8							

Evaluation of the results:

9. Cutting Forces

The cutting force in turning refers to the main cutting force F_c which is tangential and often the largest force (except hard turning). As displayed in Fig. 9.1 below, in turning, F_c is the main cutting force acting tangentially to the rotational direction. While F_c, the feed force F_f and the passive force F_p can be measured directly during turning, the active Force F_a and the resultant force R are calculated. The active force is the vectorial sum of the main cutting force F_c and feed force F_f. It is sometimes used to compare different process settings. The resultant force is the vectorial sum of the main cutting force F_c, feed force F_f, and the passive force F_p and applied to compare different process settings as well.

A knowledge of the cutting forces is useful for a variety reasons:

- knowledge of the power requirements.
- forces acting on a cutting tool.
- design and selection of machine tools.

The strength and rigidity of machine tool structures and the size of motors can be computed once the power forces are known. Furthermore, the analysis of the scientific principles of metal cutting requires knowledge of the forces that exist during cutting. Figure shows components of the resultant cutting force acting to the workpiece [1].

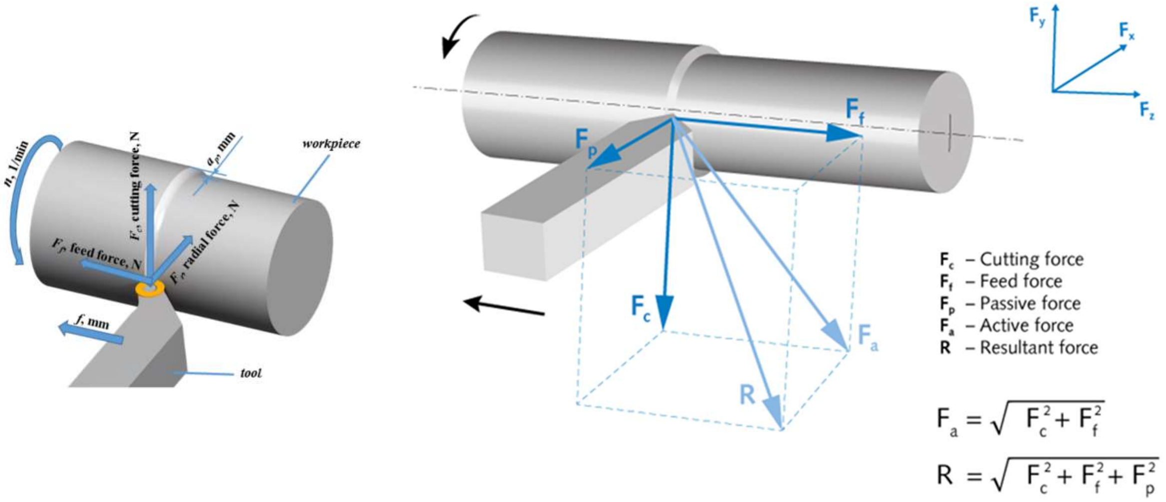


***Fig. 9.1** Components of the resultant cutting force F*

Measuring the cutting forces in turning processes pays off in a variety of applications, e.g.:

- Investigation of plastic-mechanical behavior in the actual cutting process
- Analysis of chip formation and its impact on the process
- Identification of wear processes with force progressions
- Understanding material behaviors and thus compare machinability
- Identification of machine/process abnormalities
- Understanding and optimization of machine and process parameters such as chucking, coolants, machine tool stiffness

Calculation of the cutting forces at turning:

Specific Cutting Pressure

Specific power consumptions are expressed as a ratio of a force to an area which is dimensionally (although not physically) a stress; thus, this quantity is also commonly referred to as the *specific cutting pressure* k_s *[N/mm^2, or MPa]:*

$$k_s = \frac{F_c}{S}$$

where F_c *[N]* is the cutting force
$S = f * a_p$ *[mm^2]* - cross section of the chip
f – feed, a_p – depth of cut

Specific cutting pressure is a cutting force per mm cross - section of the cut Fig. 9.2. The value of the specific cutting force depends on the feed, the method of machining, the material of the workpiece and the geometry of the cutting tool.

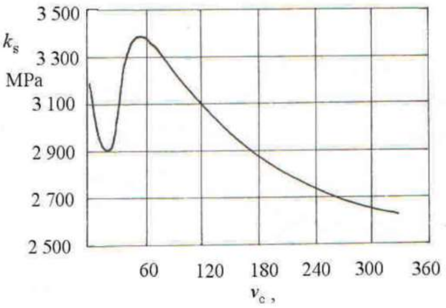


Fig. 9.2 *The size of the specific cutting pressure depending on the cutting speed for steel of medium strength [15]*

The cutting forces of some machining methods are shown in Fig. 9.3.

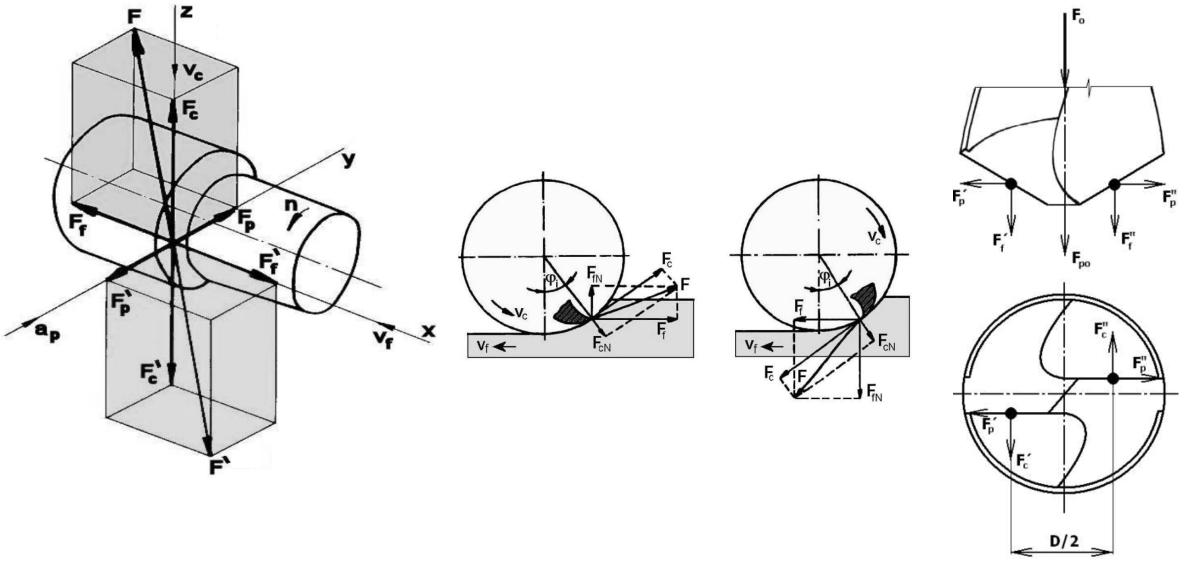


Fig.9.3 *Cutting forces for turning, milling and drilling*

Cutting forces can be measured using dynamometers. They are often designed for different machining methods. The case of turning can be seen in Fig. 9.4.

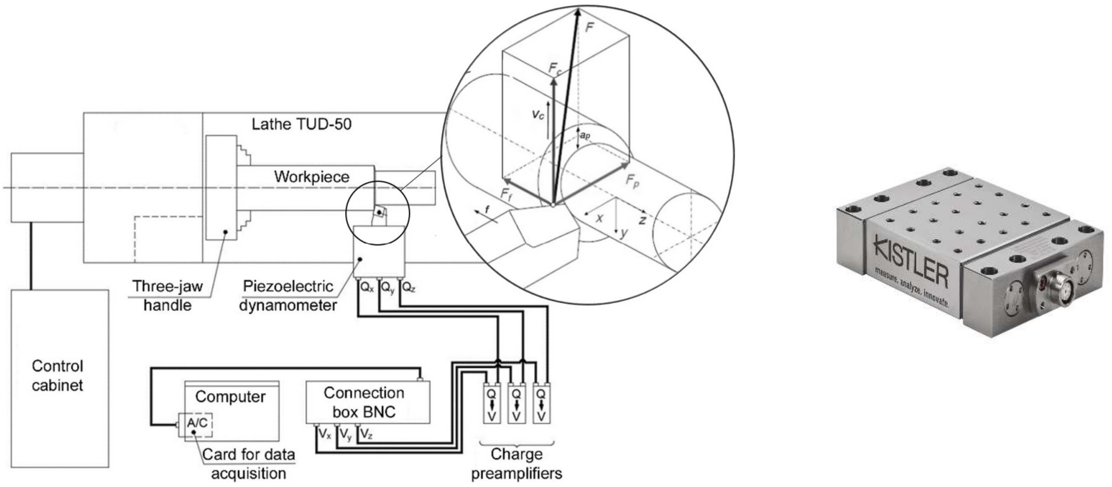


Fig. 9.4 *Principle of the measuring of cutting forces for turning with dynamometer and dynamometer*

Specific cutting pressure is therefore the main cutting force per 1 mm^2 cross section of the cut. The parameters from the table in Fig. 9.5 can be used to calculate the cutting forces.

Material of the workpiece	**f = 0,1 mm/rev**	**f = 0,2 mm/rev**	**f = 0,3 mm/rev**	**f = 0,4 mm/rev**
steel Rm = 500 – 800 MPa	4 000	2900	1 800	1 520
600 - 700	4 200	3 000	2 200	1 560
700 – 850	4 400	3 150	2 300	1 640
850 - 1000	4 600	3 300	2 400	1 720

Fig. 9.5 *Parameters of the specific cutting pressure*

A variety of trends have been observed and may be generalized as follows:
1. In single point turning of steel or cast iron with high-speed tools and usual rake angles, cutting speed has little effect on cutting forces.
2. When employing carbide tools with usual rake angles in single point turning steel and other metals producing a continuous chip (in the range of 60-180 m/min) an increase in speed maintain unpronounced decrease in strength of work (temperature raised) and a corresponding decrease in cutting forces (Fig 9.6).

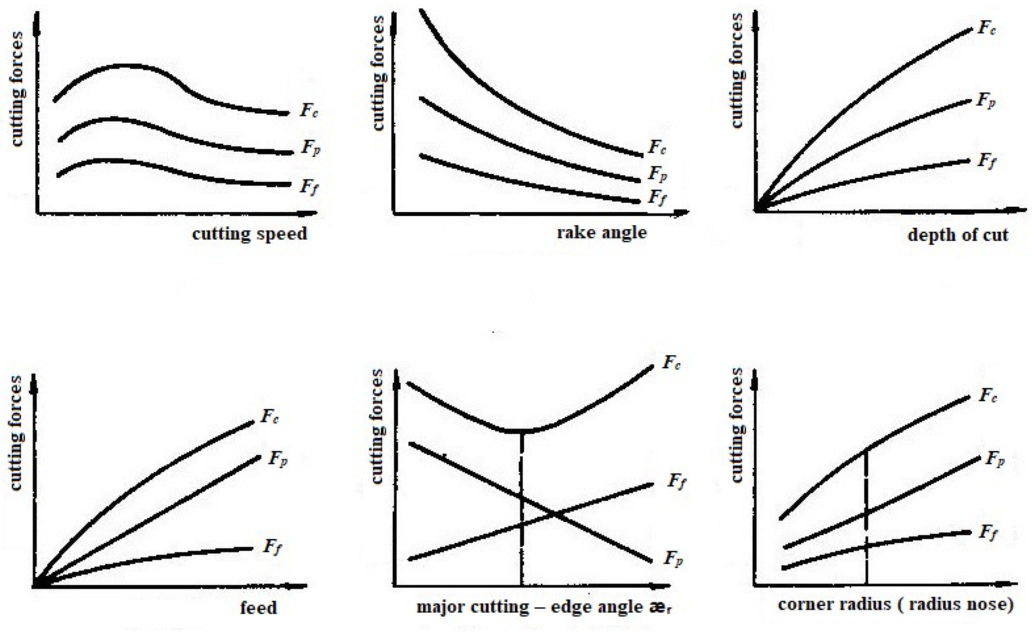


Fig. 9.6 *The effect of cutting conditions on the size of the cutting forces [17]*

$$F_c = C_{Fc} . a_p^{x_{Fc}} . f^{y_{Fc}} . k_{Fc}$$
$$F_p = C_{Fp} . a_p^{x_{Fp}} . f^{y_{Fp}} . k_{Fp}$$
$$F_f = C_{Ff} . a_p^{x_{Ff}} . f^{y_{Ff}} . k_{Ff}$$

Fig. 9.7 *The influence of cutting parameters on the size of cutting forces [17]*

Cutting forces can also be calculated using statistical equations:

Values of coefficients and exponents for carbon steel:
$C_{Fc} = 1800 – 2000$
$x_{Fc} = 1$
$y_{Fc} = 0,75$

The ratio of the individual components of the cutting forces is usually:

$$F_c : F_p : F_f = 1 : 0,4 : 0,25$$

Exercise 5:
Experimental – measuring cutting forces

Production technologies II	Title of exercise: **Measuring cutting forces**	
Name:	Study group:	Note:

Description of the experiment:

Presumed theoretical dependence:

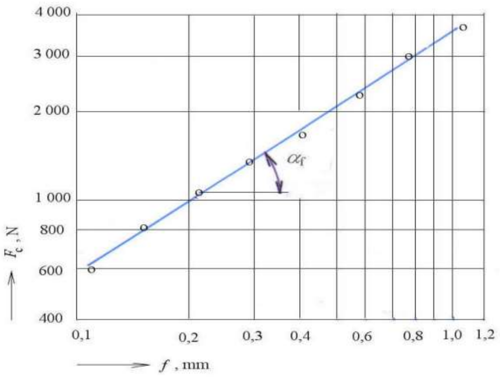


Fig. 9.8 *Dependence of the tangential force F_c on the feed.*
Cutting tool: P10, material of the workpiece: C45, $\gamma_o = 10^0$, $\text{æ}_r = 60^0$; $r_\varepsilon = 0,5$ mm; $a_p = 2$ mm

Parameters of the experiment:

Cutting tool: tool for turning - right
Material of the cutting part of the tool: cemented carbide

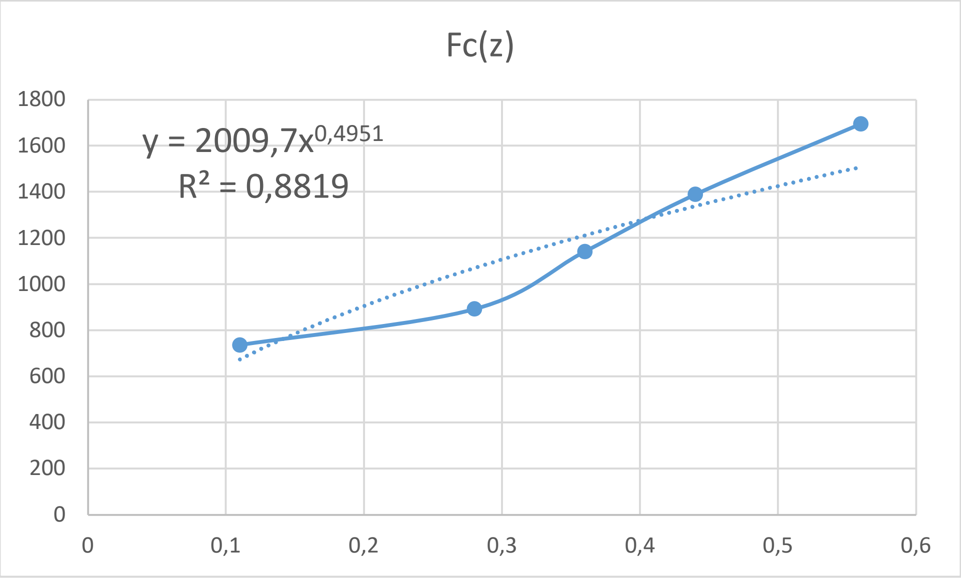
Constant parameters of the experiment:

workpiece material C45	**workpiece diameter d [mm] 72 mm**
rpm n [1/min] 250	**cutting speed *in* [m/min] 56,52 m/min**
depth of cut a_p [mm] 1 mm	

Measured values:

feed *f* [mm/rpm]	0,11	0,28	0,36	0,44	0,56
$F_{c(z)}$	736	892	1141	1389	1695
$F_{f(x)}$	358	449	437	755	855
$F_{p(y)}$	264	308	363	615	711

Graphical representation of the measured dependence:



Evaluation of measurement results:

10. Temperatures by Machining

Whenever plastic energy involved, the energy dissipated in cutting is converted into heat, which, in turn, raises the temperature in the cutting zone.

Temperature rise is a very important factor in machining because of its major adverse effects such as:

- Excessive temperature lowers the strength, hardness, stiffness, and wears resistance of the cutting tool. Tools also may soften and undergo plastic deformation; thus tool shape is altered.
- Increased heat causes uneven dimensional changes in part being machined; so hard to control dimensional accuracy and tolerance.
- Excessive temperature rise can induce thermal damage and metallurgical changes in the machined surface, adversely affecting its properties.

The main sources of heat in machining are

- the work done in shearing in the primary shear zone,
- energy dissipated as friction at the tool-chip interface, and
- heat generated as the tool rubs against the machine surface, especially for dull or worn tools.

Efforts have been expended to establish relationships among temperature and various material and process variables in cutting.

Temperature Distribution

Because the sources of heat generation in machining are concentrated in the primary shear zone and the tool-chip interface, it is to be expected that there will be severe temperature gradients in the cutting zone.

- A typical temperature distribution is shown in Fig. 10.1., Fig. 10.2. and Fig. 10.3.
- The maximum temperature is about halfway up the tool-chip interface.

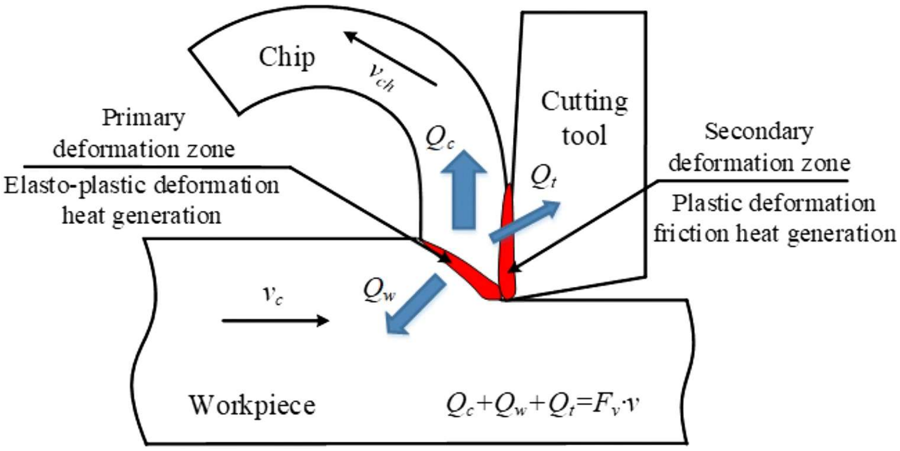


***Fig. 10.1** Sources of heat generation in the orthogonal cutting process [26]*

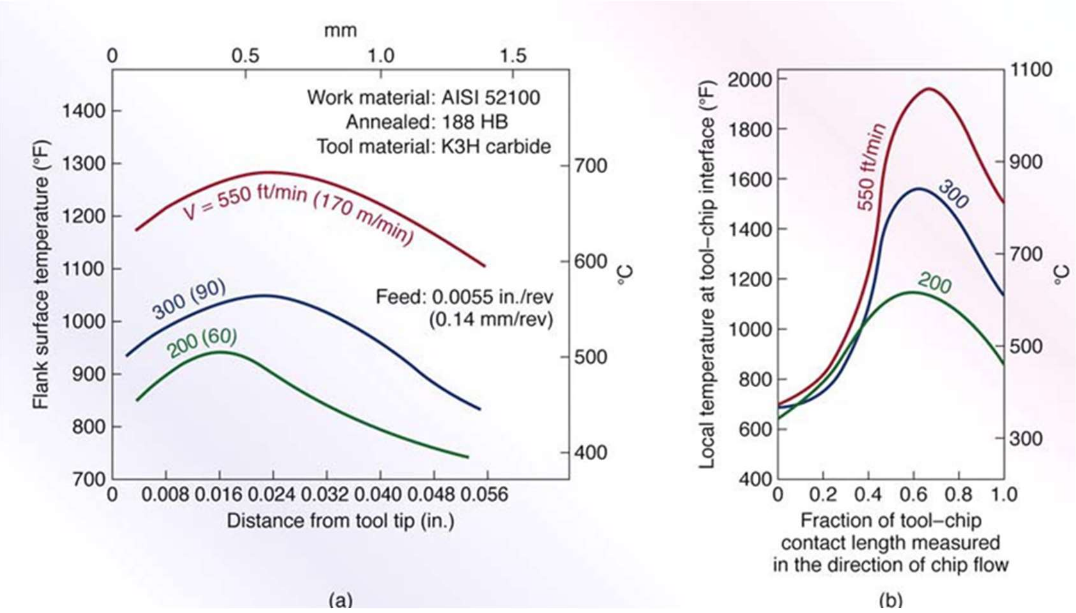


Fig. 10.2 *Temperatures developed in turning 52100 steel: (a) flank temperature distribution and (b) tool-ship interface temperature distribution. Source: After B.T.Chao and K.J.Trigger [27]*

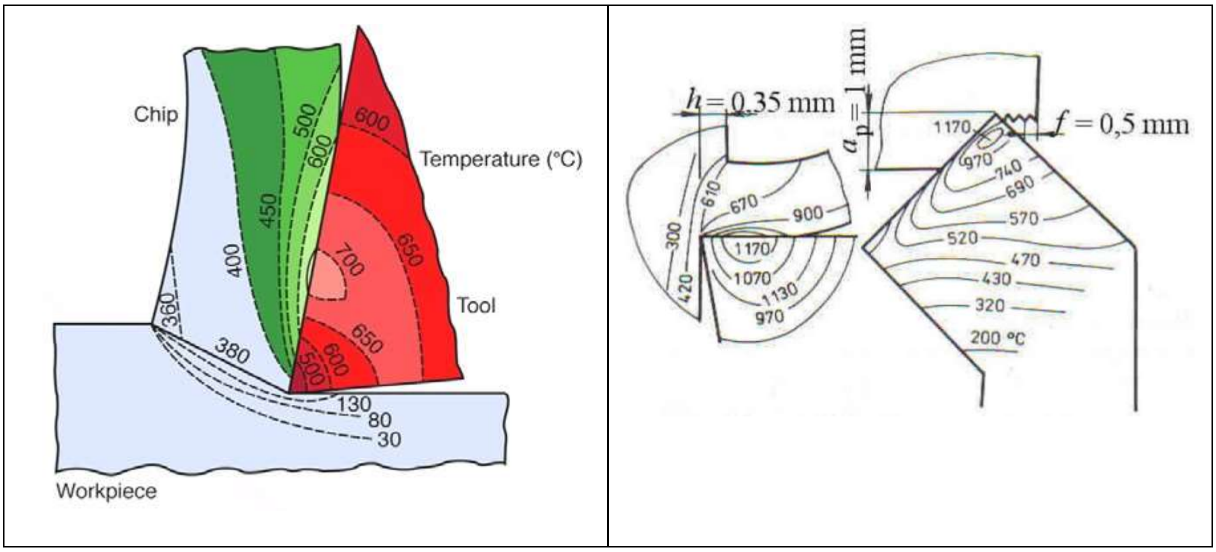


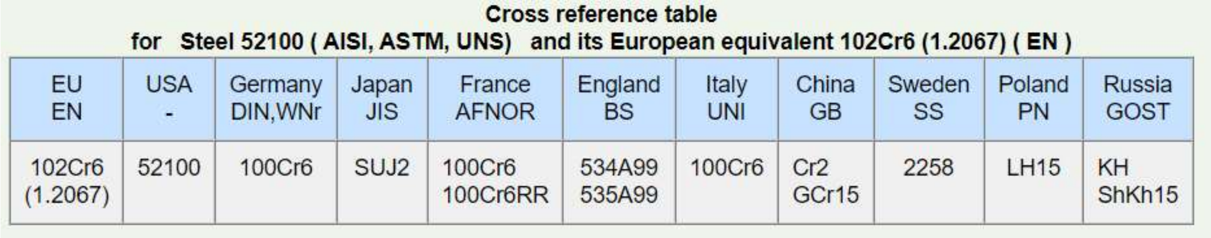
Fig. 10.3 *Typical temperature distribution in the cutting zone. Note the severe temperature gradients within the tool and the chip, and that the workpiece is relatively cool [28]*

The temperatures developed in a turning operation on 52100 (Fig. 10.4 – see the table down) steel are shown in Fig. 10.2.

- Note that the temperature increases with cutting speed and that the highest temperature is almost 1 100ºC (2 000ºF).
- The presence of such high temperatures in machining can be verified by simply observing the dark-bluish color of the chips (caused by oxidation) produced at high cutting speeds. Chips can become red hot and create a safety hazard for the operator.

- As speed increases, the time for heat dissipation decreases and hence temperature rises (eventually becoming an almost adiabatic process). Try rubbing your hands together faster and faster.
- The chip carries away most of the heat generated. It has been estimated that 90% of the energy is dissipated in the chip during a typical machining operation, with rest in the tool and the workpiece.

52 100 – STN 14 109 - Chrome steel for roller bearings (STN - Slovak norm)



Cross reference table
for Steel 52100 (AISI, ASTM, UNS) and its European equivalent 102Cr6 (1.2067) (EN)

EU EN	USA -	Germany DIN,WNr	Japan JIS	France AFNOR	England BS	Italy UNI	China GB	Sweden SS	Poland PN	Russia GOST
102Cr6 (1.2067)	52100	100Cr6	SUJ2	100Cr6 100Cr6RR	534A99 535A99	100Cr6	Cr2 GCr15	2258	LH15	KH ShKh15

Fig. 10.4 *Conversion table of designation of steels*

Next Fig. 10.5 shows proportion of the heat generated in cutting transferred into the tool, workpiece, and chip as a function of the cutting speed. Note that the chip removes most of the heat.

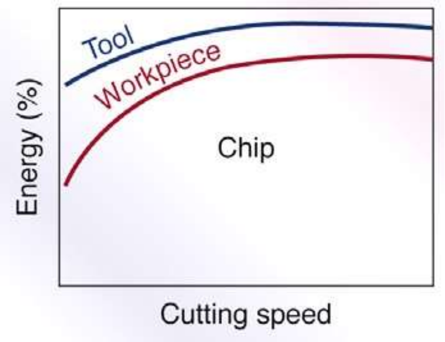


Fig. 10.5 *Heat removal from the cutting area*

Techniques for measuring temperature:

- Thermocouples embedded in ***the tool*** and/or ***the workpiece*** are may be used to determine the temperatures and their distribution in the cutting zone.
- Infrared radiation from \the cutting zone may be monitored with a radiation pyrometer. This technique indicates the only surface temperatures.

Measuring temperatures with thermocouples.

It is based on the use of the thermoelectric phenomenon:

When the connection of two conductors is heated, voltage is generated at the free ends of the conductor. The temperature can be determined at the point of contact of two metals with the help of a temperature diagram (Fig. 10.6).

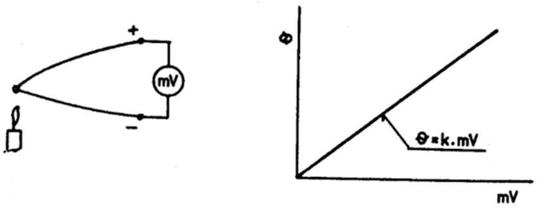


Fig. 10.6 *Principle of the measuring with the thermocouples*

Natural thermocouple method

A natural thermocouple is created by the material of the cutting tool and the workpiece (Fig. 10.7). The resulting voltage is proportional to the mean temperature of the contact points of the workpiece and the cutting tool. The tool and the workpiece must be isolated from the machine to prevent the creation of parasitic thermocouples.

The measurement principle is shown in the Fig. 10.8.

In the process of temperature measurement during machining - turning, we will change the cutting conditions: cutting speed, feed.

An important physical characteristic is the cutting temperature. It is the average temperature of the contact surfaces between the tool and the chip. Its dependence on cutting conditions can be written using the equation:

where:

$$\theta = C_\theta * v_c^{z_\theta} * f^{x_\theta} * a_p^{y_\theta}$$

where

C_θ is a coefficient that depends on the machining conditions (workpiece material, cutting wedge geometry, cutting environment).

When machining carbon steel with P20 sintered carbide, the following values of exponents *x, y* and *z* were experimentally determined:

$$z_\theta = 0{,}26 – 0{,}75$$

$$x_\theta = 0{,}13 – 0{,}45$$

$$y_\theta = 0{,}1$$

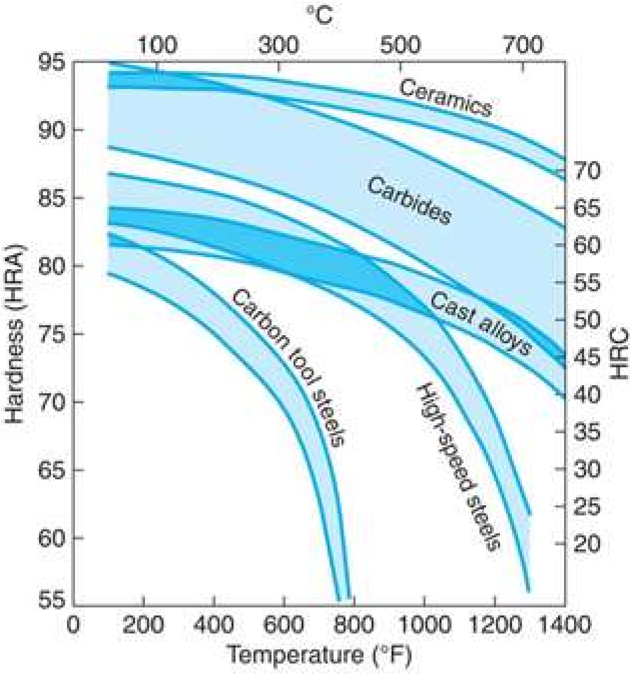


Fig. 10.7 *The hardness of various cutting tools materials as a function of temperature (hot hardness); The wide range in each group of materials is due to the variety of tool compositions and treatments available for that group.*

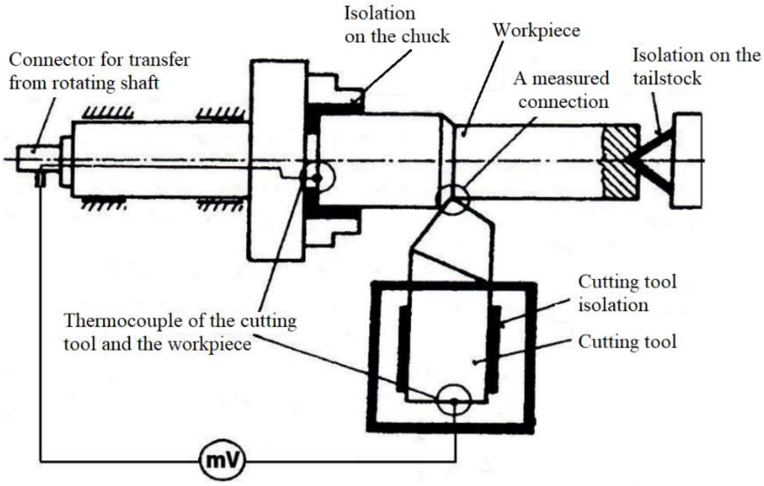


Fig. 10.8 *The principle of measurement by the method of two different metals is shown in the figure.*

Exercise 3:
Experimental: Temperature measurement during machining

Production technologies II	Title of exercise: Temperature measurement during machining		
Name:	Study group:	Note:	

1) Indicate in the table the maximum working temperatures and cutting speeds for the four cutting materials.

Cutting material	Max. working temperature	Max. cutting speed

2) Make a list of factors most affecting the temperature at the cutting site.

Attempt 1: Dependence f – T (feed - temperature)

For a given turning tool, experimentally verify the dependence of the temperature by the machining - turning from the feed.

Description of the experiment:

Presumed theoretical dependence:

Instrument type:							
Cutting edge material:							
Tool geometry							
α_o[°]	β_o[°]	γ_o[°]	χ_r [°]	ε_r [°]	χ'_r [°]	λ_s [°]	r_ε [mm]
8	77	5	90	60	30	-5	0,1

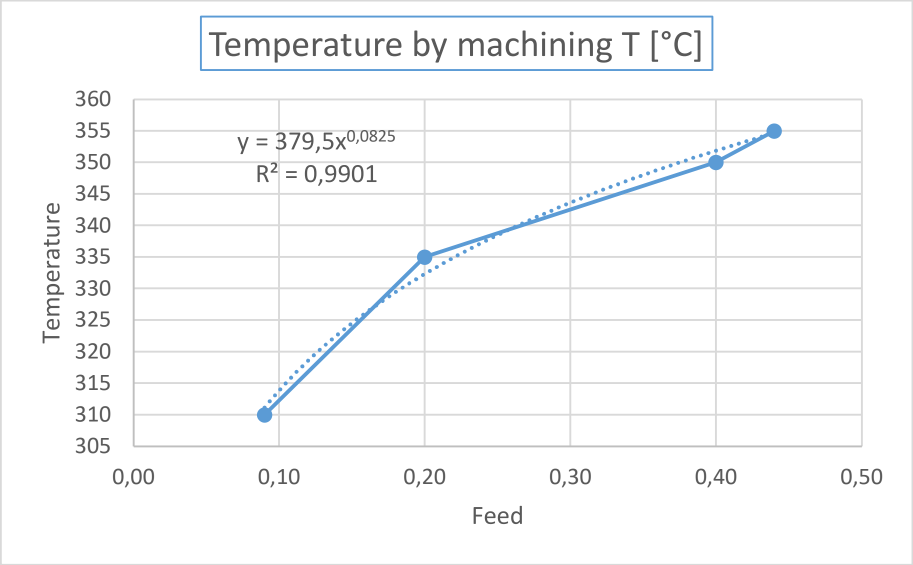
Constant parameters of the experiment:

Workpiece material C45	Workpiece diameter *d* [mm]56
Revolution n [rev/min] 355	cutting speed *in* [m/min]
	depth of cut a_p [mm] 1 mm

Measured values:

f feed [mm/rev]	0,09	0,2	0,4	0,44	
temperature by machining *T* [°C]					

Graphical representation of the measured dependence:



Evaluation of measurement results:

Attempt 2: Dependence γ_0 - T (rake angle - temperature)

Using a set of turning tools with different face angles, experimentally verify the dependence of the machining temperature on the rake angle γ_0.

Description of the experiment:

Presumed theoretical dependence:

Cutting tool N1							
Type of the cutting tool				Material of the cutting edge			
Geometry of the cutting tool							
α_o [°]	β_o [°]	γ_o [°]	χ_r [°]	ε_r [°]	χ'_r [°]	λ_s [°]	r_ε [mm]
7	72	11	70	90	20	-1	0,1
Cutting tool N2							
Type of the cutting tool				Material of the cutting edge			
Geometry of the cutting tool							
α_o [°]	β_o [°]	γ_o [°]	χ_r [°]	ε_r [°]	χ'_r [°]	λ_s [°]	r_ε [mm]
7	83	2	70	90	20	-1	0,1
Cutting tool N3							
Type of the cutting tool				Material of the cutting edge			
Geometry of the cutting tool							
α_o [°]	β_o [°]	γ_o [°]	χ_r [°]	ε_r [°]	χ'_r [°]	λ_s [°]	r_ε [mm]
7	94	-11	70	90	20	-1	0,1

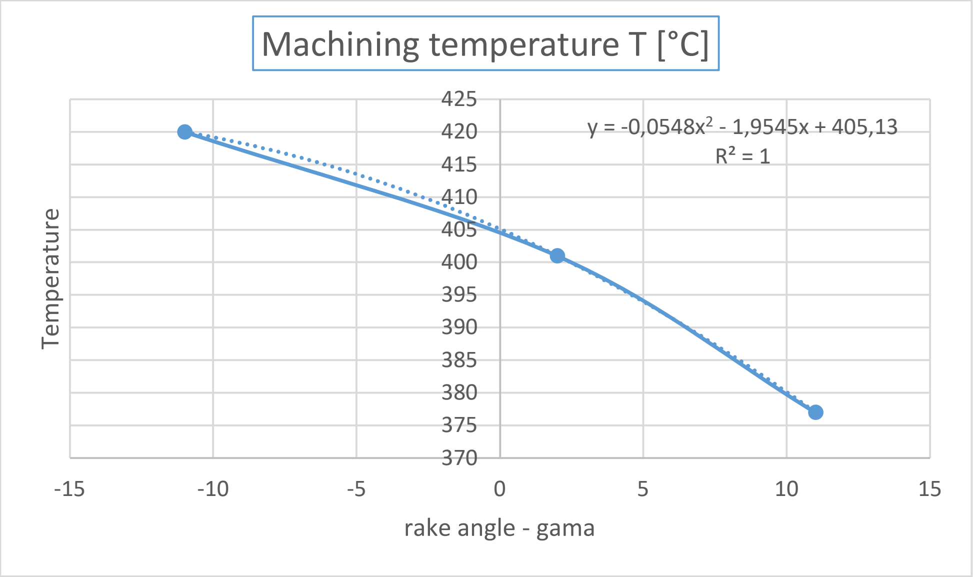
Constant parameters of the experiment:

workpiece material C45	Workpiece diameter *d* [mm] 56
N rev/min [1/min] 355	cutting speed *in* [m/min]
f feed [mm/rev] 0,2	Depth of cut a_p [mm] 1 mm

Measured values:

rake angle γ_0 [°]	11	2	-11	
machining temperature *T* [°C]	377	401	420	

Graphical representation of the measured dependence:



Evaluation of measurement results:

11. The Milling Process

Introduction

Milling is a machining process for removing material by relative motion between a workpiece and a rotating cutter having *multiple cutting edges*. More frequently, the workpiece is advanced at a relatively low rate of movement or feed to a milling cutter rotating at comparatively high speed, with the cutter axis remaining in a fixed position. A characteristic feature of the milling process is that each milling cutter tooth takes its share of the stock in the form of small individual chips. A wide variety of operations can be performed by milling (Fig. 11.1). Applications include the production of flat or contoured surfaces, slots, grooves, recesses, threads, and other configurations.

Milling methods

In ***peripheral milling*** sometimes called *slab milling*, the milled surface generated by teeth or inserts located on the periphery of the cutter body is generally in a plane parallel to the cutter axis. These milling operations are usually performed on milling machines with the spindle positioned horizontally.

Face milling is done on both horizontal and vertical machines. The milled surface resulting from the combined action of cutting edges located on the periphery and face of the cutter is generally at right angles to the cutter axis. The milled surface is flat with no relation to the contour of the teeth, except when milling is done to a shoulder. In face milling it is important to select a cutter with a diameter suited to the proposed width of cut if best results are to be obtained. A good ratio of cutter diameter to the width of the workpiece or proposed path of cut is 5:3.

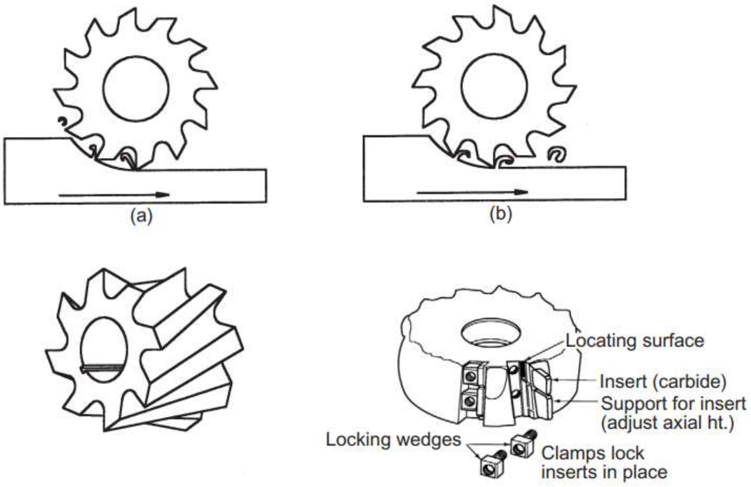


Fig. 11.1 *Conventional (up) milling (a), climb (down) milling (b), peripheral milling, and face milling*

Related milling methods

Many other milling methods can be classified as either peripheral or face milling operations (Fig. 11.2).

End milling. End mills have cutting edges on both their end faces and their peripheries. When used in face milling operations, the diameter of the cutter determines the maximum width of cut. In peripheral milling, the axial length of the teeth determines the maximum depth of cut.

Side and straddle milling.

Side milling consists of machining a plane surface perpendicular to the milling machine arbor with an arbor-mounted tool called a side milling cutter. Straddle milling entails machining two or more parallel surfaces using two or more side milling cutters spaced apart on the machine arbor.

Gang milling.

This method uses two or more cutters mounted on the machine arbor, to mill multiple surfaces simultaneously. Cutters made from different tool materials are sometimes used to help maintain effective cutting speeds when different diameters are being milled.

Gear Milling.

The machines must be equipped with dividing heads, and standard gear tooth cutters are used (most gears are now produced on gear cutting machines).

Cam Milling.

Cams, worm threads, and other helical surfaces are produced on milling machines equipped with universal dividing head. This is accomplished by rotating the workpiece while it is fed in the direction of the rotational axis.

Because of the type of workpiece being machined and/or the specific type of cutter used, however, there are a lot of further methods with less importance: thread milling, plunge milling, planetary milling, crankshaft milling, diesinking (machining of three-dimensional contoured cavities in dies and molds).

Fig. 11.2 *Types of milling cutters used in machining process [29]*

Up and down (climb) milling

If the rotation of the milling cutter is such that the tangential cutting force is generally opposed to the direction of workpiece feed and the axis of the cutter does not intersect the workpiece, the undeformed chip thickness constantly increases during the cut. This is called ***up milling*** or sometimes conventional milling (Fig. 11.3).

If the rotation of the cutter is such that the tangential cutting force is generally in the same direction as the workpiece feed and the cutter axis does not intersect the workpiece, the undeformed chip thickness uniformly decreases during the cut. This is ***down milling***, also known as ***climb milling.***

However, if the machine is equipped with the backlash eliminator, certain types of work can be best milled by climb milling. Climb milling, which can increase life up to 50 %, is effective for most milling applications. Climb milling is being used when the cutter and the workpiece are going in the same direction. Conventional milling is when the cutter and the workpiece are going in opposite direction.

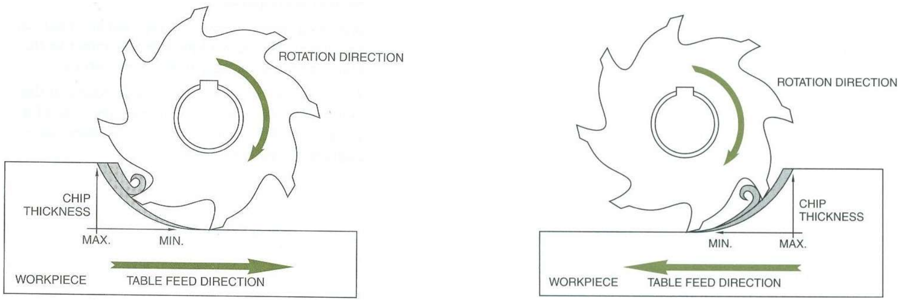


Fig. 11.3 *Conventional (up) milling and climb (down) milling [7]*

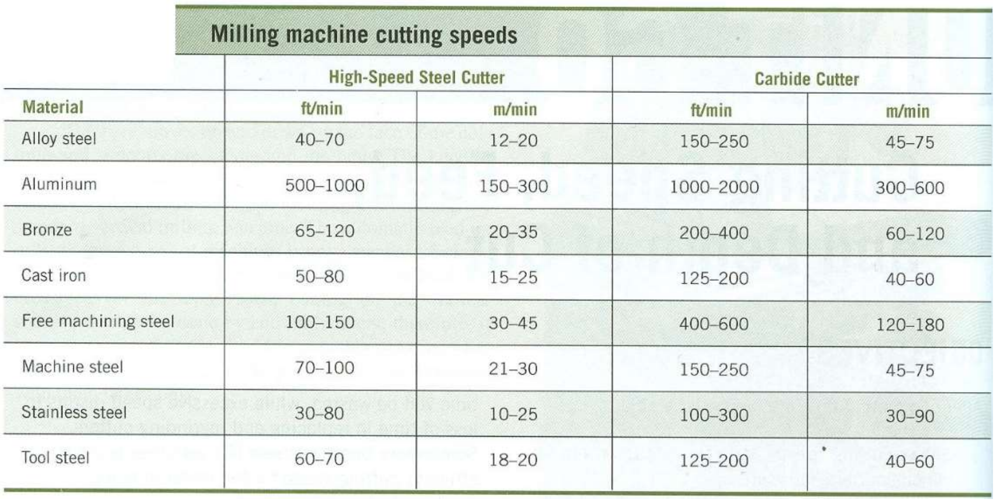
Cutting conditions in milling

As each tooth or insert of a milling cutter enters a cut, it is subjected to mechanical shock load. The magnitude of this load depends upon the workpiece material, cutter position, operating conditions and cutter geometry. Cutting forces in milling are cyclical, being roughly proportional at any position in the cut to the undeformed chip thickness at that position. Heat generated in the milling operations is also roughly proportional to the undeformed chip thickness and cutting forces.

The new surface is generated as each tooth cuts away an arc-shaped segment, the thickness of which is the feed or tooth load. Feeds are usually light, not often greater than 0.25 mm per tooth, and frequently less than 0.025 mm per tooth. However, because of the large number of teeth, the rate of metal removal is often high. The feed often varies through the cutting part of the cycle. In the up milling operation shown in Fig.11.3 (a), the feed on each tooth is very small at first and reaches a maximum where the tooth breaks contact with the work surface. If the cutter is designed to "climb mill" and rotate in the opposite direction – Fig.11.3 (b), the feed is greatest at the point of initial contact.

Cutting conditions for milling can also be determined using the tables in Fig. 11.4 and Fig. 11.5.

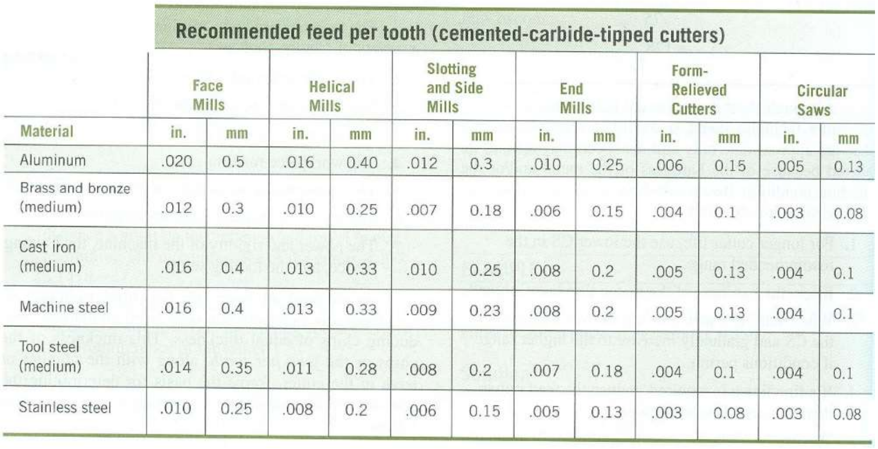
Ideal conditions for determining cutting conditions are shown in Fig. 11.6.



Milling machine cutting speeds

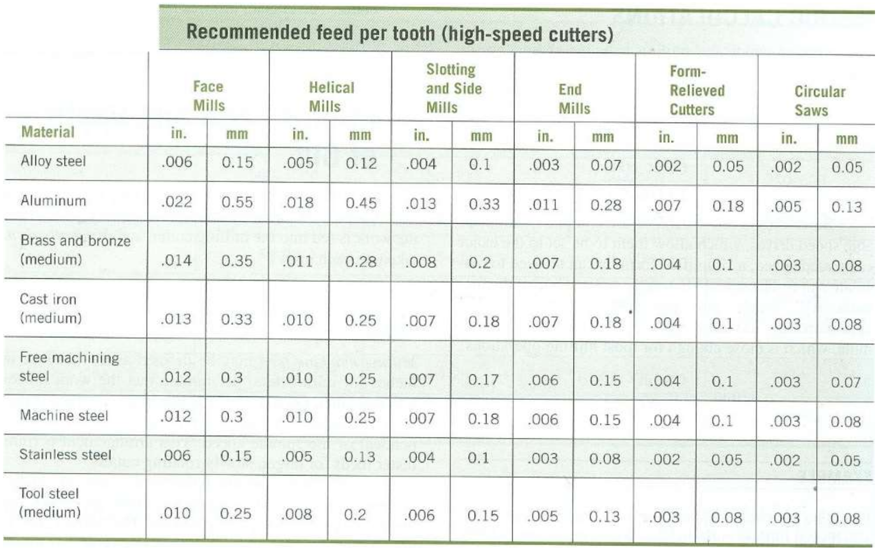
	High-Speed Steel Cutter		Carbide Cutter	
Material	**ft/min**	**m/min**	**ft/min**	**m/min**
Alloy steel	40–70	12–20	150–250	45–75
Aluminum	500–1000	150–300	1000–2000	300–600
Bronze	65–120	20–35	200–400	60–120
Cast iron	50–80	15–25	125–200	40–60
Free machining steel	100–150	30–45	400–600	120–180
Machine steel	70–100	21–30	150–250	45–75
Stainless steel	30–80	10–25	100–300	30–90
Tool steel	60–70	18–20	125–200	40–60

Fig. 11.4 *Cutting speed by milling [7]*



Recommended feed per tooth (cemented-carbide-tipped cutters)

Material	Face Mills in.	Face Mills mm	Helical Mills in.	Helical Mills mm	Slotting and Side Mills in.	Slotting and Side Mills mm	End Mills in.	End Mills mm	Form-Relieved Cutters in.	Form-Relieved Cutters mm	Circular Saws in.	Circular Saws mm
Aluminum	.020	0.5	.016	0.40	.012	0.3	.010	0.25	.006	0.15	.005	0.13
Brass and bronze (medium)	.012	0.3	.010	0.25	.007	0.18	.006	0.15	.004	0.1	.003	0.08
Cast iron (medium)	.016	0.4	.013	0.33	.010	0.25	.008	0.2	.005	0.13	.004	0.1
Machine steel	.016	0.4	.013	0.33	.009	0.23	.008	0.2	.005	0.13	.004	0.1
Tool steel (medium)	.014	0.35	.011	0.28	.008	0.2	.007	0.18	.004	0.1	.004	0.1
Stainless steel	.010	0.25	.008	0.2	.006	0.15	.005	0.13	.003	0.08	.003	0.08



Recommended feed per tooth (high-speed cutters)

Material	Face Mills in.	Face Mills mm	Helical Mills in.	Helical Mills mm	Slotting and Side Mills in.	Slotting and Side Mills mm	End Mills in.	End Mills mm	Form-Relieved Cutters in.	Form-Relieved Cutters mm	Circular Saws in.	Circular Saws mm
Alloy steel	.006	0.15	.005	0.12	.004	0.1	.003	0.07	.002	0.05	.002	0.05
Aluminum	.022	0.55	.018	0.45	.013	0.33	.011	0.28	.007	0.18	.005	0.13
Brass and bronze (medium)	.014	0.35	.011	0.28	.008	0.2	.007	0.18	.004	0.1	.003	0.08
Cast iron (medium)	.013	0.33	.010	0.25	.007	0.18	.007	0.18	.004	0.1	.003	0.08
Free machining steel	.012	0.3	.010	0.25	.007	0.17	.006	0.15	.004	0.1	.003	0.07
Machine steel	.012	0.3	.010	0.25	.007	0.18	.006	0.15	.004	0.1	.003	0.08
Stainless steel	.006	0.15	.005	0.13	.004	0.1	.003	0.08	.002	0.05	.002	0.05
Tool steel (medium)	.010	0.25	.008	0.2	.006	0.15	.005	0.13	.003	0.08	.003	0.08

Fig. 11.5 *Recommended feed per tooth for cutting materials [7]*

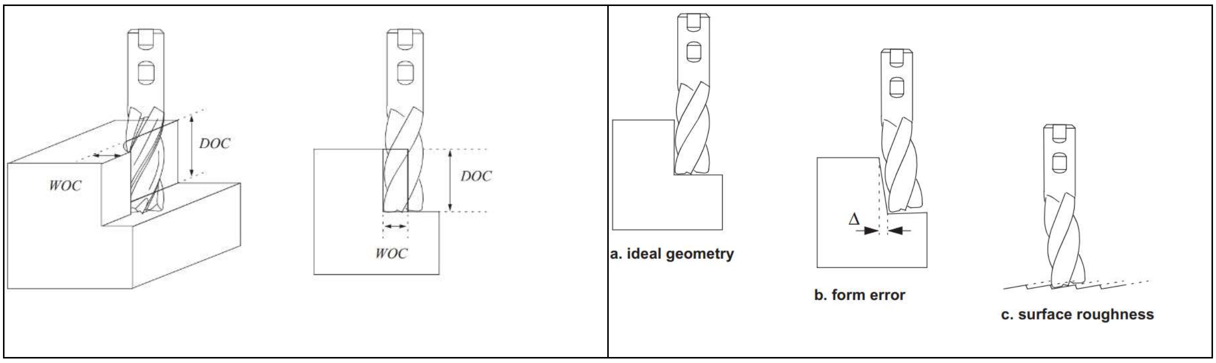


Fig. 11.6 Ideal cutting conditions of an end mill; WOC = width of cut, DOC = depth of cut and effect of tool deflection on form error and surface roughness

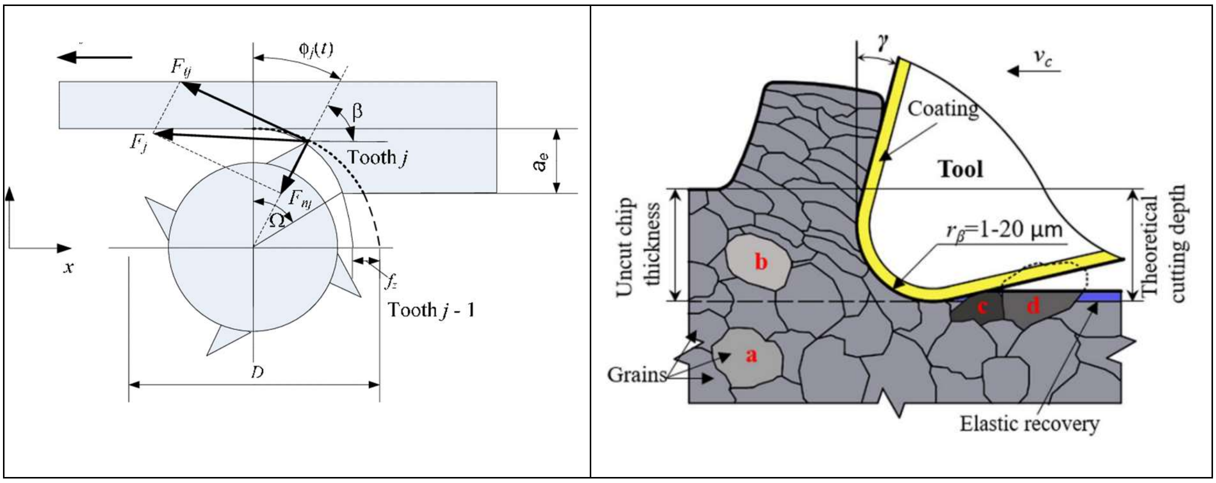


***Fig. 11.7** Analyze of the problems with the cutting forces by up (conventional) milling [30]*

Down or climb milling is preferred for several reasons wherever the machine tool and workpiece allow it (Fig. 11.7). With up or conventional milling, the undeformed chip thickness at tooth or insert entry is theoretically zero. As a result, the tooth or insert has to penetrate gradually into a layer of material that has usually been work hardened by the previous tooth or insert, so the tool life may be poor. With down milling, however, chip thickness at entry is at a maximum and any work-hardened layer is avoided. The thicker chips produced by more efficient cutting action of down milling carry more heat away, which may improve cutter life.

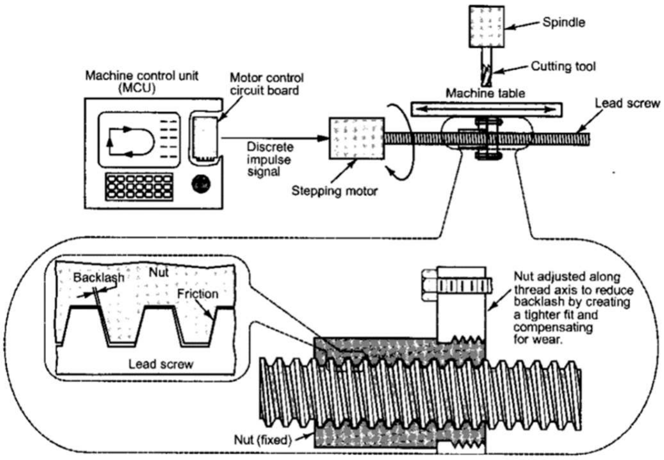


***Fig. 11.8** The machine is not equipped with the backlash eliminator*

Cutting forces by milling

Cutting forces, when down milling is performed on a horizontal spindle machine, press the workpiece down against the fixture, the fixture against the table and the table against its supports (Fig. 11.8) thus minimizing the possibility of vibration. When up milling is performed, however, the cutting forces tend to lift the workpiece from the table.

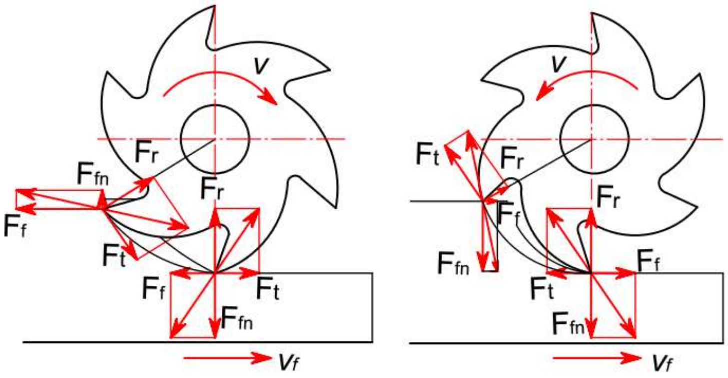


Fig. 11.9 *Cutting forces during up milling and down milling*

The force analyses of the cutters during up milling and down milling are shown in Fig. 11.9 respectively, where F_t and F_r are the tangential and radial forces of the tooth of the end-milling cutter, respectively. The stress analyses of up milling and down milling reveal that the directions of F_t on the corresponding cutter tooth are opposite, and thus, tangential force F_t is partially offset. Similarly, the directions of feed force F_{fn} are opposite during up milling and down milling.

The main parts of the milling machine can be seen in Fig.11.10.

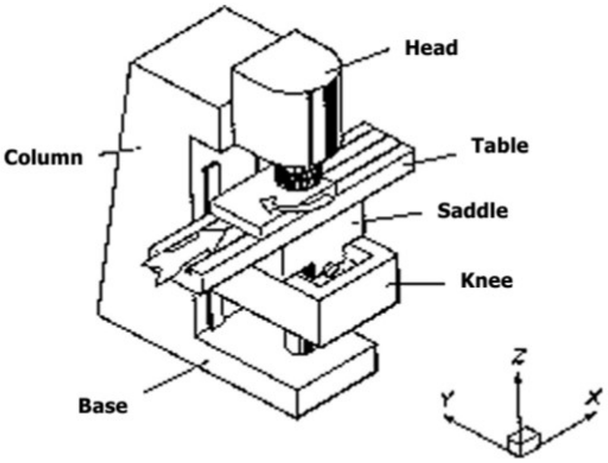


Fig. 11.10 *The main parts of the milling machine tool*

Exercise 4:
Cutting conditions by milling

Production technologies II	Title of exercise: **Analysis of cutting conditions during milling**		
Name:	Study group:	Note:	

Up milling and down milling

Describe the advantages of up milling and down milling with respect to the given experiment (shortly)

Cutting conditions by experiment:

Depth of cut: $a_p = 0,6$

Feed per tooth: $f_{th} = 0,025$

Number of teeth: $t = 4$

Feed per revolutions [mm/rev]: $f = t * f_{th}$; $f = 4*0,025 = 0,1$

Velocity of the feed: $v_f = t * f_{th} * n$; $56 = 4 * f_{th} *560$; $f_{th} = 0,025$ *mm/tooth*

Diameter of the cutting tool [mm]: $D=20$

Velocity of cutting: $v_c = \frac{\pi * D * n}{1000}$, $v_c = 35,168$ *m/min*

Roughness after milling with both methods:

Face milling

Describe the advantages of face milling

Cutting conditions by experiment:

Depth of cut: $a_p = 1\ mm$

Feed per tooth: $f_{th} = 0{,}025\ mm/tooth$

Number of teeth: $t = 4$

Feed per revolutions [mm/rev]: $f = t * f_{th}$; $f = 4 * 0{,}025 = 0{,}1$

Velocity of the feed: $v_f = t * f_{th} * n$; $56 = 4 * f_{th} * 560$, $f_{th} = 0{,}025\ mm/tooth$

Diameter of the cutting tool [mm]: $D = 65\ mm$

Velocity of cutting: $v_c = \frac{\pi * D * n}{1000}$; $v_c = 114{,}296\ m/min$; $228{,}592\ m/min$

Roughness:

Describe the both experiments:

Vocabulary (English – Slovak)

arbor	tŕň
built-up edge chip (BUE)	nárastok
cam	vačka
carbon-tool steels	uhlíková oceľ
cast cobalt base alloys	zliatiny na báze kobaltu
cemented Carbides	spekaný karbid
clearance angle	uhol chrbta
coatings	povlaky
corner radius, nose radius	polomer hrotu
corrosion-resistant steel	koróziivzdorná oceľ
cutting edge	rezná hrana
cutting force	rezná sila
cutting speed	rezná rýchlosť
cutting wedge angle	uhol rezného klina
depth of cut	hĺbka rezu
diesinking	hĺbenie
down milling	súbežné frézovanie
end mill	čelná fréza
face milling	čelné frézovanie
failure	poškodenie
failure	zlom, porucha
feed rate	rýchlosť posuvu
final diameter of workpiece	konečný priemer obrobku
finished surface	povrch po dokončovacom obrábaní
flank	chrbát
flank	opotrebenie na chrbtovej ploche
flank (back) surface	chrbtová plocha
fragile material	krehký materiál
heat-resistant steel	žiaruvzdorná oceľ
high speed steels (HSS)	rýchlorezná oceľ
length of the cut	dĺžka rezu
machinability	obrobiteľnosť
major cutting edge	hlavná rezná hrana
material removal rate	množstvo odobraného materiálu za čas
minor cutting edge (secondary cutting edge)	vedľajšia rezná hrana
original diameter of workpiece	pôvodný priemer obrobku
particularly crater wear	žliabok na čelnej ploche
rake angle	uhol čela
rake surface	čelná plocha
raw material	polotovar, polovýrobok
reamer	výstružník
rigidity	tuhosť
rough machining	hrubovanie
rounded cutting edge radius	polomer zaoblenia reznej hrany
rubbing of the tool	trenie nástroja
secondary deformation zone (Shear)	sekundárna deformačná zóna
serrated or segmented chip	drobivá alebo delená trieska
shaper work	tvarovanie
shear zone	deformačná zóna
shell drill	výhrubník
sintered carbide	spekaný karbid
slab-milling	rovinné frézovanie
spiral drill (twist drill)	skrutkovicový vrták
stress	napätie
surface	povrch

surface roughness	drsnosť povrchu
temperature rise	nárast teploty
tensile test	ťahová skúška
time of machining	čas obrábania
to deteriorate	zhoršovať
tool approach angle (outgoing angle), end cutting edge angle	uhol nastavenia vedľajšej reznej hrany
tool cutting edge inclination angle	uhol sklonu reznej hrany
tool included angle	uhol hrotu
tool material	rezný materiál
tool orthogonal clearance angle	uhol chrbta v ortogonálnej rovine
tool orthogonal rake angle	uhol čela v ortogonálnej rovine
tool orthogonal wedge angle	uhol rezného klina v ortogonálnej rovine
tool rake angle (lead angle, entering angle), side cutting edge angle	uhol nastavenia hlavnej reznej hrany
tool shape	tvar nástroja
tool wear	opotrebenie nástroja
tooth- formed mill	tvarová fréza
universal dividing head	univerzálna deliaca hlava
universal diving head	univerzálny deliaci prístroj
up milling	protibežné frézovanie
vibration	chvenie, vibrácia
waviness	vlnitosť
wear	opotrebenie
wear resistance	odolnosť voči opotrebeniu

Marking of Metal Materials according to Several Standards

marking W.Nr.	marking DIN	marking EN 10027-1	norm EN (DIN, SEW)	marking. ČSN
1.0035	St 33	S185	10025	10 004
1.0036	USt 37-2	S235JRG1	10025	11 373
1.0037	St 37-2	S235JR	10025	
1.0038	RSt 37-2	S235JRG2	10025	11 375
1.0044	St 44-2	S275JR	10025	
1.0050	St 50-2	E295	10025	11 500
1.0060	St 60-2	E335	10025	11 600
1.0070	St 70-2	E360	10025	11 700
1.0114	St 37-3 U	S235JO	10025	
1.0115	K,Q,Z St 37-3 U	S235JOC	10025	
1.0116	St 37-3 N	S235J2G3	10025	11 378
1.0118	K,Q,Z St 37-3 N	S235J2G3C	10025	
1.0120	K,Q,Z St 37-2	S235JRC	10025	
1.0121	UQSt 37-2 (Q,Z)	S235JRG1C	10025	
1.0122	RQSt 37-2 (Q,Z)	S235JRG2C	10025	
1.0128	K,Q,Z St 44-2	S275JRC	10025	
1.0138	RoSt 44-3	S275J2H	10210-1	
1.0140	K,Q,Z St 44-3 U	S275JOC	10025	
1.0141	K,Q,Z St 44-3 N	S275J2G3C	10025	
1.0143	St 44-3 U	S275JO	10025	11 443
1.0144	St 44-3 N	S275J2G3	10025	11 448
1.0149	RoSt 44-2	S275JOH	10201-1	
1.0166	St 37-3 Cu 3	S235J2G3Cu	10025	
1.0167	RSt 37-2 Cu 3	S235JRG2Cu	10025	11 379
1.0242	StE 250-2 Z	S250GD	10147	
1.0244	StE 280-2 Z	S280GD	10147	
1.0250	StE 320-3 Z	S320GD	10147	
1.0254	St 37-0	SPT360	(1629)	11 353
1.0256	St 44-0	SPT410	(1629)	11 453
1.0305	St 35-8		10028	12 021
1.0310	D 10-2	C10D	10016-2	
1.0312	St 15	DC05	10130	
1.0313	D 8-2	C7D	10016-2	
1.0319	RRStE 210.7	L210GA	10208-1	
1.0330	St 2, St 12	DC01	10130	11 321
1.0332	StW 22	DD11	10111	11 320
1.0335	StW 24	DD13	10111	11 330
1.0338	St 4, St 14	DC04	10130	11 325
1.0345	H I	P235GH	10028-2	11 368
1.0347	RRSt 3, RRSt 13	DC03	10130	
1.0392	EK 4	DC04EK	10209	
1.0402	C 22	C22	10083-2	12 024
1.0405	St 45-8		10028	12 022
1.0406	C 25	C25	10083-2	12 030
1.0413	D 15-2	C15D	10016-2	
1.0414	D 20-2	C20D	10016-2	
1.0415	D 25-2	C26D	10016-2	
1.0421	St 52.0	SPT510	(1629)	11 523
1.0425	H II	P265GH	10028-2	11 416
1.0429	StE 290.7 TM	L290MB	10028-2	
1.0438	BSt 500 S	B500N	10080	
1.0445	H IV	P295NH	10028-2	
1.0457	StE 240.7	L240NB	10028-2	
1.0459	RRStE 240.7	L240GA	10028-1	
1.0473	19 Mn 6	P355GH	10028-2	
1.0481	17 Mn 4	P295GH	10028-2	13 030
1.0484	StE 290.7	P290NB	10028-2	

1.0486	StE 285	P275N	10028-3	
1.0487	WStE 285	P275NH	10028-3	
1.0488	TStE 285	P275NL1	10028-3	
1.0490	StE 285	S275N	10113-2	
1.0491	TStE 285	S275NL	10113-2	
1.0493	StE 285	S275NH	10210-1	
1.0497	TStE 285	S275NLH	10210-1	
1.0501	C 35	C35	10083-2	12 040
1.0503	C 45	C45	10083-2	12 050
1.0511	C 40	C40	10083-2	12 041
1.0516	D 35-2	C38D	10016-2	
1.0517	D 45-2	C48D	10016-2	
1.0518	D 55-2	C56D	10016-2	
1.0528	C 30	C30	10083-2	12 031
1.0529	StE 350 Z	S350GD	10147	
1.0530	D 30-2	C32D	10016-2	
1.0533	ZSt 50-2	E295GC	10025	
1.0535	C 55	C55	10083-2	12 060
1.0539	StE 355	S355NH	10210-1	
1.0540	C 50	C50	10083-2	12 051
1.0541	D 40-2	C42D	10016-2	
1.0543	ZSt 60-2	E355GC	10025	
1.0545	StE 355	S355N	10113-2	
1.0546	TStE 355	S355NL	10113-2	
1.0549	TStE 355	S355NLH	10210-1	
1.0553	St 52-3 U	S355JO	10025	
1.0554	K,Q,Z St 52-3 U	S355JOC	10025	
1.0562	StE 355	P355N	10028-3	
1.0565	WStE 355	P355NH	10028-3	
1.0566	TStE 355	P355NL1	10028-3	11 503
1.0569	K,Q,Z St 52-3 N	S235J2G3C	10025	
1.0570	St 52-3 N	S355J2G3	10025	11 523
1.0576	RoSt 52-3	S355J2H	10210-1	
1.0578	StE 360.7 TM	L360MB	10208-2	
1.0582	StE 360.7	L360NB	10208-2	13 126
1.0585	St 52-3 Cu 3	S355J2G3Cu	10025	11 529
1.0586	D 50-2	C50D	10016-2	
1.0588	D 53-2	C52D	10016-2	
1.0601	C 60	C60	10083-2	12 061
1.0609	D 58-2	C58D	10016-2	
1.0610	D 60-2	C60D	10016-2	
1.0612	D 65-2	C66D	10016-2	
1.0614	D 75-2	C76D	10016-2	
1.0615	D 70-2	C70D	10016-2	
1.0616	D 85-2	C86D	10016-2	
1.0618	D 95-2	C92D	10016-2	
1.0622	D 80-2	C80D	10016-2	
1.0628	D 88-2	C88D	10016-2	
1.0633	ZSt 70-2	E360GC	10025	
1.0971	QStE 260 N	S260NC	10149-3	
1.0972	QStE 300 TM	S315MC	10149-2	
1.0973	QStE 300 N	S315NC	10149-3	
1.0976	QStE 360 TM	S355MC	10149-2	
1.0977	QStE 360 N	S355NC	10149-3	
1.0980	QStE 420 TM	S420MC	10149-2	
1.0981	QStE 420 N	S420NC	10149-3	
1.0982	QStE 460 TM	S460MC	10149-2	
1.0984	QStE 500 TM	S500MC	10149-2	
1.0986	QStE 550 TM	S550MC	10149-2	
1.1104	EStE 285	P275NL2	10028-3	
1.1106	EStE 355	P355NL2	10028-3	
1.1149	Cm 22	C22R	10083-1	
1.1151	Ck 22	C22E	10083-1	
1.1158	Ck 25	C25E	10083-1	

1.1163	Cm 25	C25R	10083-1	
1.1170	28 Mn 6	28Mn6	10083-1	13 141
1.1178	Ck 30	C30E	10083-1	
1.1179	Cm 30	C30R	10083-1	
1.1180	Cm 35	C35R	10083-1	
1.1181	Ck 35	C35E	10083-1	
1.1186	Ck 40	C40E	10083-1	
1.1189	Cm 40	C40R	10083-1	
1.1191	Ck 45	C45E	10083-1	
1.1201	Cm 45	C45R	10083-1	
1.1202	D 53-3	C52D2	10016-4	
1.1203	Ck 55	C55E	10083-1	
1.1206	Ck 50	C50E	10083-1	
1.1209	Cm 55	C55R	10083-1	
1.1212	D 58-3	C58D2	10016-4	
1.1220	D 55-3	C56D2	10016-4	
1.1221	Ck 60	C60E	10083-1	
1.1222	D 63-3	C62D2	10016-4	
1.1223	Cm 60	C60R	10083-1	
1.1228	D 60-3	C60D2	10016-4	
1.1232	D 68-3	C68D2	10016-4	
1.1236	D 65-3	C66D2	10016-4	
1.1241	Cm 50	C50R	10083-1	
1.1242	D 73-3	C72D2	10016-4	
1.1252	D 78-3	C78D2	10016-4	
1.1253	D 75-3	C76D2	10016-4	
1.1255	D 80-3	C80D2	10016-4	
1.1262	D 83-3	C82D2	10016-4	
1.1265	D 85-3	C86D2	10016-4	
1.1272	D 88-3	C88D2	10016-4	
1.1282	D 95-3	C92D2	10016-4	
1.3505	100 Cr 6	100Cr6	(17230)	14 109
1.3536	100 CrMo 63	100CrMo7-3	(17230)	
1.4021	X 20 Cr 13	X20Cr13	10088-1	17 022
1.4057	X 20 CrNi 17 2	X19CrNi17-2	10088-1	
1.4104	X 12 CrMoS 17	X14CrMoS17	10088-1	
1.4122	X 35 CrMo 17	X39CrMo17-1	10088-1	
1.4301	X 5 CrNi 18 10	X4CrNi18-10	10088	17 240
1.4305	X 10 CrNiS 18 9	X8CrNiS18-9	10088-1	
1.4306	G-X 2 CrNi 18 9	GX2CrNiN18-9	10088-1	
1.4401	X 5 CrNiMo 17 12 2	X4CrNiMo17-12-2	10088-1	
1.4404	G-X 2 CrNiMo 18 10	GX2CrNiMoN17-11-2	10088-1	17 346
1.4435	X 2 CrNiMo 18 14 3	X2CrNiMo18-14-3	10088-1	17 349
1.4439	G-X 3 CrNiMoN 17 13 5	GX3CrNiMoN17-13-5	10088-1	17 350
1.4460	X 4 CrNiMo 27 5	X3CrNiMoN27-5-2	10088-1	
1.4462	X 2 CrNiMoN 22 5	X2CrNiMoN22-5-3	10088-1	
1.4539	X 2 NiCrMoCu 25 20 5	X1NiCrMoCuN25-20-5	10088-1	
1.4541	X 6 CrNiTi 18 10	X6CrNiTi18-10	10088	17 247
1.4571	X 6 CrNiMoTi 17 12 2	X6CrNiMoTi17-12-2	10088	17 347
1.4713	X 10 CrAl 7	X10CrAl7	(470-76)	17 113
1.4742	X 10 CrAl 18	X10CrAl18	(470-76)	
1.4762	X 10 CrAl 24	X10CrAl24	(470-76)	
1.4828	X 15 CrNiSi 20 12	X15CrNiSi20-12	(470-76)	17 251
1.4841	X 15 CrNiSi 25 20	X15CrNiSi25-20	(470-76)	17 255
1.5415	15 Mo 3	16Mo3	10028-2	15 020
1.5330	21 MnB 5	20MnB5	10083-3	
1.5531	30 MnB 5	30MnB5	10083-3	
1.5532	38 MnB 5	38MnB5	10083-3	
1.5637	10 Ni 14	12Ni14	10028-4	
1.5662	X 8 Ni 9	X8Ni9	10028-4	
1.5680	12 Ni 19	X12Ni5	10028-4	
1.5752	14 NiCr 14	14NiCr14	10084	16 420
1.5919	15 CrNi 5	15CrNi6	10084	16 220
1.5920	18 CrNi 8	18CrNi8	10084	

1.6523	21 NiCrMo 2	21CrNiMo2	10084	
1.6580	30 CrNiMo 8	30CrNiMo8	10083-1	
1.6582	34 CrNiMo 6	34CrNiMo6	10083-1	16 343
1.6903	X 10 CrNiTi 18 10	X10CrNiTi18-10	10088-1	17 246
1.7033	34 Cr 4	34Cr4	10083-2	
1.7035	41 Cr 4	41Cr4	10083-1	14 140
1.7039	41 CrS 4	41CrS4	10083-1	
1.7131	16 MnCr 5	16MnCr5	10084	14 220
1.7139	16 MnCrS 5	16MnCrS5	10084	
1.7147	20 MnCr 5	20MnCr5	10084	14 221
1.7149	20 MnCrS 5	20MnCrS5	10084	
1.7218	25 CrMo 4	25CrMo4	10083-1	15 130
1.7220	34 CrMo 4	34CrMo4	10083-1	15 131
1.7225	42 CrMo 4	42CrMo4	10083-1	15 142
1.7226	34 CrMoS 4	34CrMoS4	10083-1	
1.7227	42 CrMoS 4	42CrMoS4	10083-1	
1.7228	50 CrMo 4	50CrMo4	10083-2	
1.7258	24 CrMo 5	24CrMo5	10028-2	
1.7335	13 CrMo 4 4	13CrMo4-5	10028-2	15 121
1.7380	10 CrMo 9 10	10CrMo9-10	10028-2	15 313
1.7707	30 CrMoV 9	30CrMoV9	10083-2	15 241
1.7733	24 CrMoV 5 5	24CrMoV5-5	10028-2	15 320
1.7735	14 CrMoV 6 9	14CrMoV6-9	10083-2	
1.8159	50 CrV 4	51CrV4	10083-2	15 260
1.8507	34 CrAlMo 5	34CrAlMo5	(17211)	
1.8519	31 CrMoV 9	31CrMoV9	(17211)	
1.8521	15 CrMoV 5 9	15CrMoV5-9	(17211)	
1.8550	34 CrAlNi 7	34CrAlNi7	(17211)	
1.8823	StE 355 TM	S355M	10113-3	
1.8825	StE 420 TM	S420M	10113-3	
1.8827	StE 460 TM	S460M	10113-3	
1.8834	TStE 355 TM	S355ML	10113-3	
1.8836	TStE 420 TM	S420ML	10113-3	
1.8838	TStE 460 TM	S460ML	10113-3	
1.8901	StE 460	S460N	10113-2	
1.8902	StE 420	S420N	10113-2	
1.8903	TStE 460	S460NL	10113-2	
1.8905	StE 460	P460N	10028-3	
1.8912	TStE 420	S420NL	10113-2	
1.8915	TStE 460	P460NL1	10028-3	
1.8918	EStE 460	P460NL2	10028-3	
1.8925	EStE 890 V	S890QL1	10137-2	
1.8928	TStE 690 V	S690QL	10137-2	
1.8931	StE 690 V	S690Q	10137-2	
1.8933	TStE 960 V	S960QL	10137-2	
1.8935	WStE 460	P460NH	10028-2	
1.8953	StE 460	S460NH	10210-1	
1.8956	TStE 460	S460NLH	10210-1	
1.8961	WTSt 37-3	S235J2W	10155	
1.8963	WTSt 52-3	S355J2G1W	10155	15 127
1.8983	TStE 890 V	S890QL	10137-2	
1.8988	EStE 690 V	S690QL1	10137-2	

Note: The Czech standard (ČSN) is almost identical to the Slovak standard (STN)

Conclusion

heory of machining is a part of production technologies and has been the largest part of engineering production for a long time. Part of modern production is the use of modern means such as CNC production machines.

At the end of it is inserted a glossary of the most used terms in the given issue. There is often a problem in marking technical materials. The embedded table at the end of the publication will certainly help to better identify technical materials in different countries.

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Anton Panda, prof. Ing., PhD. University studies – Faculty of Mechanical Engineering TU Košice (Ing.-1987); terminated doctoral studies – Faculty of manufacturing technologies TU Košice (PhD.-2002), associate professor of study branch 5.2.51 manufacturing technologies, FMT TU Košice (assoc. prof.-2008), professor of study branch 5.2.51 manufacturing technologies, FMT TU Košice (prof.-2015). 29 – years of experience in the engineering company supplying the products for demanding automotive, also farm and agricultural industry (constructor of special purpose machinery and equipment, systems analyst, head the department of development and technical preparation of production, methodist of statistical methods, commercial and technical director, director of quality). In the present expertise and design activities in the area of development, production and verification of rolling bearings, in the area of deposition with rolling bearings for various domestic and foreign customers. Since 2008 (since 1994 external) operates as pedagogue and scientist at the Faculty of manufacturing technologies TU Košice with the seat in Prešov, as well as an expert - coordinator (auditor) of quality management systems. He is the author (co-author) of 17 monographs (11 foreign, 6 domestic) – of it 3 monograph in Springer publishing, 2 university textbooks (1 foreign, 1 domestic), 16 university lecture notes, author's certificates (16), patents and discoveries (15), catalogs of bearings (2), several domestic and foreign original scientific papers in the scientific and professional journals, in Current Contents Connect journals in Web of Science (21), in impacted journals and publications led in the world renowned databases (Web of Science - 119, Scopus - 150) and in proceedings from domestic and foreign scientific conferences from the following areas: Automobile production, manufacturing technologies, experimental methods in the manufacturing technologies, machining, development, manufacturing and verification of new products in accordance with the standards EN ISO 9001 and in accordance to the specific requirements of automobile manufacturers IATF 16 949, quality control, statistical methods and techniques of quality for the production of parts, capability of machine, capability of manufacturing processes, capability of gauges and measuring equipment, technical preparation of production, product audits, system audits of quality management system, analysis of potential errors and their effects on construction (FMEA-K) and on manufacturing process/technology (FMEA-V), statistical regulation of manufacturing processes SPC, process of approval of parts to the production

PPAP, modern quality planning of product APQP, control plans and regulation, requirements the association of automobile manufacturers in Germany VDA 6.1, quality system requirements for suppliers of Ford, Chrysler, GM, specific requirements the using of EN ISO 9001:2015 in organizations ensuring the mass production in automotive industry IATF 16949, method of Poka-Yoke, quality assurance before the mass production for suppliers of automobile manufacturers in Germany VDA 4.3, quality assurance of supplies for suppliers of automobile manufacturers in Germany VDA 2, product liability, method of Global 8D (8-step method for solving of problems), etc. At these works are registered the various domestic and foreign quotations and testimonials in the worldwide databases. Solver of several projects and grant projects for engineering companies at home and abroad, solver of research tasks, author of the directives, methodological guidelines, technical regulations and other technical documentation for domestic and foreign manufacturing companies. He is auditor of quality system management on Technical University in Košice, Slovakia. Active collaboration with the university workplaces at home and abroad. He is recognized as an expert for the production of bearings in companies in Germany, Italy, China, Slovakia and Czech Republic. As the coordinator of research collective and co-author of documentation EFQM has won the Award for improvement of performance in the competition National award of Slovak Republic for quality in the year 2010 for the Technical University of Košice. In the same competition, he has won the same award in year 2012, when the Technical University of Košice has obtained the highest score in its category. Since 2014 he has a member of the Polish Academy of Sciences. Since 2014 he has a member of a member of the ASME, USA.