Metal Cutting

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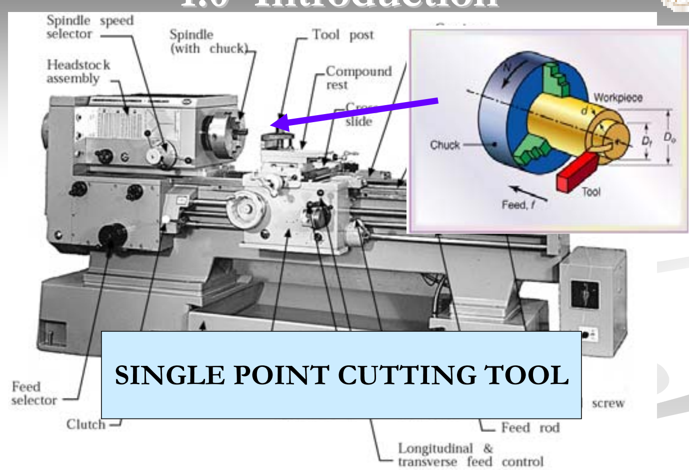
Content

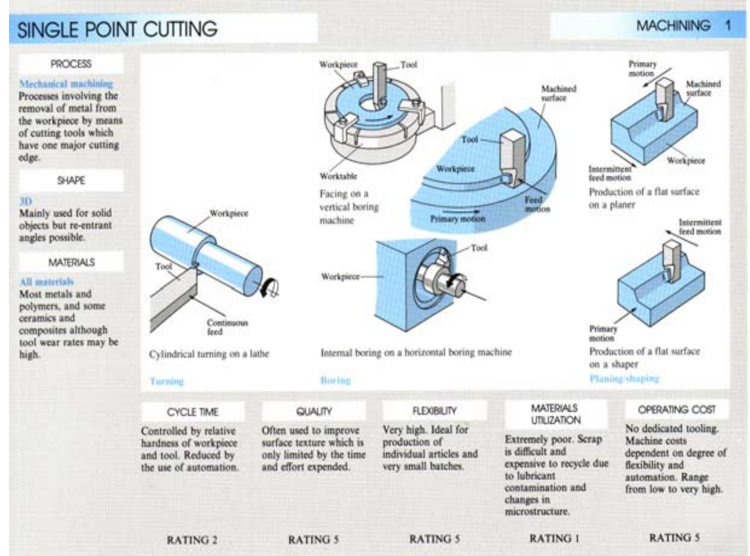
1.0 Introduction

- Machining is the removal of stock material from an initial form (usually a block or bar of material).
- Traditional or "chip-forming" machining processes remove material by using mechanical energy and are usually referred to as cutting processes (single point or multiple point). The machine used is named Machine Tools.
- The non-traditional or "chip-less" processes use electrical, thermal or chemical energies to remove metal.

1.0 Introduction



SINGLE POINT CUTTING TOOL



SINGLE POINT CUTTING — MACHINING 1

PROCESS

Mechanical machining
Processes involving the removal of metal from the workpiece by means of cutting tools which have one major cutting edge.

SHAPE

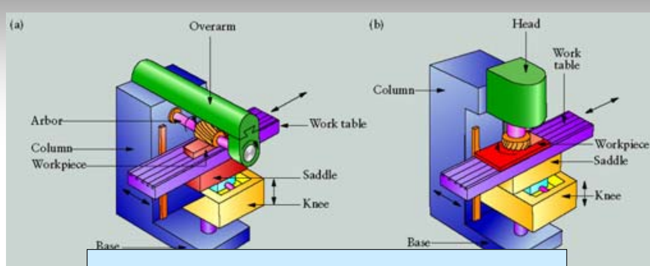
3D
Mainly used for solid objects but re-entrant angles possible.

MATERIALS

All materials
Most metals and polymers, and some ceramics and composites although tool wear rates may be high.

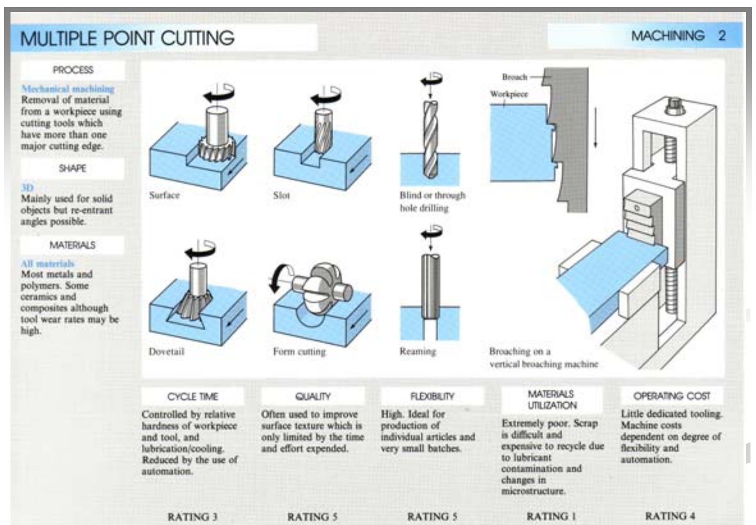
CYCLE TIME	QUALITY	FLEXIBILITY	MATERIALS UTILIZATION	OPERATING COST
Controlled by relative hardness of workpiece and tool. Reduced by the use of automation.	Often used to improve surface texture which is only limited by the time and effort expended.	Very high. Ideal for production of individual articles and very small batches.	Extremely poor. Scrap is difficult and expensive to recycle due to lubricant contamination and changes in microstructure.	No dedicated tooling. Machine costs dependent on degree of flexibility and automation. Range from low to very high.
RATING 2	RATING 5	RATING 5	RATING 1	RATING 5

1.0 Introduction



MULTI-POINT CUTTING TOOL

Schematic illustration of a (a) horizontal-spindle column-and-knee-type milling machine. (b) a vertical-spindle column-and-knee-type milling machine.



MULTIPLE POINT CUTTING — MACHINING 2

PROCESS

Mechanical machining
Removal of material from a workpiece using cutting tools which have more than one major cutting edge.

SHAPE

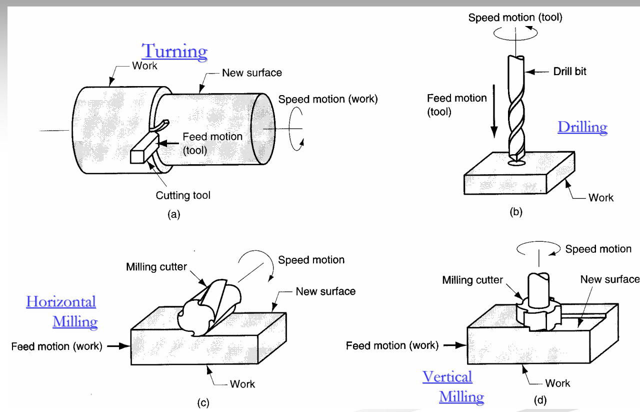
3D
Mainly used for solid objects but re-entrant angles possible.

MATERIALS

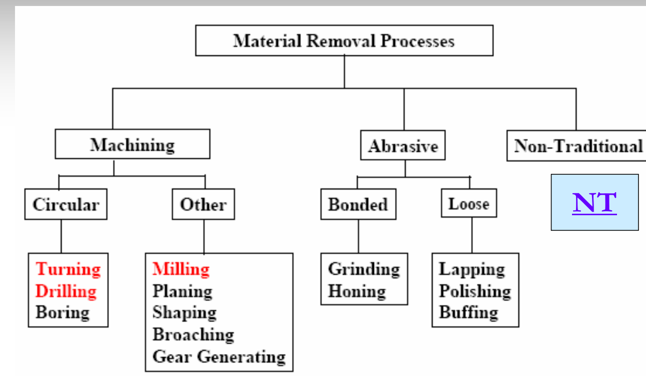
All materials
Most metals and polymers. Some ceramics and composites although tool wear rates may be high.

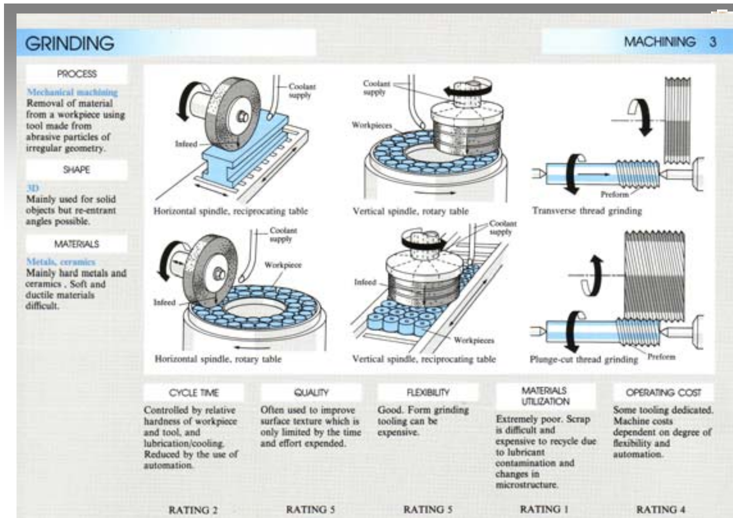
CYCLE TIME	QUALITY	FLEXIBILITY	MATERIALS UTILIZATION	OPERATING COST
Controlled by relative hardness of workpiece and tool, and lubrication/cooling. Reduced by the use of automation.	Often used to improve surface texture which is only limited by the time and effort expended.	High. Ideal for production of individual articles and very small batches.	Extremely poor. Scrap is difficult and expensive to recycle due to lubricant contamination and changes in microstructure.	Little dedicated tooling. Machine costs dependent on degree of flexibility and automation.
RATING 3	RATING 5	RATING 5	RATING 1	RATING 4

1.0 Introduction



1.1 Machining Processes Classification





1.2 Mengapa Logam Di Potong

There are commercial and technological reasons which make machining one of the most important manufacturing processes.

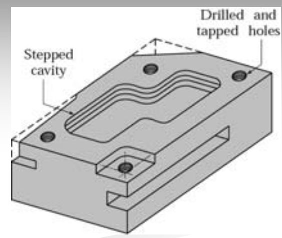
- **ACCURACY**
  - Highest of all manufacturing processes, close tolerances can be achieved.
  - Small amount of materials removed, smooth surface finishes
  - Precise tools, dies, moulds can be made.

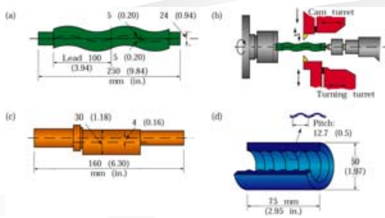
1.2 Mengapa Logam Di Potong

- **HIGHLY FLEXIBLE** – variety of work materials

  Shape can be programmed. Regular geometries (flat planes, round holes, cylinders) can be easily machined. Irregular geometries (screw threads, T-slots) can be cut using various tool shapes and tool paths.

  Many different parts can be made on one machine (general purpose).





1.2 Mengapa Logam Di Potong

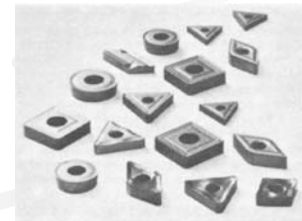
Any arbitrary shape can be machined by combining several machining operations in sequence.

- LOW COST TOOLING

  Contour is generated by path of tool rather than its shape, in most cases

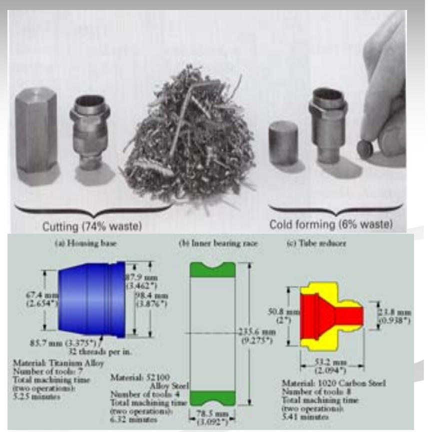
  Cutting tools are mass produced in standardized shapes/geometry

  Economical for small quantity production



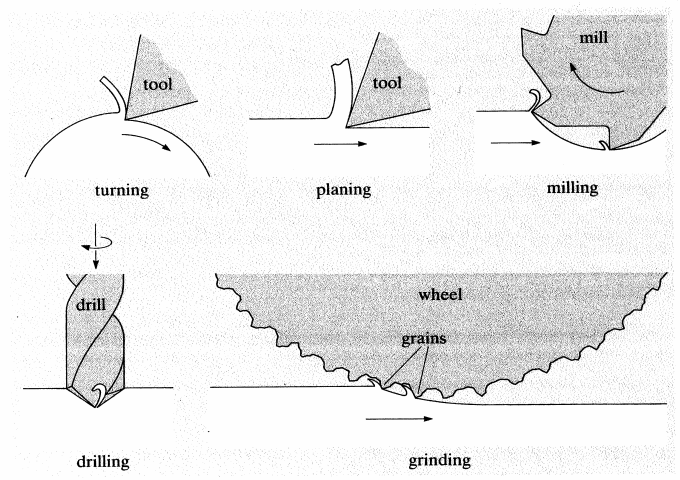
Disadvantages of metal cutting

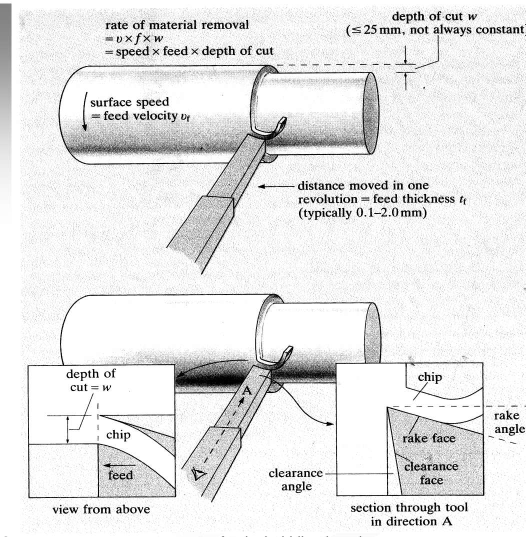
- Removal of material – become scrapped and waste
- Machining is relatively a slow process
- Need highly skilled operators
- High capital cost – machine, cutters, workholders, jigs and fixtures
- Not suitable for high volume production



2.1 General Principles

- Cutting is often used as a secondary manufacturing process to produce dimensional tolerances, surface textures and geometrical features that cannot be produced by casting, forming or powder processing.
- Cutting can be economically used as a primary manufacturing process if (a) production volumes or (b) material costs are low.
- Most cutting processes that involve physical contact with hard tooling can be modelled as a wedged shaped single point cutting.





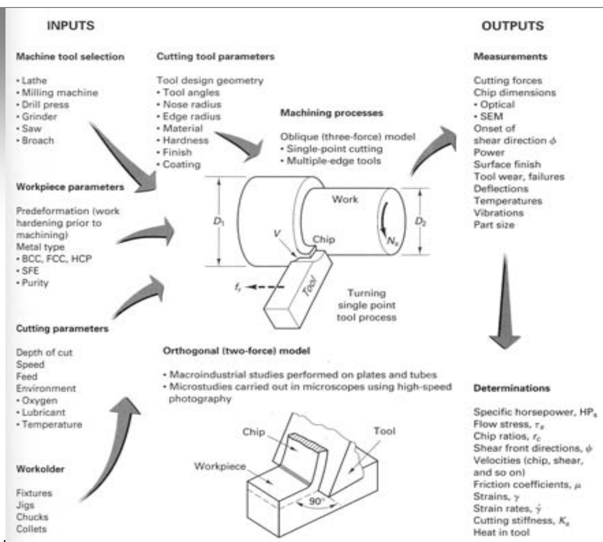
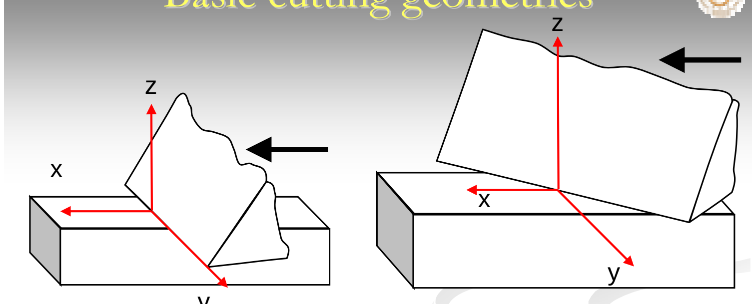


FIGURE 21-1 The fundamental inputs and outputs to machining processes.

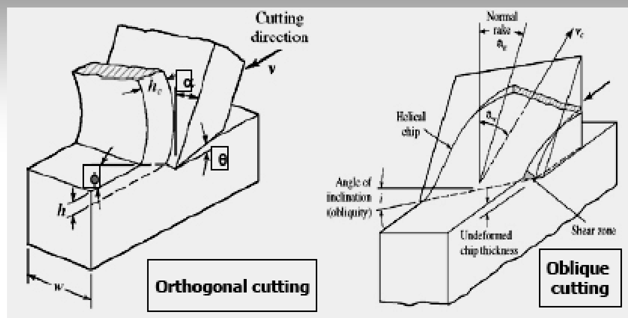
Basic cutting geometries



Orthogonal (2D) Oblique (3D)

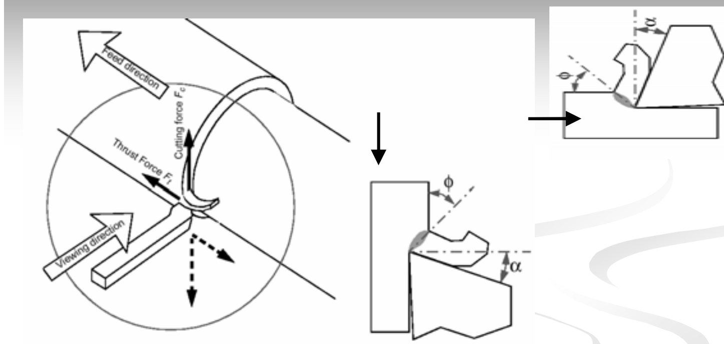
- Orthogonal → Provides insight for understanding
- Oblique → Complex

Basic Cutting Geometry



- **Orthogonal cutting:** the cutting edge of the tool is straight and perpendicular to the direction of motion.
- **Oblique cutting:** the tool edge is set at angle.

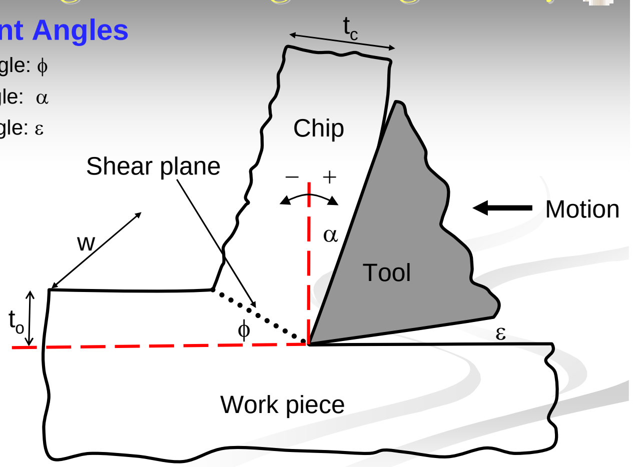
Orthogonal cutting in a lathe

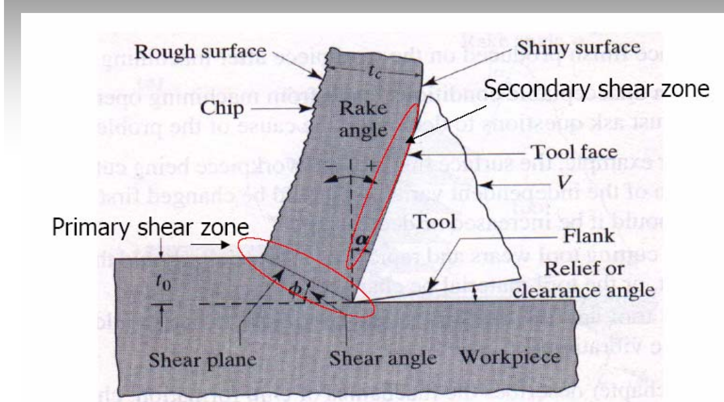


Orthogonal cutting zone geometry

Important Angles

- Shear angle: ϕ
- Rake angle: α
- Relief angle: ε

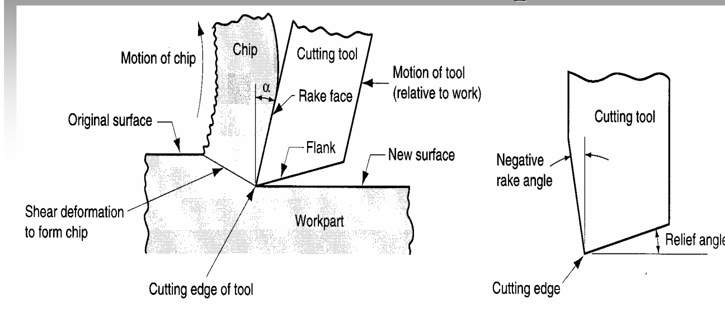




2.2 Pembentukan Serpihan

- The basic principle is the use of a cutting tool to form a chip removed from the part (by shear).
  - It requires the relative motion between the tool and part.
  - The primary motion is called *speed*, *v*, and the secondary motion is called *feed*, *f*.
  - The cutting tool needs to cut into the part, called *the depth of cut*, *d*.

2.2 Pembentukan Serpihan



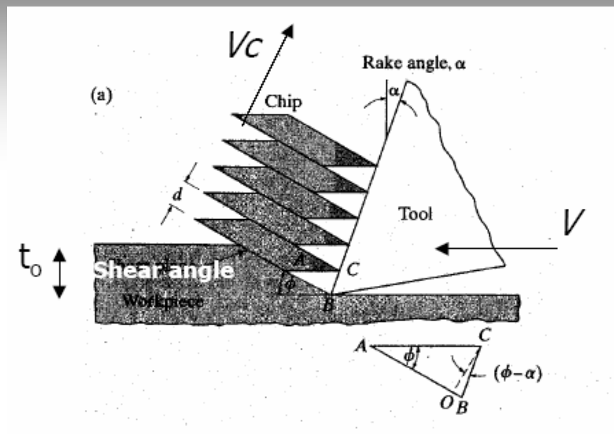
- During machining, the material is removed in form of chips, which are generated by shear deformation along a plane called the shear plane.

2.2 Pembentukan Serpihan

- A process in which a **wedge-shaped** tool engages a workpiece to remove a layer of material in the form of a **chip**.
- As the cutting tool engages the workpiece, the material directly ahead of the tool is sheared **and deformed under tremendous pressure**. The deformed material then seeks to relieve its stressed condition **by fracturing** and flowing into the space above the tool in the form of a chip.
- The deformation of a work material means that **enough force** has been exerted by the tool to **permanently reshape or fracture** the work material. If the material is reshaped, it is said to have exceeded its **elastic and plastic limits**. A chip is a combination of reshaping and fracturing.

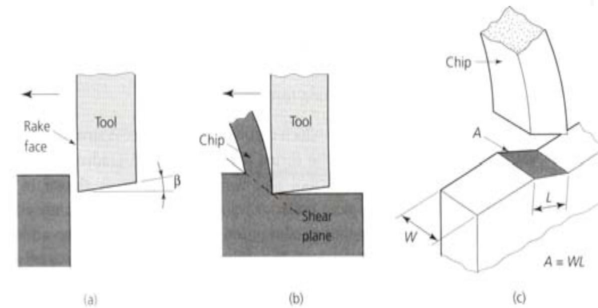
2.2 Pembentukan Serpihan

- **Regardless** of the **tool** being used or the **metal** being cut, the chip-forming process occurs by a mechanism called **plastic deformation**. This deformation can be visualized as **shearing**, that is when a metal is subjected to a load exceeding its elastic limit, the crystals of the metal elongate through the action of slipping or shearing, which takes place within the crystals and between adjacent crystals. This action is similar to the action that takes place when a **deck of cards** is given a push and sliding or shearing occurs between individual cards.



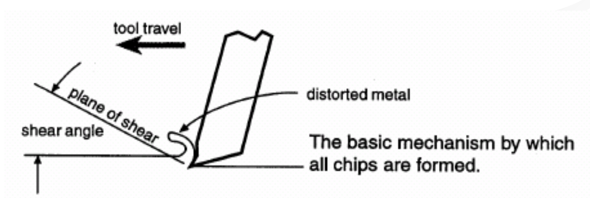
2.2 Pembentukan Serpihan

- The fundamental mode of material removal in cutting is by chip formation. The stages involved in chip removal are: workpiece moves relative to a cutting edge, which then penetrates the surface, the workpiece material near the surface is sheared by the cutting edge to form a chip.

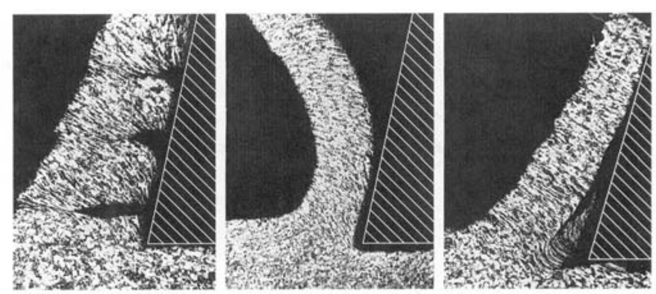


2.3 Types of Chips

- **During the machining process three basic types of chips are formed:**
  - Discontinuous chips
  - Continuous chips
  - Continuous chips with a built-up edge (BUE)



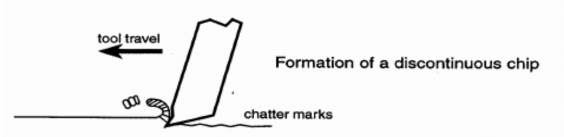
2.3 Types of Chips



Three types of chips (Left to right). Discontinuous, continuous and continuous with built-up-edge

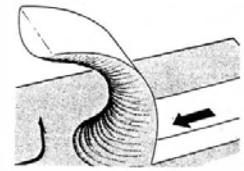
2.3 Types of Chips

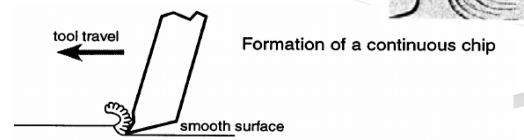
- **Discontinuous chips**
  - Typically associated with brittle metals like Cast Iron
  - As feed is increased, some compression takes place
  - As the chip starts up the chip-tool interference zone, increased stress occurs until the metal reaches a saturation point and fractures off the work-piece.
- **Conditions which favor a discontinuous type of chip**
  - Brittle work material
  - Small rake angles on cutting tools
  - Coarse machining feeds
  - Low cutting speeds
  - Major disadvantage—could result in poor surface finish



2.3 Types of Chips

- **Continuous Chips**
  - Continuous "ribbon" of metal that flows up the chip/tool zone.
  - Usually considered the ideal condition for efficient cutting action.
- **Conditions which favor a continuous type of chip**:
  - Ductile work
  - Fine feeds
  - Sharp cutting tools
  - Larger rake angles
  - Proper cutting speeds
  - Proper coolants

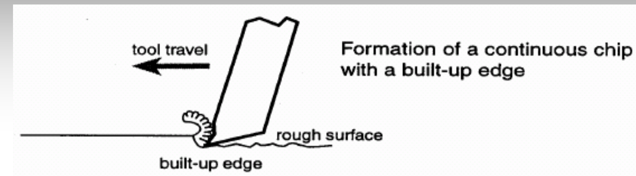




2.3 Types of Chips

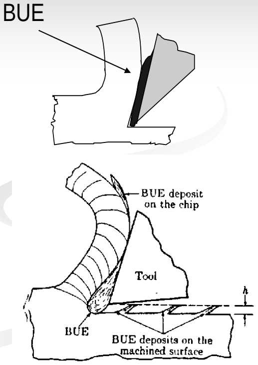
- **Continuous chips with a built-up edge (BUE)**
  - Same process as continuous, but as the metal begins to flow up the chip-tool zone, small particles of the metal begin to adhere or weld themselves to the edge of the cutting tool
  - As the particles continue to weld to the tool it effects the cutting action of the tool including the beginning of gauling
- **Conditions which favor a BUE type of chip**:
  - This type of chip is common in softer non-ferrous metals and low carbon steel
  - BUE chip formation increases as the tool begins to dull
- **Problems associated with BUE chip formation**
  - Welded edges break off and can become embedded in work-piece
  - Decreases tool life
  - Can result in poor surface finishes

2.3 Types of Chips



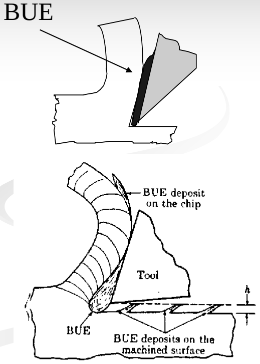
2.3 Types of Chips

- Built Up Edge (BUE)
  - Some of the cut material will attach to the cutting point.
  - This tends to cause the cut to be deeper than the tip of the cutting tool and degrades surface finish.
  - Also, periodically the built up edge will break off and remove some of the cutting tool. Thus, tool life is reduced.



2.3 Types of Chips

- Built Up Edge (BUE)
  - built up edge can be reduced by:
    - Increasing cutting speed
    - Decreasing feed rate
    - Increasing rake angle
    - Reducing friction (by applying cutting fluid)



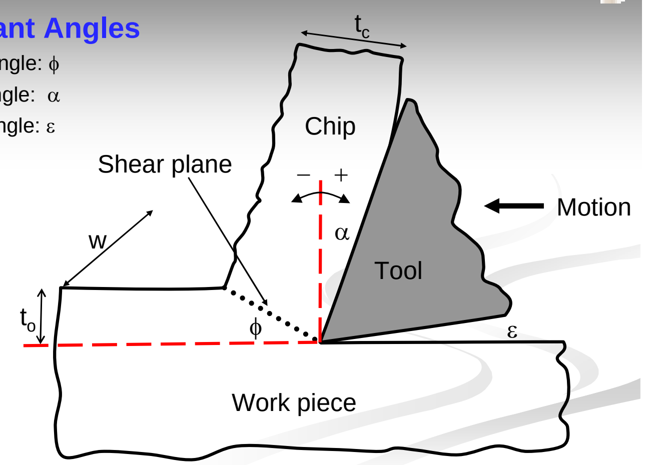
2.4 Sudut Satah Ricih

- A cutting model is required to be able to predict the angle at which a chip will shear and to relate this angle to the angle the tool tip makes with the workpiece. An understanding of these relationships will lead to a prediction of chip types and therefore provide control over surface finish. This is particularly important, in an automated system, when a computer is required to set up cutting parameters for particular workpiece. The basic mechanics of cutting can be studied by developing a two-dimensional or orthogonal cutting model.

Orthogonal cutting model

Important Angles

- Shear angle: ϕ
- Rake angle: α
- Relief angle: ε



Persamaan sudut satah ricih

- Is the plane where slip occurs to begin chip formation. A plane which separate the deformed and undeformed crystal structure of the work material.
- Based of a simplified orthogonal cutting model, shear angle can be accurately estimated.
- As an indicator or parameter on the mechanics of metal cutting.
- Terangkan 3 cara untuk mendapatkan nilai bagi tebal serpihan

Shear angle - chip thickness

- This indicates that as the rake angle decreases and/or as the friction at the tool-chip interface increases, the shear angle decreases, and the chip is thus thicker. The rake angle α can thus be used to control the chip thickness.
- The chip thickness is an important dependent variable in single-point machining. Thicker chips mean that higher cutting energy is required. More of the input power is converted to heat because of the increased shear strain. Different types of chips are formed for different chip thickness and this significantly influences the final surface finish.

2.5 Daya Pemotongan

ASSUMPTIONS

- process adequately represented by two-dimensional geometry
- tool is perfectly sharp tool only contact workpiece on its front (rake face)
- primary deformation occurs in a very thin zone adjacent to the shear plane
- cutting edge is perpendicular to cutting direction
- the chip does not flow to the side
- continuous chip without built up edge
- tool cutting edge is wider than the workpiece
- minimum work principle applicable

Daya Pemotongan

Three Sets Of Forces

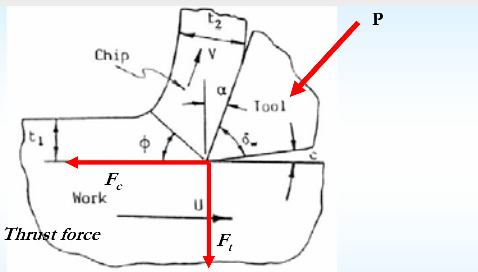
- Forces acting on the cutting edge, Fc, Ft, Fr
- Forces at the cutting edge-chip interface, F, N
- Forces on the shear plane, Fs, Fn

Three Laws Of Mechanics Applicable

- The law of addition and resolution of vectors
- Newton first law on the equilibrium of forces
- Newton third law on the action and reaction of forces

The cutting force

- Externally applied forces

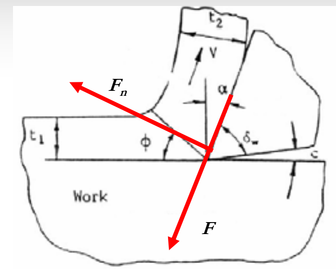


F_c – *Cutting force*, F_t – *Thrust force*

U = Cutting speed (m/min)	ϕ = Shear angle (deg.)
V = Chip velocity (m/min)	α = Tool rake angle (deg.)
t_1 = Undeformed chip thickness (mm)	c = Tool clearance angle (deg.)
t_2 = Chip thickness (mm)	δ_w = Wedge angle (deg.)

The cutting force

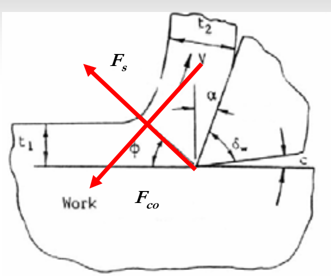
- Forces on the tool



F – *Friction force*, F_n – *Normal force*

The cutting force

- Forces on the chip

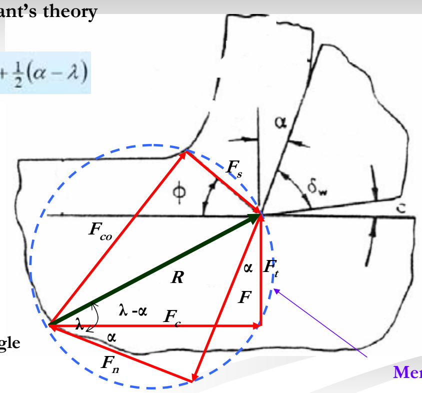


F_s – *Shear force*, F_{co} – *Compressive force*

The cutting force

- Merchant's theory

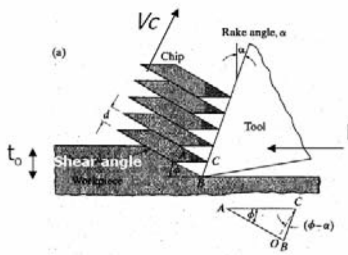
$$\phi = \pi/4 + \tfrac{1}{2}(\alpha - \lambda)$$



λ – friction angle

Basic cutting geometry

- We will use the orthogonal model



Continuity

$V \cdot t_o = V_c \cdot t_c$

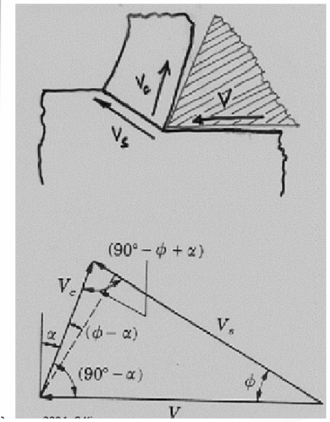
t_c: *chip thickness*

t_o: *depth of cut*

Cutting ratio: *r <1*

$$\frac{V_c}{V}=\frac{t_o}{t_c}=r=\frac{\sin(\varphi)}{\cos(\varphi-\alpha)}$$

Velocity diagram in cutting zone



Law of sines

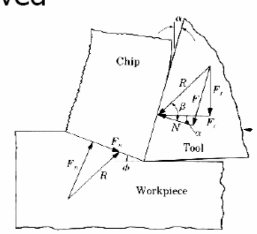
$$\frac{V}{\cos(\varphi-\alpha)}=\frac{V_s}{\cos(\alpha)}=\frac{V_c}{\sin(\varphi)}$$

$$\frac{V_c}{V}=\frac{t_o}{t_c}=r=\frac{\sin(\varphi)}{\cos(\varphi-\alpha)}$$

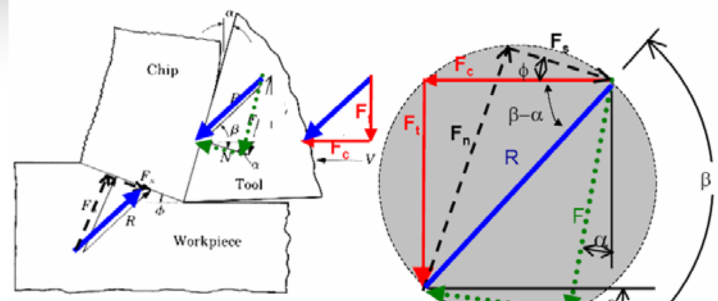
$$V_c=\frac{V\sin(\varphi)}{\cos(\varphi-\alpha)}$$

Forces and power

- FBD at the tool-workpiece contact
- What are the forces involved
  - Thrust force, Ft
  - Cutting force, Fc
  - Resultant force, R
  - Friction force, F
  - Normal Force, N
  - Shear Force, Fs, Fn



E. Merchant's cutting diagram



Source: Kalpajkian

FBD of Forces

$F = R \cdot \sin(\beta)$ $\quad \beta$ = Friction Angle $\quad Ft = R \cdot \sin(\beta - \alpha)$

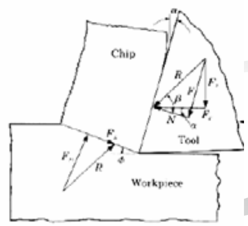
$N = R \cdot \cos(\beta)$ $\quad \mu = \tan(\beta)$ $\quad Fc = R \cdot \cos(\beta - \alpha)$

$$F_s = F_c \cdot \cos(\varphi) - F_t \cdot \sin(\varphi) = R\cos(\varphi + \beta - \alpha)$$

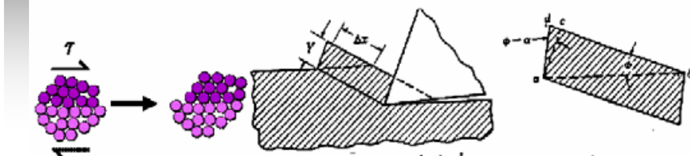
$$F_n = F_c \cdot \sin(\varphi) + F_t \cdot \cos(\varphi)$$

$$\mu = \frac{F}{N} = \frac{F_t + F_c \cdot \tan(\alpha)}{F_c - F_t \cdot \tan(\alpha)}$$

Typcially: $0.5 < \mu < 2$



Analysis of shear strain



$$\gamma = \frac{\Delta x}{\Delta y} = \frac{bc + cd}{ac} = \cot\phi + \tan(\phi - \alpha)$$

- What does this mean:
  - Low shear angle = large shear strain
- Merchant's assumption: Shear angle adjusts to minimize cutting force or max. shear stress
- Can derive:

$$\phi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2}$$

Shear angle

$$Fc = R \cdot \cos(\beta - \alpha)$$

$$F_s = F_c \cdot \cos(\varphi) - F_t \cdot \sin(\varphi) = R\cos(\varphi + \beta - \alpha)$$

$$F_c = Fs\ \cos(\beta - \alpha) / \cos(\varphi + \beta - \alpha)$$

$F_s = As.\sigma s$ (area of shear plane. shear strength)

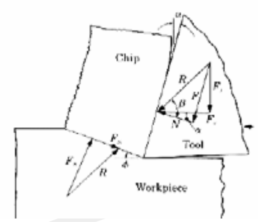
$$F_c = \sigma_s \frac{A}{\sin\varphi} \cos(\beta - \alpha) / \cos(\varphi + \beta - \alpha)$$

$dFc/d\varphi = 0 \longrightarrow \phi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2}$

Things to think about

- As rake angle decreases or friction increases
  - Shear angle decreases
  - Chip becomes thicker
  - Thicker chip = more energy dissipation via shear
  - More shear = more heat generation
  - Temperature increase!!!

$$\varphi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2}$$



Power

Power input : $F_c \cdot V$ => shearing + friction

Power for shearing : $F_s \cdot V_s$

Specific energy for shearing : $u_s = \dfrac{F_s \cdot V_s}{w \cdot t_o \cdot V}$ ← MRR

Power dissipated via friction : $F \cdot V_c$

Specific energy for friction : $u_f = \dfrac{F \cdot V_c}{w \cdot t_o \cdot V}$

Total specific energy : $u_s + u_f = \dfrac{F \cdot V_c}{w \cdot t_o \cdot V} + \dfrac{F_s \cdot V_s}{w \cdot t_o \cdot V}$

Experimantal data

Specific energy (rough estimate)

Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

Material	Specific energy $W \cdot s/mm^3$	Specific energy $hp \cdot min/in.^3$
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4