MANUFACTURING PROCESSES: (TA-202)

Fundamentals of Cutting

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ORGANIZATION

NATURE OF RELATIVE MOTION BETWEEN THE TOOL AND WORKPIECE

FUNDAMENTALS OF CUTTING

FACTORS INFLUENCING CUTTING PROCESS

MECHANICS OF CHIP FORMATION

TYPES OF CHIPS

CHIP BREAKERS

CUTTING TOOL

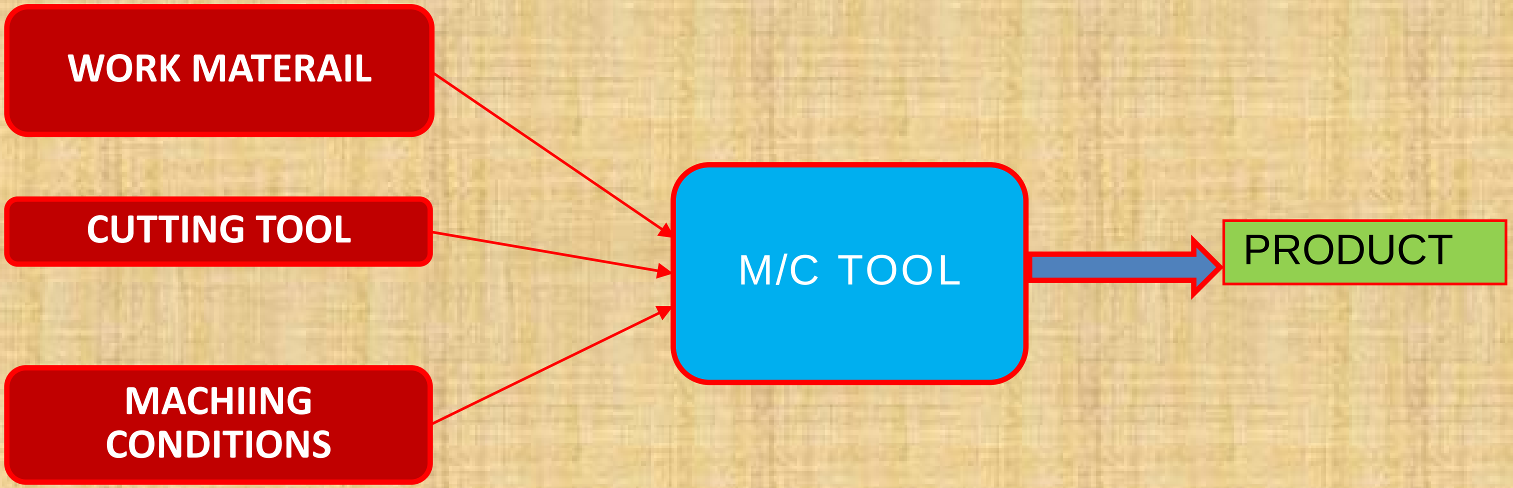
TYPES OF CUTTING

TEMPERATURE DISTRIBUTION

TOOL WEAR

ACKNOWLEDGEMENT: A GOOD NO. OF PHOTOGRAPHS ARE FROM THE BOOK BY KALPAKJIAN

INEFFICIENT BUT MOST IMPORTANT MANUFACTURING PROCESS



WORK MATERAIL

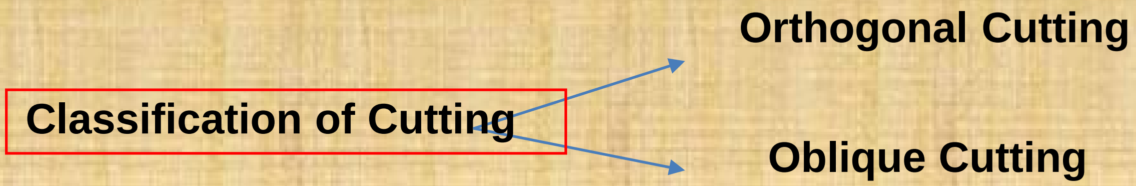
CUTTING TOOL

MACHIING CONDITIONS

M/C TOOL

PRODUCT

Metal Cutting Plastic Deformation/Flow Process



Classification of Cutting

Orthogonal Cutting

Oblique Cutting

MATERIAL REMOVAL PROCESSES

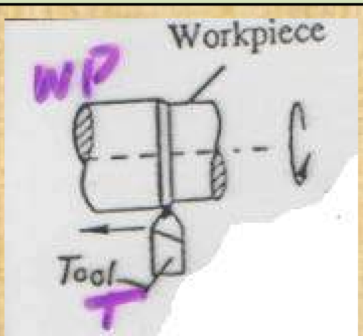
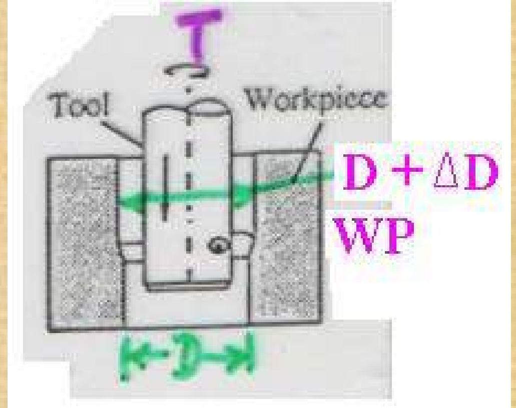
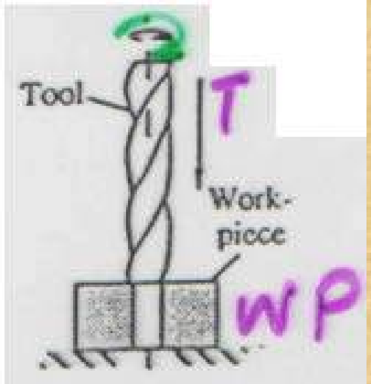
MRPs

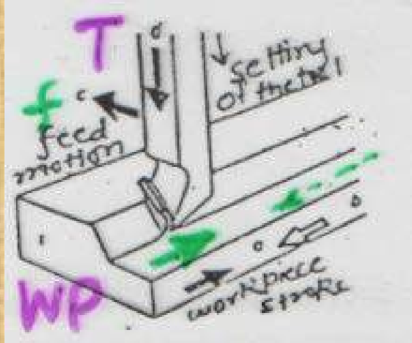
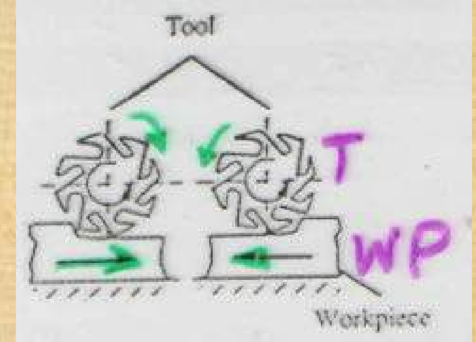
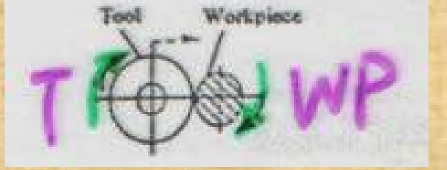
- Traditional
  - Cutting
    - Circular Shape
      - Turning
      - Drilling
      - Boring
    - Other/Prismatic Shape
      - Milling
      - Planning
      - Shaping
      - Gear Cutting
      - Broaching
  - Finishing
    - Bonded Abrasive
      - Grinding
      - Honing
      - Coated Abrasive
    - Loose Abrasive
      - Lapping
      - Polishing
- Advanced

Metal Cutting: Relative Motion between workpiece & cutting edge of tool

Cutting Tools: 1. Single Point tool
2. Multiple Point tool

NATURE OF RELATIVE MOTION BETWEEN THE TOOL AND WORKPIECE

OPERATION	MOTION OF JOB	MOTION OF CUTTING TOOL	FIGURE OF OPEARTION
TURNING	ROTARY	TRANSLATORY (FORWARD)	
BORING	ROTATION	TRANSLATION (FORWARD)	
DRILLING	FIXED (NO MOTION)	ROTATION AS WELL AS TRANSLATORY FEED	

PLANING	TRANSLATORY	INTERMITTENT TRANSLATION	
MILLING	TRANSLATORY	ROTATION	
GTRINDING	ROTARY / TRANSLATORY	ROTARY	

WHAT IS THE BASIC DIFFERENCE BETWEEN ?

TURNING
BORING
PLANING

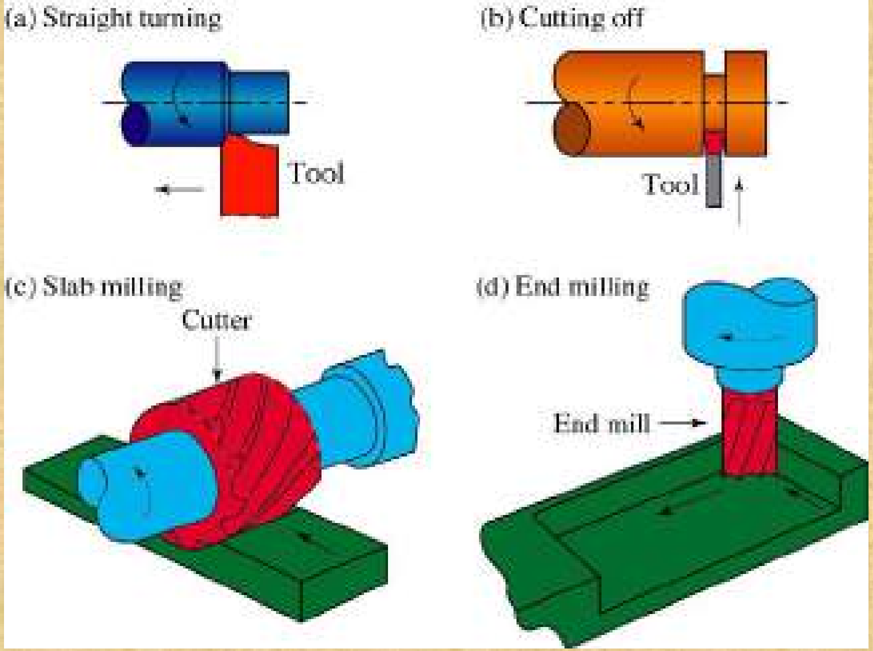
AND

DRILLING
MILLING
GRINDING

- SINGLE VS MULTI POINT
- CONTINUOUS AND INTERMITTENT

Fundamentals of Cutting

Examples of cutting processes.



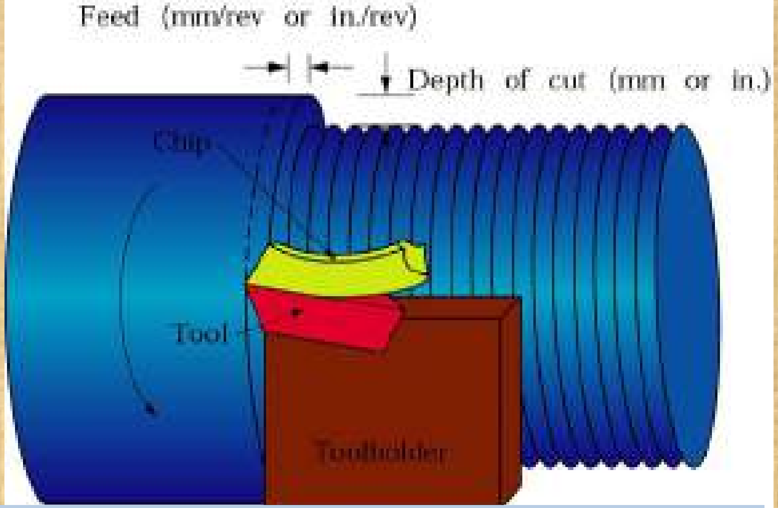


Figure: Basic principle of the turning operations.

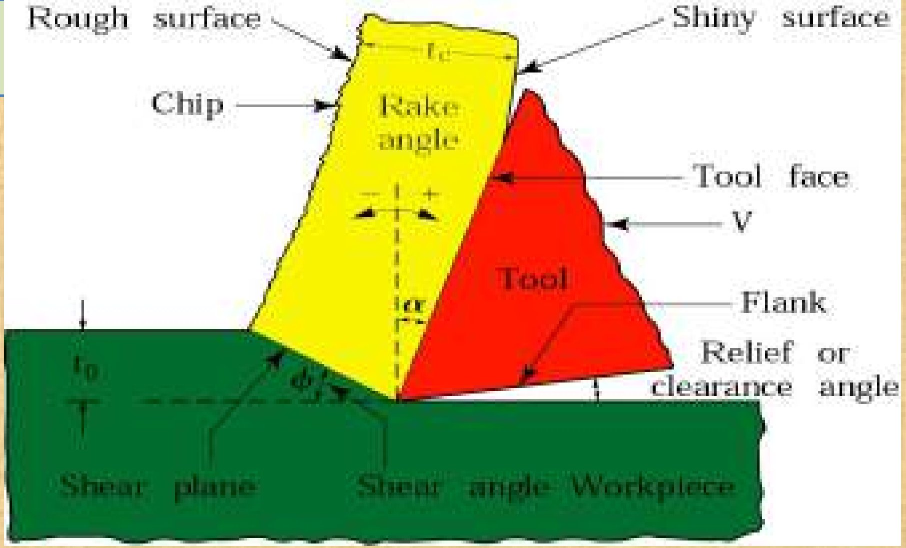


Figure: Two-dimensional cutting process, also called orthogonal cutting. Note that the tool shape and its angles, depth of cut, t_o, and the cutting speed, V, are all independent variables.

Types of Cutting

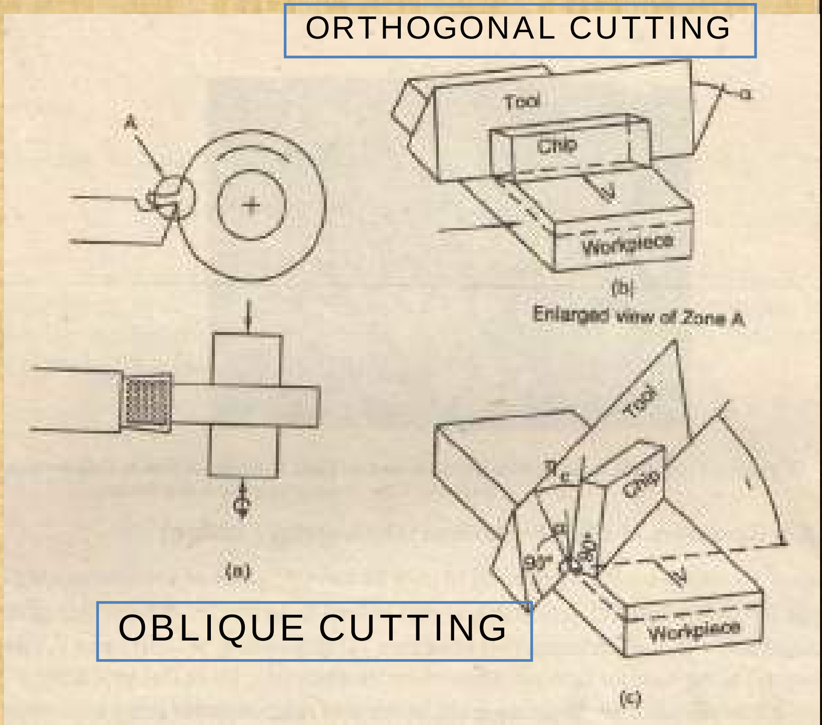
o Orthogonal Cutting (2-D Cutting):

Cutting edge is (1) straight, (2)parallel to the original plane surface on the work piece and (3)perpendicular to the direction of cutting. For example:

Operations: Lathe cut-off operation, Straight milling, etc.

o Oblique Cutting (3-D Cutting):

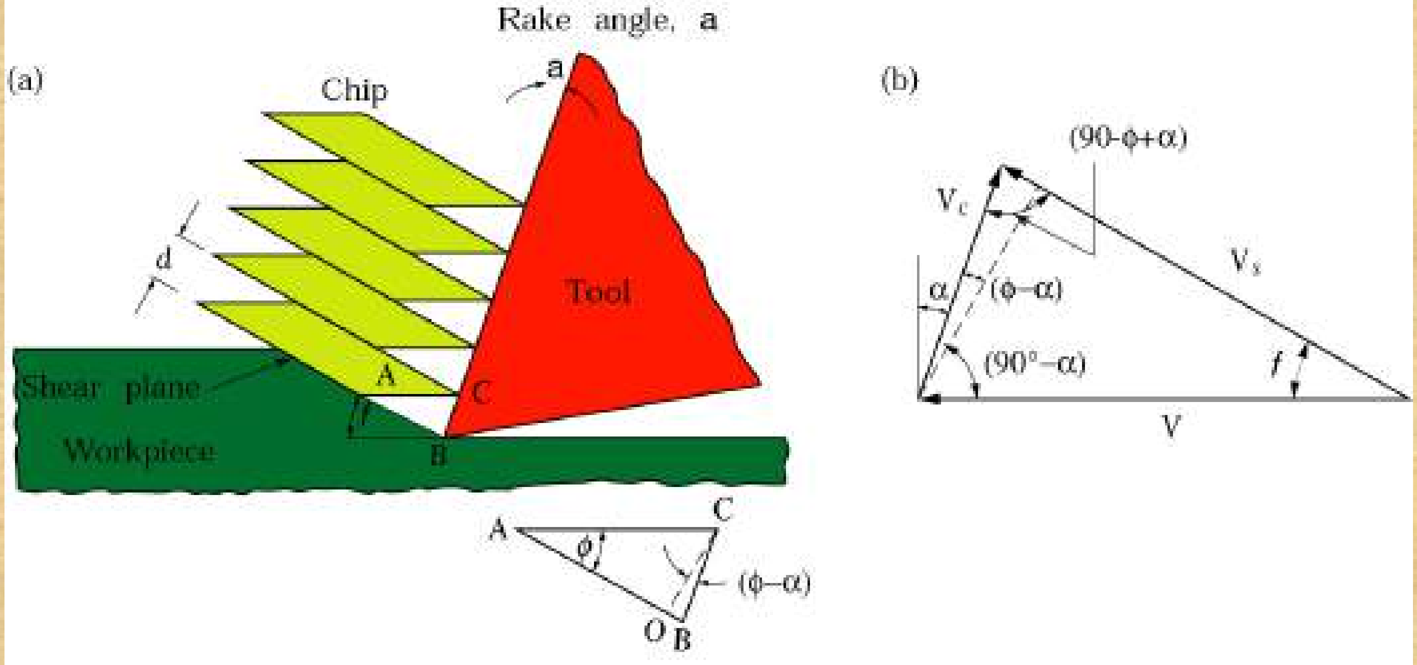
Cutting edge of the tool is inclined to the line normal to the cutting direction. In actual machining, Turning, Milling etc. / cutting operations are oblique cutting(3-D)



Factors Influencing 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.
TOOL ANGLES	AS ABOVE, INFLUENCE ON CHIP FLOW DIRECTION, RESISTANCE TO TOOL CHIPPING.
CONTINUOUS CHIP	GOOD SURFACE FINISH; STEADY CUTTING FORCES; UNDESIRABLE IN AUTOMATED MACHINERY.
BUILT-UP EDGE CHIP	POOR SURFACE FINISH, THIN STABLE EDGE CAN PROTECT TOOL SURFACES.
DISCONTINUOUS CHIP	DESIRABLE FOR EASE 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, DIMENSIONAL ACCURACY, TEMPERATURE RISE, FORCES AND POWER.
TOOL WEAR MACHINABILITY	RELATED TO TOOL LIFE, SURFACE FINISH, FORCES AND POWER

Mechanics of Chip Formation



(a) Basic mechanism of chip formation in metal cutting. (b) Velocity diagram in the cutting zone.

V=> Cutting velocity, Vs= Shear velocity, Vc=Chip velocity

Φ= Shear angle, α=Rake angle

MECHANICS OF CHIP FORMATION

- ✓ Plastic deformation along shear plane (Merchant)
- ✓ The fig. where the work piece remains stationary and the tool advances in to the work piece towards left.
- ✓ Thus the metal gets compressed very severely, causing shear stress.
- ✓ This stress is maximum along the plane is called shear plane.
- ✓ If the material of the workpiece is ductile, the material flows plastically along the shear plane, forming chip, which flows upwards along the face of the tool.
- ✓ The tool will cut or shear off the metal, provided by;
    - The tool is harder than the work metal
    - The tool is properly shaped so that its edge can be effective in cutting the metal.
    - Provided there is movement of tool relative to the material or vice versa, so as to make cutting action possible.

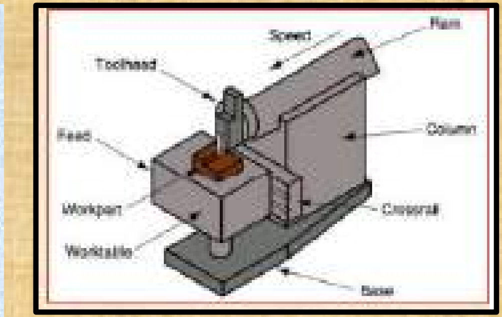


Fig: Shaping operation

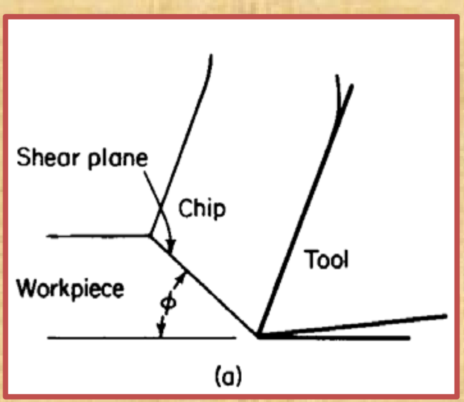


Fig: Shear Plane

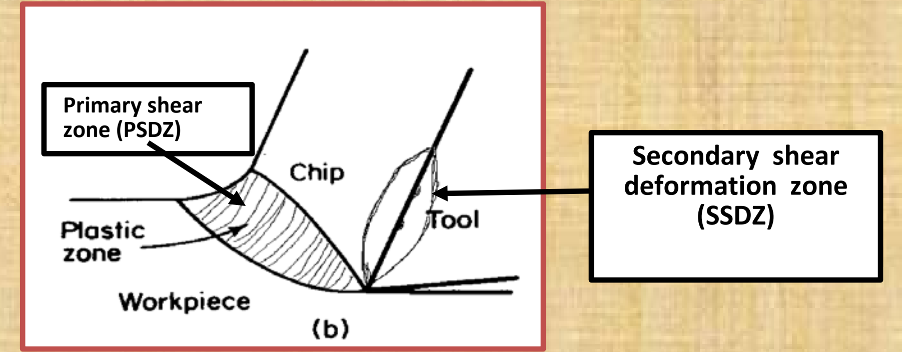


Fig: Shear deformation zones

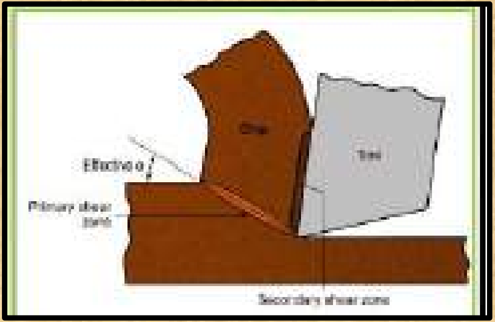
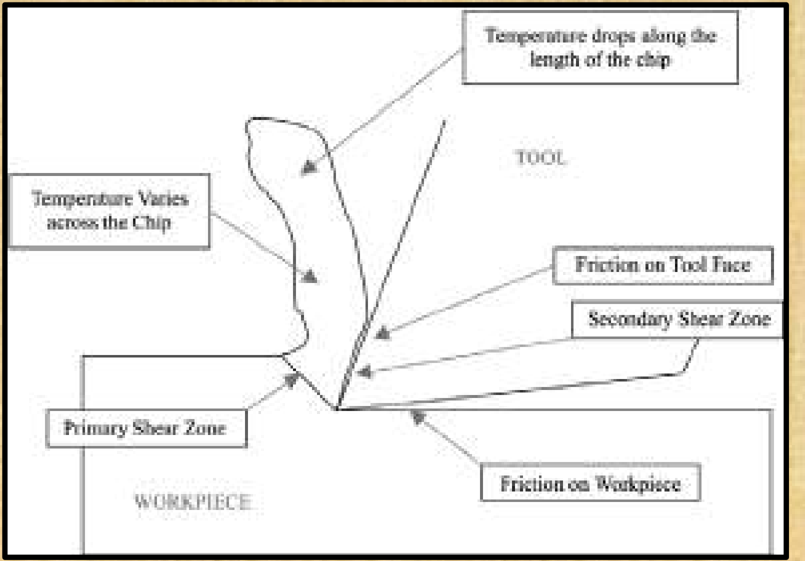


Fig: Shear deformation zones

CHIP FORMATION

Types of Chips

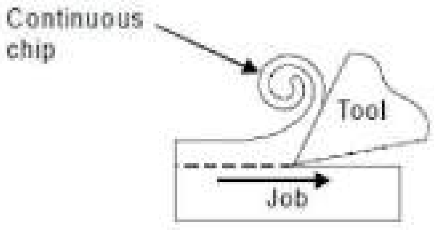
- ✓ Continues Chips
- ✓ Discontinues Chips
- ✓ Continuous Chips with Built up Edge (BUE)



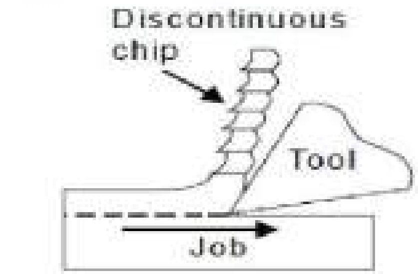
Fig; Schematic of chip formation

Conditions for Continuous Chips:

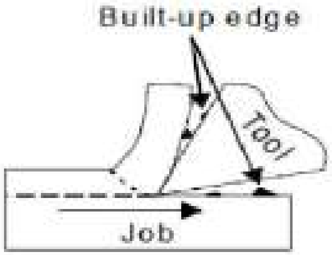
- Sharp cutting edges
- Low feed rate (f)
- Large rake angle ()
- Ductile work material
- High cutting speed (v=)
- Low friction at Chip-Tool interface



(a) Continuous chips



(b) Discontinuous chips



(c) Chips with built-up edge

Fig; Schematic of different types of chip

Types of Chips

(a) Continuous chip with narrow, straight primary shear zone;

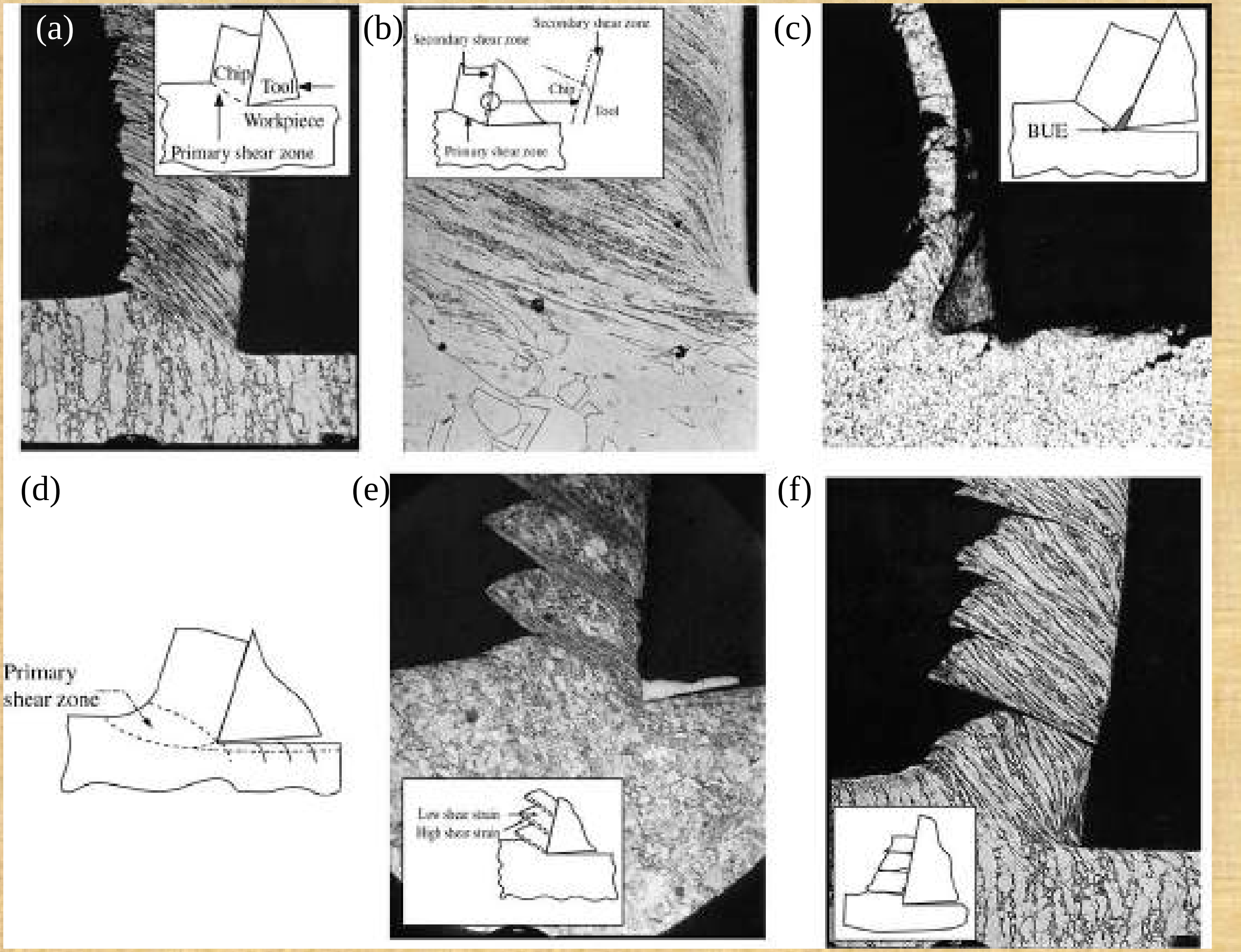
(b) Secondary shear zone at the chip-tool interface;

(c) Continuous chip with built-up edge

(d) Continuous chip with large primary shear zone

(e) Segmented or nonhomogeneous chip and

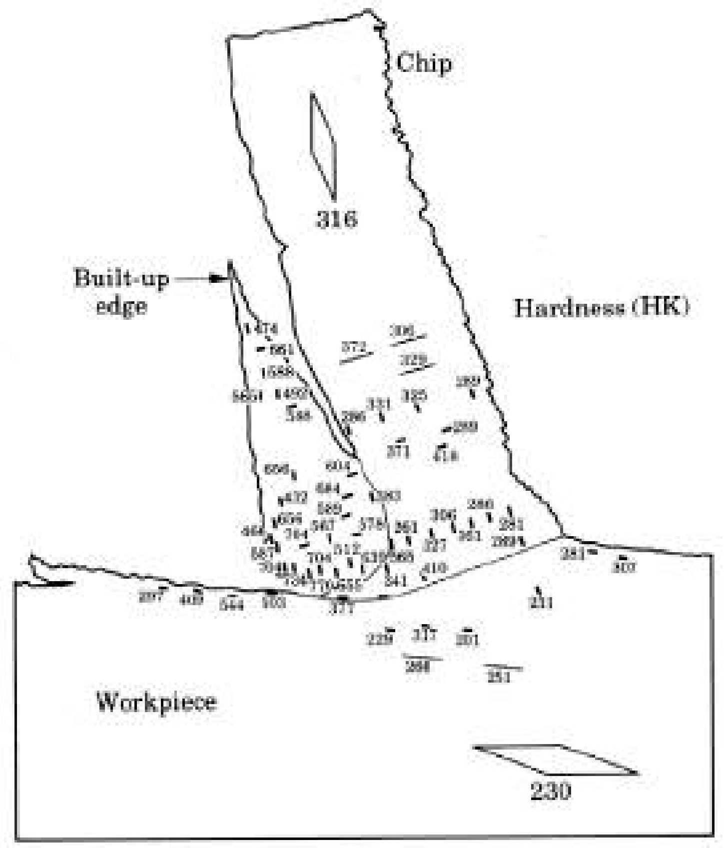
(f) Discontinuous chip.



Source: After M. C. Shaw, P. K. Wright, and S. Kalpakjian.

Built-Up Edge Chips

(a)



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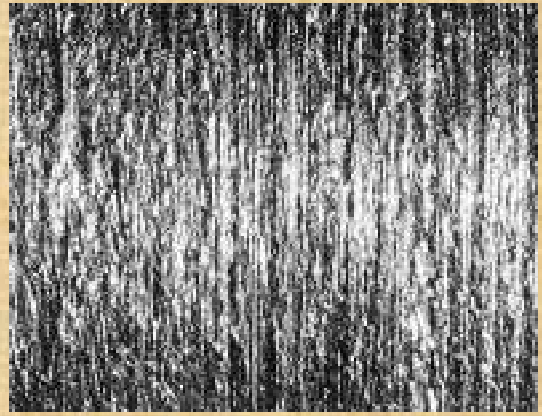
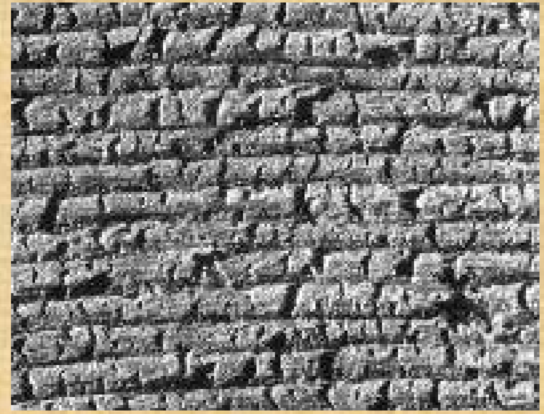


TURNING LAY

(c)



MILLING LAY

(a) Hardness distribution in the cutting zone for 3115 steel. Note that some regions in the built-up edge are as much as three times harder than the bulk metal.

(b) (b) Surface finish in turning 5130 steel with a built-up edge. (c) surface finish on 1018 steel in face milling. Magnifications: 15X. *Source*: Courtesy of Metcut Research Associates, Inc.

Continuous chip Results in:

- Good surface finish
- High tool life
- Low power consumptions

Discontinuous Chip:

Chip in the form of discontinuous segments:

- Easy disposal
- Good surface finish

Conditions for discontinuous chips:

- Brittle Material
- Low cutting speed
- Small rake angle

Built up Edge:

Conditions for discontinuous chips:

High friction between Tool & chip

Ductile material

Particles of chip adhere to the rake face of the tool near cutting edge

Chip- Breaking

- The chip breaker break the produced chips into small pieces.
- The work hardening of the chip makes the work of the chip breakers easy.
- When a strict chip control is desired, some sort of chip breaker has to be employed.
- The following types of chip breakers
  - a) Groove type
  - b) Step type
  - c) Secondary Rake type
  - d) Clamp type

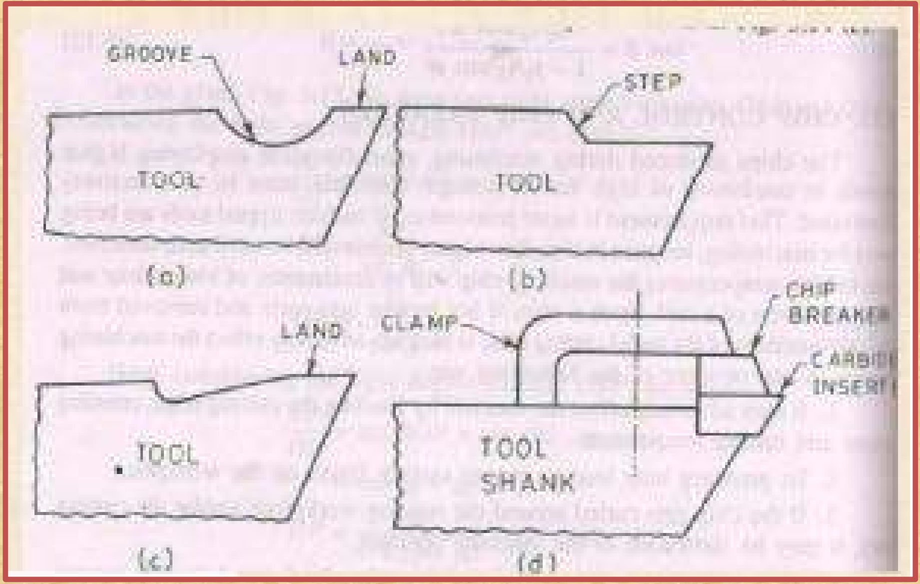
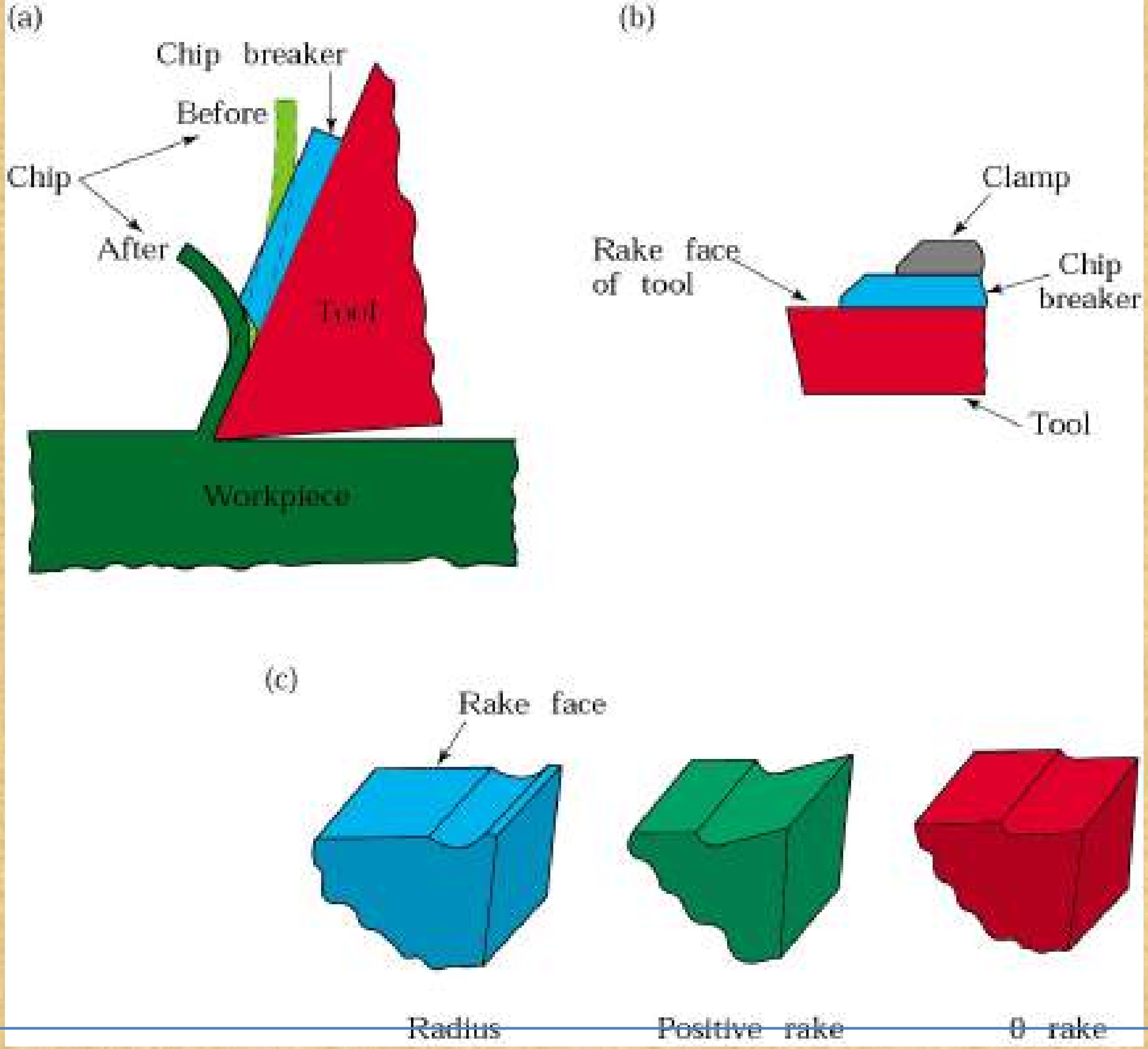


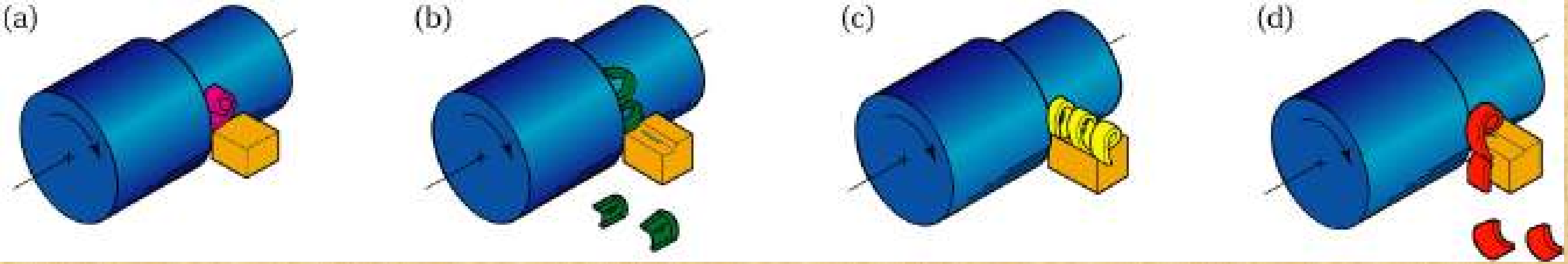
Fig: Schematics of different types of chip barkers

Chip Breakers



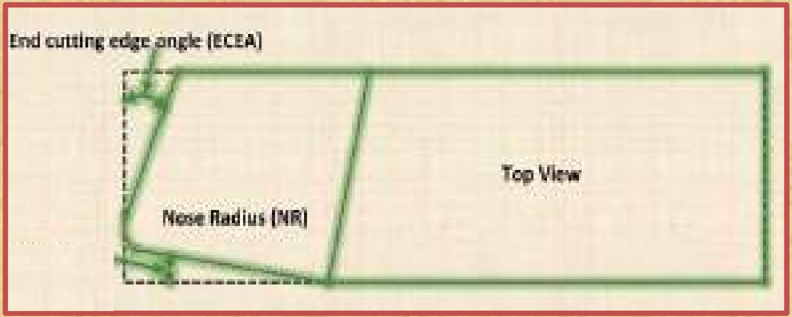
(a) Schematic illustration of the action of a chip breaker. Note that the chip breaker decreases the radius of curvature of the chip. (b) Chip breaker clamped on the rake face of a cutting tool. (c) Grooves in cutting tools acting as chip breakers.

Examples of Chips Produced in Turning

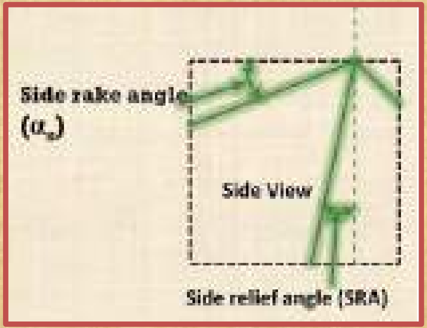


Various chips produced in turning: (a) tightly curled chip; (b) chip hits workpiece and breaks; (c) continuous chip moving away from workpiece; and (d) chip hits tool shank and breaks off. *Source*: G. Boothroyd, *Fundamentals of Metal Machining and Machine Tools*. Copyright © 1975; McGraw-Hill Publishing Company.

Tool Nomenclature/Angles



(a)



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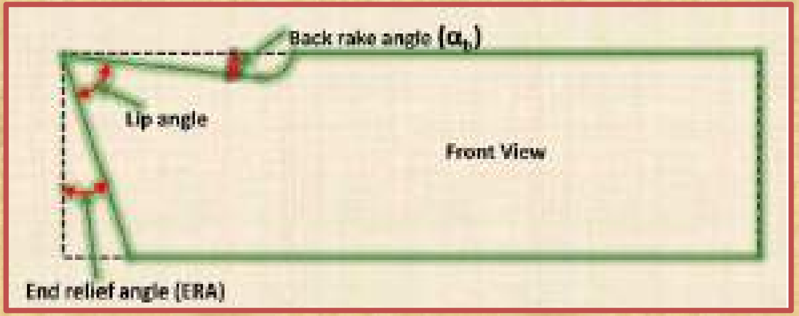

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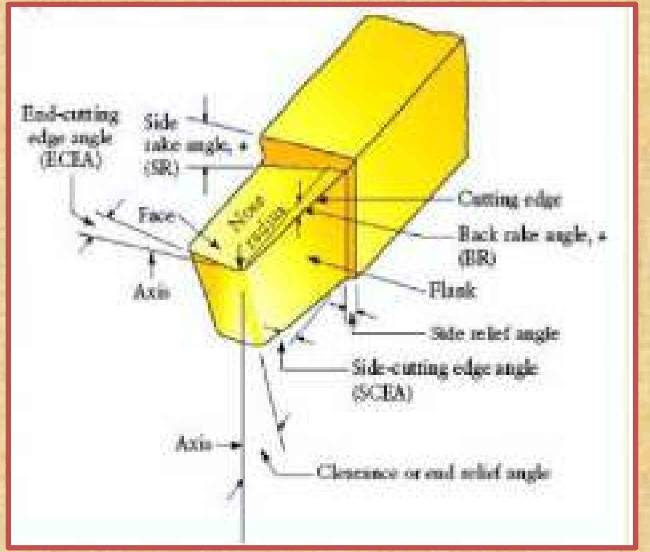


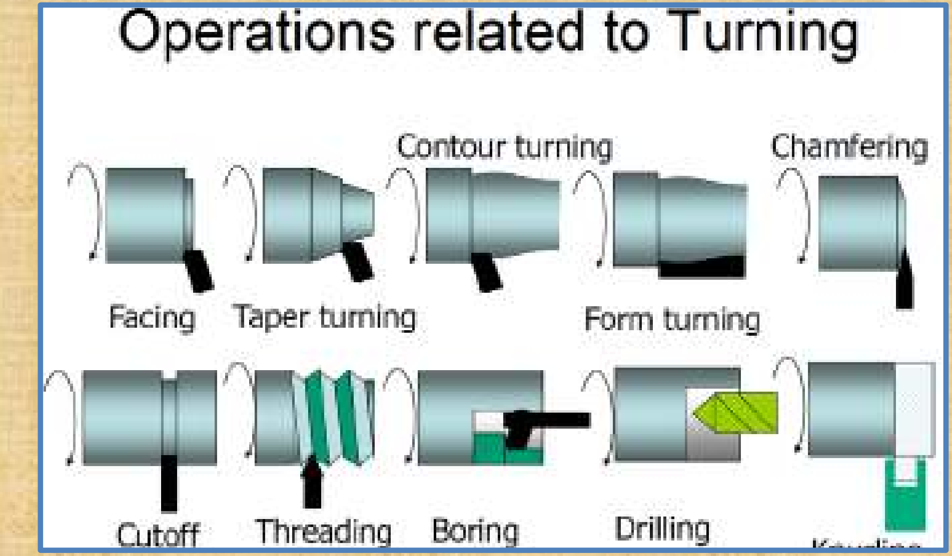
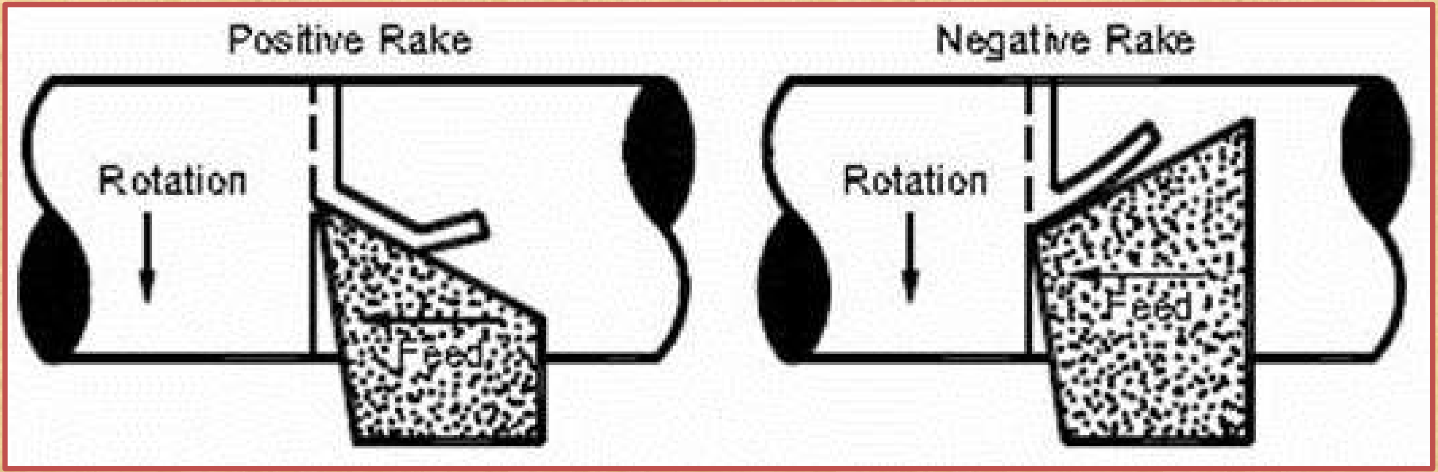
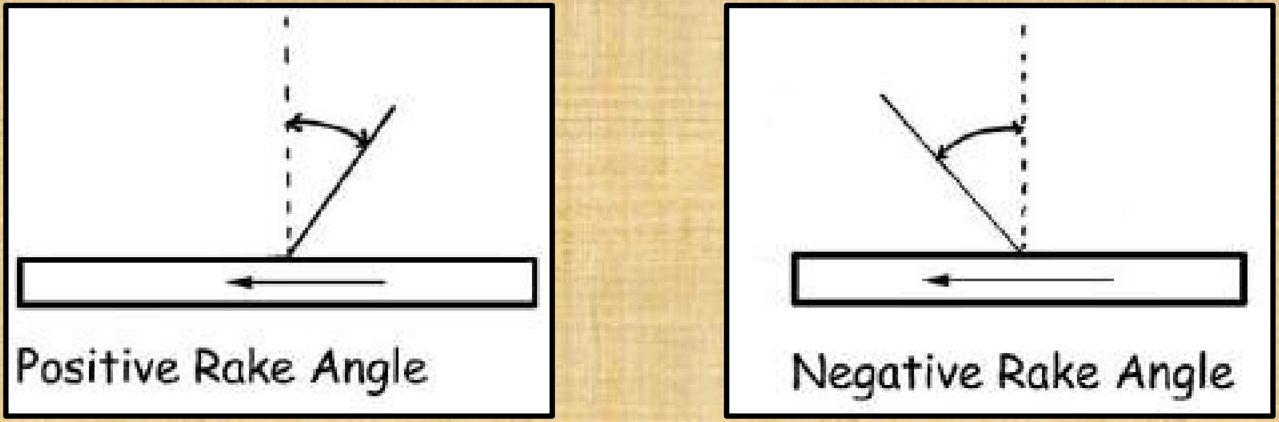


Fig: Turning Operations

Tool Nomenclature/Angles





(a)

(b)

Fig: Terms used in metal cutting (a) Positive rake; (b) Negative rake

Right-Hand Cutting Tool

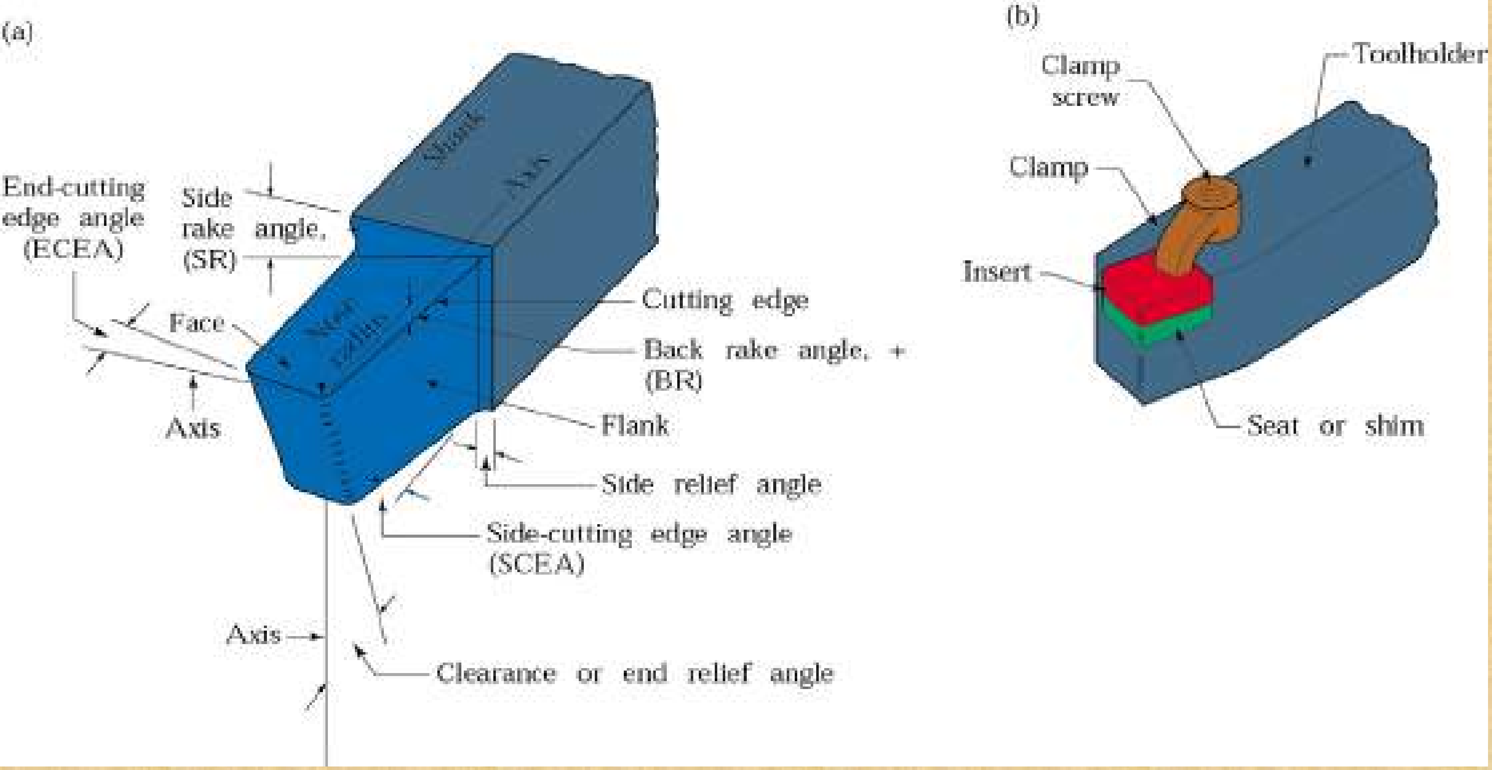


Figure 20.10 (a) Schematic illustration of a right-hand cutting tool. Although these tools have traditionally been produced from solid tool-steel bars, they have been largely replaced by carbide or other inserts of various shapes and sizes, as shown in (b). The various angles on these tools and their effects on machining are described in Section 22.3.1.

Types of Cutting

- **Orthogonal Cutting (2-D Cutting):**

Cutting edge is straight, parallel to the original plane surface at the work piece and perpendicular to the direction of cutting.

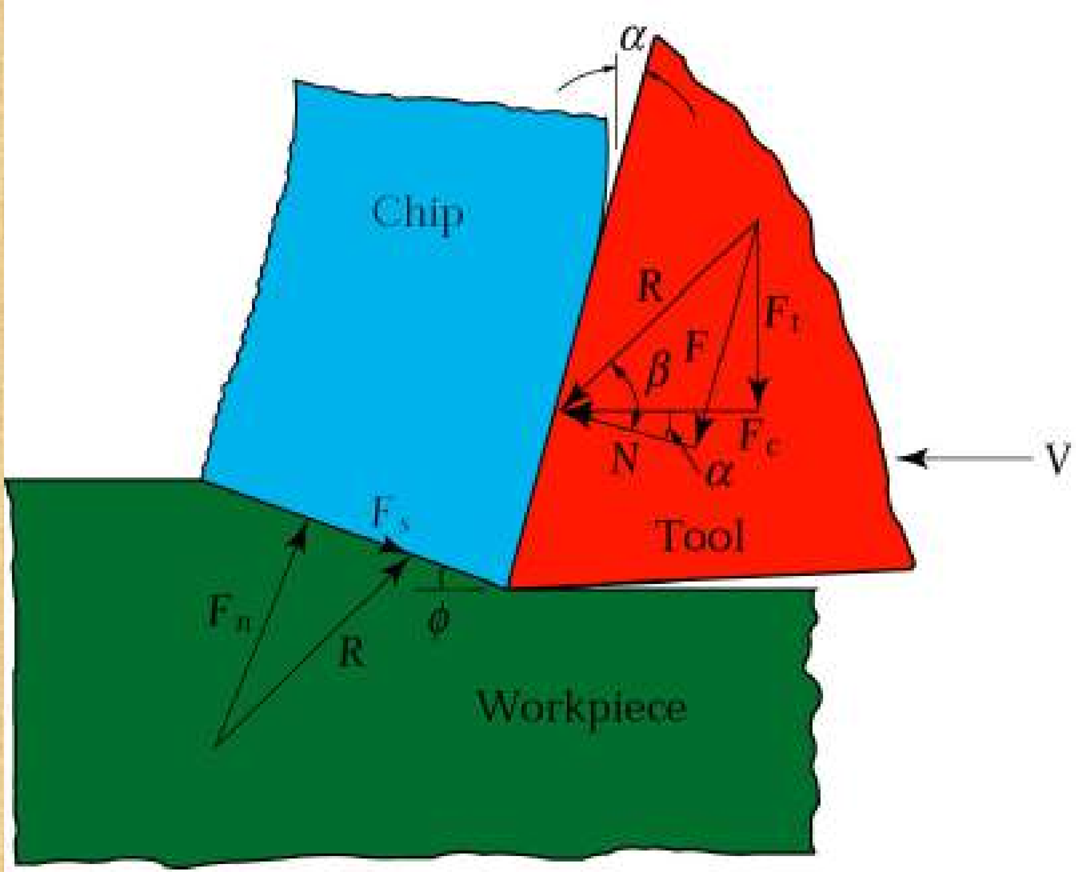
E.g. Operations:

- Lathe cut-off tools
- Straight milling cutters etc.

- **Oblique Cutting:**

Cutting edge of the tool is inclined to the line normal to the cutting direction. In actual machining, Turning, Milling etc/ cutting operations are oblique cutting(3-D

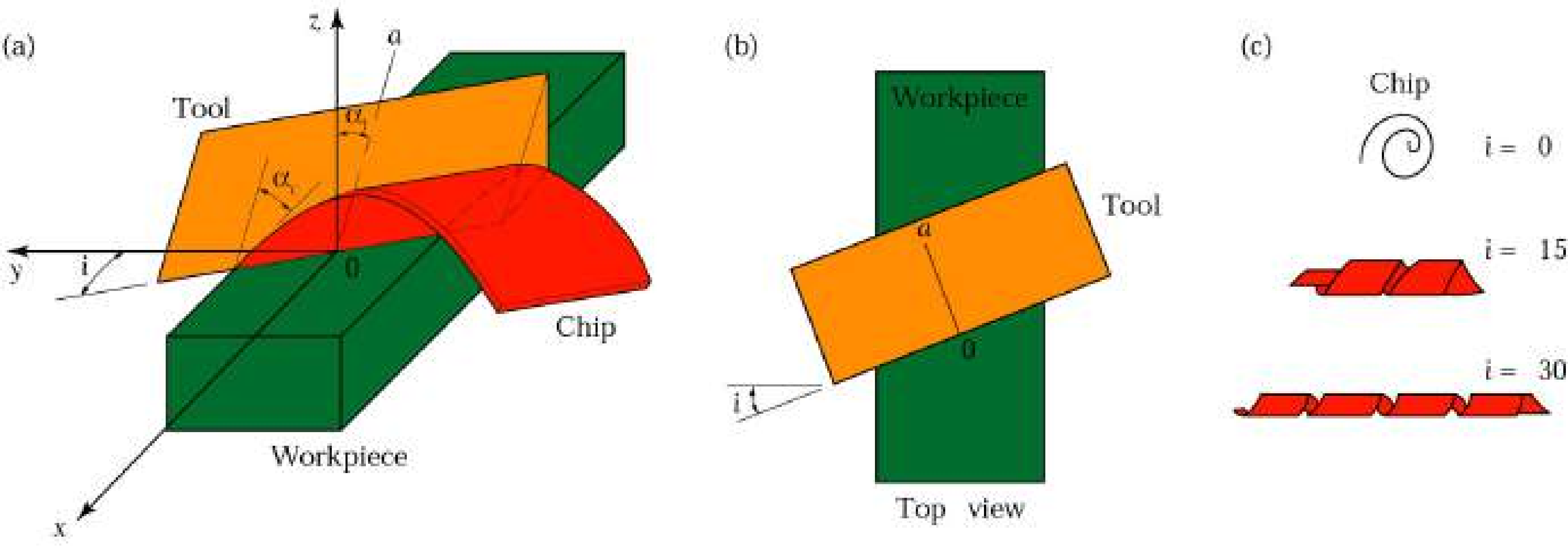
Forces in Two-Dimensional Cutting / Orthogonal Cutting



Forces acting on a cutting tool in two-dimensional cutting.

Note that the resultant force, *R*, must be collinear to balance the forces.

Cutting With an Oblique Tool



(a) Schematic illustration of cutting with an oblique tool.

(b) Top view showing the inclination angle, *i*.

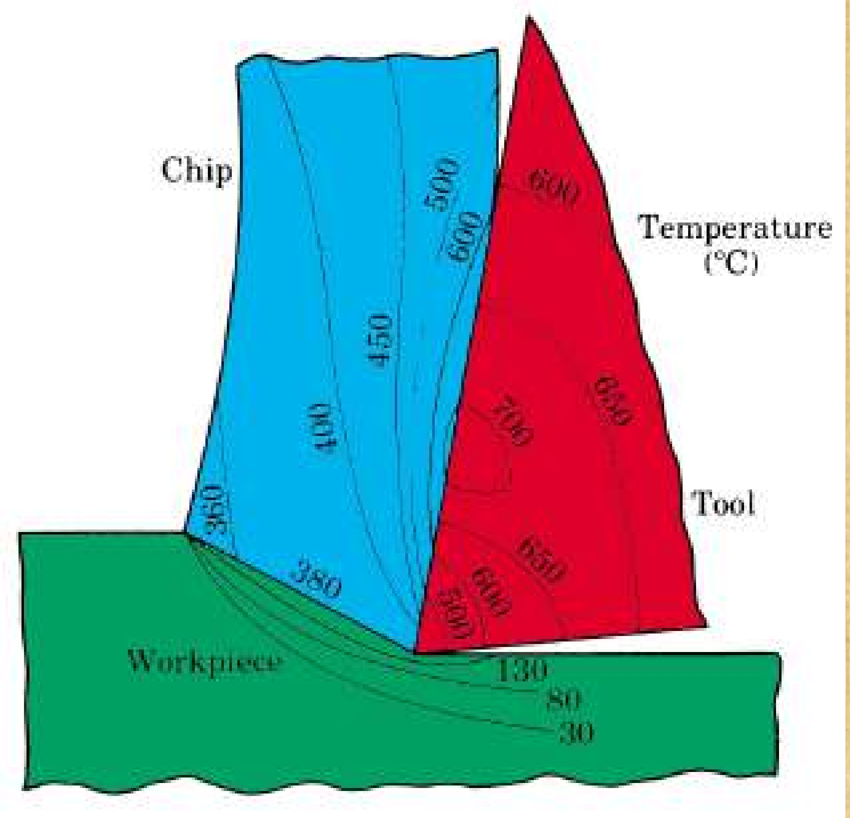
(c) Types of chips produced with different inclination.

Approximate Energy Requirements in Cutting Operations

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

	Specific energy	
Material	**W-s/mm^3**	**hp-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
Nickel alloys	0.4–0.6	0.15–0.2
Refractory alloys	4.9–6.8	1.8–2.5
Stainless steels	3.8–9.6	1.1–3.5
Steels	3.0–5.2	1.1–1.9
Titanium alloys	2.7–9.3	1.0–3.4
	3.0–4.1	1.1–1.5

Temperature Distribution and Heat Generated

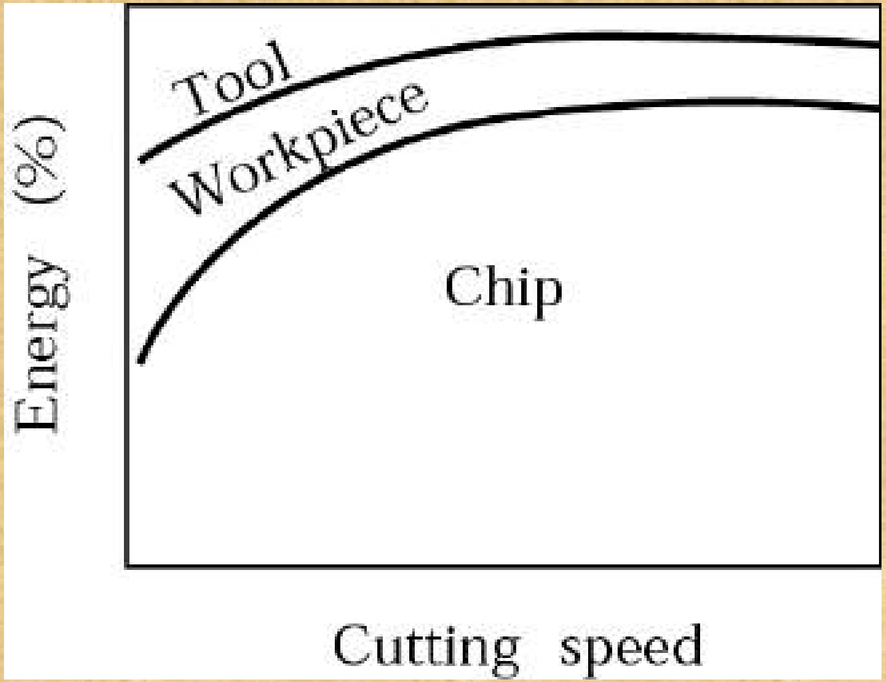


Typical temperature distribution in the cutting zone. Note the steep temperature gradients within the tool and the chip. :

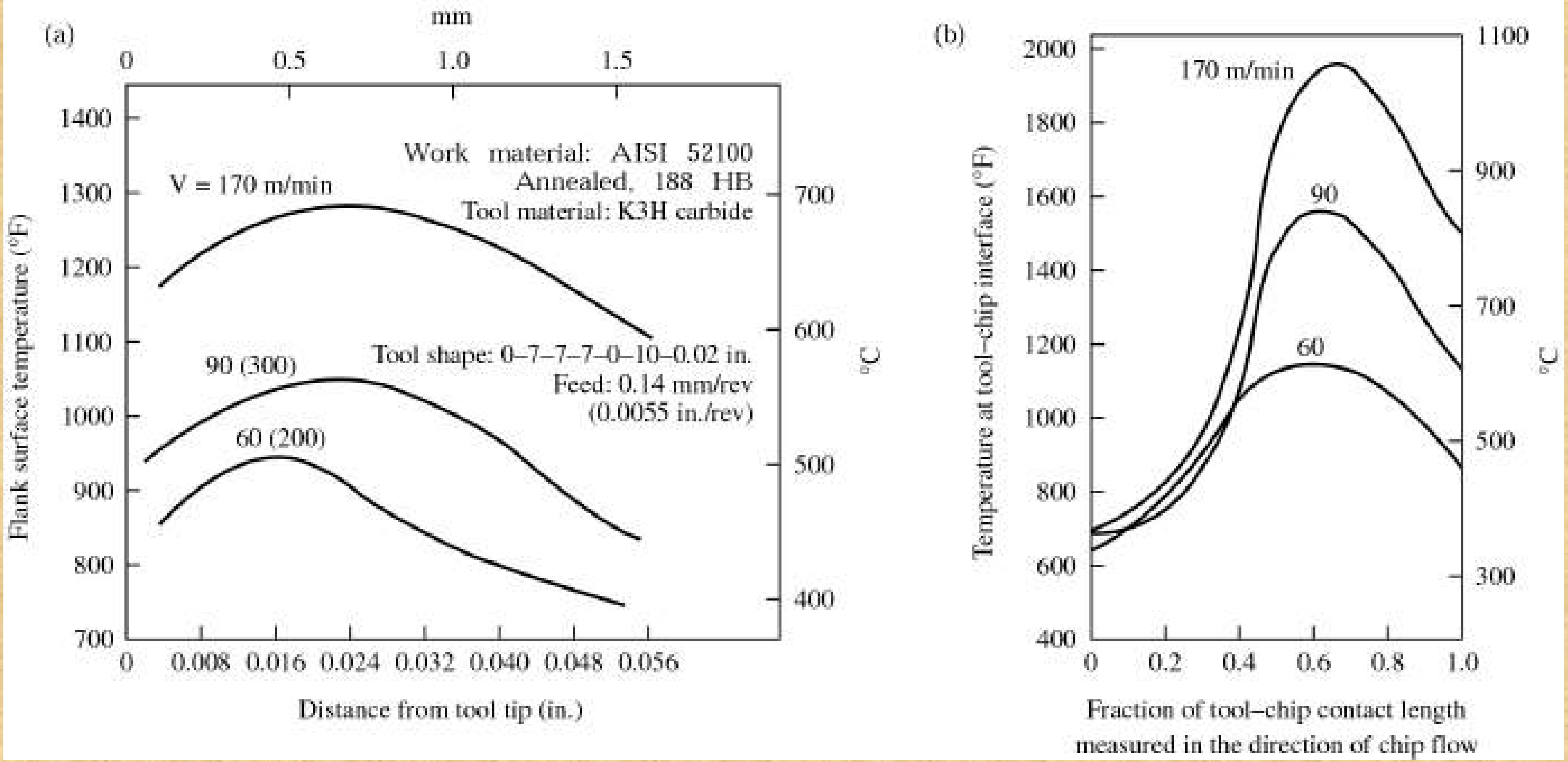
G. Vieregge. *Source*

Percentage of the heat generated in cutting going into the workpiece, tool, and chip, as a function of cutting speed.

Note:Chip carries away most of the heat.



Temperature Distributions



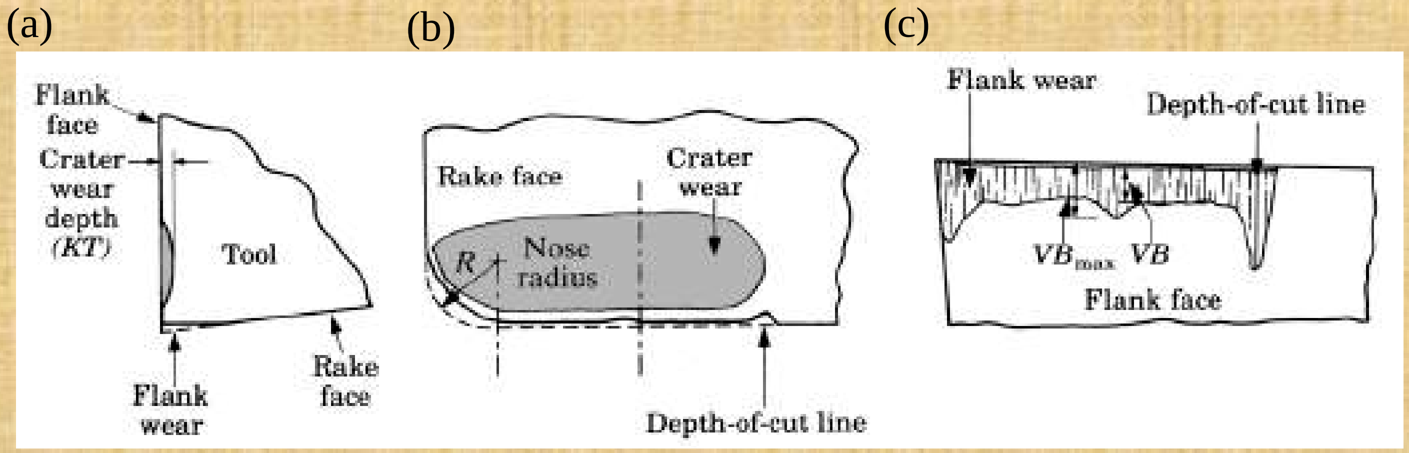
Temperatures developed in turning 52100 steel:

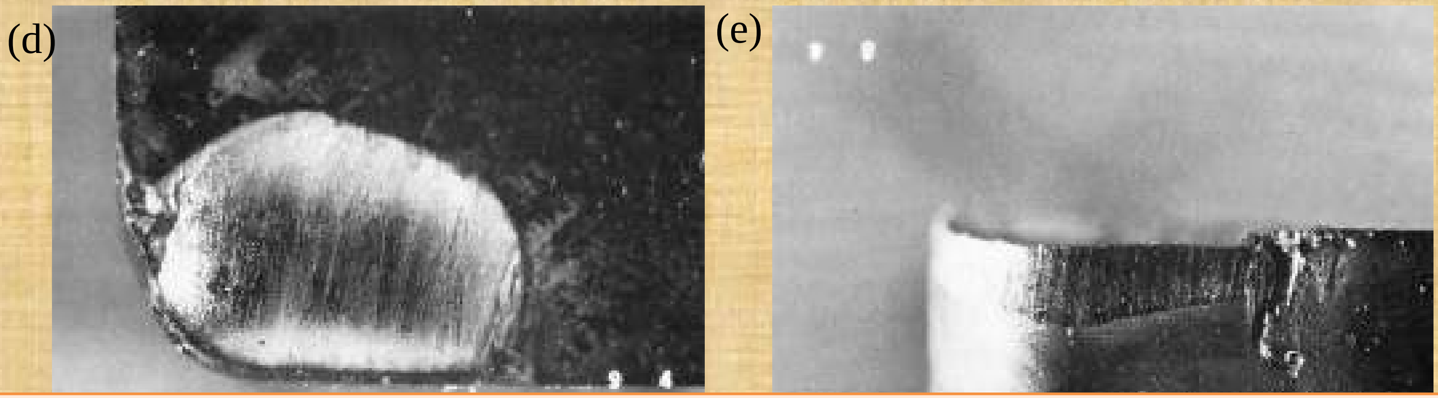
(a) flank temperature distribution; and

(b) tool-chip interface temperature distribution.

Source: B. T. Chao and K. J. Trigger.

Flank and Crater Wear





(a) Flank and crater wear in a cutting tool. Tool moves to the left.

(b) View of the rake face of a turning tool, showing nose radius *R* and crater wear pattern on the rake face of the tool.

(c) View of the flank face of a turning tool, showing the average flank wear land VB and the depth-of-cut line (wear notch).

(d) Crater and (e) flank wear on a carbide tool. *Source*: J.C. Keefe, Lehigh University.

Tool Wear

Allowable Average Wear Land (VB) for Cutting Tools in Various Operations

	Allowable wear land (mm)	
Operation	**High-speed Steels**	**Carbides**
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: 1 mm = 0.040 in.

Surfaces Produced by Cutting

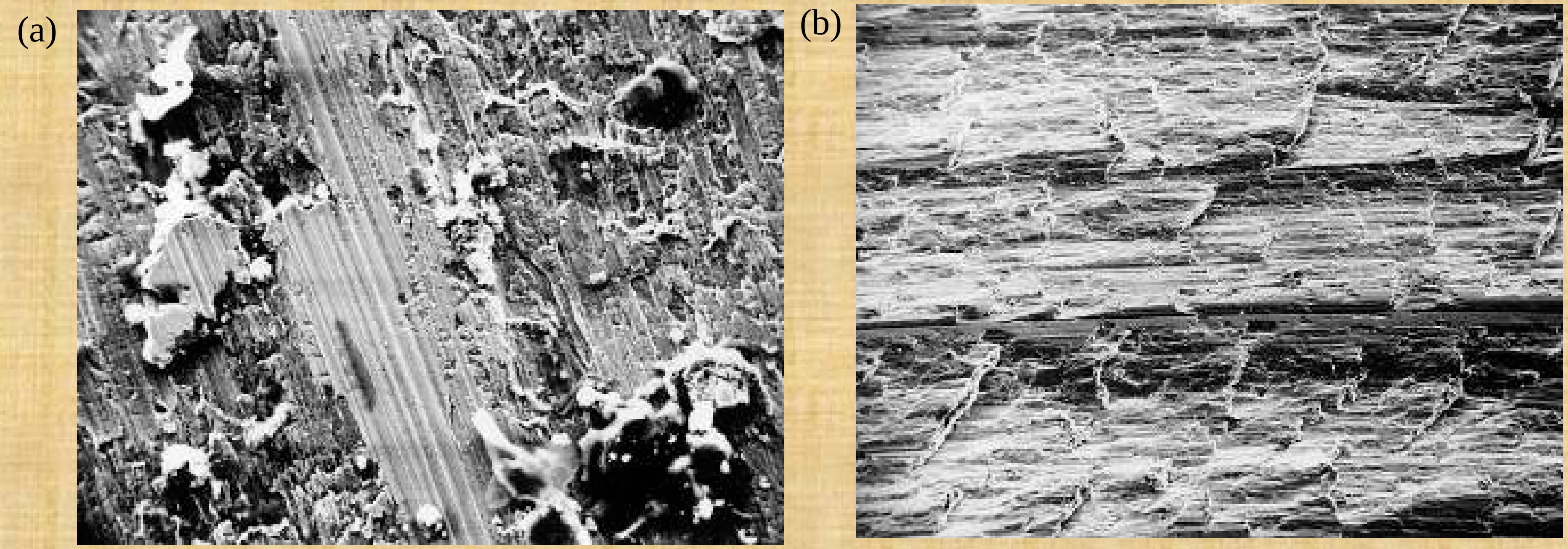
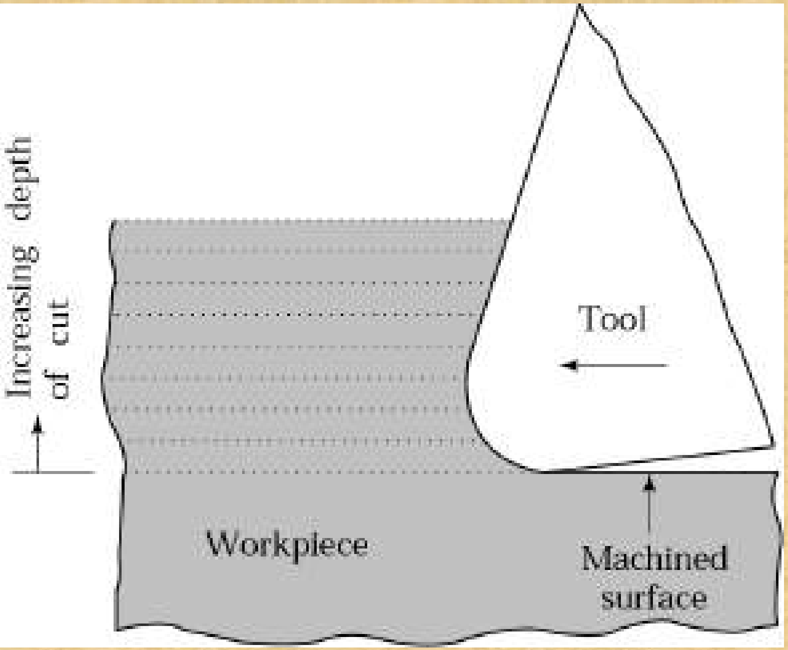


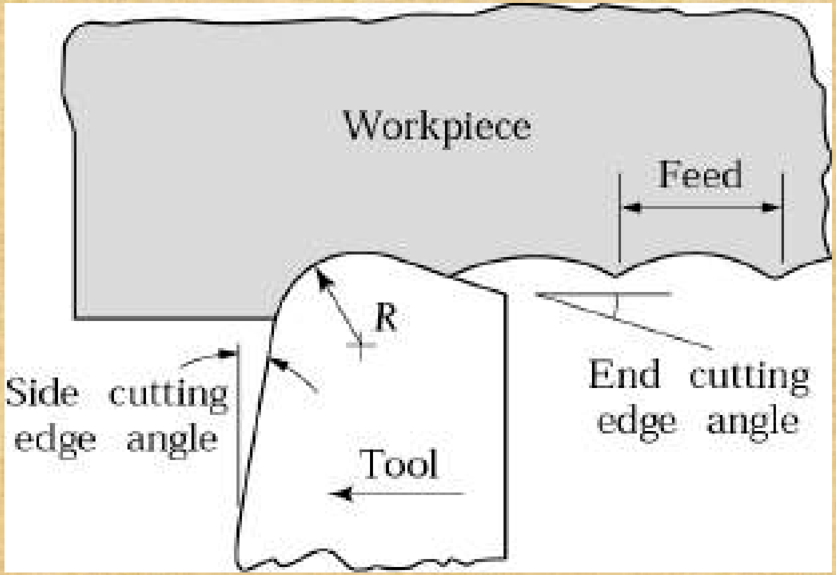
Figure 20.21 Surfaces produced on steel by cutting, as observed with a scanning electron microscope: (a) turned surface and (b) surface produced by shaping. *Source*: J. T. Black and S. Ramalingam.

Dull Tool in Orthogonal Cutting and Feed Marks



Schematic illustration of a dull tool in orthogonal cutting (exaggerated). Note that at small depths of cut, the positive rake angle can effectively become negative, and the tool may simply ride over and burnish the workpiece surface.

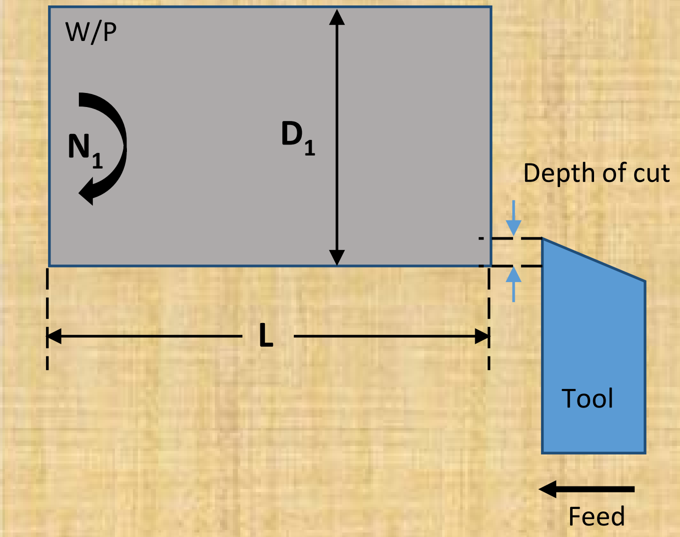
Schematic illustration of feed marks in turning (highly exaggerated).



Problem-1:

A turning operation has to be performed on an aluminum rod of diameter50 mm and length 300mm. The Spindle speed of lathe is given to be 500 RPM. The feed and depth of cut are 0.15mm/rev and 0.3 mm respectively. Draw a neat sketch of the turning operation described above. Find out the cutting speed in mm/s and the volumetric material removal rate (MRR_v).

Solution:



Turning operation

$$N_1 = 500 RPM$$

$$f_1 = 0.15 mm/rev$$

$$d_1 = 0.3 mm$$

$$CuttingSpeed, \ V_c = \omega.R$$

$$V_c = \left[\frac{500 \times 2\pi}{60}\right] \times 25$$

$$V_c = 1308.9 mm/\sec$$

$$MRR_v = \left(\pi \times D_1 \times N_1\right) f_1 \cdot d_1$$

$$MRR_v = \left(V_c\right) f_1 \cdot d_1$$

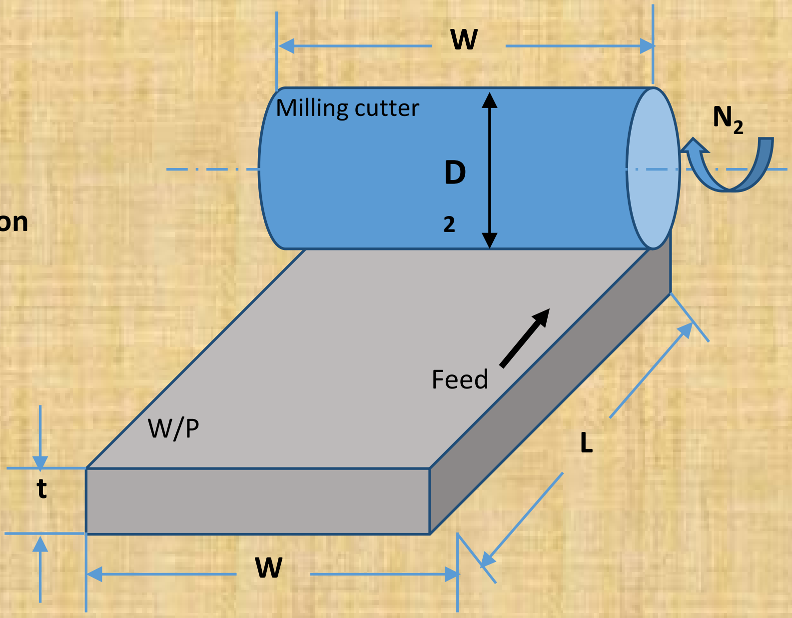
$$MRR_v = 1308.9 \times 0.15 \times 0.3$$

$$MRR_v = 58.905 \ mm^3/\sec$$

Problem-2

An aluminum block of length 50 mm and width 70 mm is being milled using a slab milling cutter with 50 mm diameter. The feed of the table is 15 mm/min. The milling cutter rotates at 60 RPM in clockwise direction and width of cut is equal to the width of the workpiece. Draw a neat sketch of the milling operation describing above conditions. The thickness of the workpiece is 20 mm. If depth of cut of 2 mm is used then find out cutting speed and volumetric material removal rate (MRR_v).

Solution:



Milling operation

$$Milling\ Cutter\ Diameter, D_2 = 50mm$$

$$Width\ of\ cut, WOC = 70mm$$

$$Depth\ of\ cut, d_2 = 2mm$$

$$feed, f_2 = 15mm/\min$$

$$Cutting\ Speed,\ V_c = \frac{\pi DN_2}{1000} m/\min$$

$$V_c = \left[\frac{50\times\pi\times 60}{1000}\right]\times 25$$

$$V_c = 9.424m/\min$$

$$MRR_v = WOC\cdot f_2\cdot d_2$$

$$MRR_v = 70\times\frac{15}{60}\times 2$$

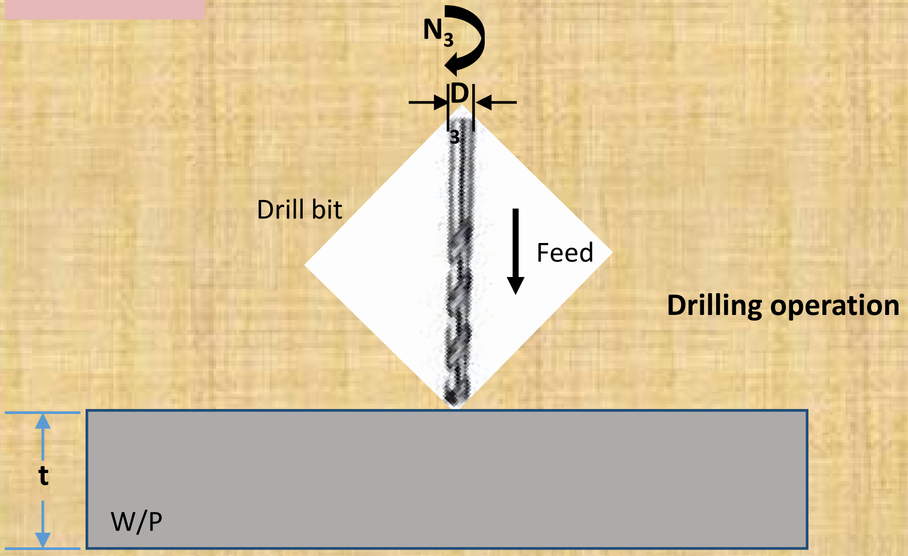
$$MRR_v = 35\ mm^3/\sec$$

Problem-3

Following the milling operation, a through hole is to be drilled on the same workpiece.

Find out the cutting speed and volumetric material removal rate if the drill of diameter 10 mm is being rotated at same RPM as in case of milling cutter with feed rate as 0.5 mm/rev.

Solution:



$$Diameter\ of\ Drill, D_3 = 10mm$$

$$N_3 = 60 RPM$$

$$feed, f_3 = 0.5 mm/rev$$

$$Cutting\ Speed,\ V_c = \frac{\pi N_3 D_3}{1000} m/\min$$

$$V_c = \left[\frac{\pi \times 60 \times 10}{1000}\right] m/\min$$

$$V_c = 1.884 m/\min = 31.4 mm/\sec$$

$$MRR_v = \frac{\pi \times {D_3}^2}{4} \times f_3 \times N_3$$

$$MRR_v = \frac{\pi \times 10^2}{4} \times 0.5 \times 60$$

$$MRR_v = 2356.19\ mm^3/\min = 39.27 mm^3/\sec$$

THANK YOU

Crater Wear

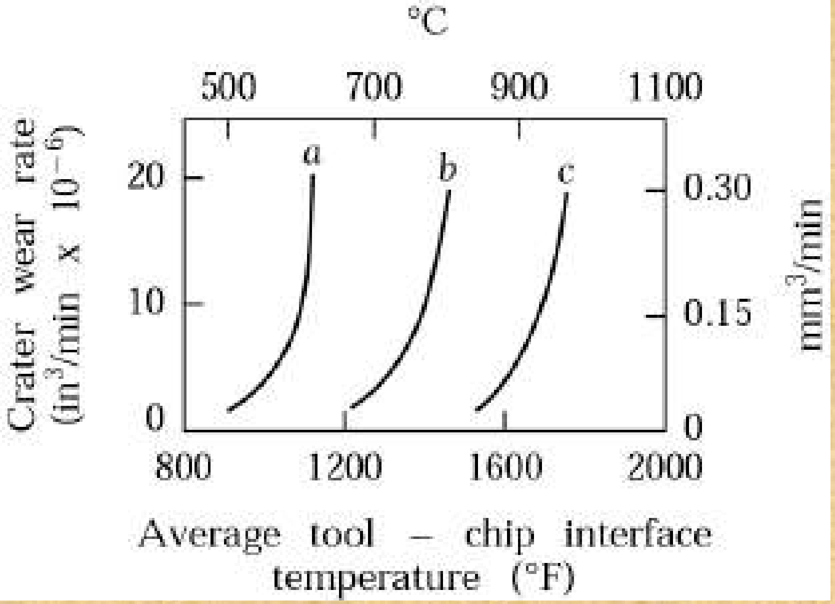
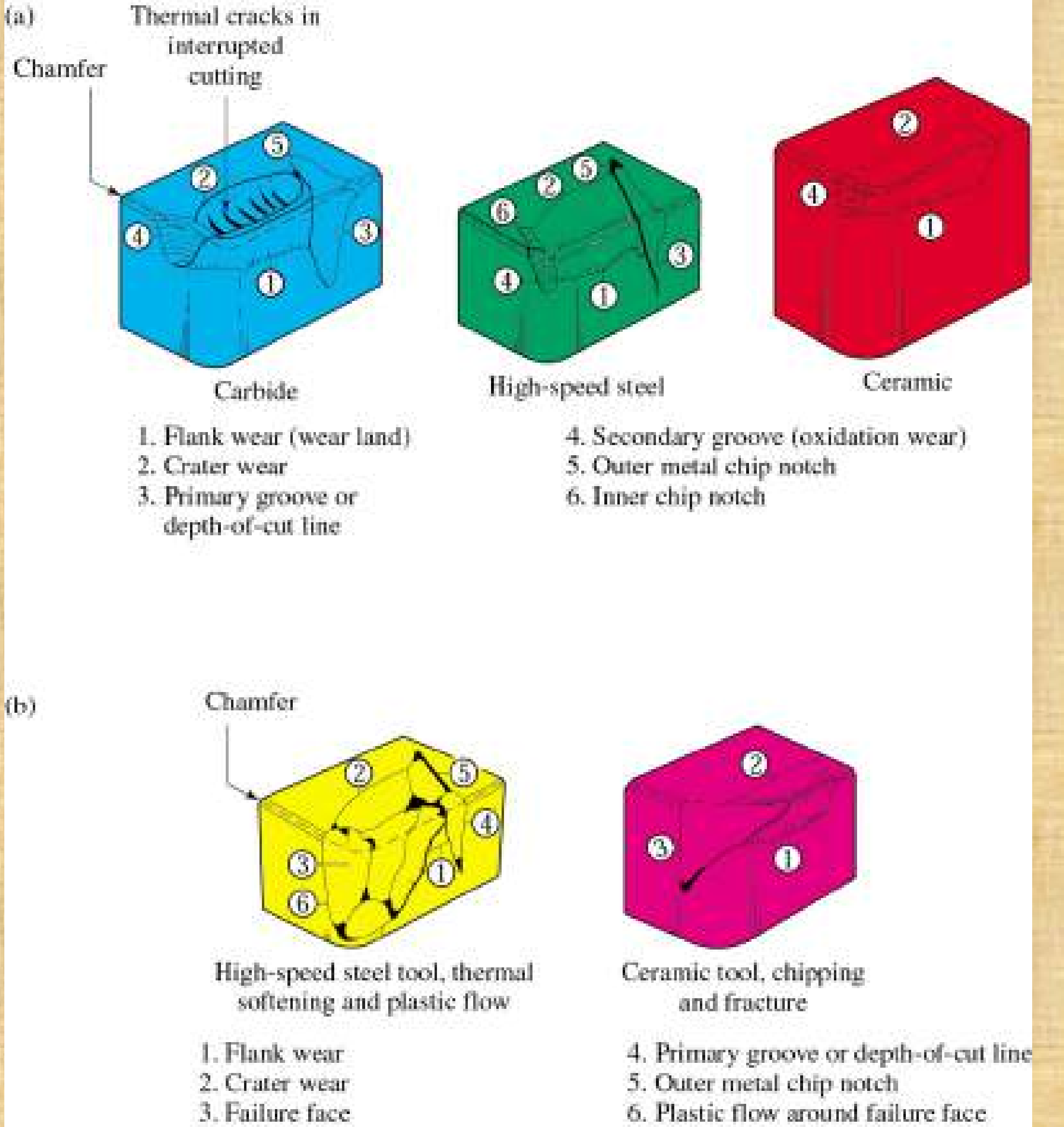


Figure 20.19 Relationship between crater-wear rate and average tool-chip interface temperature: (a) High-speed steel; (b) C-1 carbide; and (c) C-5 carbide. Note how rapidly crater-wear rate increases as the temperature increases. *Source*: B. T. Chao and K. J. Trigger.

Cutting tool (right) and chip (left) interface in cutting plain-carbon steel. The discoloration of the tool indicates the presence of high temperatures. *Source*: P. K. Wright.

Examples of Wear and Tool Failures

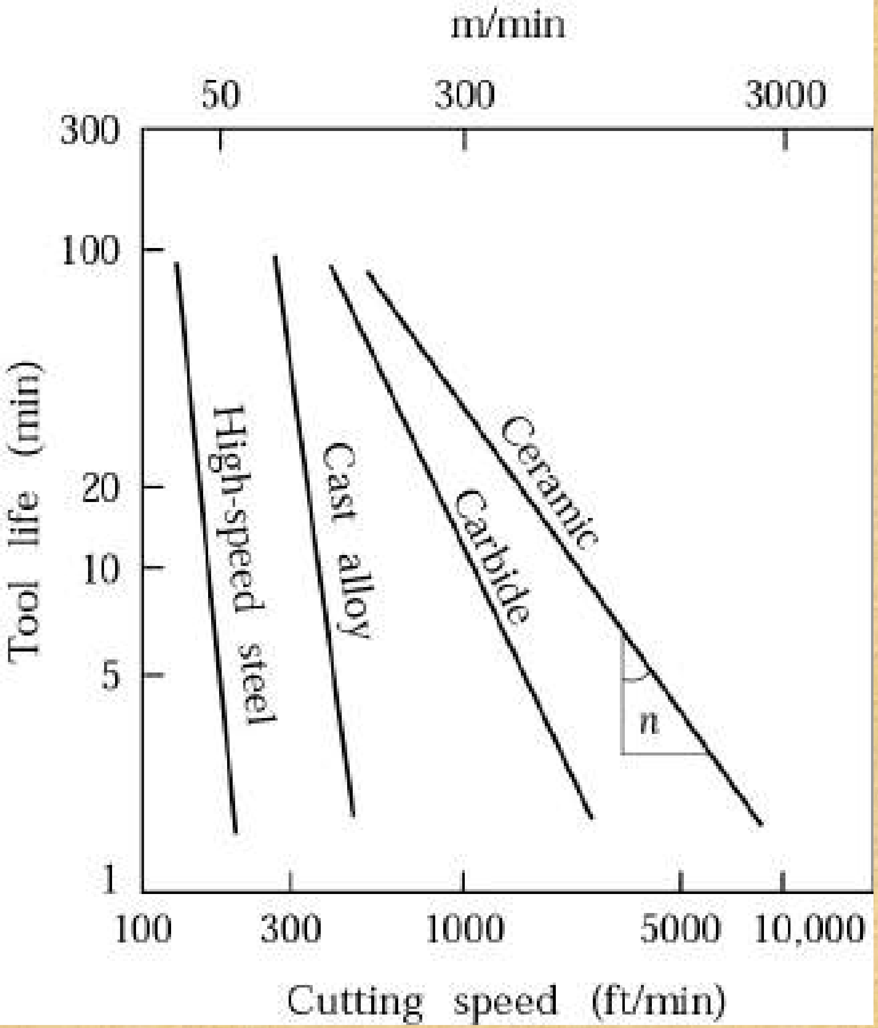
Figure 20.18 (a) Schematic illustrations of types of wear observed on various types of cutting tools. (b) Schematic illustrations of catastrophic tool failures. A study of the types and mechanisms of tool wear and failure is essential to the development of better tool materials.



Range of *n* Values for Eq. (20.20) for Various Tool Materials

High-speed steels	0.08–0.2
Cast alloys	0.1–0.15
Carbides	0.2–0.5
Ceramics	0.5–0.7

Tool Life



Tool-life curves for a variety of cutting-tool materials. The negative inverse of the slope of these curves is the exponent *n* in the Taylor tool-life equations and *C* is the cutting speed at *T* = 1 min.