ME 312
Manufacturing Technology II

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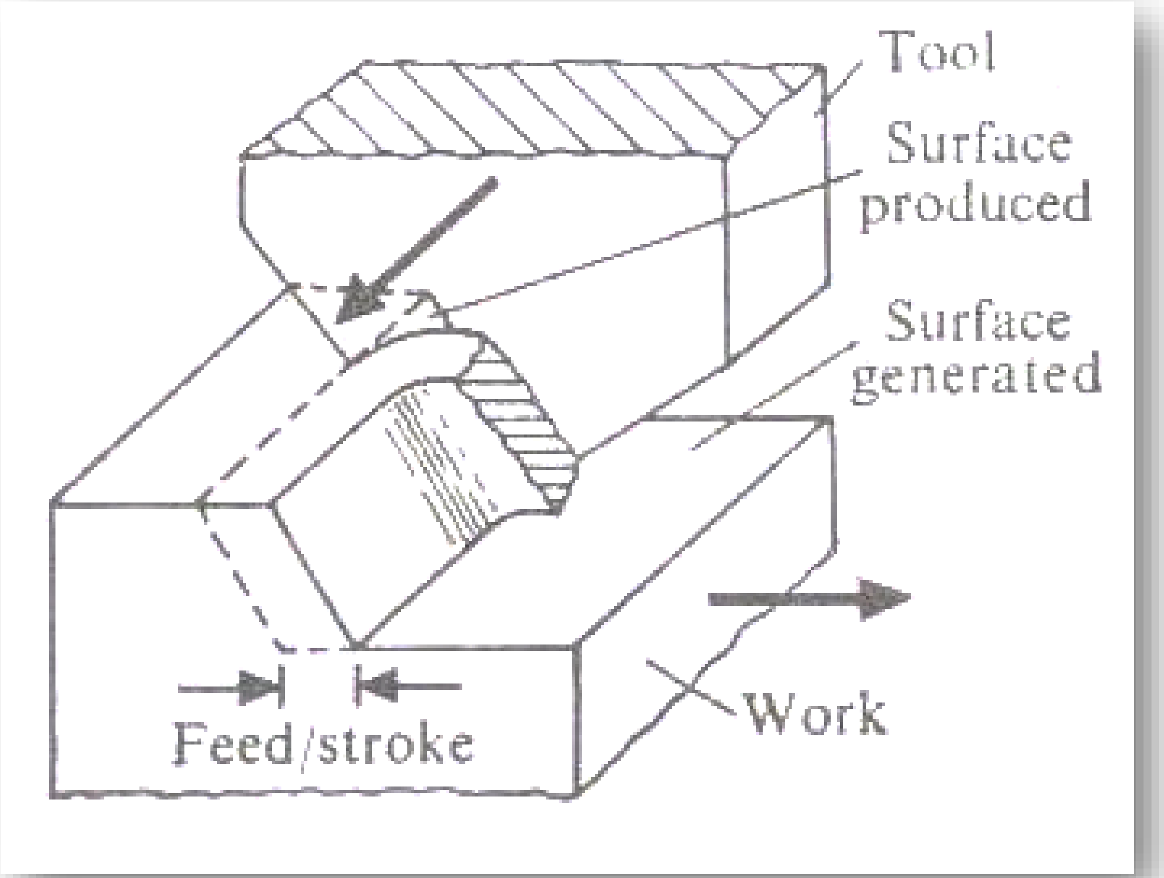
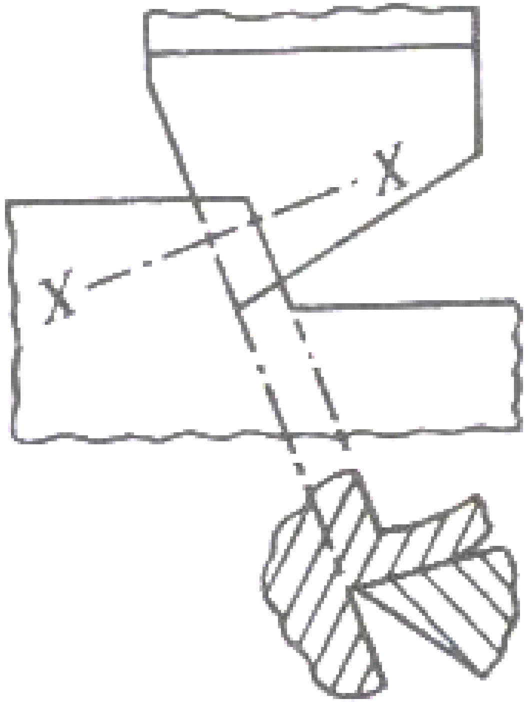
Shaping and planing

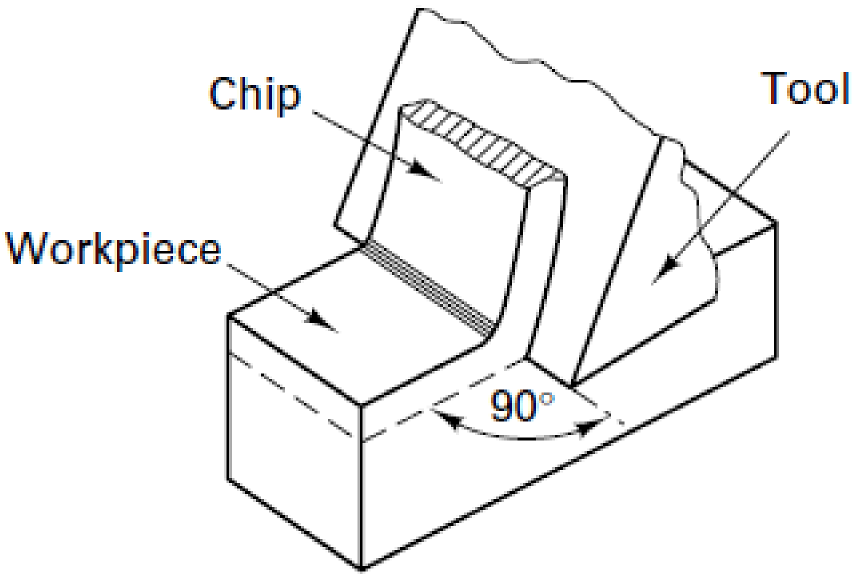
Intermittent cutting operation

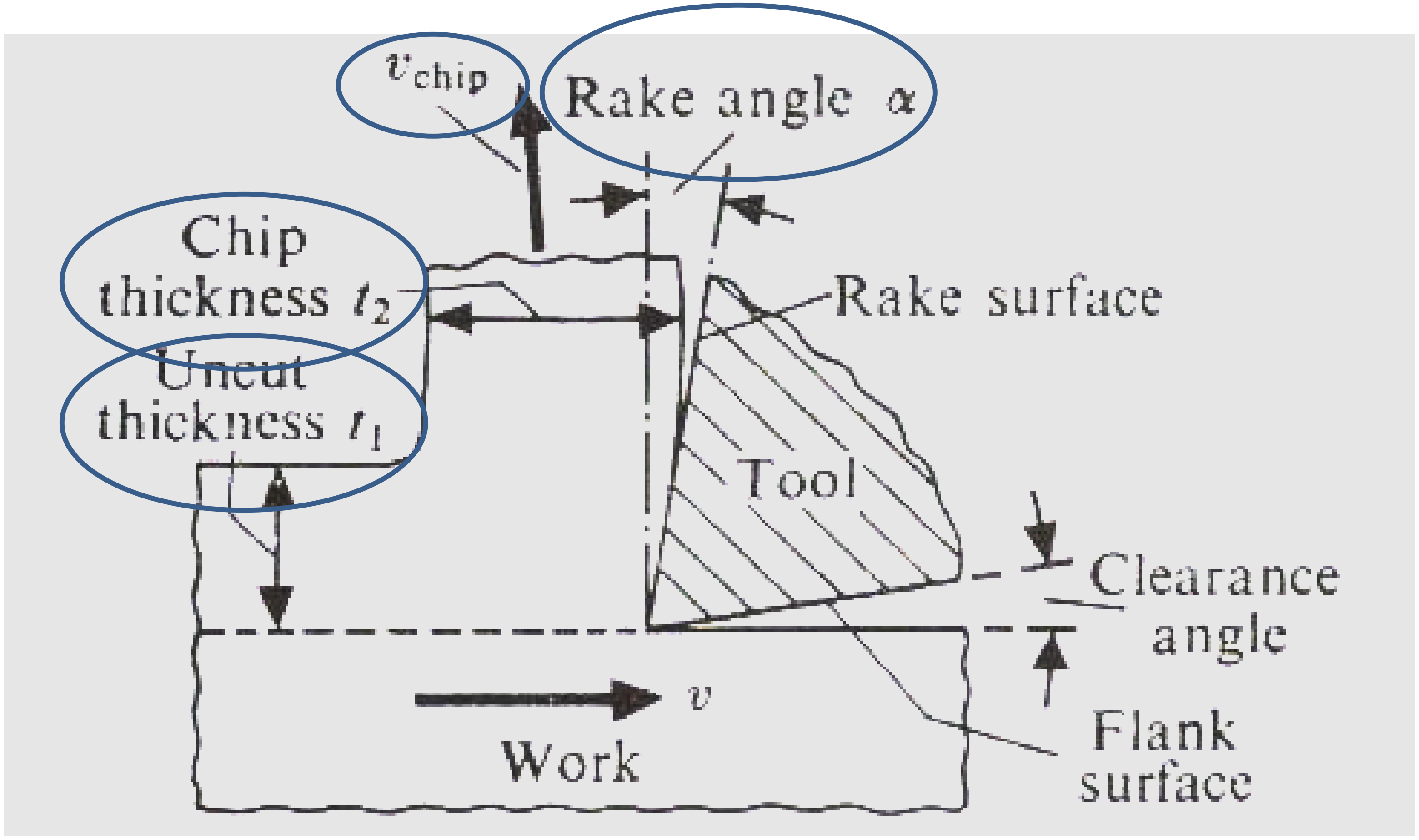




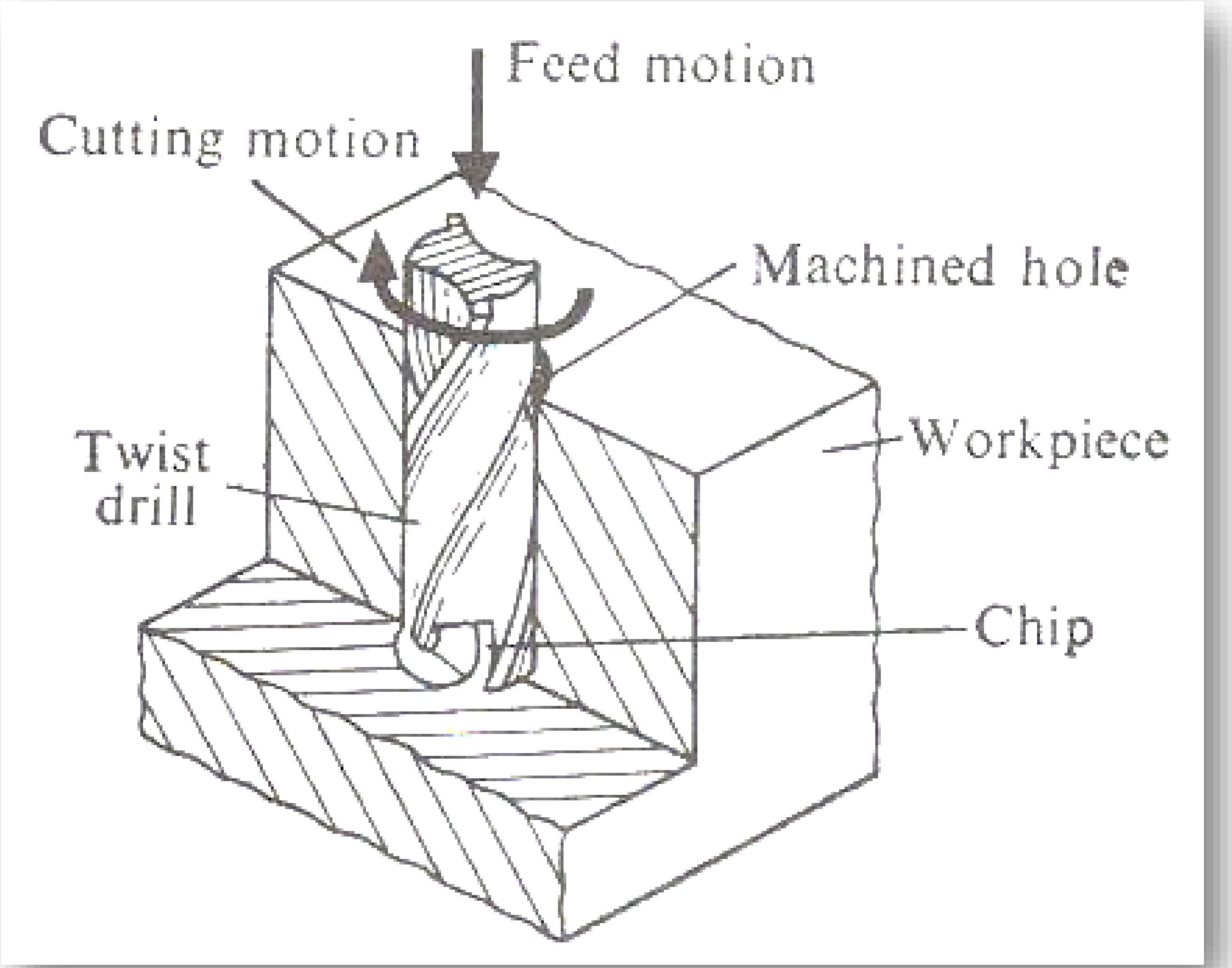
(a) Shaping

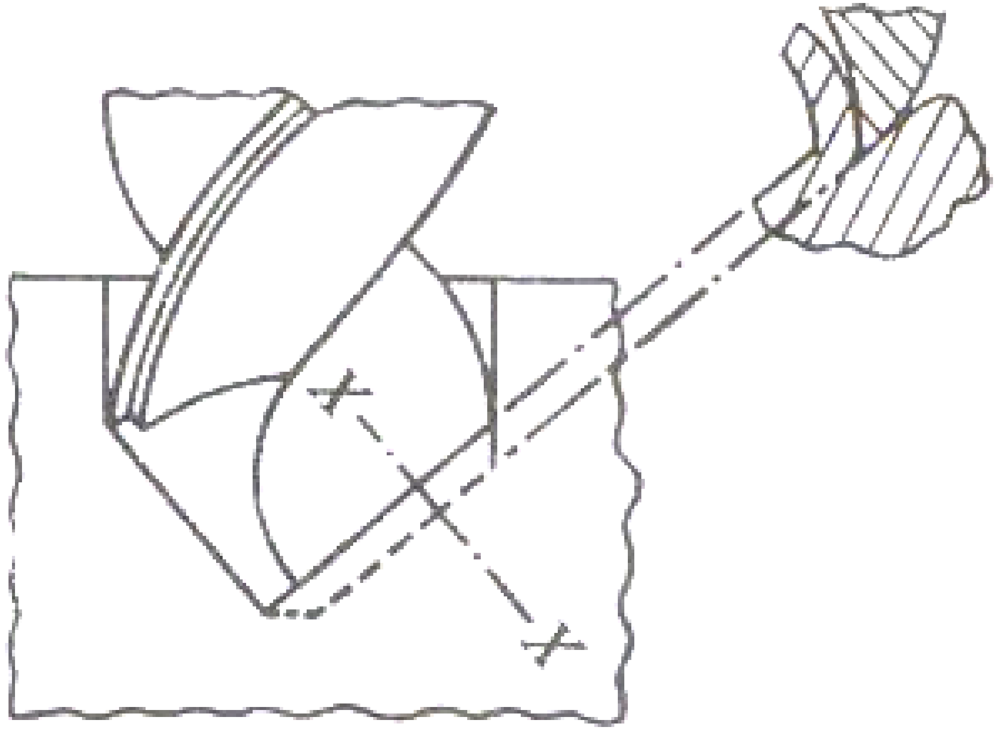
Basic machining operation and important parameters





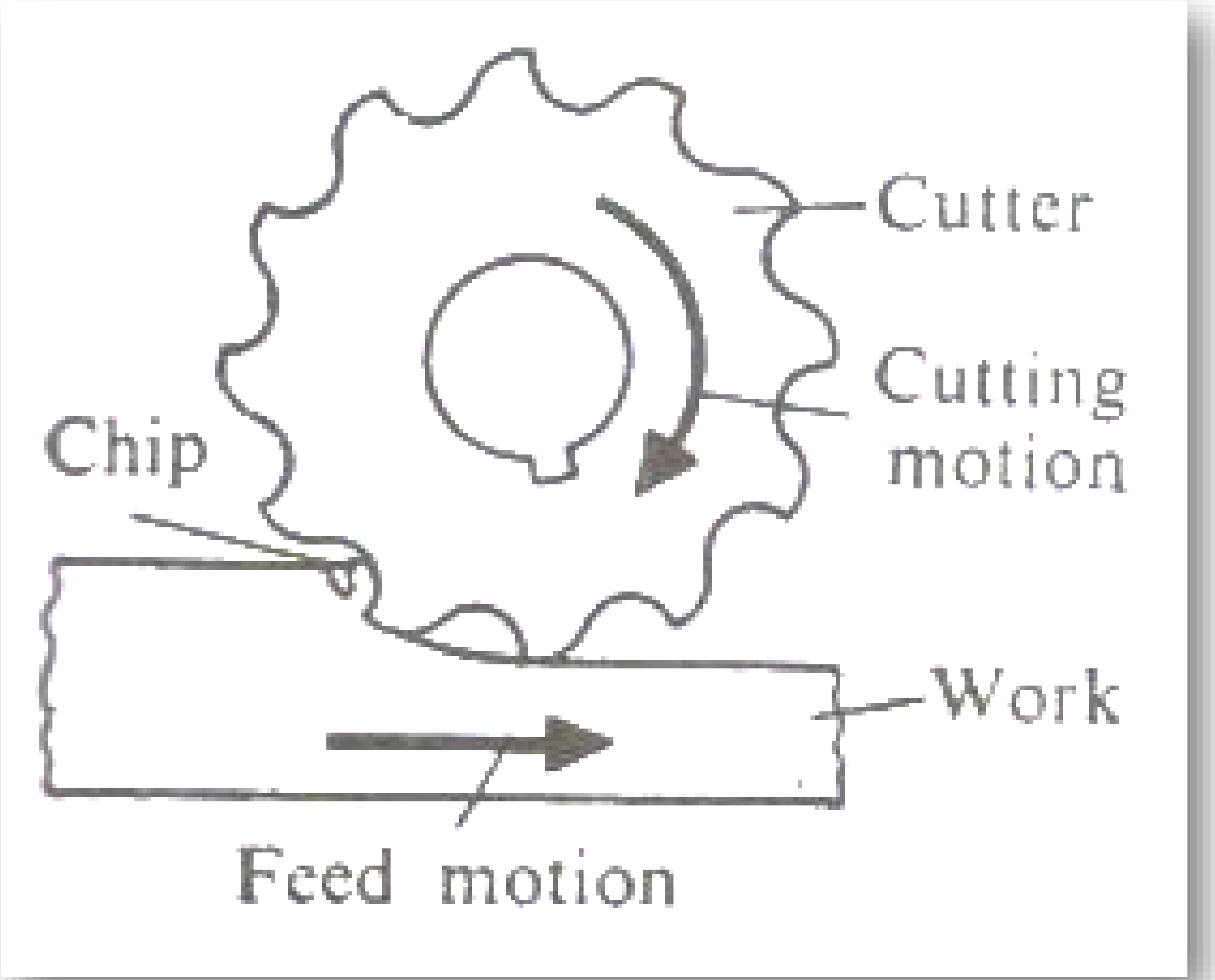
Drilling operation

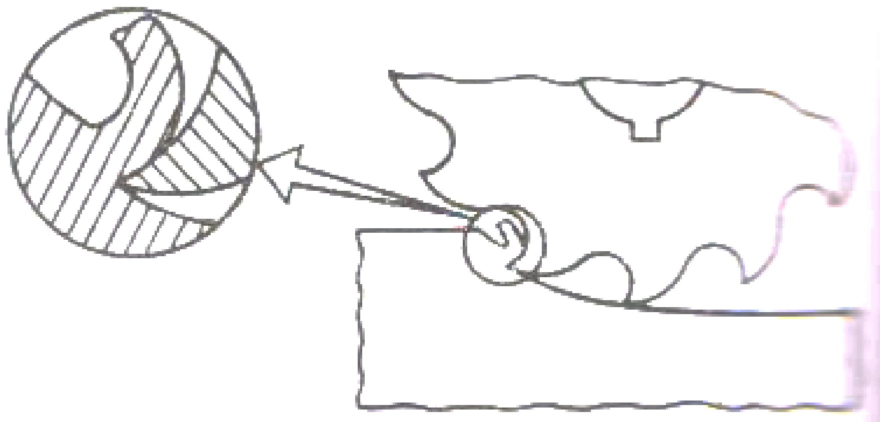




(c) Drilling

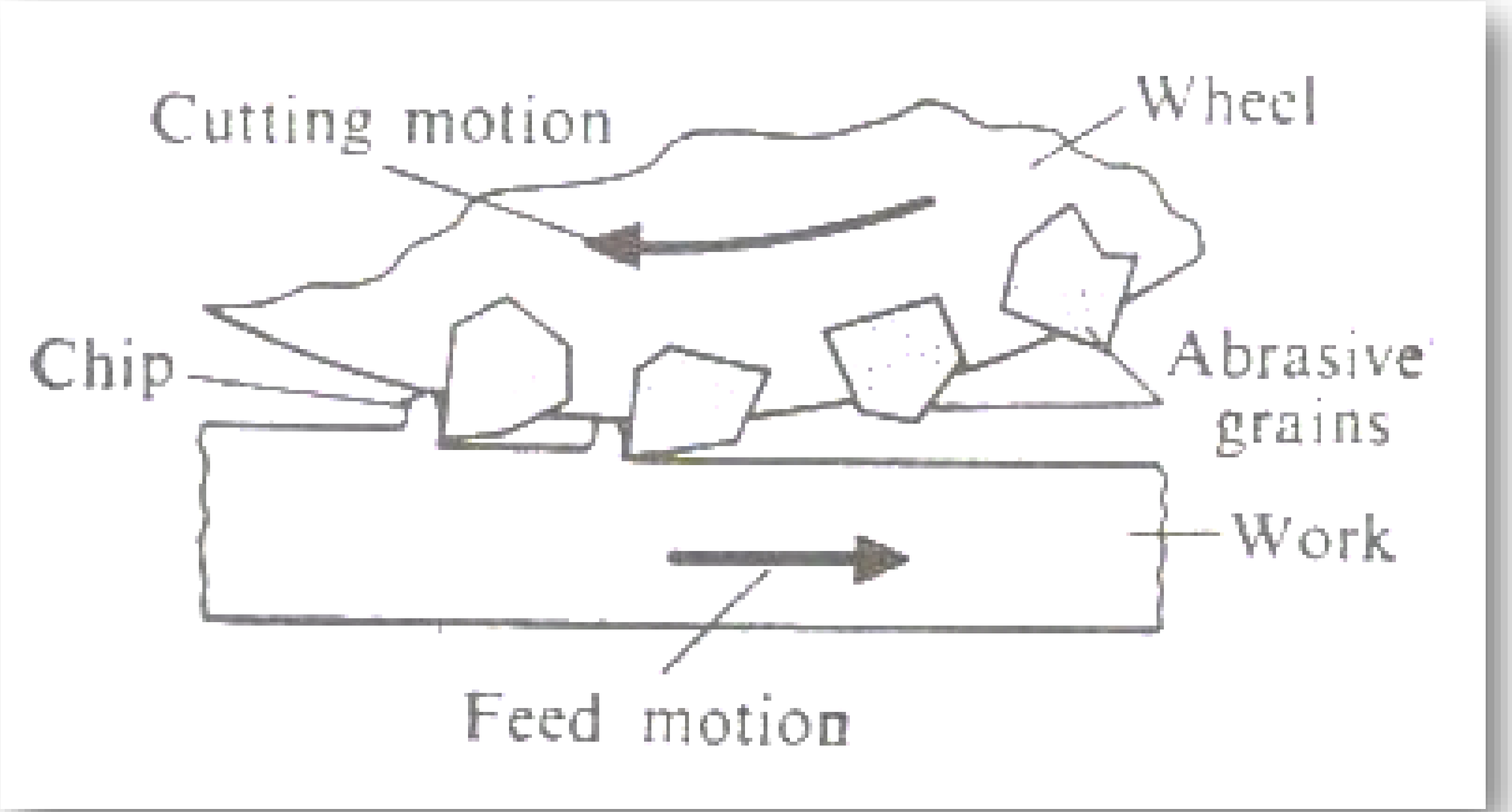
Milling operation



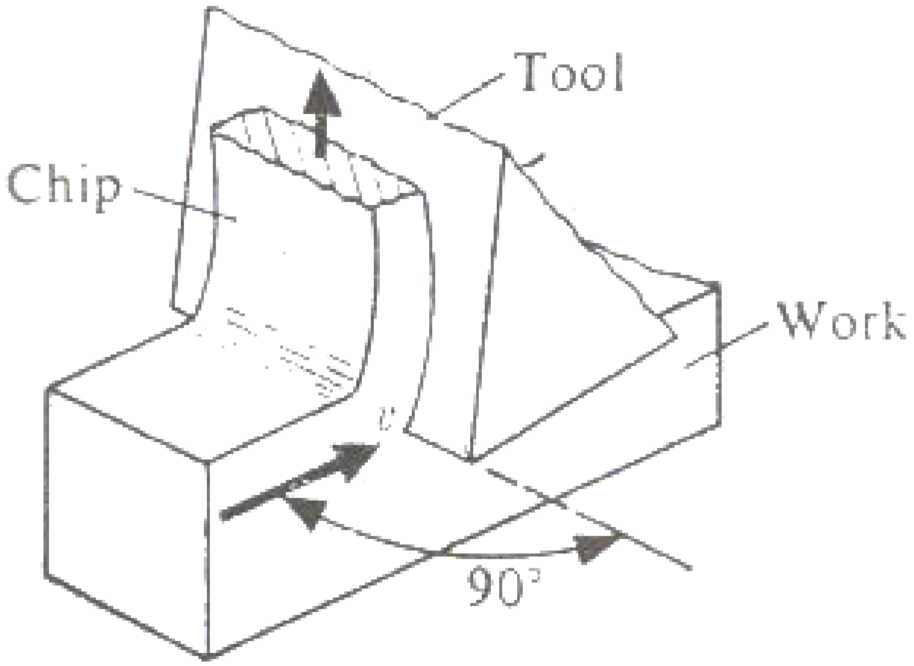


(d) Milling

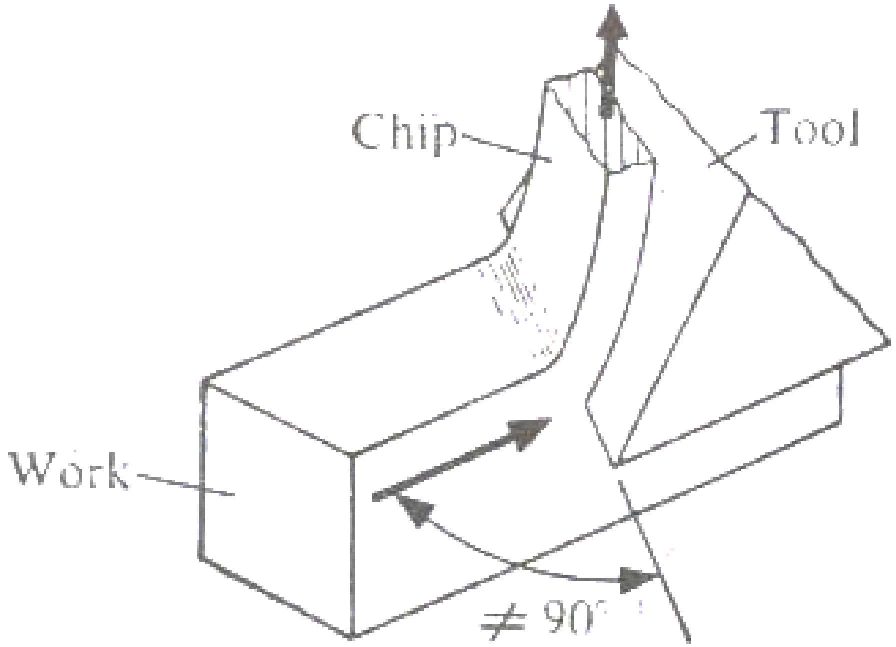
Grinding operation



Orthogonal and oblique machining



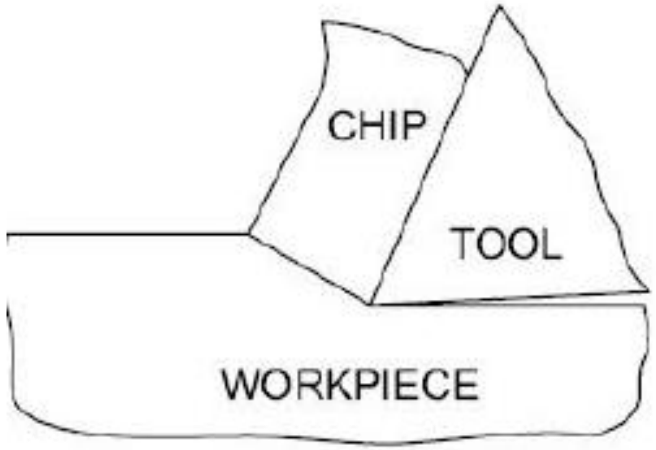
Orthogonal machining



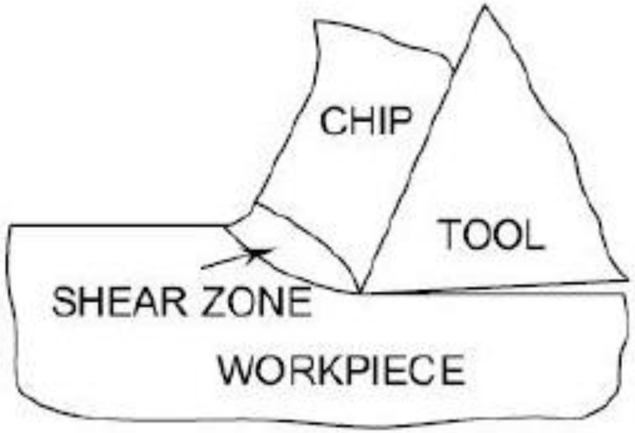
Oblique machining

Shear zone

- Thin shear plane model
  - Easier for analysis
  - For higher speeds
- Thick shear plane model
  - More realistic
  - For lower speeds



(a) Thin shear plane model



(b) Shear plane model

Mechanics of orthogonal cutting

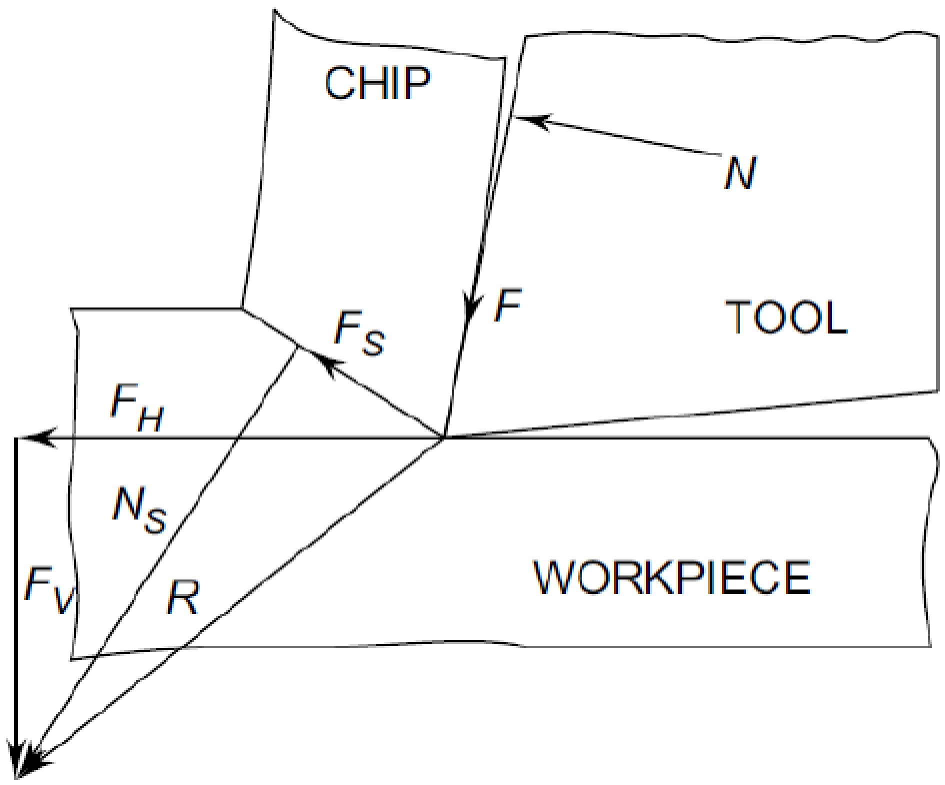
- Merchant's thin shear plane model considering the minimum energy principle.
- Applicable for cutting at very high cutting speeds which is generally practiced in production.

Assumptions

- The tool is perfectly sharp.
- Workpiece has NO contact along the clearance face.
- The surface where shear is occurring is a plane.
- The cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as the work moves past it.
- The chip does not flow to either side or no side spread.
- Uncut chip thickness is constant.
- Width of the tool is greater than the width of the work.
- A continuous chip without any BUE is produced.
- Work moves with a uniform velocity.
- The stresses on the shear plane are uniformly distributed.

Merchant’s analysis

- Fv-Force perpendicular to the primary tool motion (thrust force)
- Fs-Force along the shear plane
- Ns-Force normal to the shear plane
- F -Frictional force along the rake face
- N -Normal force perpendicular to the rake face
- R = R'



Free body diagram of chip

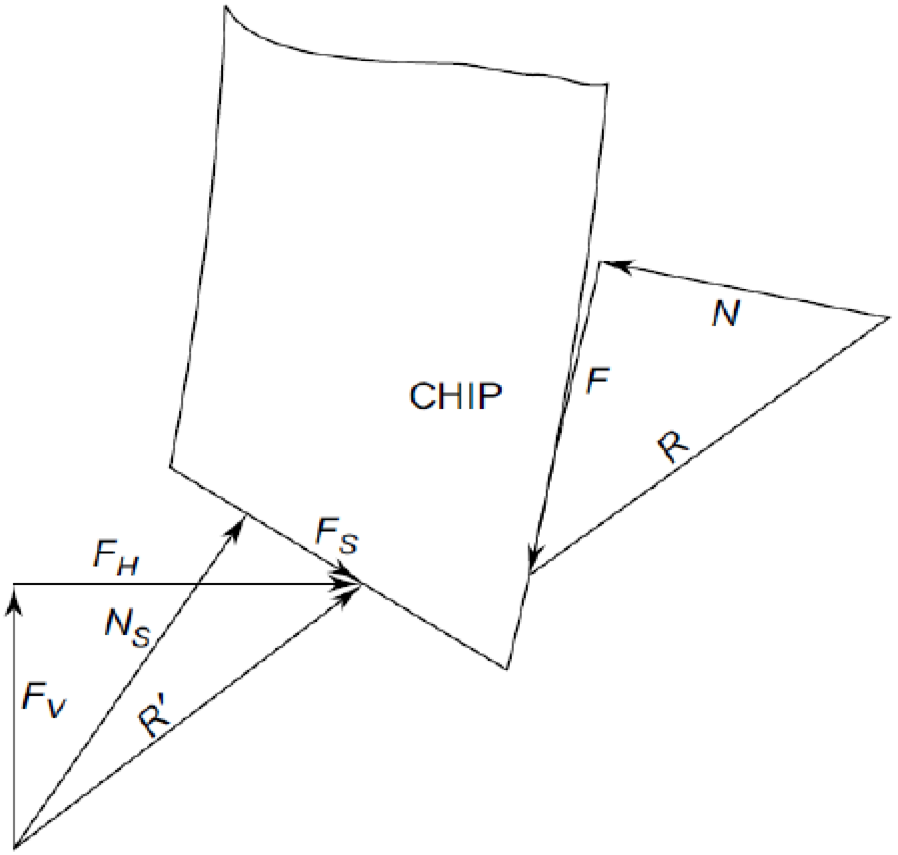


Fig. 2.14 *Forces acting on an isolated chip in metal cutting.*

Cutting tools: materials

- Form stability of cutting tools: key factor
- Must provide maximum resistance to any tendency of alteration of geometric shape

  "Proper selection of tool material"

- Tool must be harder than work piece
- How much harder?
  - 35 to 50 %

Cutting tools: materials

- During machining as speed increases,
  - Rate of deformation increases (strain rate)
  - Apparent strength (resistance to plastic deformation) increases
- But at elevated temperatures
  - Hardness of work material decreases
  - Easier to cut
  - Hardness of tool material also decreases
- Hardness measured in Labs is ideal (not real)

Properties of an ideal tool material

- Hardness : should be appreciably higher than that of work material at elevated temperatures (Hot hardness)
- Tough enough to withstand shocks: toughness
- Large resistance to wearing action
- Coefficient of friction between work and tool should be low
- Thermal conductivity and specific heat should be high

Carbon tool steels

- C (0.6 to 1.5%) + Mn + Si + W + Mo + Cr + V
- Earliest tool steel
- After 200^{o} C, not working
- Low speed cutting, 5 m/min
- Machining of wood, brass, aluminium
- Easy to manufacture angles by grinding

Alloying elements

- Mo: Strength, high resistance to heat and wear
- W: Hardness
- V: Good structural strength but soft
- Mn: Hard but oxidizes at elevated temperatures
- Cr: Very hard metal
- Si: Hard but brittle

HSS (High speed steel)

- Taylor and white in early of the 20^{th} Century
- Machining speed 30 m/min, 3 to 6 times more than Carbon tool steel
- W+Mo+V+Cr+Co
- High hardness and good abrasion resistance
- High hot hardness
- After 650^{o}, hardness drops
- Can be made by using Powder Metallurgy technique

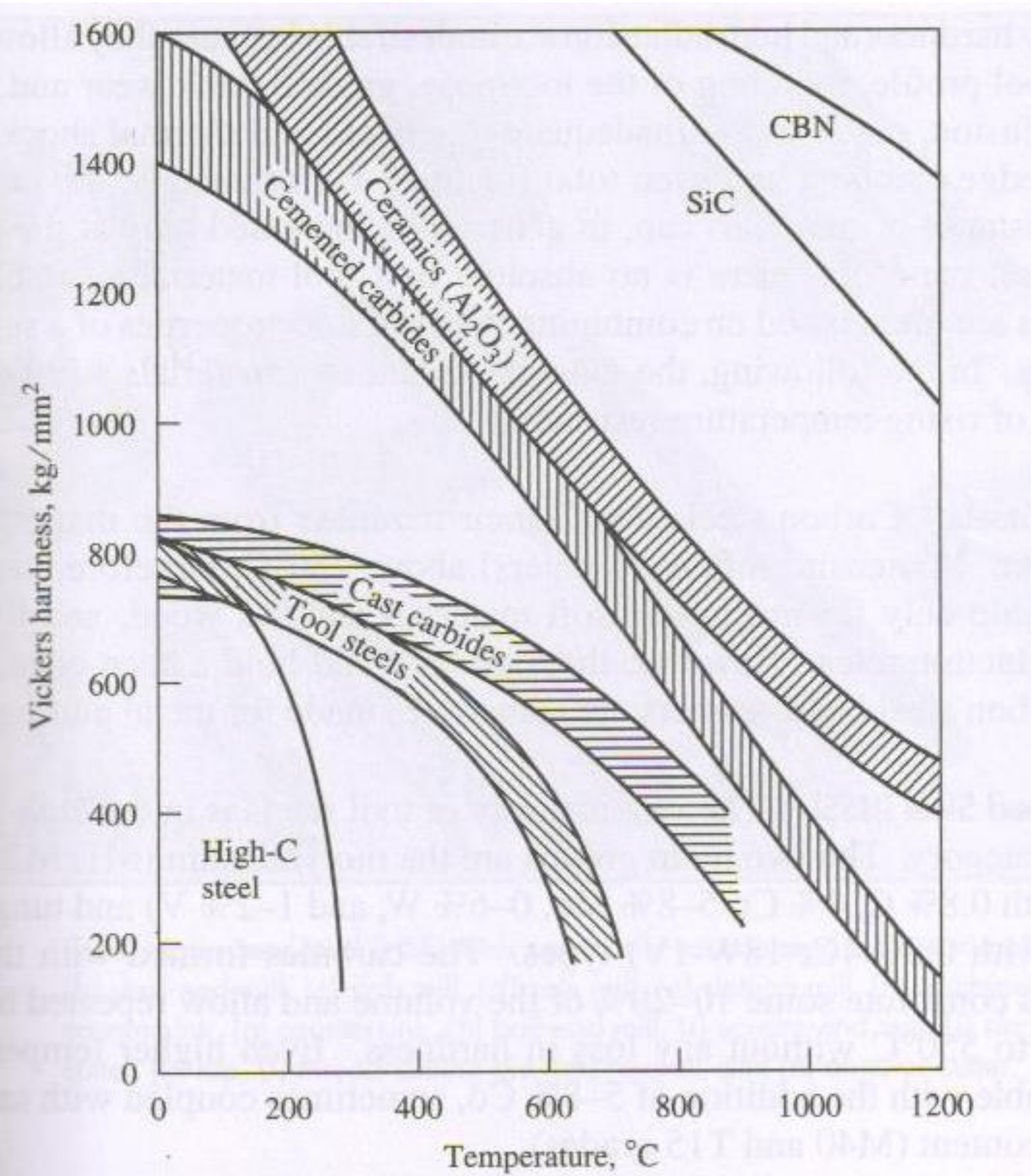
Typical compositions of HSS

AISI steel type	% Chemical composition						
	C	*Cr*	*V*	*W*	*Mo*	*Co*	*Weq*
T1	0.70	4.0	1.0	18.0			18.0
T6	0.80	4.25	1.5	2.0	0.90	12.0	21.8
M1	0.80	4.0	1.0	1.5	8.0		17.5
M6	0.80	4.0	1.50	4.0	5.0	12.0	14.0
M30	0.85	4.0	1.25	2.0	8.0	5.0	18.0
M42	1.10	3.75	1.15	1.50	9.50	8.25	20.5

Commonly used HSS tools for machining

Some high-speed steel (HSS) tools commonly encountered: (*a*) gear-tooth cutter, (*b*) shell-end mill, (*c*) slab mill, (*d*) side mill, (*e*) slotting mill, (*f*) combined drill and countersink, (*g*) countersink, (*h*) ball-end mill, (*i*) square-end mill, (*j*) single-angle cutter, (*k*) tap, (*l*) thread-cutting die, (*m*) reamer, and (*n*) angular cutter.

Variation of hardness of various cutting tool materials



Cast cobalt alloys (Stellites)

- Cutting of non-ferrous metals
- Cr + Mo + W + C + Mn + Si + Ni + Cobalt
- Can be manufactured by powder metallurgy technique
- Form tools
- At elevated temperatures provides good hardness and toughness
- Provides cutting speed of about 25% more than HSS

Typical compositions of Stellites

Nominal % composition								Grade
Cr	*W*	*Mo*	*C*	*Mn*	*Si*	*Ni*	*Co*	
30	4.5	1.5	1.1	1.0	1.5	3.0	rest	Roughing
31	10.5	—	1.7	1.0	1.0	3.0	rest	General purpose
32	17.0	—	2.5	1.0	1.0	2.5	rest	Finishing

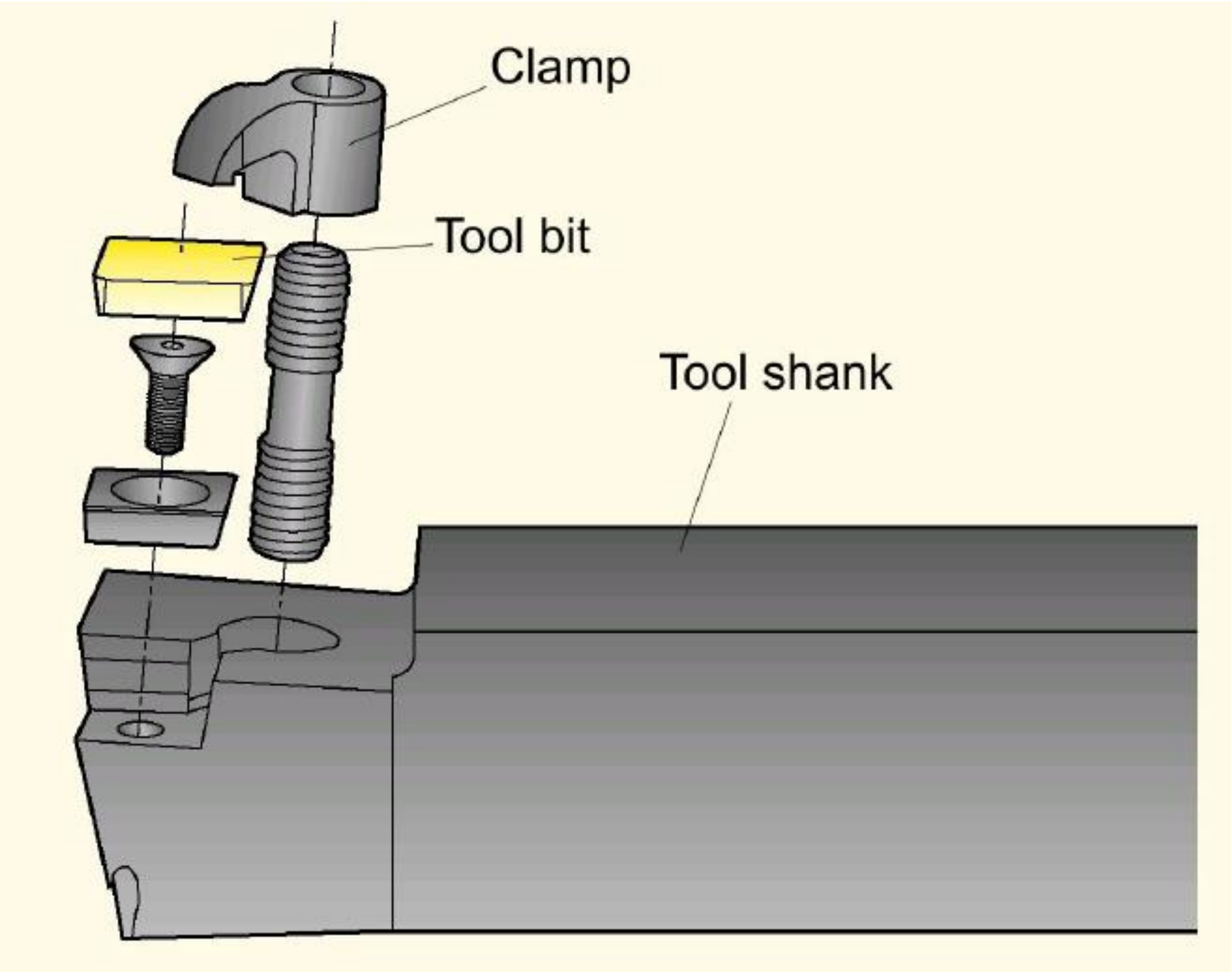
Cemented carbides

- 1926, Germany: an important invention in the cutting tool industry, contributing the largest % share nowadays
- Cemented carbides are produced by the cold compaction of the tungsten carbide (WC) powder in a binder such as cobalt (Co), followed by liquid-phase sintering
- High hot hardness
- Machining speed 150 m/min
- Carbides are more brittle and expensive
- The usual composition of the straight grade carbides is 6wt% Co and 94wt% WC, with the cobalt composition ranging from 5 to 12wt%

Cemented carbides

- Addition of titanium carbide (TiC) increases the hot hardness, wear resistance, and resistance to thermal deformation, but decreases the strength. The usual composition is about 5–25wt%.
- ‘Ti’ reduces cratering and abrasive wear when machining steel
- Cemented carbides, being expensive, are available in insert form in different shapes such as triangle, square, diamond, and round.

Tool-insert assembly



Coated carbides (WW II)

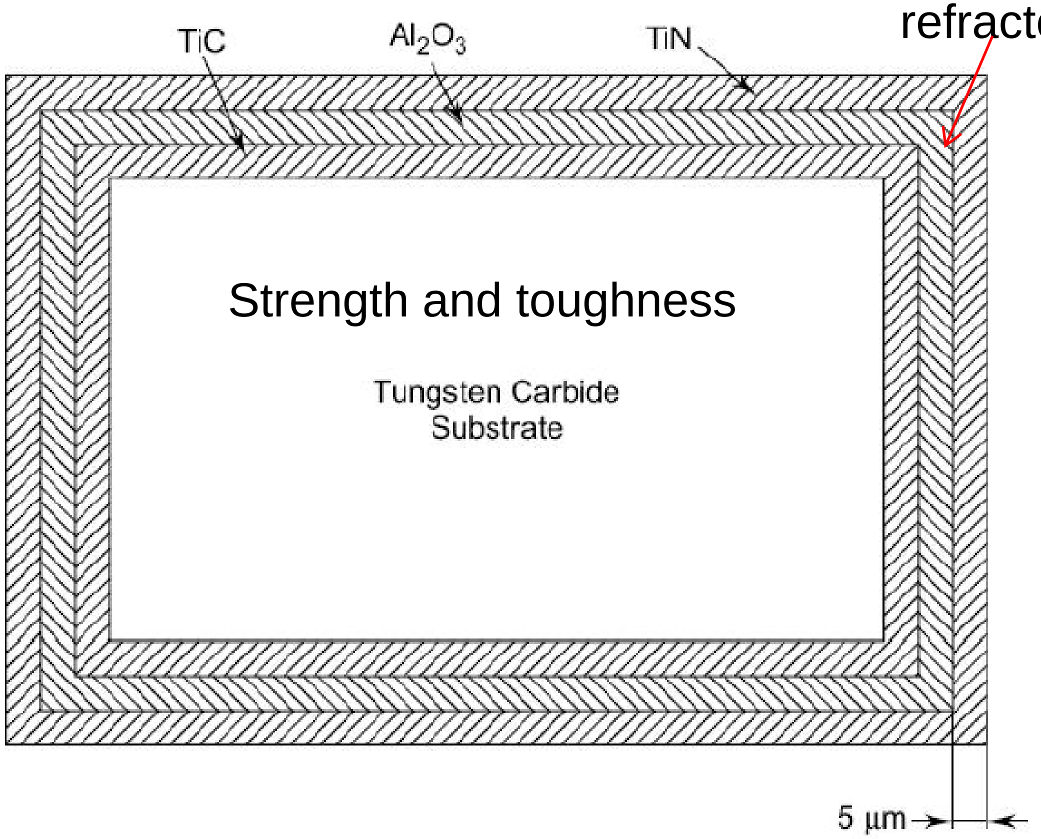
- Hard and refractory coatings on conventional tool materials
- Thin coating of TiN reduces friction and discourages formation of BUEs
- Ceramic coatings: good abrasion resistance
- High resistance to diffusion wear, resistance to oxidation wear and high hot hardness
- Machining speed 350 m/min

Schematic of multi-coated cemented carbide

Hardness and
refractoriness

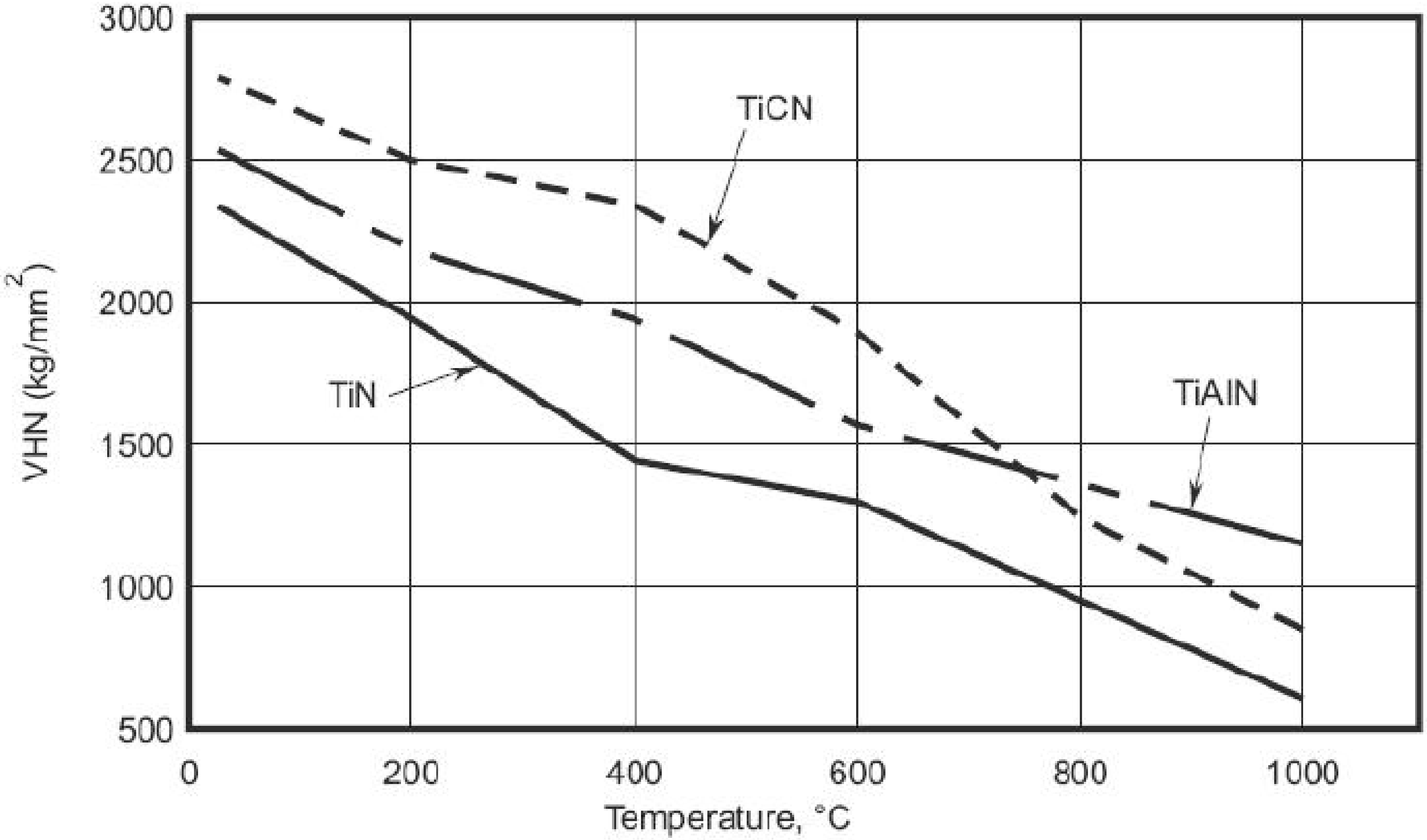
Chemical vapor
deposition (CVD)
technique

Atom-by-atom
deposition

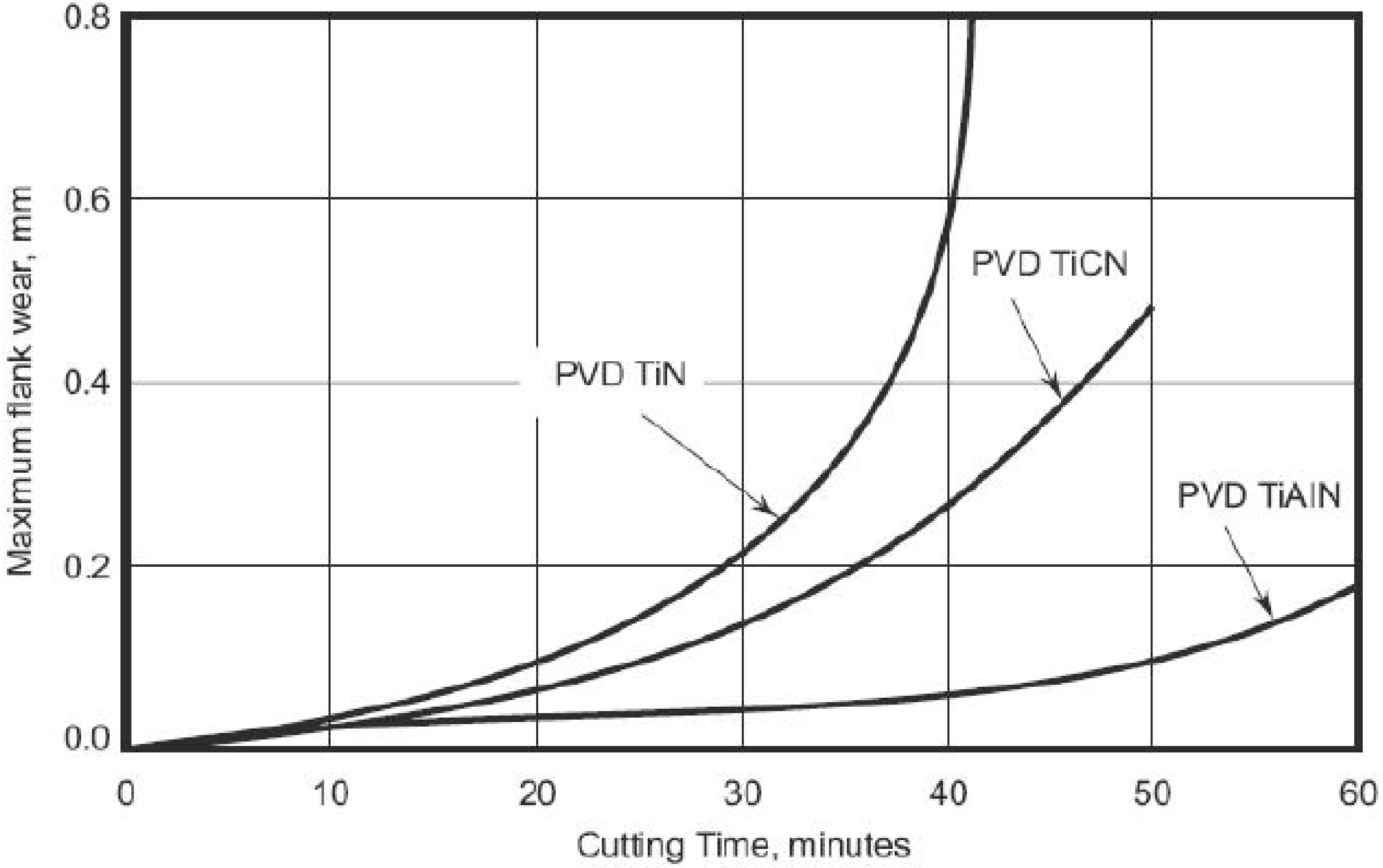


Strength and toughness

Coated carbides

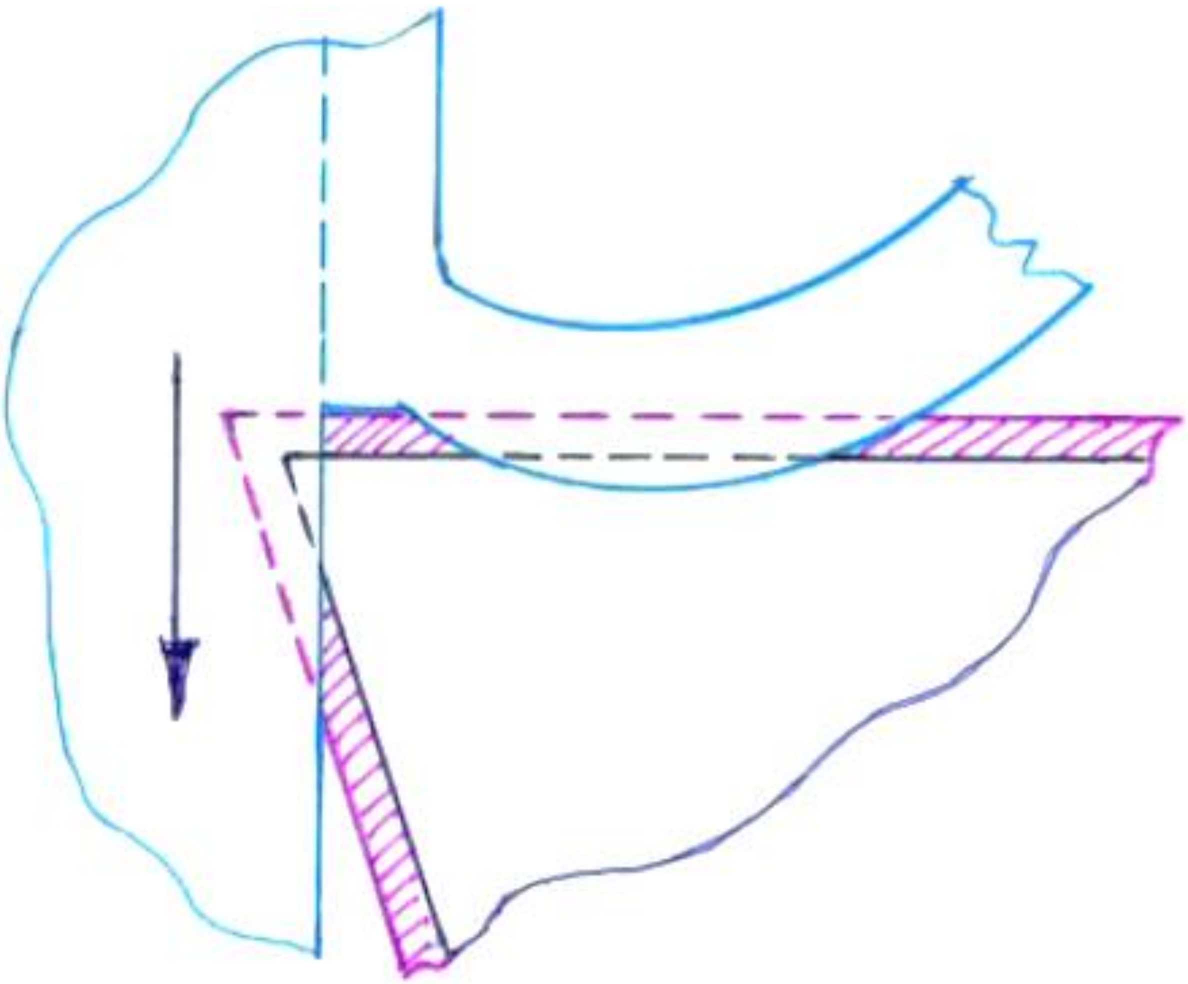


Coated carbides



Improvement in tool life with different types of coatings on carbide tool machining AISI 1045 steel (305 m/min, 0.75 mm doc, 0.15 mm/rev) (Jindal, Santhanam, Schleinkofer, and Shuster).

Role of coating even after rupture



Coated carbides

- Share: 40% of all cutting tools used in industry
- Multiple coatings
  - Higher tool life
  - Broader range of materials

Ceramics

- Ceramics : alumina (Al_2O_3) based high refractory materials
- High-speed machining of difficult-to-machine materials
- Can withstand very high temperatures, are chemically more stable and have higher wear resistance than other cutting tool materials
- Low strength, poor thermal characteristics and tendency to chip
- Machining speed 600 m/min

Diamond

- Hardest known (Hardness ~ 8000 kg/mm^2) material that can be used as a cutting tool material
- High hardness, good thermal conductivity, low friction, non-adherence to most materials, and good wear resistance.
- Artificial diamonds, are basically polycrystalline (PCD) in nature
- Can be formed for any given shape with a substrate of cemented carbide

Diamond tool

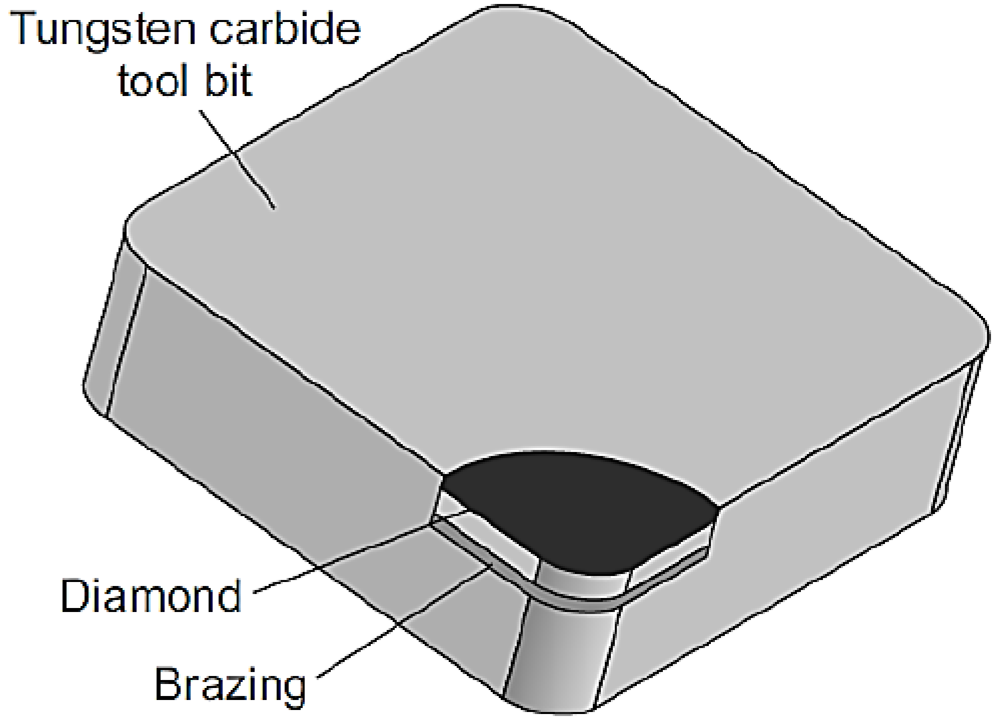


Fig. 2.30 *Polycrystalline diamond brazed to the carbide tool bit.*

Cubic Boron Nitride (CBN)

- Cubic Boron Nitride (CBN) next in hardness only to diamond (Hardness ~ 4700 kg/mm^2)
- Not a natural material but produced in the laboratory using a high temperature/ high pressure process similar to the making of artificial diamond
- More expensive than cemented carbides, but in view of the higher accuracy and productivity possible for difficult-to-machine materials, they are used in special applications

Cutting tool materials

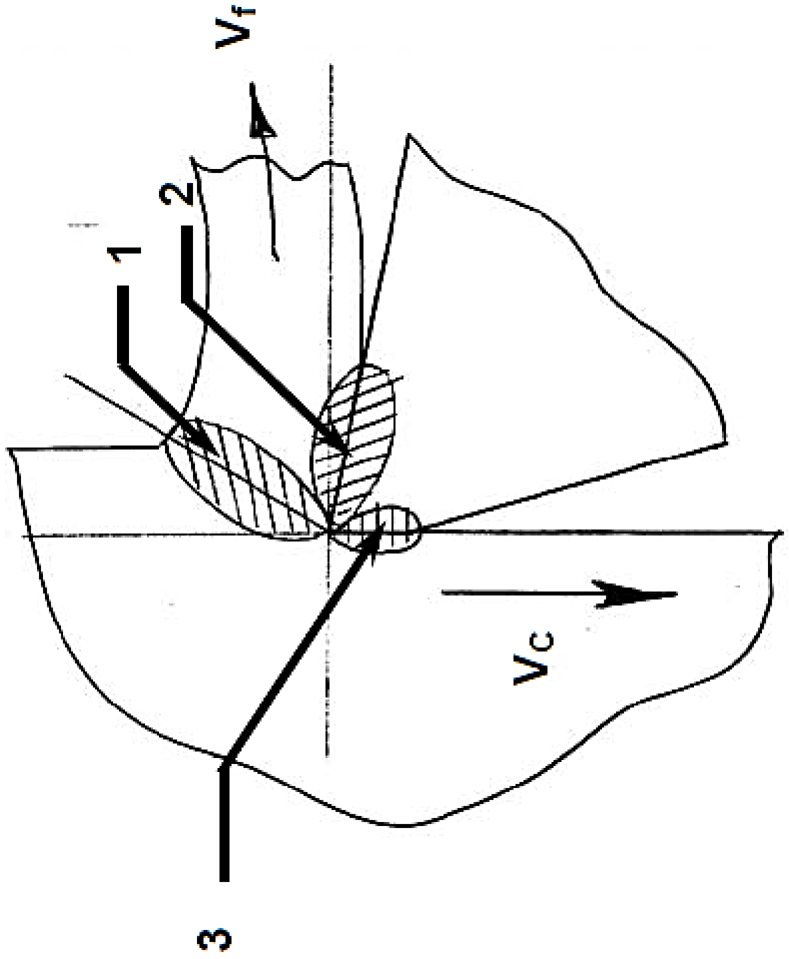
Carbon steels	Low strength, softer materials, non ferrous alloys, plastics	Low cutting speeds, low strength materials
HSS	All materials of low and medium strength and hardness	Low to medium cutting speeds, low to medium strength materials
Cemented carbides	All materials upto medium strength and hardness	Not suitable for low speed application
Ceramics	Cast iron, Ni-base super alloys, non ferrous alloys, plastics	Not for low speed operation or interrupted cutting. Not for machining Al, Ti alloys.

Heat generation and tool temperature

- During machining: plastic deformation at high rate, most of the spent energy is converted into heat
- Cutting of low strength material : no big problem
- Cutting of high strength material : temperature rises with speed -> tool strength decreases -> faster wear and failure

Cutting temperatures

- Sources of generation



1. Primary heat source: plastic deformation at the shear zone

2. Secondary heat source: sliding of the chip over the tool rake surface

3. Rubbing of the flank over the machined surface

Distribution of heat generated

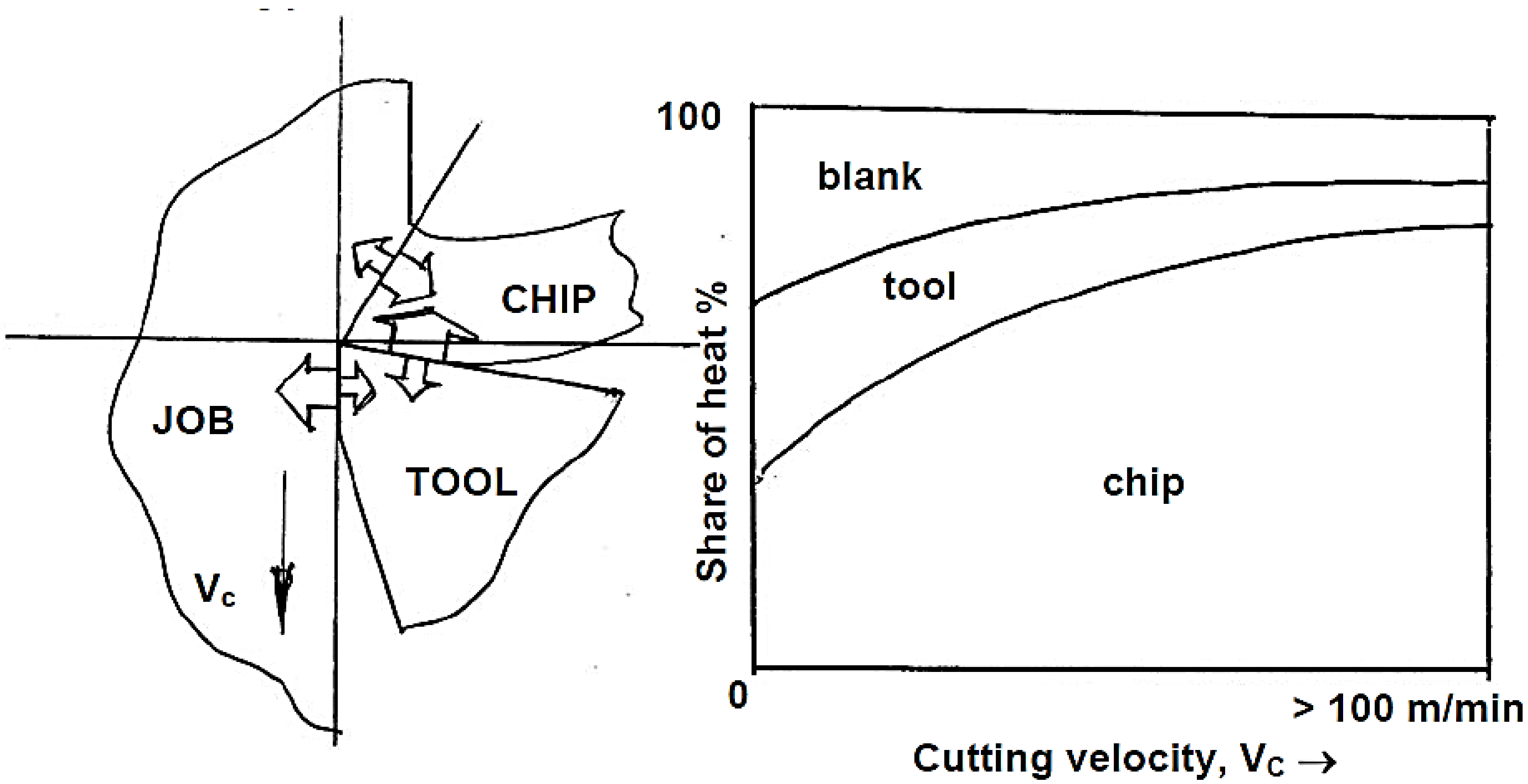
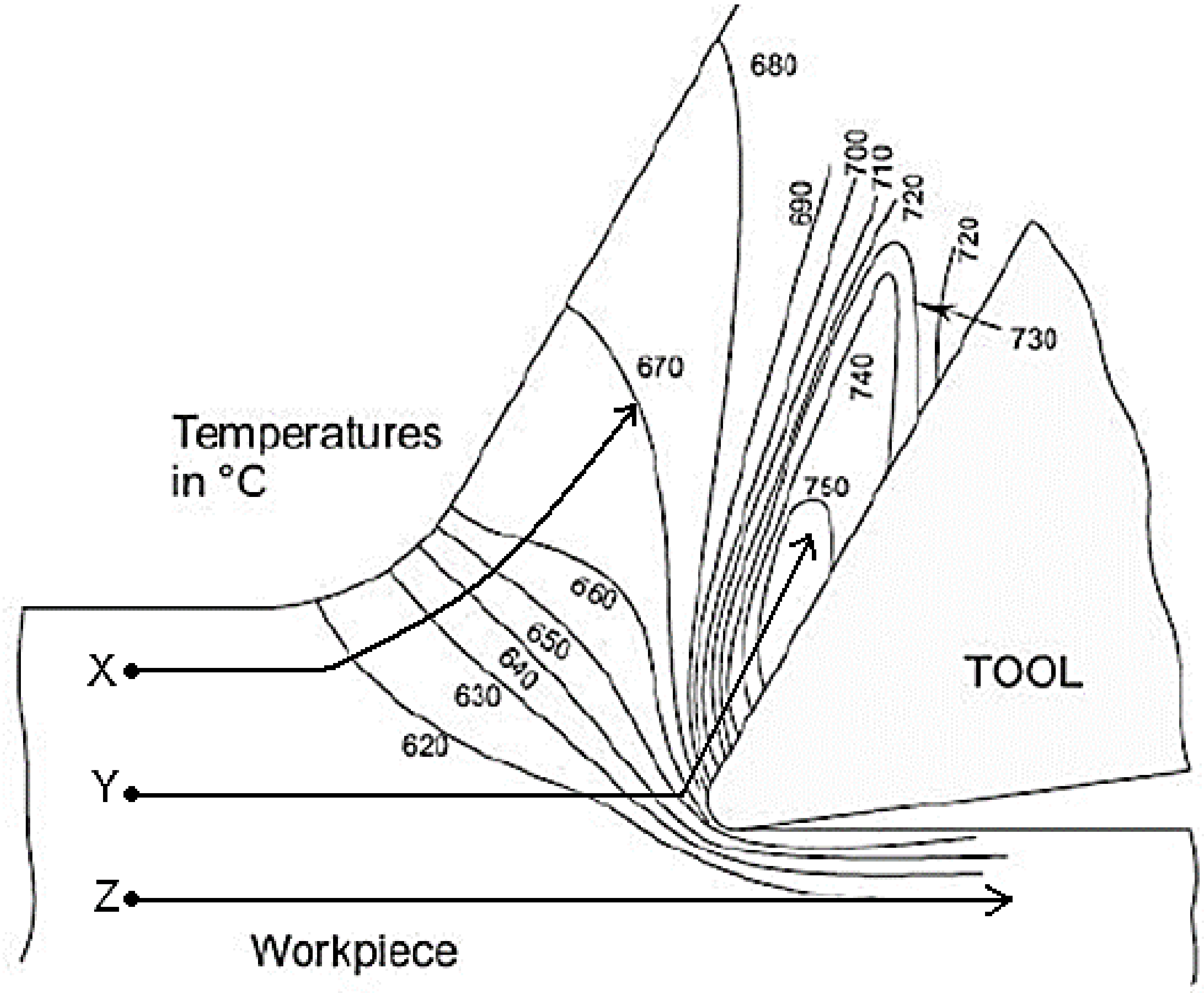


Fig. 2.7.2 *Apportionment of heat amongst chip, tool and blank.*

Effects of high cutting temperatures

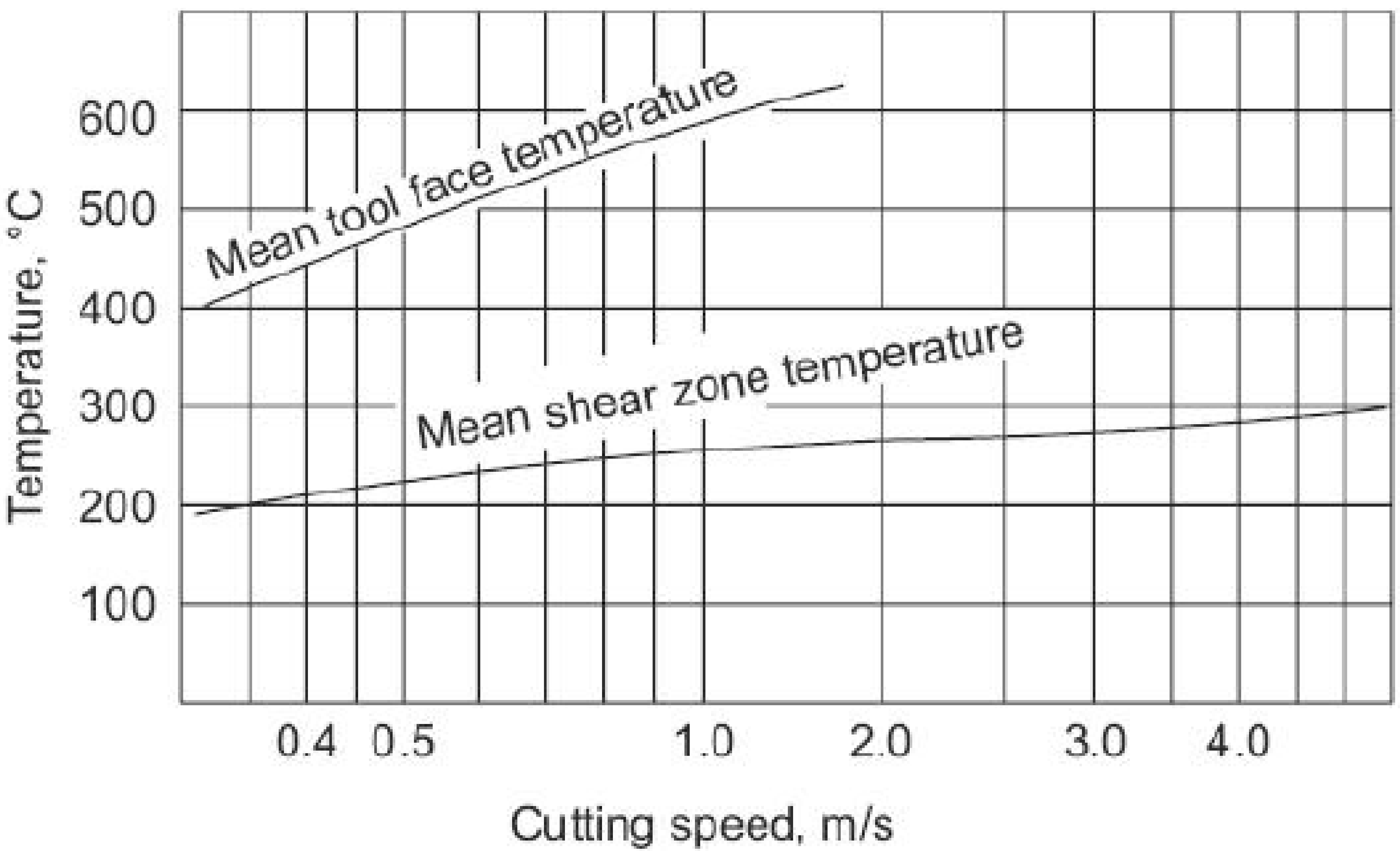
- Rapid tool wear, reduces tool life
- Plastic deformation of the cutting edge
- Thermal flaking and fracturing of cutting edges
- Formation of BUE
- Dimensional inaccuracies of job due to thermal distortion
- Surface damage by oxidation, rapid corrosion and burning
- Induction of thermal residual stresses and micro-cracks on machined surface.

Cutting temperature distribution

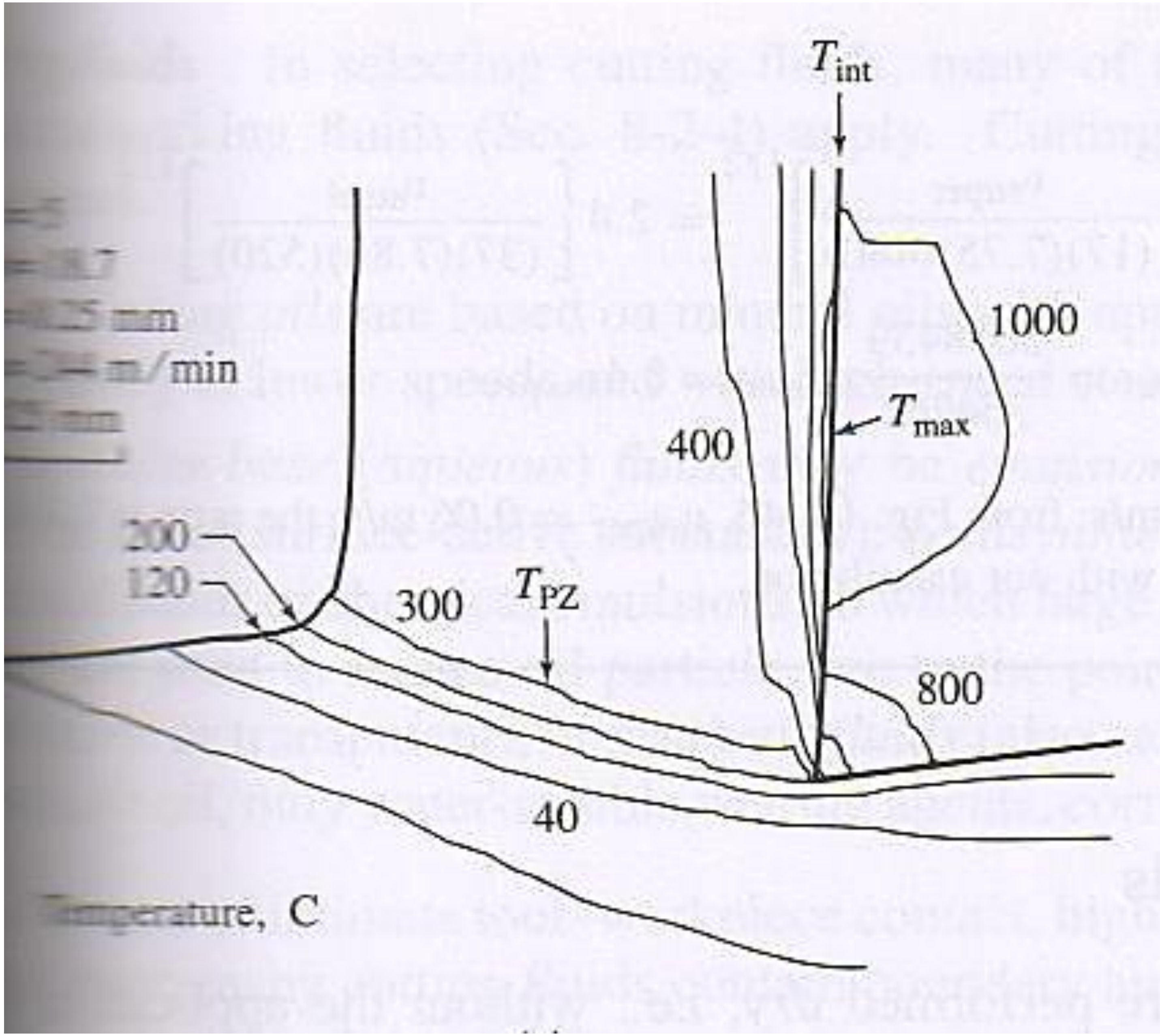


Temperature contours in a cutting tool (Boothroyd).

Effect of cutting speed on Temperature



Temperature distribution over rake surface



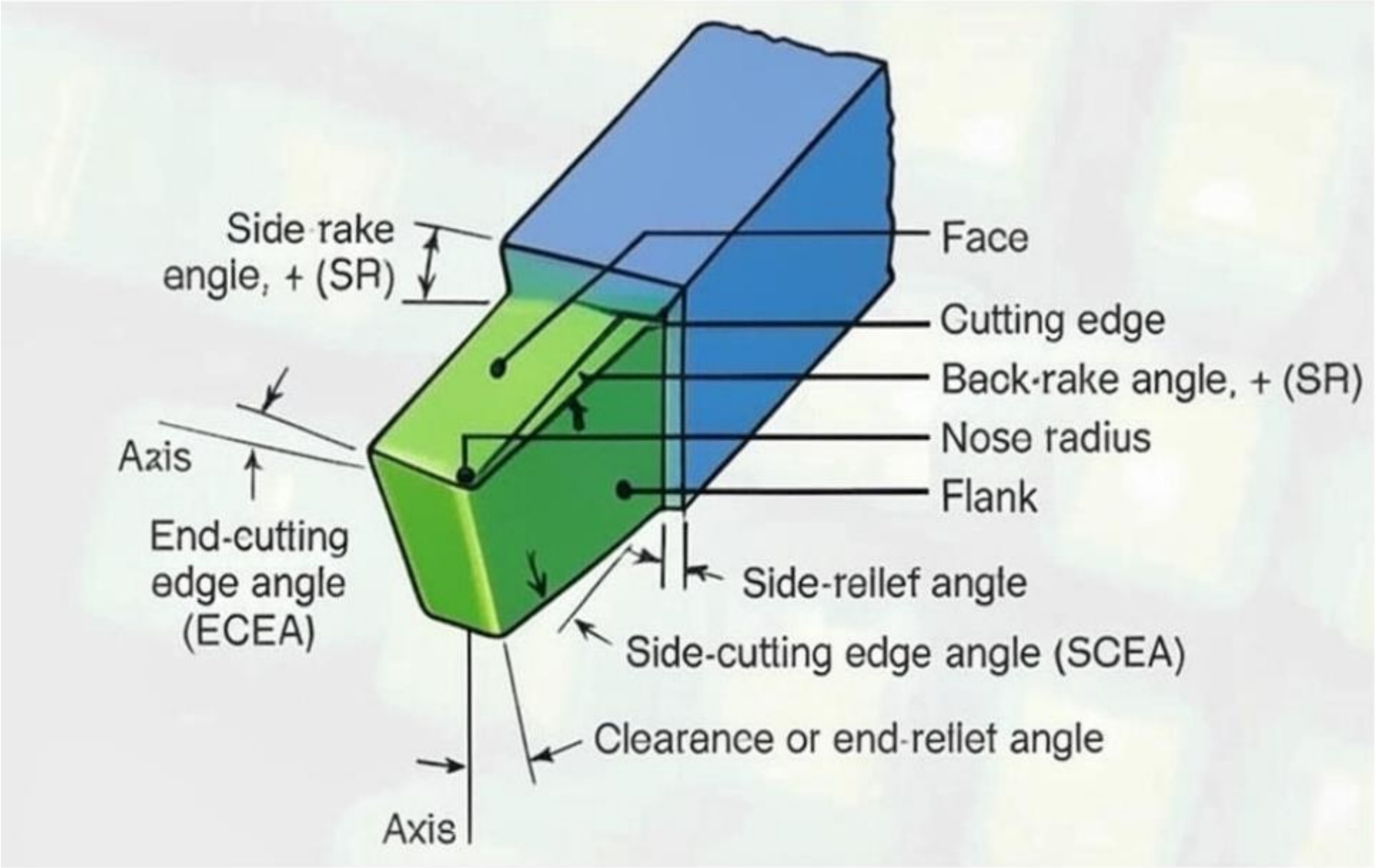
α = 5
Ø = 18.7

t_1 = 0.25 mm
v = 244 m/min

Cutting of AISI 1016 steel with a carbide tool

(J. A. Schey, Introduction to Manufacturing Processes, MGH, 2011)

Single point cutting tool geometry



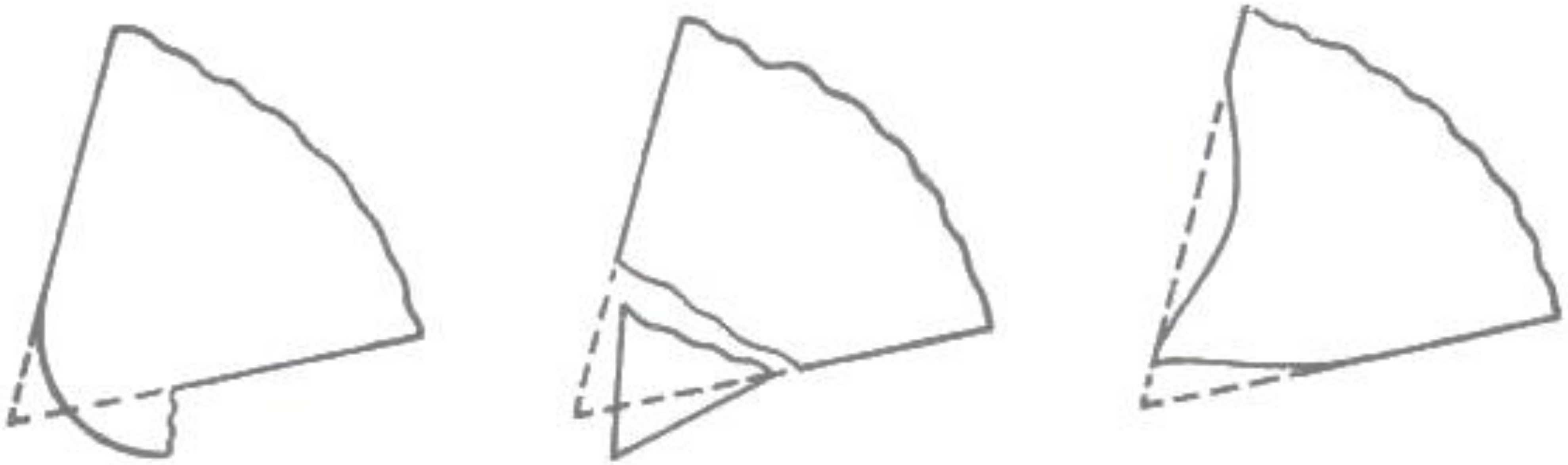
Single point cutting tool

American Standards Association (ASA) system

ASA system of turning tool designation						
γ_Y	γ_X	α_Y	α_X	ϕ_e	ϕ_s	r
0º	5º	6º	6º	10º	30º	1/12

Back rake angle	0°
Side rake angle	5°
Back clearance angle	6°
Side clearance angle	6°
End cutting edge angle	10°
Approach angle	30°
Nose radius	1/12 inch

Tool life and Modes of tool failure



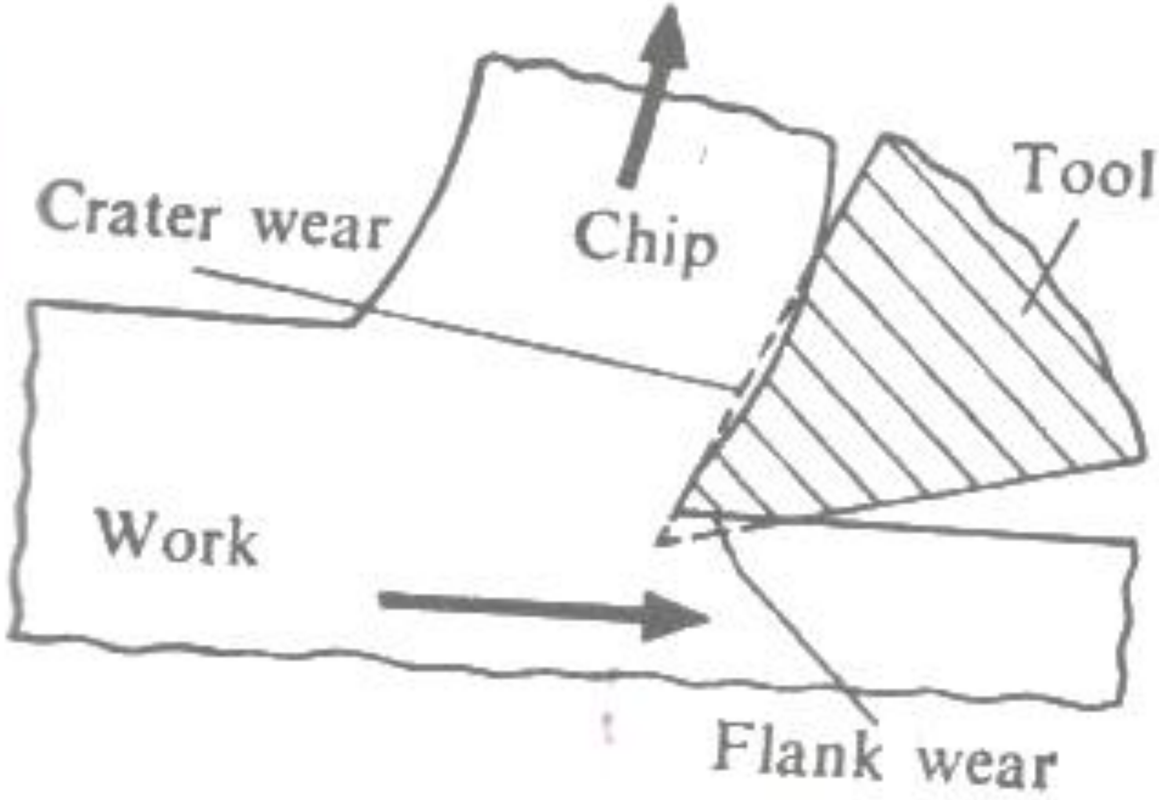
(a) Plastic deformation

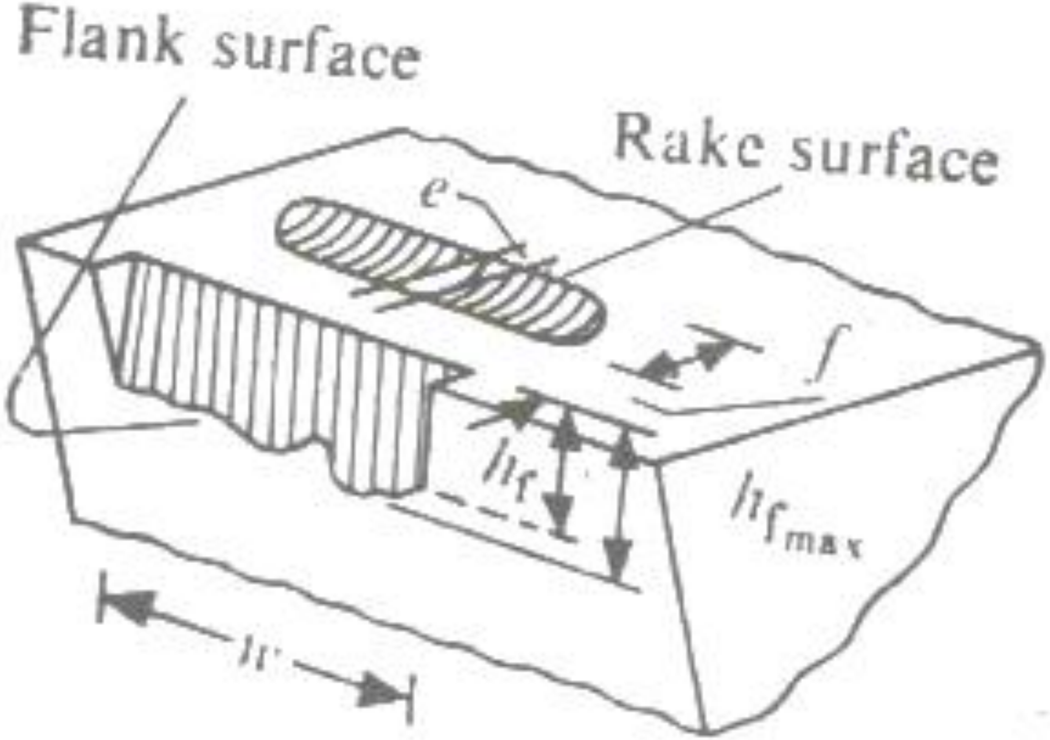
(b) Mechanical breakage

(c) Failure through gradual wear

Fig. 4.18 Modes of cutting tool failure.

Tool wear


Crater wear
Chip
Tool
Work
Flank wear


Flank surface
Rake surface
e
f

Friction and wear

- Solid surface slides over another > resisting force
- Asperities
- Initially, real contact at high points only
- Large localized stresses> plastic deformation
- Contact area increases> no further plastic deformation
- Welding of asperities

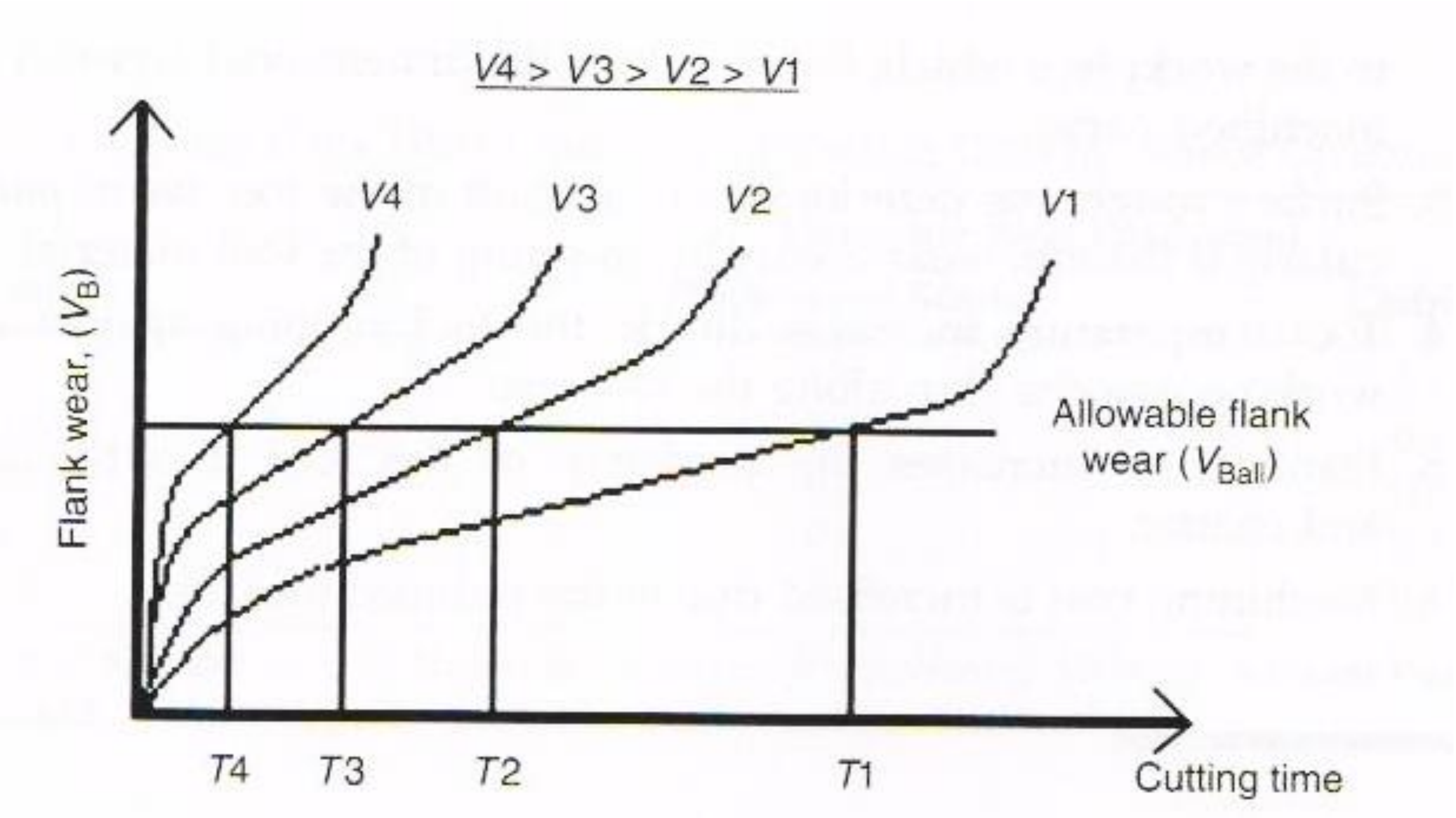
Wear

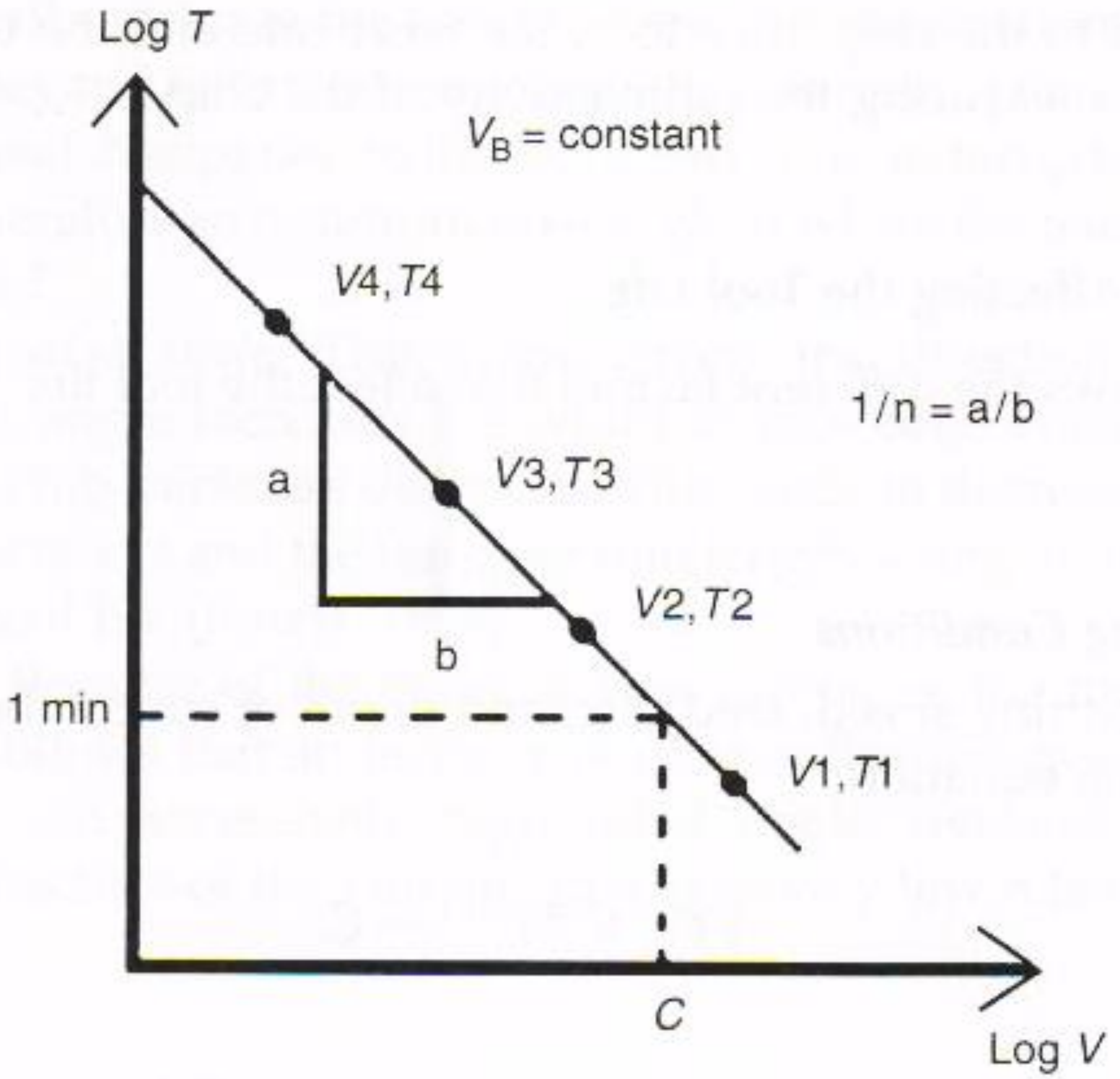
- Shearing of asperities during sliding motion
- Gradual loss of material from both materials
- Transfer of material
- Abrasion: Ploughing action by dislodged material
- Adhesion: Welding of asperities of similar materials, then shearing during sliding motion

Wear

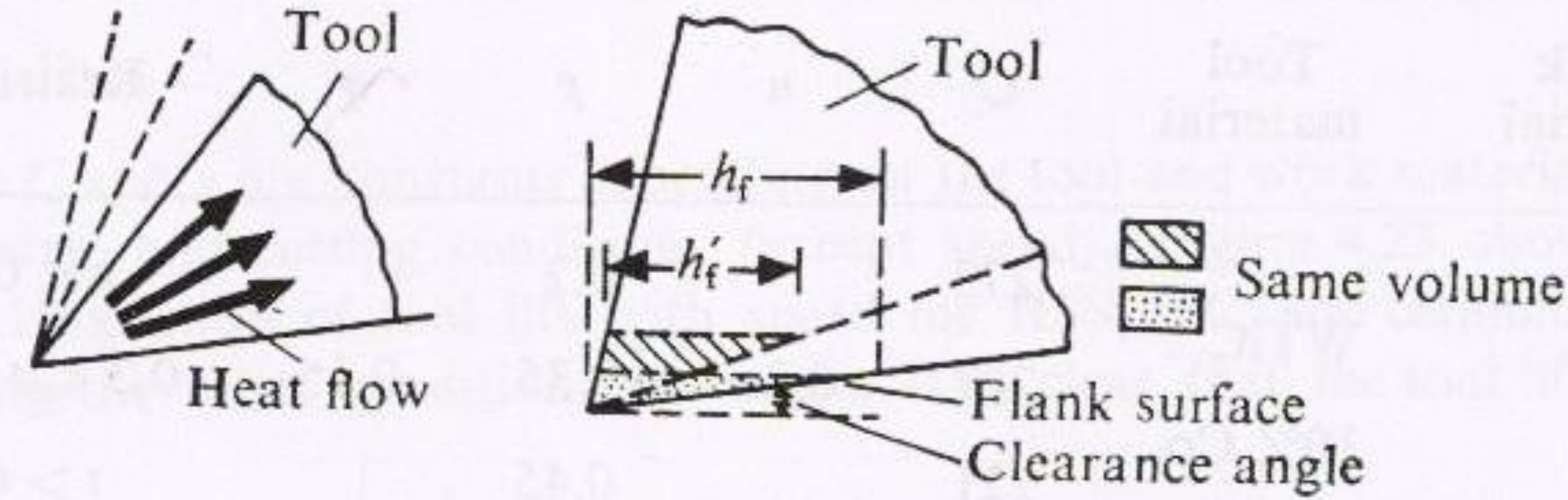
- Diffusion: Atoms in a crystal lattice always move from a region of high concentration to one of low concentration.

Variation of flank wear with cutting time at different cutting




Log T
V_B = constant
$V4, T4$
1/n = a/b
a
$V3, T3$
$V2, T2$
b
1 min
$V1, T1$
C
Log V

Effect of variation in tool angles



(a) Dependence of heat conduction on tool angle

(b) Dependence of flank wear on clearance angle

Effect of tool wear