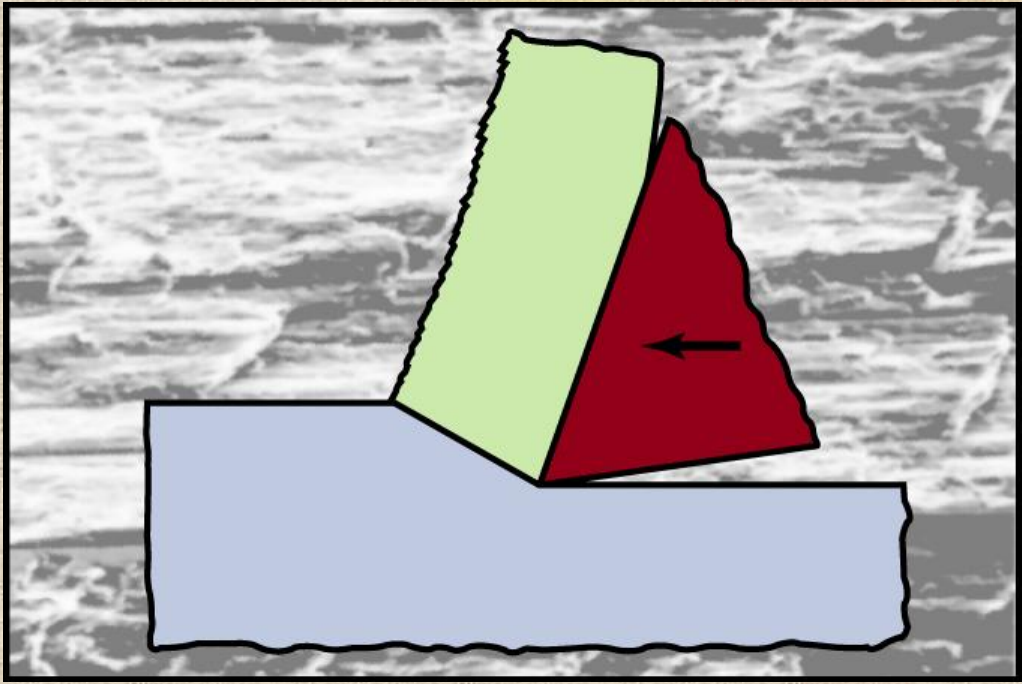
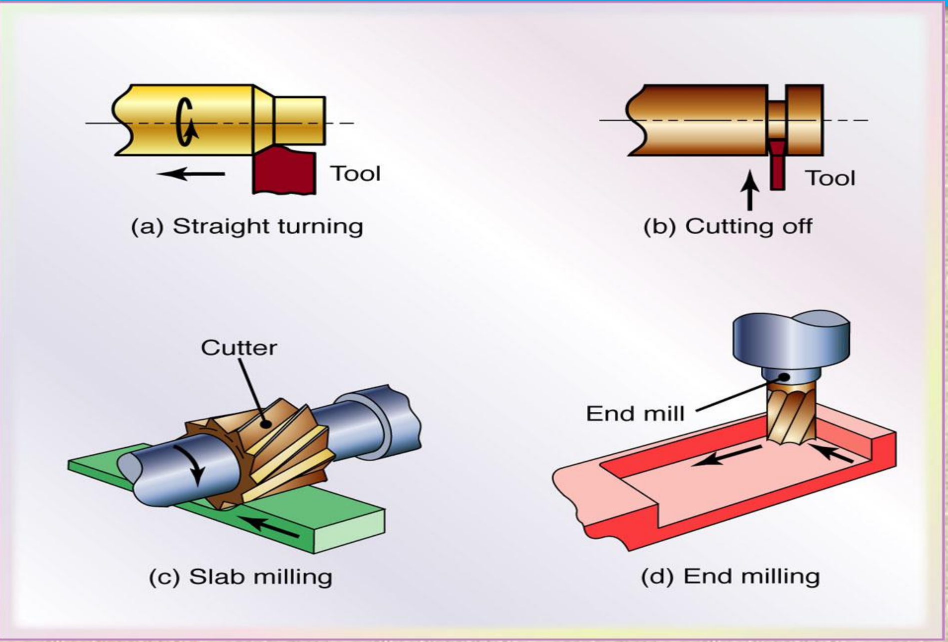
TOPICS

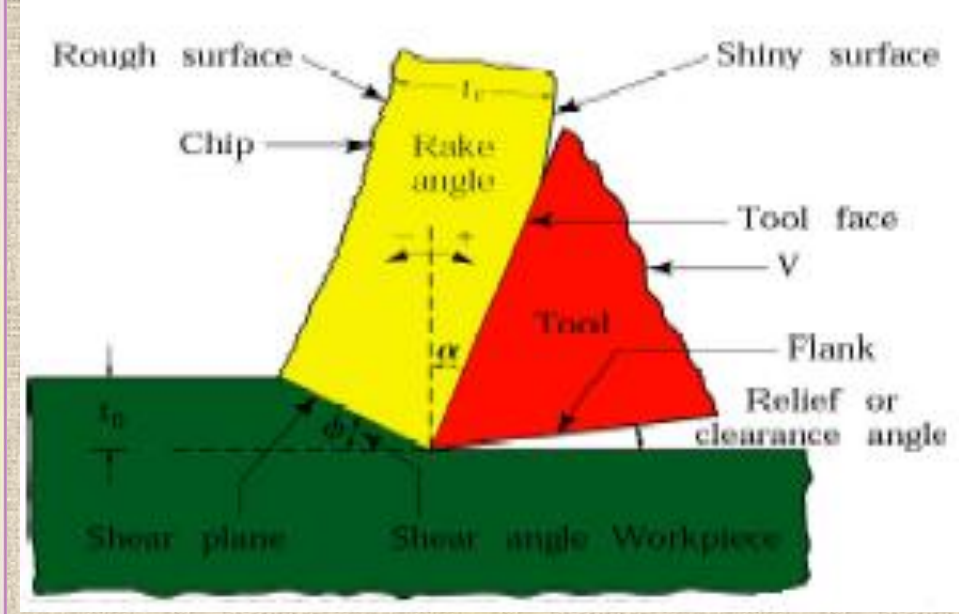
- Introduction
- Mechanics of chip formation
- Types of chips produced in meta cutting
- Mechanics of oblique cutting
- Cutting forces and power
- Temperature in cutting
- Tool life : Wear and failure
- Surface finish and integrity



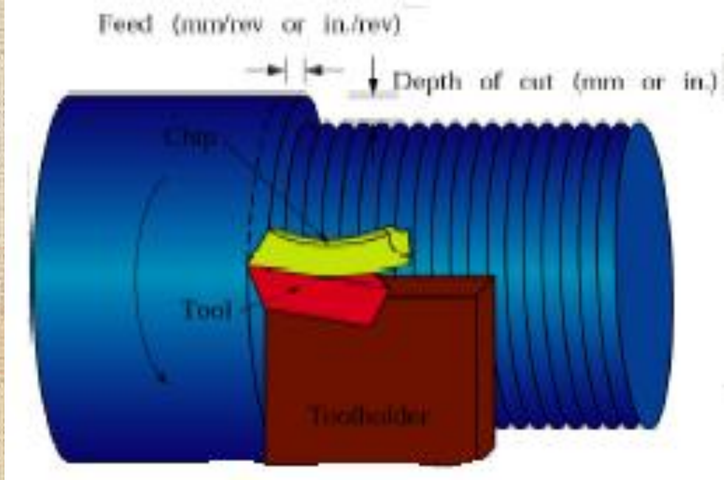
Fundamentals of cutting



Examples of cutting process



- Schematic illustration of a two-dimensional cutting process, also called orthogonal cutting. Note that the tool shape and its angles, depth of cut, to,and the cutting speed are all independent variables.



Basic principle of turning operation

Introduction :

- Cutting process : Remove material from the surface of the work piece by producing chips
- Turning operation : the work piece is rotated an a cutting tool removes a layer of material as it moves to the left
- Cutting off: Cutting tool moves radially inwards and separated the right piece from the back of the blank.
- Slab-milling rotating cutting tool removes a layer of material from the surface of the work piece
- End-milling rotating cutter travels along a certain depth in the work piece and produces a cavity

Factors influencing cutting process

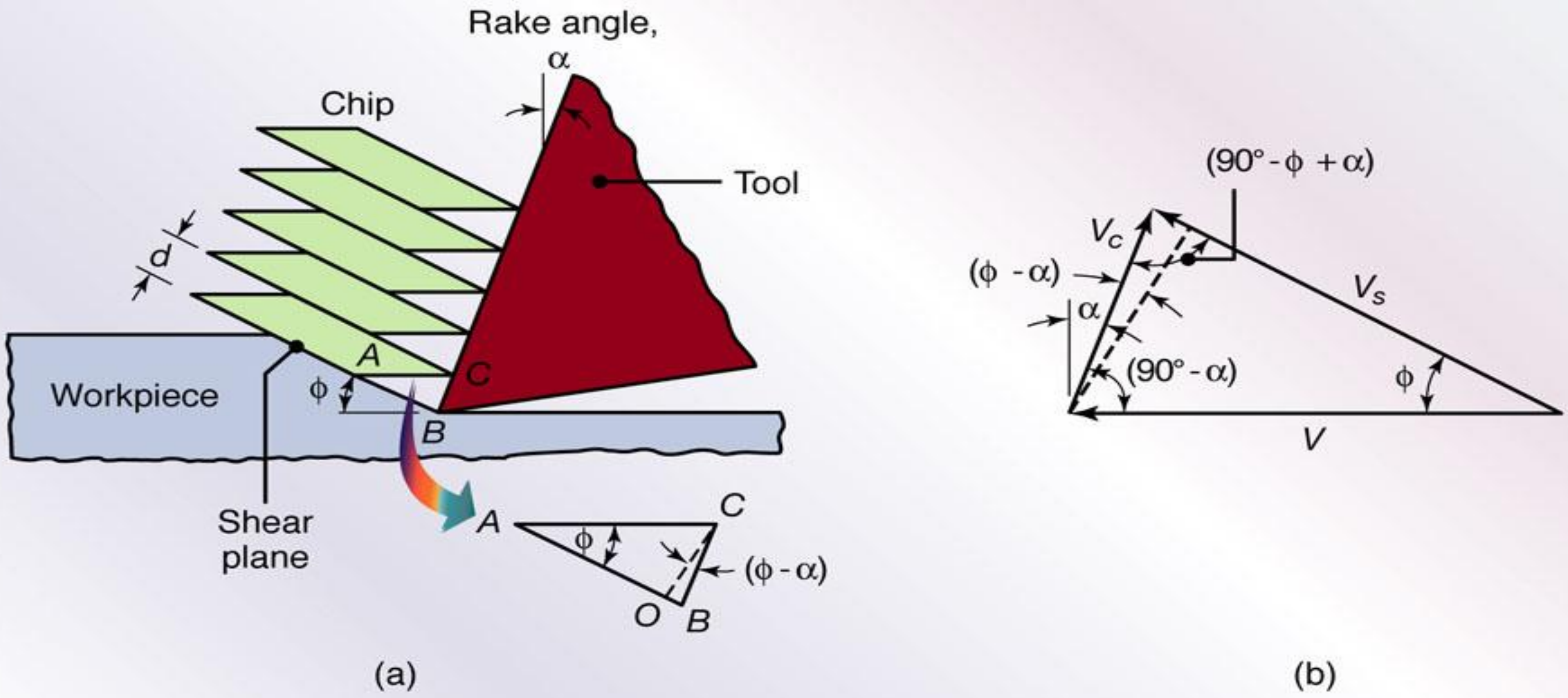
Parameter	Influence and interrelationship
Cutting speed depth of cut,feed,cutting fluids.	Forces power,temperature rise,tool life,type of chips,surface finish.
Tool angles	As above;influence on chip flow direction;resistance to tool chipping.
Continuous chip	Good surface finish;steady cutting forces;undesirable in automated machinery.
Built-up-edge chip	Poor surface finish,thin stable edge can product tool surface.
Discontinuous chip	Desirable for ease of chip disposal;fluctuating cutting forces;can affect surface finish and cause vibration and chatters.
Temperature rise.	Influences surface finish,dimensional accuracy,temperature rise,forces and power.
Tool wear	Influences surface finish,dimensional accuracy,temperature rise,forces and power.
Machinability	Related to tool life,surface finish,forces and power

Mechanics of chip formation :

- Orthogonal cutting
- Rake angle – Alpha
- Relief angle (clearance angle)
- Shear angle (Pi)
- Thickness of a chip – Tc
- Depth of cut- T0
- Cutting ratio r = To / Tc

  = Sin Pi / Cos (pi- Alpha)

Mechanism of chip formation



Schematic illustration of the basic mechanism of chip formation in metal cutting. (b) Velocity diagram in the cutting zone.

Mechanism of chip formation

- Chip compression ratio = 1 / r
- Always > unity
- On the basis of fig 20.4-a
- Shear strain gama
- Gama = AB/OC = AO/OC + OB/OC
- Gama = Cot Pi + tan (Pi – Alpha)
- Note : for actual cutting operation shear strain > 5

Mechanism of chip formation

- Shear angle adjusts itself to minimize cutting force
- Shear plane is the plane of maximum shear stress
- Pi = 45 + Alpha / 2 – Beta / 2
- Beta : Friction angle
- Mu – coefficient of friction
- Mu = tan beta

Mechanism of chip formation

- Mass continuity has to be maintained
- So , we have
- V To = Vc Tc
- Vc = Vr
- Vc = V Sin pi / Cos (pi – Alpha)
- Vc : Velocity of a chip
- V : Cutting Speed
- Vs : Velocity of shearing
- From trigonometric relation
- V / cos (pi – Alpha) = Vs / Cos (Alpha) = Vc / Sin (pi)

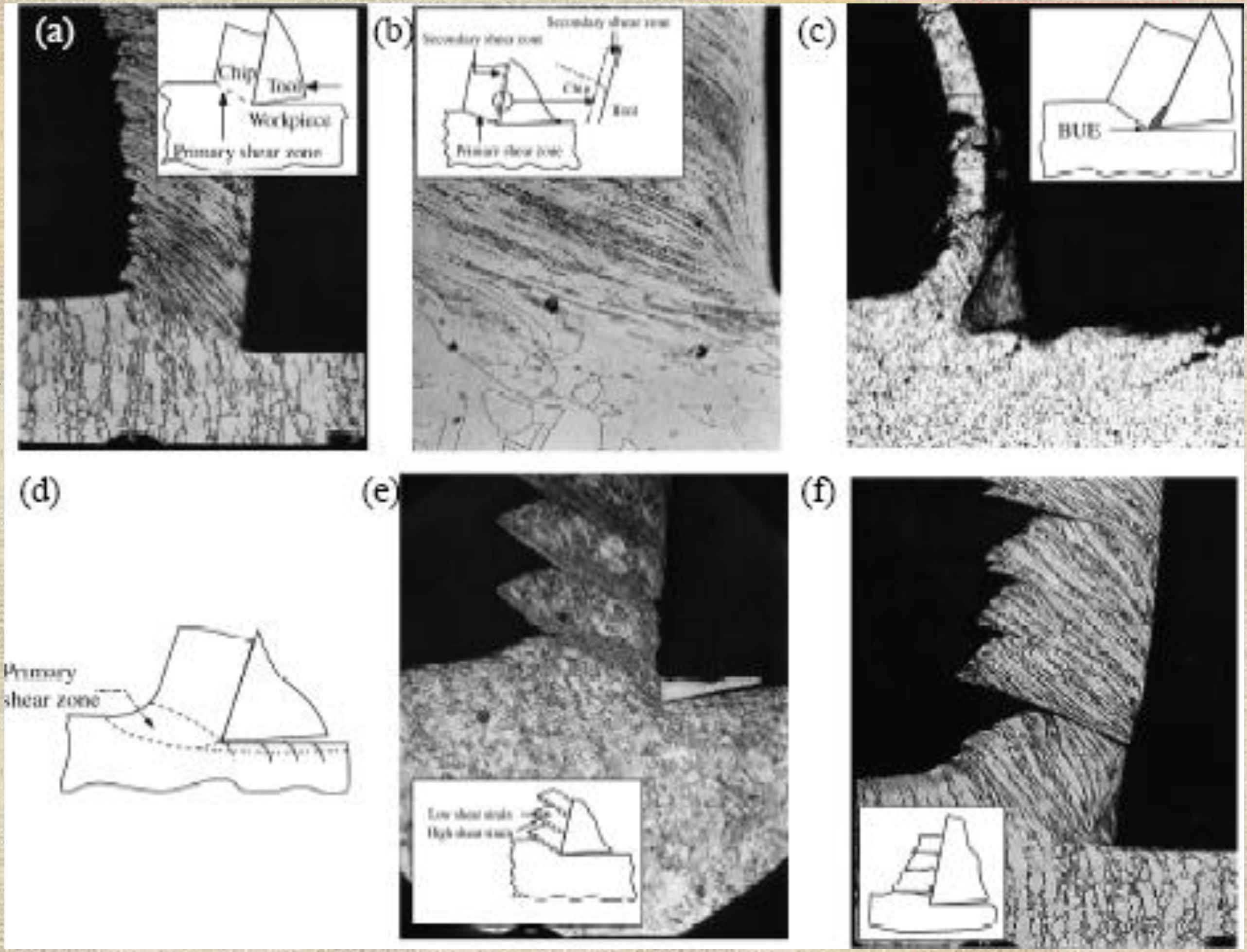
Types of chips

Continuous

Built up edge

Serrated or segmented

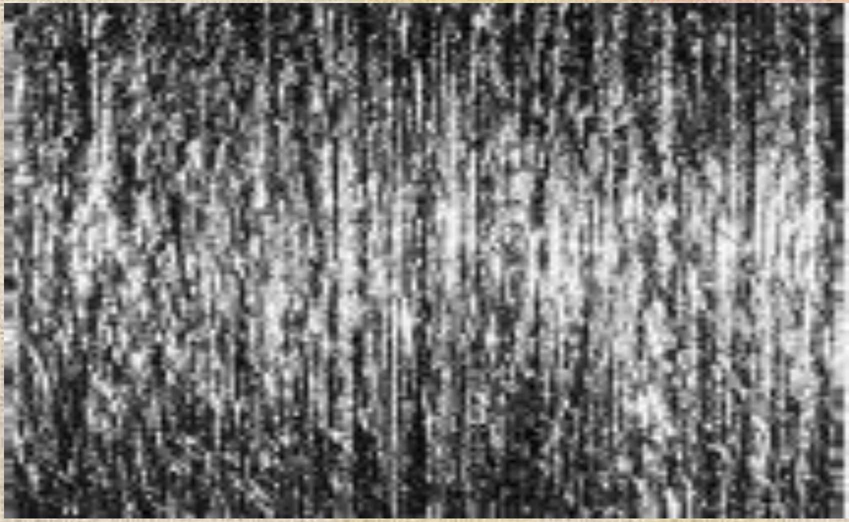
Discontinuous



Basic types of chips and their photomicrographs produced in metal cutting (a) continuous ship with a narrow,straight primary shear zone; (b) secondary shear zone at the chip tool interface;(c) continuous chip with large primary shear zone; (d) continuous chip with built-up-edge;(e) segmented or nonhomogeneous chip and (f) discontinuous chips

Continuous chips

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



(b) Surface finish in turning 5130 steel with a built-up edge

(c) Surface finish on 1018 steel in face milling

Continuous chips

- Continuous chips are usually formed at high rake angles and/or high cutting speeds.
- A good surface finish is generally produced.
- continuous chips are not always desirable, particularly in automated machine tools,
- tend to get tangled around the tool
- operation has to be stopped to clear away the chips.

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- Discontinuous chips consist of segments that may be firmly or loosely attached to each other

- These chips occur when machining hard brittle materials such as cast iron.

- Brittle failure takes place along the shear plane before any tangible plastic flow occurs

- Discontinuous chips will form in brittle materials at low rake angles (large depths of cut).

Temperature In Cutting

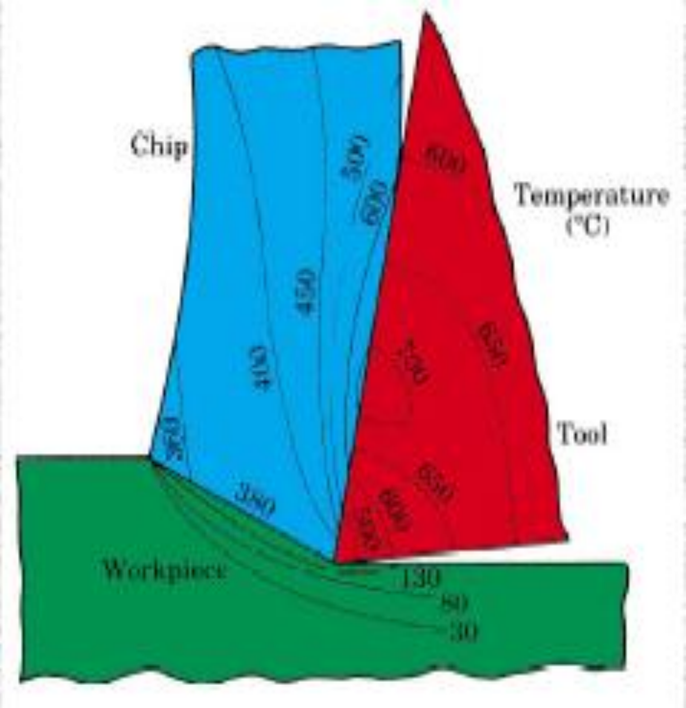


Fig:Typical temperature distribution in the cutting zone.

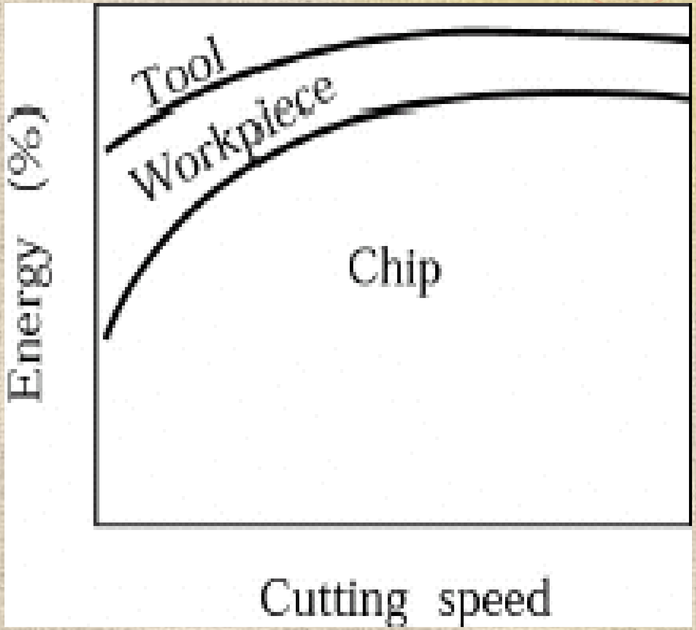


Fig:Percentage of the heat generated in cutting going into the workpiece,tool,and chip,as a function of cutting speed.

Temperature Distributions

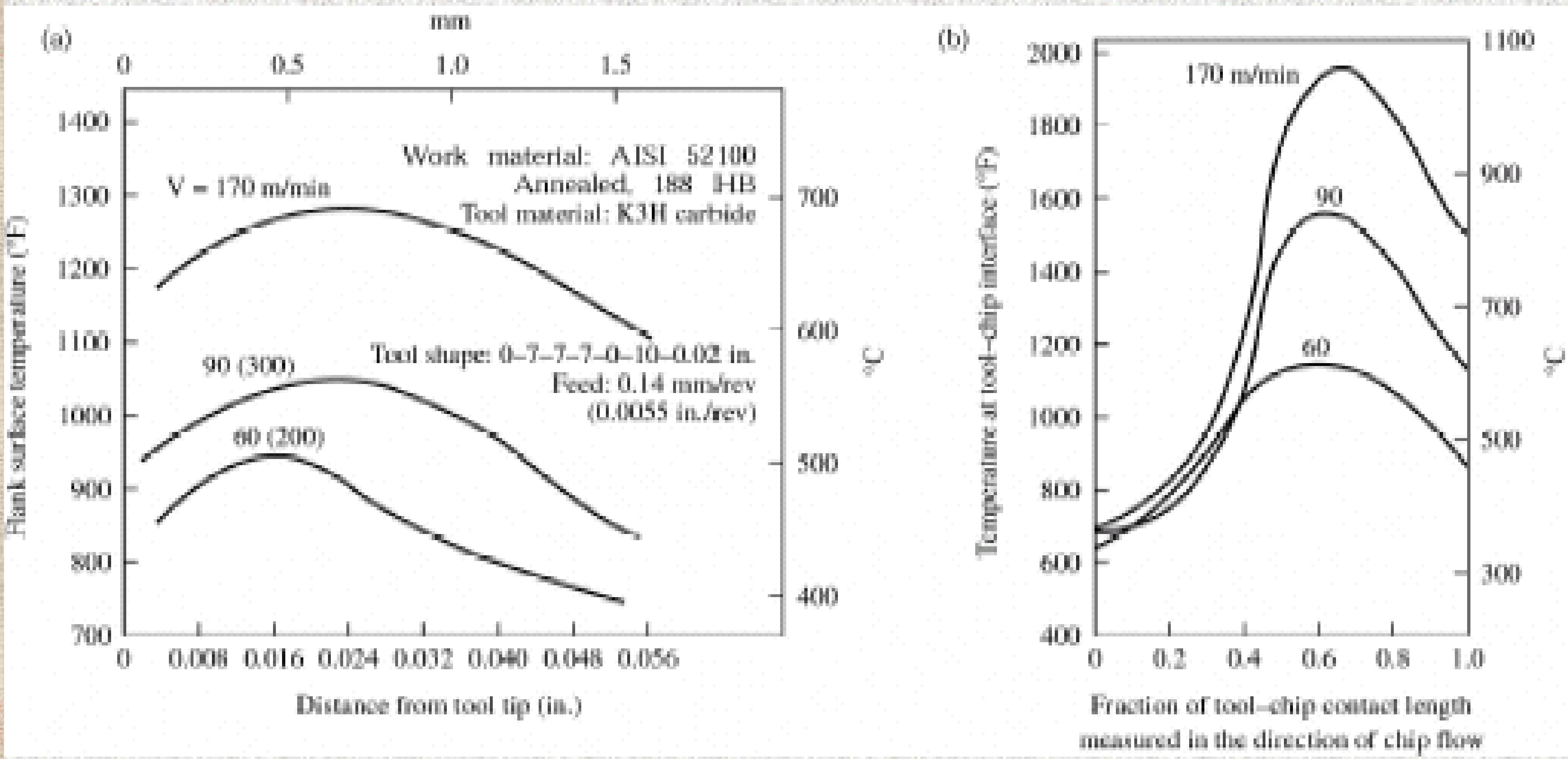


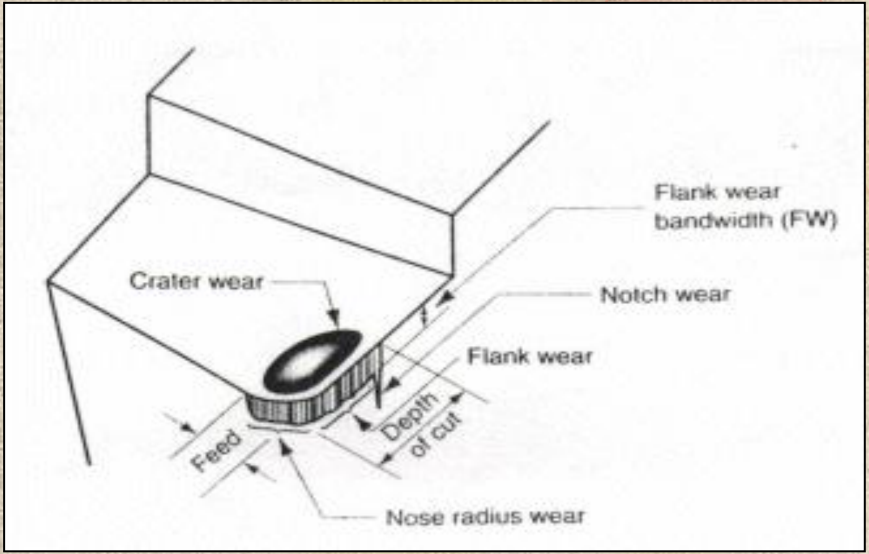
Fig:Temperatures developed in turning 52100 steel: a) flank temperature distribution;and b)tool-chip interface temperature distribution

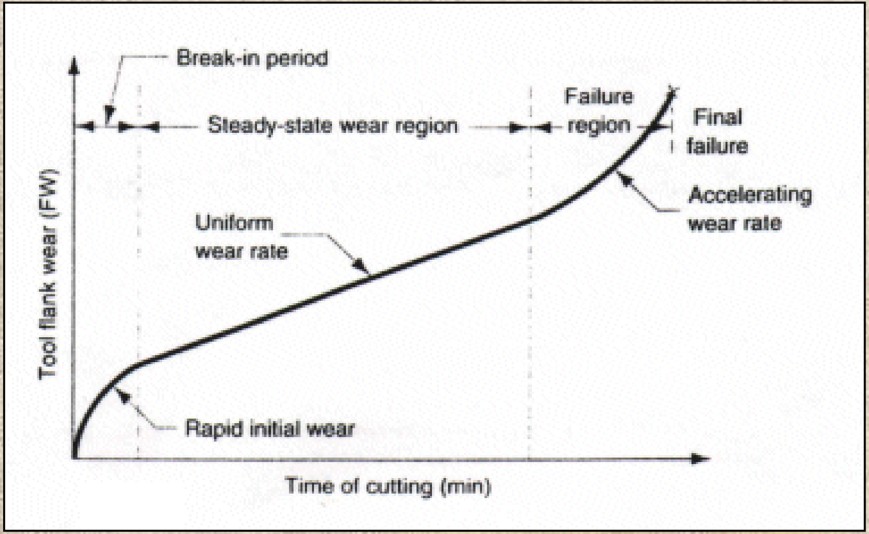
Cutting tool related terms

- Single point versus multiple point
- Cratering –wear that forms a concave region on the tool
- Tool life – length of cutting time that a tool can be used
- Toughness – capacity to absorb energy without failing
- Hot hardness –capacity to retain hardness at high temperatures
- Cermet – combination of TiC, TiN, TiCN (CN = carbonitride), with nickel and/or molybdenum as binders
- Chip breaker – geometry designed into tool to break stringy chips
- Cutting fluid – Any liquid/gas applied to improve cutting performance

Tool wear:

- Abrasion - dominant cause of flank wear
- Adhesion – high pressure localized fusion and rupturing
- Diffusion – Loss of hardening atoms at tool-chip boundary (contributes to crater wear)
- Plastic deformation – contributes to flank wear
- Three pronounced wearing regions



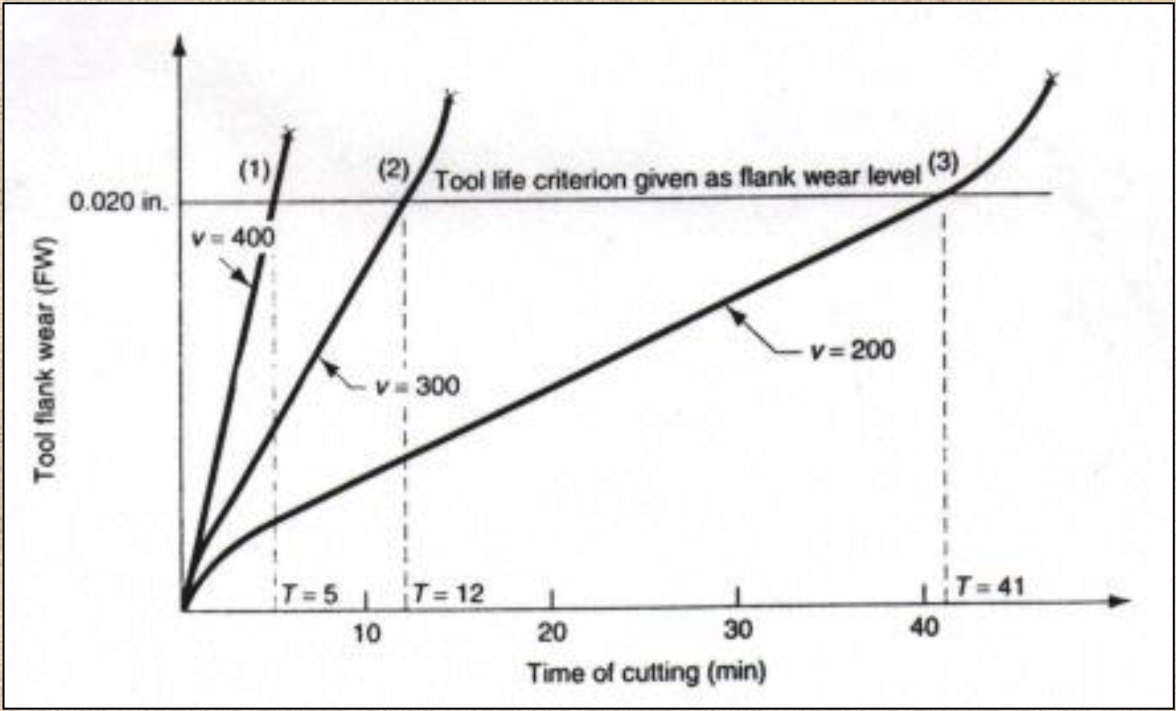


Tool life:

Tool life – length of cutting time that a tool can be used or a
certain flank wear value has occurred (0.02”)

Taylor’s tool life equation:

$v T^n = C$ *(exponential again!)*



v = cutting speed
n = cutting exponent
C = cutting constant

Note: n and C depend on speed, work material, tool material, etc. C has units of fpm and is the speed at which the tool life lasts 1 min, i.e.,
$v T^n = C (1)^n = C$.

Operator’s tool life:

Tool life is measured by:

- Visual inspection of tool edge
- Tool breaks
- Fingernail test
- Changes in cutting sounds
- Chips become ribbony, stringy
- Surface finish degrades
- Computer interface says
  - power consumption up
  - cumulative cutting time reaches certain level
  - cumulative number of pieces cut reaches certain value

Tool life example

The n and C values in Table 23.2 in the text are based on a feed rate of 0.01 in./rev and a depth of cut of 0.10 in. Determine and compare the cubic inches of steel removed for each of the following tool materials if a 15 minute tool life is required in each case: a) HSS b) ceramic

Solution:

Approach is to determine the MRR = v f d. We are given the feed rate and the depth of cut; thus, need to calculate the cutting speed.

Given Taylor's equation and the n and C values, we can solve for v and thus determine the MRR.

Given the MRR, we multiply it by the cutting time to get the volume of material removed.

Tool life example

Solution for HSS:

From Table 23.2, n = 0.125 and C = 200 ft/min (for steel cutting)

From $v T^n = C$ we solve for v:

$$v = 200/(15)^{0.125} = 142.6 \text{ ft/min}$$

Now, get the MRR:

$$MRR = (142.6)(12)(0.01)(0.10) = 1.71 \text{ in}^3/\text{min}$$

Volume removed in 15 min is $(15)(1.71) = 25.66 \text{ in}^3$

Tool life example

Solution for ceramic:

From Table 23.2: $n = 0.6$ and $C = 10{,}000$ ft/min

From $v\,T^n = C$ we solve for v:

$$v = 10{,}000/(15)^{0.6} = 1969.5 \text{ ft/min}$$

Now, get the MRR:

$$MRR = (1969.5)\,(12)\,(0.01)\,(0.10) = 23.63 \text{ in}^3/\text{min}$$

Volume removed in 15 min is (15) (23.63) = 354.5 in^3

Ceramic about an order-of-magnitude more effective than HSS!

Cutting tool materials

- Plain carbon and low alloy steels – rarely used today

- High-speed steel (HSS) – primary alloys are tungsten (AISI T grade > 12%) or molybdenum (M grade, 5 – 8%).... sometimes coated with TiN to improve performance, toughness good

- Cast cobalt alloys – cobalt (50%), chromium (30%), and tungsten (20%), improved wear resistance, but toughness < HSS

Cutting tool materials

•Cemented carbides, cermets, and coated carbides – related materials that are a composite of ceramic and metallic materials. Cemented carbides use tungsten carbides….cermets use titanium carbides. Coated carbides use coatings of TiC or Al_2O_3 to improve wear properties. Higher WC contents in cemented carbides detrimental to steel cutting (affinity of steel with carbon in WC), but ok for other metals. Alloying with TiC and TaC reduces this problem.

•Ceramics – Primarily Al_2O_3... not good in dynamic (higher speeds, shock) cutting situations.

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Cutting tool materials:

- Synthetic polycrystalline diamond (SPD) and cubic boron nitride (CBN) – typically used as coating on base tool material such as WC-Co…there is an affinity of SPD with iron and nickel; CBN does not have this affinity… expensive.

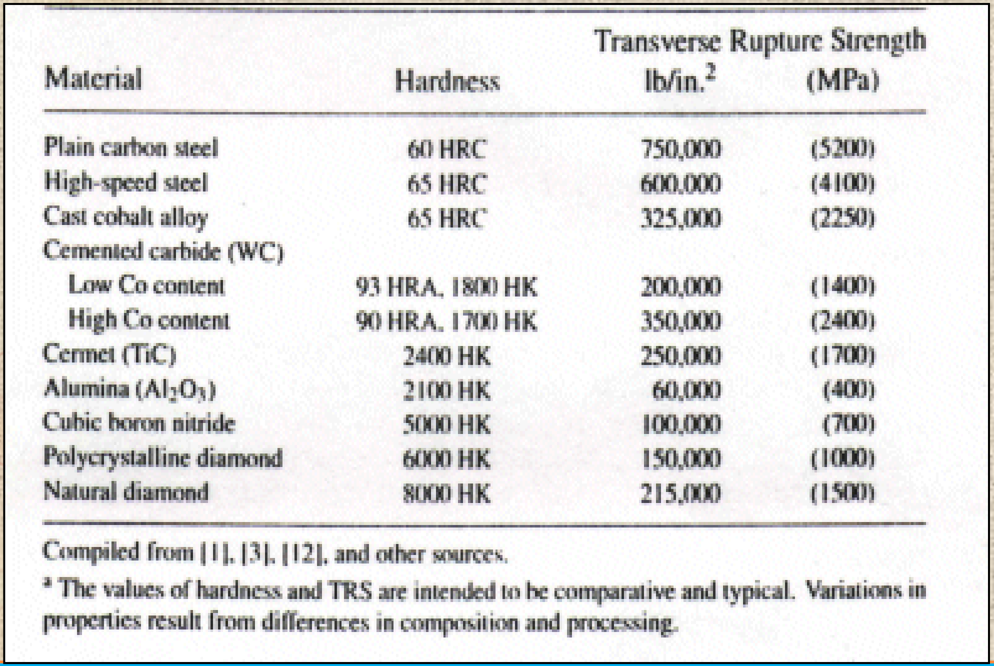
Cutting tool materials – HSS alloying

Element	Properties
Tungsten	Increases hot hardness Hard carbides formed, improving abrasion resistance
Molybdenum	Increases hot hardness Hard carbides formed, improving abrasion resistance
Chromium	Depth hardenability during heat treat Hard carbides formed, improving abrasion resistance Some corrosion resistance
Vanadium	Combines with carbon for wear resistance Retards grain growth for better toughness
Cobalt	Increases hot hardness, toughness
Carbon	Hardening element Forms carbides

Cutting tool materials

Most modern cutting tool materials are a matrix of materials designed to be very hard. Important terms are toughness, hardness and hot hardness. Note that the rake angle is chosen small (near 0 deg) for the harder, more brittle tool materials to keep the tool in compression.

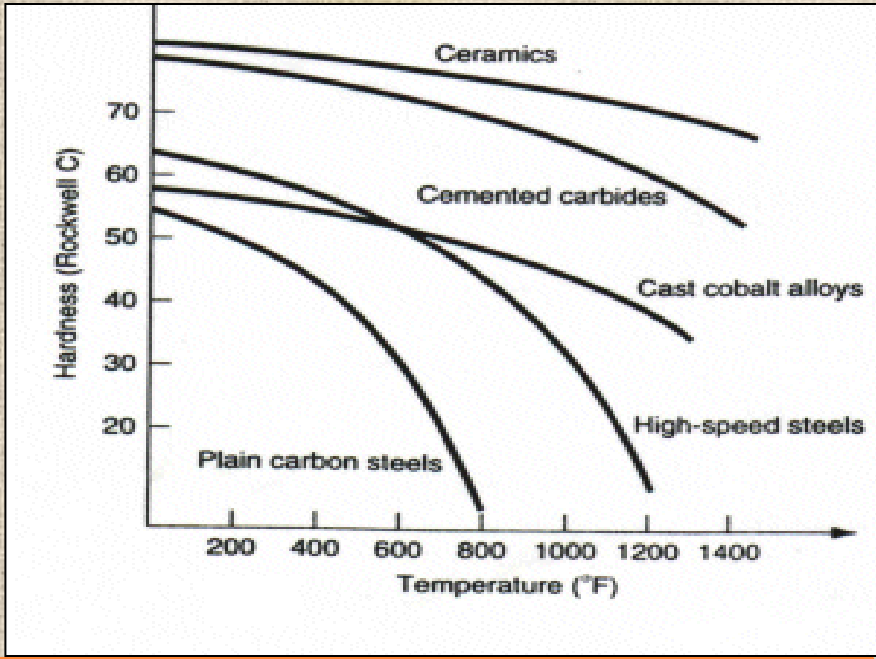
U (Specific Energy) is a measure of toughness, while the table shows typical hardness values at room temperature for cutting tool materials. The figure shows how hardness degrades with increasing temperature.



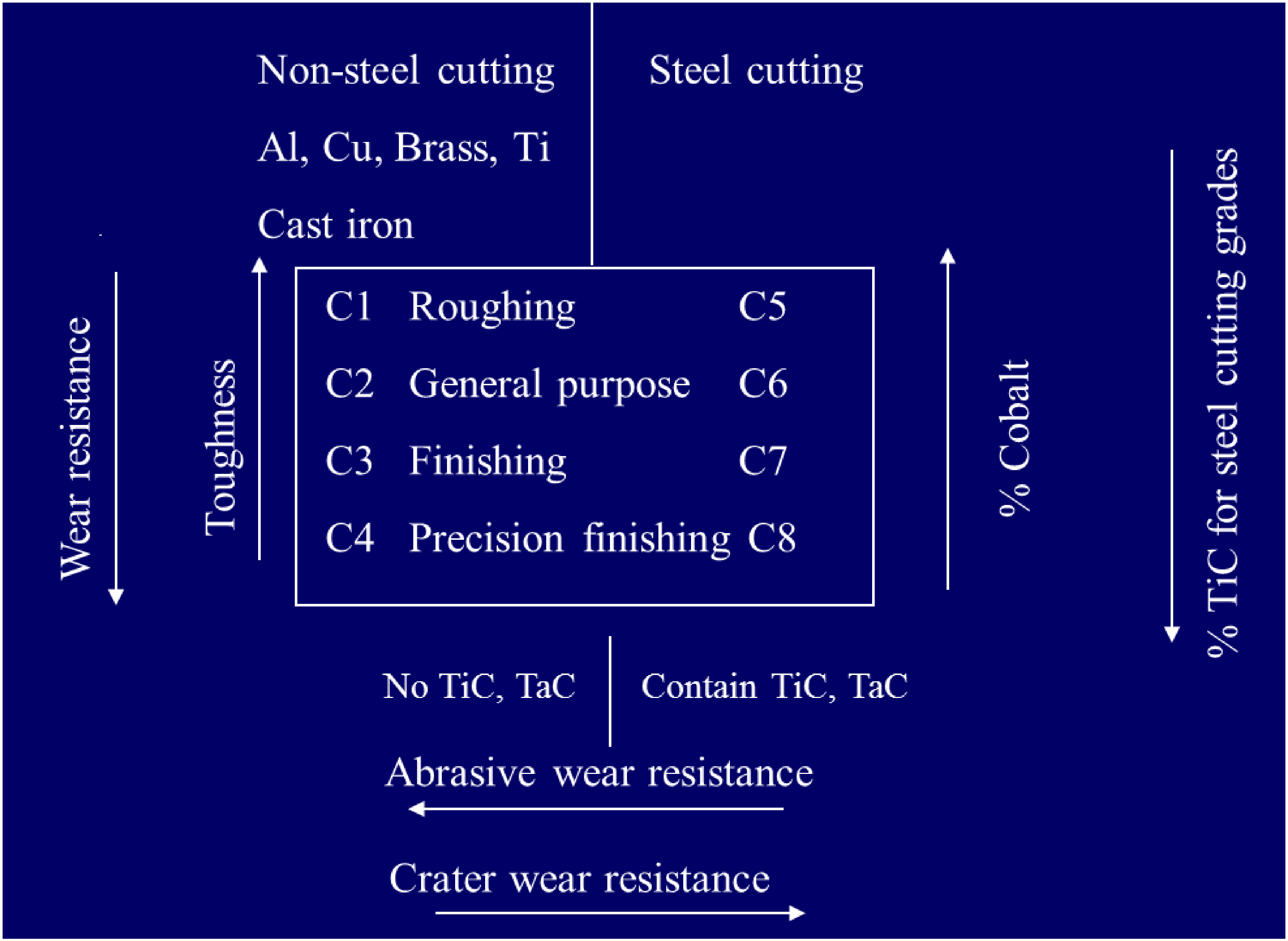
Material	Hardness	Transverse Rupture Strength lb/in.^{2}	(MPa)
Plain carbon steel	60 HRC	750,000	(5200)
High-speed steel	65 HRC	600,000	(4100)
Cast cobalt alloy	65 HRC	325,000	(2250)
Cemented carbide (WC)			
Low Co content	93 HRA, 1800 HK	200,000	(1400)
High Co content	90 HRA, 1700 HK	350,000	(2400)
Cermet (TiC)	2400 HK	250,000	(1700)
Alumina (Al_2O_3)	2100 HK	60,000	(400)
Cubic boron nitride	5000 HK	100,000	(700)
Polycrystalline diamond	6000 HK	150,000	(1000)
Natural diamond	8000 HK	215,000	(1500)

Compiled from [1], [3], [12], and other sources.

[a] The values of hardness and TRS are intended to be comparative and typical. Variations in properties result from differences in composition and processing.



Cemented carbide classification



Non-steel cutting

Al, Cu, Brass, Ti

Cast iron

Steel cutting

Wear resistance

Toughness

C1 Roughing C5

C2 General purpose C6

C3 Finishing C7

C4 Precision finishing C8

% Cobalt

% TiC for steel cutting grades

No TiC, TaC

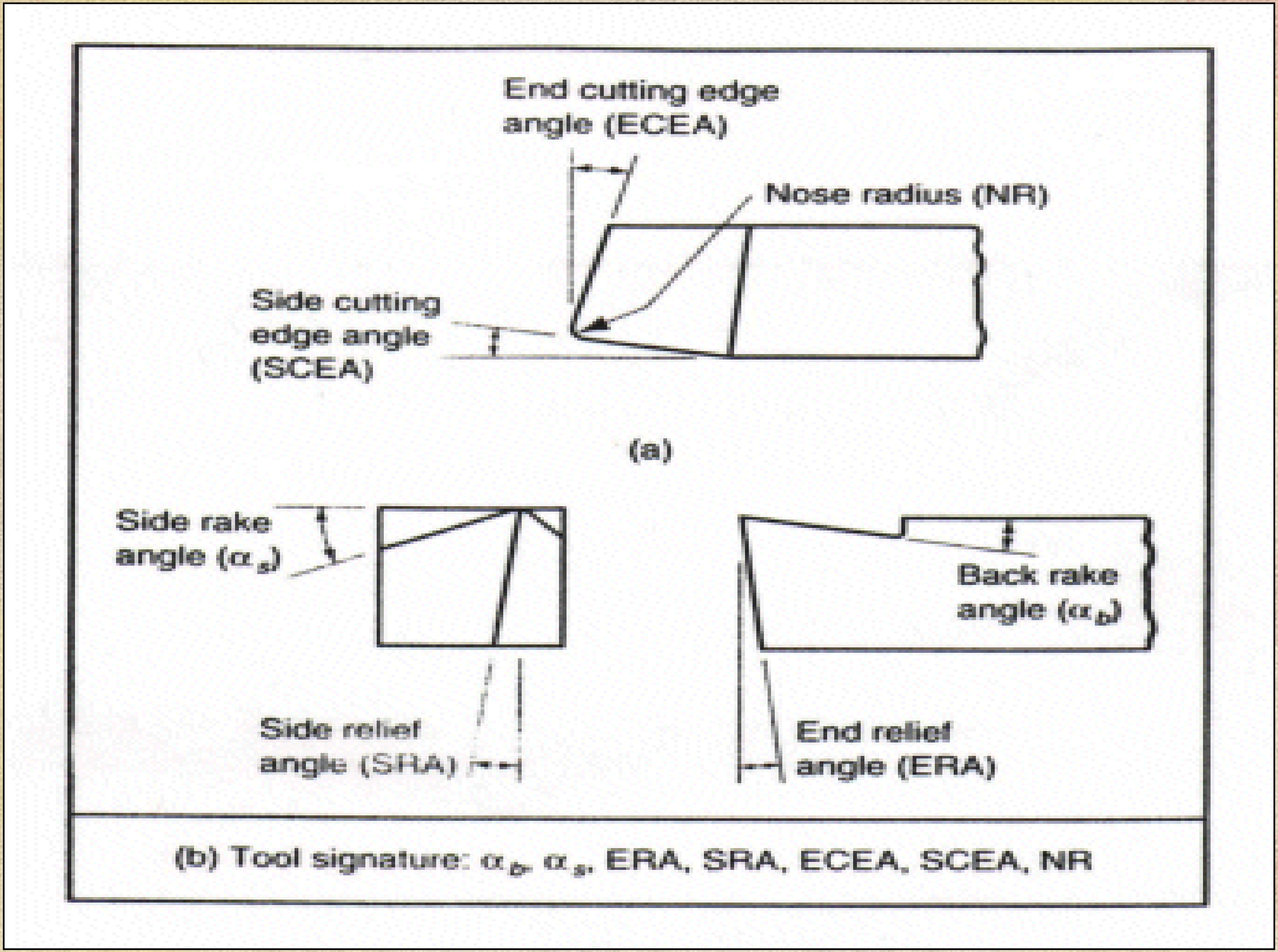
Contain TiC, TaC

Abrasive wear resistance

Crater wear resistance

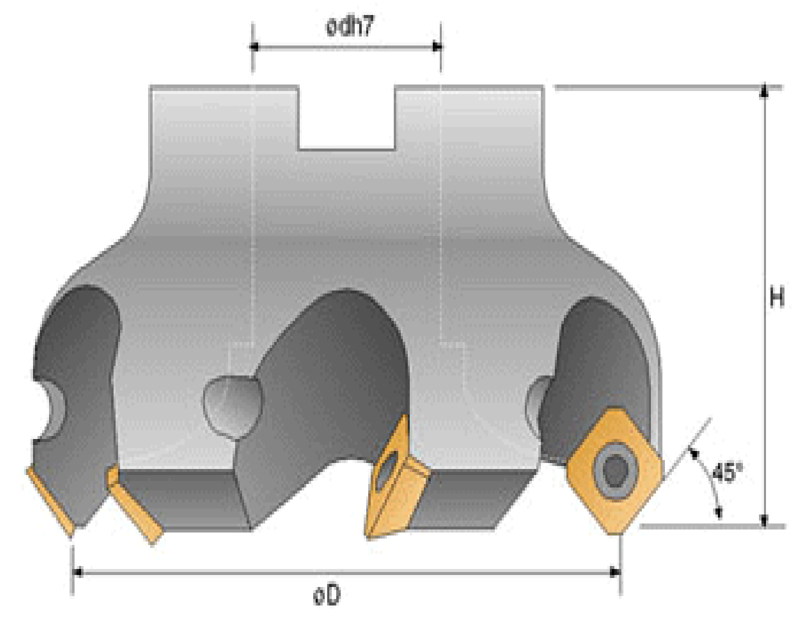
Cutting tool geometry

Elements of a single point tool geometry

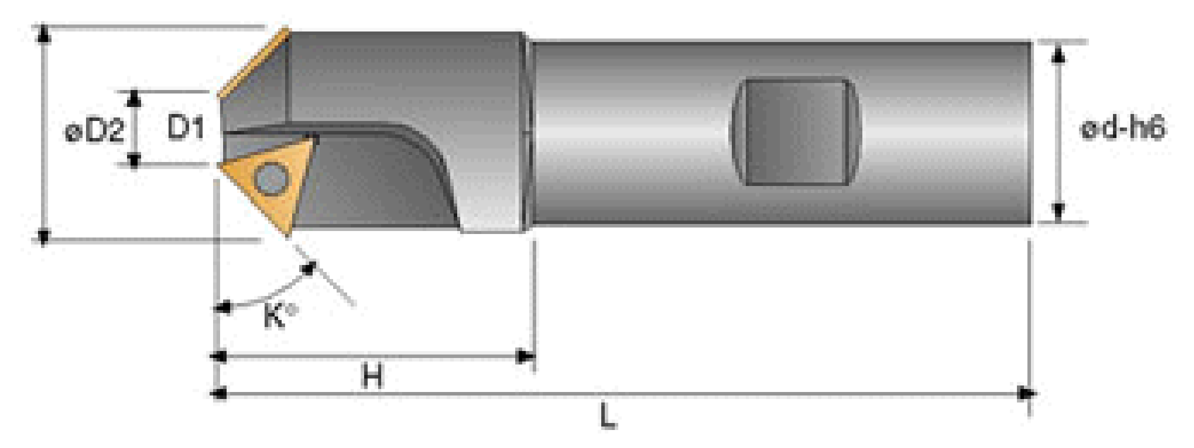


(b) Tool signature: α_b, α_s, ERA, SRA, ECEA, SCEA, NR

Milling tool geometry



Face cutter

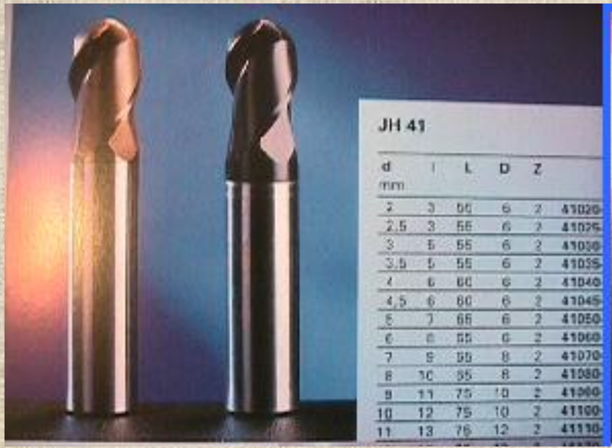


Chamfering cutter

Cutting tool geometry

Mini-cutters

Coated tools



JH 41

d mm	l	L	D	Z	
2	3	55	6	2	41020
2.5	3	55	6	2	41025
3	5	55	6	2	41030
3.5	5	55	6	2	41035
4	6	60	6	2	41040
4.5	6	60	6	2	41045
5	7	65	6	2	41050
6	8	55	6	2	41060
7	9	55	8	2	41070
8	10	55	8	2	41080
9	11	75	10	2	41090
10	12	75	10	2	41100
11	13	75	12	2	41110

Cutting fluids

Lubricants – purpose is to reduce friction… usually oil based

Coolants – purpose is to transport heat… usually water based

Both lose their effectiveness at higher cutting speeds!

Cutting fluids is used to:

- Reduce friction and wear
- Cool the cutting zone
- Reduce forces and energy consumption
- Flush away the chips from the cutting zone
- Protect the machined surface from environmental corrosion
- Depending on the type of machining operation, a coolant, a lubricant, or both are used
- Effectiveness of cutting fluids depends on type of machining operation, tool and work piece materials and cutting speed

Cutting-fluid Action

- Cutting fluid seep from the sides of the chip through the *capillary action* of the interlocking network of surface asperities in the interface
- Discontinuous cutting operations have more straightforward mechanisms for lubricant application, but the tools are more susceptible to thermal shock

Effects of Cutting Fluids on Machining

A machining operation is being carried out with a cutting fluid that is an effective lubricant. What will be the changes in the mechanics of the cutting operation if the fluid is shut off?

Effects of Cutting Fluids on Machining

- Chain of events taking place after the fluid is shut off:
- Friction at the tool–chip interface will increase
- The shear angle will decrease in accordance
- The shear strain will increase
- The chip will become thicker
- A built-up edge is likely to form

As a result:

- The shear energy in the primary zone will increase
- The frictional energy in the secondary zone will increase
- The total energy will increase
- The temperature in the cutting zone will rise
- Surface finish will to deteriorate and dimensional tolerances may be difficult to maintain

Types of Cutting Fluids

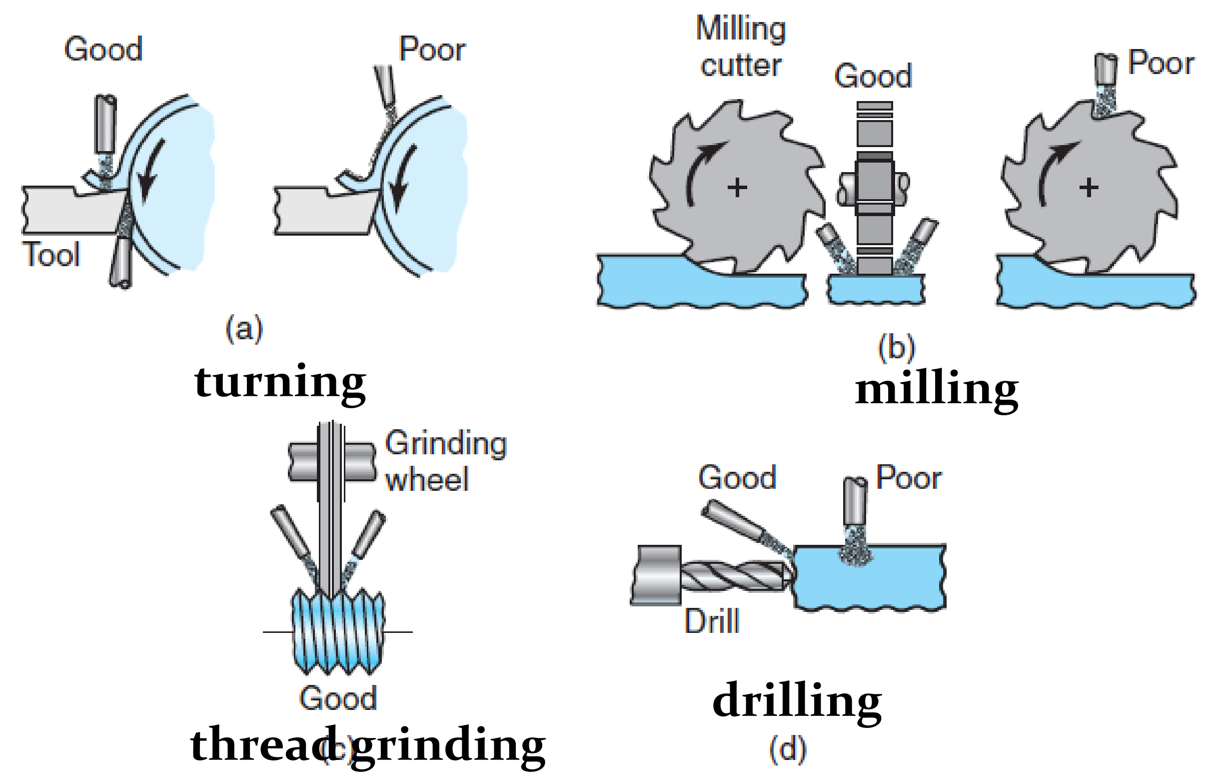
4 general types:

1. **Oils** - mineral, animal, vegetable, compounded, and synthetic oils,
2. **Emulsions** - a mixture of oil and water and additives
3. **Semisynthetics** - chemical emulsions containing little mineral oil
4. **Synthetics** - chemicals with additives

Methods of Cutting-fluid Application

4 basic methods:

1. Flooding
2. Mist
3. High-pressure systems
4. Through the cutting tool system



Selection of a cutting fluid based on:

- Work piece material and machine tools
- Biological considerations
- Environment
- Machine-tool operator is in close proximity to cutting fluids, thus health effects is a primary concern
- Progress has been made in ensuring the safe use of cutting fluids
- Recycling involves treatment of the fluids with various additives, agents, biocides, deodorizers and water treatment

High speed machining characteristics

Question – does Taylor's equation even apply for HSM?

- > 500 *linear* in/min
- spindle speeds > 10,000 rpm
- *surface* cutter speeds > 1200 ft/min
- spindles in the 50 hp range
- head tilt speeds > 1000 deg/min
- balanced tool holders
- problems with tool deflection
- must operate within machine harmonics

The speed brake pivots up from between the two rudders on an F-15 fighter. High speed machining made it practical for Boeing to mill this part complete out of solid aluminum, instead of assembling it from about 500 smaller components. When assembly was part of the process, the required lead time for one speed brake was about three months. Now, that lead time is measured in days.

High speed machining at Remmele

Remmele's High Speed and High Velocity technology provide distinct advantages in increasing product performance.

- Weight Reduction (thin walls to 0.010"/0.25mm)
- Time Savings
- Reduced Distortions and Warping

High Speed Machining is high volume metal removal within a range of high surface-cutting speeds (feet per minute) and feeds (in/min).

High Velocity Machining exhibits significant reduction in machining forces and power absorption, and dramatically shifts the heat energy distribution from the cutter/workpiece to the chip.

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