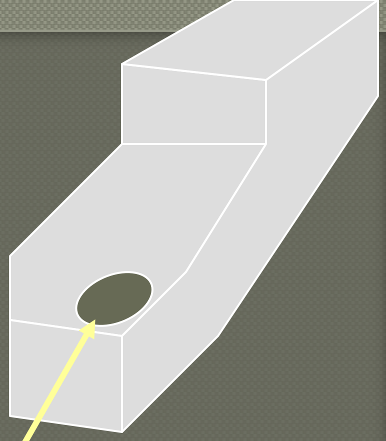
Cutting Tool Technology

ME 482 - Manufacturing Systems

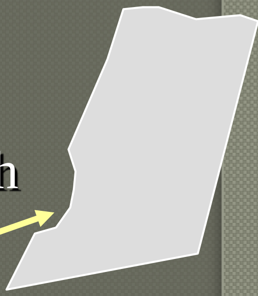
Objectives

- Introduce tool terminology
- Review reasons for tool wear, including failure modes
- Introduce cutting parameters and Taylor's tool life equation
- Consider a tool life example
- Review tool materials
- Review modern tool technologies (papers)

Cutting tool related terms



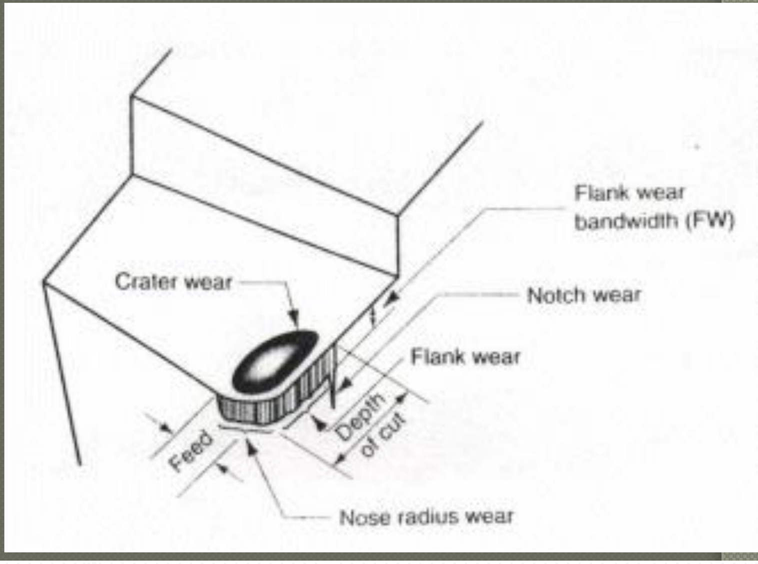
- Single point versus multiple point
- Cratering –wear that forms a concave region on the tool
- Tool life – length of cutting time that a tool can be used
- Toughness – capacity to absorb energy without failing
- Hot hardness –capacity to retain hardness at high temperatures
- Cermet – combination of TiC, TiN, TiCN (CN = carbonitride), with nickel and/or molybdenum as binders

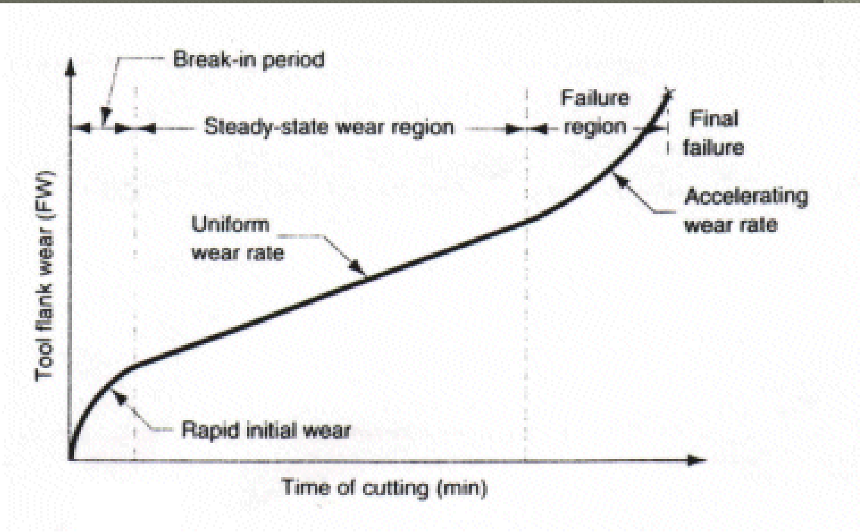


- Chip breaker – geometry designed into tool to break stringy chips
- Cutting fluid – Any liquid/gas applied to improve cutting performance

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 occ

Taylor's tool life equation:

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

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

Tool Material	n	C ft/min	(m/min)
Plain carbon tool steel			
Nonsteel cutting	0.1	200	(70)
Steel cutting	0.1	60	(20)
High-speed steel			
Nonsteel cutting	0.125	350	(120)
Steel cutting	0.125	200	(70)
Cemented carbide			
Nonsteel cutting	0.25	2700	(900)
Steel cutting	0.25	1500	(500)
Cermet			
Steel cutting	0.25	2000	(600)
Coated carbide			
Steel cutting	0.25	2200	(700)
Ceramic			
Steel cutting	0.6	10000	(3000)

For turning at feed = 0.01"/rev. and depth = 0.100 "

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 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

+ Hardness

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.

+ Hardness

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.

+ Hardness

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

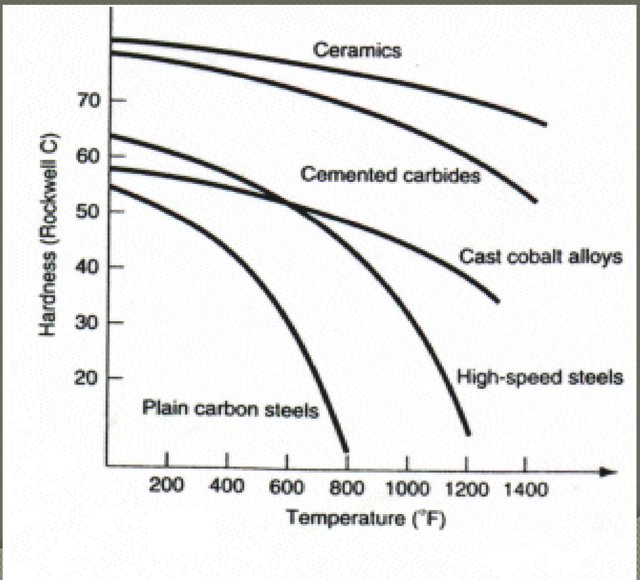
Most modern cutting tool materials are a matrix of materials designed to be very hard. Important terms are toughness, hardness and hot hardness. Note that the rake angle is chosen small (near 0 deg) for the harder, more brittle tool materials to keep the tool in compression.

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.

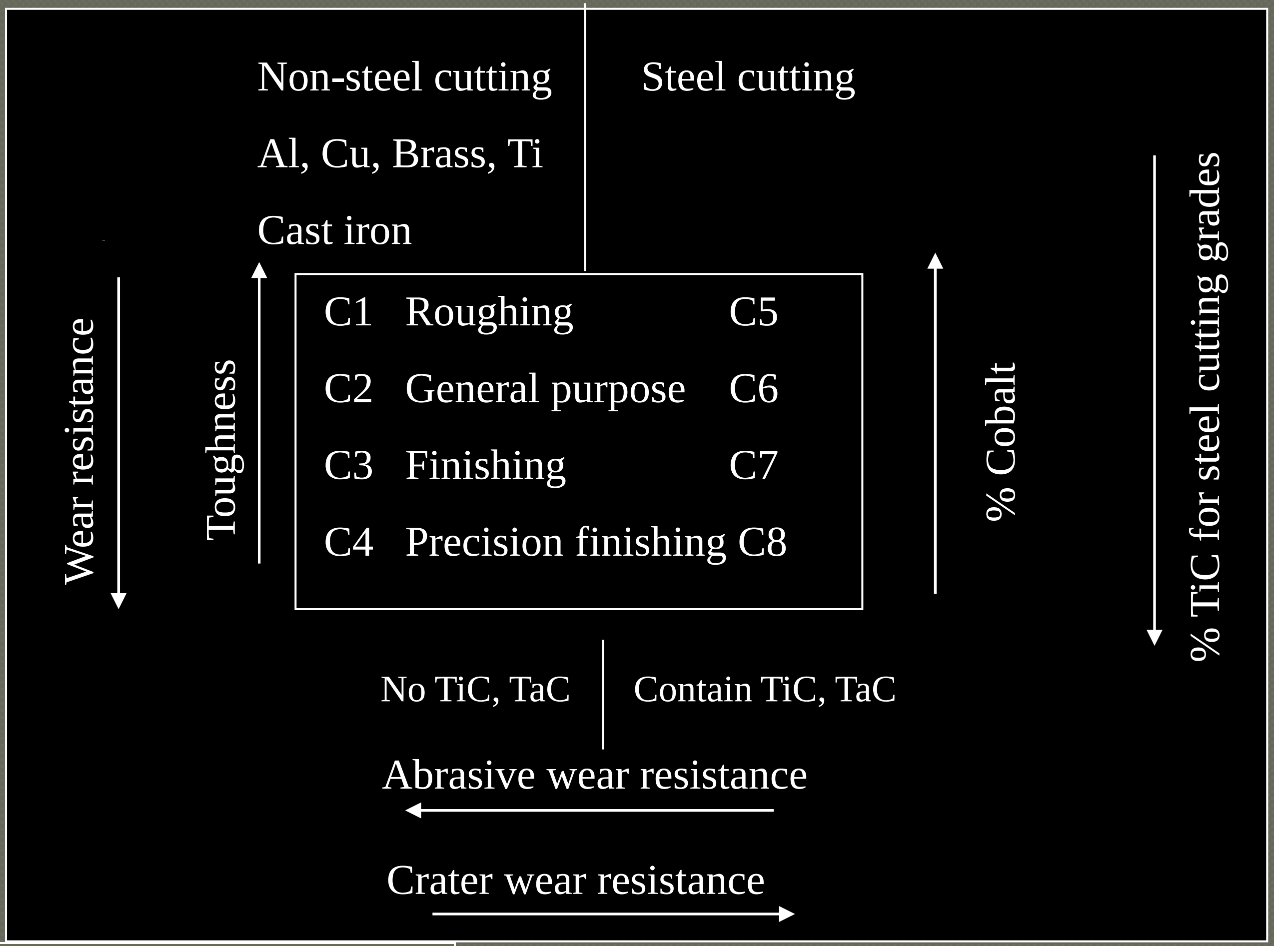
Material	Hardness	Transverse Rupture Strength lb/in.^{2}	(MPa)
Plain carbon steel	60 HRC	750,000	(5200)
High-speed steel	65 HRC	600,000	(4100)
Cast cobalt alloy	65 HRC	325,000	(2250)
Cemented carbide (WC)			
Low Co content	93 HRA, 1800 HK	200,000	(1400)
High Co content	90 HRA, 1700 HK	350,000	(2400)
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.

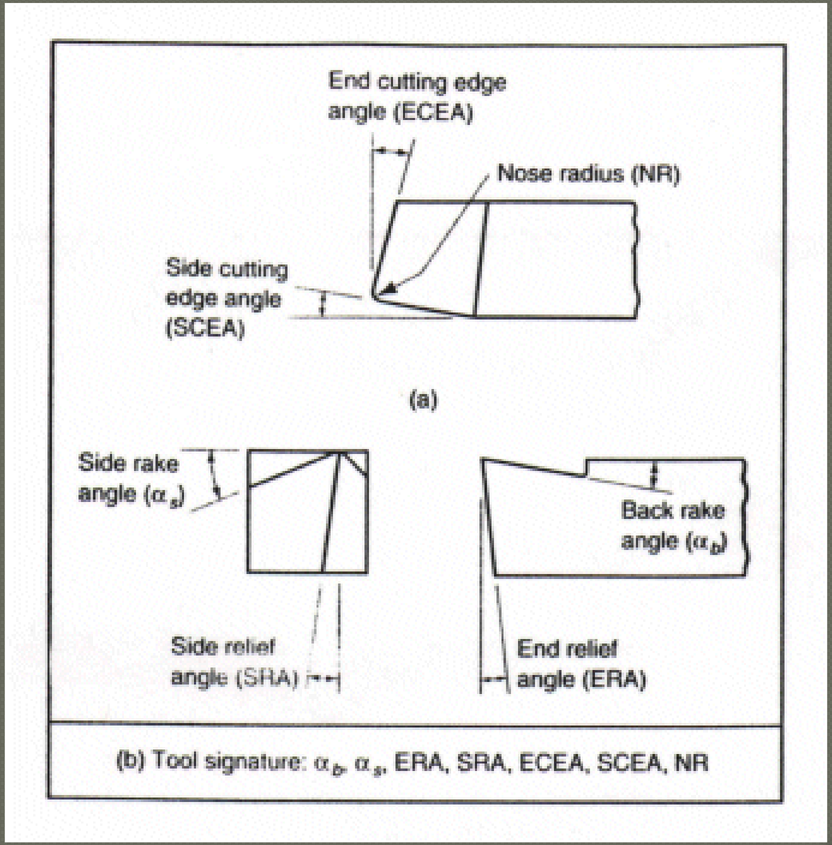


Cemented carbide classification



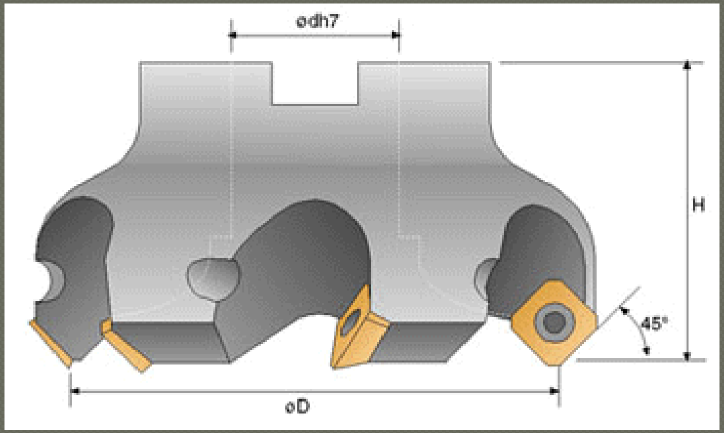
Cutting tool geometry

7 elements of a single point tool geometry

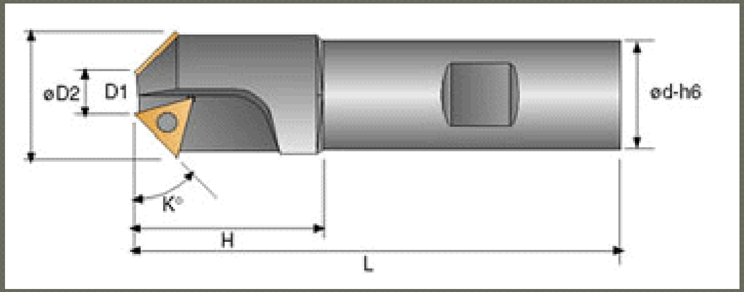


Milling tool geometry

Face cutter



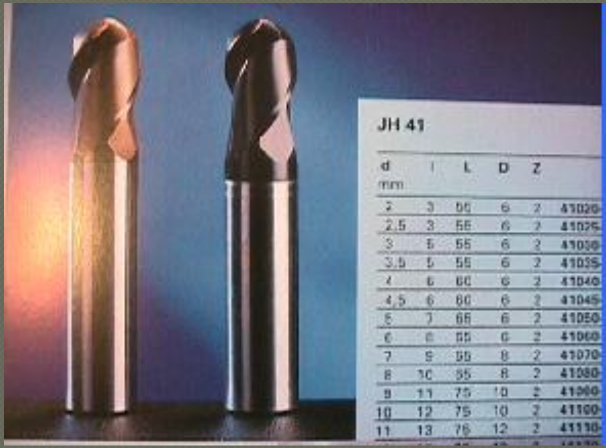
Chamfering cutter



Cutting tool geometry

Mini-cutters

Coated tools



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!

High speed machining characteristics

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

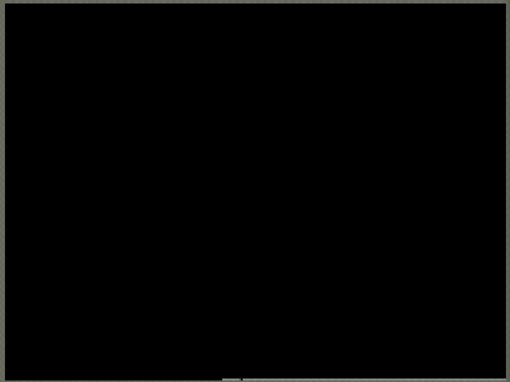
- > 500 *linear* in/min
- spindle speeds > 10,000 rpm
- *surface* cutter speeds > 1200 ft/min
- spindles in the 50 hp range
- head tilt speeds > 1000 deg/min
- balanced tool holders
- problems with tool deflection
- must operate within machine harmonics

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.