Metal Cutting - 3

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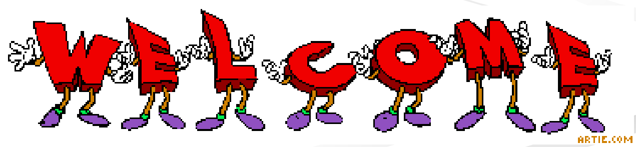

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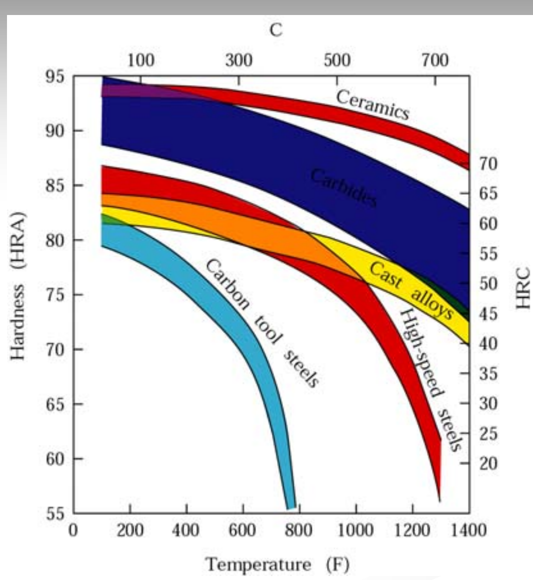
Mata alat terdedah kepada suhu + tegasan yang tinggi dan geseran. Beberapa ciri utama perlu dimiliki.

- Kekerasan - terutama red hardness
- Keliatan yang tinggi – merintangi daya hentaman & kejutan, e.g. interrupted cut.
- Rintangan haus & lelasan yang tinggi
- Kebolehaliran haba yang tinggi
- Kestabilan kimia

4. Bahan Alat – Ciri Utama



The hardness of various cutting-tool materials as a function of temperature (hot hardness). The wide range in each group of materials is due to the variety of tool compositions and treatments available for that group.

Typical Properties of Tool Materials

Table 21.1

Property	High-speed steels	Cast alloys	Carbides: WC	Carbides: TiC	Ceramics	Cubic boron nitride	Single-crystal diamond*
Hardness	83–86 HRA	82–84 HRA 46–62 HRC	90–95 HRA 1800–2400 HK	91–93 HRA 1800–3200 HK	91–95 HRA 2000–3000 HK	4000–5000 HK	7000–8000 HK
Compressive strength							
MPa	4100–4500	1500–2300	4100–5850	3100–3850	2750–4500	6900	6900
psi $x10^3$	600–650	220–335	600–850	450–560	400–650	1000	1000
Transverse rupture strength							
MPa	2400–4800	1380–2050	1050–2600	1380–1900	345–950	700	1350
psi $x10^3$	350–700	200–300	150–375	200–275	50–135	105	200
Impact strength							
J	1.35–8	0.34–1.25	0.34–1.35	0.79–1.24	< 0.1	< 0.5	< 0.2
in.- lb	12–70	3–11	3–12	7–11	< 1	< 5	< 2
Modulus of elasticity							
GPa	200	–	520–690	310–450	310–410	850	820–1050
psi $x10^6$	30	–	75–100	45–65	45–60	125	120–150
Density							
kg/m^3	8600	8000–8700	10,000–15,000	5500–5800	4000–4500	3500	3500
$lb/in.^3$	0.31	0.29–0.31	0.36–0.54	0.2–0.22	0.14–0.16	0.13	0.13
Volume of hard phase, %	7–15	10–20	70–90	–	100	95	95
Melting or decomposition temperature							
°C	1300	–	1400	1400	2000	1300	700
°F	2370	–	2550	2550	3600	2400	1300
Thermal conductivity, W/ m K	30–50	–	42–125	17	29	13	500–2000
Coefficient of thermal expansion, $x10^{-6}$ °C	12	–	4–6.5	7.5–9	6–8.5	4.8	1.5–4.8

*The values for polycrystalline diamond are generally lower, except impact strength, which is higher.

General Characteristics of Cutting-Tool Materials

TABLE 21.2 General Characteristics of Cutting- Tool Materials. These Tool Materials Have a Wide Range of Compositions and Properties; Thus Overlapping Characteristics Exist in Many Categories of Tool Materials.

	Carbon and low- to medium- alloy steels	High speed steels	Cast- cobalt alloys	Uncoated carbides	Coated carbides	Ceramics	Polycrystalline cubic boron nitride	Diamond
Hot hardness	——		Increasing		——→			
Toughness	←——		Increasing		——			
Impact strength	←——		Increasing		——			
Wear resistance	——		Increasing		——→			
Chipping resistance	←——		Increasing		——			
Cutting speed	——		Increasing		——→			
Thermal-shock resistance	←——		Increasing		——			
Tool material cost	——		Increasing		——→			
Depth of cut	Light to medium	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Very light for single crystal diamond
Finish obtainable	Rough	Rough	Rough	Good	Good	Very good	Very good	Excellent
Method of processing	Wrought	Wrought, cast, HIP* sintering	Cast and HIP sintering	Cold pressing and sintering	CVD or PVD†	Cold pressing and sintering or HIP sintering	High-pressure, high-temperature sintering	High-pressure, high-temperature sintering
Fabrication	Machining and grinding	Machining and grinding	Grinding	Grinding		Grinding	Grinding and polishing	Grinding and polishing

Source : R. Komanduri, Kirk- Othmer Encyclopedia of Chemical Technology , (3d ed.). New York: Wiley, 1978.
* Hot- isostatic pressing.
† Chemical- vapor deposition, physical- vapor deposition.

Operating Characteristics of Cutting-Tool Materials

TABLE 21.3

Tool materials	General characteristics	Modes of tool wear or failure	Limitations
High-speed steels	High toughness, resistance to fracture, wide range of roughing and finishing cuts, good for interrupted cuts	Flank wear, crater wear	Low hot hardness, limited hardenability, and limited wear resistance
Uncoated carbides	High hardness over a wide range of temperatures, toughness, wear resistance, versatile and wide range of applications	Flank wear, crater wear	Cannot use at low speed because of cold welding of chips and microchipping
Coated carbides	Improved wear resistance over uncoated carbides, better frictional and thermal properties	Flank wear, crater wear	Cannot use at low speed because of cold welding of chips and microchipping
Ceramics	High hardness at elevated temperatures, high abrasive wear resistance	Depth-of-cut line notching, microchipping, gross fracture	Low strength, low thermo-mechanical fatigue strength
Polycrystalline cubic boron nitride (cBN)	High hot hardness, toughness, cutting-edge strength	Depth-of-cut line notching, chipping, oxidation, graphitization	Low strength, low chemical stability at higher temperature
Polycrystalline diamond	Hardness and toughness, abrasive wear resistance	Chipping, oxidation, graphitization	Low strength, low chemical stability at higher temperature

Source: After R. Komanduri and other sources.

Jenis Bahan Alat

- Carbon steels
- Medium alloy steels
- Cast Cobalt Alloys (Stellites)
- High speed steels
- Carbides
  - WC-Co Alloys
  - WC-TiC-TaC/NbC-Co Alloys
  - Coated carbdes
- Ceramics
  - Alumina based
  - AL2O3/TiC – Cermets
  - Sialons
- Cubic Boron Nitride
- Diamonds
  - Natural
  - Polycrystalline

Jenis Bahan Alat

CARBON STEELS

- Most common before the turn of the last century
- Low room temperature and hot hardness (HB = 700 Kg/mm2)
- Begin to loose strength 200 – 300 0C
- Used at very low speed <5 m/min
- Today used as hand held tools, eg. Taps, cheap drills, files

MEDIUM ALLOY STEELS

- In 1870 carbon steels were replaced with alloyed steels
- Better hot hardness than low carbon steel and hence permitted higher metal removal rates
- Mo & Cr Have been used as alloying elements
- Limitations – low wear resistance, dimensional stability
- Still used as – drills, taps, reamers etc

Jenis Bahan Alat

CAST COBALT ALLOYS (STELLITES)

- Introduced for cutting applications about the same time as HSS tools
- Consists basically of cobalt rich chromium-tungsten-carbon cast alloys
- Having properties and applications in ranges where HSS not very successful
- They can retain their hardness at elevated temperatures hence can be used at higher cutting speeds
- Stellites are hard as cast and can not be softened or heat treated, are hence used in cast state
- Major applications – difficult to machine materials , e.g. Aerospace industries

Jenis Bahan Alat

HIGH SPEED STEELS

- Were introduced in 1905 – by F W Taylor
- Could machine steels x 6 faster
- Available as molybdenum based (BM) and tungsten based (BT)
- Manufacturing techniques – cast and cold work, sintering
- Applications – form tools, taps, hand held tools

Influence Of Alloying Elements

- Essential for secondary hardening and good wear resistance
- Mo + W form M6C Carbides
- Equal nos. of atoms of Mo + W are reqd to produce same properties. Since atomic wt. of Mo is about ½ of W, therefore average of Mo in BM steels is usually about ½ of W in equivalent BT steels.
- BM steels are tougher than that of BT steels but they give similar performance.
- They promote red hardness
- In BT steels W 12 – 19%
- In BM steels Mo 4 – 10%

Jenis Bahan Alat

Tool Failure Modes And Wear Mechanisms In HSS Tools

- Flank face wear
- Crater wear
- Chipping
- Attrition
- Diffusion
- Plastic deformation
- Abrasion
- Notching

Jenis Bahan Alat

CARBIDES

- Covers wide range of tools in which WC is the basic material held in the matrix of cobalt. WC acts as cutting medium and cobalt provides the bond
- Developed in 1930' in Germany
  - Cemented carbides
  - Triple carbides
  - Coated carbides

CEMENTED CARBIDES

- Composition -WC = 70 – 96%, Co = 4 – 30%
- Most popular for cutting are WC = 94% and Co = 6%
- Co wets WC and binds together
- Twice the speed of WC
- Not as tough as HSS, fine grain structure helps
- Machine vibration a problem
- For any application, if above grade fractures – larger Co content
- If increased wear resistance is requied – finer grains & low Co content

Jenis Bahan Alat

Application areas

- Machining of Cast Iron and non ferrous, not steels (wear out quickly if cut steels)
- Available as indexable inserts, used with the +ve rake geometry
- Most popular 6 degree +ve
- Successful for the machining of super alloys

TRIPLE GRADES

- Steel cutting grades
- Triple carbide WC – TiC – TaC/NbC – Co
- Typical composition – TiC 16 – 20%, TaC 12 – 15%, Co 5 – 10%, WC - Balance
- Grain size 2µm

Used at speeds often 3x higher than WC – Co Alloy tools (should be used only at higher speeds)

- Most popular geometry +6 degree rake angle

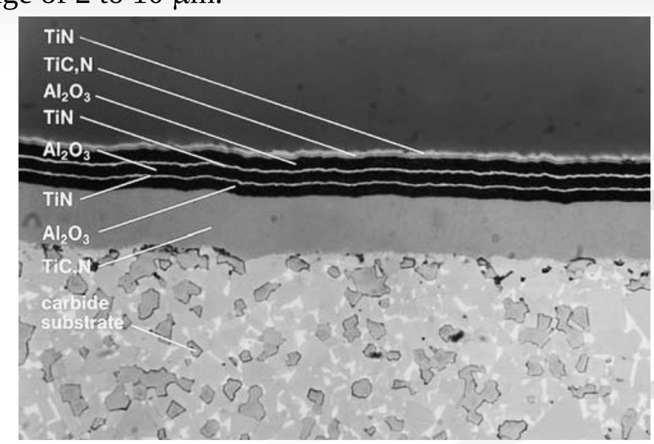
Jenis Bahan Alat

COATED CARBIDES

- 2 – 3 µm Layer of hard materials is coated on WC-Co Tools or triple carbide tools
- TiC, TiN and Al2O3 are most popular
- Tools are available with double and triple coatings
- (CVD and PVD techniques)
- Recommended for machining cast iron and steels at higher speeds
- Not recommended for interrupted cutting
- Not good for tools which need regrinding

Multiphase Coatings

Multiphase coatings on a tungsten-carbide substrate. Three alternating layers of aluminum oxide are separated by very thin layers ot titanium nitride. Inserts with as many as thirteen layers of coatings have been made. Coating thicknesses are typically in the range of 2 to 10 µm.



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ISO CLASSIFICATION

- Based on applications and broadly divided into three categories (P, M, K) and colour coded (blue, yellow and red) for convenience.
- P-grade are highly alloyed multi carbides used mainly for machining hard steel and steel casting
- M-grade are low alloyed multi carbide alloys which are multi purpose non steel grades used for machining high temperature alloy low strength steels, CI, free machining steels and non ferrous metals and their alloys
- K-grades are straight WC grades for machining hard grey CI, chilled casting, plastics, glass, composites, rubber etc.

Jenis Bahan Alat

GUIDELINES FOR SELECTING A CARBIDE GRADE

- Choose a grade with the lowest Co content and the finest grain size consistent with adequate strength to eliminate chipping.
- Use straight WC grades if cratering, seizure or galling are not experienced and for work materials other than steels
- Use grades containing TiC when cutting steels to reduce cratering and abrasive wear.
- Use a multi carbide grade containing W – Ti – Ta and/or lower binder content for heavy cuts in steel where high temperature and pressure deform the cutting edge plastically.

The proper grade of cemented carbide for a given application should provide crater wear resistance, abrasion resistance, and adequate toughness to prevent microchipping of the cutting edge.

Use the proper geometry (+6 rake angle being the most popular)

Jenis Bahan Alat

CERAMIC TOOLS

- Al_2O_3 Based – white in colour, very brittle, good for CI
- CERMET - Al_2O_3 + TiC, for machining CI & Steels, good wear & chemical resistance
- Si_3N_4 Based – machining aerospace materials
- SiC Based

ALUMINA CERAMIC TOOLS

- Manufactured by powder metallurgy route
- Initial cost of raw material is low but processing is expensive hence higher overall cost
- High hardness 1500 – 1700 HV
- Low toughness, thermal and shock resistance
- Chemically inert
- Can cut up to 700 m/min, CI and steels
- Are becoming popular with the introduction of more rigid machine tools.

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Cermets are Al_2O_3 based with 30% by weight of TiC.

These tools have proved very successful for machining of certain materials.

Their better performance is attributed to the presence of TiC.

SIALON CERAMIC TOOLS

- These are silicon nitride based materials
- Si_3N_4 are known for their high strength, wear resistance, excellent thermal shock properties, resistance to corrosion, a combination of all these properties should make Si_3N_4 a useful engineering ceramic
- Manufacturing route – reaction bonded & hot pressing
- **Si Al O N** is an acronym of silicon, aluminium, oxygen and nitrogen.
- Its properties can be tailor made

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APPLICATION OF SIALON CERAMIC TOOLS

- Nickel based super alloys
- Cast iron
- Titanium alloys
- Conditions for Ni-based materials
- Machining cast iron
- Tool change frequency = 85 components with carbides
- = 450 components with Sialon
- Sialon tools should be used with a – ve geometry, 0 back rake angle and – 6 side rake angle is recommended

Jenis Bahan Alat

GUIDELINES FOR USING CERAMIC TOOLS

- Always use ceramic tools with a – ve geometry
- Use of coolant should be avoided, if required flood cool the cutting edge
- Never use these tools with a sharp cutting edge
- Use them at maximum recommended speed, feed and doc
- Use good clamping and seating arrangements
- Use them on rigid machines free of vibration

Jenis Bahan Alat

CUBIC BORON NITRIDES

- Developed in 60's to machine difficult to machine materials
- Very hard (next to diamonds)
- Chemically inert
- Used to machine

  Hardened steels

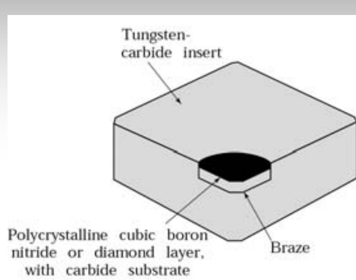
  Chilled cast iron

  Super alloys

  Carbides

  Ceramics

Cubic Boron Nitride



Construction of a polycrystalline cubic boron nitride or a diamond layer on a tungsten-carbide insert.

Inserts with polycrystalline cubic boron nitride tips (top row) and solid polycrystalline CBN inserts (bottom row).

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DIAMOND TOOLING

- Natural diamond & Polycrystalline diamonds

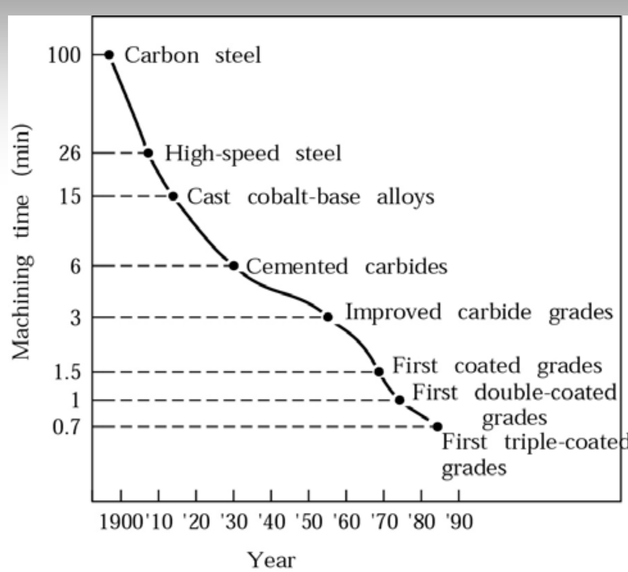
Natural diamond (single crystal)

- Hardest material known, High wear resistivity
- Ability to maintain sharp edge (on soft materials)
- Problems - Extreme brittleness, Poor chemical resistance, Diamonds are expensive

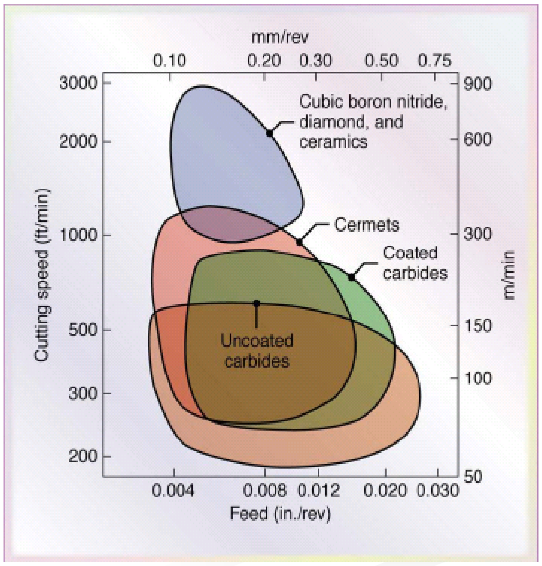
Polycrystalline diamonds

- Man made diamonds fabricated at high pressure (50k bar) + 15000 c
- Instead of single crystal a number of randomly oriented crystals, hence no cleavage
- Usually available as a layer bonded to WC substrate
- WC gives toughness and PCD maintain sharp edge
- PCD has high hardness
- High thermal conductivity
- More abrasion resistance than natural diamond
- Excellent performance when machining al castings

Cutting tool development

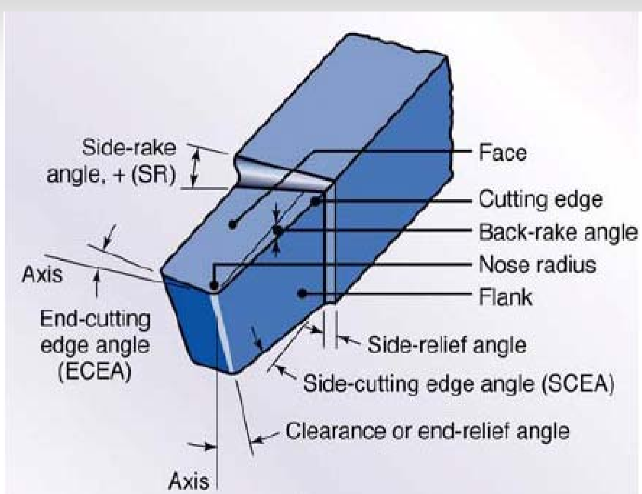


Feeds & Speeds for Tool Materials

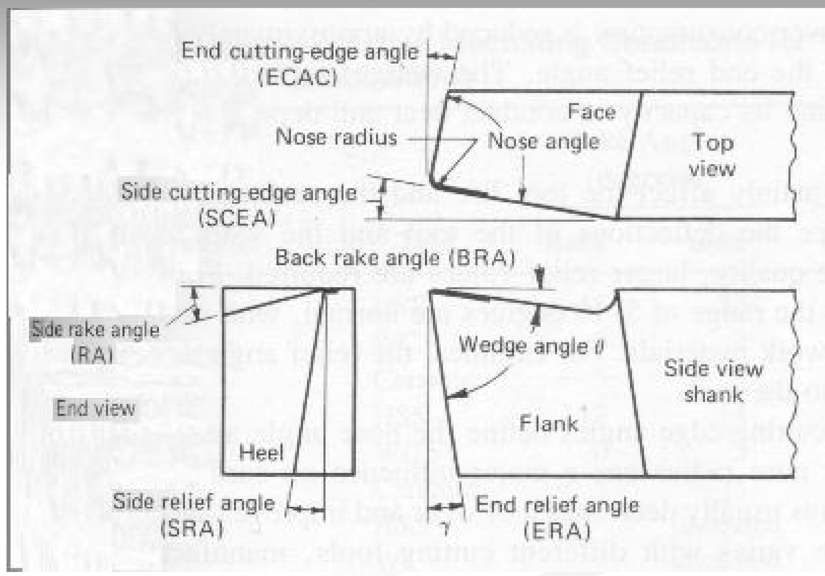


Tool Geometry

- Refer Text



Tool Geometry



Tool Geometry

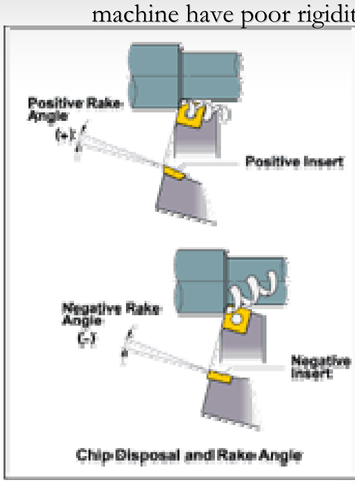
- **Rake angle**
  - In a single point tool, the orientation of the rake face is defined by two angles, back rake angle (αb) and side rake angle (αs).
  - Together, these angles are influential in determining the direction of chip flow (disposal) across the rake face, cutting resistance, cutting temperature, and tool life.

Effect of Rake Angle

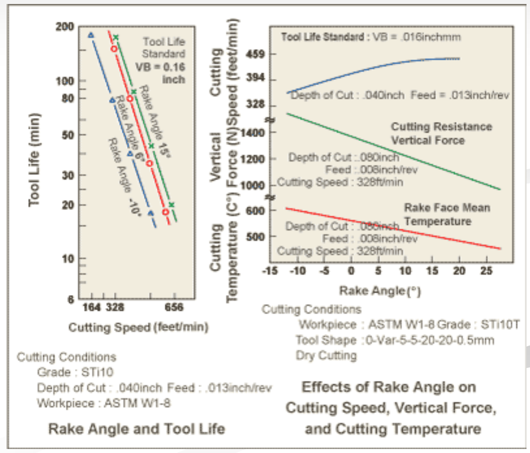
- Increasing rake angle in the positive (+) direction improves sharpness.
- Increasing rake angle by 1° in the positive (+) direction decreases cutting power by about 1%.
- Increasing rake angle in the positive (+) direction lowers cutting edge strength and in the negative (-) direction increases cutting resistance.

When to Increase Rake Angle in the negative direction
Hard workpiece, uncut surface cutting and when cutting edge strength is required such as in interrupted cutting and

When to Increase Rake Angle in the Positive direction
Soft workpiece, workpiece is easily machined and when workpiece or the machine have poor rigidity



Chip Disposal and Rake Angle



Rake Angle and Tool Life

Effects of Rake Angle on Cutting Speed, Vertical Force, and Cutting Temperature

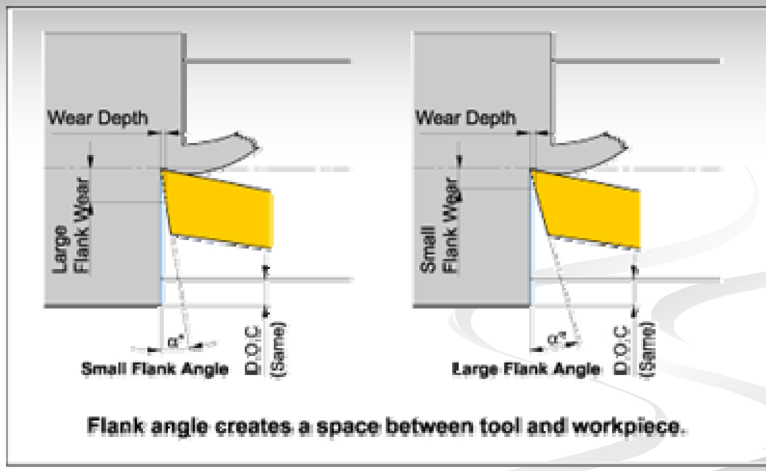
Tool Geometry

- End relief or Clearance angle (ERA) & Side relief angle (SRA)
  - These angles determine the amount of clearance between the tool and the freshly cut work surface, preventing friction and ensure smooth feed. Also known as the flank angle.

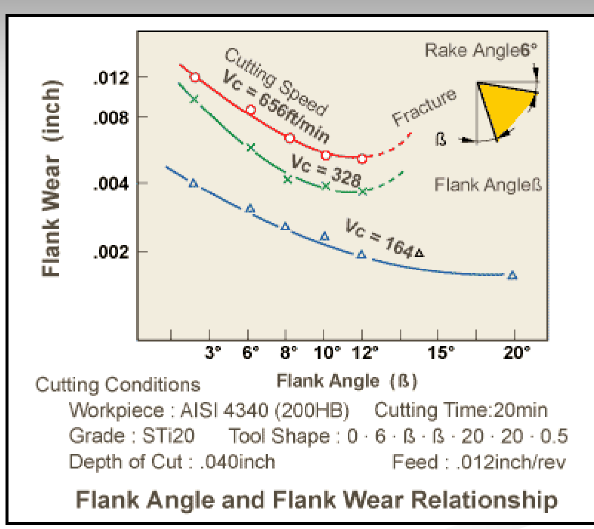
Effects of Flank Angle

- Increasing flank angle decreases flank wear occurrence.
- Increasing flank angle lowers cutting edge strength.

Tool Geometry



Tool Geometry

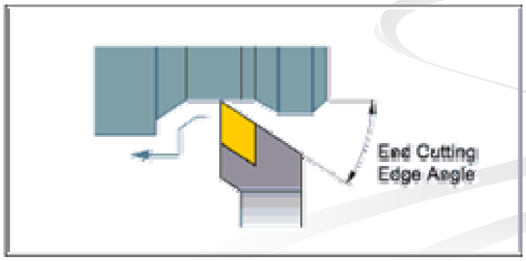


When to Decrease Flank Angle
- Hard workpieces.
- When cutting edge strength is required.

When to Increase Flank Angle
- Soft workpieces.
- Workpieces suffer from work hardening easily.

Tool Geometry

- End Cutting Edge angle (ECEA)
  - Provides a clearance between the trailing edge of the tool and the newly generated work surface, thus reducing rubbing and friction against the surface.
  - End cutting edge angle prevents wear on tool and workpiece surface and is usually 5°~15°.



Tool Geometry

Effects of End Cutting Edge Angle

- Decreasing end cutting edge angle increases cutting edge strength, but it also increases cutting edge temperature.
- Decreasing end cutting edge angle increases back force and can result in chattering and vibration while machining.
- Small end cutting edge angle in roughing and large angle in finishing are recommended.

Tool Geometry

- Side cutting edge angle (SCEA)
  - Determines the entry of the tool into the work and can be used to reduce sudden force the tool experiences as it enters a workpart.
  - Side cutting edge angle and corner angle lower impact load and effect feed force, back force, and chip thickness.

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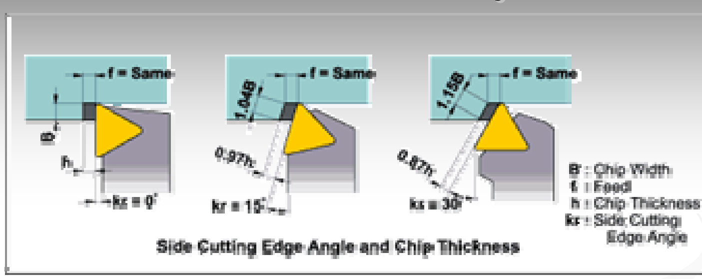
Tool Geometry



Effects of Side Cutting Edge Angle (Lead Angle)

1. At the same feed rate, increasing side cutting edge angle increases chip contact length and decreases chip thickness. As a result, cutting force is dispersed on a longer cutting edge and tool life is prolonged.
2. Increasing side cutting edge angle increases force a'. Thus, thin, long workpieces suffer from bending in some cases.
3. Increasing side cutting edge angle decreases chip control.
4. Increasing side cutting edge angle decreases chip thickness and increases chip width. Thus, breaking chips is difficult.

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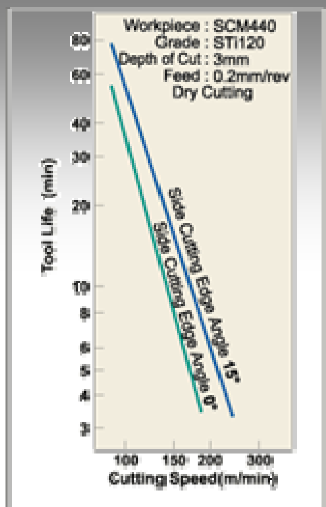
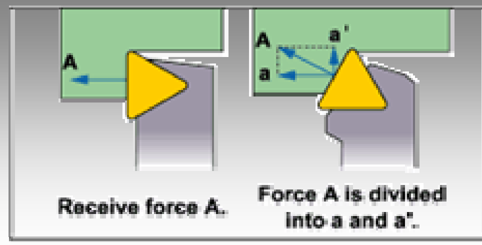


Side Cutting Edge and Tool Life



When to Decrease Lead Angle

- Finishing with small depth of cut.

- Thin, long workpieces.

- When the machine has poor rigidity.

When to Increase Lead Angle

- Hard workpieces which produce high cutting temperature.

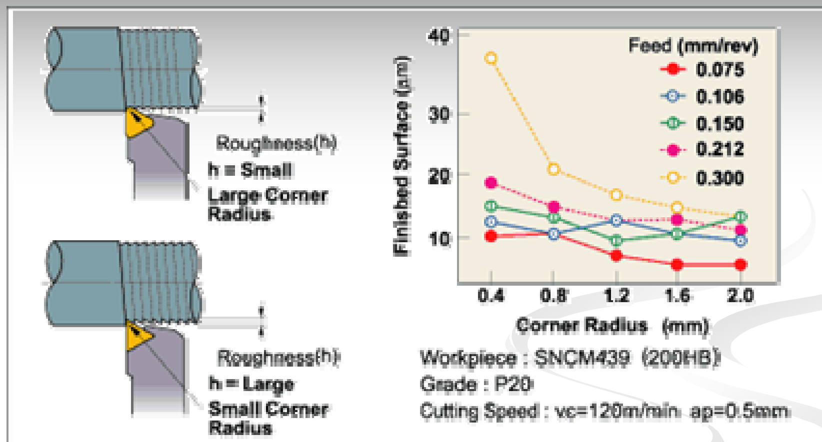
- When roughing a thick diameter workpiece.

- When the machine has high rigidity.

Tool Geometry

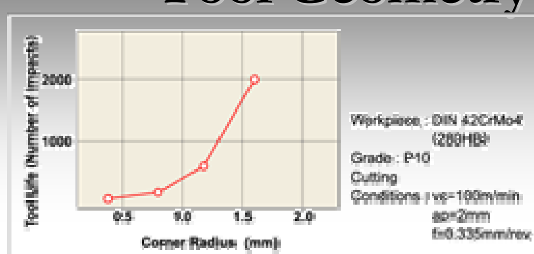
- Nose radius (NR), or corner radius
  - The tool point formed by SCEA and ECEA, determines to a large degree the texture of the surface generated in the operation. A very pointed tool (small nose radius) results in very pronounced feed marks on the surface.
- Radius effects cutting edge strength and finished surface. In general, corner radius 2~3 times the feed is recommended.

Tool Geometry

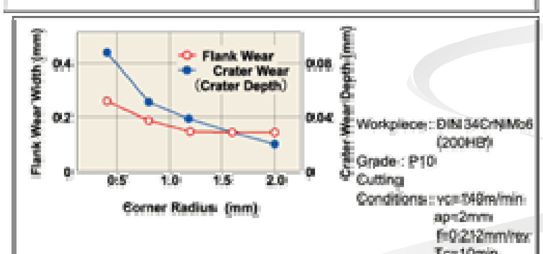


Corner Radius and Finished Surface

Tool Geometry



Corner Radius Size and Tool Life Due to Fracturing



Corner Radius Size and Tool Wear

Tool Geometry

Effects of Corner Radius

- Increasing corner radius improves finished surface roughness.
- Increasing corner radius improves cutting edge strength.
- Increasing corner radius too much increases cutting resistance and causes chattering.
- Increasing corner radius decreases flank and rake wear.
- Increasing corner radius too much results in poor chip control.

Tool Geometry

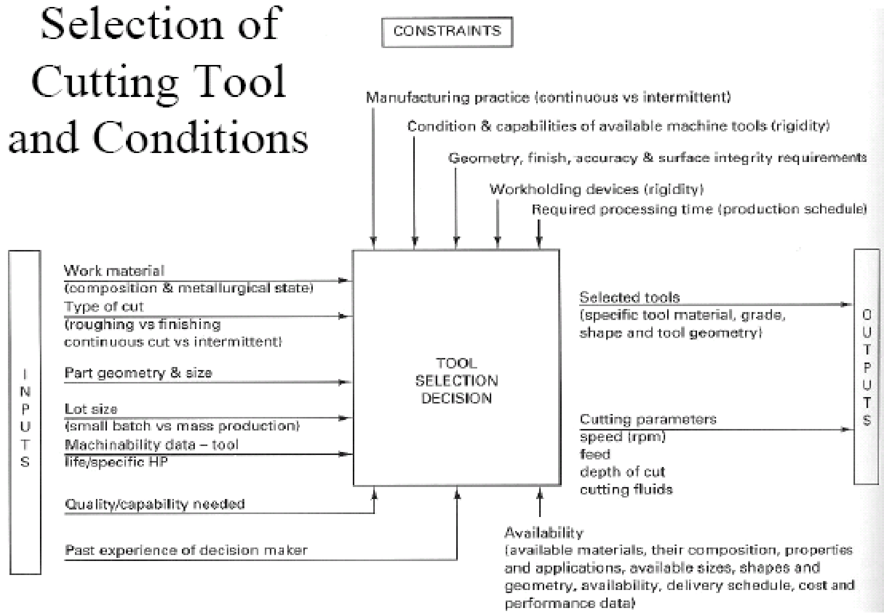
When to Decrease Corner Radius
Finishing with small depth of cut. Thin, long workpieces. When the machine has poor rigidity.
When to Increase Corner Radius
When cutting edge strength is required such as in interrupted cutting and uncut surface cutting. When roughing a workpiece with large diameter. When the machine has high rigidity.

Tool Geometry

- The seven elements of tool geometry for a single point tool, when specified in the following order, they are collectively called tool geometry signature : (α_b), (α_s), ERA, SRA, ECEA, SCEA, NR.

Pemilihan Alat Pemotong

Selection of Cutting Tool and Conditions



Cecair Pemotongan

Cutting Lubricants
Overview

- Use of cutting oil will prolong tool life
- If oil is used, insure proper ventilation
- Use extreme care when applying oil…squirt can is recommended
- Cutting oil is messy…use oil sparingly based on application
- Apply with squirt can while machine is running
- Use brush to apply prior to machine start up

Cecair Pemotongan

Cutting Fluids
Benefits & Cautions

- Benefits of Using Cutting Fluids
  - Lubrication of tools to improve the flow of chips at the cutting face
  - Cooling of the tool & work piece for improved dimensional stability
  - Reduction in built-up edge
  - Improvement in surface finish
  - Helps flush away chips….very important during horizontal boring
- Cautions
  - Unsteady flow of coolant could cause cracking of carbide tools
  - Damaging thermal variation in the cutting tool can be intensified when utilizing cutting fluid during an interrupted cutting process
  - Carbide inserts cannot stand the thermal shock associated with coolant being turned on and off.

Cecair Pemotongan

Choice of cutting fluid

- Dictated by the machining operation, the workpiece material, the tool material and the cutting data. Generally, better lubrication should be sought with;
  - Low speeds
  - Difficult-to-machine materials
  - Difficult operations
  - Demands for better surface texture
- Improved cooling should be chosen for;
  - High speeds
  - Easy-to-machine materials
  - Simple operations
  - Problems with built-up-edge.

Cecair Pemotongan

- Jenis-jenis cecair pemotongan – rujuk teks

Material	Type of fluid
Aluminum	D, MO, E, MO FO, CSN
Beryllium	MC, E, CSN
Copper	D, E, CSN, MO FO
Magnesium	D, MO, MO FO
Nickel	MC, E, CSN
Refractory	MC, E, EP
Steels (carbon and low alloy)	D, MO, E, CSN, EP
Steels (stainless)	D, MO, E, CSN
Titanium	CSN, EP, MO
Zinc	C, MC, E, CSN
Zirconium	D, E, CSN

Note: CSN, chemicals and synthetics; D, dry; E, emulsion; EP, extreme pressure; FO, fatty oil; and MO, mineral oil.