ME338 – Manufacturing Process II
Lecture 3 : Chip formation & Tool geometry

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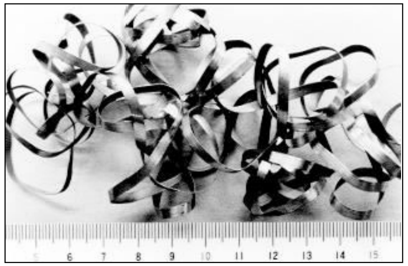
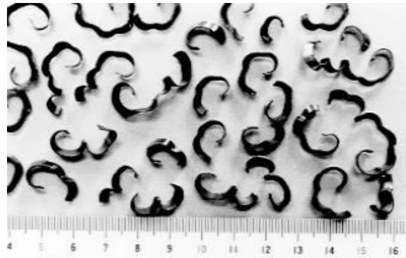
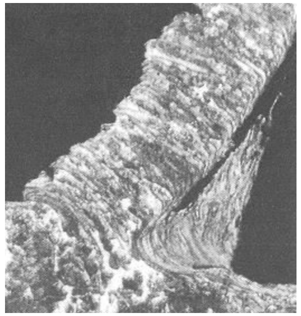
Different types of chips



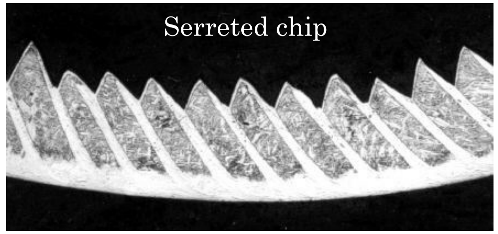
Continuous chip (ductile materials, high speed)



Discontinuous chip (brittle material



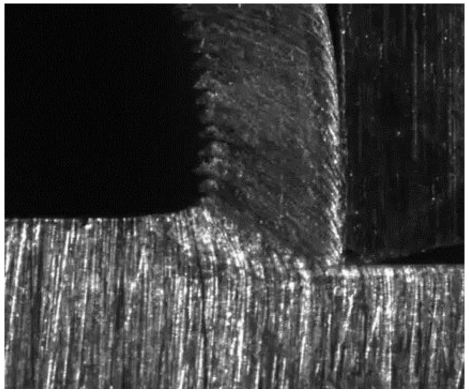
Continuous chip with BUE

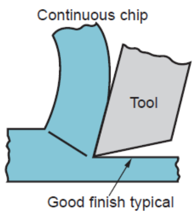


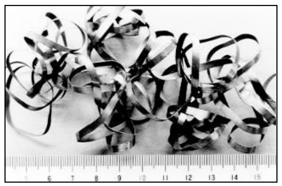
low thermal conductivity materials

Continuous chips

- The lower boundary is below the machined surface, subjecting the machined surface to distortion, as depicted by the distorted vertical lines.
- This situation occurs particularly in machining soft metals at higher speeds and high rake angles (sharp edge).
- Although they generally produce good surface finish, CCs are not always desirable. Safety risks





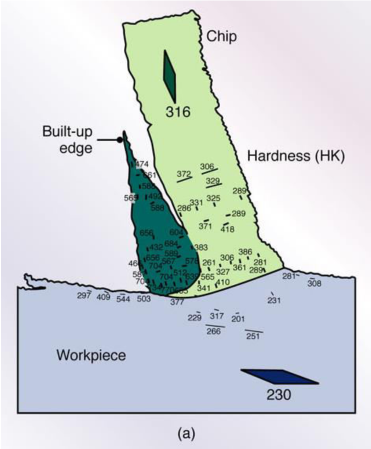


Factors:
- Ductile material
- High cutting speed
- Low depth of cut
- Large rake angle

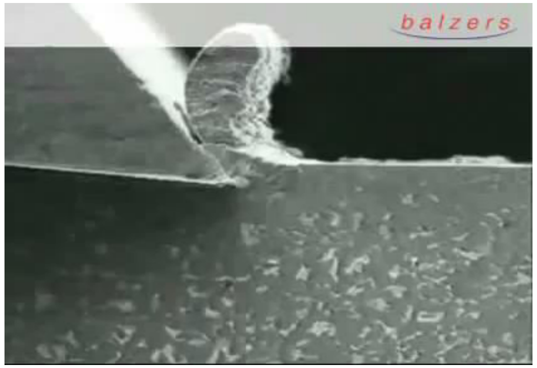
Discontinuous Chips (DC)

- DCs consist of segments that may be firmly or loosely attached to each other DCs usually form under the following conditions:
- Factors that encourage DC chips:
  - Very low or very high cutting speeds/ Large depths of cut/ Low rake angles.
  - Brittle material / Lack of an effective cutting fluid.
- Because of the discontinuous nature of chip formation, forces continually vary during cutting.

Continuous chips with Buildup edge



Hardness distribution with a built-up edge in the cutting zone (material, 3115 steel).



<u>Continuous chip with BUE</u>

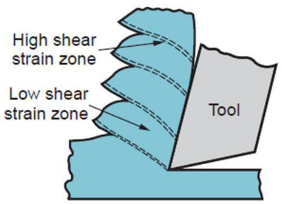
- Ductile material
- Stronger adhesion between chip and tool face
- High depth of cut
- Small rake angle

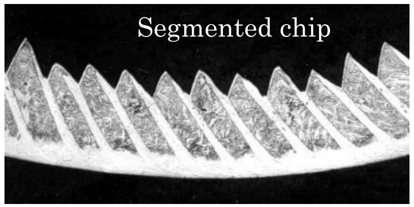
Continuous chips with Buildup edge

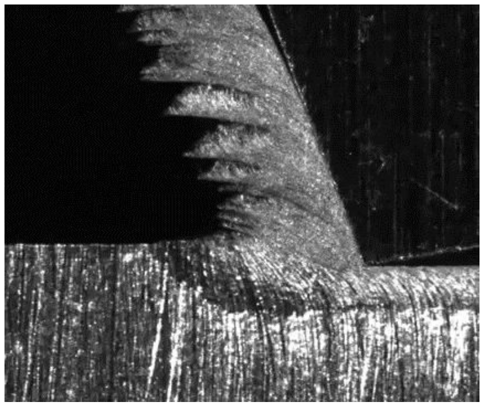
- BUE, consisting of layers of material from the workpiece that are gradually deposited on the tool, may form at the tip of the tool during cutting.
  - As it becomes larger, BUE becomes unstable and eventually breads up.
  - Part of BUE material is carried away by the tool side of the chip; the rest is deposited randomly on the workpiece surface.
  - Because of work hardening and deposition of successive layers of material, the hardness of BUE increases significantly.
- The tendency for a BUE to form is reduced by any of the following practices:
  1. Increase the cutting speeds,
  2. Decreasing depth of cut
  3. Increasing the rake angle, Using a sharp tool
  4. Using an effective cutting fluid
  5. Use a cutting tool that has lower chemical affinity for the workpiece material.

Serrated Chips

- Serrated chips: semi-continuous chips with zones of low and high shear strain
- Metals with low thermal conductivity and strength that decreases sharply with temperature, such as titanium, exhibit this behavior.
- The chips have a saw-tooth-like appearance.



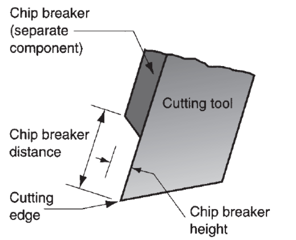


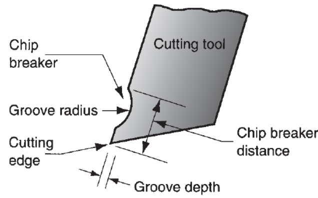


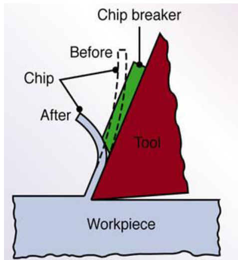
low thermal conductivity materials

Chip control/chip breaker (CB)

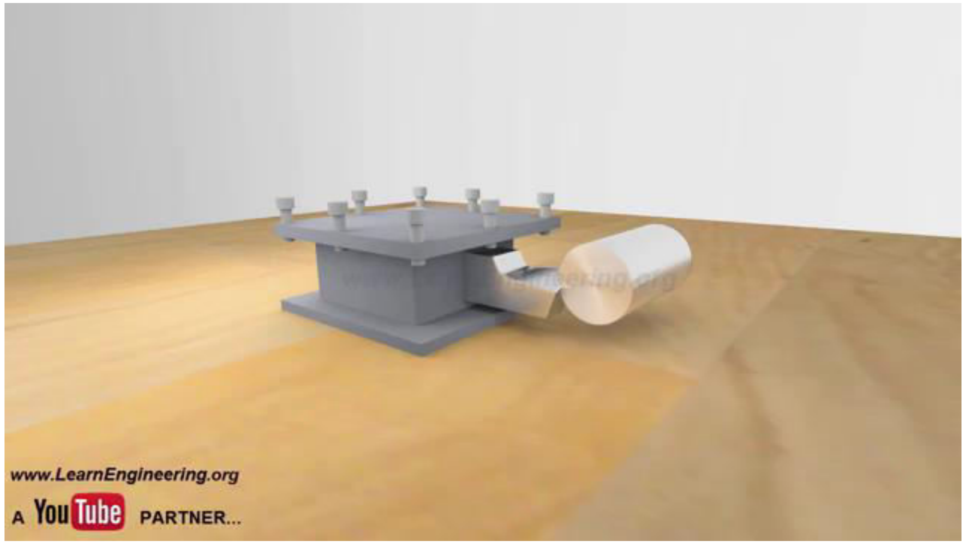
- Chip produced during high speed machining of ductile materials are very long & curly that are undesirable
  - Safety concern for workers
  - May entangled with cutting tool, workpiece
- Higher speed > higher temperature > chip with bluish color, long coils
- Chip breaker to break continuous chips
  - Obstruction type / Groove type
- CBs increase the effective rake angle of the tool and, consequently, increase the shear angle.



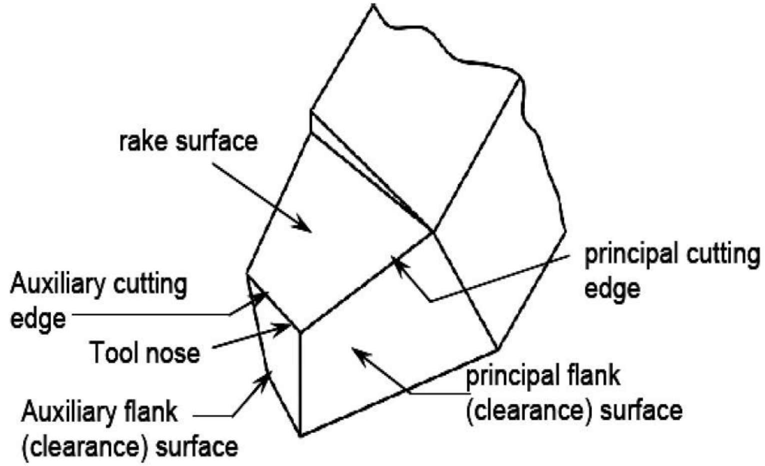




Video : Single point cutting tool



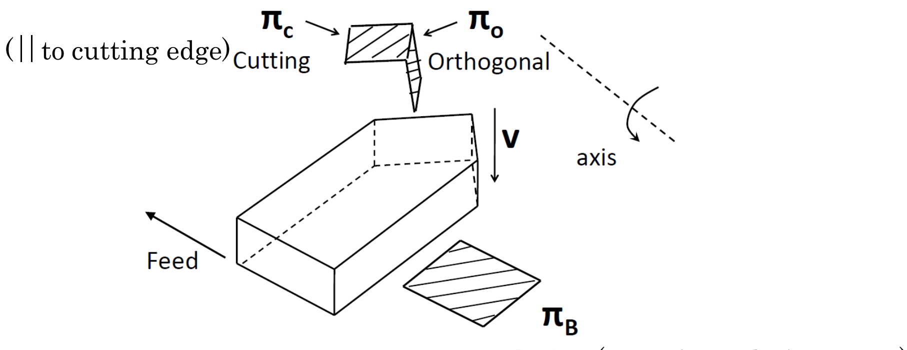
Single Point (edge) Tool Geometry



- Cutting tool have 2 cutting edges : Major (Principal) and minor (Auxiliary)
  - Their meeting point is termed as 'nose'
- Tool surface where chip flow is 'Rake surface'
- Surface closer to the 'machined' finished is known as 'Flank'

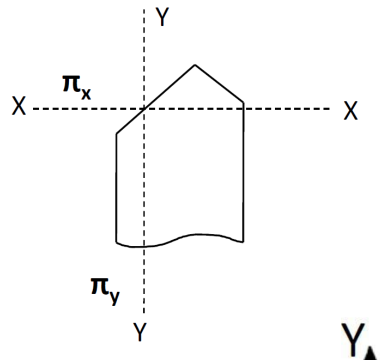
Tool nomenclature systems

- Cutting tool have 6 important angles: each with major/minor edges
  - Rake angle, relief (clearance), cutting edge angles
  - Combination of 6 angles, and 1 nose radius – tool signature
- Various tool standards exists to define tool geometry are available
- ISO System : Orthogonal (ORS)/ Normal Reference System (NRS)
- American Standards Association (ASA) system is popular

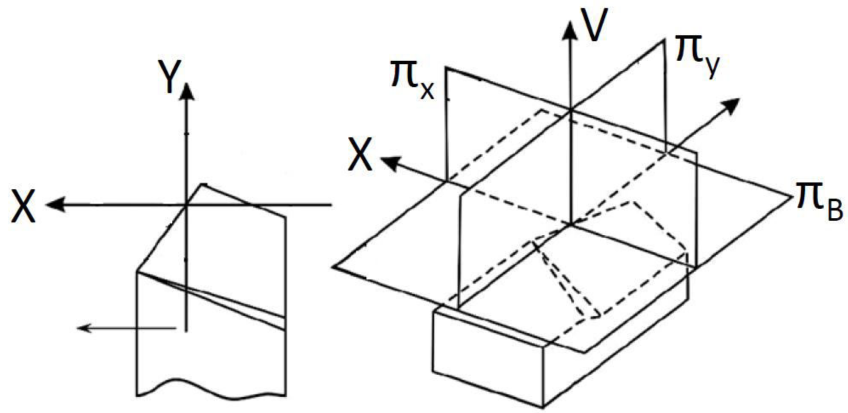


Tool Reference Planes

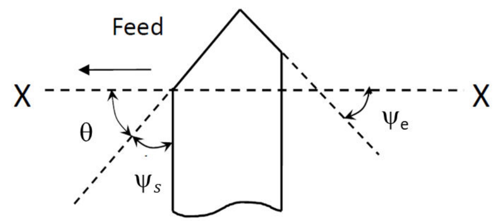
Reference Planes – ASA system

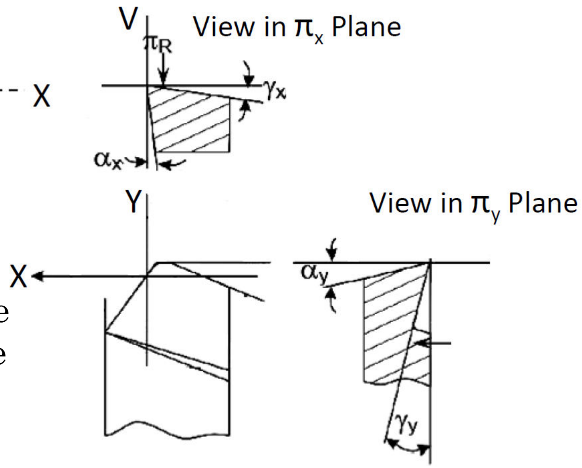


(π_B) Basic plane : where tool shank, ⊥ to cutting velocity
(π_X) Cutting plane : along the longitudinal feed direction (primary motion) and ⊥ to Base plane (π_B)
(π_Y) Transverse plane : ⊥ to both π_B, π_X planes



Tool Angles – ASA System





θ = Plain approach angle

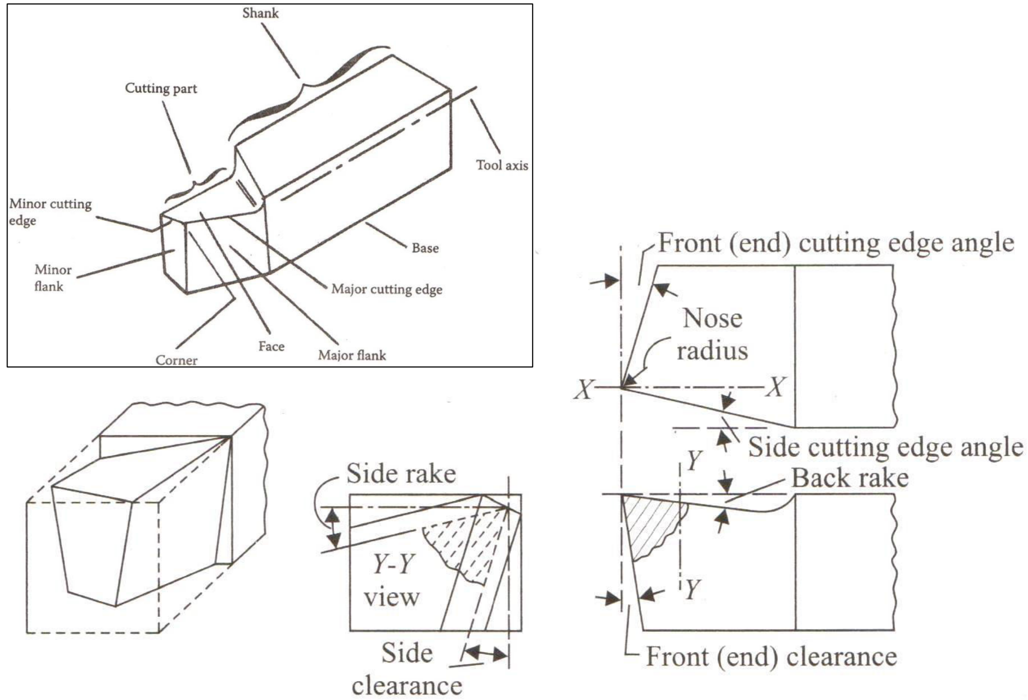
ψ_s = Side cutting edge angle

ψ_e = End cutting edge angle

$$\phi = 90° - \psi_s$$

Side cutting edge angle is also known as 'Lead' angle

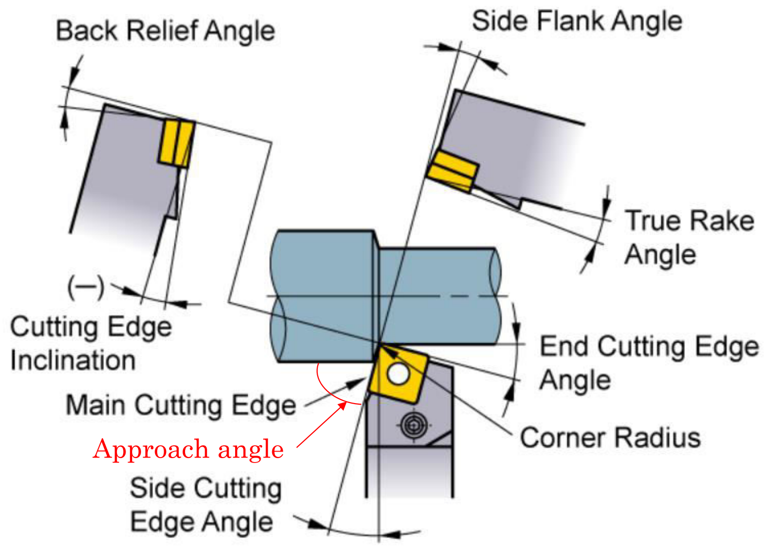
Cutting tool geometry : ASA Nomenclature



Tool Geometry : ASA Nomenclature

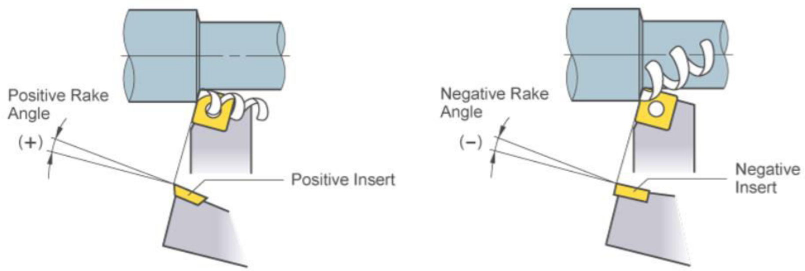
- Cutting tool have 6 important angles: each with major/minor edges
- American system
- Cutting tool signature (American system)
  - Back rake angle (α_b) (°)
  - Side rake angle (α_s)(°)
  - Front (end) clearance (relief) angle (δ_e)(°)
  - Side clearance (relief) angle (δ_b)(°)
  - Front (end) cutting edge angle (ψ_e)(°)
  - Side cutting edge angle (ψ_s) (°)
  - Nose radius (r) (mm)
- Tool signature Example : 6°-10°-7°-7°-10°-20°-0.5

Cutting tool geometry : Various angles



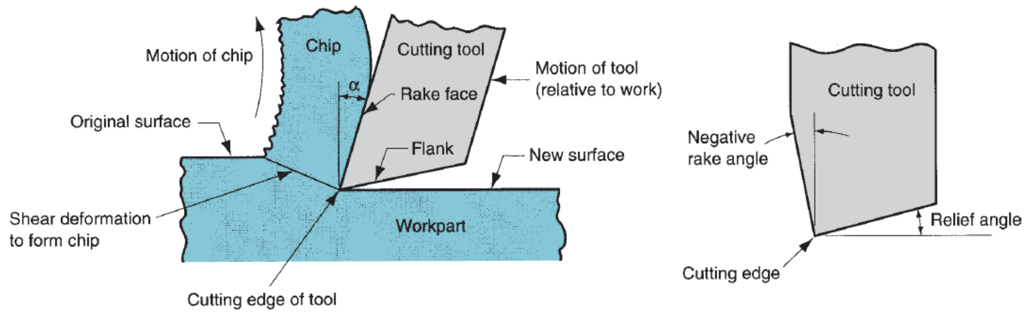
Approach angle = 90° – side cutting edge angle

Effect of rake angle

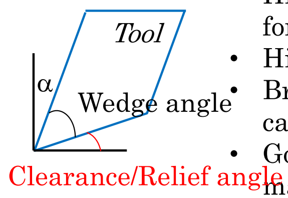


- Rake angle is cutting edge angle that has a large effect on cutting resistance, chip disposal, cutting temperature and tool life.
- Increasing rake angle in the positive (+) direction improves:
  - Tool Sharpness. Thumb rule : Increasing rake angle by 1° in the positive (+) direction decreases cutting power by about 1%.
  - Lowers cutting edge strength and in the negative (-) direction increases cutting resistance.
- Negative rake angle: hard workpiece, When cutting edge strength is required such as uncut surface
- Positive rake angle: soft workpieces, workpiece is easily machined

Positive/ Negative rake angle

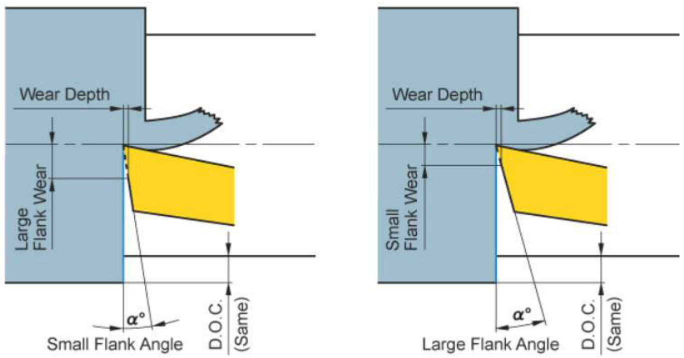


Positive rake angle
- Tool sharp and pointed edge
- Relatively weak
- Reduces cutting forces
- Low/moderate cutting speeds
- Good for softer work material



Negative rake angle
- Increases cutting edge strength
- Higher, compressive cutting forces
- High speed cutting
- Brittle tool materials like carbide, ceramics
- Good for harder work materials

Relief/Flank/Clearance angle

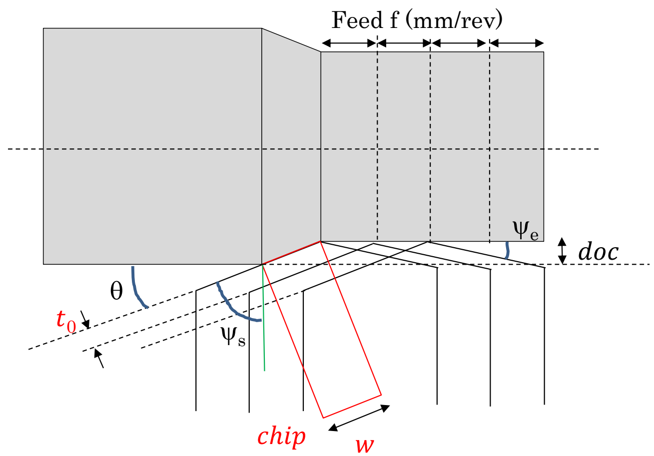


- Flank angle prevents friction between flank face and finished workpiece surface resulting in smooth surface finish.
- Increasing flank angle decreases flank wear occurrence and lowers the cutting edge strength.
- Reduced flank angle is used for harder material, when higher cutting edge strength is needed
- Higher flank angle is used for softer workpiece

Effect of cutting edge angles

θ = Plain approach angle
ψ_s = Side cutting edge angle
ψ_e = End cutting edge angle

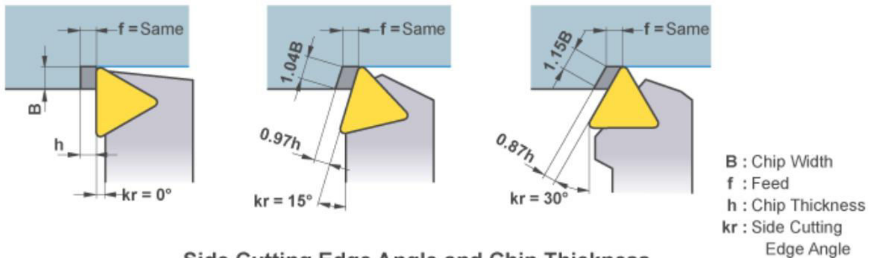
$$\theta = 90° - \psi_s$$



$t_0 = f \cos \psi_s$

$w = d / \cos\psi_s$

Effect of Side cutting edge angle (lead angle)



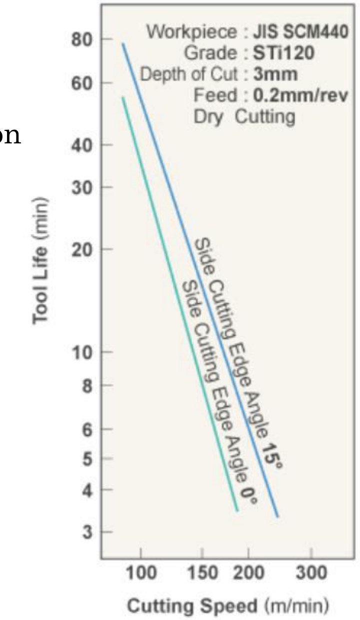
Side Cutting Edge Angle and Chip Thickness

- The side cutting edge angle reduces the impact load and affects the amount of feed force, back force and chip thickness
- Increasing the side cutting edge angle:
  - Increases the chip contact length
  - Decreases chip thickness and increases chip width. Thus, breaking chips is difficult.

http://www.mitsubishicarbide.com/en/technical_information/tec_turning_tools/tec_hsk-t/tec_hsk-t_technical/tec_turning_cutting_edge

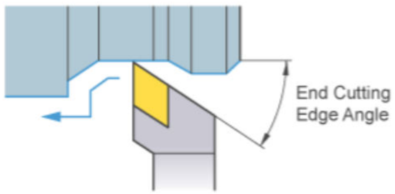
Effects of Side Cutting Edge Angle

- At the same feed rate, increasing the side cutting edge angle increases the chip contact length and decreases chip thickness.
  - As a result, the cutting force is dispersed on a longer cutting edge and tool life is prolonged.
- When to reduce Side cutting edge angle
  - Finishing with small depth of cut
  - thin long workpiece
  - when machine has poor rigidity
- When to increase Side cutting edge angle
  - hard workpiece which produce high cutting temperature
  - when roughing a workpiece with larger diameter
  - when the machine has high rigidity



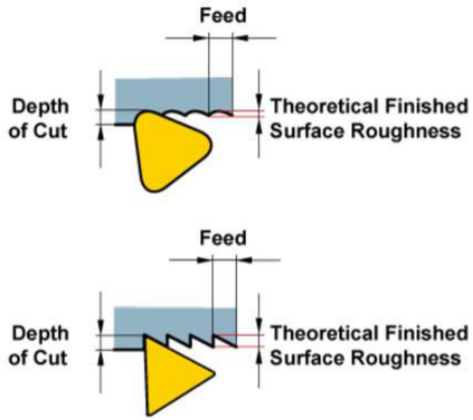
Effects of End Cutting Edge Angle

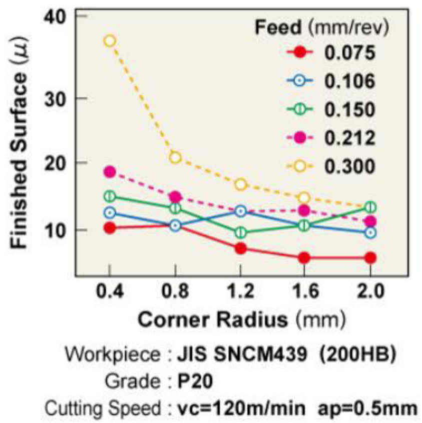
- The end cutting edge angle avoids interference between the machined surface and the tool (end cutting edge).
- Usually 5°–15°.



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

Nose radius of cutting tool





- Radius effects the cutting edge strength and finished surface.
- In general, a corner radius 2–3 times the feed is recommended.

Effect of Tool corner radius

- Increasing the corner radius:
  - Improves the surface finish.
  - Improves cutting edge strength.
  - Increases the cutting resistance and causes chattering.
  - Decreases flank and rake wear.
  - Results in poor chip control.