Module
2
Mechanics of Machining

Lesson
6
Orthogonal and oblique cutting

Instructional Objectives

At the end of this lesson, the student would be able to

(i) define and distinguish, with illustrations, between orthogonal cutting and oblique cutting
(ii) identify the causes of oblique cutting and chip flow deviation
(iii) determine angle of chip flow deviation.
(iv) illustrate and deduce effective rake angle
(v) state the effects of oblique cutting

(i) Orthogonal and oblique cutting

It is appears from the diagram in Fig. 6.1 that while turning ductile material by a sharp tool, the continuous chip would flow over the tool's rake surface and in the direction apparently perpendicular to the principal cutting edge, i.e., along orthogonal plane which is normal to the cutting plane containing the principal cutting edge. But practically, the chip may not flow along the orthogonal plane for several factors like presence of inclination angle, λ, etc.

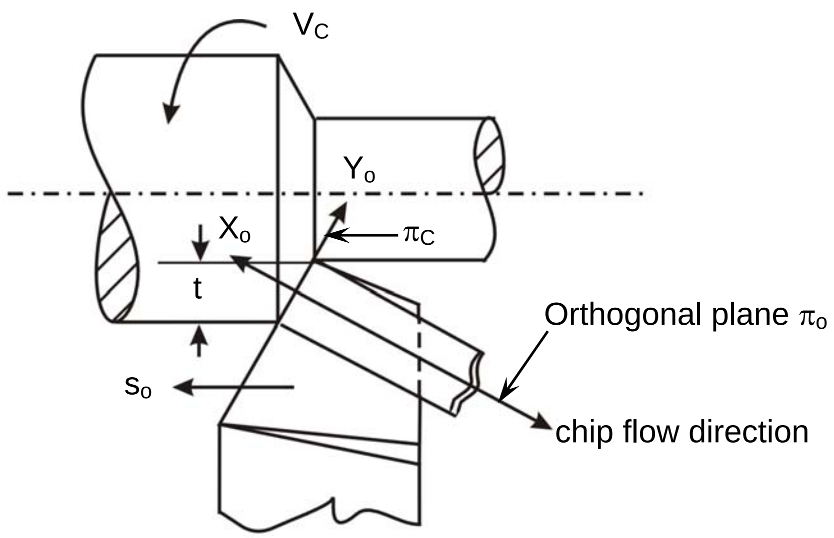

Fig. 6.1 *Ideal direction of chip flow in turning*

The role of inclination angle, λ on the direction of chip flow is schematically shown in Fig. 6.2 which visualises that,

- when λ=0, the chip flows along orthogonal plane, i.e, $\rho_c = 0$
- when $\lambda \neq 0$, the chip flow is deviated from π_o and $\rho_c = \lambda$ where ρ_c is chip flow deviation (from π_o) angle

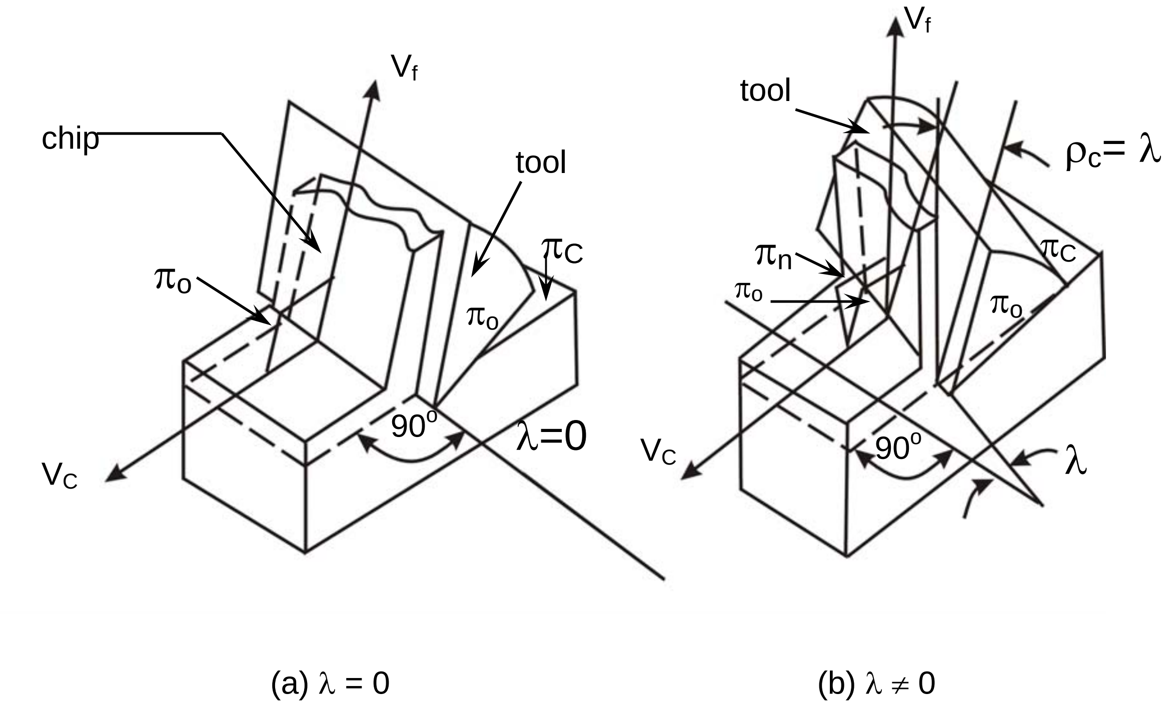

Fig. 6.2 *Role of inclination angle, λ on chip flow direction*

Orthogonal cutting: when chip flows along orthogonal plane, π_o, i.e., $\rho_c = 0$
Oblique cutting : when chip flow deviates from orthogonal plane, i.e. $\rho_c \neq 0$
But practically ρ_c may be zero even if λ= 0 and ρ_c may not be exactly equal to λ even if $\lambda \neq 0$. Because there are some other (than λ) factors also which may cause chip flow deviation.
Pure orthogonal cutting: This refers to chip flow along π_o and $\phi=90^o$ as typically shown in Fig. 6.3 where a pipe like job of uniform thickness is turned (reduced in length) in a center lathe by a turning tool of geometry; λ=0 and $\phi=90^o$ resulting chip flow along π_o which is also π_x in this case.

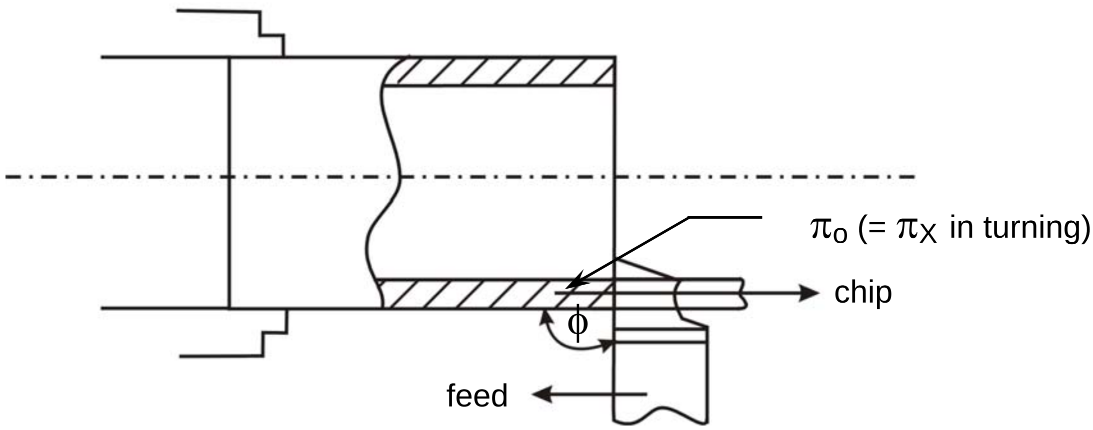

Fig. 6.3 *Pure orthogonal cutting (pipe turning)*

(ii) Causes and amount of chip flow deviation

The deviation of chip flow in machining like turning by single point tool may deviate from the orthogonal plane due to the following three factors:

- Restricted cutting effect (RCE)
- Tool-nose radius (r)
- Presence of inclination angle, $\lambda \neq 0$.

- **Restricted cutting effect**

In machining like turning, shaping etc by single point turning tool, the metal removal is accomplished mainly by the principal cutting edge. But the auxiliary cutting edge also takes part in machining to some extent depending upon the auxiliary cutting edge angle, ϕ_1 and the magnitude of feed, s_o, as indicated in Fig. 6.4. A small volume of the job in the form of a helical rib of small triangular section remains uncut. This causes surface roughness, in the form of fine threads called feed marks or scallop marks as shown in Fig. 6.4. The work material flows out in the form of chip at velocity V_A when the auxiliary cutting edge plays negligible role on chip formation. But when the auxiliary cutting edge keeps sizeable contact with the workpiece, then the material that comes out from that edge at velocity say V_B, interferes with the main stream of the chip causing chip flow deviation from the direction of V_A by an angle say ψ from the direction of V_A as shown in Fig. 6.4. This phenomenon is called **restricted contact cutting effect (RCE).**

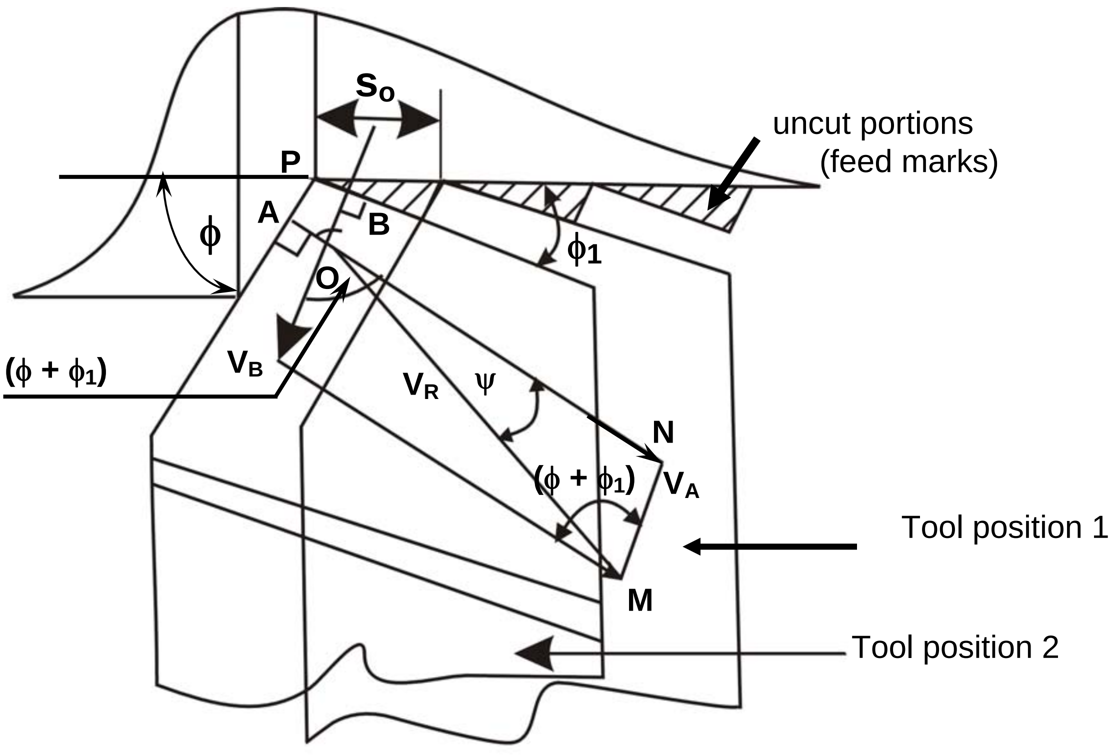

Fig. 6.4 *Chip flow deviation by Restricted Cutting Effect (RCE)*

From Fig. 6.4,

Angle $\angle APB = 180^o - (\phi + \phi_1)$ (6.1)

And $\angle AOB = (\phi + \phi_1)$ (6.2)

From properties of triangle, ΔAMN,

$$\frac{V_B}{\sin\psi} = \frac{V_A}{\sin(\phi+\phi_1-\psi)}$$

or, $$\frac{\sin(\phi+\phi_1-\psi)}{\sin\psi} = \frac{V_A}{V_B} \quad (6.3)$$

Assuming [Rozeinberg and Evemein] $$\frac{V_A}{V_B} = \frac{(t/\sin\phi)}{s_o/2} = \frac{2t}{s_o\sin\phi} \quad (6.4)$$

Equation (6.4) can be rewritten as

$$\frac{\sin(\phi+\phi_1)\cos\psi - \cos(\phi+\phi_1)\sin\psi}{\sin\psi} = \frac{2t}{s_o\sin\phi} \quad (6.5)$$

On simplification, equation (6.4), ψ can be expressed as,

$$\tan\psi = \frac{\sin(\phi+\phi_1)}{\frac{2t}{s_o\sin\phi} + \cos(\phi+\phi_1)} \quad (6.5)$$

Equation (6.5) indicates that even in absence of λ the chip flow may deviate, and the angle of deviation, ψ, though small, depends upon the cutting angles and depth of cut to feed ratio (t/s_o).

- **Effect of tool nose radius, r**

Equation (6.5) indicates that chip flow deviation is significantly influenced by the principal cutting edge angle, ϕ. In nose radiused tool, the value of ϕ continuously varies starting from zero over the curved portion of the principal cutting edge. Such variation in ϕ reasonably influences the chip flow deviation. Therefore, to incorporate the effect of tool nose radiusing also, the ϕ in equation (6.5) need to be replaced by the average value of ϕ i.e., ϕ_{avg} which can be determined with the help of the diagram shown in Fig. 6.5.

From Fig. 6.5,

$$\phi_{avg} = \frac{\overline{AB}x\frac{\phi}{2} + \overline{BC}x\phi}{\overline{AB}+\overline{BC}} \quad (6.6)$$

where, $\overline{AB} = r\phi$

and $\overline{BC} = \frac{t_2}{\sin\phi} = \frac{t-t_1}{\sin\phi}$

here $t_1 = r - r\cos\phi$

Thus, $$\phi_{avg} = \frac{\frac{\phi}{2} + [\frac{t}{r}+\cos\phi-1]\frac{1}{\sin\phi}}{1+\frac{[\frac{t}{r}+\cos\phi-1]}{\phi\sin\phi}} \quad (6.7)$$

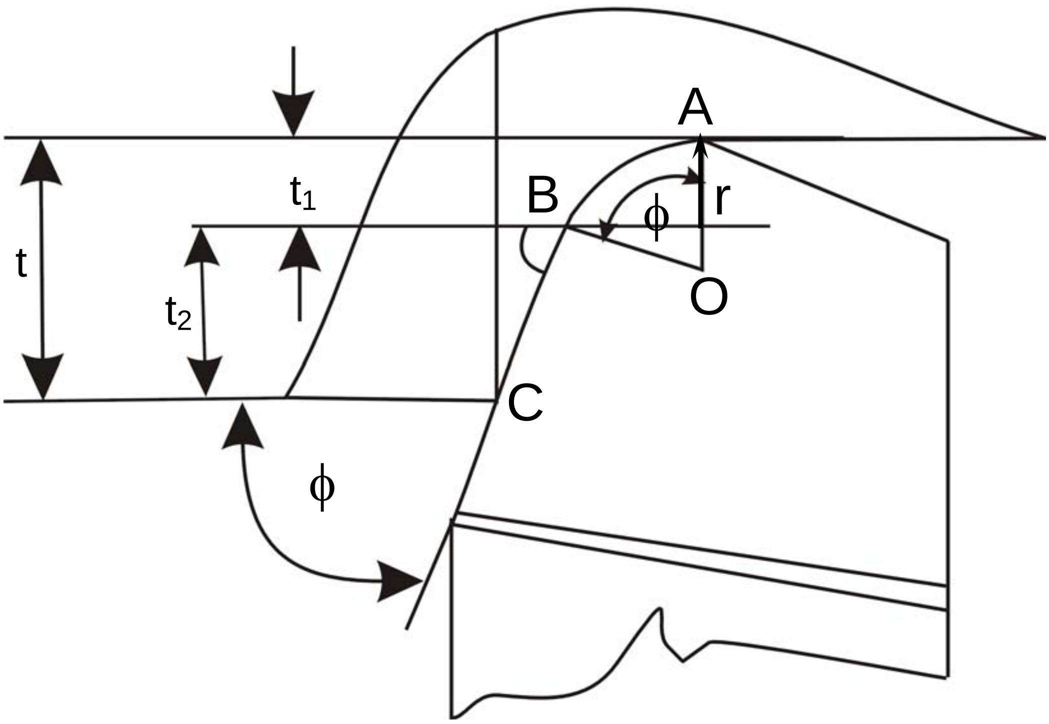

Fig. 6.5 *Variation of principal cutting edge angle in nose radiused tools.*

It is to be noted in equation (6.7) that the difference between ϕ and ϕ_{avg} is governed mainly by the depth of cut to nose radius ratio, i.e., $\frac{t}{r}$.

Therefore to incorporate the effect of nose radiusing along with restricted contact cutting effect, the ϕ in equation (6.5) has to be replaced by ϕ_{avg} to be determined by equation (6.7) resulting,

$$\tan\psi = \frac{\sin(\phi_{avg} + \phi_1)}{\frac{2t}{s_o \sin\phi_{avg}} + \cos(\phi + \phi_{avg})} \qquad (6.8)$$

- **Effect of inclination angle, λ**

In absence of RCE and nose radius the chip flow deviation will be governed only by the value of λ as indicated in Fig. 6.6.

Therefore the combined effects of RCE, tool nose radiused and presence of λ will cause chip flow deviation angle, ρ_c as

$$\rho_c = \psi + \lambda \qquad (6.9)$$

Generally, compared to λ, ψ is very small.

So approximately [s(S)tabler], $\rho_c = \lambda$ where λ may be positive or negative.

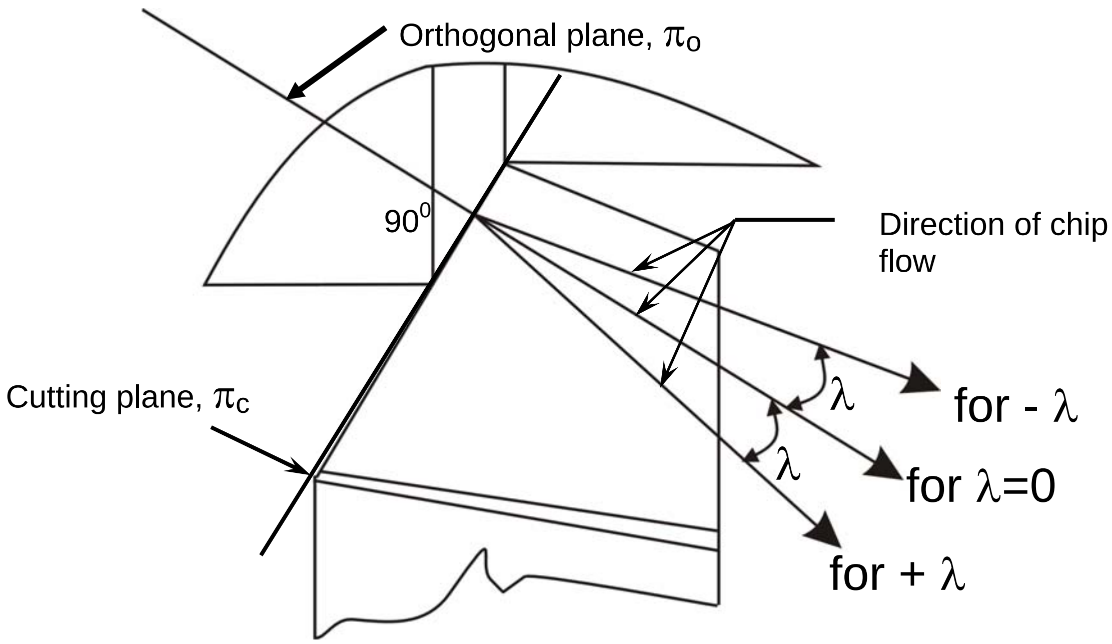

Fig. 6.6 *Role of inclination angle on chip flow direction*

(iii) Effective Rake, γ_e

It has already been realized that the value of rake angle plays vital roles on both mechanism and mechanics of machining. There are different rake angles but that rake angle is obviously the most significant which is taken in the direction of actual chip flow. This rake is called Effective Rake (γ_e)

Definition of γ_e: The angle of inclination of the rake surface from π_R and is measured on that plane which is perpendicular to the reference plane and is taken in the direction of actual chip flow as shown in Fig. 6.7.

In Fig. 6.7, OC is the deviation of apparent chip flow but OD represents the actual direction of chip flow which is deviated from OC by the chip flow angle, ρ_c. Z_o, AB and DE are perpendicular to π_R. Y_o' is parallel to Y_o and Y_n' is taken parallel to the axis Y_n.

In this figure, DOE represents effective rake angle, γ_e.

From Fig. 6.7,

$$\sin \gamma_e = \frac{DE}{OD} = \frac{DF + EF}{\dfrac{OC}{\cos \rho_c}} \qquad (6.10)$$

where, $DF = AB = \dfrac{AC}{\cos \lambda}$

$$EF = AF \sin \lambda$$

$$AF = BD = CD - BD$$
$$AC = OC \sin \gamma_n$$
$$CD = OC \tan \rho_c$$

Combining all those equations, it appears that,

$\sin\gamma_e = \cos\lambda\cos\rho_c\lambda\sin\gamma_n + \sin\lambda.\sin\rho_c$ (6.11)

Assuming [stabler] $\lambda=\rho_c$

$\sin\gamma_e = \cos^2\lambda\sin\gamma_n + \sin^2\lambda$ (6.12)

where,

$\tan\gamma_n = \tan\gamma_o.\cos\lambda$

it is again to be noted that

if $\lambda = 0$; $\gamma_e \cong \gamma_n = \gamma_o$ (6.13)

In case of oblique cutting, which is practically more common, the actual direction of chip flow and the corresponding rake angle, i.e., effective rake should be used for more reasonably accurate analysis and assessment of cutting forces, friction and tool wear.

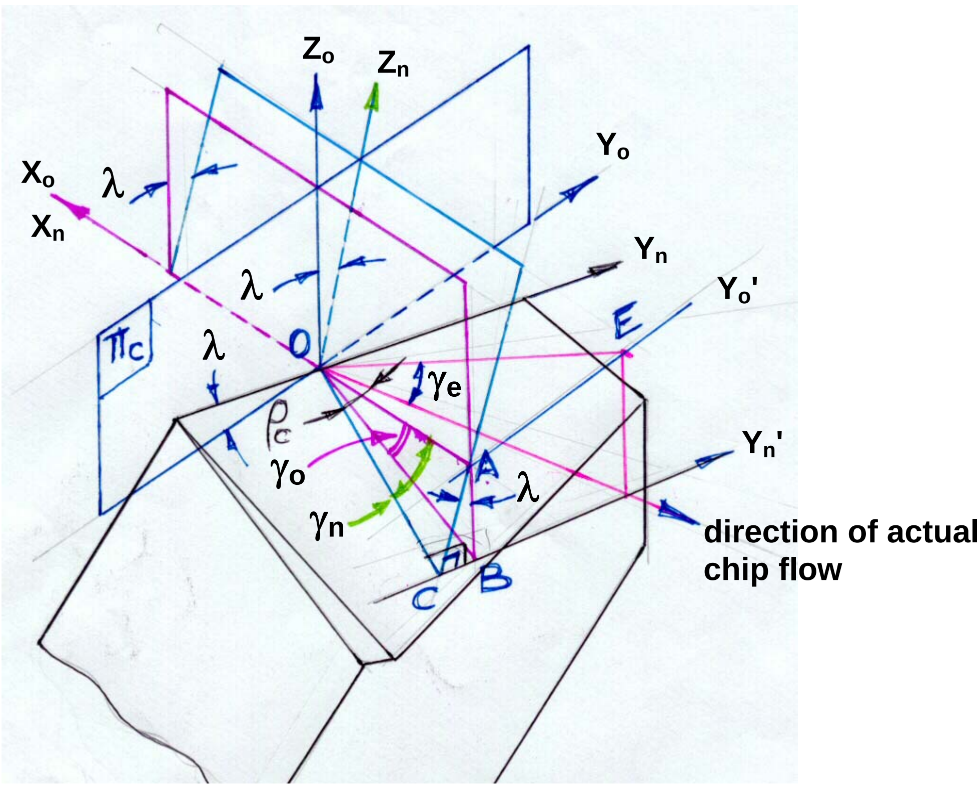

Fig. 6.7 Effective rake angle, γ_e

(iv) Effects of oblique cutting

In contrary to simpler orthogonal cutting, oblique cutting causes the following effects on chip formation and mechanics of machining:

- Chip does not flow along the orthogonal plane;
  Positive λ causes

- o Chip flow deviation away from the finished surface, which may result
  - — lesser further damage to the finished surface
  - — but more inconvenience to the operator
- o reduction of mechanical strength of the tool tip
- o increase in temperature at the tool tip
- o more vibration in turning slender rods due to increase in P_Y (transverse force)

On the other hand, negative λ may enhance tool life by increasing mechanical strength and reducing temperature at the tool tip but may impair the finished surface.

- The chip cross-section may change from rectangle (ideal) to skewed trapezium
- The ductile metals(materials) will produce more compact helical chips if not broken by chip breaker
- Analysis of cutting forces, chip-tool friction etc. becomes more complex.

NOTE: For specifying angles stick to ISO standards,

for ex:

shear angle is ϕ

Inclination angle is ***i***

Exercise - 6

A. Quiz test

Select the correct answer from the given four options

1.Cutting will be called orthogonal when

(a) $\lambda = 0$

(b) $\lambda = 0$ and $\phi = 90^o$

(c) chip flows along π_O plane

(d) $\lambda = 0$ and r (nose radius) = 0

2.In turning, chip will flow along π_O only when

(a) RCE is absent

(b) nose radius is zero

(c) $\lambda = 0$

(d) all of the above conditions

3.Deviation of chip flow from p_O (?)does not depend upon

(a) cutting velocity
(b) feed
(c) depth of cut
(d) nose radius

4.Effective rake in any turning process is measured on

(a) π_X
(b) π_O
(c) π_n
(d) none of the above

B. Problem

1. Under what geometrical condition the values of γ_e, γ_n, γ_o and γ_x (suffix properly) of a turning tool will be same ?

2. Estimate the value of γ_e for turning a rod at s_o= 0.24 mm/rev and t = 4.0 mm by a tool of geometry 10^o, 8^o, 7^o, 6^o, 15^o, 75^o, 1.2 (mm) – NRS

A. Quiz Test - answers

1 – (c)
2 – (d)
3 – (a)
4 – (d)

Q. 1 When γ_e, γ_n, γ_o and γ_x become same ?

Ans

- $\gamma_o = \gamma_x$ when $\phi = 90^o$ i.e., $\pi_o = \pi_x$
- $\gamma_n = \gamma_o$ when $\lambda = 0^o$ i.e., $\pi_n = \pi_o$
- $\gamma_e = \gamma_n$ when $\lambda = 0^o$ & $\rho_C = \psi \pm \lambda = 0$ i.e., $\psi = 0$
- $\psi = 0$ when nose radius, r = 0,
  i.e. $\phi_{avg} = \phi$ and RCE is absent i.e., $\phi_1 > 20^o$

Q. 2 Given : t = 4.0, s_o = 0.24 mm/rev and $\lambda = 10^o$, $\gamma_n = 8^o$, $\phi = 75^o$, $\phi_1 = 15^o$, r = 1.2 mm. Determine γ_e

Ans.

- $\sin\gamma_e = \cos\lambda\cos\rho_c\sin\gamma_n + \sin\lambda\sin\rho_c$ (1)
- $\rho_c = \psi + \lambda$ [Stabler's rule] (2)

$$\tan\psi = \frac{\sin(\phi_{avg} + \phi_1)}{\frac{2t}{s_o \sin\phi_{avg}} + \cos(\phi_{avg} + \phi_1)}$$

- ϕ_{avg}= [ϕ/2+(t/r-cosϕ+1)/sinϕ] / [1+(t/r–cosϕ+1)/ϕsinϕ = 62.71^o
- Put the values, get ψ = 1.65^o
- Hence ρ_c = 1.65^o + 10^o= 11.65^o
- Put values of λ, ρ_c and γ_n in equation 1;

get γ_e = 5.69^o Ans