Sheet MetalWorking Processes:

1. Cutting Operations

- Cutting of sheet metal is accomplished by a shearing action between two sharp cutting edges.
- Figure (3-55) illustrates steps of cutting process.
- If clearance between punch and die is correct, the two fracture lines meet, resulting in a clean separation of the w.p.
- The cutting operation includes ***shearing, blanking, and punching*** which utilize the shearing mechanism to cut the sheet metal.

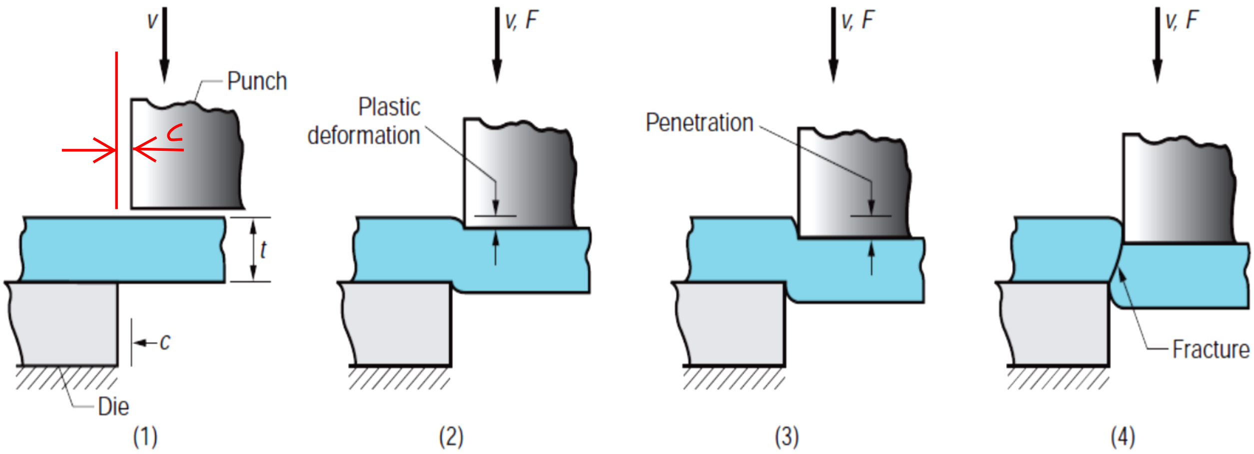


Figure (3-55) Sheet metal cutting process: (1) before punch contacts the w.p. (2) punch begins to push into w.p. causing plastic deformation (3) punch compresses and penetrates into w.p. causing a smooth cut surface (4) fracture is initiated at the opposing cutting edges that separate the sheet metal. v: velocity, F: applied force, t: w.p. thickness, c: clearance

Shearing:

- It is a sheet metal cutting operation along a straight line between two cutting edges.
- Figure (3-56) shows the shearing process.
- It is performed on a machine called a ***power shears*** or ***squaring shears***.
- The upper blade of power shears is often inclined to reduce the cutting force.

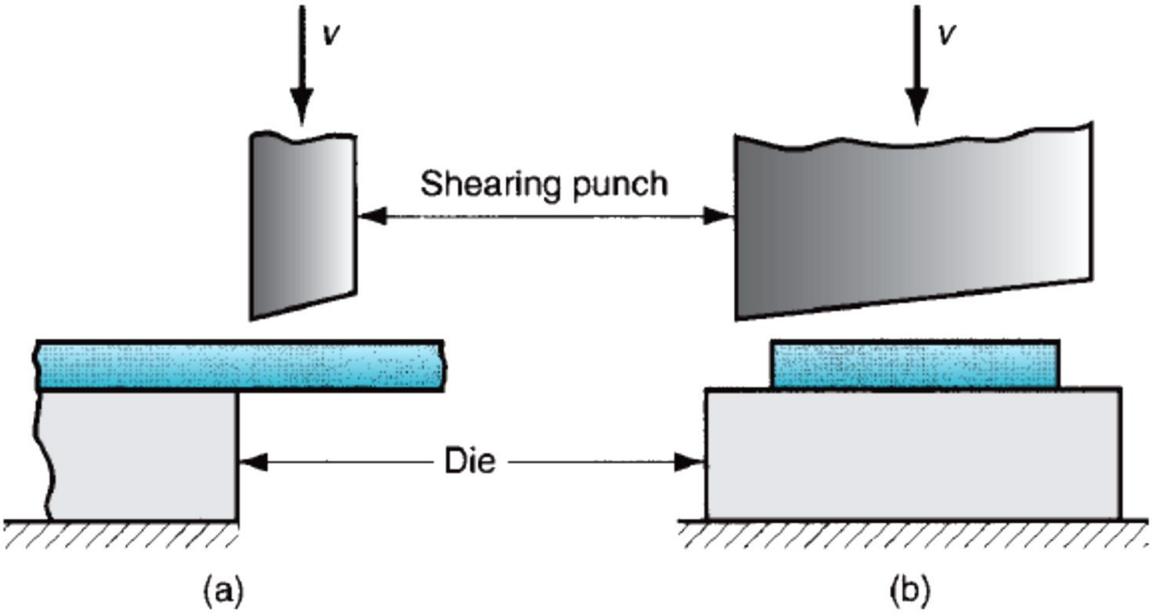


Figure (3-56) shearing operation: (a) side view (b) front view of power shears equipped with inclined upper cutting blade

Blanking:

- It involves cutting of sheet metal along a closed outline in a single step to separate the piece from surrounding stock.
- Figure (3.57) explains blanking process.

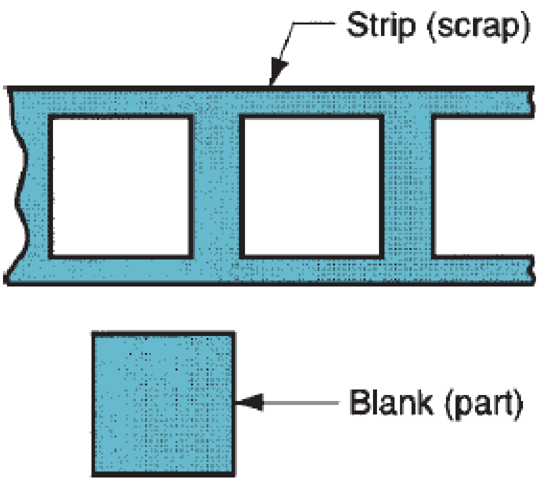


Figure (3-57) Blanking operation

Punching:

- It is similar to blanking except that it produces a hole.
- Figure (3-58) states punching operation.

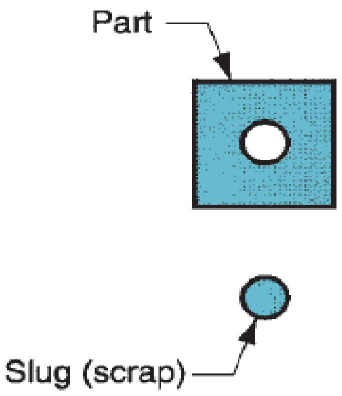


Figure (3-58) Punching operation

Engineering Analysis of Sheet Metal Cutting:

- Process parameters in sheet metal cutting: ***clearance*** between punch and die, ***stock thickness***, ***strength of sheet metal***, and ***length of the cut.***

Clearance:

$$c = A_c t$$

c: clearance between punch and die (mm).

A_c: clearance allowance, constant depending on metal type.

t: stock thickness (mm).

Typical values of (c) are from 1% to 8% of stock thickness.

- Effect of improper clearance is shown in figure (3-59)

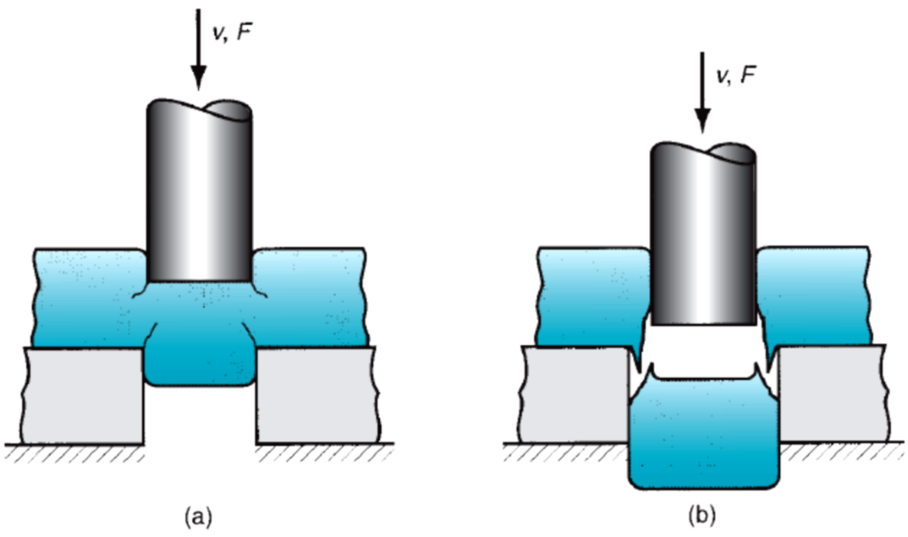


Figure (3-59) effect of clearance (a) too small clearance, causes fracture lines tend to pass each other resulting in larger cutting force (b) too large clearance, causes metal is pinched between cutting edges and oversized burr results.

Punch and Die Sizes:

- Figure (3-60a) explains punch and die sizes.

1. Punch and die sizes for a round blank of diameter D_b

Blanking punch diameter $= D_b - 2c$

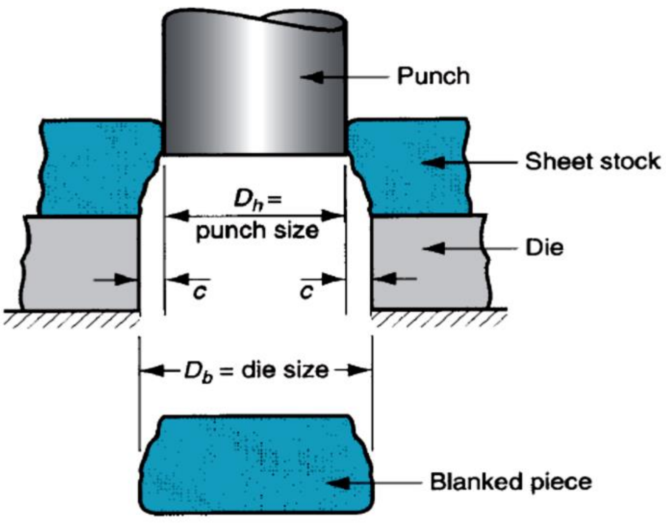
Blanking die diameter $= D_b$

2. Punch and die sizes for a round hole of diameter D_h

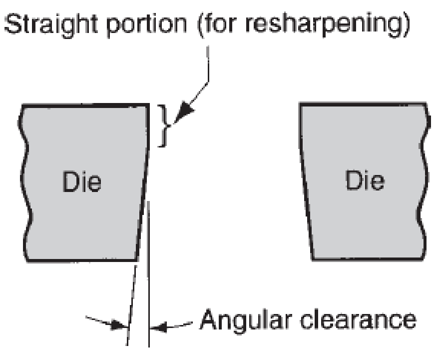
Hole punch diameter $= D_h$

Hole die diameter $= D_h + 2c$

- In order for slug or blank to drop through the die, the die opening must have an angular clearance of (0.25º to 1.5º on each side), see figure (3-60b).



(a)



(b)

Figure (3-60): (a) die size determines blank size D_b ; punch size determines hole size D_h, (b) Angular clearance

Cutting Forces in Sheet Metalworking:

- It can be determine from

$$F_{smc} = StL$$

Or

$$F_{smc} = 0.7(TS)tL$$

F_{smc}: *sheet metal cutting force (N).*

S: shear strength of sheet metal (MPa).

TS: ultimate tensile strength (MPa).

t: stock thickness (mm).

L: length of the cut edge (mm).

In blanking, punching and similar operations, L is perimeter length of blank or hole being cut.

Example (18):

Around disk of 150-mm diameter is to be blanked from a strip of 3.2-mm, half-hard cold rolled steel whose shear strength = 310 MPa. Determine (a) the appropriate punch and die diameters, and (b) blanking force.
Take: A_c=0.075

Solution:

(a) Since we have blank production, then we use:
Blanking punch diameter = $D_b - 2c$ = *punch diameter*
Blanking die diameter = D_b = *die diameter = blank diameter =*

$c = A_c\, t = 0.075\ (3.2) = 0.24$ mm

die diameter = ***150 mm*** **Answer**

punch diameter = 150 – (2 x 0.24) = ***149.52 mm*** **Answer**

(b) Blanking force: $F_{smc} = StL$

L= length of cut edge = perimeter of blank = $\pi D_b = \pi(150) = 471mm$

$\therefore F_{smc} = 310(3.2)(471) = \mathbf{467.23\ kN}$ **Answer**

Example (19):

A compound die will be used to blank and punch a large washer out of 6061ST aluminum alloy sheet stock 3.50 mm thick. The outside diameter of the washer is 50.0 mm and the inside diameter is 15.0 mm. The aluminum sheet metal has a tensile strength = 310 MPa. Determine (a) the punch and die sizes for the blanking operation, and the punch and die sizes for the punching operation, (b) the minimum tonnage press (force) to perform the blanking and punching operation (1) assume that blanking and punching occur simultaneously and (2) assume that punching occurs first, then blanking. Take: A_c=0.06

Solution:

(a) $c = A_c t = 0.06(3.5) = 0.21\ mm$

- For blanking operation:

Die diameter = blank diameter = D_b = **50mm** **Answer**

Punch diameter = $D_b - 2c = 50 - (2 \times 0.21) = \mathbf{49.58\ mm}$ **Answer**

- For punching operation:

Punch diameter = D_h = *hole diameter* = ***15mm*** **Answer**

Die diameter = $D_h + 2c = 15 + (2 \times 0.21) = \mathbf{15.42mm}$ **Answer**

(b) Determine the minimum required force (tonnage):

- **Blanking and punching occur simultaneously:**

$F_{smc} = 0.7(TS)tL$

L = *length of cut edge* = *perimeter of blank and hole* = $50\pi + 15\pi = 204.2mm$

$\therefore F_{smc} = 0.7(310)(3.5x204.2) = \mathbf{155.1\ kN}$ **Answer**

- **Punching occurs first, then blanking:**

Longest cut edge length will determine the minimum force required:

(Blanking length of cut = 50π) **is greater than** (Punching length of cut = 15π)

$\therefore F_{smc} = 0.7(310)(3.5x50\pi) = \mathbf{119.3\ kN}$ **Answer**

2. Bending Operations

- Bending in sheet metal working is defined as straining of the metal around a straight axis (neutral axis).
- During bending, the metal on inside of neutral plane is compressed, while on outside of neutral plane is stretched as shown in figure (3-61).
- Bending produces little or no change in thickness of sheet metal.

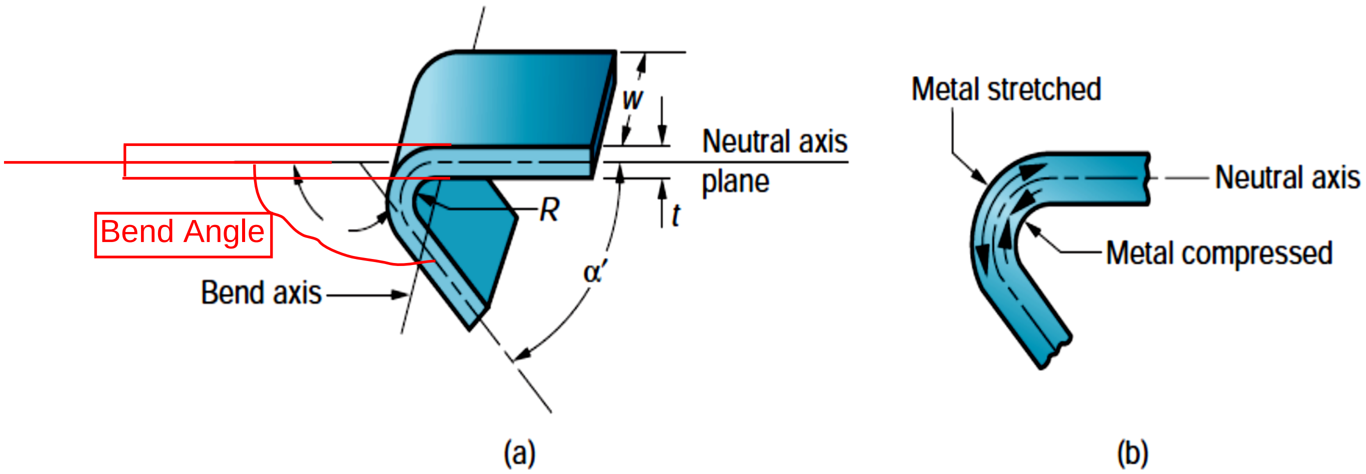


Figure (3-61): (a) bending of sheet metal (b) both compression and tensile elongation of the metal occur in bending.

<u>V-Bending:</u>

- The sheet metal is bent between a V-shaped punch and die.
- Figure (3-62a) explains this process.
- Very obtuse to very acute angles can be made with V-dies.
- It is used for low-production operations.

<u>Edge Bending:</u>

- It is performed on a wiping die (involves cantilever loading of sheet metal).
- Figure (3-62b) explains this process.
- Pressure pad is used to hold the base of w.p. against the die by F_h.
- Bend angles can be 90º or less than.
- Bend angles greater than 90º require more complicated wiping dies.
- Pressure pad and wiping dies are more complicated and costly than V-dies.
- It is used generally for high production rates.

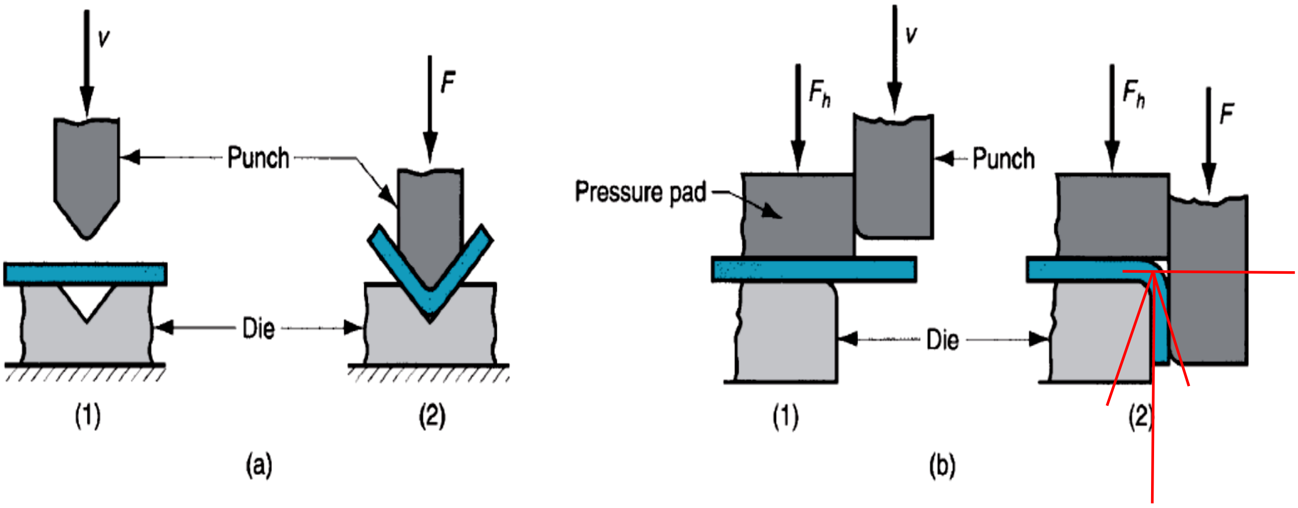
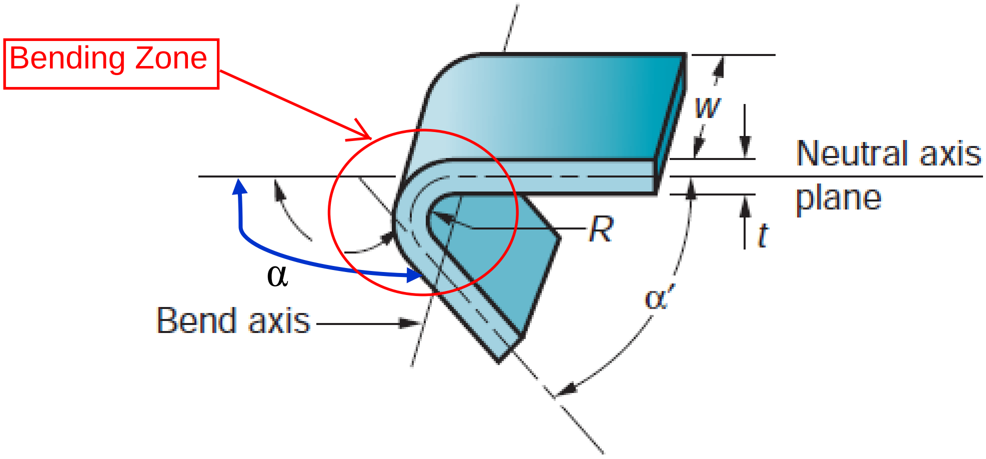


Figure (3-62): (a) V-bending and (b) edge bending; (1) before and (2) after bending. v: punch velocity, F: applied bending force, F_h: blank holding force

Engineering Analysis of Bending:

- The figure below shows the important terms in sheet metal bending:



Where:

t: thickness of sheet metal (w.p.)

α: bend angle

α' : angle of bent part (included angle)

$\alpha' + \alpha = 180°$

R: bend radius (it is determined by radius on the tooling used to perform the bending)

Width

w: thickness of sheet metal (w.p.)

Bend Allowance

- If ***R*** < relative to ***t*** → w.p. tends to stretch during bending.
- It is important to estimate amount of stretching that occurs if any, so that, final part length after bending will match the specified dimension.
- It is important to determine the neutral axis length before bending to account for stretching of final bent section.
- This length called the **Bend Allowance**:

$$A_b = 2\pi \frac{\alpha}{360}(R + K_{ba}t)$$

A_b: bend allowance (mm)

α: bend angle (degrees)

R: bend radius (mm)

t: stock thickness (mm)

K_{ba}: factor to estimate stretching (predicts that stretching occurs only if bend radius is small relative to w.p. thickness)

$K_{ba} = 0.33$ ***if*** $R < 2t$

$K_{ba} = 0.5$ ***if*** $R \geq 2t$

Amount of Stretching (AoS) = Bent Section Length (BSL) - Bend Allowance

$$Aos = BSL - A_b$$

$$BSL = 2\pi \frac{\alpha}{360}(R + 0.5t)$$

Neutral Axis Length after Bending = Neutral Axis Length before Bending + AoS

Springback

- When bending pressure is removed at end of deformation, the elastic energy remains in the bent part, causing it to recover partially toward its original shape.
- Springback = Elastic Recovery.
- It is defined as increase in included angle of bent part relative to included angle of forming tool after the tool is removed as shown if figure (3-63).

$$SB = \frac{\alpha' - \alpha'_t}{\alpha'_t}$$

SB: springback

α': included angle of bent part (degrees)

α_t': included angle of bending tool (degrees)

SB increases with E and Y of sheet metal.

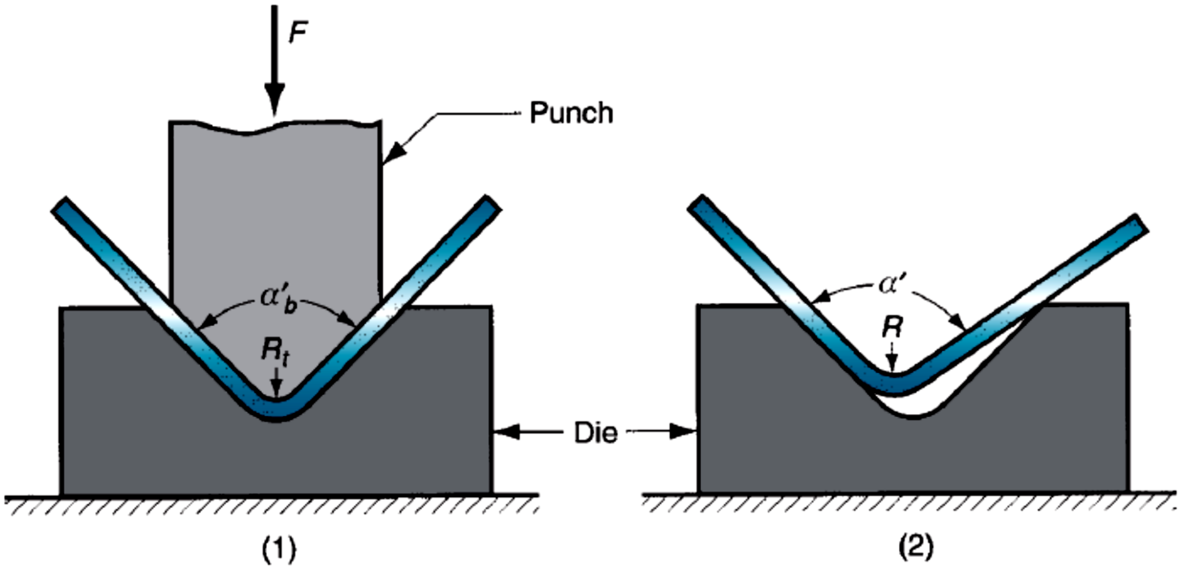


Figure (3-63) springback shows as a decrease in bend angle and an increase in bend radius: (1) during the operation, the w.p. is forced to take the radius R_t and included angle $\alpha_t' = \alpha_b'$ which is determined by the bending tool (punch in V-bending); (2) after the punch is removed, w.p. springs back to radius R and included angle α'.

- Two common methods to compensate the springback are:
  (1) Overbending: punch angle and radius are fabricated slightly smaller than specified angle on final part.
  (2) Bottoming: squeezing the w.p. at the end of stroke, thus plastically deforming it in the bend region.

Bending Force

- Bending force F_b depends on: (1) geometry of punch and die (2) w.p. strength (3) w.p. thickness (4) w.p. width
- Maximum bending force:

$$\boldsymbol{F_b = \frac{K_{bf}(TS)wt^2}{D}}$$

TS: w.p. tensile strength (MPa)

D: die opening, *t*: w.p. thickness, *w*: w.p. width in direction of bend axis.

K_{bf}: constant that accounts for differences encountered in an actual bending.

K_{bf} = 1.33 for V-bending and K_{bf} = 0.33 for edge-bending

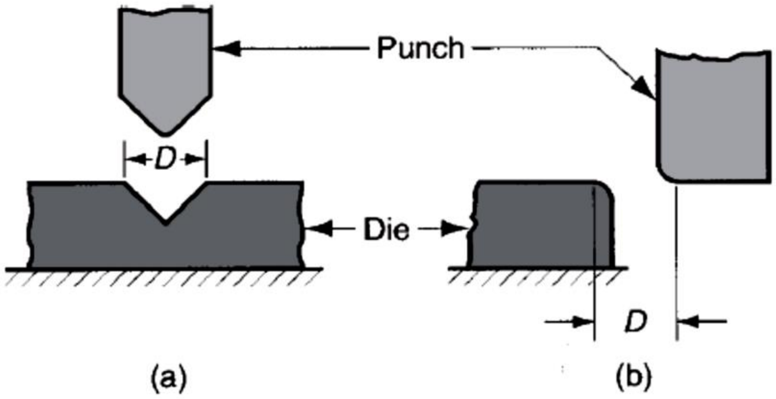
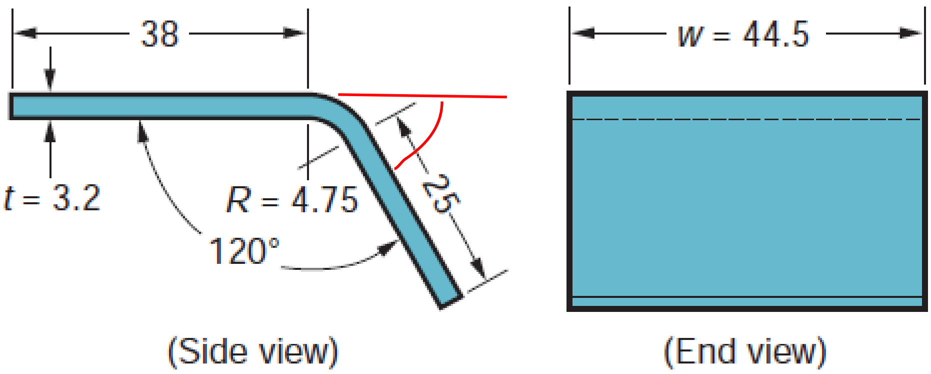


Figure (3-64) die opening dimension *D*: (a) V-die (b) wiping-die

Example (20):

A sheet-metal blank is to be bent as shown in figure below (all dimensions in mm). The metal has a modulus of elasticity = 205 MPa, yield strength = 275 MPa, and tensile strength = 450 MPa. Determine (a) the starting w.p. size and (b) the bending force if a V-die is used with a die opening dimension = 25 mm.



Solution:

(a) Starting Blank Size = 38 + 25 + A_b

$A_b = 2\pi \frac{\alpha}{360}(R + K_{ba}t)$, R=4.75mm, t=3.2mm, 2t=6.4mm, $\therefore R < 2t$

$\therefore K_{ba} = 0.33$, $\alpha = 180° - 120° = 60°$

$$\therefore A_b = 2\pi \frac{60}{360}(4.75 + 0.33x3.2) = 6.08mm$$

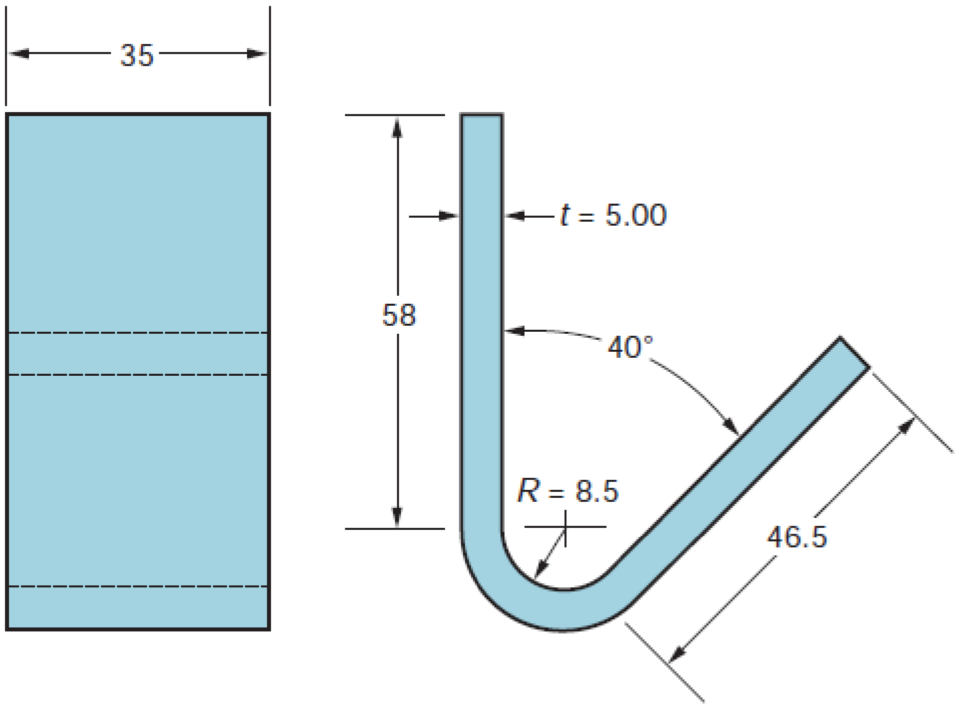
$\therefore Starting\ Blank\ Size = 38 + 25 + 6.08 = \mathbf{69.08mm}$ **Answer**

(b) $F_b = \frac{K_{bf}(TS)wt^2}{D}$, K_{bf}= 1.33 for V-die

$\therefore F_b = \frac{K_{bf}(TS)wt^2}{D} = \frac{1.33(450)(44.5)3.2^2}{25} = \mathbf{10.908\ kN}$ **Answer**

Example (21):

A bending operation is to be performed on 5mm thick cold-rolled steel (600MPa tensile strength). The w.p. is shown in figure below (all dimensions in mm). Determine (a) the blank size required to bend this w.p. (b) the bending force if used a V-die with die opening of 40mm.



Solution:

(a) → ~~(c)~~ Starting Blank Size = 46.5 + 58 + A_b

$A_b = 2\pi \frac{\alpha}{360}(R + K_{ba}t)$, R=8.5mm, t=5mm, 2t=10mm, $\therefore R < 2t$

$\therefore K_{ba} = 0.33$, $\alpha = 180° - 40° = 140°$

$\therefore A_b = 2\pi \frac{140}{360}(8.5 + 0.33x5) = 24.8mm$

$\therefore Starting\ Blank\ Size = 46.5 + 58 + 24.8 = \mathbf{129.3mm}$ **Answer**

(b) → ~~(d)~~ $F_b = \frac{K_{bf}(TS)wt^2}{D}$, K_{bf}= 1.33 for V-die

$\therefore F_b = \frac{K_{bf}(TS)wt^2}{D} = \frac{1.33(600)(35)5^2}{40} = \mathbf{17.5\ kN}$ **Answer**

Example (22):

An L-shaped part is to be bent in a V-bending operation on a press brake from a flat blank 4.0 in by 1.5 in that is 0.156 in thick. The bend of 90° is to be made in the middle of the 4-in length. (a) Determine the dimensions of the two equal sides that will result after the bend, if the bend radius = 0.1875 in. For convenience, these sides should be measured to the beginning of the bend radius. (b) Determine the length of the part's neutral axis after the bend.

Solution:

(a) R/t = 0.1875/0.156 = 1.2 < 2 ⟹ K_{ba}=0.33, $\alpha = 180° - 90° = 90°$

$$A_b = 2\pi\frac{90}{360}(0.1875 + 0.33x0.156) = 0.3754\ in$$

$$\therefore Dimensions\ of\ each\ side = \frac{4-0.3754}{2} = \mathbf{1.8123\ in}$$ **Answer**

(b) *Neutral Axis Length after Bending = Neutral Axis Length before Bending+AoS*

Aos = BSL - A_b

$$BSL = 2\pi\frac{\alpha}{360}(R + 0.5t) = 2\pi\frac{90}{360}(0.1875 + 0.5x0.156) = 0.417\ in$$

∴ *AoS = 0.417 – 0.3754 = 0.0416 in*

∴ *Neutral Axis Length after Bending = 4 +0.0416 =* ***4.0416 in*** **Answer**

Example (23):

A bending operation is to be performed on 4 mm thick cold-rolled steel sheet that is 25 mm wide and 100 mm long. The sheet is bent along the 25 mm direction, so that the bend is 25 mm long. The resulting sheet metal part has an acute angle of 30° and a bend radius of 6 mm. Determine (a) the bend allowance and (b) the length of the neutral axis of the part after the bend.

Solution:

(a) R/t = 6/4 = 1.5 < 2 ⟹ K_{ba}=0.33, $\alpha = 180° - 30° = 150°$

$$A_b = 2\pi\frac{150}{360}(6 + 0.33x4) = \mathbf{19.164\ mm}$$ **Answer**

(b) *Neutral Axis Length after Bending = Neutral Axis Length before Bending+AoS*

Aos = BSL - A_b

$$BSL = 2\pi\frac{\alpha}{360}(R + 0.5t) = 2\pi\frac{150}{360}(6 + 0.5x4) = 20.944\ mm$$

∴ *AoS = 20.944 – 19.164 = 1.78 mm*

∴ *Neutral Axis Length after Bending = 100 + 1.78 =* ***101.78 mm*** **Answer**