Chapter 9

Design for Sheet Metalworking

OutLine

9.1 Introduction

Parts are made from sheet in two ways:

1. **Dies to**
   - Make blanks
   - change shape of blanks
   - add features through piercing operations
2. **CNC punching machines**
   - arrays of sheet metal parts from individual sheets.
   - punches in rotating turrets (turret presses)

9.1 Introduction

TABLE 9.1 Standard U.S. Sheet Metal Thickness

Steels Gage no.	(mm)	Aluminum alloys (mm)	Copper alloys (mm)	Titanium alloys (mm)
28	0.38	0.41	0.13	0.51
26	0.46	0.51	0.28	0.63
24	0.61	0.63	0.41	0.81
22	0.76	0.81	0.56	1.02
20	0.91	1.02	0.69	1.27
19	1.07	1.27	0.81	1.60
18	1.22	1.60	1.09	1.80
16	1.52	1.80	1.24	2.03
14	1.91	2.03	1.37	2.29
13	2.29	2.29	2.06	2.54
12	2.67	2.54	2.18	3.17
11	3.05	3.17	2.74	3.56
10	3.43	4.06	3.17	3.81
8	4.17	4.83	4.75	4.06
6	5.08	5.64	6.35	4.75

- Stiffness per unit cost in sheet form is max for steels

9.1 Introduction

TABLE 9.2 Sheet Metal Properties and Typical Costs

Alloy	Cost ($/kg)	Scrap value ($/kg)	Specific gravity	UTS (MN/m^2)	Elastic modulus (GN/m^2)	Max. tensile strain
Steel, low-carbon commercial quality	0.80	0.09	7.90	330	207	0.22
Steel, low-carbon, drawing quality	0.90	0.09	7.90	310	207	0.24
Stainless steel T304	6.60	0.40	7.90	515	200	0.40
Aluminum, 1100, soft	3.00	0.80	2.70	90	69	0.32
Aluminum, 1100, half hard	3.00	0.80	2.70	110	69	0.27
Aluminum, 3003, hard	3.00	0.80	2.70	221	69	0.02
Copper, soft	9.90	1.90	8.90	234	129	0.45
Copper, 1/4 hard	9.90	1.90	8.90	276	129	0.20
Titanium, Grade 2	19.80	2.46	4.50	345	127	0.20
Titanium, Grade 4	19.80	2.46	4.50	552	127	0.15

9.2 DEDICATED DIES AND PRESS WORKING

A sheet metal part is produced through a series of shearing and forming operations.

1. Individual dies on separate presses
2. Progressive die: different stations within a single die.
   - Strip is moved incrementally through die while press cycles.
   - punches at different positions along die produce successive features in part.

9.2 DEDICATED DIES AND PRESS WORKING

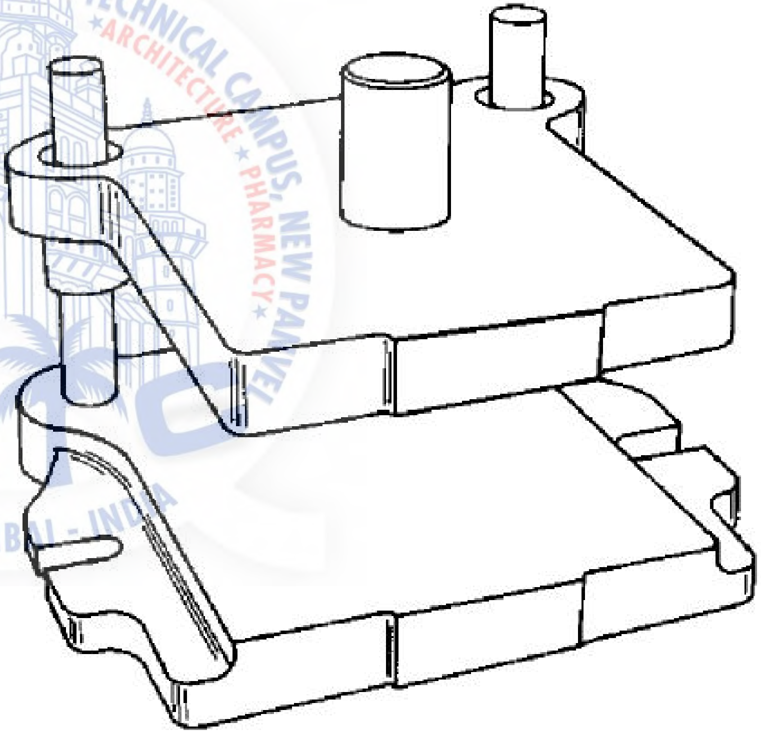


FIG. 9.1 Die set.

9.2 DEDICATED DIES AND PRESS WORKING –Cut-off operation

- applies to parts that have two parallel edges & "jigsaw" together along length of strip.
- Trailing edge of part must be precise inverse of leading edge

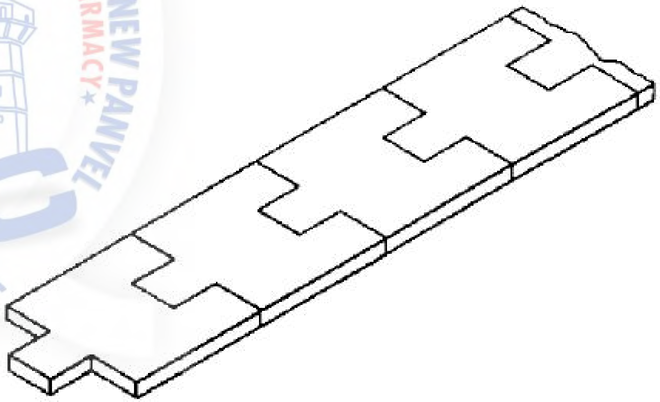
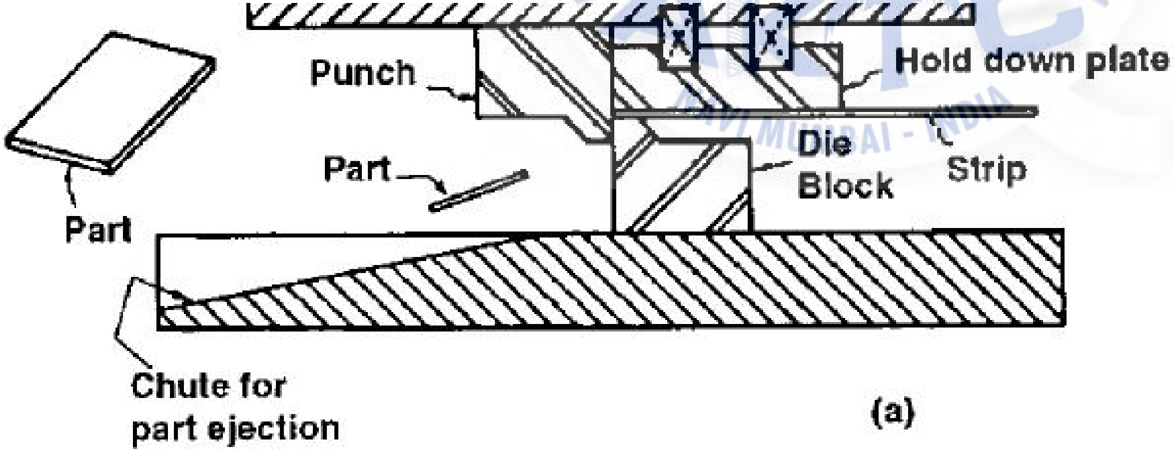


FIG. 9.3 Cut-off part design.

9.2 DEDICATED DIES AND PRESS WORKING –Cut-off operation

Advantages:

- Simple tooling
- Minimization of manufactured scrap.
- Manufactured scrap: scrap sheet metal produced as a direct result of the manufacturing process.



9.2 DEDICATED DIES AND PRESS WORKING

Part-off die

- Sheet metal part designed with two parallel edges, but ends cannot jigsaw together.
- Two die blocks and a punch passing between them to remove material separating ends of adjacent parts.
- Sheared ends should not meet strip edges at an angle less than about 15° to ensure a good-quality sheared edge with a min of tearing & edge distortion at ends of cut.
- Avoid Full semicircular ends or corner blend radii

9.2 DEDICATED DIES AND PRESS WORKING

Part-off die

- Part-off process offers same advantage as cut-off
- Die is a little more complex than a cutoff die.

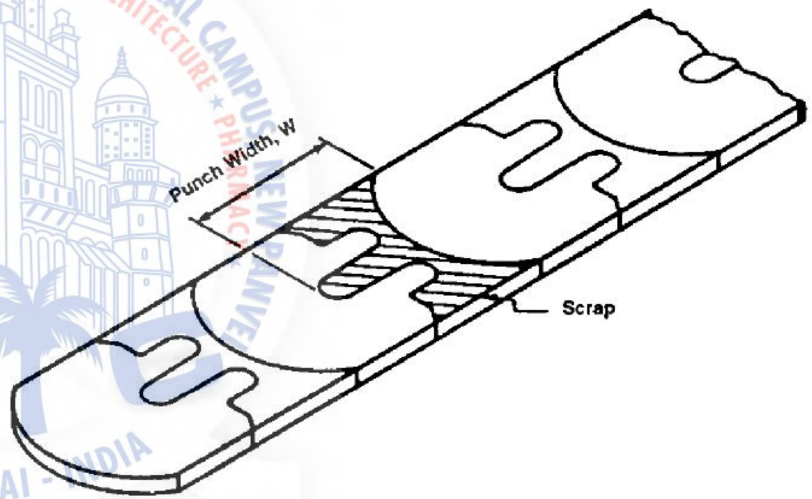


FIG. 9.4 Part-off part design.

9.2 DEDICATED DIES AND PRESS WORKING

Part-off die

- Scrap is increased because adjacent parts must be separated by at least twice sheet metal thickness to allow adequate punch strength.

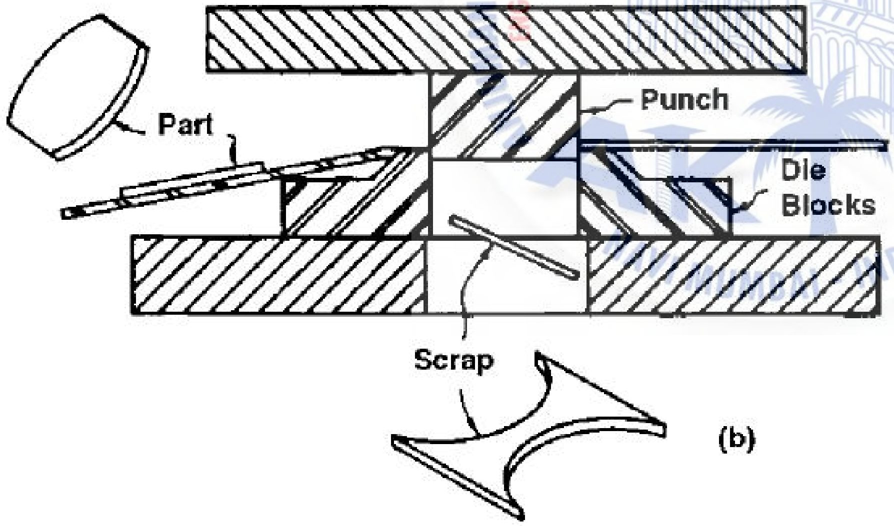


FIG. 9.5 Die elements of cut-off and part-off dies. (a) Cut-off die. (b) Part-off die.

9.2 DEDICATED DIES AND PRESS WORKING – blanking die

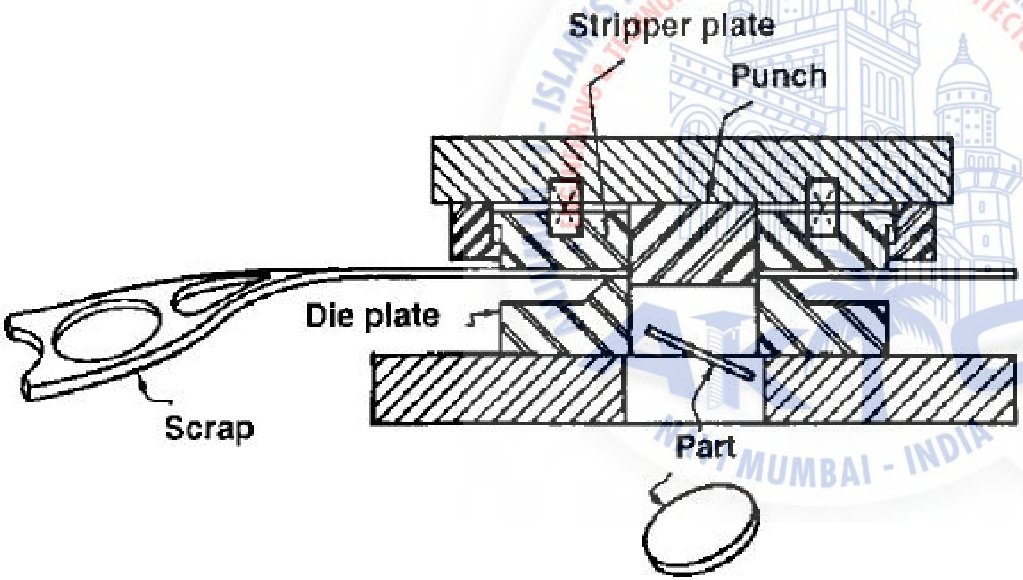


FIG. 9.6 Blanking die.

- parts do not have two straight parallel edges.
- Blank can be almost any closed contour.
- Increase in mfg scrap.
- Edges of part must be separated from edges of strip by nearly ***twice sheet metal thickness*** to minimize edge distortion.

9.2 DEDICATED DIES AND PRESS WORKING – blanking die

- Extra scrap area / part = 4 × material thickness × part length
- Blanking dies are more expensive to produce than cut-off or part-off dies.
  - Additional plate, stripper plate, positioned above die plate with separation sufficient to allow sheet metal strip to pass between.
  - Stripper plate aperture matches contour of punch so that it uniformly supports strip while punch is removed from it on upward stroke of press.

9.2 DEDICATED DIES AND PRESS WORKING – cut off & drop-through die

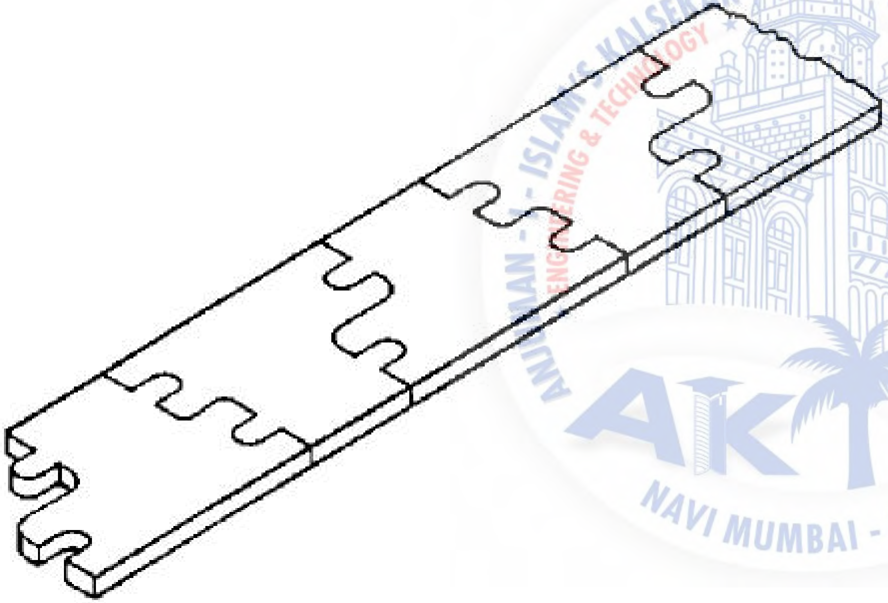


FIG. 9.7 Part design for cut-off and drop-through.

- If both ends are symmetric, then adjacent parts can be arranged on strip at a 180° orientation to each other.
- Each press stroke produces two parts.

9.2 DEDICATED DIES AND PRESS WORKING – cut off & drop-through die

- A rounded edge on the die side of part from initial deformation as sheet is pressed downward against die edge.
- Final separation of part from strip is by brittle fracture, which leaves a sharp edge, or burr, on punch side of part.
- Sharp edges on opposite sides of adjacent parts.
- **De-burring**: sharp edges must be removed: tumbling

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- For each type of die the cost includes a basic die

$$C_{ds} = 120 + 0.36\,A_u \qquad (9.1)$$

- C_{ds} = die set purchase cost, $
- A_u = usable area between guide pillars, cm²

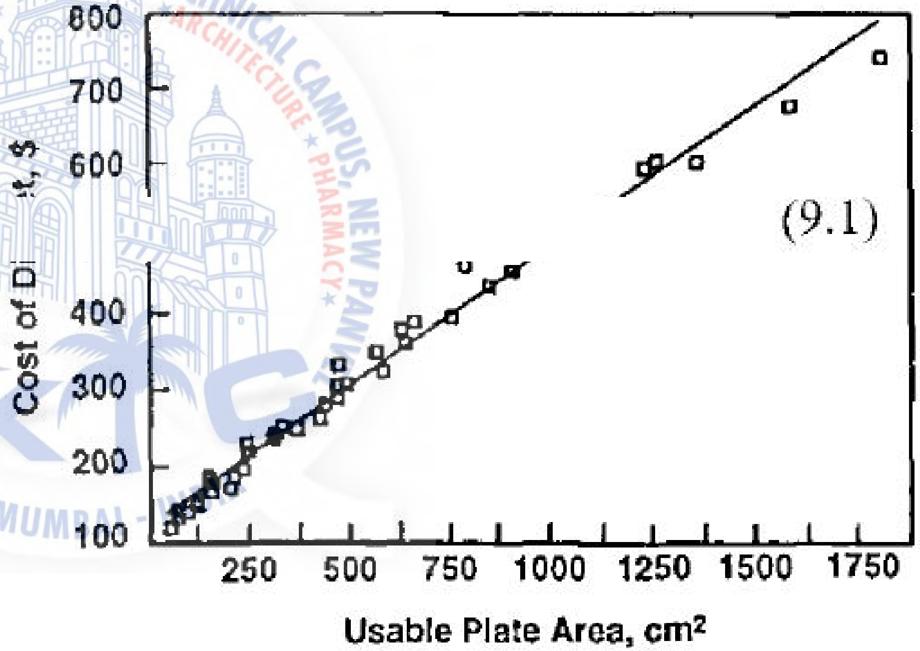


FIG. 9.8 Die set cost versus usable area.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- Mfg point system to estimate cost of tooling elements such as:
  - die plate
  - Punch
  - punch retaining plate
  - stripper plate, etc.
- The system includes time for:
  - mfg die elements
  - Assembly
  - tryout of die
- Assembly includes custom work on die set:
  - drilling and tapping of holes
  - fitting of metal strips or dowel pins to guide sheet metal stock in die

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- Basic mfg points are determined by:
  1. size of punch
  2. complexity of profile to be sheared
- Profile complexity is measured by index X_p as

$$X_p = P^2/(LW) \quad (9.2)$$

  - P = perimeter length to be sheared, cm
  - L, W = length & width of smallest rectangle surrounding the punch, cm

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- L and W:
  - **Blanking die, or a cut-off and drop-through die:** length & width of smallest rectangle surrounding the entire part.
  - **Part-off die:** L is distance across strip while W is width of zone removed from between adjacent parts.
  - **Cut-off die:** L and W are dimensions of a rectangle surrounding end contour of part.
- for either cut-off or part-off, min punch width W of about 6 mm should be allowed to ensure sufficient punch strength.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

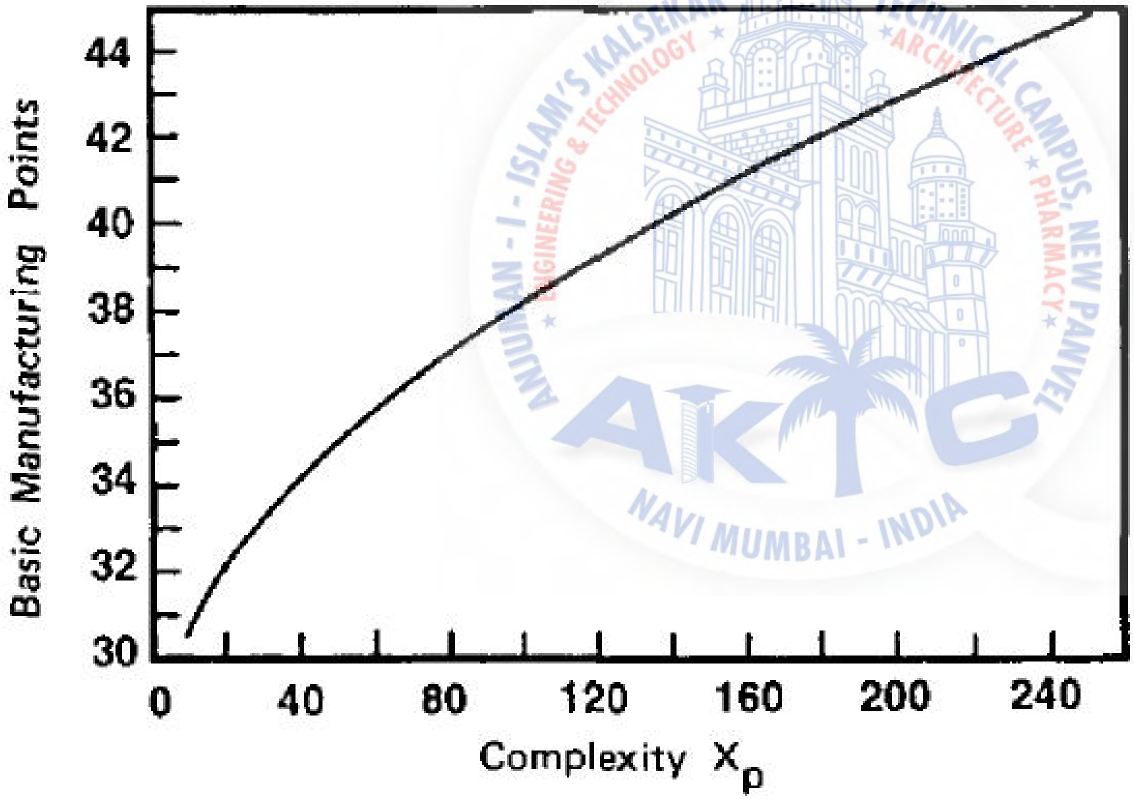


FIG. 9.9 Basic manufacturing points for blanking die.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

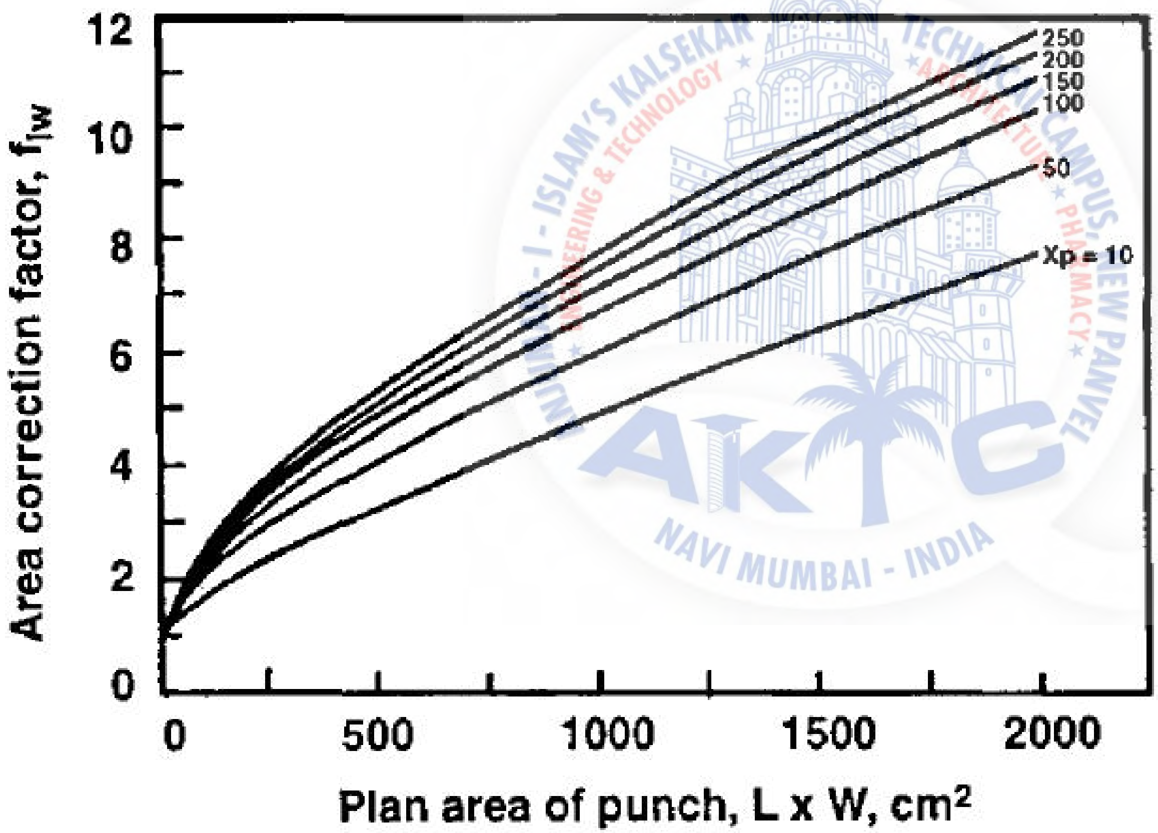


FIG. 9.10 Area correction factor.

- Basic point score is multiplied by a correction factor for the plan area of punch

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- Basic manufacturing points:
  - Part-off die: 9% less than for blanking
  - Cut-off die: 12% less than for blanking
- For die mfg, where CNC wire EDM is used to cut the necessary profiles in:
  - die blocks
  - punch blocks
  - punch holder plates
  - stripper plates
  - each mfg point in Fig. 9.9 corresponds to one equivalent hour of die making.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- This includes time for cutting, squaring, & grinding required tool steel blocks & plates.
- Estimated point score from Figs. 9.9 & 9.10 does not include effect of:
  - thicker-gage sheet metal
  - higher-strength sheet metal
  - very large production volumes of parts

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- Recommendations on die plate thickness h_d fit quite well with the relationship

$$h_d = 9 + 2.5 \times \log_e(U/U_{ms})Vh^2 \text{ mm} \qquad (9.3)$$

  - U = ultimate tensile stress of sheared sheet metal
  - U_{ms} = ultimate tensile stress of annealed mild steel
  - V = required production volume, thousands
  - h = sheet metal thickness, mm
  - value of h_d is usually rounded to nearest one eighth of an inch to correspond with standard tool steel stock sizes.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

- Mfg points in Fig. 9.9 were determined for the condition

$$(U/U_{ms})Vh^2 = 625 \tag{9.4}$$

- Or h_d = 25 mm
- cost of dies changes with die plate thickness according to a thickness factor f_d:

$$f_d = 0.5 + 0.02h_d \tag{9.5}$$

- Or f_d = 0.75 Whichever is the larger.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Mfg points M_p for a blanking die:

$$M_p = f_d f_{1w} M_{po} \tag{9.6}$$

- M_{po} = basic mfg points (Fig. 9.9)
- f_{1w} = plan area correction factor (Fig. 9.10)
- f_d = die plate thickness correction factor (Eq. 9.5)

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- A sheet metal blank 200mm long by 150mm wide, plain semicircular ends with radius 75 mm.
- 500,000 parts, 16 gage low carbon steel.
- Estimate cost of a blanking die to produce part and % of manufactured scrap.

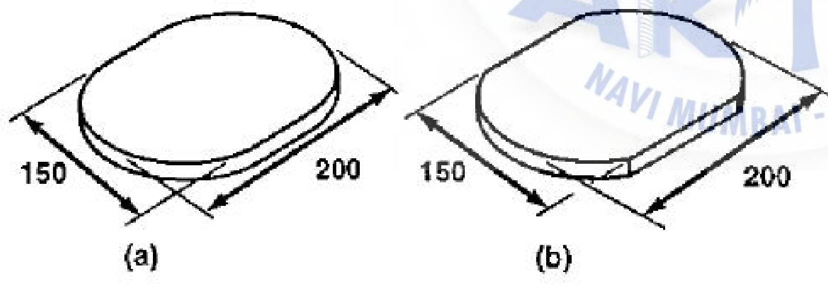


FIG. 9.11 Sheet metal part (dimensions in mm). (a) Blanking design. (b) Part-off design.

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- Required blank area =200 x150 mm².
- 50mm space is allowed around part for securing of die plate & installation of strip guides
- Required die set usable area A_u is

  $A_u = (20 + 2 \times 5) \times (15 + 2 \times 5) = 750\ cm^2$
- Eq 9.1: cost of die set

  $C_{ds} = 120 + (0.36 \times 750) = \$390$

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- Perimeter of Required blanking punch, P = 571 mm
- L, W = 150 and 200 mm
- Perimeter complexity index $X_p = 571^2/(150 \times 200) = 10.9$
- Basic mfg point score (Fig. 9.9), $M_{po} = 30.5$
- plan area LW = 300 cm^2
- correction factor (Fig. 9.10) = 2.5

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- For 500,000 parts of thickness 1.52mm , die plate thickness (Eq 9.3) h_d = 26.6 mm
- Die plate thickness correction factor (Eq. 9.5) f_d =1.03
- Total die mfg points M_p =1.03x2.5x30.5=78.5 hour
- $40/h for die making
- Blanking die cost = 390+78.5x40 = $3530

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- Area of each part A_p = 251.7 cm²
- Separation between each part on strip and between part and strip edges should be 3.04mm (twice material thickness),
- area of sheet used for each part, As =(200+3.04) x (150 +2 x 3.04) mm² = 316.9 cm²
- Scrap % = (316.9 - 251.7)/316.9 x 100 = 20.6

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- If part were redesigned with 80mm radius ends (Fig. 9.11b), it could then be produced with a part-off die. What would be die cost and % of mfg scrap for this case?
- perimeter to be sheared = length of two 80 mm arcs = $P = 388.9$mm
- With 3.04mm separating parts end to end on strip: L, W of part-off punch =106.5 and 150mm

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- Complexity index X_p = 388.92/(106.5 x 150) = 9.5
- part plan area = 300 cm², mfg points are the same as for blanking die.
- part-off dies are 9% less expensive than blanking dies for same C_{px} value, and values of f_d and f_{1w} are unchanged, total die mfg hours are
- M = 0.91 x 1.03 x 2.5 x 30.5 = 71.4
- $40/h for die making
- Part-off die cost = 390 + 71.4 x 40 = $3,250

9.2 DEDICATED DIES AND PRESS WORKING – Cost of Individual Dies

Example

- Area of each part = 257.9 cm^2
- edges of strip correspond to edges of part
- area of sheet used for each part A_s = (200 + 3.04) x 150 mm^2 = 304.6 cm^2
- Scrap % = (304.6 – 257.9)/304.6 x 100 = 15.3

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations

- **A piercing die:** same as blanking die except that material is sheared by punching action to produce internal holes or cut-outs in the blank.
- **Piercing dies:** several punches
- Individual punch areas have only a minor effect on final die cost.
- **Main cost drivers:**
  1. number of punches
  2. size of part
  3. perimeter length of cutting edges of any nonstandard punches.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations

- **Nonstandard punch:** cross-sectional shape other than circular, square, rectangular, or obround
- **Mfg point score:** three main components

1. Based only on area of part to be pierced, base manufacturing score is:

$$M_{po} = 23 + 0.03LW \text{ h} \qquad (9.7)$$

  - L, W = length & width of rectangle enclosing all holes to be punched, cm

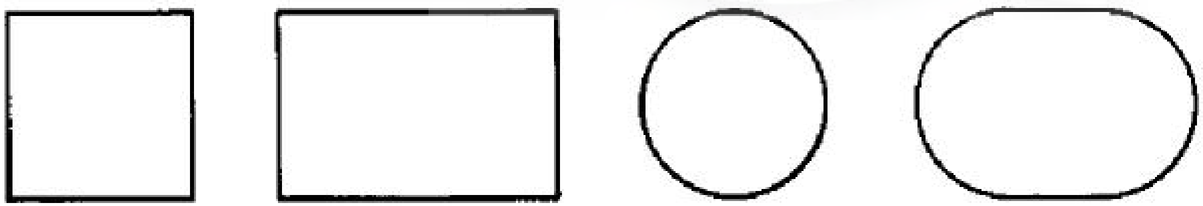


FIG. 9.12 Standard punch shapes.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations

- Eq 9.7 predicts number of hours to mfg:
  1. basic die block
  2. punch retaining plate
  3. stripper plate
  4. die backing plate
- This must be added to time to mfg punches and to produce corresponding apertures in die block.
- This time depends upon:
  1. number of required punches
  2. total perimeter of punches

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations

2. Mfg time M_{pc} for custom punches

$$M_{pc} = 8 + 0.6P_p + 3N_p \text{ h} \tag{9.8}$$

- P_p = total perimeter of all punches, cm
- N_p = number of punches
- **Eq 9.8:** estimates time to mfg nonstandard punches & for cutting corresponding die apertures

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations

3. Standard punch shapes (Fig. 9.12):

- Mfg hours, Mps for standard punches and die inserts, and for time to cut appropriate holes in punch retaining plate and

$$M_{ps} = KN_p + 0.4N_d\, h \qquad (9.9)$$

- K = 1 for round holes
- K = 3.5 for square, rectangular, or obround holes
- N_p = number of punches
- N_d = number of different punch shapes and sizes

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations - Example

- Determine cost of piercing die to punch three holes.
- Rectangle that surrounds the three holes has dimensions 120 x 90 mm
- nonstandard "C" shaped hole has a perimeter length equal to 260mm.

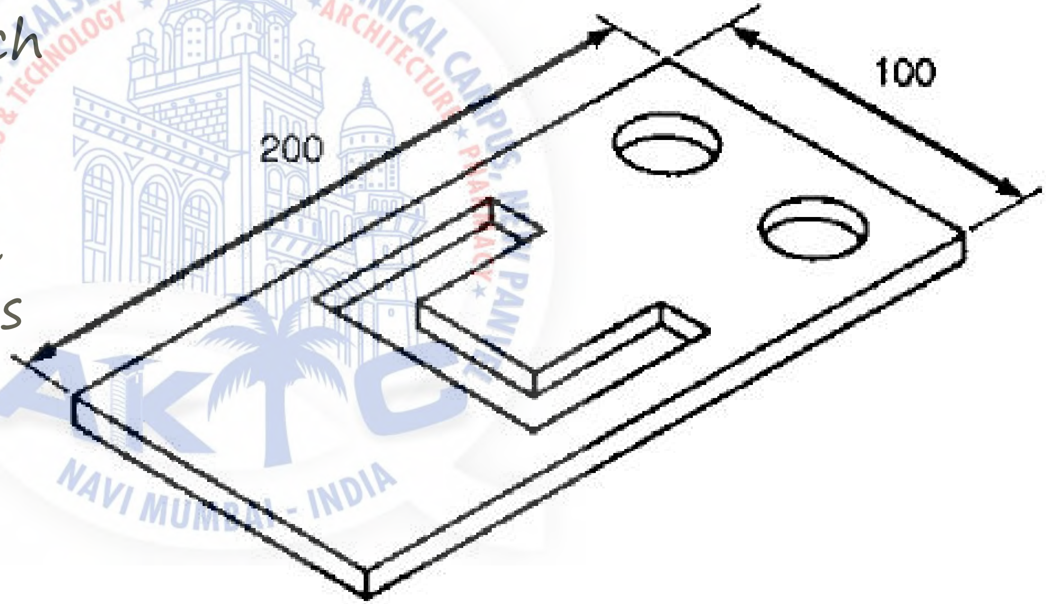


FIG. 9.13 Part design with three punched holes.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Piercing Operations - Example

- Base mfg score (Eq. 9.7) = M_{po} = 23 + 0.03(12 x 9) = 26 h
- Number of hours required to mfg custom punching elements for nonstandard aperture (Eq 9.8)

  M_{pc} = 8 + 0.6 x 26 + 3 = 26.6 h
- Equivalent mfg time for punches, die plate inserts, etc., for the two "standard" circular holes (Eq 9.9)

  M_{ps} = 2 x 2 + 0.4 x 1 = 4.4 h
- 50 mm space is allowed around part in die set
- required plate area = Au = (20+2 x 5) x (10+2 x 5) = 600 cm^2
- die set cost = $336
- Estimated piercing die cost, assuming $40/h for die making = 336 + (26 + 26.6 + 4.4) x 40 = $2,616

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

Bends are typically produced by one of two die-forming methods:

1. **V-die and punch combination (Fig. 9.14a)**
   - *Least expensive type of bending die*
   - *difficulty of precisely positioning metal blank and a resulting lack of precision in bent part*
2. **Wiper die (Fig. 9.14b)**
   - *Greater control of bend location on part*

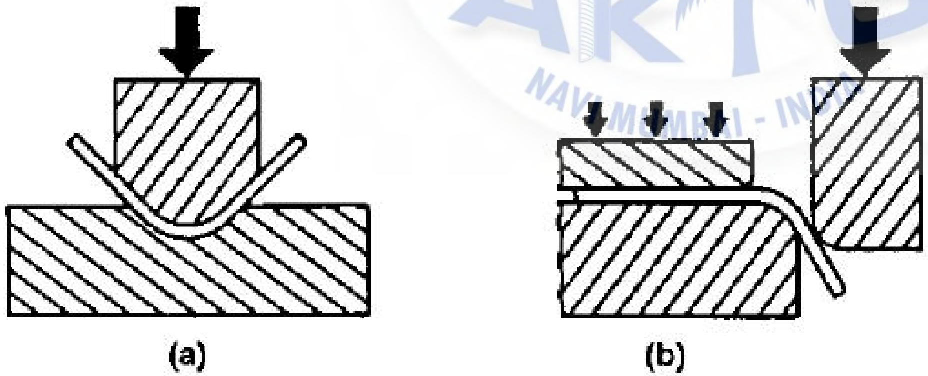


FIG. 9.14 Basic bending tools (a) v-die. (b) Wiper die.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

- U-die (double-wiper die)
- Z-die (double v-die)

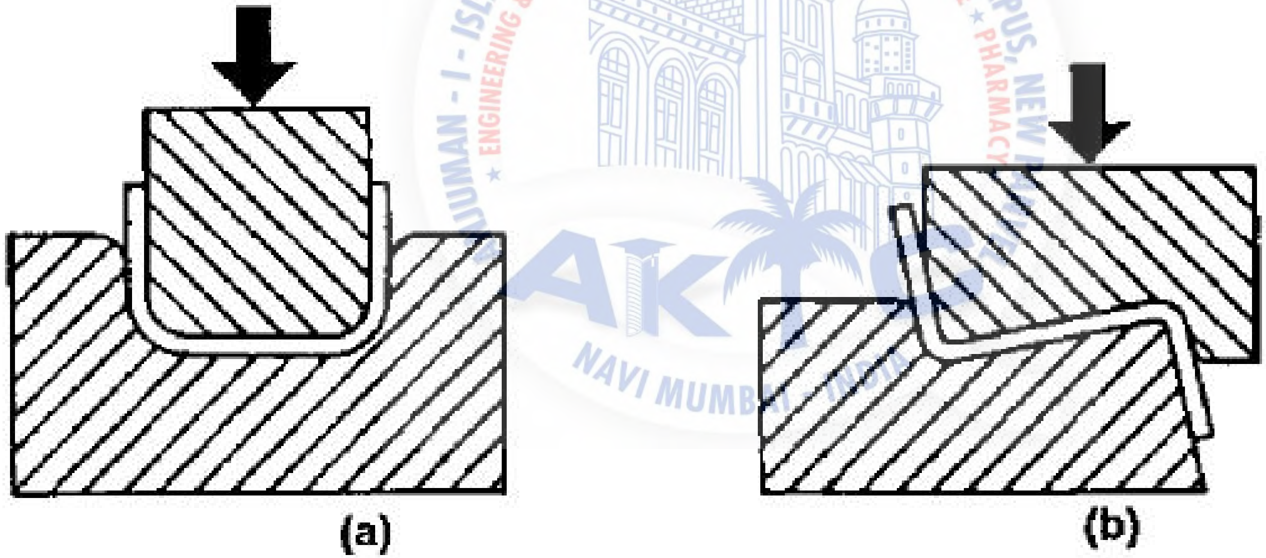


FIG. 9.15 Basic methods of producing multiple bends. (a) u-die. (b) z-die.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

part shown can be formed in a single die.

- a z-die first forms front step.
- Lower die block then proceeds to move downward against spring pressure so that stationary wiper blocks adjacent to the three other sides displace the material upward.

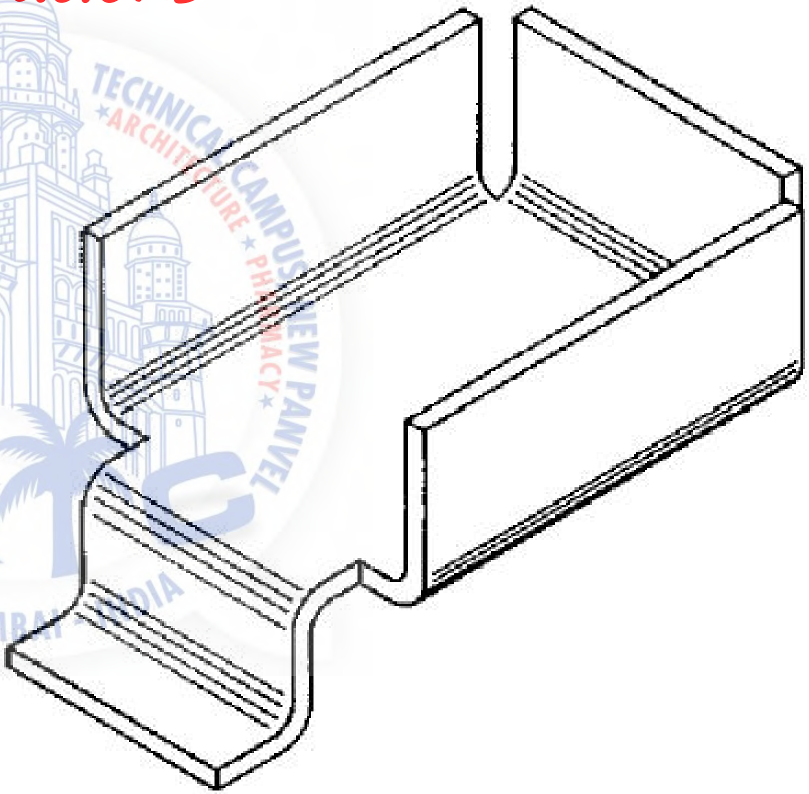


FIG. 9.16 Multiple bends produced in one die.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

In order to determine number of separate bending dies required for a particular part, apply the following rules:

1. Bends that lie in the same plane, such as the four bends surrounding the central area in Fig. 9.16, can usually be produced in one die.
2. Secondary reverse bends in displaced metal, such as lower step in Fig. 9.16, can often be produced in the same die using a z-die action.
3. Secondary bends in displaced metal that would lead to a die-locked condition will usually be produced in a separate die.

9.2 DEDICATED DIES AND PRESS WORKING – Individual

Dies for Bending Operations

- Bends a, c, and d or bends a, b, and d could be formed in one die by a combination of a wiper die and a z-die.
- Remaining bend would then require a 2nd wiper die and a separate press operation.
- Bend b could be produced in the 2nd die using a tooling arrangement (Fig. 9.18).

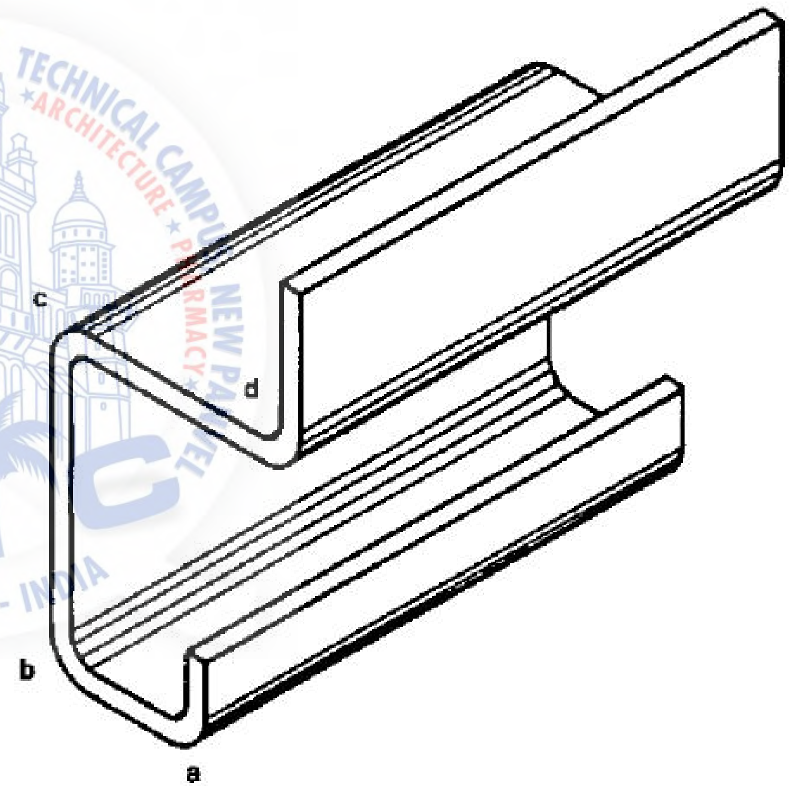


FIG. 9.17 Part design requiring two bending dies.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

- Bend b could be produced in the 2nd die using a tooling arrangement (Fig. 9.18).

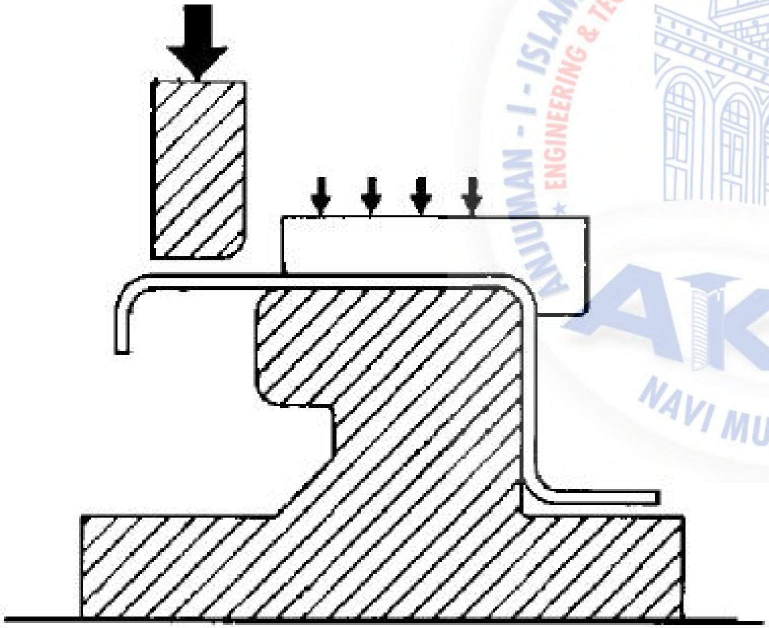


FIG. 9.18 Wiper-die arrangement to produce bend b in Fig. 9.17.

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

Cost of bending dies:

- A point score related to tool mfg hours.
- Based on area of flat part to be bent and final depth of bent part, the base die mfg score for bending is:

$$M_{po} = (18 + 0.023LW) \times (0.9 + 0.02D) \quad (9.10)$$

- L,W = length & width of rectangle surrounding part, cm
- D = final depth of bent part, cm, or 5.0, whichever is larger

9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

- Additional number of points are added for length of bend lines to be formed and for number of separate bends to be formed simultaneously:

$$M_{pn} = 0.68L_b + 5.8N_b \tag{9.11}$$

- L_b = total length of bend lines, cm
- N_b = number of different bends to be formed in die

- Cost of a die set must be added according to Eq. 9.1

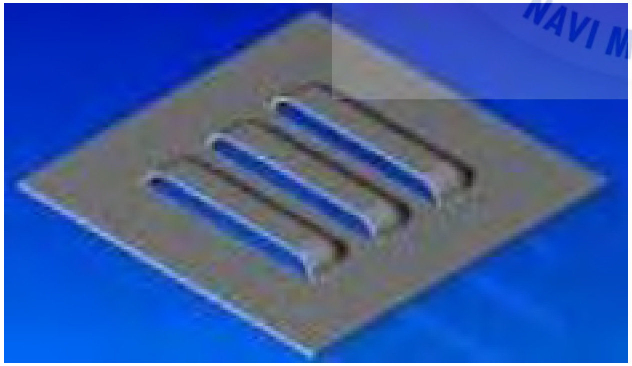
9.2 DEDICATED DIES AND PRESS WORKING – Individual Dies for Bending Operations

Example

- Fig. 9.16: Part is produced from a flat blank 44cm long by 24cm wide.
- Five bends
- Total length of bend lines = 76 cm
- Height of formed part from top edge of box to bottom of step = 12cm
- Eq. 9.10: M_{po} = [18+0.023x(44 x 24)]x(0.88+0.02 x 12) =42.3x1.12 = 47.4h
- Additional points for bend length & multiple bends:
  M_{pn} = 0.68 x 76 + 5.8 x 5 = 80.7 h
- 5.0 cm clearance around part in die set, then cost of die set is estimated from Eq. 9.1
  C_{ds} = 120 + 0.36 x (54 x 34) = $780
- $40/h for tool making
- cost of bending die: C_d = 780 + (47.4 + 80.7) x 40 = $5900

9.2 DEDICATED DIES AND PRESS WORKING – Miscellaneous Features

- **A lance:** cut in sheet metal part that is required for an internal forming operation.
- Cutting edges of punch are pressed only partway through the material thickness, sufficient to produce the required shear fracture.



9.2 DEDICATED DIES AND PRESS WORKING – Miscellaneous Features

- **Depressions:** localized shallow-formed regions produced by pressing sheet downward into a depression in the die plate with a matching profile punch.
- **Beads**: Patterns of long, narrow depressions onto the open surfaces of sheet metal parts in order to increase bending stiffness.
- In a depression sheet material reduces in thickness as a result of being stretched around the punch profile.

9.2 DEDICATED DIES AND PRESS WORKING – Miscellaneous Features

- Depression on left side of part (Fig. 9.19), assume material is stretched by around 15% in every direction.
- Because volume of metal stays constant after forming, thickness will have been reduced by nearly 30%.
- Embossed region on right side of part (Fig. 9.19) is reduced in thickness by direct compression between punch and die.

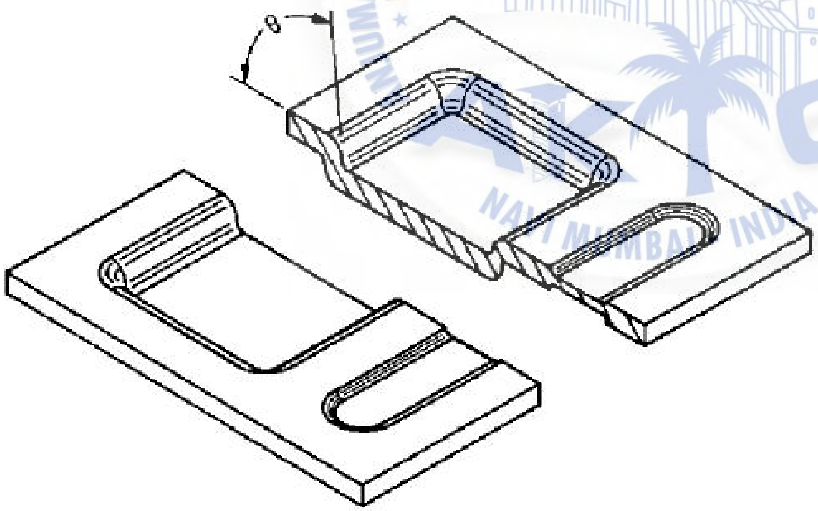
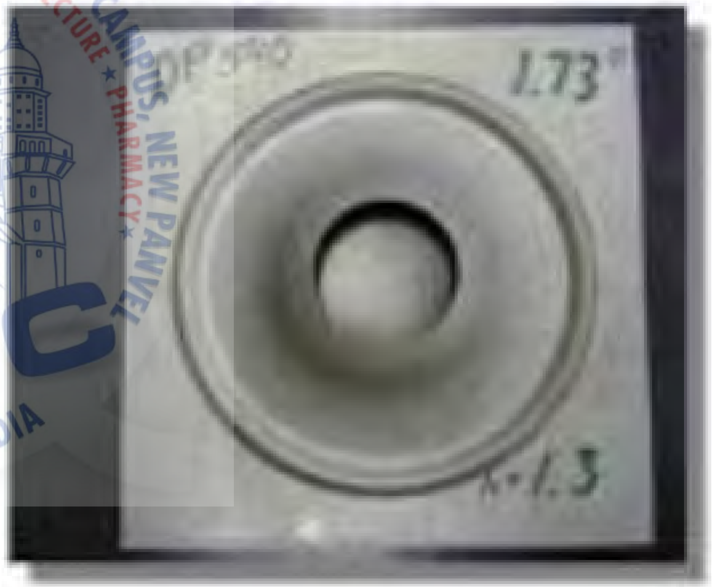


FIG. 9.19 Shallow formed and embossed regions of sheet metal part.

9.2 DEDICATED DIES AND PRESS WORKING – Miscellaneous Features

- **Hole flanges:** produced by pressing a taper or bullet-nosed cylindrical punch into a smaller punched hole.
- Material is stretched by entry of larger punch and displaced in direction of punch travel.
- **Due to ductility limitations:** flanged height = 2 to 3 *sheet metal thickness



9.2 DEDICATED DIES AND PRESS WORKING – Miscellaneous Features

- Cost of dies for these miscellaneous operations can be determined from equations for costs of piercing dies.
- Eq 9.7 : determine base cost of die plates, punch blocks, etc.
- Eq. 9.8: Additional cost of punch and die machining
- Parameter P_p = perimeter of forming or cutting punches
- Number M_{px} of additional hours of punch and die

$$M_{px} = 0.13 N_{sp}^{1.27} \text{ h} \quad (9.12)$$

- N_{sp} = total number of separate surface patches to be machined on punch faces and matching die surfaces

9.2 DEDICATED DIES AND PRESS WORKING – Progressive Dies

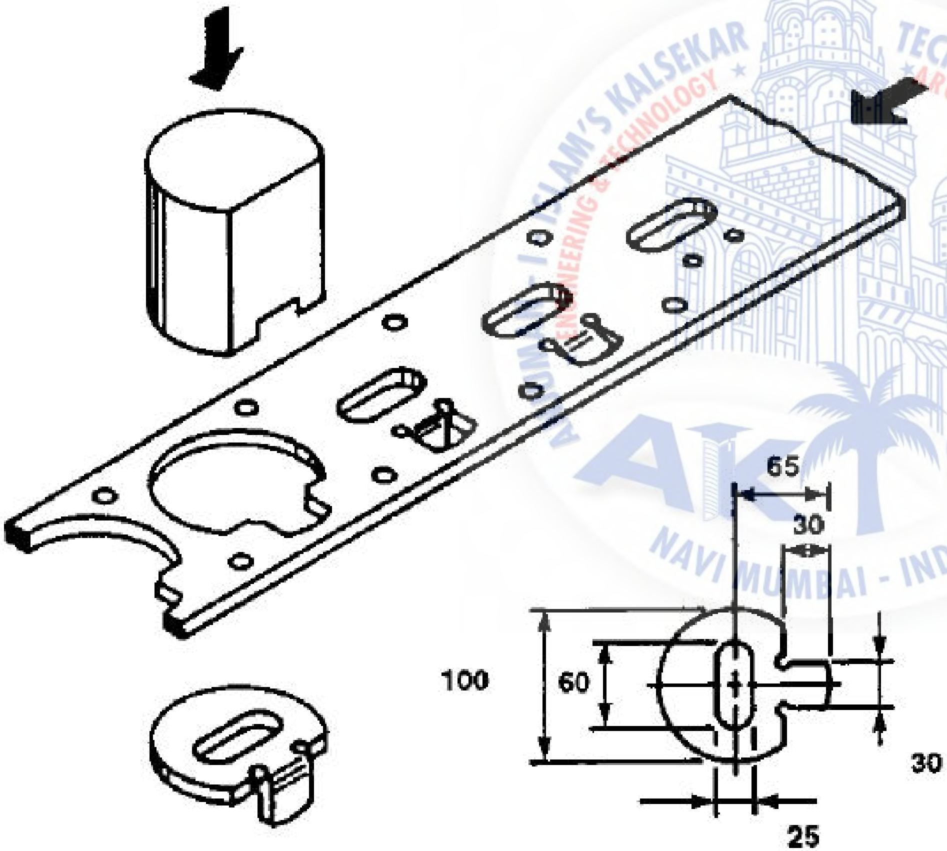


FIG. 9.20 Multistation die operation with strip feed.

- Multi-station die on a single press.
- Stations within die carry out different piercing, forming, & shearing operations as sheet metal is transported incrementally through die.

9.2 DEDICATED DIES AND PRESS WORKING – Progressive Dies

- **For complex-shaped parts, perimeter will usually be sheared in increments at different stations with only final parts of profile being sheared at last station.**
  - More uniform distribution of shearing forces among different stations, resulting in balanced loads on die.
  - Bending operations to be performed with wiper dies when portions of perimeter around bend have been removed.
- Two additional holes in strip (Fig. 9.20) are punched at 1st station & then engaged with taper-nosed punches at 2nd station.
  - more precise registration between stations so that part accuracy does not depend on accuracy of strip feeding mechanism.

9.2 DEDICATED DIES AND PRESS WORKING – Progressive Dies-Cost

$C_{pd} = 2C_{id}$ (9.13)

- C_{pd} = cost of single progressive die
- C_{id} = cost of individual dies for blanking, cut-off or part-off, piercing, and forming operations for the same part
- Factor of 2: moderate complex parts
- Factor of 3: very complex parts
- Factor of 1.5: very simple parts

9.3 PRESS SELECTION

TABLE 9.3 Mechanical Presses

Bed size: Width (cm)	Bed size: Depth (cm)	Press force (kN)	Operating cost ($/hr)	Maximum press stroke (cm)	Strokes (per min)
50	30	200	55	15	100
80	50	500	76	25	90
150	85	1750	105	36	35
180	120	3000	120	40	30
210	140	4500	130	46	15

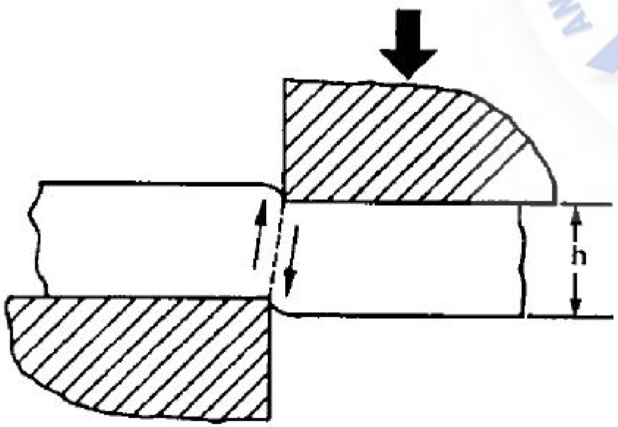


FIG. 9.21 Shearing operation.

- Required force f for: blanking, piercing, lancing, etc., is given by

$$f = 0.5 U h l_s \ kN$$

  - h = gage thickness, m
  - l_s = length to be sheared, m

9.3 PRESS SELECTION

Example: circular disks 50 cm in diameter are to be blanked from No. 6 gage commercial-quality, low-carbon steel.

- (Tables 9.1 & 9.2):
  - thickness of 6 gage steel = 5.08×10^{-3} m
  - ultimate tensile strength, $U = 330 \times 10^3$ kN/m²
- required blanking force $f = 0.5 \times (330 \times 10^3) \times (5.08 \times 10^{-3}) \times (\pi \times 50 \times 10^{-2}) =$ 1316.6kN
- **Table 9.3:** 1750kN press

9.3 PRESS SELECTION

Bending or shallow forming operations:

- required forces are usually much less than for shearing.
- **Fig. 9.22:** assume inside bend radius, $r = 2*h$

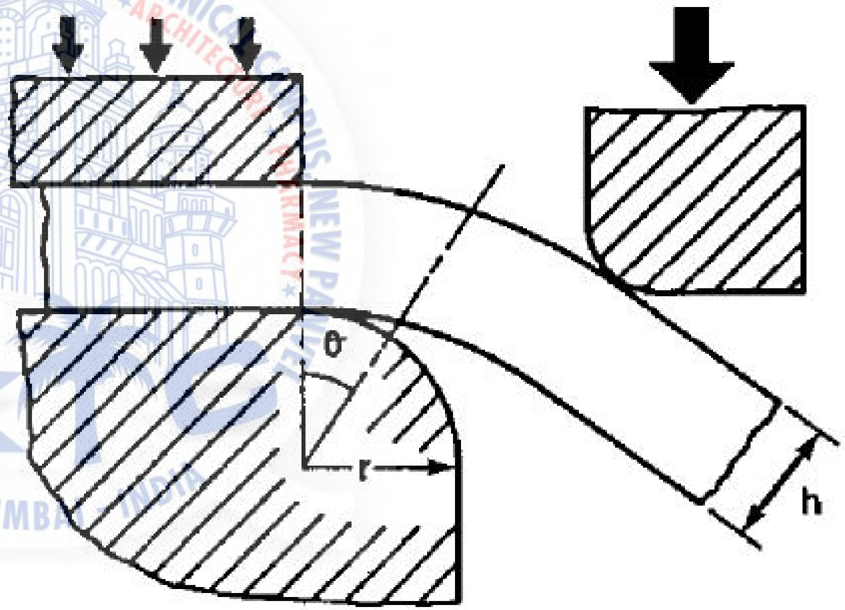


FIG. 9.22 Wiper die bending operation.

9.3 PRESS SELECTION

Under these conditions, as material is bent around die profile, through increasing angle θ:

- length of outer surface increases to $3h\theta$.
- length of centerline of material (neutral axis) remains nearly constant at $2.5h\theta$.
- strain in outer fibers of material is:

$$e = (3h\theta - 2.5h\theta)/2.5h\theta = 0.2 \qquad (9.15)$$

- strain decreases to zero from outer fibers to centerline, and then becomes compressive, increasing to nearly -0.2 on inside surface.

9.3 PRESS SELECTION

- average strain in bent material = 0.5e
- work done per unit volume on material as it forms around die = stress * strain
- assume that punch radius = 2 * thickness
- **90° bend:** punch moves down, while in contact with part, through a distance of ~5h.

$$V = \pi((3h)^2 - (2h)^2)L_b/4 = 5\pi h^2 L_b/4 \qquad (9.16)$$

- L_b = bend length

9.3 PRESS SELECTION

- energy balance:

$$0.5e \times U \times 5\pi h^2 L_b/4 = f \times 5h \quad (9.17)$$

- f = average press force that moves through distance 5h

$$f = 0.08 U h L_b \ kN \quad (9.18)$$

- Eary and Reed [4] give an empirical relationship for wiper die bending as

$$f = 0.333 U L_b h^2/(r_1 + r_2) \ kN \quad (9.19)$$

  - r_1 = profile radius of punch
  - r_2 = profile radius of die

9.3 PRESS SELECTION

Shallow forming (Fig. 9.19): vertical resisting force from walls is

$$f = Uh \sin \theta L \, kN \quad (9.20)$$

- L = perimeter of depression.
- for a depression with vertical walls (θ = 90°) required punch force can approach twice force required to shear material around perimeter.

9.3 PRESS SELECTION

Fig. 9.19: required force for an embossing operation is

$$f = \phi U A \, kN \qquad (9.21)$$

- A = area to be embossed
- Φ = constraint factor > 1
- As size of embossed region increases, factor Φ increases exponentially.

9.3 PRESS SELECTION

Cycle Times

Ostwald, time to:

1. load a blank or part into a mechanical press,
2. operate the press, and
3. remove part following the press operation

- is proportional to perimeter of rectangle enclosing part:

$$t = 3.8 + 0.11(L + W)\ \mathrm{s} \qquad (9.22)$$

- L, W = rectangular envelope length & width, cm
- **Apply 2/3 of time given by Eq 9.22 for shearing or piercing of flat parts (automatic press ejection)**

9.3 PRESS SELECTION

Cycle Times – Example

Fig. 9.20: compare cycle times and processing costs for using individual dies to those for progressive die working. Part is made from No. 8 gage stainless steel.

- Ultimate tensile stress = 515MN/m^2
- Outer perimeter of part = 370 mm
- thickness = 4.17mm
- Eq 9.14: required shear force for blanking outer perimeter, $f_1 = 0.5 \times (515 \times 10^3) \times (4.17 \times 370 \times 10^{-6}) = 397kN$
- For piercing obround cutout with perimeter 149mm, required force, f_2 = 160 kN

9.3 PRESS SELECTION

Cycle Times – Example

- Force required for bending tab across ~25 mm bend line, with assumed 6mm tool profile radii, is given from Eq. (9.19) as

  $f_3 = 0.333 x 515 x 10^3 x (25 x 10^{-3}) x (4.172 x 10^{-6} / ((6+6) x 10^{-3}) = 6.2 kN$

- Table 9.3: blanking operation would require 500 kN press, and piercing and bending operations could be carried out on the smallest 200 kN press.

9.3 PRESS SELECTION

Cycle Times – Example

Individual Dies

- For blanking and piercing operations: assume automatic ejection of blanks and scrap.
- cycle time for these two operations will be 2/3 of time for loading and unloading given by Eq. (9.22):

  $t_1 = 0.67 \times (3.8 + 0.11(10 + 11.5)) = 0.67 \times 5.4 = 3.6s$
- For bending operation, part unloading is required:

  $t_2 = 5.4\ s$
- Table 9.3: press hourly rates
- processing cost per part, $C_p = [(3.6/3600)x76 + (3.6/3600)x55 + (5.4/3600) \times 55] \times 100$ cents = 21.4 cents

9.3 PRESS SELECTION

Cycle Times – Example

Progressive Die

- required press force, $f = f_1 + f_2 + f_3 = 563$ kN
- space required for four die stations = 4 x 100 + 3(2 x 4.17) = 418.5 mm
- Table 9.3: press has:
  - press force = 1750 kN
  - operating cost =105 $/h
  - press speed = 35 strokes/min
- estimated cycle time per part = $t = 60/35 = 1.7s$
- processing cost per part, $C_p = (1.7/3600) \times 105 \times 100 = 5.0$ cents

9.6 DESIGN RULES

- For parts that are to be manufactured with dedicated dies, design outer profile with parallel straight edges defining part width.
- To allow for satisfactory shearing in cut-off or part-off operations, end profiles should meet straight edges at angles no less than 15°.

9.6 DESIGN RULES

- No narrow projections or notches that will require narrow weak sections in either punches or die plates (dimensions marked "a" in Fig. 9.27)

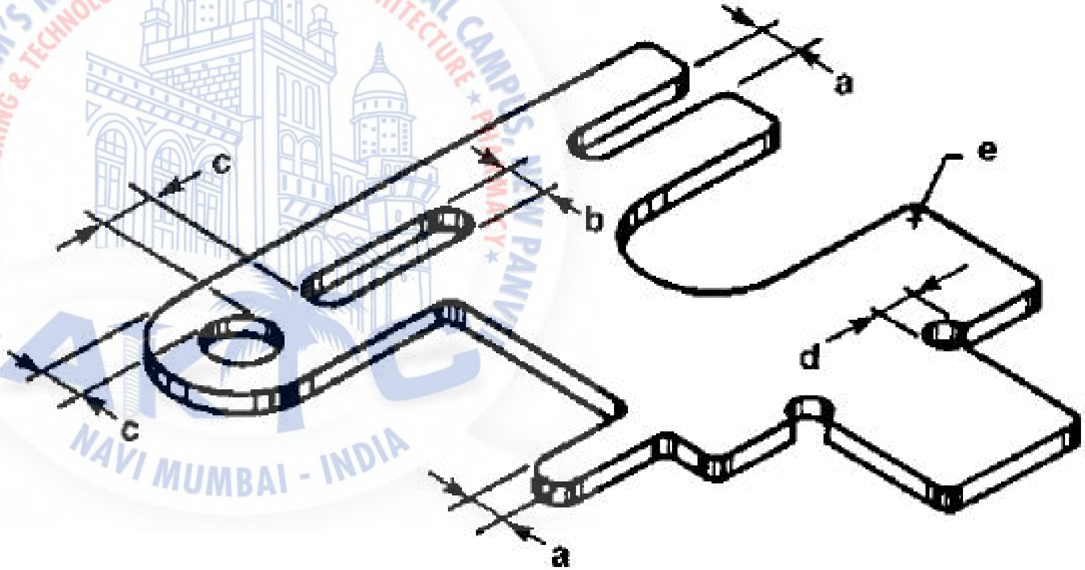


FIG. 9.27 Critical dimensions in the design of a sheet metal blank.

9.6 DESIGN RULES

- Avoid Small holes or narrow cut-outs that will require fragile punches.
- Internal punched holes should be separated from each other, and from outside edge, with sufficient clearance to avoid distortion of narrow sections of work-piece material during punching.

9.6 DESIGN RULES

- Both feature dimensions and feature spacings should be at least twice material thickness.
- Fig. 9.27, satisfactory blanking and punching will require that dimensions labeled "a" through "d" should all be greater than or equal to twice gage thickness.

9.6 DESIGN RULES

- "e", corner radii in die plate: Radii equal to at least twice gage thickness will minimize corner stress concentrations in die plate, which may lead to crack formation and failure.

9.6 DESIGN RULES

- Incorporate relief cut-outs dimensioned as "d," at ends of proposed bend lines that terminate at internal corners in outer profile.
- If for any reason holes that intersect outer profile must be punched later, then diameter should be **at least three times gage thickness** to accommodate offset loading to which punch will be subjected.

9.6 DESIGN RULES

- When formed features are being considered, principal design constraint is max tensile strain the material can withstand (Table 9.2).
- Fig. 9.28:
  - component made from low-carbon, commercial-quality steel
  - Transition from surface to top of bridge = 45°.

9.6 DESIGN RULES

$$\text{Bridge length} = L - 2H/\tan(45) + 2H/\sin(45) = L + 0.82H \qquad (9.28)$$

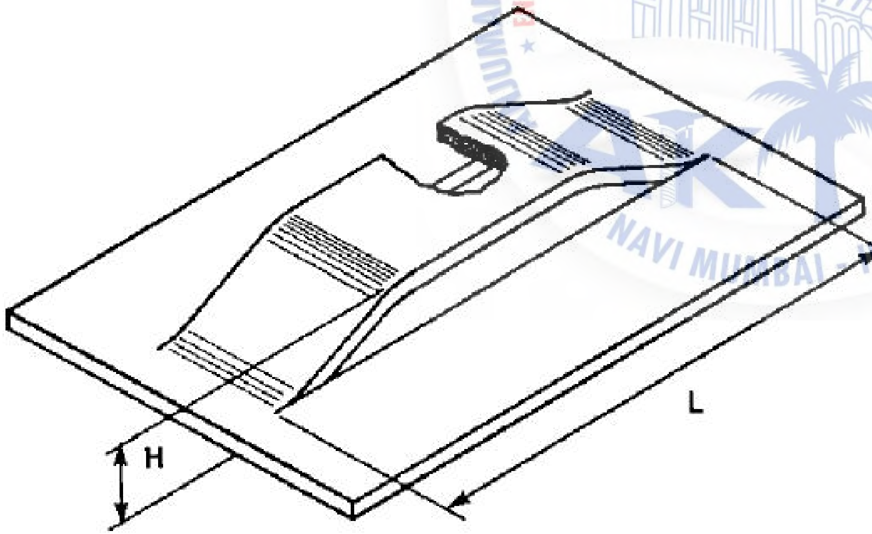


FIG. 9.28 Lanced and formed bridge.

9.6 DESIGN RULES

- Assuming uniform stretching of bridge, tensile strain along bridge is

$$e = 0.82H/L \tag{9.29}$$

- If max permissible strain in tension is 0.22 (Table 9.2), then from Eq. (9.29) successful forming will be assured if

$$L > 3.7H \tag{9.30}$$

- Length of bridges > 4 times height
- For different materials or varying geometries, tensile strains must be estimated & compared to permissible max value.

9.6 DESIGN RULES

Louver (Figure 9.29):

- Length of front edge must be greater than a certain multiple of louver opening height *H*, determined by material ductility and end ramp angles exactly as in the bridge calculation.

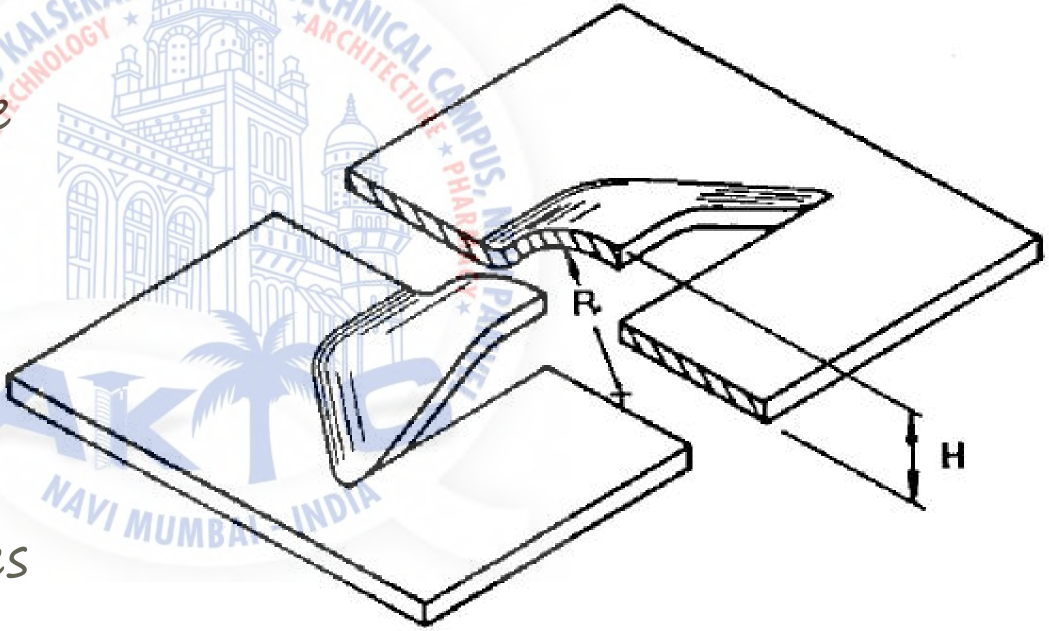


FIG. 9.29 Lanced and formed louver.

9.6 DESIGN RULES

- Stretching also occurs at right angles to louver edge where material is stretched upward into a circular arc.
- This will not cause material failure, since front edge of louver will be pulled backward as tensile stress develops in the surface.
- Choice of radius R (Fig. 9.29) is more one of appearance and amount of space taken up by a single louver.

9.6 DESIGN RULES

Hole flange (Figure 9.30)

- Hole flanging: provide increased local thickness for tapping of screw threads
- Hole flange is formed by pressing a taper-nosed punch of diameter D into a smaller punched hole of diameter d.
- Tensile strain around top edge of formed flange is

$$e = (D - d)/D \tag{9.31}$$

9.6 DESIGN RULES

Hole flange (Figure 9.30)

- e < permissible material ductility
- Typical values of flange height in sheet steel components range between 2 and 3 times material gage thickness.

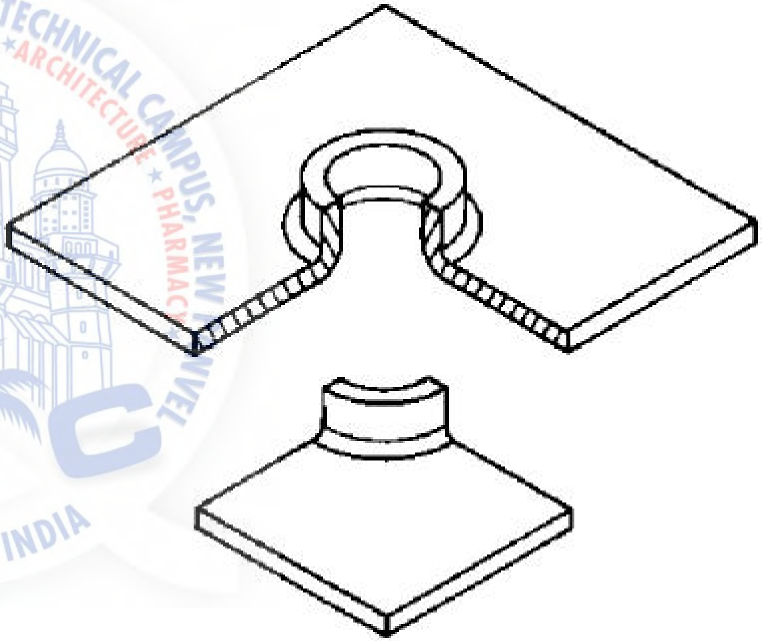


FIG. 9.30 Formed hole flange.

9.6 DESIGN RULES

Beads (Fig. 9.31)

- Ribs may be circular V-shaped.
- For a required height, H, width and shape of rib must be chosen so that required amount of stretching across rib does not exceed material ductility.

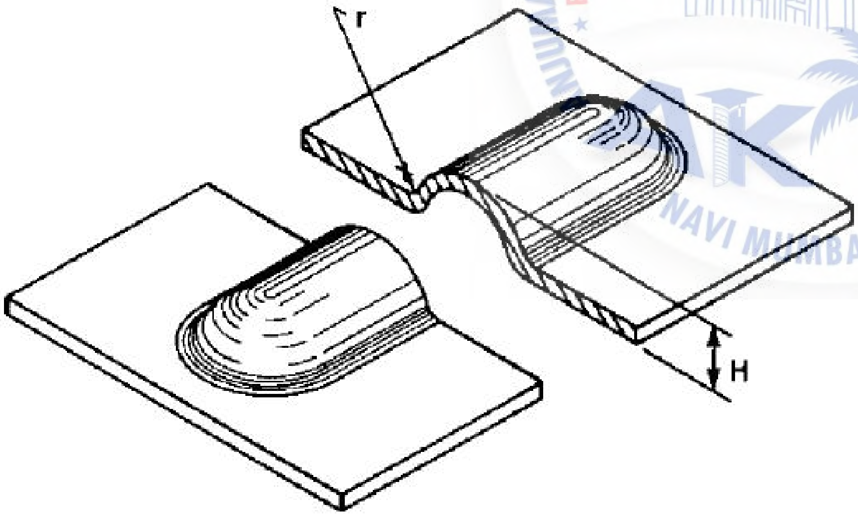


FIG. 9.31 Cross section of rib.

- Radius at base of rib must be greater than a certain value to prevent overstraining material on underside of part.

9.6 DESIGN RULES

Beads (Fig. 9.31)

- Max tensile strain in bending is in the outer fibers of the sheet on the outside of the bend and is governed by the ratio of inside bend radius, r, to sheet gage thickness, h.
- For a bend through any angle θ, length of outer surface is

$$L_s = (r + h)\theta \quad (9.32)$$

- length of surface in center of sheet (neutral axis) is

$$L_o = (r + h/2)\theta \quad (9.33)$$

- strain on outer surface is

$$e = (L_s - L_o)/L_o = 1/(1 + 2r/h) \quad (9.34)$$

- Radius r is defined precisely by profile radius of bending tool:
- convex radius of die block for a wiper die
- convex radius of punch in a v-die.

9.6 DESIGN RULES

Beads (Fig. 9.31)

- Min acceptable radius value can be obtained from Eq. (9.34) and ductility of material to be bent.
- Example: low-carbon, commercial-quality steel with ductility 0.22, Eq. (9.34) gives

$$e = 0.22 = 1/(1 + 2r/h)$$

or

$$r = 1.77h$$

- Inside bend radius ≥ twice sheet thickness (limiting value for a material with 20% ductility)

9.6 DESIGN RULES

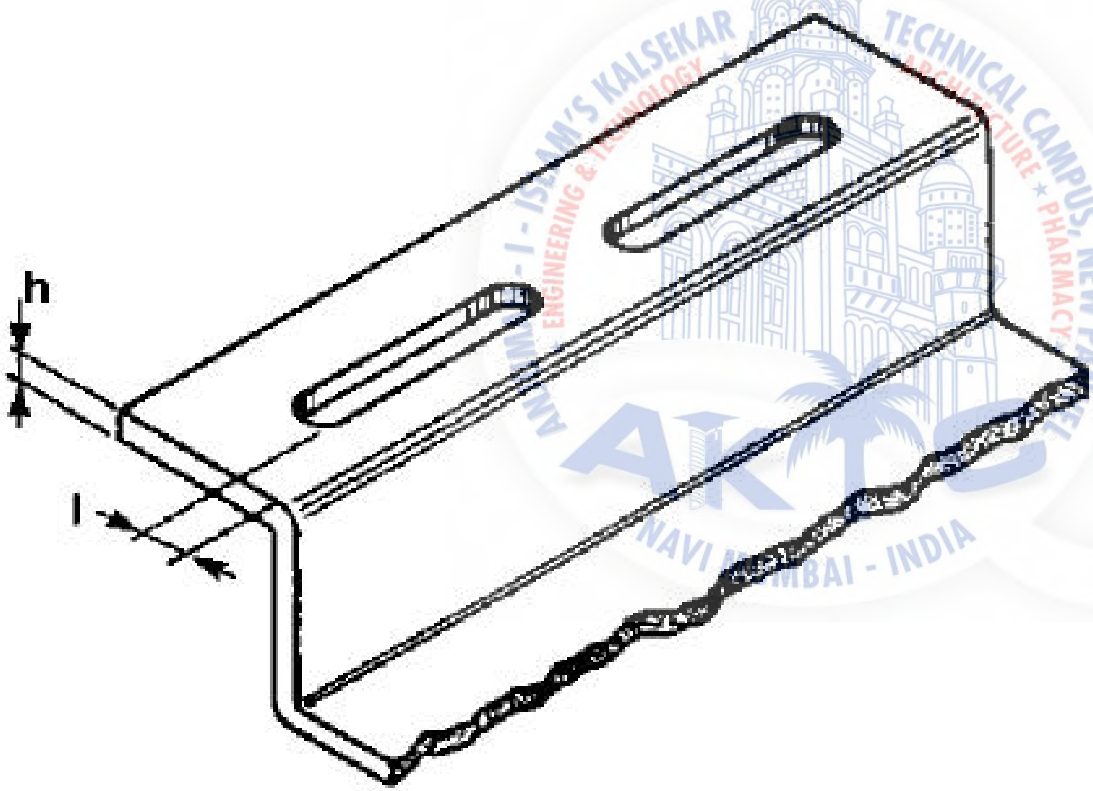


FIG. 9.32 Punched slots adjacent to a bend.

- **Fig. 9.32:** slots would almost certainly have to be punched after the bending operation.
- This is because small separation, l, of edges of slots from bend line would result in distortion of slots during bending if they were punched first.

9.6 DESIGN RULES

- If part contains other holes or slots that are now on nonparallel surfaces to the one shown, then two separate dies and operations are needed for punching where one would otherwise have been sufficient.
- Edge of circular holes should preferably be 2 times sheet thickness from beginning of a bend.
- For slots parallel to a bend this clearance should increase to 4 times sheet thickness.

9.6 DESIGN RULES

- Blanked parts or punched holes with max dimensions up to 10cm can be held to tolerances of around ±0.05 mm
- As part size increases, precision is more difficult to control
- For a part with dimensions as large as 50 cm permissible tolerances are in the range of ±0.5 mm.
- For formed parts, or formed features, variation tends to be larger and minimum tolerances attainable are in the range of ±0.25 mm for small parts.
- A tight tolerance between punched holes, which are on parallel surfaces separated by bends, would require holes to be punched after bending at greater expense.
- If holes are on nonparallel surfaces, then machining may be necessary to obtain required accuracy.

9.6 DESIGN RULES

Minimization of manufactured scrap

- nesting
- If individual dies are to be used, then part should be designed if possible for cut-off or part-off operations.
- Figure 9.33:
  - cut-off design lacks elegance of rounded end profiles.
  - acute sharp corner will be removed during debarring

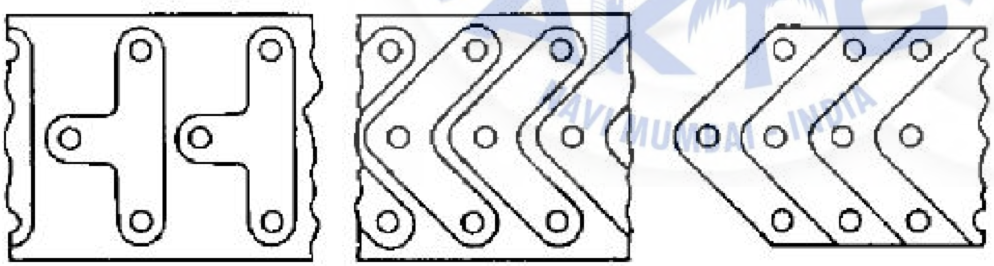


FIG. 9.33 Design changes of a three-hole bracket for minimization of manufactured scrap.