ME5005/ME4002 DESIGN FOR MANUFACTURE PRODUCTION ENGINEERING

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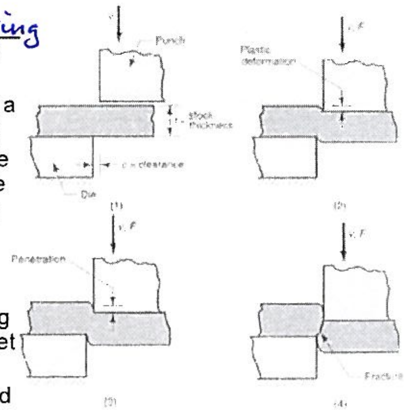
Lecture 15: Sheet Metal Working

Sheet metal working

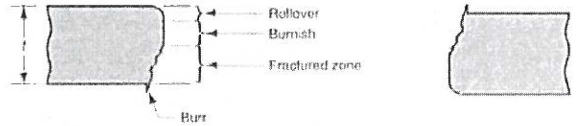
- Sheet metal working applies to thin sheets of material typically between about 0.4 mm and 6 mm thick
  - Sheets more than 6mm thick are referred to as plate
- Usually carried out as cold working
  - Increases strength of thin components
  - A warm process may be used if the material is brittle
- Sheet metal working may be subdivided into three different processes:
- *Cutting*:
  - Part of the sheet is separated or removed
- *Bending*:
  - Part of the sheet is plastically deformed
- *Drawing*:
  - Most of the material is plastically deformed
- Most sheet metal working is in steel, aluminium or brass

The shearing process

- Cutting occurs using a shearing action between two sharp edges
- The upper cutting edge (punch) sweeps down past a stationary cutting edge (die)
- *Plastic deformation* occurs as the punch pushes into the workpiece
- *Penetration* occurs as the punch compresses the workpiece and cuts into the metal producing a smooth surface
- *Fracture* occurs at the two cutting edges, the two fracture lines meet and the material separates
- Clearence between the die and punch is critical for a clean cut



Cut edges

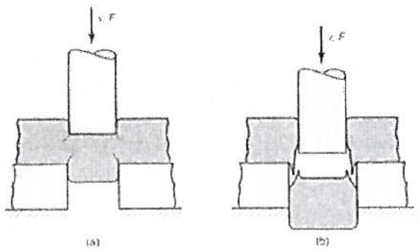


- The sheared edges of the sheet and component have four very distinctive surfaces:
  - Rollover
    - Surface depression made by punch before cutting occurs
  - Burnish
    - Smooth surface from penetration of the punch into the workpiece before fracture begins
  - Fracture Zone
    - Surface along the fracture lines through the material
  - Burr
    - A sharp corner on the edge caused by stretching and elongation of the metal during final separation
  - Sequence of surfaces is reversed on the other side of the cut

Effects of clearance

- Typical values of *clearance* c are between 4% and 8% of the sheet thickness t
- If the clearance is too small, the fracture lines pass each other
  - Double burnishing
  - Higher cutting force
- If the clearance is too Large material becomes pinched between the die and punch
  - Side wall fails by tensile tearing
  - Excessive burring
- The clearance may be found using:

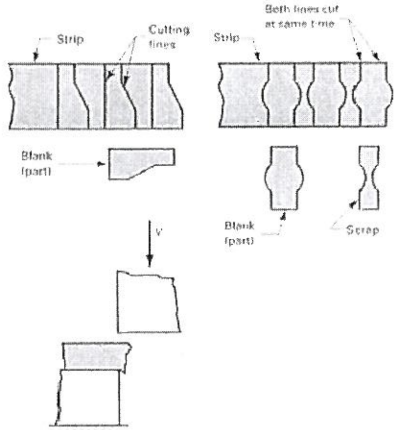
$$c = at$$



Metal Group	Allowance a
Soft Al alloys	0.045
Hard Al alloys; Brass; Soft steels	0.060
Hard steels	0.075

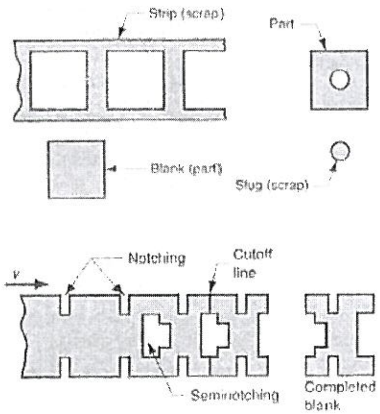
Open cutting operations

- Shearing :
  - Metal is cut along a straight line, basic cut
- Cutoff :
  - Shapes are fully nested (no waste)
  - Open cut (crosses the full width of the strip)
- Parting :
  - Partially nested shapes (some waste)
  - Open cut still used
- Shaving :
  - Precision post-cutting with small clearance ($0.01t$)



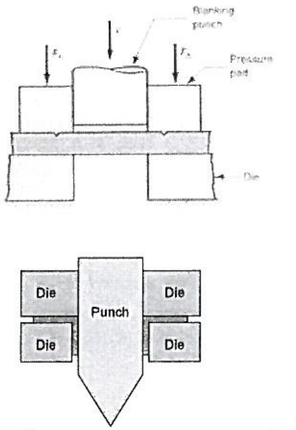
Closed cutting operations

- Blanking :
  - Cutting occurs on a closed contour
  - Removed shape is the required component
- Punching :
  - Identical to blanking but the remaining strip is the required component
- Notching :
  - Removed section is on the edge of the strip
- Semi-Notching :
  - Identical to punching but contour will be on the edge of the finished component



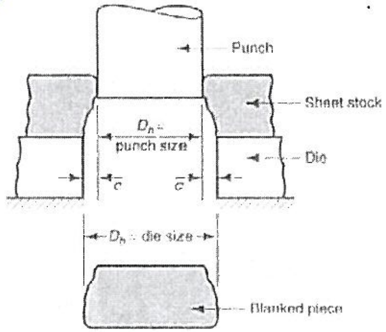
Other operations

- Fine blanking:
  - Used to produce close-tolerance blanks in a single cutting operation
  - A pressure pad with V-shaped projections holds the sheet in place with a holding force F_h
  - Sheet is compressed, prevents distortion at edges
  - Blanking punch velocity v is slower than for normal blanking
- Piercing :
  - Produces holes, but unlike punching a blank or slug is not produced
  - Sharp pointed punch used

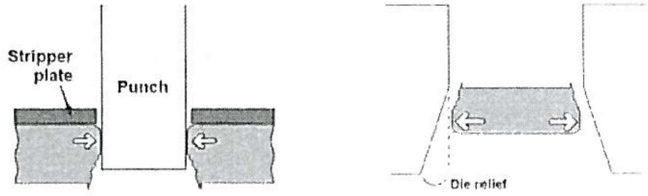


Die size and clearance

- The die opening must always be larger than the punch size
- Location of clearances determined by whether the piece removed is the desired part (blank) or scrap (slug)
- To produce a round *blank* of diameter D_b :
  - Punch size = $D_b - 2c$
  - Die size = D_b
- To produce a round *hole* of diameter D_h :
  - Punch size = D_h
  - Die size = $D_h + 2c$

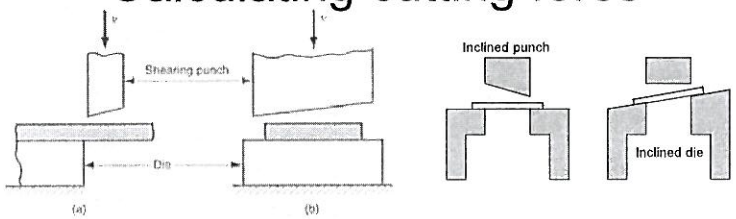


Die relief



- After plastic deformation and fracture, the material will elastically recover
- The hole in the strip will grip the punch
  - Stripper plate holds the sheet in place while punch is withdrawn
- The blank will expand in the die
- The die must be *tapered* to allow the blank or slug to drop out
- This angular clearance is known as *die relief*
  - Typically 0.25° to 1.5° all the way round

Calculating cutting force



- Maximum cutting force F_{max} can be estimated using either:

$$F_{max} = GtL$$

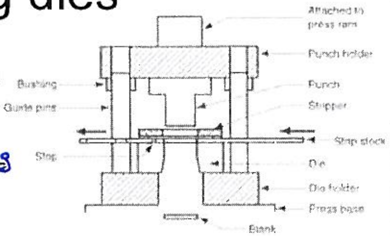
- Or if shear strength G is not known:

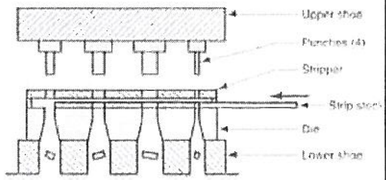
$$F_{max} = 0.7\sigma_{UTS}tL$$

- Clearence may be neglected when calculating length of cut, L
- Cutting force will be reduced if either of the blades are inclined
  - typically 4°-10°
- An inclined punch results in perfect holes and distorted *blanks*
- An inclined die results in distorted *holes* and perfect *blanks*

Cutting dies

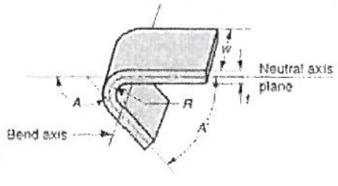
- *Drop-through die* is most common
  - Blanks simply fall through the die into a collector
- With large area blanks, a dishing defect often results where the blank is ~~tac~~warped
  - blank is unsupported during cutting
  - remedied using a *return-type die* in which a sprung-loaded block supports the blank from underneath
- Compound dies can perform several punching, blanking or cutting operations simultaneously
  - e.g.: washers

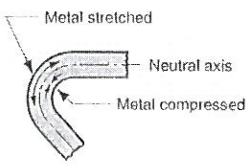




Bending

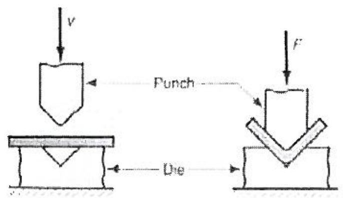
- Requires a significant distance between the shearing forces to produce a bending moment about a linear *bend* axis
- A *neutral plane* exists in the sheet where the tensile stresses on the top surface change to compressive stresses on the bottom
  - bending produces little or no change in the sheet thickness t
- Bend radius R is normally specified on the inside of the corner, rather than at the neutral plane
- The sheet is bent through the *bend angle, A* resulting in a a part with an included angle, $A' = A + 180°$

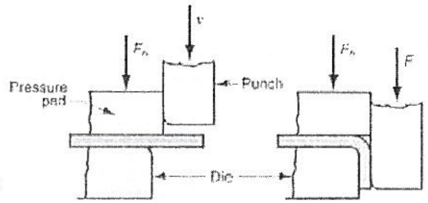




Bending operations

- Most common types are *V-bending* and *wiping*
- V-bending requires the lowest loads as the distance between the shearing forces is largest
  - Used for low volume production
- Wiping or *edge bending* is more expensive due to the additional complexity
  - More precise
  - Used for high volume production
- Both methods can produce a range of included angles A' from very obtuse to very acute





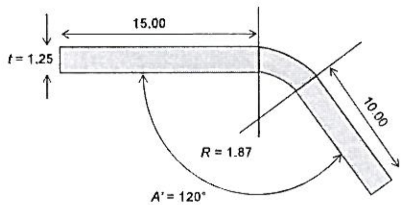
Bend allowance

- If R is small compared to t, the metal will stretch during bending
- This stretch must be estimated for each bend to predict the final component geometry
- The *bend allowance BA* may be found using:

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

where K_{ba} is a stretching factor:

If $R < 2t$, $K_{ba} = 0.33$
If $R \geq 2t$, $K_{ba} = 0.50$

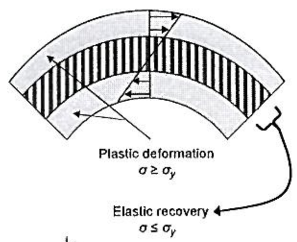


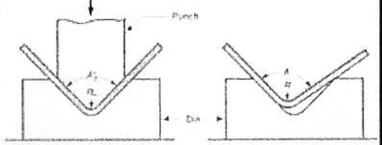
- To estimate the starting blank length for the above component (all in mm):
  $R/t = 1.87/1.25 = 1.5 < 2$
- so $K_{ba} = 0.33$:
  $A = 180° - A' = 60°$
  $BA = 2\pi 60/360(1.87 + 0.33x1.25)$
  $BA = 2.39mm$
- $L_0 = 15.00+10.00+2.39 = 27.39mm$

Springback

- The stresses in the sheet during bending vary from tensile on the top surface to compressive on the bottom surface
  - Plastic deformation
- Either side of the neutral axis, the stress will be below the elastic limit
- This region will elastically recover when the bending force is removed, resulting in *springback*
- Defined as the increase in the included angle of the bent part relative to the included angle of the forming tool:

$$SB = \frac{A' - A'_b}{A'_b}$$

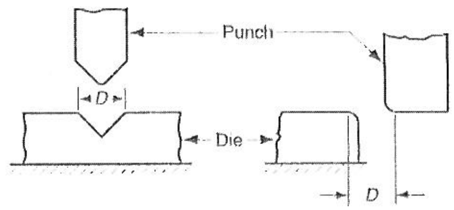




Compensating for springback

- Three common methods of springback compensation
  - Overbending:
    - Springback in the final component is estimated
    - The punch angle is made smaller than the specified angle so that the part elastically recovers into the desired shape
    - Empirical, inaccurate
  - Bottoming:
    - Sheet is squeezed locally at the bend
    - More of the material deforms plastically
    - Less material to elastically recover
    - Usually achieved with a small protuberance on the bend radius
  - Stretch forming:
    - A tensile force is applied to the sheet to increase stresses near the neutral plane and reduce the size of the elastically recoverable region

Bending force

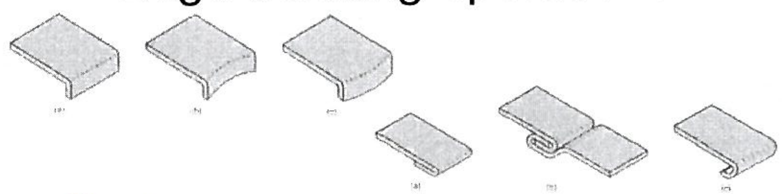


- The force required for bending depends on material properties and die dimensions:

$$F = \frac{K_{bf}\sigma_T w t^2}{D}$$

- The bending force constant K_{bf} is determined by the type of bending:
  - V-bending: $K_{bf}=1.33$
  - Wiping: $K_{bf}=0.33$

Edge bending operations

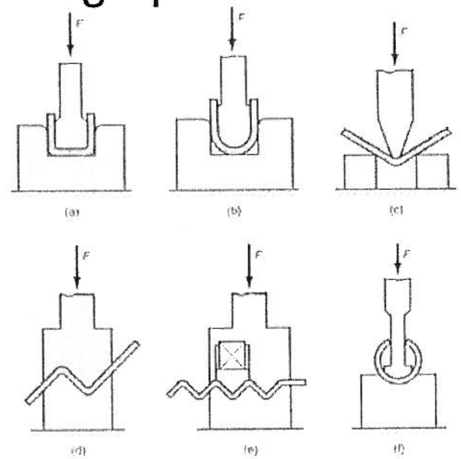


- Flanging is when the edge of a part is bent by 90° to form a rim
  - Strengthens or stiffens the part
  - Flange may be (a) straight, (b) stretched or (c) shrunk
- Hemming is where the sheet edge is folded over itself in more than one bending operation
  - Eliminates sharp edges, increases strength, improves appearance
- Seaming is where two hems are assembled together
- *Curling* or *beading* is where the edge is rolled rather than folded
  - Similar benefits as hemming
  - Also forms other components, e.g. hinges

Other bending operations

- A range of different shapes may also be formed by bending in dies similar to V-bending

a) Channel bending
b) U-bending
c) Air-bending
d) Offset bending
e) Corrugating
f) Tube forming



Drawing

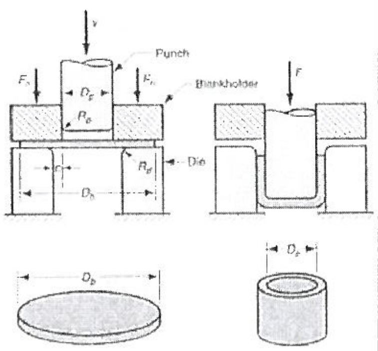
- Drawing is used to form cup-shaped or other hollow-shaped parts
  - blank is held in place by a blankholder with holding force F_h
  - corners of punch and die must be radiused otherwise blanking occurs
- Clearance: $c = 1.1t$
- For drawing in a single operation :
  1. Drawing ratio DR should be ≤ 2 :

$$DR = \frac{D_b}{D_p}$$

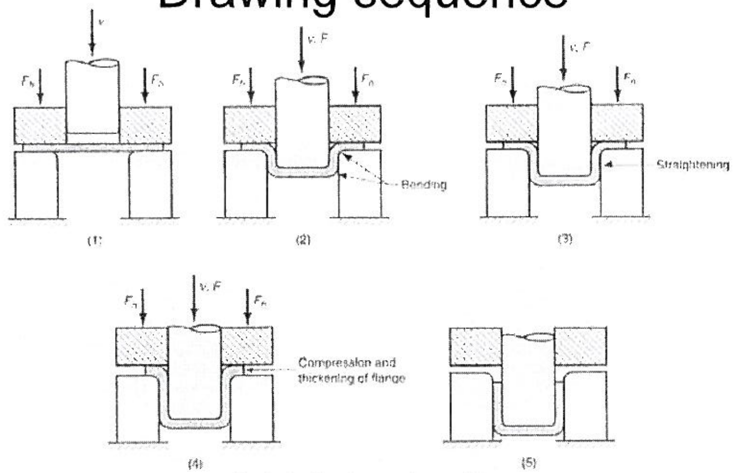
  2. Reduction r should be ≤ 0.5:

$$r = \frac{D_b - D_p}{D_b}$$

  3. Thickness to diameter ratio t/D_b should be > 1%



Drawing sequence



Forces in drawing

- The force F required to perform a drawing operation may be estimated using:

$$F = \pi D_p t \sigma_T \left(\frac{D_b}{D_p} - 0.7 \right)$$

- The 0.7 is a friction correction factor
- The holding pressure should be set at 1.5 % of σ_y of the metal
- The holding force F_h is then found from the holding pressure, and the area of the starting blank held by the blankholder:

$$F_h = 0.015\sigma_y \pi[D_b^2 - (D_p + 2.2t + R_d)^2]$$

- To estimate the blank diameter (for cups and other axisymmetric shapes):
  - Assume initial blank and final component volumes are equal
  - Assume negligible wall thinning occurs
  - Solve for D_b

Defects in drawing

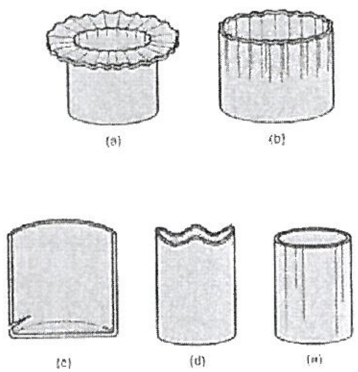
a) Wrinkling in the flange caused by compressive buckling
   - Blankholder force F_h insufficient

b) Wrinkling in the wall occurs if the flange is drawn into the die

c) Tearing in the wall usually occurs near sharp corners
   - Blankholder force F_h excessive

d) Earing produced by *anisotropy* in the sheet metal

e) Surface scratches produced by insufficient lubrication, contaminants or rough dies



Other drawing processes

- Redrawing is essentially a two-stage drawing process used where the deformation required is too great for a single operation
  - amount of deformation should be about half the previous drawing ratio
- Drawing without using a blankholder may also be achieved if:

$$\frac{D_b - D_p}{t} < 5$$

- The draw die must have a lead-in funnel or cone
  - reduced cost as tooling simpler