SHEET-METAL FORMING PROCESS

Ch # 16
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Shearing:

Sheet metal subjected to shear stress developed between a punch and a die is called *shearing*.

Fig : (a) Schematic illustration of shearing with a punch and die, indicating some of the process variables. Characteristic features of (b) a punched hole and (c) the slug. Note that the scales of the two figures are different.
Shearing (Cont’d)

- Shearing usually starts with formation of cracks on both the top and bottom edges of the work piece. These cracks meet each other and separation occurs.

**Process parameters:**
- Shape of the material for the punch and die
- Speed of the punching, lubrication and clearance
Several operations based on shearing performed
Punching – sheared slug discarded
Blanking – Slug is the part and the rest is scrap

Fig-16.4 -a
Other shearing operations:

- Die cutting
- Fine blanking
- Slitting
- Steel rules
- Nibbling
- Scrap in shearing
- Tailor welded blanks
Shearing dies:

Clearance: function of type of material, its temper and its thickness and of the size of the blank and its proximity to the edges

- Clearance of soft materials are less than harder grades

Punch & die shapes:

- Surfaces of punch and die are flat
- Punch force builds rapidly and entire thickness is sheared at the same time.
- Bending is suitable for shearing thick surfaces
Fig 16.3 (a) Effect of the clearance, $c$, between punch and die in the deformation zone in shearing. As the clearance increases, the material trends to be pulled into the die rather than be sheared.
 Compound dies:

Several operations on the same strip performed in one stroke at one station with a compound die.

Fig 16.11 Schematic illustrations: (a) before and (b) after blanking a common washer in a compound die. Note the separate movements of the die (or blanking) and the punch.
Progressive dies:

Parts produced with multiple operations such as, punching, blanking and notching are made at high production rates in progressive dies.

16.11 (c) Schematic illustration of making a washer in a progressive die

(d) Forming of the top piece of an aerosol spray can in a progressive die. Note the part is attached to the strip until the last operation is completed
**Transfer dies:**

- Sheet metal undergoes different operations at different stations in a straight line or circular path.

**Tool and Die Material:**

- Carbides are used for high production rates.
Other sheet metal cutting methods:

- Band saw
- Flame cutting
- Laser beam cutting
- Friction sawing
- Water-jet cutting
TYPICAL RANGE OF AVERAGE NORMAL ANISTROPY ($R_{\text{avg}}$) FOR VARIOUS SHEET METALS

<table>
<thead>
<tr>
<th>Metal</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>0.2</td>
</tr>
<tr>
<td>Hot rolled steel</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Cold rolled rimmed steel</td>
<td>1.0-1.35</td>
</tr>
<tr>
<td>Cold rimmed aluminum–killed steel</td>
<td>1.35-1.8</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.6-0.8</td>
</tr>
<tr>
<td>Copper and Brass</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Titanium</td>
<td>4-6</td>
</tr>
</tbody>
</table>

Table 16.2
Yield point elongation:

- Low carbon steels exhibit this behavior.
- This produces lueder’s bands (stretch strain marks).
- These marks can be eliminated by reducing thickness of sheet 0.5% to 1.5% by cold rolling process.

Fig 16.12 (a) Yield-point elongation in a sheet-metal specimen (b) Lueder’s bands in a low-carbon steel sheet.
Anisotropy:

- Anisotropy is caused by thermo-mechanical processing of sheet.

2-types
- Crystallographic anisotropy
- Mechanical fibering

Fig 16.33 Strains on a tensile-test specimen removed from a piece of sheet metal. These strains are used in determining the normal and planar anisotropy of sheet metal.
**Grain size:**

- Grain size affects mechanical properties & surface appearance
- The coarser the grain the rougher the appearance

**Sheet metal formability:**

- Sheet metal undergoes two forms of deformation
- Stretching
- Drawing
Cupping test:

The sheet metal specimen is clamped between two circular flat dies and a steel or round punch is pushed hydraulically into the sheet metal until a crack begins to appear on the stretched specimen.

Fig 16.13 (a) A cupping test (the Erichsen test) to determine the formability of sheet metals. (b) Bulge-test results on steel sheets of various widths. The specimen farthest left is subjected to, basically, simple tension. The specimen farthest right is subjected to equal biaxial stretching.
Bending sheet and plate:

In bending outer fibers are in tension and inner fibers are in compression.

Fig 16.17 (a) and (b) The effect of elongated inclusions (stringers) on cracking, as a function of the direction of bending with respect to the original rolling direction of the sheet. (c) Cracks on the outer surface of an aluminum strip bent to an angle of 90 degree. Note the narrowing of the top surface due to the Poisson effect.
Bend allowance:

- \( L_b = \alpha \left( R + K T \right) \)
  
  \( \alpha \) – bend angle (radians)
  
  \( T \) - sheet thickness
  
  \( R \) - bend radius
  
  \( K \) - constant

- Bend allowance for ideal case the sheet thickness; \( k=0.5 \)
  
  \( L_b = \alpha (R+(T/2)) \)

_in practice the value of K ranges from 0.33-0.5_

- Minimum bend radius

- Engineering strain on a sheet during bending
  
  \( E = \frac{1}{2R/T} + 1 \)

- As \( R/T \) decreases, tensile strain at outer fiber increases and material cracks

- Ratio at which the crack appears on outer surface is minimum bend radius
Spring back:

- In Bending, after plastic deformation there is an elastic recovery; this recovery is called spring back.
- Spring back can be calculated approximately in terms of radii $R_i$ and $R_f$.
- $$\frac{R_i}{R_f} = 4 \left( \frac{R_i \gamma}{E_T} \right)^3 - 3 \left( \frac{R_i \gamma}{E_T} \right) + 1$$
- Spring back increases as the $R/T$ ratio and yield stress of material increase, and as the elastic modulus $E$ decreases.

Fig 16.19: Spring back in bending. The part tends to recover elastically after ending, and its bend radius becomes larger. Under certain conditions, it is possible for the final bend angle to be smaller than the original angle (negative spring).
Compensation for spring back

- Over bending of part
- Bottoming the punch – coin the bend area by subjecting it to high localized compressive between the technique tip of the punch and the die surface.
- Stretch bending – Part is subjected to tension while being bent. In order to reduce spring back bending may also be carried to reduce spring back bending may also be carried out at elevated temperatures
Bending force:

Maximum bending force, \[ P = \frac{KYLT^2}{W} \]

K – constant ranges from 0.3 (wiping die) – 0.7 (u-die) - 1.3 (V-die)
Y – yield stress
L- length of the bend
T- thickness of sheet

For a V-die
Max bending force, \[ P = \frac{(UTS)LT^2}{W} \]

UTS – Ultimate tensile strength
Common bending operations:

Press brake forming

- Used for sheets 7M(20ft) or longer and other narrow pieces
- Long dies in a mechanical or hydraulic press for small production runs
- Die material range from hardwood to carbides.
**Roll bending:**

Plates are bent using a set of rolls, various curvatures can be obtained by adjusting the distance between three rolls.

**Bending in 4-slide machine**

- Used for short pieces
- Controlled and synchronized with vertical die movements to form the part of desired shape

*Fig 16.21 Common die-bending operations, showing the die-opening dimensions, W, used in calculating bending forces*
Beading:

The periphery of the sheet metal is bent into the cavity of a die.

Fig 16.24 (a) Bead forming with a single die (b) Bead forming with two dies, in a press brake.
Flanging:

- Flanging is a process of bending the edges of sheet metals to 90°.
- Shrink flanging – subjected to compressive hoop stress.
- Stretch flanging – subjected to tensile stresses.

Fig 16.25 Various flanging operations:
(a) Flanges on a flat sheet.
(b) Dimpling.
(c) The piercing of the sheet metal to form a flange. In this operation, a hole does not have to be prepunched before the bunch descends. Note however, the rough edges along the circumference of the flange. (d) The flanging of a tube; note the thinning of the edges of the flange.
**Dimpling**:  
- First hole is punched and expanded into a flange  
- Flanges can be produced by piercing with shaped punch  
- When bend angle < 90 degrees as in fitting conical ends its called flanging
**Hemming:**

- The edge of the sheet is folded over itself
- This increases stiffness of the part
  - The metal strip is bent in stages by passing it through a series of rolls

**Seaming:**

- Joining two edges of sheet metal by hemming specifically shaped rollers used for watertight and airtight joints
Roll forming:
- Roll forming is used for continuous lengths of sheet metal
- Used for large production runs

Fig: Schematic illustration of the roll-forming process
Special tooling required to avoid buckling and folding

Fig 16.28 Methods of bending tubes. Internal mandrels, or the filling of tubes with particulate materials such as sand, are often necessary to prevent collapse of the tubes during bending. Solid rods and structural shapes can also be bent by these techniques.
Bulging:

Process involves placing tabular, conical or curvilinear part into a split-female die and expanding it.
**Segmented die:**

- Individuals are placed inside the parts and mechanically expanded in radial direction and finally retracted.

**Stretch forming**

- Sheet metal clamped along its edges and stretched over a die or form block in required directions.
Stretch forming

Fig: Schematic illustration of a stretch forming process. Aluminum skins for aircraft can be made by this process.
Deep drawing:

- Punch forces a flat sheet metal into a deep die cavity.

- Round sheet metal block is placed over a circular die opening and held in a place with blank holder & punch forces down into the die cavity.
Deep drawing process:

- Wrinkling occurs at the edges

Fig 16.32 (a) Schematic illustrations of the deep-drawing process on a circular sheet-metal blank. The stripper ring facilitates the removal of the formed cup from the punch (b) Process variables in deep drawing. Except for the punch force, $F$, all the parameters indicated in the figure are independent variables.
Deep drawability:

- Deep drawability is expressed in LDR.

- Limiting drawing ratio (LDR)
  \[ \text{LDR} = \frac{\text{Max blank dia}}{\text{punch dia}} = \frac{D_o}{D_p} \]

- Drawability of metal is determined by normal anisotropy (R) or plastic anisotropy.

\[ R = \frac{\text{width strain}}{\text{thickness strain}} = \frac{E_w}{E_t} \]
Earing or planar anisotropy:

- Edges of cups may be wavy; this phenomenon is called Earing.
- The above condition is called planar anisotropy.
- Del R = R0 – 2 R45 + R 90 / 2
  Where Del R = 0 => no ears formed
  Height of the ears increases Del R increases.

Fig 16.45 Earning in a drawn steel cup, caused by the planar anisotropy of the sheet metal.
Deep drawing Practice:

- Blank holder pressure – 0.7% -1.0 % of Yield strength + UTS
- Clearance usually – 7% -14 % > sheet thickness
- Draw beads are used to control flow of blank into die cavity.
- Ironing is a process in which the thickness of a drawn cup is made constant by pushing of the cup through ironing rings.
- Redrawing – Containers or shells which are too difficult to draw in one operation undergo redrawing
Drawing without blank holder:

Deep drawing without blank holder must be provided with sheet metal which is sufficiently thick to prevent wrinkling

Range: \( D_0 - D_p < 5T \)
Lowers forces and increases drawability

commonly used lubricants are mineral oils, soap solutions, heavy duty emulsions.

Tooling & equipment for drawing:
Tool & die materials are tool steels, cast irons, carbides
Equipment is hydraulic press or mechanical press
Rubber forming:

- In bending and embossing of sheet metal, the female die is replaced with rubber pad.

Hydro-form (or) fluid forming process:

- The pressure over rubber membrane is controlled throughout the forming cycle, with max pressure up to 100 Mpi.
- As a result, the friction at the punch-cup interface increases, this increase reduces the longitudinal tensile stresses in the cup and delays fracture.
**Spinning:**

- Shaping thin sheets by pressing them against a form with a blunt tool to force the material into a desired form.

- **Conventional spinning:**
  A circular blank if flat or performed sheet metal held against a mandrel and rotated, while a rigid metal is held against a mandrel and rotated, while a rigid tool deforms and shapes the material over the mandrel.
Fig 16.40 (a) Schematic illustration of the conventional spinning process (b) Types of parts conventionally spun. All parts are antisymmetric
**Shear spinning**: Known as power spinning, flow turning, hydro-spinning, and spin forging. Produces axisymmetric conical or curvilinear shape. Single rollers and two rollers can be used. It has less wastage of material. Typical products are rocket-motor casing and missile nose cones.
Tube spinning:

- Thickness of cylindrical parts are reduced by spinning them on a cylindrical mandrel rollers
- Parts can be spun in either direction
- Large tensile elongation up to 2000 % are obtained within certain temperature ranges and at low strain rates.
Super Plastic forming:

Advantages:
- Lower strength is required and less tooling costs
- Complex shapes with close tolerances can be made
- Weight and material savings
- Little or no residual stress occurs in the formed parts

Disadvantages:
- Materials must not be super elastic at service temperatures
- Longer cycle times
Explosive forming:

- Explosive energy used for metal forming
- Sheet-metal blank is clamped over a die
- Assembly is immersed in a tank with water
- Rapid conversion of explosive charge into gas generates a shock wave. The pressure of this wave is sufficient to form sheet metals.
Peak pressure (due to explosion):

caused due to explosion, generated in water

\[ P = k \left( \frac{3\sqrt{w}}{R} \right)^9 \]

P- in psi
K- constant
TNT- trinitrotoluene
W- weight of explosive in pounds
R- the distance of explosive from the work piece
Diffusion Bonding and Superplastic Forming

Fig: Types of structures made by diffusion bonding and super plastic forming of sheet metal. Such structures have a high stiffness-to-weight ratio.
THE END