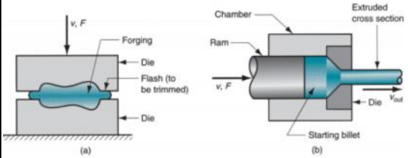
Chapter 3: Sheet Metalworking [Shearing, Blanking & Punching] (Lecture 8)

Deformation Processes

>> Starting workpart is shaped by application of forces that exceed the yield stress of the material

>> Examples: (a) forging and (b) extrusion



Stress-Strain Relationships

>> Types of Static Stresses:

1. Tensile – stretching (pull) the material
2. Shear - causing adjacent portions of the material to slide against each other (apply forces in opposite direction)
3. Compressive – squeezing the material

Tensile Test

Engineering stress:

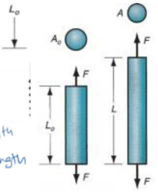
$$\sigma_e = \frac{F}{A_o}$$

→ force apply
→ original cross-section

Engineering strain:

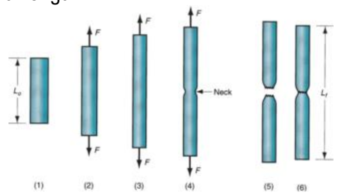
$$e = \frac{L - L_o}{L_o}$$

→ change in length
→ original length



Tensile Test Sequence

>> (1) No load; (2) uniform elongation; (3) Maximum load; (4) necking; (5) fracture; (6) putting pieces back together to measure final length

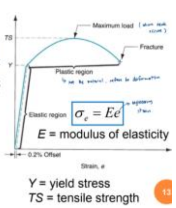


Typical Engineering Stress-Strain Plot

>> Two regions:

→ Elastic region: Material returns to its original length when the stress is removed.

→ Plastic region: Permanent deformation, material does not return to its original length when the stress is removed.



Strain/Work Hardening

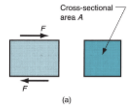
>> What is happening between Y and TS on the curve

>> defined as metal becoming stronger as strain increases

Shear Stress

>> F = applied force; A = area where force is applied

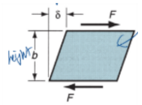
$$\tau = \frac{F}{A}$$



Shear Strain

>> δ = deflection of the element; b = distance over which deflection occurs

$$\gamma = \frac{\delta}{b}$$



Shear Stress

>> Shear stress at fracture = shear strength S

>> Shear strength can be estimated from tensile strength: S ≅ 0.7(TS) (use when only tensile strength is given)

Basic Types of Metal Forming Processes

>> Bulk deformation – start with a block of material and apply compression force or some tension force

→ Compression forces: Rolling, Forging, Extrusion

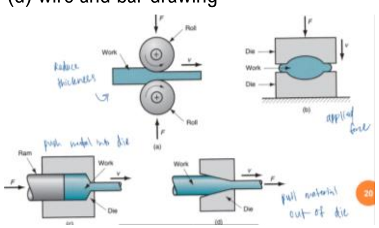
→ Tension force: Wire and bar drawing

>> Sheet metalworking

→ Bending operations, deep or cup drawing, shearing processes

Bulk Deformation Processes

>> (a) Rolling, (b) forging, (c) extrusion and (d) wire and bar drawing



Sheet Metalworking

>> Cutting and forming operations performed on relatively thin sheets of metal

>> Thickness of sheet metal = 0.4 mm to 6 mm (if thickness > 6 mm → plate)

>> Operations usually performed as cold working i.e. operating temperature below 30% of melting point of the metal (Kelvin)

>> Most commonly used metals: low carbon steel (0.06 to 0.15% carbon), aluminum and titanium

Advantages of Sheet Metal Parts

>> High strength; Good dimensional accuracy; Good surface finish; Relatively low cost; Economical mass production for large quantities

Sheet Metalworking Terminology

>> Punch-and-die = tooling to perform cutting, bending, and drawing

>> Stamping press = machine tool that performs most sheet metal operations

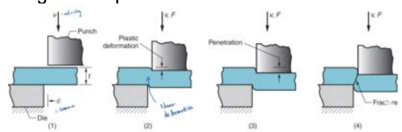
>> Stampings = sheet metal products

Shearing

>> Cutting material without producing chips (unlike machining)

Sheet Metal Cutting

(1) Just before the punch contacts the workpiece; (2) the punch pushes into the workpiece, causing plastic deformation; (3) the punch penetrates into the workpiece causing a smooth cut surface; and (4) fracture is initiated at opposing cutting edges to separate the sheet



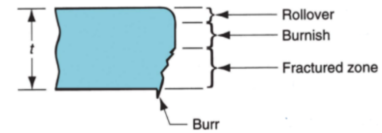
Characteristics of Shear Edges

Rollover - Depression made by the punch prior to cutting

Burnish - Smooth region resulting from penetration of the punch prior to fracture

Fracture zone - Relatively rough surface caused by the fracture of the metal as the punch goes down

Burr - Sharp corner edge caused by the elongation of the metal during the final stage of separation



Shearing, Blanking and Punching

>> Shearing to separate large sheets

>> Blanking to cut part perimeters out of sheet metal

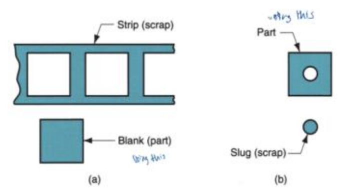
>> Punching to make holes in sheet metal

* ALL are shearing processes, all cutting metal by shear stress if material

Blanking and Punching

>> Blanking (a) - sheet metal cutting to separate a piece of metal (called a blank) from the surrounding sheet

>> Punching (b) - similar to blanking except that the cut piece is scrap, called a slug



Punch and Die Sizes

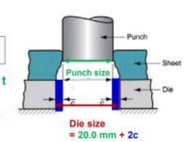
For both punching and blanking:

Die size = Punch size + 2 x clearance

clearance c= allowance a x thickness t

For punching: hole size = Punch size

For blanking: blank size = Die size



For a round *blank* of diameter D_b:

- Blanking punch diameter = D_b - 2c
- Blanking die diameter = D_b

where c = clearance

For a round *hole* of diameter D_h:

- Hole punch diameter = D_h
- Hole die diameter = D_h + 2c

where c = clearance

Clearance

>> Distance between punch cutting edge and die cutting edge

>> Typical values range between 4% and 8% of sheet thickness:

→ Clearance too small: cause non-optimal fracture and too large forces

→ Clearance too big: causes oversized burr

Clearance in Sheet Metal Cutting

>> c = clearance; a = allowance; and t = sheet thickness

>> Allowance a is determined according to the type of metal (softer metal, deforms more, smaller allowance)

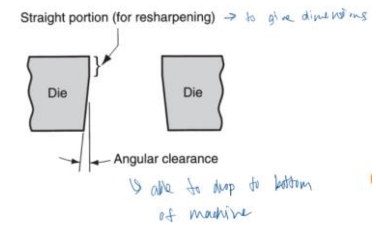
$$c = at$$

Metal Group	Allowance a
1100S and 5052S aluminum alloys, all tempers	0.045
2024ST and 6061ST aluminum alloys; brass, soft cold rolled steel, soft stainless steel	0.060
Cold rolled steel, half hard; stainless steel, half hard and full hard	0.075

Angular Clearance

>> Purpose: allows slug or blank to drop through the die

>> Typical values: 0.25° to 1.5° on each side



Important Points

>> SHEARING, BLANKING, & PUNCHING

→ Determine the die and punch sizes; Clearance; Force of operation required

>> BENDING

→ Determine the starting blank length; Meaning of Bend allowance, k factor, neutral axis; Bending force required for certain operation

>> DEEP DRAWING

→ Determine starting blank size; Whether the operating is feasible; Reasons for defects

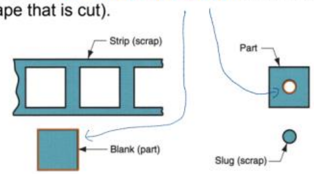
Chapter 3: Sheet Metalworking [Bending Operations] (Lecture 9)

Cutting Forces Calculation

Important for determining the press size (tonnage)

$$\boxed{F = S\,t\,L = 0.7(TS)\,t\,L}$$

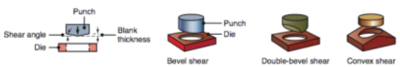
where S = shear strength of metal, t = sheet thickness, and L = length of cut edge (perimeter of the shape that is cut).



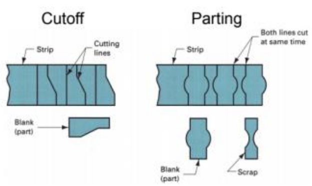
>> Assumptions:
Neglect minor effect of clearance in calculating L (perimeter)
Entire length is made at the same time (maximum cutting force calculated)

Shear Angles

>> Advantages: reduces the cutting force; reduces shock on the press; cutting gradually over a longer stroke

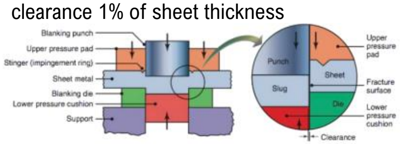


Other Cutting Operations



Fine Blanking

>> shearing process which produces very highly precise workpieces with completely smooth, tear-free sheared surfaces
>> more precise, costly and complex
>> triple action press – control cracks & clearance 1% of sheet thickness

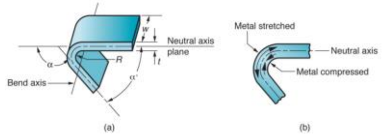


Bending

>> forming of solid parts, where angled or ring-shaped workpieces are produced from sheet or strip metal

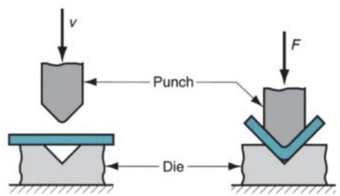
Sheet Metal Bending

>> (a) Straining of sheet metal around a straight axis to take a permanent bend
(b) Metal on the inside of the neutral plane is compressed, while the metal on the outside of the neutral plane is stretched



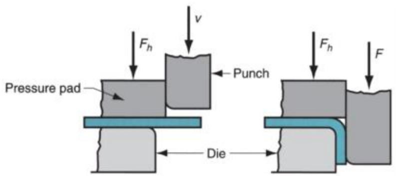
Types of Sheet Metal Bending – V-bending

>> performed with V-shaped die
>> Low production quantity
>> V-dies are simple & inexpensive



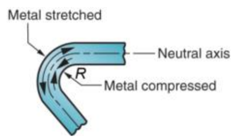
Types of Sheet Metal Bending – Edge bending

>> performed with a wiping die
>> High production quantity
>> Dies are more complicated and costly (especially if angle > 90°)

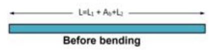


Stretching during Bending

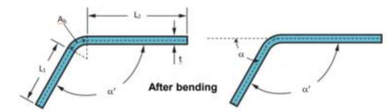
>> If the bend radius R is small relative to the sheet thickness, the metal tends to stretch during bending.
>> Important to estimate amt of stretching, so final part length = specified dimension
>> Problem: to determine length of neutral axis of part before bending → blank size



Required Blank Length



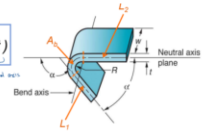
L = total length of starting blank
A_b = *bend allowance*



t = sheet thickness
L_1, L_2 = length of straight portions after bending (specified by design)
α = bend angle
α' = included angle
$\alpha + \alpha' = 180°$

Bend Allowance Formula

$$\boxed{A_b = 2\pi \overbrace{\frac{\alpha}{360}}^{\text{to convert to radian}} \underbrace{(R + K_{ba}t)}_{\text{portion of neutral axis}}}$$



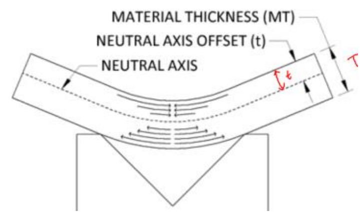
A_b = bend allowance
α = bend angle (in degree)
R = bend radius
t = sheet thickness
K_{ba} = streching factor:
- If $R < 2t$, $K_{ba} = 0.33$
- If $R \geq 2t$, $K_{ba} = 0.50$

neutral axis remains in middle plane

Starting blank size:

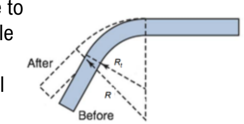
$$\boxed{\begin{aligned} L &= L_1 + A_b + L_2 \\ w &= \text{blank width} \end{aligned}}$$

>> A_b is the length of the neutral axis within the bended portion
>> Neutral axis is at plane where the length before & after bending remains the same; has 0 net stress; no deformation there
>> For bending with little stretch: (bend on big material)
R ≥ 2t, $K_{ba} = 0.50$
>> For bending with large stretch: (bend on small material)
If R < 2t, $K_{ba} = 0.33$

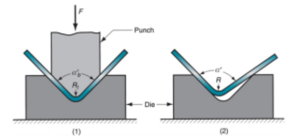


Springback

>> Increase in the included angle of the bent part relative to the included angle of the forming tool after the tool is removed

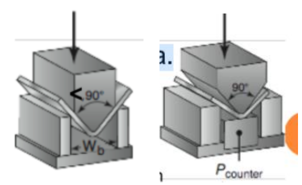


>> Reason: When the bending pressure is removed, the elastic energy remains in the bent part, causing it to recover partially toward its original shape
>> seen as a decrease in bend angle and an increase in bend radius:
(1) during bending, the workpiece is forced to take the radius R_t and angle αb' of the bending tool;
(2) after the punch is removed, the workpiece springs back to R and α'



Springback Compensation

>> Methods of reducing or eliminating springback in bending operations:
→ Overbending: bend more than required to allow for springback; e.g. included angle after bending <90°, after springback, angle = 90°
→ high compressive pressure causes plastic deformation at the bend area



Bending Forces

- Maximum bending force is estimated as follows:

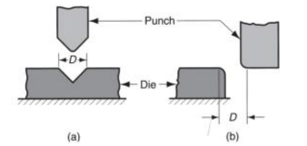
$$\boxed{F = \frac{K_{bf}(TS)wt^2}{D}}$$

where F = bending force; TS = tensile strength of the sheet metal; w = part width in the direction of the bend axis; D = die opening; and t = sheet thickness.

For V-bending, $K_{bf} = 1.33$; for edge bending, $K_{bf} = 0.33$.

Die Opening Dimensions

Die opening dimension D for (a) V-die, (b) wiping die:



Chapter 3: Sheet Metalworking [Drawing Operations] (Lecture 10)

Drawing

>> Sheet metal forming to make cup-shaped, box-shaped, or other complex-curved, hollow-shaped parts

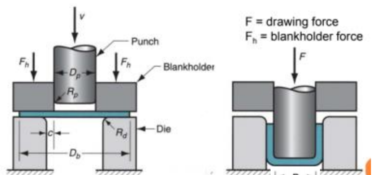
>> Sheet metal blank is positioned over the die cavity & then the punch pushes metal into the opening

>> Products: beverage cans, ammunition shells, automobile body panels

>> aka deep drawing (to distinguish it from wire and bar drawing)

Deep Drawing of a Cup

>> (left) before the punch contacts the workpiece; (right) near end of the stroke



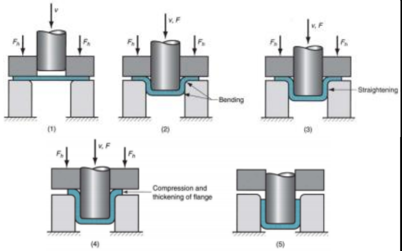
D_b = blank diameter, R_d = die radius
D_p = punch diameter, R_p = punch radius

Clearance in Drawing

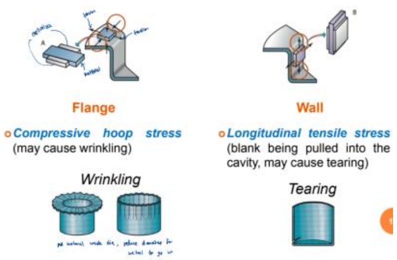
>> Sides of punch and die separated by a clearance c given by: $\boxed{c = 1.1\,t}$
where t = sheet thickness
→ clearance ~10% greater than sheet thickness

Drawing Sequence

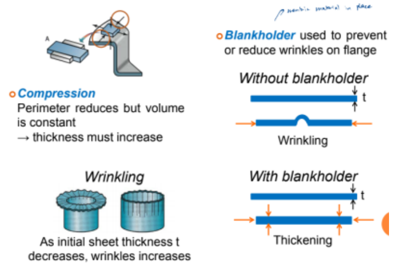
(1) Punch makes initial contact with the workpiece (blank)
(2) Downwards movement of the punch, metal bends along the die
(3) Straightening to form the cup wall, tensile stress on the cup wall
(4) Friction and compression; compressive stress on the flange
(5) Final cup shape showing effects of thinning in the cup walls



Major Stresses in Flange and Wall



Compression in Flange and Wrinkles



Effect of Blankholder Force

>> F_h too low: Causes wrinkles

>> F_h too high: prevents metal from flowing into die cavity; may cause tearing due to stretching of metal (more tension)

Tests of Drawing Feasibility

>> Three criteria are used to test for drawability: Drawing ratio, Reduction, Thickness-to-diameter ratio

Drawing Ratio DR

Most easily defined for cylindrical shape (e.g. cup)

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

where D_b = blank diameter; and D_p = punch diameter

internal diameter

Indicates severity of a given drawing operation

- Upper limit: $DR \le 2.0$; i.e. if DR > 2.0, the operation is not feasible.

Reduction R

Defined for cylindrical shape:

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

Value of r should be ≤ 0.50.

Thickness-to-Diameter Ratio T/D_B

>> Thickness t of starting blank divided by blank diameter: Desirable for t/Db ratio to be greater than 1%.; As t/Db decreases, tendency for wrinkling increases

Tests of Drawing Feasibility

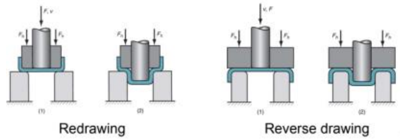
>> Conditions for drawability
→ DR ≤ 2.0
→ r ≤ 0.50
→ t/D_b > 1%

>> If the limits on DR, r and t/Db are not respected, then the operation is not feasible in one step, redrawing is required

A blank can be drawn in 2 steps or more with annealing between the steps (reduce stress in material; recover ductility)

Redrawing & Reverse Drawing

>> If shape change is too severe to be produced in one single drawing step, redrawing or reverse drawing can be used



Blank Size Determination

>> After checking tests of drawing feasibility

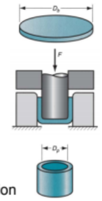
>> Starting sheet metal blank >= final product volume; Assume negligible thinning of part wall; Neglect die and punch radii

Drawing Force

- Calculation of drawing force is required to determine the tonnage of the press:

represent friction

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



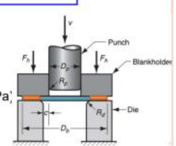
F = maximum drawing force (N)
D_p = punch diameter (mm)
D_b = starting blank diameter (mm)
t = original sheet thickness (mm)
TS = tensile strength (MPa)
0.7 = correction factor to account for friction

Blankholder Force or Holding Force

- Holding pressure ≈ 0.015 x yield strength
- Holding force ≈ holding pressure x starting area of the blank held by blankholder

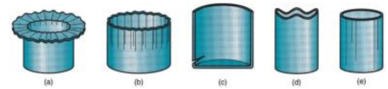
$$\boxed{F_h = \frac{0.015 Y \pi}{4}\left\{D_b^2 - \left(D_p + 2.2t + 2R_d\right)^2\right\}}$$

F_h = blankholder force (N)
D_p = punch diameter (mm)
D_b = starting blank diameter (mm)
t = original sheet thickness (mm)
Y = yield strength of sheet metal (MPa)
R_d = die corner radius (mm)



Defects in Drawing Operations

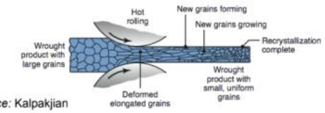
(a) wrinkling can occur either in the flange or (b) in the wall (due to compression), (c) tearing (due to high tensile stresses that cause thinning and failure), (d) earing (due to anistropy), and (e) surface scratches (due to poor lubrication, punch/die not smooth)



Reason for Earing

>> Anisotropy of starting sheet causes earing

Sheet metal produced by rolling



Source: Kalpakjian