Department of Mechanical Engineering
GENERAL SIR JOHN KOTELAWALA DEFENCE UNIVERSITY

WORKSHOP TECHNOLOGY

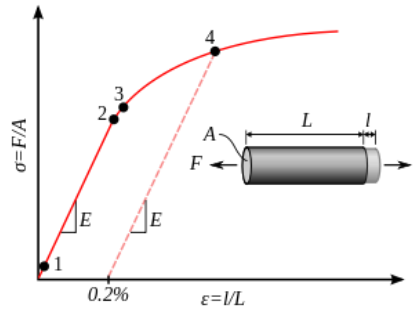
Metal Forming

METAL FORMING

By plastic deformation processes in which the volume and mass of metal are conserved and the metal is displaced from one location to another.

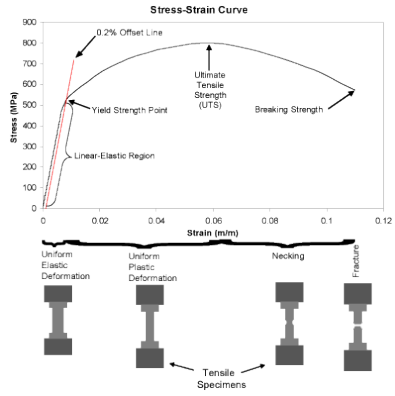
- The tool, usually called a *Die*, applies stresses that exceed yield strength of metal.
- The metal takes a shape determined by the geometry of the die.

2



- Typical yield behavior for non-ferrous alloys.
  1: True elastic limit
  2: Proportionality limit
  3: Elastic limit
  4: Offset yield strength

3

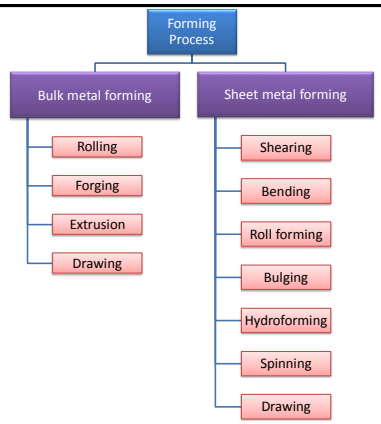


5

Content

- Process Classification
  - Bulk Deformation Process
  - Sheet Metal Working
- Temperature in Metal Forming
- Friction & Lubrication

6



7

Bulk Metal Forming

1. Characterized by significant plastic deformations and massive shape changes.
2. The ratio *cross-section area/volume* is small.
3. Starting work shapes include cylindrical billets and rectangular bars.
4. Hot or warm working conditions are preferred although some operations are carried out at room temperature.
5. The main categories of sheet metal forming are
   - Rolling - compression process to reduce the thickness of a slab by a pair of rolls.
   - Forging - compression process performing between a set of opposing dies.
   - Extrusion - compression process squeezing metal flow through a die opening.
   - Drawing - pulling a wire or bar through a die opening.

8

Sheet Metal Working

1. In sheet metalworking operations, the cross-section of work piece does not change, the material is only subjected to shape changes.
2. The ratio cross-section area/volume is very high.
3. Sheet metal processes involve plane stress loadings and lower forces than bulk forming.
4. Sheet metalworking operations are performed on thin (less than 6 mm) sheets, strips or coils of metal.
5. Almost all sheet metal forming is considered to be secondary processing.
6. The main categories of sheet metal forming are

– Shearing - not a forming process but a cutting process.
– Bending - straining of a metal sheet to form an angle bend.
– Drawing - forming a sheet into a hollow or concave shape.

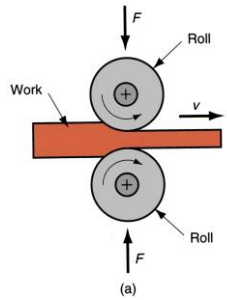
9

Bulk Metal Forming

10

Bulk Metal Forming

1. Rolling - compression process to reduce the thickness of a slab by a pair of rolls.



(a)

11

ROLLING

- **The process of plastically deformation metal by passing it between the rolls is known as rolling.**
- **The work is subjected to high compressive stresses from squeezing action of rolls.**
- **The frictional force between metal and rolls is responsible for drawing the metal into the rolls.**
- **Classification of Rolling Process**
  - **i) Hot Rolling**
  - **ii) Cold Rolling**

12

<u>Hot Rolling:</u>

- **Hot working above the re-crystallization temperature**
- **It is employed where large reduction in cross-sectional area is required.**
- **Used for bars, rods, rails etc.**

<u>Cold Rolling:</u>

- **Cold working below the re-crystallization temperature**
- **Employed for finishing the metal to given specification of sizes and surface quality.**
- **Produces sheets, strips and foils with good surface finish and increased mechanical strength.**

13

Rolling

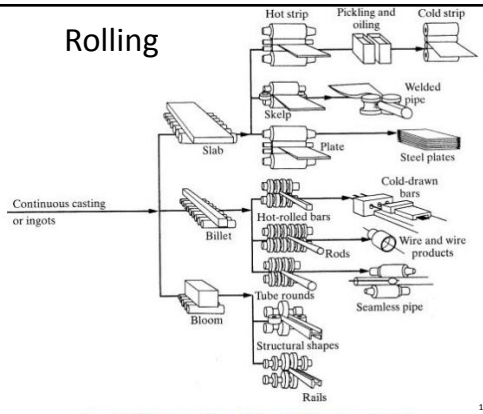


Figure 1. Different types of flat- and shaped-rolling processes [P 321]

14

ROLLED PRODUCTS

i) Bloom:
- First breakdown product of ingots
- Square cross section of 150*150 mm or more
- Generally, square in cross-section

ii) Billet:
- Further reduction of bloom by rolling results a billet
- 40*40 mm or more is rolled from a bloom

iii) Slab:
- A hot rolled ingot with a width to thickness ratio of 2:1 at least
- 40*250 mm or more is rolled from an ingot or a bloom

Blooms, billets and slabs are known as semi-finished products because they are subsequently formed into other mill products.

15

iv) Plate:
- **It has thickness greater than ¼ in.**

v) Sheet and Strip:
- **Generally have thickness lesser than ¼ in.**

vi) Foil:
- **Thickness is very small just as 0.002 in.**

Billets and other unfinished rollings are further rolled to I-sections, T-sections, Angles, Channels, Girders etc..

16

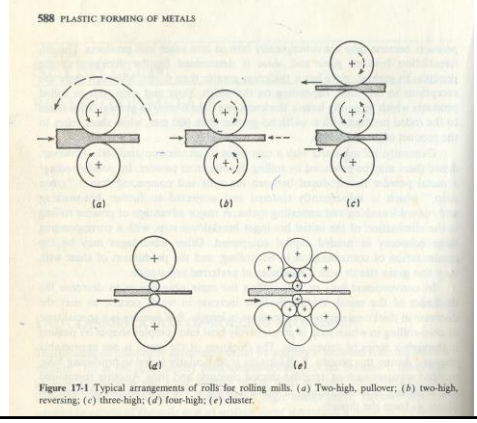


Figure 17-1 Typical arrangements of rolls for rolling mills. (*a*) Two-high, pullover; (*b*) two-high, reversing; (*c*) three-high; (*d*) four-high; (*e*) cluster.

17

Roll configurations in rolling mills

- Two-high and three-high mills are generally used for initial and intermediate passes during hot rolling, while four-high and cluster mills are used for final passes.
- Last two arrangements are preferred for cold rolling because roll in these configurations are supported by back-up rolls which minimize the deflections and produce better tolerances.

18

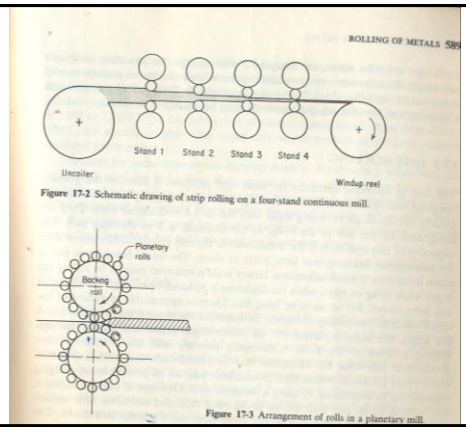


Figure 17-2 Schematic drawing of strip rolling on a four-stand continuous mill.

Figure 17-3 Arrangement of rolls in a planetary mill.

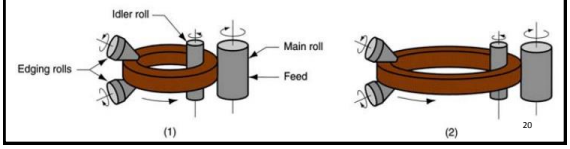
19

- Shape rolling

  The work is deformed by a gradual reduction into a contoured cross section (I-beams, L-beams, U-channels, rails, round, squire bars and rods, etc..)

- Ring rolling

  Thick-walled ring of small diameter is rolled into a thin-walled ring of larger diameter.

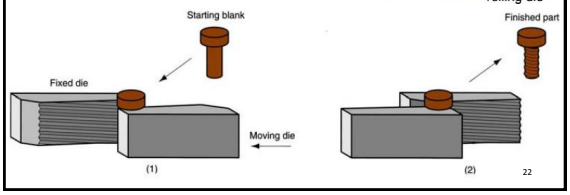


20

21

- Thread rolling

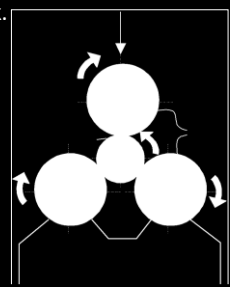
  Threads are formed on cylindrical parts by rolling them between two thread dies.



22

- Gear rolling

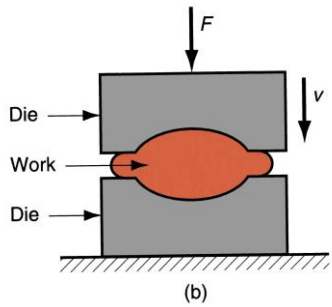
  Gear rolling is similar to thread rolling with three gears (tools) that form the gear profile on the work.



23

Bulk Metal Forming

2. Forging - compression process performing between a set of opposing dies.



24

Simple Forging Press

25

Forging

- **Forging** is manufacturing process where metal is pressed, pounded or squeezed under great pressure into high strength parts.

26

The forging process

- Heated metal to be shaped is placed on a Die. Pressure is applied to the metal with the help of a press or hammer and due to this impact the malleable metal conforms to the die cavity shape.
- Extreme pressure is produced when the die halves are closed. The seam of the die as well as punch acts as a relief valve. Once the metal object is shaped, flashing is removed.
- Use of a proper lubricant during the process helps to prevent sticking of the workpiece with the die. It also acts as a thermal insulator and helps the wear and tear on the die.

27

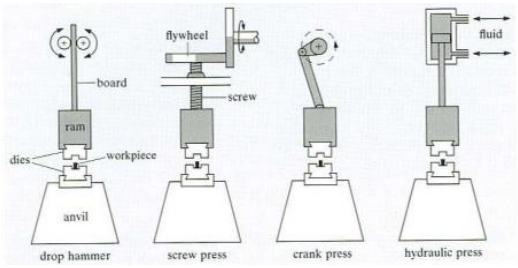
Advantages of Forging

- The forgings are consistent in shape and do not have any voids, porosity, inclusions, or defects.
- This is especially helpful in later finishing and coating operations as surface preparation is minimized.
- Parts that are produced by this method have high strength to weight ratio.
  Ex: used in the design of the aircraft frames
- It offers low cost for moderate to long runs.

28

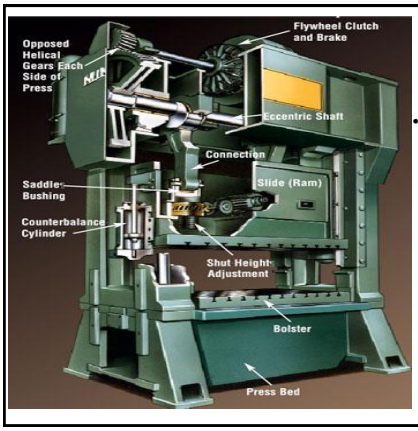
Forging Machines

- There are 4 Basic types of forging machines



–Forge hammer applies an impact load
–Forge press applies gradual pressure

29



- **Mechanical Press -** The ram is actuated using a flywheel. Stroke motion is not uniform.

30

- **Hydraulic Press -** Longer strokes than mechanical presses, and develop full force throughout the stroke. Stroke motion is of uniform speed, especially adapted to deep drawing operations

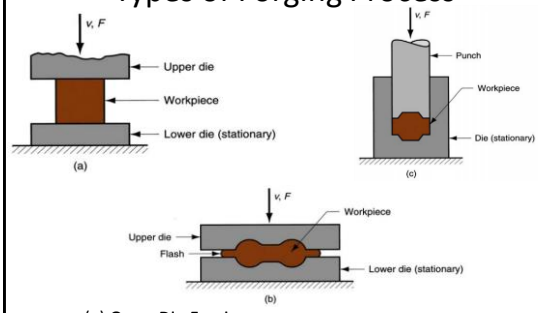
31

Typical Values of Velocity for Different Forging Eqpt

Forging machine	Velocity range, ms^{-1}
Gravity drop hammer	3.6-4.8
Power drop hammer	3.0-9.0
Mechanical press	0.06-1.5
Hydraulic press	0.06-0.30

32

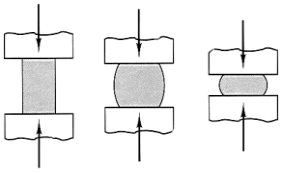
Types of Forging Process



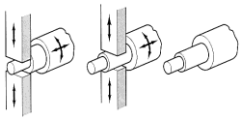
(a) Open-Die Forging,
(b) Close-Die Forging (Flashless)
(c) Impression Die Forging

33

- Open-die forging
  - Known as *upsetting*, it involves compression of a work between two flat dies, or plates.



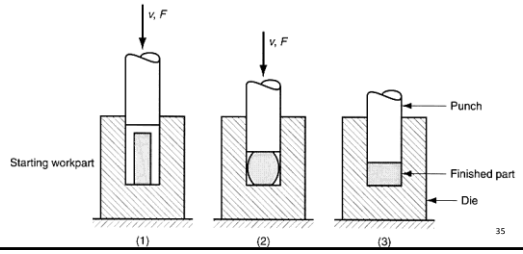
Sequence in open-die forging illustrating the unrestrained flow of material. Note the barrel shape that forms due to friction and inhomogeneous deformation in the work



Open-die forging of a multi diameter shaft

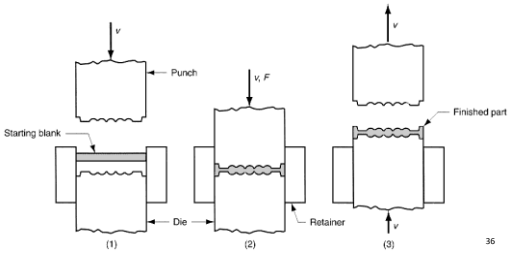
34

- Flashless forging (Close Die Forging)
  - The work material is completely surrounded by the die cavity during compression and no flash is formed.
  - Most important requirement in flashless forging is that the work volume must equal the space in the die cavity to a very close tolerance.



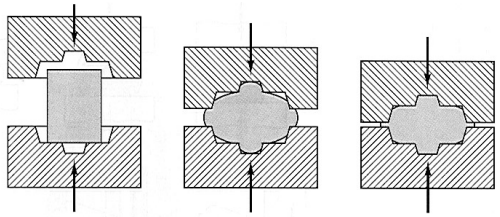
35

- Coining
  - Special application of flashless forging in which fine detail in the die are impressed into the top and bottom surfaces of the workpiece. There is a little flow of metal in coining.



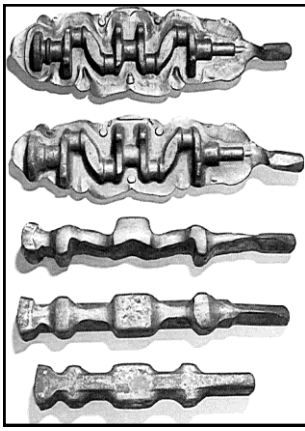
36

- Impression-die forging
  - In impression-die forging, some of the material flows radially outward to form a flash.



Schematics of the impression-die forging process showing partial die filling at the beginning of flash formation in the center sketch, and the final shape with flash in the right-hand sketch.

37

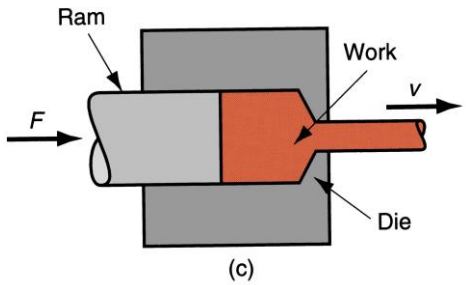


- Stages (from bottom to top) in the formation of a crankshaft by hot impression-die forging

38

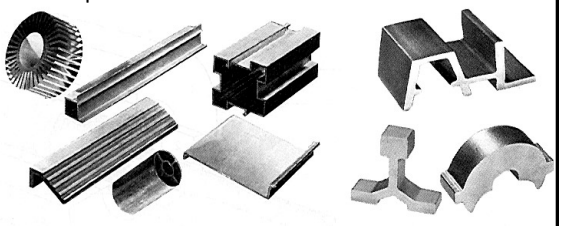
Bulk Metal Forming

3. Extrusion - compression process squeezing metal flow through a die.



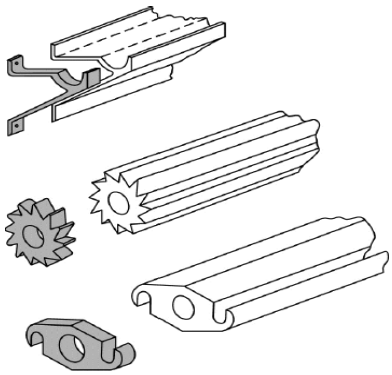
39

- Extrusion is a Bulk Deformation Process in which the work is forced to flow through a die opening to produce a desired cross-sectional shape.



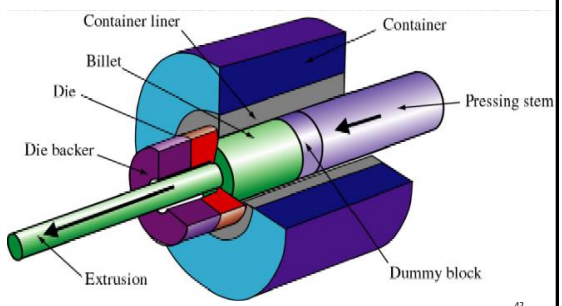
- Used for ductile materials
  Copper, Steel, Aluminum and Magnesium
  Also used for some plastics and rubbers

40



41

- Direct extrusion to produce solid cross section. Schematic shows the various equipment components

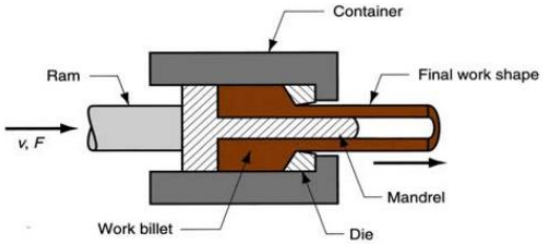


42

- Extrusion is performed in different ways therefore different classifications are available:
  - Direct and indirect extrusion
  - Hot and cold extrusion
  - Continuous and discrete extrusion

43

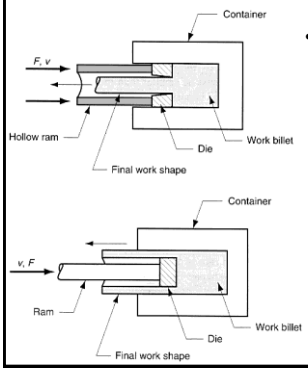
Direct and indirect extrusion



- Direct extrusion to produce hollow or semi-hollow cross section.

44

Indirect extrusion



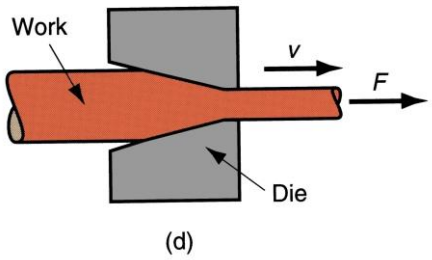
- In indirect extrusion (backward, inverse extrusion) the material flows in the direction opposite to the motion of the ram to produce a solid (top) or a hollow cross section (bottom).

45

Bulk Metal Forming

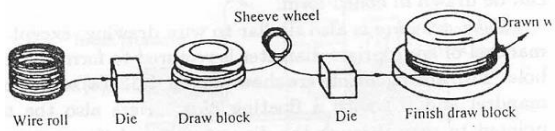
4. Drawing - pulling a wire or bar through a die opening.

It is basically a cold working process.



46

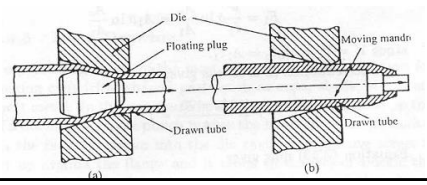
- Annealing before each drawing operation permits large area reduction.
- Tungsten Carbide dies are used for drawing hard wires, and diamond dies are the choice for fine wires.



47

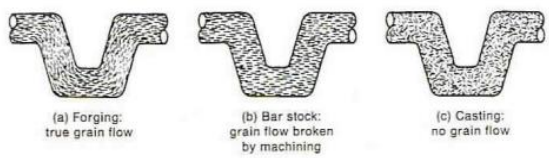
Tube drawing

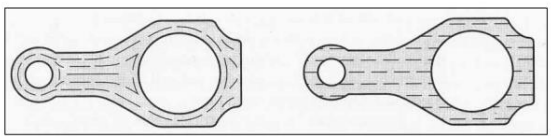
- Tube drawing is also similar to wire drawing, except that a mandrel.
  - floating plug
  - moving mandrel
- Appropriate diameter is required to form the internal hole.



48

Microstructure Differences





Forging Machining

49

Temperature in Metal working

- Three temperature ranges in metal forming:
  - Cold working
  - Warm working
  - Hot working

50

Temperature in Metal working

- Any deformation operation can be done with lower forces and power at elevated temperature.
- Increase in temperature
  - Decrease in strength
  - Increase in ductility & malleability
  - Decrease in the rate of strain hardening
  - All effects that would tend to promote ease of deformation.

51

Cold working

- Also called work-hardening or Strain Hardening
- Performed at room temperature or slightly above. Less than 0.3 T_m
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required
  - These operations are *near net shape* or *net shape* processes

52

Melting point of various metals

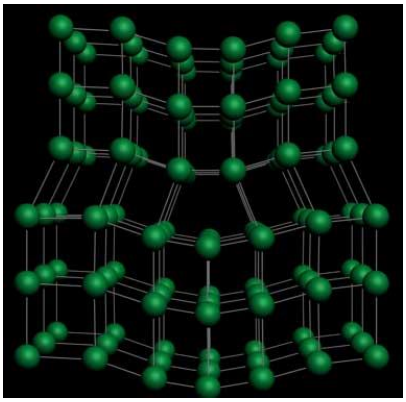
Elements	Symbol	Melting Point Celsius
Tin	Sn	232
Lead	Pb	327
Zinc	Zn	419
Aluminum	Al	659
Magnesium	Mg	670
Bronze (90 Cu 10 Sn)	Cu+Sn	850-1000
Brass (85 Cu 15 Zn)	Cu+Zn	900-940
Silver	Ag	961
Gold	Au	1063
Copper	Cu	1083
Cast Iron	C+Si+Mn+Fe	1260
Stainless Steel	Cr+Ni+Mn+C	1363
Iron	Fe	1530
Carbon	C	3600

53

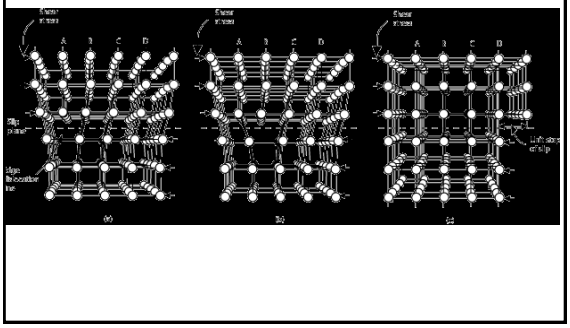
Strain Hardening

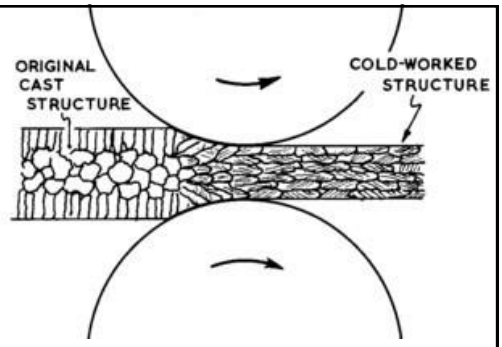
- Is the process of making a metal harder and stronger through plastic deformation.
- When a metal is plastically deformed, dislocations move and additional dislocations are generated.
- The more dislocations within a material, the more they will interact and become pinned or tangled.
- This will result decrease the mobility of the dislocations and a strengthening of the material.
- This type of strengthening is commonly called cold-working. It is called cold-working because the plastic deformation must occurs at a temperature low enough that atoms cannot rearrange themselves.
- When a metal is worked at higher temperatures (hot-working) the dislocations can rearrange and little strengthening is achieved.

54



55





- During cold rollling (above) metal becomes work hardened.

57

Advantages

- Better accuracy
- Better surface finish
- Strain hardening increases strength and hardness
- Grain flow during deformation provides directional properties
- **Contamination problems are minimized**
- No heating is needed

Disadvantages

- Higher forces and power are required
- Surface should be cleansed
- **Heavier and more powerful equipment is required**
- Ductility and strain-hardening limits the extent of forming

58

Warm working

Temperature between room temperature and re-crystallization temperature, roughly about $0.3\ T_m$ - $0.5\ T_m$

– Advantages against cold working

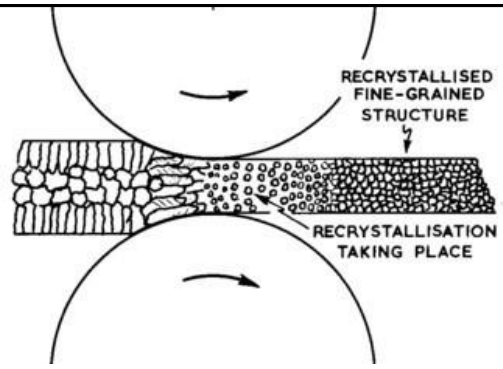
- Lower forces and power
- More intricate work geometries possible
- Need for annealing may be reduced/eliminated
- **Tools last longer**

59

Hot working

- Deformation at temperature above recrystallization temperature typically between $0.5T_m$ to $0.75T_m$
- Higher plastic deformation than cold working or warm working. Because of,
  - Strength coefficient is substantially less than at room temperature
  - Strain hardening exponent is zero (theoretically)
  - Ductility is significantly increased

60



- During a hot rolling process re-crystallisation can take place.

61

Advantages of Hot Working vs. Cold Working

- Lower forces and power required
- Larger deformation possible
- Metals that usually fracture in cold working can be hot formed
- Strength properties of product are generally isotropic

62

Disadvantages of Hot Working

- Lower dimensional accuracy
- Higher total energy required (due to the thermal energy to heat the workpiece)
- Work surface oxidation (scale), poorer surface finish
- Shorter tool life

63

Isothermal Forming

Preheating the tools to the same temperature as the work metal. This eliminates the surface cooling and the resulting thermal gradient in the workpart.

Normally applies to highly alloyed steels, titanium alloys and high-temperature nickel alloys.

64

Friction in Metal Forming

- In most metal forming processes, friction is undesirable:
  - Metal flow is retarded
  - Forces and power are increased
  - Wears tooling faster
- Friction and tool wear are more severe in hot working

65

Friction and Lubrication

- Lubrication is used to reduce friction at the workpiece-tool interface
- Lowers forces and increases drawability
- Better surface finish
- Removes heat from the tooling
- Commonly used lubricants are mineral oils ,soap solutions, heavy duty emulsions.

66

Considerations in Choosing a Lubricant

- Type of forming process (rolling, forging, sheet metal drawing, etc.)
- Hot working or cold working
- Work material
- Chemical reactivity with tool and work metals
- Ease of application
- Cost

67

Material Behavior in Metal Forming

- Plastic region of stress-strain curve is primary interest because material is plastically deformed
- In plastic region, metal's behavior is expressed by the flow curve
- Stress and strain in flow curve are true stress and true strain

$$\sigma = K \varepsilon^{n}$$

n - Strain hardening exponent (strain hardening index)

σ - applied Stress on the material

ε - Strain

K - Strength Coefficient

68

Tabulation of n and K Values for Several Alloys

Material	n	K (MPa)
• Low-carbon steel (annealed)	0.21	600
• 4340 steel alloy (annealed)	0.12	2650
• 304 stainless steel (annealed)	0.44	1400
• Copper (annealed)	0.44	530
• Naval brass (annealed)	0.21	585
• 2024 Aluminum alloy (heat treated—T3)	0.17	780
• AZ-31B Magnesium alloy (annealed)	0.16	450

71

Comparison of metal forming processes

Metal Forming Process	Advantages	Limitations
Open-die forging	• Inexpensive tooling and equipment. • Simple to operate. • Wide range of workpiece sizes can be used. • Suitable for low production volume.	• Can be used for simple shapes only. • Fairly skilled operators are required. • Production rate is low. • Dimensional accuracy and surface finish achieved are poorer. • Finishing required for achieving final shape.
Closed-die forging	• Suitable for high production rate. • Can be used for production of complex shapes. • Good dimensional accuracy and reproducibility	• High equipment and tooling cost. • Appropriate die set for production of each component. • More than one step required for each forging. • Finishing required for achieving final shape.
Hot rolling	• High production rate. • Suitable for large reduction. • Wide range of shapes (Billets, blooms, slabs, sheets, bars, tubes, structural sections, etc.) can be produced	• High equipment cost • Suitable for production of large sections. • Poor dimensional accuracy and finish.

72

Metal Forming Process	Advantages	Limitations
Cold rolling	• High production rate. • Suitable for production of plates, sheets, foils, etc. • Good dimensional accuracy and finish.	• High equipment cost. • Deformation limited to small reductions.
Hot extrusion	• Moderate cost of equipment and toolings. • Suitable for large reduction. • Complex sections and long products can be produced.	• Only constant cross-section can be produced. • Components with thin walls are difficult to produce. • Lubrication is necessary. • Dimensional accuracy and finish achieved are not good.
Impact extrusion	• High production rate. • Good finish and dimensional accuracy. • Generally no finishing is required. • Suitable for production of thin sections.	• Suitable for production of light components from softer materials. • Deformation limited to small reductions.

73

Metal Forming Process	Advantages	Limitations
Drawing	• Low equipment and tooling cost. • Good surface finish and dimensional accuracy. • High production rate. • Long lengths of rounds, tubings, square, angles, etc. can be produced.	• Deformation limited to small reductions. • Production of constant cross-sections only. • Lubrication is necessary.
Deep drawing	• High production rate. • Moderate equipment and tooling cost. • Good surface finish.	• Limited to forming of thin sheets. • Forming of shallow or deep parts of simple shapes only. • Finishing required
Punching and blanking	• High production rate. • Low cost of labour. • Almost any shape can be obtained. • Moderate equipment cost.	• Limited to thin sheet applications. • Cost of tooling can be high.

74

75