Forging and Extrusion Processes

Dr. N S Mahesh
Introduction

• Practically all metals, which are not used in cast form are reduced to some standard shapes for subsequent processing.
• Manufacturing companies producing metals supply metals in form of ingots which are obtained by casting liquid metal into a square cross section.
  – Slab (500-1800 mm wide and 50-300 mm thick)
  – Billets (40 to 150 sq mm)
  – Blooms (150 to 400 sq mm)
• Sometimes continuous casting methods are also used to cast the liquid metal into slabs, billets or blooms.
• These shapes are further processed through hot rolling, forging or extrusion, to produce materials in standard form such as plates, sheets, rods, tubes and structural sections.
Forming and Shaping Processes

- Forging of Metals
- Sheet-Metal Forming Processes
- Extrusion and drawing of Metals
- Forming and shaping Plastics and Composite materials
- Rapid Prototyping
- Processing of PM, Ceramics, Glass and Superconductors
Sequence of operations for obtaining different shapes
Forging

- Forging is the working of metal into a useful shape by hammering or pressing.
- The oldest of the metalworking arts (primitive blacksmith).
- Replacement of machinery occurred during early the Industrial revolution.
- Forging machines are now capable of making parts ranging in size of a bolt to a turbine rotor.
- Most forging operations are carried out hot, although certain metals may be cold-forged.
Forging

• Forging is perhaps oldest metal working process and was known even during prehistoric days when metallic tools were made by heating and hammering.

• Forging is basically involves plastic deformation of material between two dies to achieve desired configuration.

• Depending upon complexity of the part forging is carried out as open die forging and closed die forging.

• In open die forging, the metal is compressed by repeated blows by a mechanical hammer and shape is manipulated manually.

• In closed die forging, the desired configuration is obtained by squeezing the workpiece between two shaped and closed dies.
Forging

- On squeezing the die cavity gets completely filled and excess material comes out around the periphery of the die as flash which is later trimmed.
- Press forging and drop forging are two popular methods in closed die forging.
- In press forging the metal is squeezed slowly by a hydraulic or mechanical press and component is produced in a single closing of die, hence the dimensional accuracy is much better than drop forging.
- Both open and closed die forging processes are carried out in hot as well as in cold state.
- In forging favorable grain orientation of metal is obtained
Forging

- Forged articles have outstanding grain structures and the best combination of mechanical properties.
- Wrenches, and automotive crankshafts and piston connecting rods are typical articles formed by forging

A macroetched section through a forging indicates that the grain flow follows the contour of the component, which often maximizes strength in the direction of greatest operating stress.
Some Disadvantages of Forging

- Some disadvantages of forging are the high cost and high residual stress produced.

- Most forging processes are expensive because of the cost of making dies, so long production runs are usually necessary to reduce costs.

- The high residual stresses in forgings are often released when they are machined and cause warping when heavy cuts are taken.
Microstructure as a function of manufacturing method

(a) Casting  (b) Machining form a blank  (c) Forging

Each process has its own advantages and limitations regarding external and internal characteristics, material properties, dimensional accuracy, surface finish and the economics of production

Ref [3]
Effect of forging on microstructure

- The formation of a grain structure in forged parts is elongated in the direction of the deformation.
- The metal flow during forging provides fibrous microstructure (revealed by etching). This structure gives better mechanical properties in the plane of maximum strain but (perhaps) lower across the thickness.
- The workpiece often undergo recrystallisation, therefore, provide finer grains compared to the cast dendritic structure resulting in improved mechanical properties.
Orientation of Grains

Castings

Cast structure

Mainly epitaxial, dendritic or equiaxed grains

Forgings

Fibre structure in forged steels

Redistribution of grains in the working directions

© M.S Ramaiah School of Advanced Studies - Bangalore
Flow lines in Forging

Flow lines in forging

Metal Flow
Parting-line location and its influence on grain-flow patterns in a channel section forging

a. Parting lines resulting in metal flow patterns that cause defects

b. Parting lines resulting in smooth flow lines at stressed sections
Classification of Forging processes

By equipment
1) Forging hammer or drop hammer
2) Press forging

By process
1) Open - die forging
2) Closed - die forging
Open Die Forging

• Most forging processes begin with open die forging

• Open die forging is hot mechanical forming between flat or shaped dies in which the metal flow is not completely restricted

• The stock is laid on a flat anvil while the flat face of the forging hammer is struck against the stock.

• The equipment may range from the anvil and hammer to giant hydraulic presses
Upsetting with Barrelling

Forging force, \( F = Y_f \pi r^2 \left(1 + \frac{2\mu r}{3h}\right) \)

a) Solid cylindrical billet upset between two flat dies
b) Uniform deformation of the billet without friction
c) Deformation with friction
Cogging operation on a rectangular bar

a) Cogging operation on a rectangular bar

b) Reducing the diameter of a bar by open-die forging

c) The thickness of a ring being reduced by open-die forging
Stages in Open-Die Forging

(a) forge hot billet to max diameter
(b) “fuller: tool to mark step-locations
(c) forge right side
(d) reverse part, forge left side
(e) finish (dimension control)
Closed Die Forging

- The shaping of hot metal within the cavities or walls of two dies that come together to completely enclose the workpiece.
Impression-Die Forging

(a) through (c) stages in impression-die forging of a solid round billet

(d) Standard terminology for various features of a forging die
Forging a rod, Fullering and Edging

a) Stages in forging a connecting rod for an internal combustion engine

b) Fullering

c) Edging operations to properly distribute the material when preshaping the blank for forging
Hammer forging two connecting rods; (a) bar stock; after (b) fullering, (c) “rolling”, (d) blocking, (e) finishing, (f) trimming; (g) the flash; (h) the forging dies.
Forged components for automotive applications

Steering knuckle

Flange

Rail

© M.S Ramaiah School of Advanced Studies - Bangalore
Drop forged components (Auto)
Forged components for automotive applications
Forged components for automotive applications
The coining process
# Metals in decreasing order of Forgeability

<table>
<thead>
<tr>
<th>Metal or alloy</th>
<th>Approximate range of hot-forging temperatures (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloys</td>
<td>400-550</td>
</tr>
<tr>
<td>Magnesium alloys</td>
<td>250-350</td>
</tr>
<tr>
<td>Copper alloys</td>
<td>600-900</td>
</tr>
<tr>
<td>Carbon- and low-alloy steels</td>
<td>850-1150</td>
</tr>
<tr>
<td>Martensitic stainless steels</td>
<td>1100-1250</td>
</tr>
<tr>
<td>Austenitic stainless steels</td>
<td>1100-1250</td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>700-950</td>
</tr>
<tr>
<td>Iron-based superalloys</td>
<td>1050-1180</td>
</tr>
<tr>
<td>Cobalt-based superalloys</td>
<td>1180-1250</td>
</tr>
<tr>
<td>Tantalum alloys</td>
<td>1050-1350</td>
</tr>
<tr>
<td>Molybdenum alloys</td>
<td>1150-1350</td>
</tr>
<tr>
<td>Nickel-based superalloys</td>
<td>1050-1200</td>
</tr>
<tr>
<td>Tungsten alloys</td>
<td>1200-1300</td>
</tr>
</tbody>
</table>
Defects in forged parts

Examples of defects in forged parts. a) laps formed by web buckling during forging. b) internal defects caused by an oversized billet.
Typical forging defects

- Pitted surface, due to oxide scales occurring at high temperature stick on the dies.
- Surface cracking, due to temperature differential between surface and centre, or excessive working of the surface at too low temperature.
- Microcracking, due to residual stress.
- Flash line crack, after trimming-occurs more often in thin workpieces. Therefore should increase the thickness of the flash.
- Cold shut or fold, due to flash or fin from prior forging steps is forced into the workpiece.
- Internal cracking, due to secondary tensile stress.
Extrusion of metals

- Extrusion is the process by which a block/billet of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure.
- In general, extrusion is used to produce cylindrical bars or hollow tubes or for the starting stock for drawn rod, cold extrusion or forged products.
- Most metals are hot extruded due to large amount of forces required in extrusion.
- Complex shape can be extruded from the more readily extrudable metals such as aluminum.
Extrusion Products

Typical parts produced by extrusion are trim parts used in automotive and construction applications, window frame members, railings, aircraft structural parts.

Example: Aluminum extrusions are used in commercial and domestic buildings for window and door frame systems, prefabricated houses/building structures, roofing and exterior cladding, curtain walling, shop fronts, etc.

Furthermore, extrusions are also used in transport for airframes, road and rail vehicles and in marine applications.
Classification of extrusion processes

There are several ways to classify metal extrusion processes;

**By direction**
- Direct / Indirect extrusion
- Forward / backward extrusion

**By operating temperature**
- Hot / cold extrusion

**By equipment**
- Horizontal and vertical extrusion
• The metal billet is placed in a container and driven through the die by the ram.  
• The dummy block or pressure plate, is placed at the end of the ram in contact with the billet.  
• Friction is at the die and container wall - requires higher pressure than indirect extrusion.  

• The hollow ram containing the die is kept stationary and the container with the billet is caused to move.  
• Friction at the die only (no relative movement at the container wall) requires roughly constant pressure.  
• Hollow ram limits the applied load.
• Metal is forced to flow in the same direction as the punch.
• The punch closely fits the die cavity to prevent backward flow of the material.

• Metal is forced to flow in the direction opposite to the punch movement.
• Metal can also be forced to flow into recesses in the punch.
Cold extrusion

Cold extrusion is the process done at room temperature or slightly elevated temperatures. This process can be used for most materials-subject to designing robust enough tooling that can withstand the stresses created by extrusion.

Metals that can be extruded: lead, tin, aluminum alloys, copper, titanium, molybdenum, vanadium, steel.

cold extruded parts: collapsible tubes, aluminum cans, cylinders, gear blanks.

Advantages

• No oxidation takes place.
• Good mechanical properties due to severe cold working as long as the temperatures created are below the recrystallisation temperature.
• Good surface finish with the use of proper lubricants.
Hot extrusion

Hot extrusion is done at fairly high temperatures, approximately 50 to 75% of the melting point of the metal. The pressures can range from 35-700 MPa.

• The most commonly used extrusion process is the hot direct process. The cross-sectional shape of the extrusion is defined by the shape of the die.

• Due to the high temperatures and pressures and its detrimental effect on the die life as well as other components, good lubrication is necessary. Oil and graphite work at lower temperatures, whereas at higher temperatures glass powder is used.
Case Study
Costs of a rod made by forging and casting
Cost-per-piece in Forging

Typical (cost-per-piece) in forging
The light weight forged piston

- Difference between forging and casting processes for making piston
Forged piston (left) and cast piston (right).

The left weights 255g, the compression height is 23mm and total height is 41mm.

The right weights 360g, the compression height is 28 mm and total height is 50mm
Controlled forging process for piston

1) The installed heater controls the forging temperature of the material, enabling the shaping of the thin portion

2) The temperature control and the developed lubricant prevent the die from seizure

3) The quantitative lubricant control maintains the quality of the forged pistons

4) The billets (disk shape) for forging are prepared from a continuously cast bar which has a round cross-section
Forming of Automobile Steel Wheels

Aluminum, casting, one piece

Steel, sheet metal forming, two pieces
Conventional Forming of Automobile Steel Wheels

One-Piece Press Forming

1) Only multi-stage stamping
2) Omission of welding process
3) Continuous forming
4) Reduction in cost
5) Increase of wheel strength

Disk forming  Rim forming
Blanking  Bending and welding
Press forming  Roll forming
Welding  Two pieces

© M.S Ramaiah School of Advanced Studies - Bangalore
One-Piece Press Forming

Blank $\rightarrow$ (a) Deep drawing and redrawing $\rightarrow$ (b) Reverse drawing

(c) 1st flaring $\rightarrow$ (d) 2nd flaring $\rightarrow$ (e) 3nd flaring

(f) Rim finishing $\rightarrow$ (g) Disk finishing

Forming of deeply drawn cup into wheel

$\phi 77\text{mm}, t_0 = 0.5\text{mm}$
Surface Roughness for Various Metalworking Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Roughness (R_a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>μ</td>
</tr>
<tr>
<td>Sand casting</td>
<td></td>
</tr>
<tr>
<td>Hot rolling</td>
<td></td>
</tr>
<tr>
<td>Forging</td>
<td></td>
</tr>
<tr>
<td>Permanent mold casting</td>
<td></td>
</tr>
<tr>
<td>Investment casting</td>
<td></td>
</tr>
<tr>
<td>Extruding</td>
<td></td>
</tr>
<tr>
<td>Cold rolling, drawing</td>
<td></td>
</tr>
<tr>
<td>Die casting</td>
<td></td>
</tr>
</tbody>
</table>

Surface roughness in casting and other metalworking processes.
Summary

• Forging machines
• Forging operations
• Case study - forging of Piston
• Forging defects
• Extrusion process
  have been discussed

Thank You