CHAPTER 14
FORGING OF METALS

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Introduction

- What is forging?
  - A process in which the workpiece is shaped by compressive forces applied through dies and tools.
  - Was initially used by hammering metals with tools in shaping jewelry and coins.
  - Can be performed using a hammer and an anvil.

- Forging results in discrete parts
  - Bolts, rivets, connecting rods, shafts for turbines, gears, hand tools.
Introduction

- Temperature
  - Room or elevated

- Cold forging
  - requires greater force
  - Good dimensional accuracy and surface finish

- Hot forging
  - requires less force
  - dimensional accuracy and surface finish not as good

- Finishing operations are generally required
  - Heat treating

- Precision forging
  - New trend
  - Goal is to obtain near-net shaped parts

- Grain structure in forging can be controlled
  - Results in good strength and toughness

(a) Casting  
(b) Machining  
(c) Forging
Open-Die Forging

What is it?
- A workpiece is placed between two flat dies and reduced in height by compression.
- Sizes may be very small up to 75 ft (23 meter)

Other names
- Flat-die forging
- Upsetting

Ideal shape
- Deformed uniformly

Barreling
- Also called pancaking
- Shape deforms like a barrel
- Caused by
  - higher frictional forces at the contact surface to the die.
    - High frictional forces at contact surface reduces deformation there.
  - Thermal effects
    - Hot workpiece is cooled quickly when in contact with the cool die. The material close to the surface has higher resistance to deformation.

Coggin
- Also called: drawing out
- An open die forging operation in which the thickness of the bar is reduced by successive forging steps.
### Characteristics of Forging Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open die</td>
<td>Simple, inexpensive dies; useful for small quantities; wide range of sizes available; good strength characteristics</td>
<td>Limited to simple shapes; difficult to hold close tolerances; machining to final shape necessary; low production rate; relatively poor utilization of material; high degree of skill required</td>
</tr>
<tr>
<td>Closed die</td>
<td>Relatively good utilization of material; generally better properties than open-die forgings; good dimensional accuracy; high production rates; good reproducibility</td>
<td>High die cost for small quantities; machining often necessary</td>
</tr>
<tr>
<td>Blocker type</td>
<td>Low die costs; high production rates</td>
<td>Machining to final shape necessary; thick webs and large fillets necessary</td>
</tr>
<tr>
<td>Conventional type</td>
<td>Requires much less machining than blocker type; high production rates; good utilization of material</td>
<td>Somewhat higher die cost than blocker type</td>
</tr>
<tr>
<td>Precision type</td>
<td>Close tolerances; machining often unnecessary; very good material utilization; very thin webs and flanges possible</td>
<td>Requires high forces, intricate dies, and provision for removing forging from dies</td>
</tr>
</tbody>
</table>
Impression-Die Forging

- The workpiece acquires the shape of the die cavities (impressions are mad)

- The process:
  - The blank is created by
    - Cutting from an extruded or drawn bar stock
    - Powder metallurgy
    - Casting
    - Preform blank in a prior forging operation

- Blank is placed in the lower die
- The upper die descends
- The workpiece deforms due to the compressive forces applied.

- Fullering (Figure b)
  - Material is distributed away from an area

- Edging (Figure c)
  - Material is forced into an area
Figure 14.5 (a) through (c) Stages in impression-die forging of a solid round billet. Note the formation of flash, which is excess metal that is subsequently trimmed off (see Fig. 14.7). (d) Standard terminology for various features of a forging die.
Figure 14.7 (a) Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash required to ensure proper filling of the die cavities. (b) Fullering and (c) edging operations to properly distribute the material when preshaping the blank for forging.
Impression-Die Forging (cont.)

- **Blocking**
  - Uses blocking dies. Results in almost the proper shape

- **Finishing**
  - In impression dies.
  - This gives the final details of the forging

- **Removal of flash**
  - Flash: Material the flows out through the parting line

- **Closed Die forging**
  - No flash is formed. The material completely fills the cavity.
    - Undersized blanks: don’t fill the cavity completely
    - Oversized blanks: flash is created. Excessive pressure is needed → dies may fail prematurely.
Comparison of Forging With and Without Flash

- The right side of the sphere experiences flashless forging.
- The left side experiences forging with flash.
Precision Forging

- Trend of today...
- Near-net shape, near-net-forging
  - Formed part is close to the final dimensions
- Special dies with higher accuracy
- Greater forces are required
  - Material used: those requiring low forging loads
    - Aluminum alloys, magnesium alloys
- Final part requires less machining
- Good surface finish
- Cost: Tradeoff
  - Higher investment
    - More expensive dies
    - Higher loads
    - Higher accuracy in positioning of the workpiece
  - Financial advantage
    - Less material is wasted
    - Less machining is required
Coining

- Completely closed-die forging process
- Used in:
  - Minting coins, medallions, and jewelry
- Lubricants can’t be used
  - Can become entrapped in the cavity, hindering full closure of the die \(\rightarrow\) some surface details may not be imprinted
Related Forging Operations

- **Heading**
  - Upsetting operation (flat-die forging)
  - Performed at the end of a round rod/wire
  - Example: heads of bolts
  - Buckling may occur
    - Unsupported length-to-diameter ratio max: 3:1

- **Piercing**
  - Indenting but not breaking through
  - May be followed by punching
  - Used to produce a cavity in the workpiece

- **Hubbing**
  - Pressing a hardened punch into the block of metal
  - Typically has a specific tip geometry
  - Used to make dies for forging operations

Figure 14.11 (a) Heading operation, to form heads on fasteners such as nails and rivets. (b) Sequence of operations to produce a bolt head by heading.

Figure 14.12 A pierced round billet, showing grain flow pattern. 
*Source: Courtesy of Ladish Co., Inc.*
Figure 14.12 A pierced round billet showing grain-flow pattern (see also Fig 14.12c).  
Source: Courtesy of Ladish Co., Inc.
ROLL FORGING
- Cross section of the bar is reduced or shaped by passing it through a pair of rolls with shaped grooves.

SKEW ROLLING
- Used for making ball bearings
- Round wire/rod is fed into the roll gap. Spherical blanks are formed.
- Spherical balls can also be formed by upsetting (flat-die forging) pieces sheared from a round bar.

ISO THERMAL FORGING or HOT-DIE FORGING
- Dies are heated to the same temperature as the hot workpiece
- Expensive and low production
- Complex parts with good dimensional accuracy
Forging Die Design

- The material will flow in the direction of least resistance. Shape the workpiece accordingly.

- Preshape
  - Material should not easily flow into the flash
  - Minimize sliding at the workpiece-die interface
  - CAE software can be used to aid in understanding the flow of material: mold-flow software

- Die design features
  - Flash
  - Gutter
  - Land
  - Parting line
  - External and internal draft angles
    - Internal: 7-10°
    - External: 3-5°
  - Radii: small are not good
Die inserts
- Higher accuracy
- Better material
- Easier to replace
- Reduces the cost

Figure 14.6 Die inserts used in forging an automotive axle housing.
Die Materials and Lubrication

- Requirements for die materials
  - Strength and toughness at elevate temperatures
  - Hardenability and ability to harden uniformly
  - Resistance and to mechanical and thermal shock
  - Wear resistance
  - Common materials are tool and die steels

- Lubrication
  - Reduces friction and wear
  - Effect the forces required and the flow of metal in the cavities
  - Can act as a thermal barrier between the die and workpiece (slows the rate of cooling)
  - Acts as a parting agent
  - Used: graphite, glass, molybdenum disulfide
Forgeability

- Ability of material to undergo deformation without cracking
- No test is universally accepted
- Common tests
  - Upset a solid cylindrical specimen and observe cracking
    - The greater the deformation prior to cracking, the higher the forgeability
  - Hot-twist test
    - A round specimen is twisted continuously until it fails

<table>
<thead>
<tr>
<th>Metal or alloy</th>
<th>Approximate range of hot forging temperature (°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-base superalloys</td>
<td>1050–1180</td>
</tr>
<tr>
<td>Cobalt-base 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-base superalloys</td>
<td>1050–1200</td>
</tr>
<tr>
<td>Tungsten alloys</td>
<td>1200–1300</td>
</tr>
</tbody>
</table>

Forgeability of metals are in descending order
Forging Defects

- Surface cracking
- Insufficient volume to fill the cavity
- Grain flow pattern is important
  - Flow lines may reach a surface perpendicularly: end grains
    - Act as stress raisers
    - Be attacked by the environment
- Forging defects can cause fatigue failures
Figure 14.16 Examples of defects in forged parts. (a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem. (b) Internal defects caused by an oversized billet. Die cavities are filled prematurely, and the material at the center flows past the filled regions as the die closes.
Forging Machines: Presses

Presses

- Hydraulic press
  - Operate at a constant speed
  - They are load limited (press stops if the load required exceeds its capacity)
  - Takes longer than other types of forging machines → workpiece may cool
  - Capacity
    - 125MN for open forging
    - 450 MN – 730 MN (differs in different countries) closed-die forging
  - Compared to mechanical presses
    - Higher initial cost, slower
    - Require less maintenance

Schematic illustration of the principles of various forging machines. (a) Hydraulic press.
Forging Machines: Presses (cont.)

- Mechanical press
  - High production rates
  - Require less operating skills than other forging processes
  - 2.7 MN – 107 MN
  - Knuckle-joint mechanical press
    - Very high forces can be applied with this design

- Screw Press
  - Forging load is transmitted through a vertical screw
  - Used for both open- and closed-die forging operations

b) Mechanical press with an eccentric drive; the eccentric shaft can be replaced by a crankshaft to give the up-and-down motion to the ram.
(c) Knuckle-joint press.
(d) Screw press.
Forging Machines: Hammers

- Derive their energy from potential energy of the ram
  - $V = mgh$
- High speeds
- Types
  - Gravity drop hammers
    - Free-falling ram
  - Power drop hammers
    - Downstroke is accelerated by steam, air, hydraulic pressure
  - Counterblow hammers
    - Two rams approach each other simultaneously
    - Vertical or horizontal
# Speed Range of Forging Equipment

## TABLE 14.4

<table>
<thead>
<tr>
<th>Equipment</th>
<th>m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic press</td>
<td>0.06–0.30</td>
</tr>
<tr>
<td>Mechanical press</td>
<td>0.06–1.5</td>
</tr>
<tr>
<td>Screw press</td>
<td>0.6–1.2</td>
</tr>
<tr>
<td>Gravity drop hammer</td>
<td>3.6–4.8</td>
</tr>
<tr>
<td>Power drop hammer</td>
<td>3.0–9.0</td>
</tr>
<tr>
<td>Counterblow hammer</td>
<td>4.5–9.0</td>
</tr>
</tbody>
</table>
Forging Practice and Process Capabilities

- Prepare slug, billet, or preform by shearing, sawing, cutting off
- For hot forging
  - Heat the workpiece
  - Preheat and lubricate the dies
- For cold forging
  - Lubricate the blank
- Forge in appropriate dies
- Remove flash by trimming, machining, grinding
- Clean forging, check dimensions
  - Machine if necessary
- Additional operations
  - Heat treating
- Inspect the forging
- Tolerance: +/- 0.5% to +/- 1% of the dimensions
- Automation in forging
  - Loading and unloading into the furnace
  - Mechanical manipulators are used to move the billets in the dies
  - Important in the manufacturing of high quantity parts
    - Gears, axles, nuts, bolts
Die Manufacturing Methods

➢ Dies are made by:
  ▪ Casting, forging, machining, grinding, and electrical or electrochemical methods of die sinking.
  ▪ Most common: machines dies from forged die blocks
  ▪ Hubbing
    • Pressing a hardened punch into the block of metal
    • Typically has a specific tip geometry
    • Used to make dies for forging operations
Die Failures

- Improper design
  - Sharp corners
  - Abrupt changes in cross sections
  - Small radii
- Defective materials
- Improper heat treatment and finishing operations
- Overheating
- Excessive wear
- Overloading
- Misuse
- Improper handling

- Residual stresses can cause serious injury
  - Dies resting may suddenly disintegrate
    - Pieces will fly away at high speeds → injury and death
  - Metal shielding should be used around dies
The Economics of Forging

- Tool and die costs range from moderate to high
- Tool and die costs are spread over the parts manufactured
- Labor costs in forging are moderate
  - Reduced by automation
Example of Forging: Wrench

- High alloy steel
  - Alloy → chrome vanadium
  - High strength
- Strain hardened
- Mass produced
- Drop-forged
Thank You