BMM3643 Manufacturing Processes Bulk Metal Forming Processes (Forging Operations)

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Chapter Synopsis

This chapter will introduced students to a broad topic of metal forming processes which involved a large amount of permanent (plastic) deformation. Permanent deformation of metals were formed under tension, compression, shear or a combination of loads. There are two categories of deformation such as bulk deformation and sheet metal forming. Types of material used and proper selection of forming and shaping bulk metal will impact on product quality as well as manufacturing costs.

Chapter Information

Lesson Objectives:

Bulk Metal Forming Processes

Lesson Objective:

At the end of this lecture, students should be able to understand and explain the following:

- Introduction to forming and shaping bulk metal processes
- Understand various types of forging operations
- Analyze the defects occurred by different forging operations
- Differentiate a variety of forging machines and their characteristics

Introduction to Bulk Metal Forming Processes

- Metal forming is a shaping production process that applied the permanent deformation by using loads.
- These processes are designed to exploit the property of engineering materials (mostly metals) known as plasticity.
- All processes was done in the solid state, therefore no handling of liquid metals.
- The amount of waste can be reduced substantially compare to material removal operations.
- However, the forces required are usually high to deform the metals.
- Machinery and tooling also expensive and normally suitable for mass production

Introduction to Bulk Metal Forming Processes (continue)

- Significant change in surface area, reduction of thickness and cross-section work material (overall geometry materials will be changed)
- Work material temperature can be one of most important process variables.
- An increase in temperature brings a decrease in strength, an increase in ductility, and a decrease in the rate of strain hardening – these effects help in promote the ease of deformation.
- Bulk metal forming processes can be classified based on working temperature:
  - i. Hot working
  - ii. Cold working
  - iii. Warm working

Bulk Metal Forming - Hot Working

- Hot working is plastic deformation of metals at a temperature above the recrystallization temperature.
- About 0.6 times of the material melting point based on absolute temperature scale (Kelvin or Degree Celsius)
- The recrystallization temperature varies greatly according to different materials.
- For example: Tin is near hot-working conditions at room temperature, Steels require temperatures near 1093°C, Tungsten has hot working temperature about 2204°C.

Bulk Metal Forming - Cold Working

- Cold working is the plastic deformation of metals at a temperature below the recrystallization temperature.
- Usually less than 0.3 times the workpiece melting temperatures.
- Normally it is performed at room temperature, but mildly elevated temperature will be applied to provide increased ductility and reduced strength.

Bulk Metal Forming - Warm Working

- Deformation produced at temperatures intermediate between hot and cold working.
- Temperatures applied are slightly above room temperature but below the recrystallization temperature.
- $0.3T_m < T < 0.6T_m$ where T_m = melting point (absolute temperature) for metals

Advantages & Disadvantages of Hot Working

Advantages:

- Big amount of forming is possible
- Lower forces and power are required
- Forming of materials with low ductility
- No hardening work - no additional annealing is required

Disadvantages:

- Lower accuracy and surface finish
- Higher production cost
- Shorter tool life

Advantages and Limitations of Cold Working

Advantages:

– Required no heating element
– Good surface finish
– Better accuracy and flatness
– Better reproducibility
– Mechanical properties are improved (e.g: strength, fatigue and wear)
– Contamination problems can be minimized

Limitations:

– Higher forces are required
– Heavier and more powerful of equipment needed
– Less ductility of metals
– Undesirable residual stresses occurred
– Metal surfaces must be clean

Advantages & Limitations of Warm Working

Advantages:

- Used lower forces and power than required in cold working.
- More intricate work geometries possible to be produced.
- The needs for annealing can be reduced or eliminated due to less residual stresses.

Limitation:

- Some investment in furnaces is needed.

Classification of Bulk Metal Forming Processes: Working Temperature

- Hot working processes:
  - Forging, Extrusion, Drawing, Rolling
  - Forming of tubes and pipes, etc.
- Cold working processes:
  - Sheet metal working: Bending, Shearing, Deep drawing, Blanking, etc.

Types of Forging Processes

1. Open-die forging

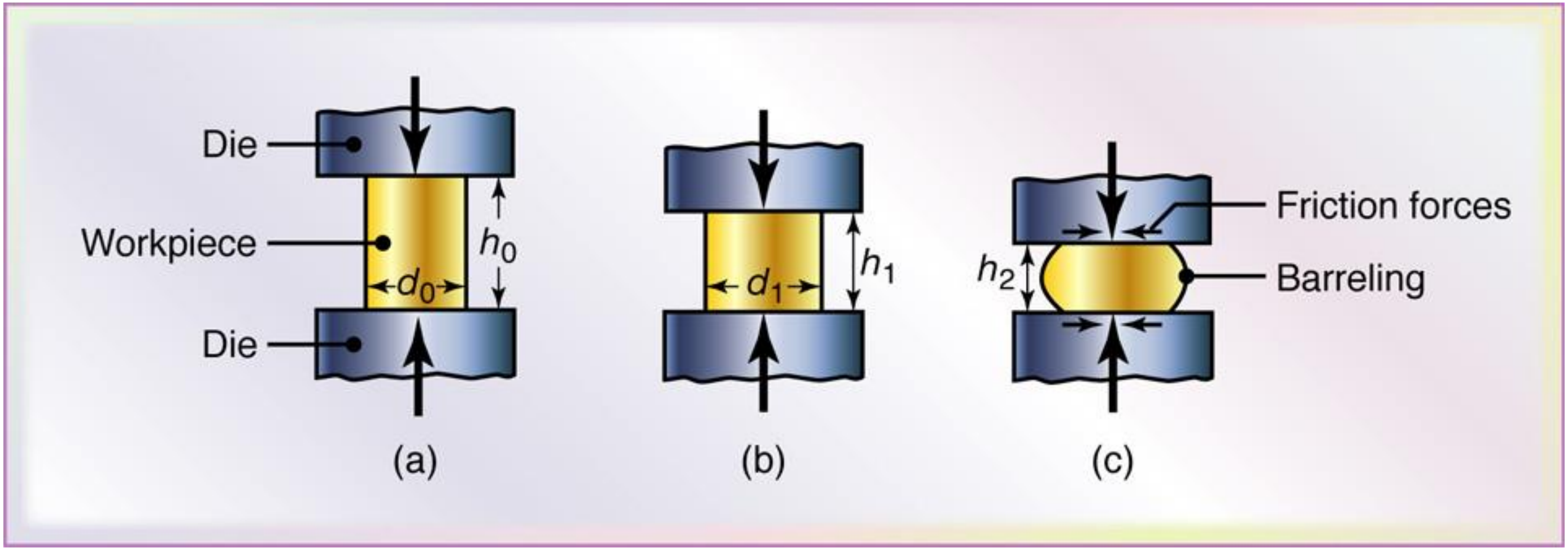
2. Closed-die forging (Impression)

3. Precision forging (Flashless)

Open-die Forging

- Work is compressed between two flat dies, allowing metal to flow laterally without constraint.
- Common names include *upsetting* or *upset forging.*

SCHEMATIC OF OPEN-DIE FORGING



(a) Solid cylindrical billet upset between two flat dies.

(b) Uniform deformation of the billet without friction.

(c) Deformation with friction. Note barrelling of the billet caused by friction forces at the billet-die interfaces.

Source by Kalpakjian Book, 2014

Formulae of Open-die Forging Force

- Forging force, F, in an open-die forging operation can be estimated as:

$$F = Y_f \pi r^2 \left(1 + \left(2\mu r / 3h\right)\right)$$

Y_f = flow stress (true stress)

μ = coefficient of friction between the workpiece and the die

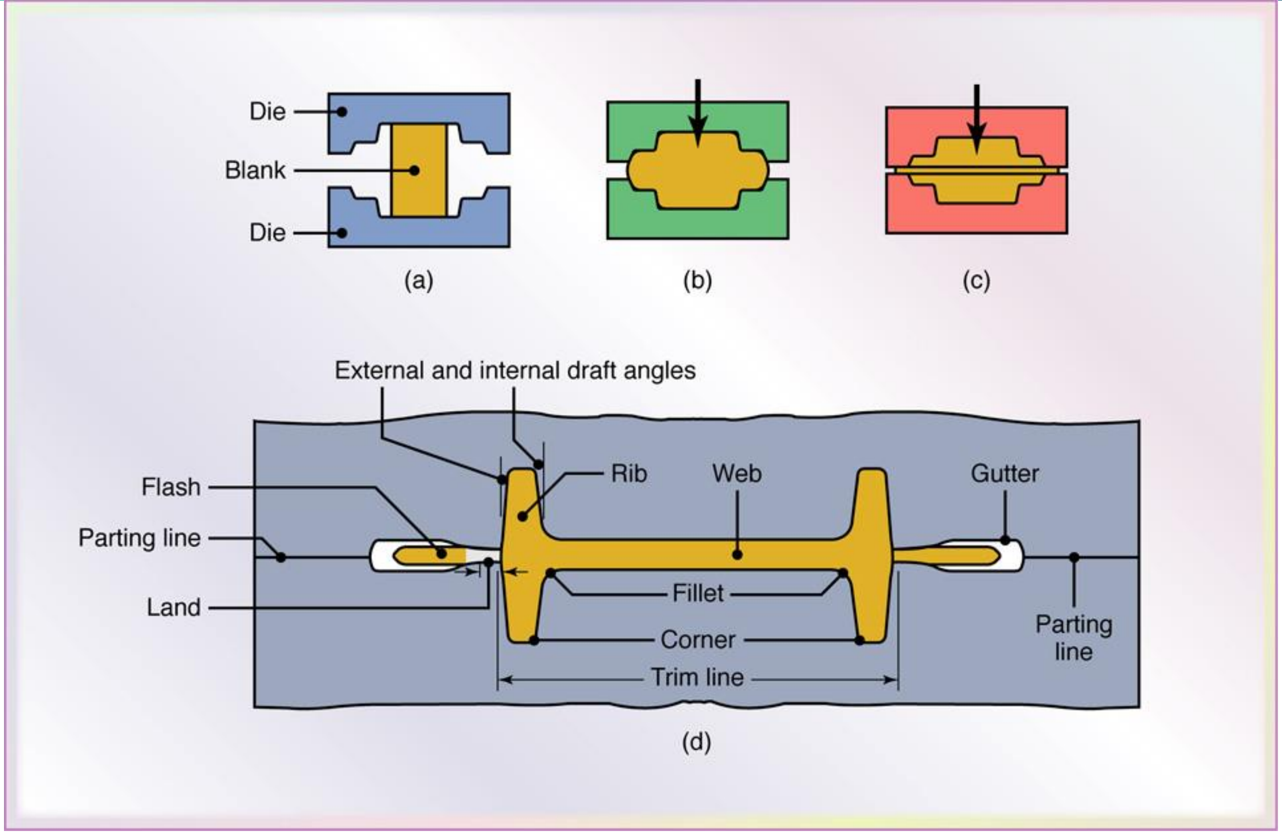
r = radius of the workpiece

h = height of the workpiece

Closed-die Forging

- Die surfaces contain a cavity or impression (desired part’s design) that will be forced onto the work material, thus allowing metal to flow - flash created
- The work material will imprint the shape of the die cavities while being forged between two shaped dies.

Closed-Die Forging



(a) - (c): Stages in close-die forging of a solid round billet. Note the formation of flash, which is excess metal that is subsequently trimmed off (d) Standard terminology for various features of a forging die.

Source by Kalpakjian Book, 2014

Formulae of Closed-Die Forging Force

- Forging force, F in an closed-die forging operation can be calculated as:

$$F = kY_fA$$

Yf = flow stress (true stress)

k = multiplying factor

A = projected area of the forging, including flash

Advantages & Limitations
Closed-Die Forging Versus Machining Operations

Advantages:

– Higher production rates
– Conservation of metal (less waste)
– Greater strength
– Favorable grain orientation in the metal

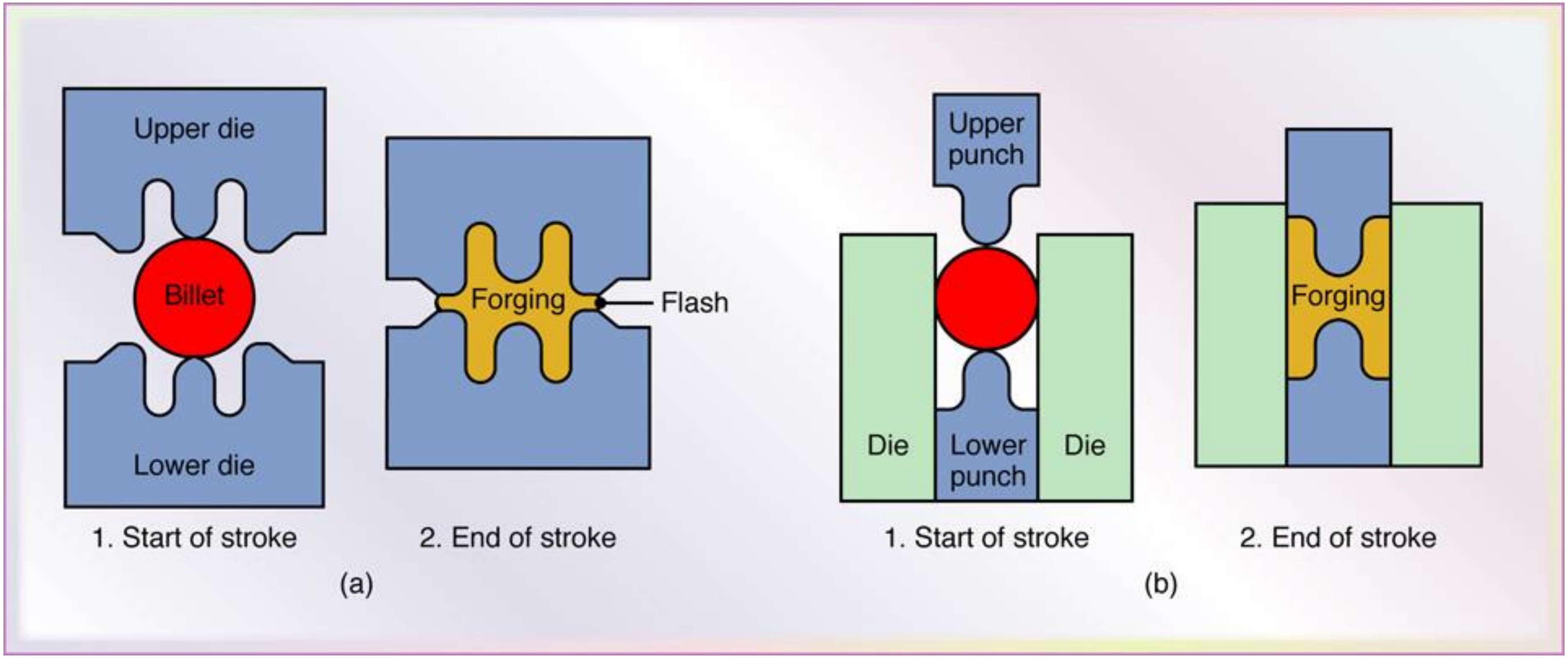
Limitations:

– Not capable of close tolerances

Precision Forging

- Special dies used to produce parts in order to obtain excellent accuracies.
- Little excess material on the forged part (flashless).
- The work material volume must equal with die cavity volume follows very close dimensional tolerance.
- Process control more demanding than closed-die forging.
- Best suited to part geometries that are simple and symmetrical.

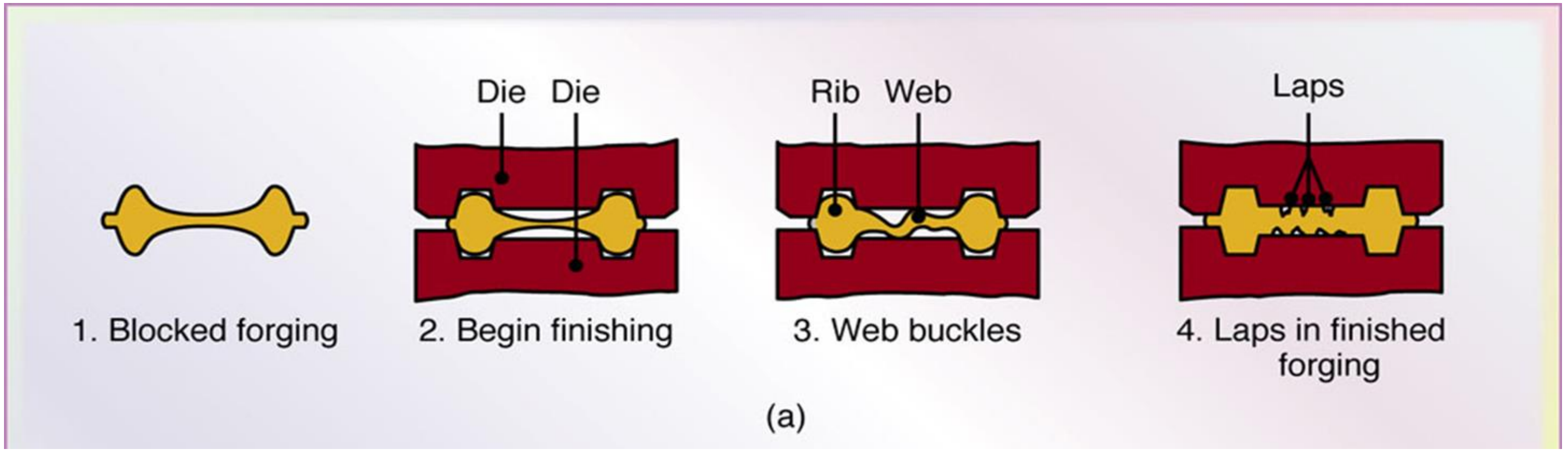
Closed-Die Forging Versus Precision Forging



Comparison of closed-die forging with flash (left side) and precision or flashless forging (right side) of a round billet. *Source* After H. Takemasu, V. Vazquez, B. Painter, and T. Altan.

Types of Forging Defects

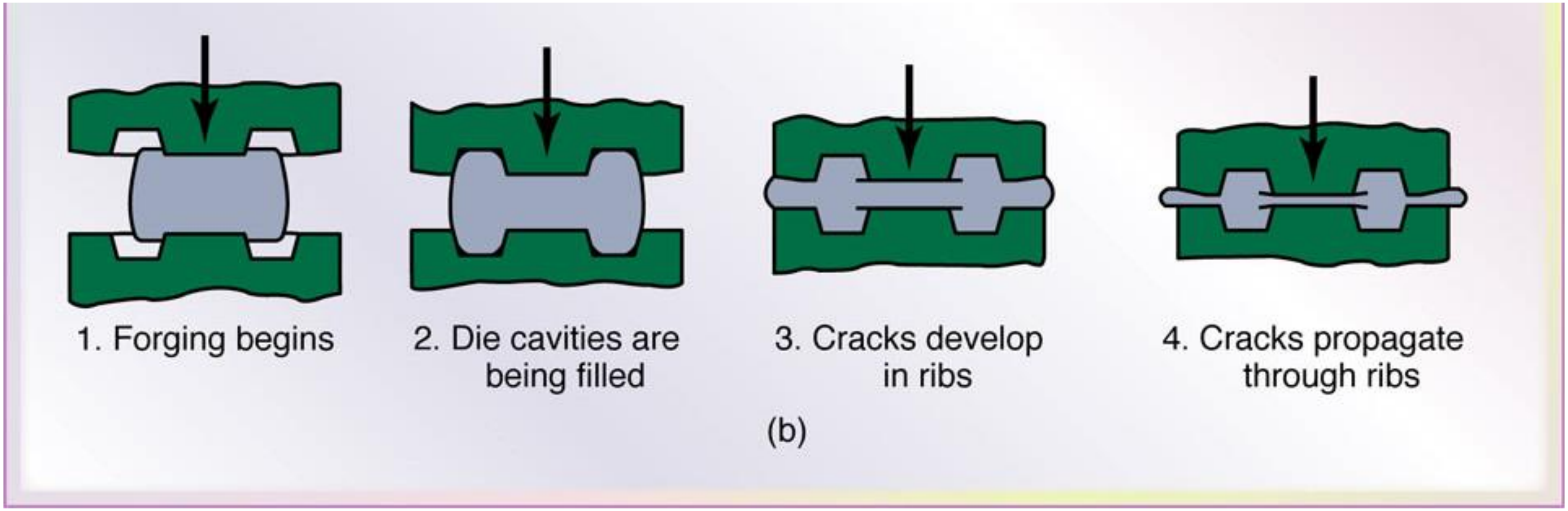
- Surface cracking
- Internal defects
- Web buckling (laps formation)



Examples of defects in forged parts. (a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem.

Source by Kalpakjian Book, 2014

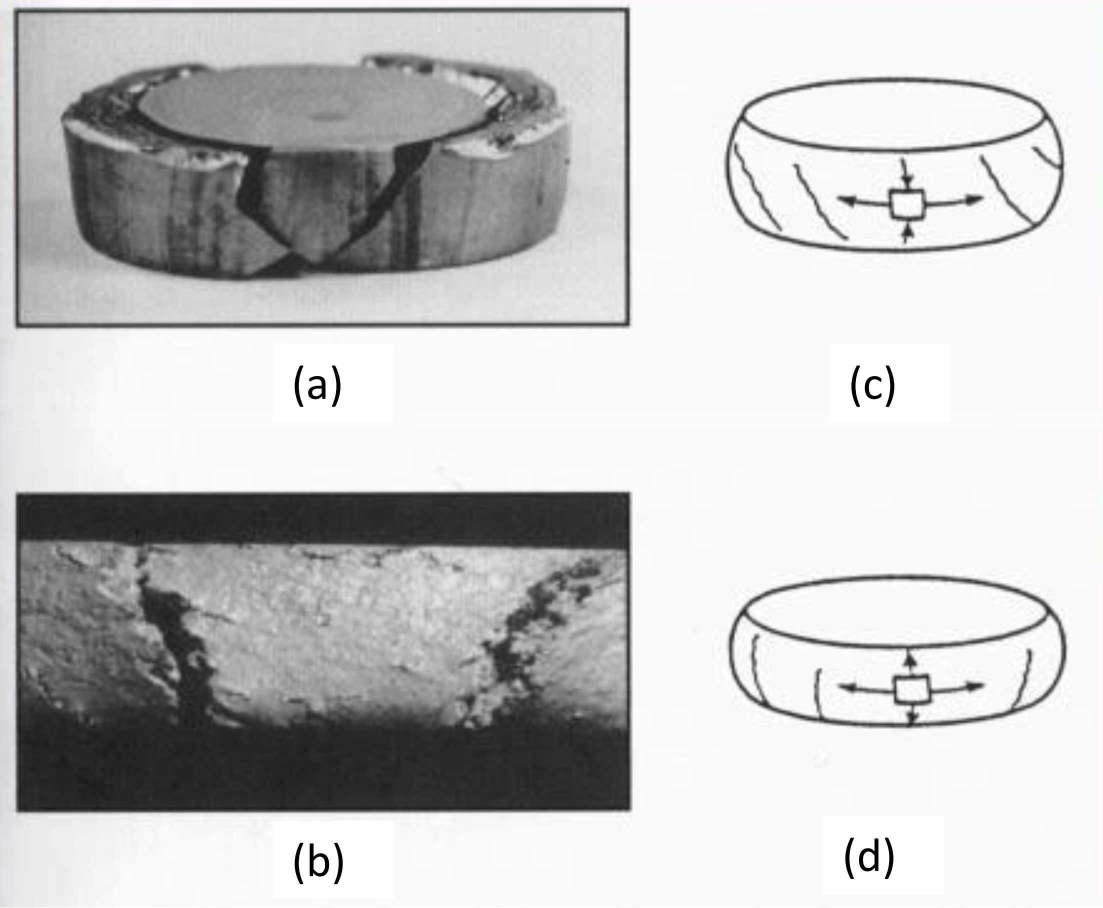
Types of Forging Defects (continue)



Examples of defects in forged parts. (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.

Source by Kalpakjian Book, 2014

TYPES OF FORGING DEFECTS (CONTINUE)



Fracture may occur by (a) exhausting ductility in cold working or by (b) intergranular fracture in hot working. (c) & (d) The direction of cracks depends on the relative magnitudes of secondary tensile stresses generated by bulging.

Source by Kalpakjian Book, 2014

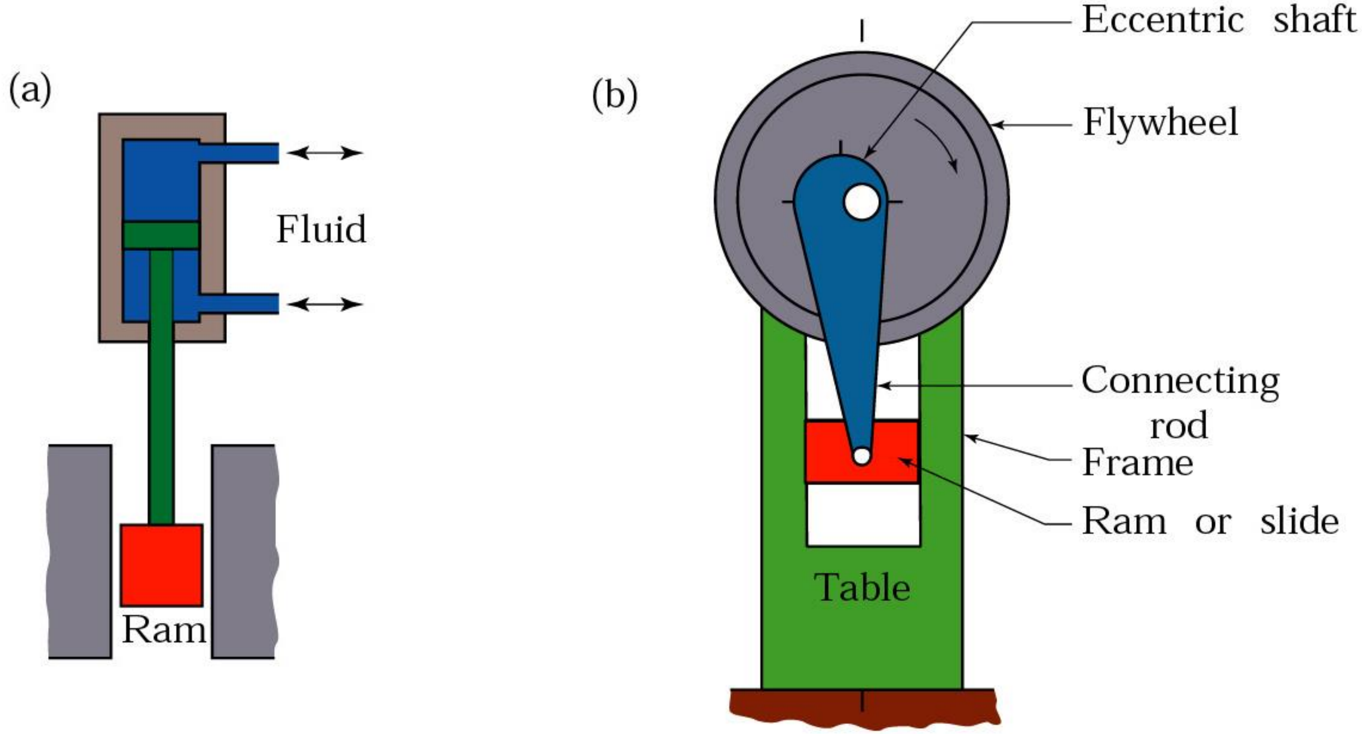
Forging Machines

- A variety of forging machines, with a range of capacities, speeds and speed-stroke characteristics.
- These machines are generally classified as:
  1. Presses: Hydraulic press, mechanical press, screw press & knuckle-joint.
  2. Hammers: Gravity drop hammer & power drop hammer.

Forging Machines: Presses

- **Hydraulic press**
  1. Operate at constant speeds and load limited.
  2. Large amounts of energy can be transmitted to a workpiece by a constant load throughout a stroke
- **Mechanical presses**
  1. These presses can be either the crank or the eccentric type.
  2. The energy is generated by a large flywheel to an eccentric shaft.
- **Knuckle-joint**
  1. Due to the linkage design, very high forces can be applied in this operations.
- **Screw presses**
  1. Derive the energy from a flywheel.
  2. The forging load is transmitted through a vertical screw.
  3. The ram comes to a stop when the flywheel energy is dissipated.
  4. Suitable for small production quantities and precision parts such as turbine blades
  5. Capacities ranges 1.4 MN to 280 MN.

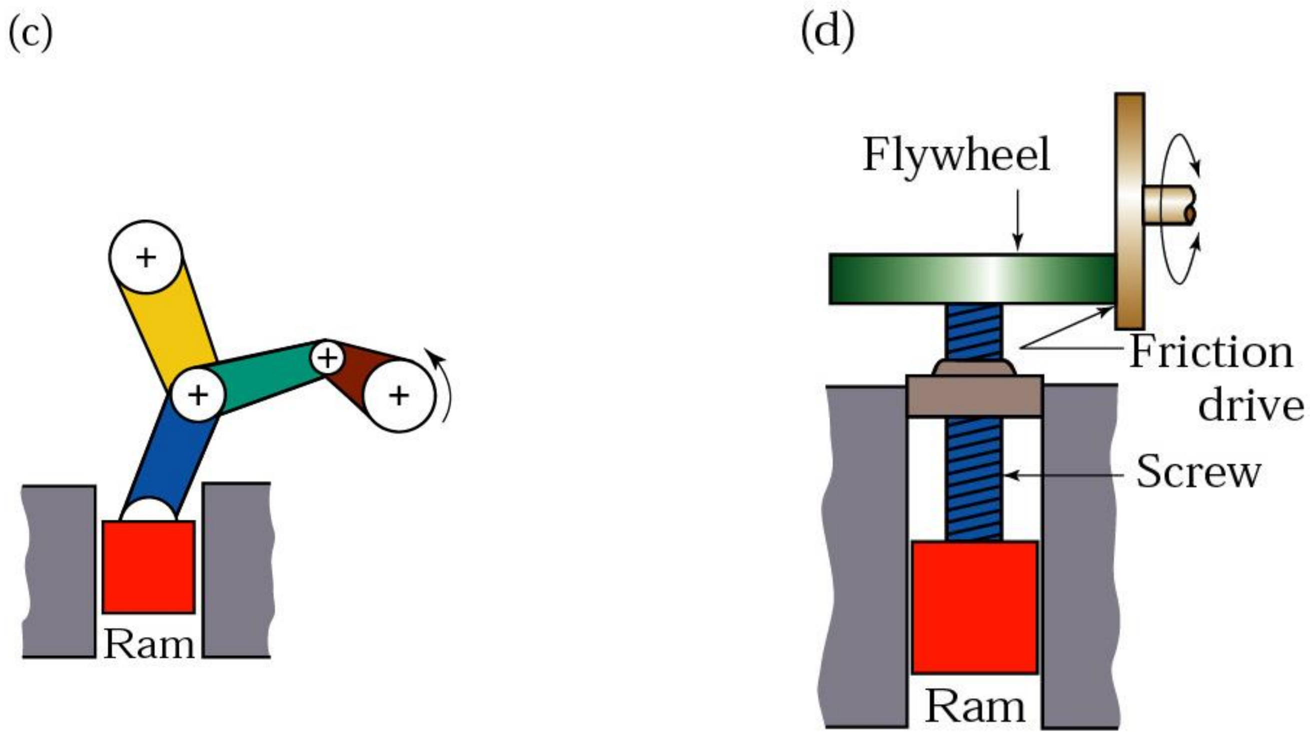
PRINCIPLES OF VARIOUS FORGING MACHINE - PRESSES



Schematic diagram of (a) Hydraulic press (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.

Source by Kalpakjian Book, 2014

PRINCIPLES OF VARIOUS FORGING MACHINE - PRESSES



Schematic diagram of (c) Knuckle-joint press and (d) Screw press.

Source by Kalpakjian Book, 2014

Forging Machines: Hammer

- Derive the energy from the potential energy of the ram which is converted to kinetic energy
- Operate at high speed (gravitational acceleration)
- Most commonly used for impression-die forging
- Hammer are available in variety designs:

    i. Gravity drop hammer
    - drop forging where the energy is derived from free-falling hammer.
    - the energy of the hammer depends on the ram's weight and height of its drop.

    ii. Power drop hammer
    - the ram's downstroke is accelerated by steam, air, hydraulic.
    - Ram weights range from 225 kg to as mush as 22, 500 kg.
    - Energy capacity ranging up to 1150 kJ.

PRINCIPLES OF VARIOUS FORGING MACHINE - HAMMER

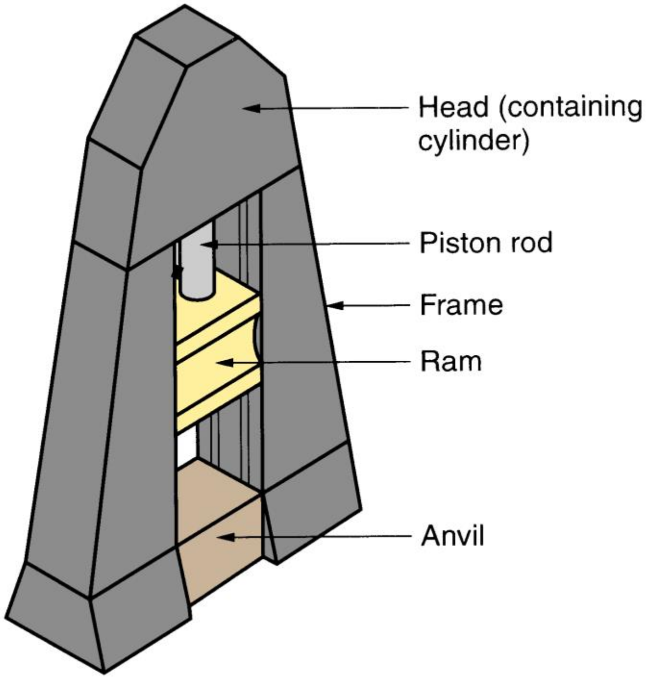


Figure showing details of a drop hammer for closed-die forging.

Source by Kalpakjian Book, 2014

Advantages & Limitations: Hammers

Advantages:

- high speed resulting low forming time, thus minimize the cooling of hot forging.
- Low cooling rate allows the forging of complex shape

Disadvantage:

- impact energy transmitted through anvil into floor of building

End of sub-chapter
Bulk Metal Deformation Processes