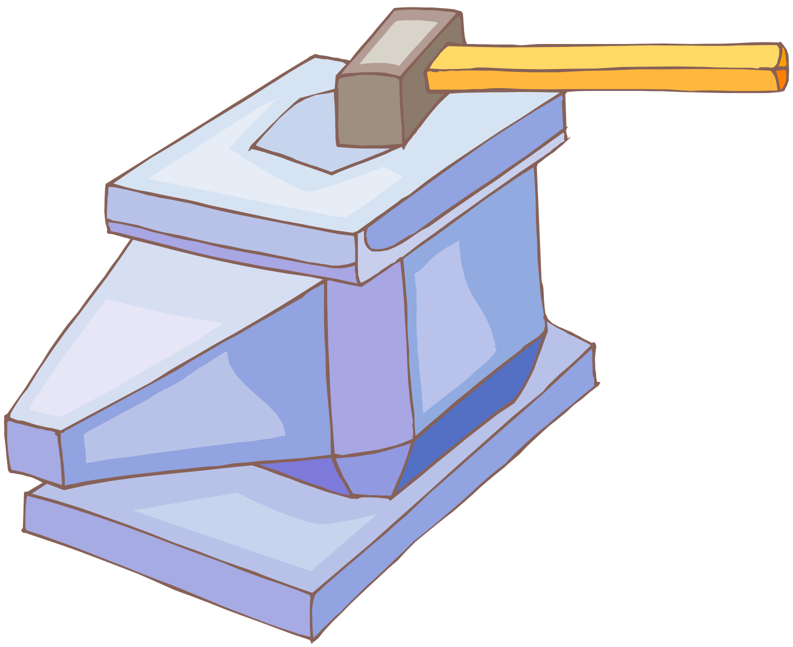
LECTURE-08
BULK DEFORMATION PROCESSES -FORGING



Nikhil R. Dhar, Ph.D
Department of Industrial & Production Engineering
BUET

Overview of Metal Forming

Metal forming can be classified as

- **Bulk deformation processes** – generally characterized by significant deformations and massive shape changes; and the surface area-to- volume of to work is relatively small.
  - Forging
  - Extrusion
  - Rolling
  - Wire and bar drawing
- **Sheet metal forming process**
  - Bending operations
  - Deep or cup drawing
  - Shearing processes
  - Miscellaneous

Forging

- Forging is a deformation process in which the work is compressed between two dies, using either impact or gradual pressure to form the part. Today, forging is an important industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications. These components include engine crankshafts and connecting rods, gears, aircraft structural components, and jet engine turbine parts. In addition, steel and other basic metals industries use forging to establish the basic forms of large components that are subsequently machined to final shape and dimensions.

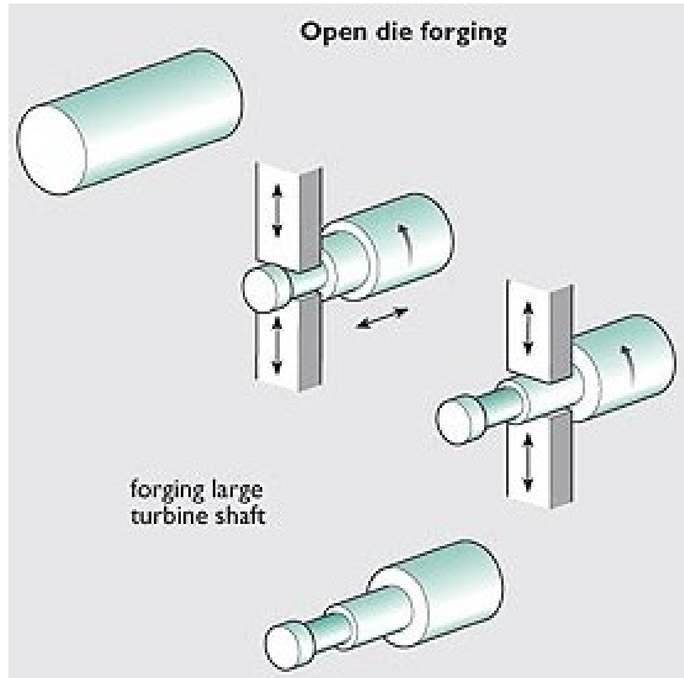
- Forging is carried out in many different ways. One way to classify forging is by working temperature. Most forging operations are performed hot or warm, owing to the significant deformation demanded by the process and the need to reduce strength and increase ductility of the work metal. However, cold forging is also very common for certain products. The advantage of cold forging is the increased strength that results from strain hardening of the component.

- Either impact or gradual pressure is used in forging. The distinction derives more form the type of equipment used than differences in process technology. A forging machine that applies an impact load is called a forging hammer, while one that applies gradual pressure is called a forging press. Another difference among forging operations is the degree to which the flow of the work metal is constrained by the dies. By this classification there are three types of forging operations like (i) **Open-die forging**, (ii) **Impression or Close die forging** and (iii) **Flashless 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.

- Open-die hot forging is an important industrial process. Shapes generated by open-die operations are simple; examples include shafts, disks, and rings. In some applications, the work must often be manipulated (for example, rotating in steps) to effect the desired shape change. Open-die forging process is shown in the following Figure.
- The skill of the human operator is a factor in the success of these operations. An example of open-die forging in the steel industry is the shaping of a large, square cast ingot into a round cross section. Open-die forging operations produce rough forms, and subsequent operations are required to refine the parts to final geometry and dimensions.



Open-Die Forging

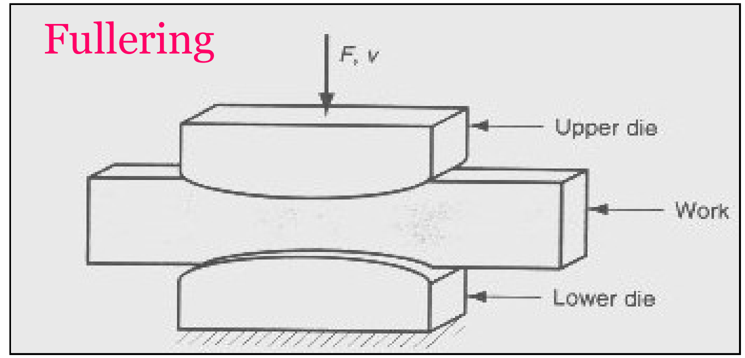
- An important contribution of open-die hot forging is that it creates favorable grain low and metallurgical structure in the metal. Operations classified as open-die forging or related operations include fullering, edging, and cogging, as shown in the next diagrams.

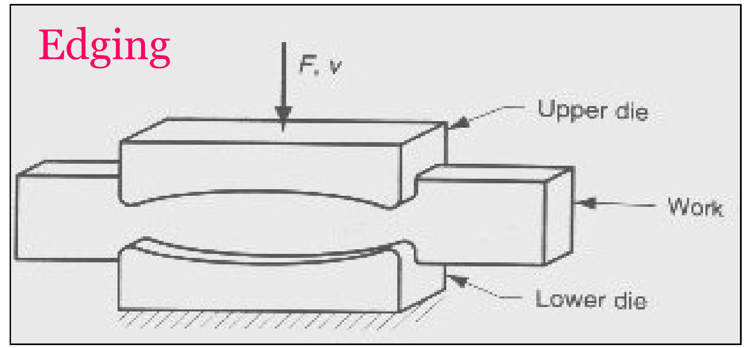
Fullering is a forging operation performed to reduce the cross section and redistribute the metal in a workpart in preparation for subsequent shape forging.

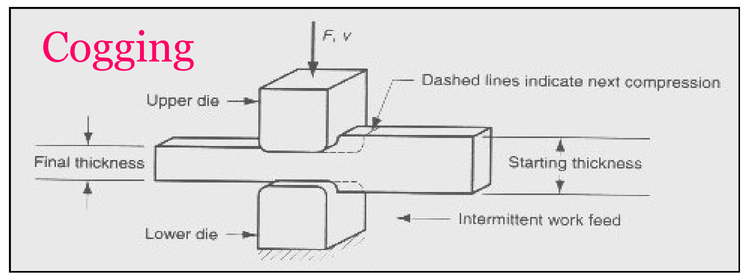
It is accomplished by dies with convex surfaces. Fullering die cavities are often used designed into multicavity impression dies so that the starting bar can be rough formed before final shaping.

Edging is similar to fullering, except that the dies have concave surfaces.

Cogging operation consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length. It is used in the steel industry to produce blooms and slabs from cast ingots. It is accomplished using open dies with flat or slightly contoured surfaces. The term *incremental forging* is sometimes used for this process.







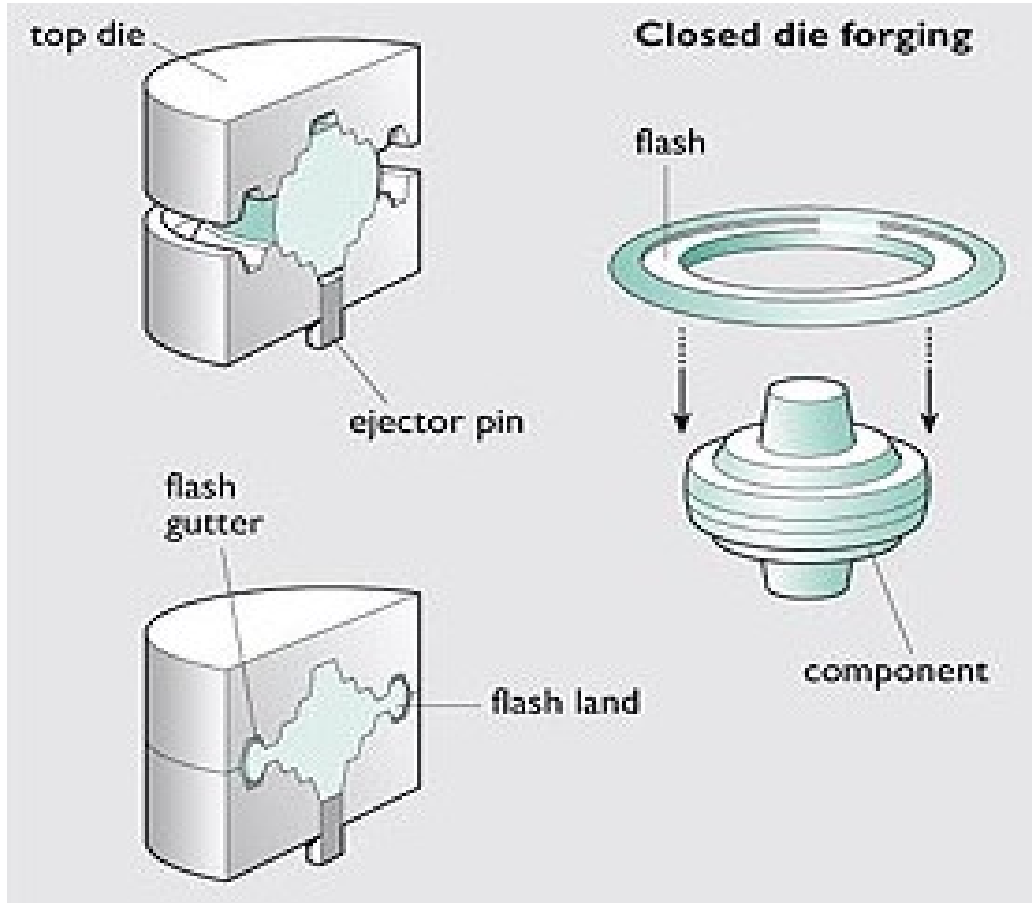
Advantages and Limitations

- **Advantages**
  - Simplest type of forging
  - Dies are inexpensive
  - Wide range of part sizes, ranging from 30-1000lbs
  - Good strength qualities
  - Generally good for small quantities

- **Limitations**
  - Simple shapes only
  - difficult to hold close tolerances
  - machining necessary
  - low production rate
  - poor utilization of material
  - high skill required

Impression or Close Die Forging

In impression-die forging, sooometimes called closed die forging, the die surfaces contain a shape or impression that is imparted to the work during compression, thus constraining metal flow to a significant degree as shown in following Figure. In this type of operation, a portion of the work metal flows beyond the die impression to form flash and must be trimmed off later. The process is shown in the following Figure as a three step sequence. The raw workpiece is shown as a cylindrical part similar to that used in the previous open-die operation.



Impression die forging

Advantages and Limitations

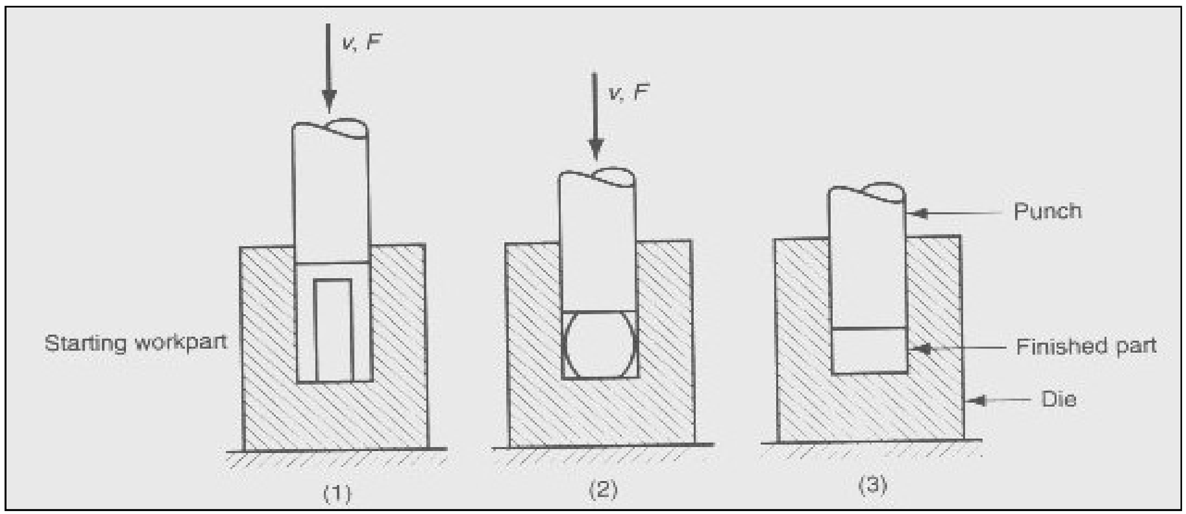
- **Advantages**
  - Good utilization of material
  - Better properties than Open Die Forgings
  - Dies can be made of several pieces and inserts to create more advanced parts
  - Presses can go up to 50,000 ton capacities
  - Good dimensional accuracy
  - High production rates
  - Good reproducibility

- **Limitations**
  - High die cost
  - Machining is often necessary
  - Economical for large quantities, but not for small quantities

Flashless Forging

Flashless *forging* is sometimes called closed-die forging in industry terminology. However, there is a technical distinction between impression-die forging and true closed-die forging. The distinction is that in closed-die forging the raw workpiece is completely contained within the die cavity during compression, and no flash is formed. This process is shown in the following figure. Flashless forging imposes requirements on process control that are more demanding than impression-die forging. Most important is that the work volume must equal the space in the die cavity within a very close tolerance. If the starting blank is too large, excessive pressures may cause damage to the die or even the press. If the blank is too small, the cavity will not be filled. Because of the special demands made on flashless forging, the process lends itself best to part geometries that are usually simple and symmetrical and to work materials such as aluminum and magnesium and their alloys. Flashless forging is often classified as a **precision forging process**.

Flashless forging: (1) just before initial contact with work piece (2) partial compression and (3) final punch and die closure. v=velocity & F=applied force



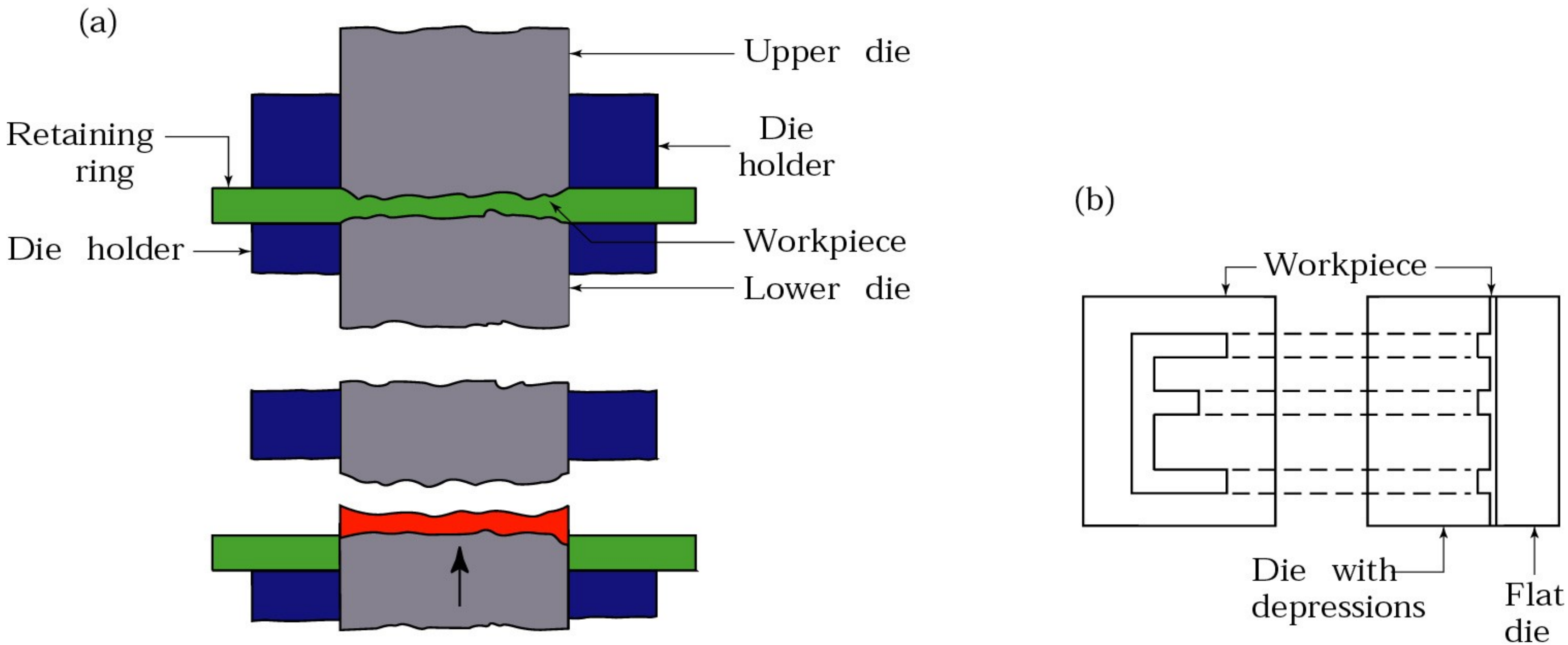
Advantages and Limitations

- **Advantages**
  - Close dimensional tolerances
  - Very thin webs and flanges are possible
  - Very little or no machining is required
  - Little or no scrap after part is produced
  - Cheaper to produce from less finishing operations and faster production
  - Typical applications are gears, connecting rods, and turbine blades
  - Common materials used in precision forging are aluminum, magnesium alloys, steel, and titanium

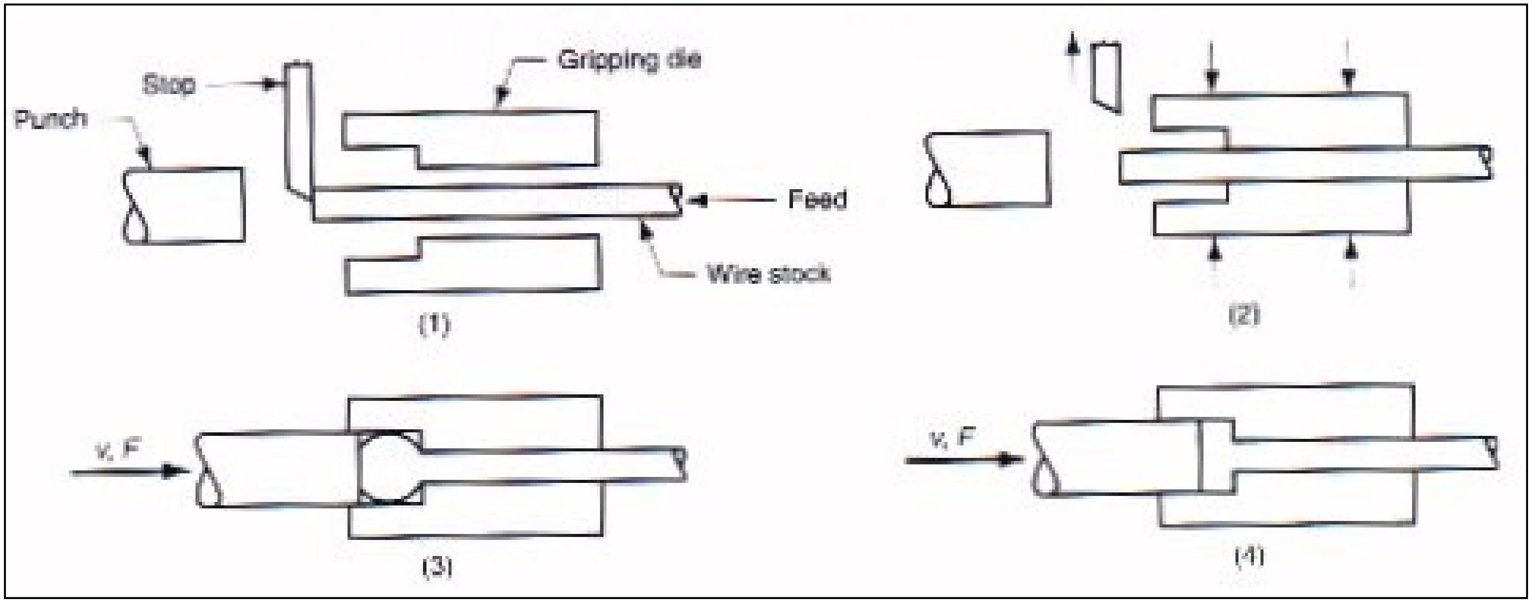
- **Limitations**
  - High forging forces
  - Thus higher capacity equipment is required
  - Intricate dies leading to increased die cost
  - Precise control over the Blank's volume and shape
  - Accurate positioning of the Blank in the die cavity

Forging Operations

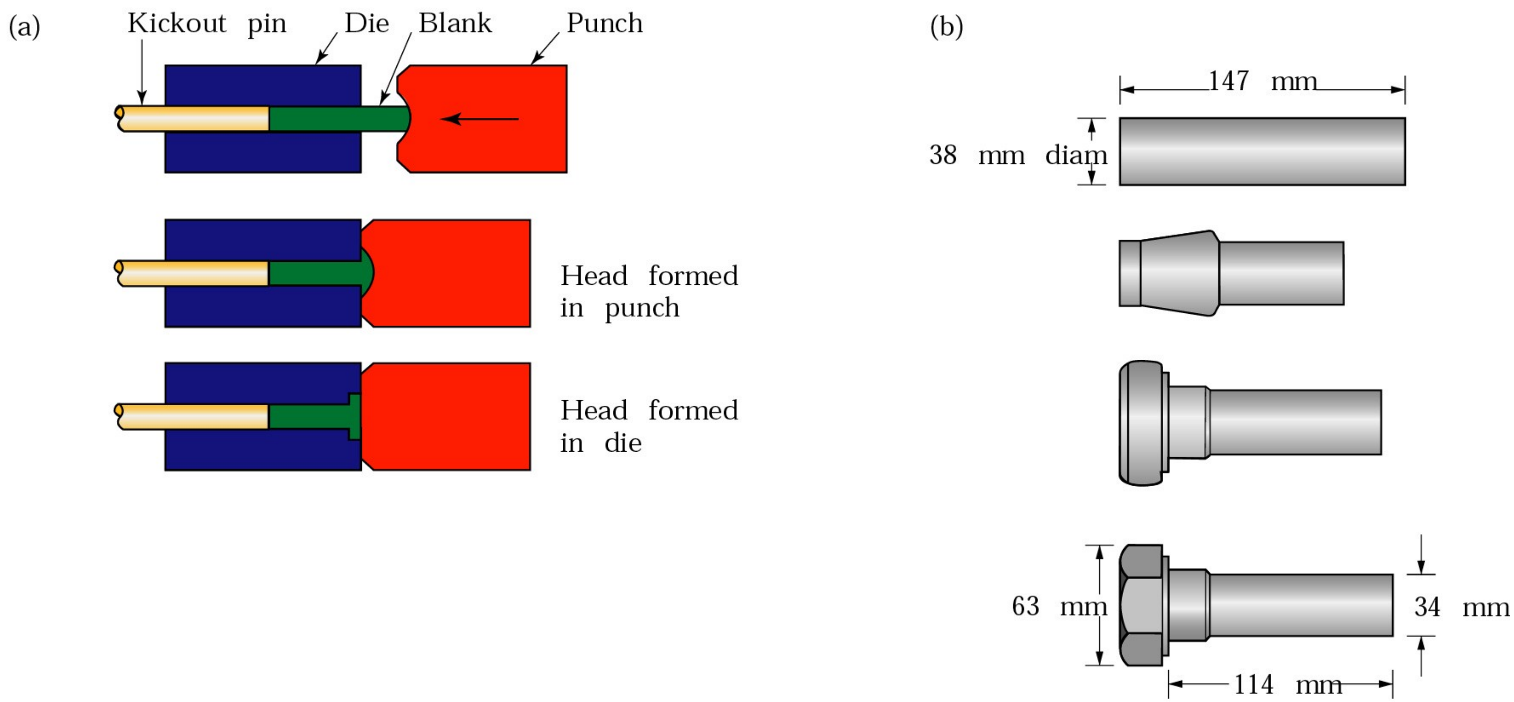
- **Coining** is a special application of flashless forging in which fine details in the die are impressed into the top and bottom surfaces of the workpart.
  - Closed-die forging process
  - Used for minting coins, medallions, & jewelry
  - Lubricants can not be used in coining
  - Can be used to improve surface finish



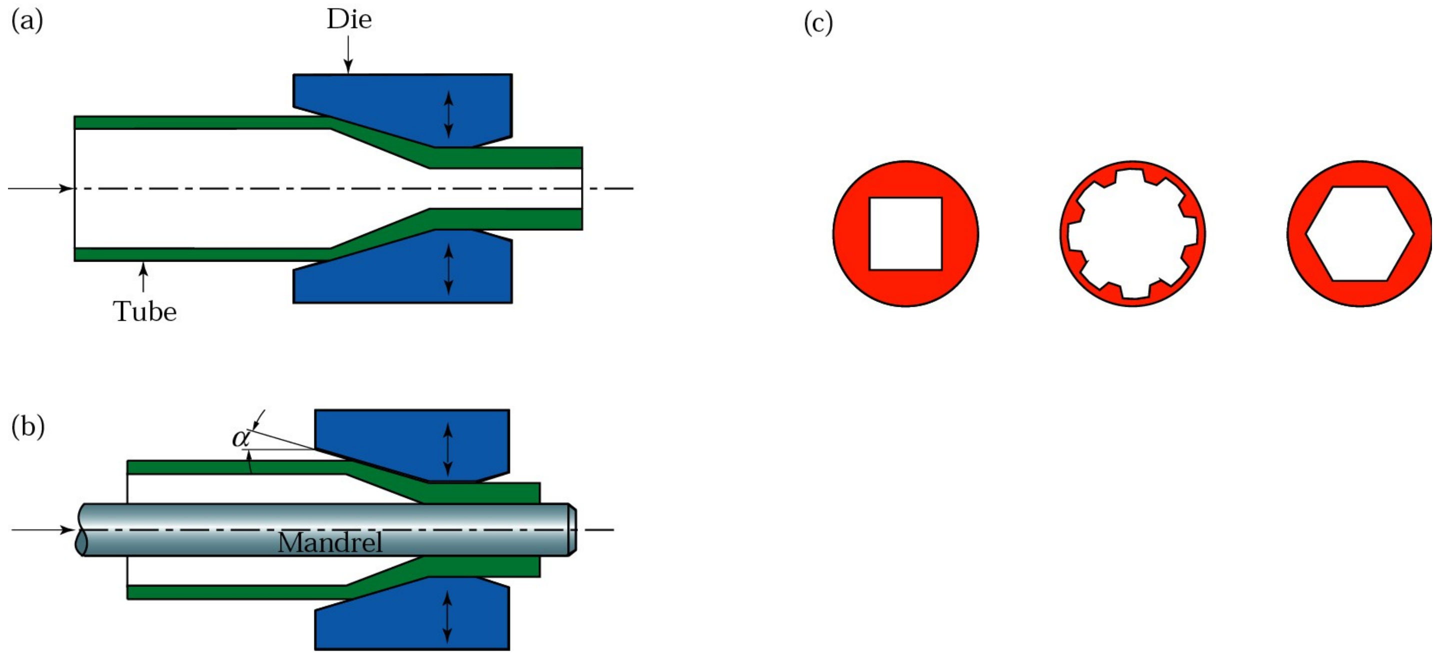
- **Upsetting**: Upsetting is a deformation operation in which a cylindrical workpart is increased in diameter and reduced in length. However, as an industrial operation, it can also be performed as closed-die forging, as shown in the following Figure. Upsetting is widely used in the fastener industry to form the heads of nails, bolts, and similar hardware products.



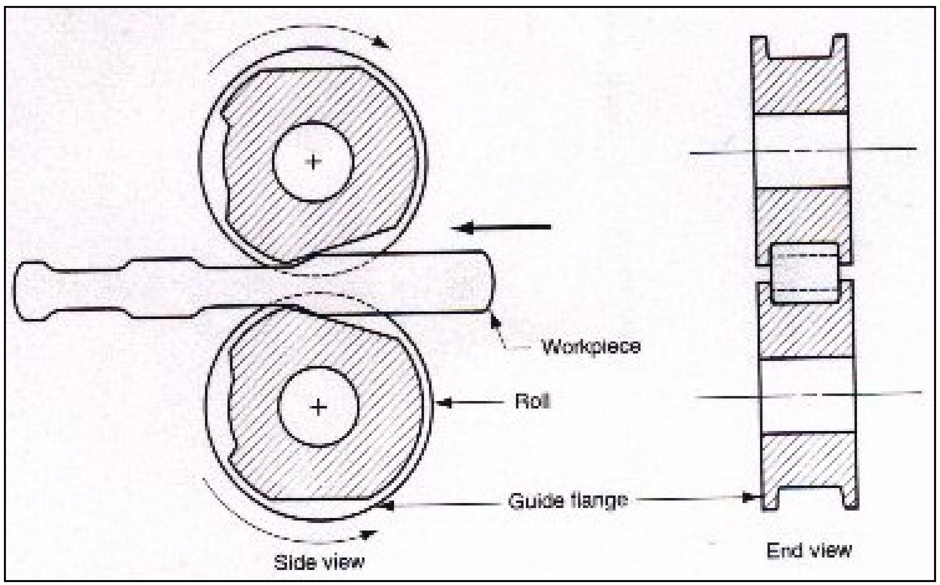
- **Heading**: The following Figure illustrates a variety of heading applications, indicating various possible die configurations. Owing to these types of applications, more parts are produced by upsetting than any other forging operation. It is performed as a mass production operation - cold, warm, or hot - on special upset forging machines, called headers or formers.
  - Care must be taken so that work piece does not buckle
  - Can be highly automated



- **Swaging and Radial Forging**: Swaging and radial forging are forging processes used to educe the diameter of a tube or solid rod. Swaging is often performed on the end of a workpiece to create a tapered section. The swaging process shown is accomplished by means of rotating dies that hammer a workpiece radially inward to taper it as the workpiece is fed into the dies. **Radial forging** is similar to swaging in its action against the work and is used to create similar shapes. The difference is that in radial forging the dies do not rotate around the workpiece; instead , the work is rotated at it feeds into the hammering dies.



- **Roll Forging**: Roll forging is a deformation process used to reduce the cross section of a cylindrical (or rectangular) workpiece by passing it through a set of opposing rolls that have grooves matching the desired shape of the part. The typical operation is shown in the following Figure. Roll forging is generally classified as a forging process, even though it utilizes rolls. The rolls do not turn continuously in roll forging, but rotate through only a portion of one revolution corresponding to the desired deformation to be accomplished on the part. Roll-forged parts are generally stronger and possess favorable grain structure compared to competing processes, such as machining, that might be used to produce the same part geometry.

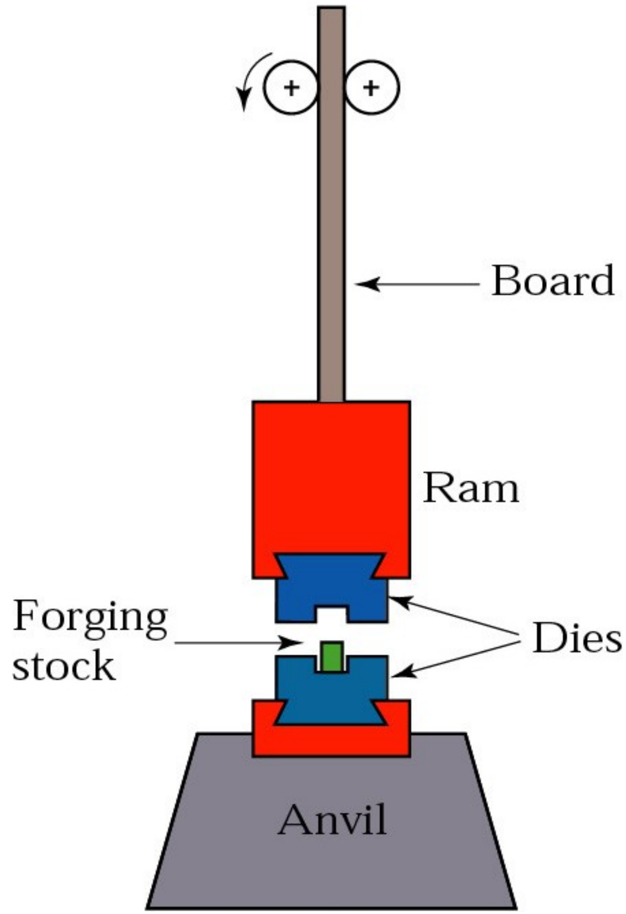


Forging Machines

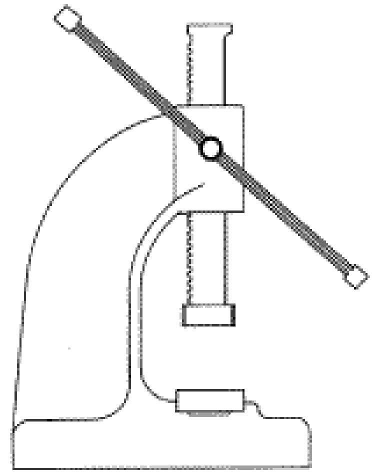
- Equipment used in forging consists of forging machines, classified as **forging hammers** and **presses**, and **forging dies**, which are the special tooling used in these machines. In addition, auxiliary equipment is needed, such as furnaces to heat the work, mechanical devices to load and unload the work, and trimming stations to cut away the flash in impression-die forging.

- **Forging Hammers**: Forging hammers operate by applying an impact load against the work. The term drop hammer is often used for these machines, owing to the means of delivering impact energy. Drop hammers are most frequently used or impression-die forging. The upper portion of the forging die is attached to the ram, and the lower portion to the anvil. In the operation, the work is placed on the lower die, and the ram is lifted and then dropped. When the upper die strikes the work, the impact energy causes the part to assume the form of the die cavity.

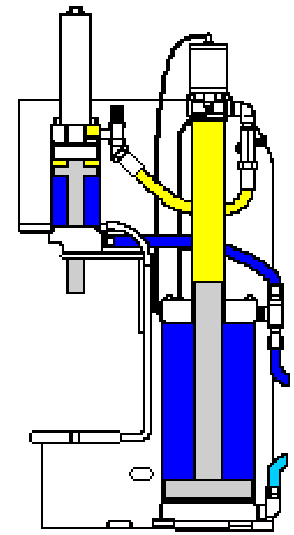
- Drop hammers can be classified as **gravity drop hammers** and **power drop hammers**.
  - **Gravity drop hammers** achieve their energy by the falling weight of a heavy ram. The force of the blow is determined by the height of the drop and the weight of the ram.
  - **Power drop hammers** accelerate the ram by pressurized air or steam. One disadvantage of the drop hammers is that a large amount of the impact energy is transmitted through the anvil and into the floor of the building. This results in a great deal of vibration for the surrounding area.



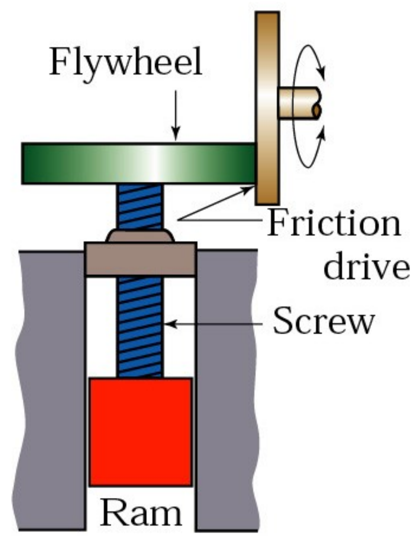
- **Forging Presses**: Presses apply gradual pressure, rather than sudden impact, to accomplish the forging operation. Forging presses include **mechanical presses, hydraulic presses, and screw presses.**
  - **Mechanical presses** typically operate by means of eccentrics, cranks, or knuckle joints, which convert the rotating motion of a drive motor into the translational motion of the ram. These mechanisms are very similar to those used in stamping presses. Mechanical presses typically achieve very high forces at the bottom of the forging stroke.
  - **Hydraulic presses** use a hydraulically driven piston to actuate the ram.
  - **Screw presses** apply force by a screw mechanism that drives the vertical ram. Both screw drive and hydraulic drive operate at relatively low ram speeds and can provide a constant force throughout the stroke. These machines are therefore suitable for forging (and other forming) operations that require a long stroke.



Mechanical Press



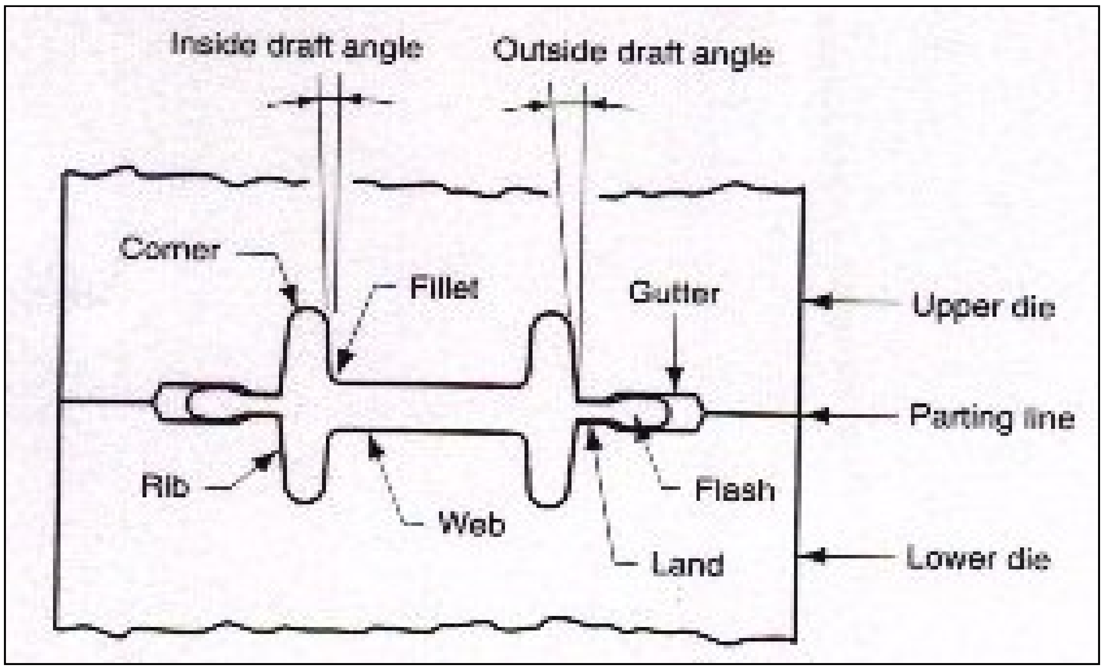
Hydraulic Press



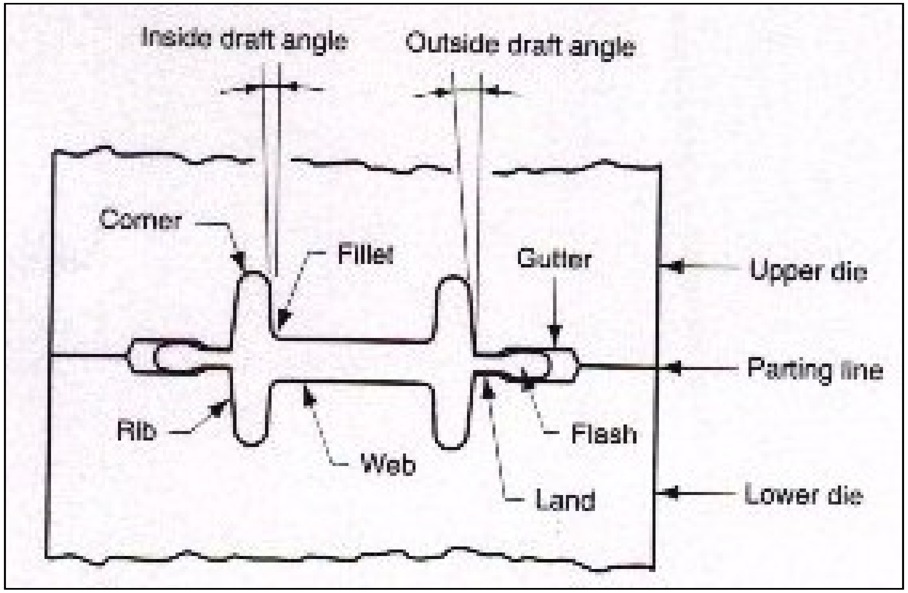
Screw Press

Terminology of Impression Die Forging

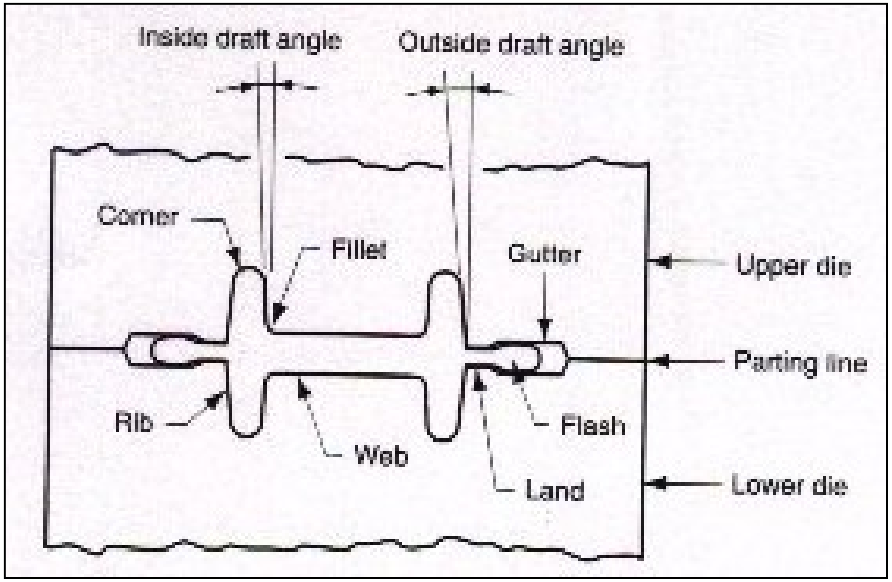
Proper die design is important in the success of a forging operation. Parts to be forged must be designed based on knowledge of the principles and limitations of this process. The purpose of the next slides is to describe some of the terminology and guidelines used in the design of forgings and forging dies. Design of open dies is generally straightforward since the dies are relatively simple in shape. The following details apply to impression dies and closed dies. The following Figure shows some of the terminology in an impression die.



- **Parting line:** The parting line is the plane that divides the upper die from the lower die. Called the flash line in impression-die forging, it is the plane where the two die halves meet. Its selection by the designer affects grain flow in the part, required load, and flash formation.
- **Draft:** Draft is the amount of taper on the sides of the part required to remove it from the die. The term also applies to the taper on the sides of the die cavity. Typical drat angles are 3o on aluminum and magnesium parts and 5o to 7o on steel parts. Draft angles on precision forgings are near zero.
- **Webs and ribs:** A web is a thin portion of the forging that is parallel to the parting line, while a rib is a thin portion that is perpendicular to the parting line. These part features cause difficulty in metal low as they become thinner.



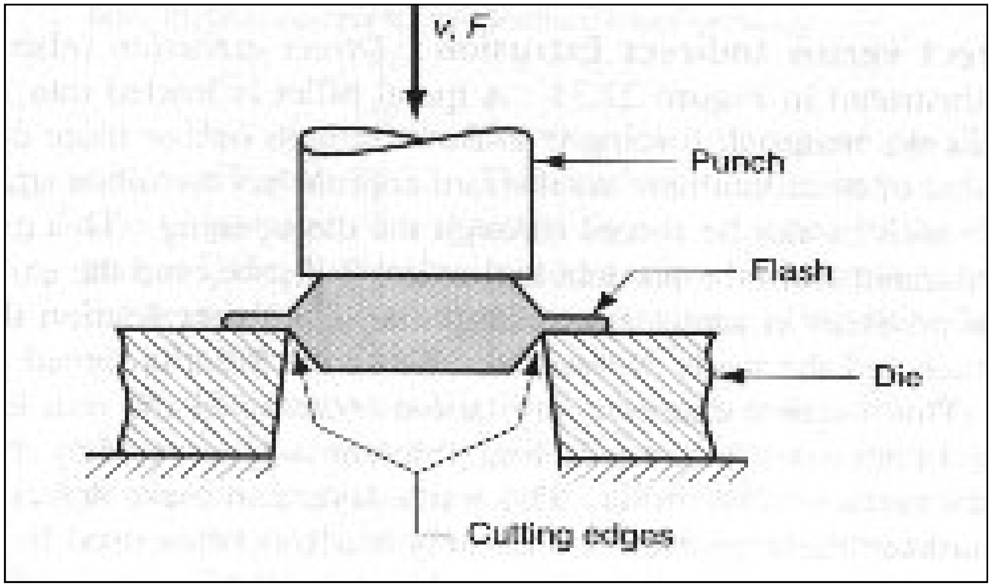
- **Fillet and corner radii:** Fillet and corner radii are shown in the diagram. Small radii tend to limit metal flow and increase stresses on the die surfaces during forging.
- **Flash:** Flash formation plays a critical role in impression-die forging by causing pressure buildup inside the die to promote filling of the cavity. This pressure buildup is controlled by designing a flash land and gutter into the die as shown. The land determines the surface area along which lateral flow of metal occurs, thereby controlling the pressure increase inside the die. The gutter permits excess material to escape without causing the forging load to reach extreme values



Trimming

- Trimming is an operation used to remove flash on the workpart in impression-die forging. In most cases, trimming is accomplished by shearing, as shown in the next slide, in which a punch forces the work through a cutting die, the blades for which have the profile of the desired part.

- Trimming is usually done while the work is still hot, which means the that a separate trimming press is included at each forging hammer or press. In cases where the work might be damaged by the cutting process, trimming may be done by alternative methods, such as grinding or sawing.



Trimming operation (shearing process) to remove the flash after impression die forging