<u>Open-Die Forging Practice</u>:

- Shapes generated by open-die operations are simple; examples include shafts, disks and rings.
- In some applications, dies have slightly contoured surfaces that help to shape w.p.
- In addition, w.p. must often be manipulated (e.g., rotating in steps) to effect the desired shape change.
- An example of open-die forging in 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.
- An important contribution of open-die hot-forging is that it creates a favorable grain flow and metallurgical structure of the final product.

- Open-die forging operations include:
    1. **Fullering.**
    2. **Edging.**
    3. **Cogging.**

These operations are used to perform w.p. ready for closed-die forging.

Figure (3-40) explains these operations.

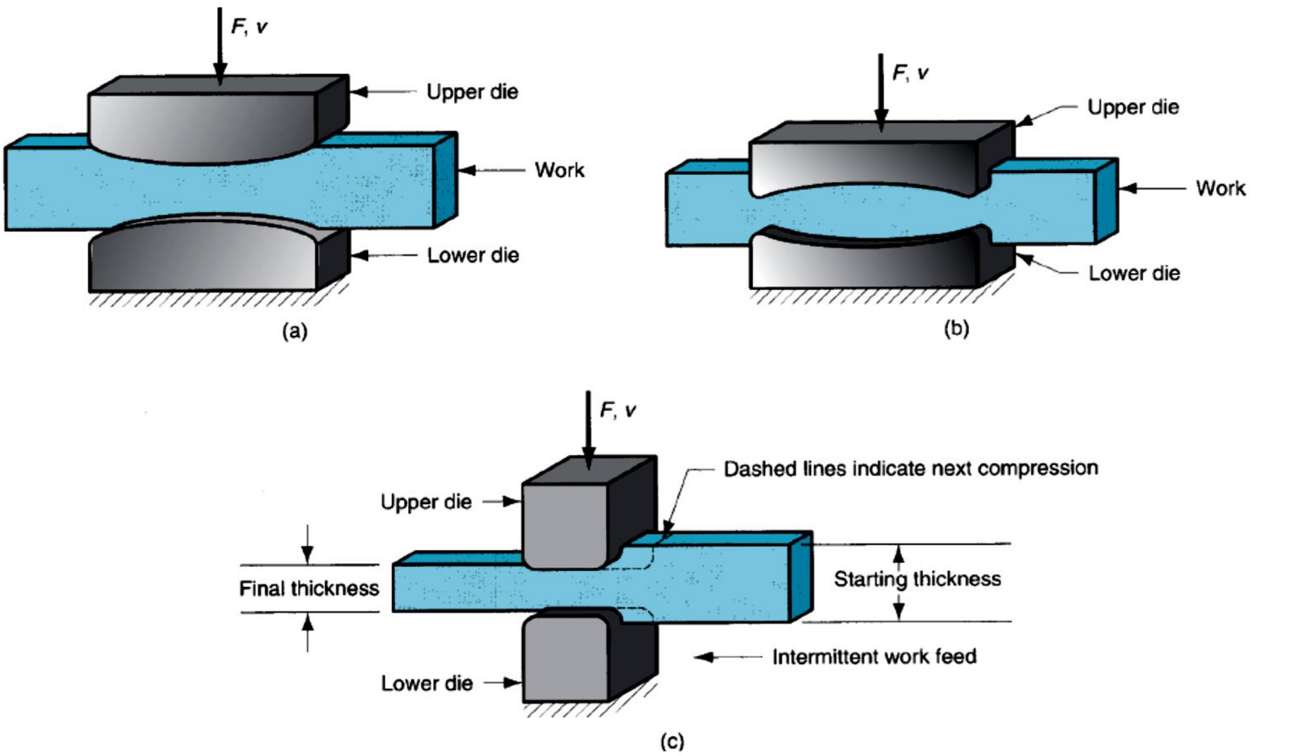

Figure (3-40) open-die operations: (a) fullering, (b) edging, (c) cogging

1. Fullering

- It is a forging operation performed to reduce the cross-section and redistribute the metal in certain regions in preparation for subsequent shape forging.
- The metal is distributed away from an area.
- It is accomplished by dies with convex surfaces.
- Fullering die cavities are often designed into multi-cavity impression dies, so that the starting bar can be rough formed before final shaping.

2. Edging

- It is similar to fullering, except that the dies have concave surfaces.
- The metal is gathered into a localized area.

Thus, the fullering and edging are performing a technique to make material flow easier in die cavity for the subsequent processes.

3. Cogging

- It is operation consists of a sequence of forging compressions along the length of a w.p. 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 dies with flat or slightly contoured surfaces.
- It is called sometimes incremental forging.

Advantages of Open-Die Forging

- Simple process.
- Simple products.
- Inexpensive dies.
- Wide range of product sizes are available.
- Good strength characteristics of final product.

Limitations of Open-Die Forging

- Limited to simple shapes.
- Poor close tolerances.
- Require further machining.
- Low production rate.
- Relatively poor utilization of material.
- High degree of skill required.

Impression-Die Forging:

- Also called closed-die forging.
- It is performed with dies that contain the inverse of the desired shape of the part.
- The w.p. acquires the shape of the die cavity hence the term impression.
- Figure (3-41) states this type of forging.

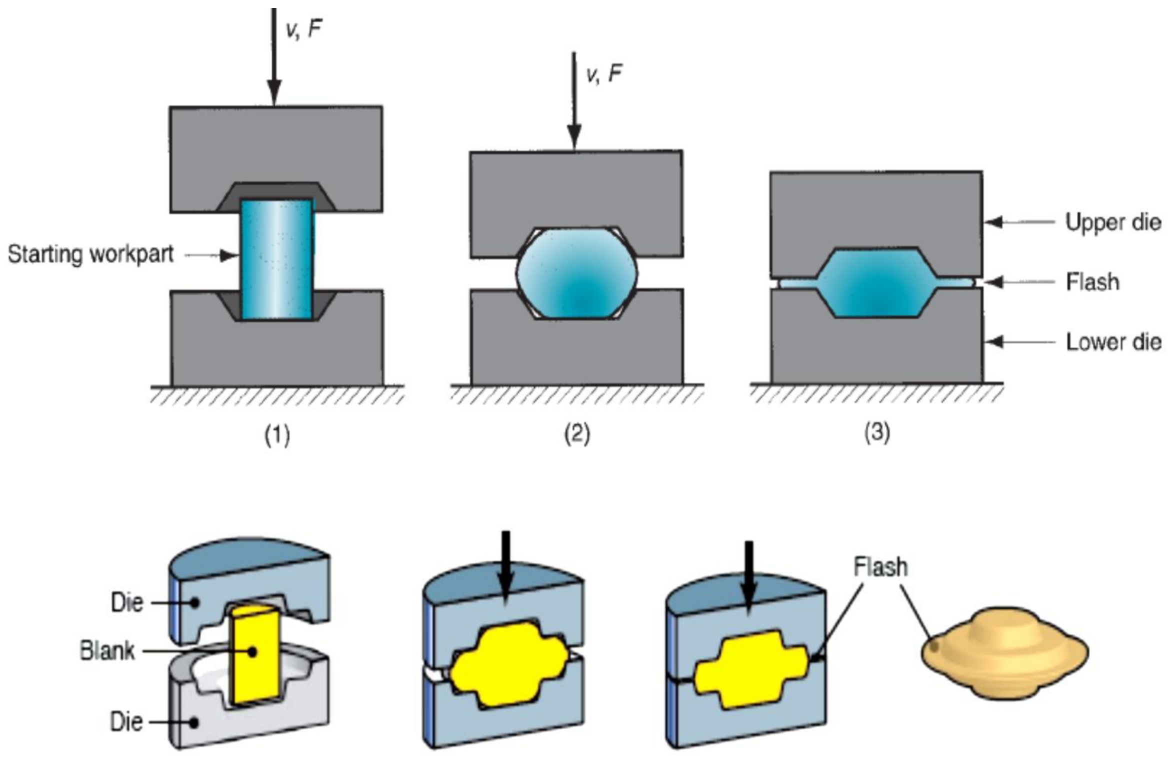

Figure (3-41) steps in impression-die forging: (1) prior to initial contact with w.p., (2) partial compression, (3) final die closure.

- As the die closes to its final position, flash is formed by metal that flows beyond die cavity and into small gap between the die plates.
- The function of formed flash is as follows: once flash begins to form in the die gap, friction resists continued flow of metal into the gap, thus constraining the bulk of w.p. to remain in the die cavity.
- Restricting metal flow causes the compression pressure on w.p. to increase significantly, thus forcing the metal to fill the intricate details of die cavity.
- In hot forging, metal flow is further restricted because thin flash cools quickly in the die gap, thereby increasing its resistance to deformation.
- The formed flash must be cut away from the final product in a subsequent trimming operation.
- The force applied in this process is significantly greater than open-die forging, because of flash formation and more complex shapes made by impression die forging.

- The force is determined by:

$$F_{fg} = K_f Y_f A$$

F_{fg}: maximum forging force in the operation which is reached at end of forging stroke, when A is greatest and friction is maximum.
A: projected area of the w.p. including flash.
Y_f: flow stress
K_f: forging shape factor

- In hot forging, Y_f = yield strength of the metal at elevated temperature.

Advantages of Impression-Die Forging Compared to Machining Part

- Higher production rates.
- Conservation of metal.
- Greater strength.
- Favorable grain orientation of metal. Comparison of grain flow in forging and machining is shown in figure (3-42).

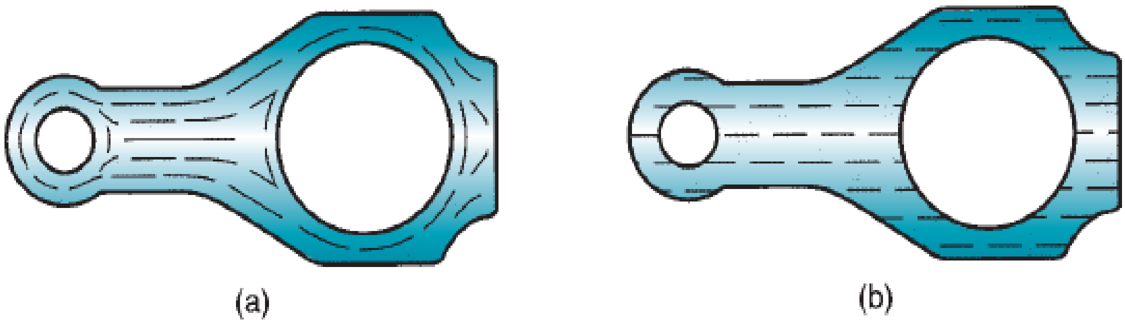

Figure (3-42) comparison of metal grain flow in a part that is: (a) hot forging with finish machining (b) machined complete

Limitations of Impression-Die Forging

- Not capable to achieve of close tolerance of workpiece
- Machining is often required to achieve w.p. accuracies.
- Machining is required to achieve precision finishing especially for (holes, threads, and surfaces that mate with other components).

Precision Forging (PF)

- Improvements in technology of impression-die forging led to ***precision forging*** as shown in figure (3-43).
- Forgings have thinner sections can be produced.
- Can produce more complex geometries.
- Can produce closer tolerances.
- Reduce the machining allowances.
- Reduce the flash formation significantly.
- Common metals used for PF are aluminum and titanium.
- Can be classified as near net shape or net shape processes depending on whether machining is required or not.

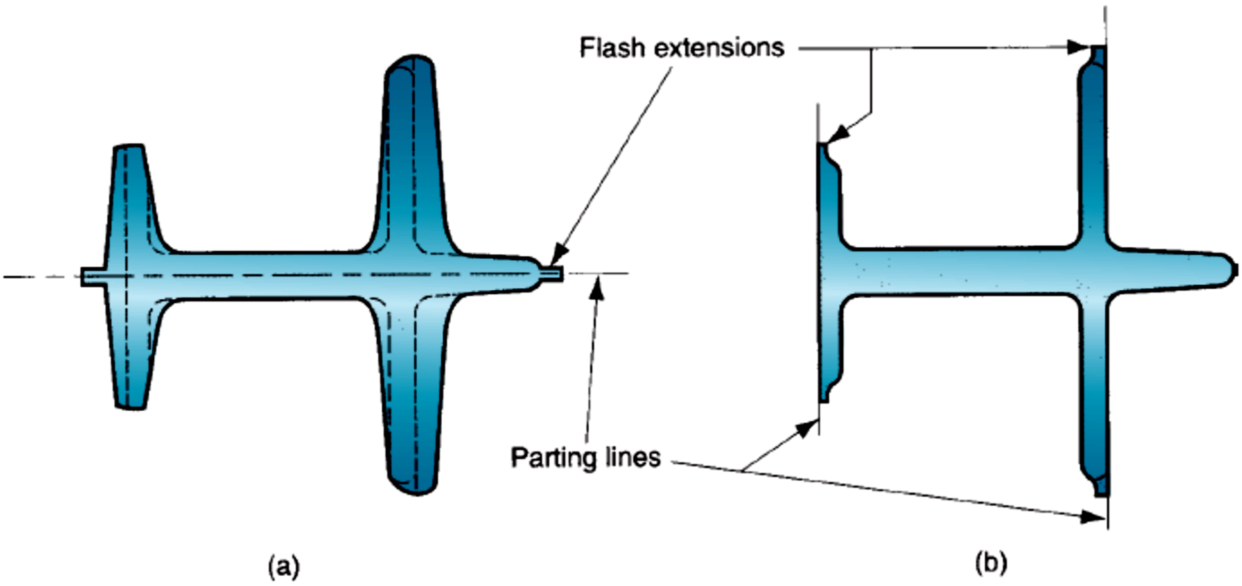

Figure (3-43) cross-sections of (a) conventional impression-die forging (b) precision forging. Dashed lines in (a) indicate subsequent machining required to make geometry equivalent to precision forging.

Flashless (Closed-Die) Forging:

- There is no flash formation during forging process.
- In this process, w.p. volume must equal the space in die cavity within a very close tolerance.
- If starting w.p. is too large than die cavity, excessive pressure may cause damage to the die or press machine.
- Figure (3-44) explains this process.
- If starting w.p.is too small, the cavity will not be filled.

- Materials such as aluminum and magnesium and their alloys can be forged in this process.
- Flashless forging is often classified as a precision forging.
- The force is determined as in impression-die process by:

$$\boldsymbol{F_{fg} = K_f Y_f A}$$

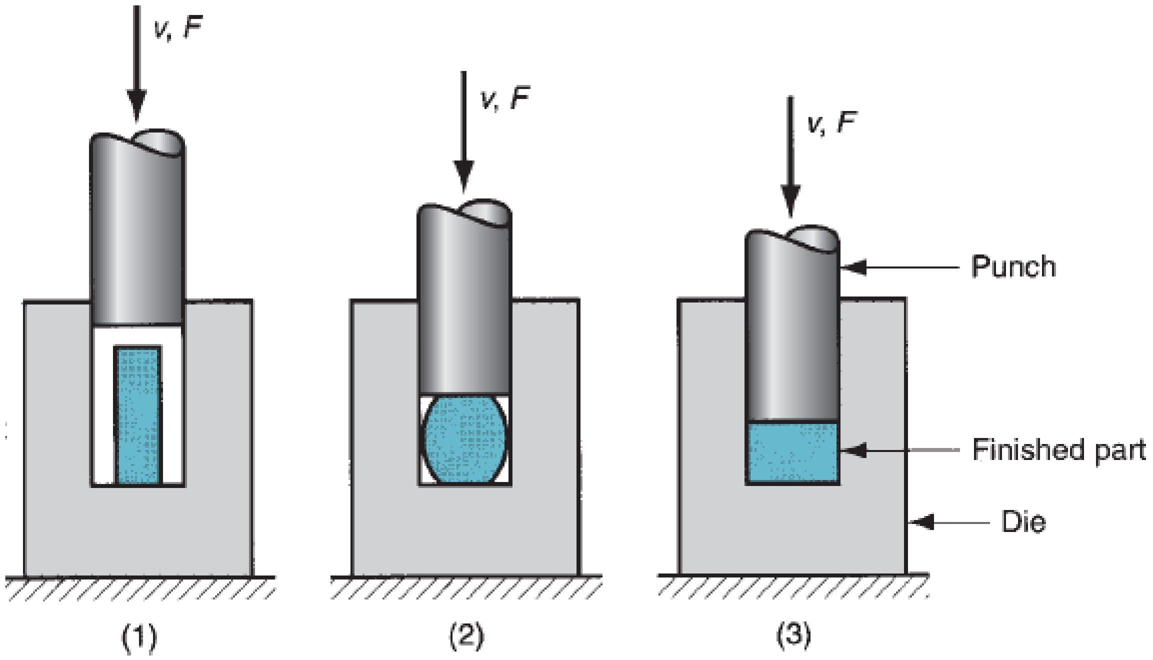

Figure (3-44) Flashless forging (1) before initial contact with w.p. (2) partial compression (3) final punch and die closure.

- ***Coining Process*** is a special application of flashless (closed-die) forging.
- In coining, fine details in die are impressed into the top and bottom surfaces of w.p.
- There is little flow of metal in coining, however, pressures required to reproduce the surface details in die cavity are high.
- Common application of coining is in the minting of coins as shown in figure (3-45).
- The coining process also provides good surface finish and dimensional accuracy on w.ps. made by other operations.

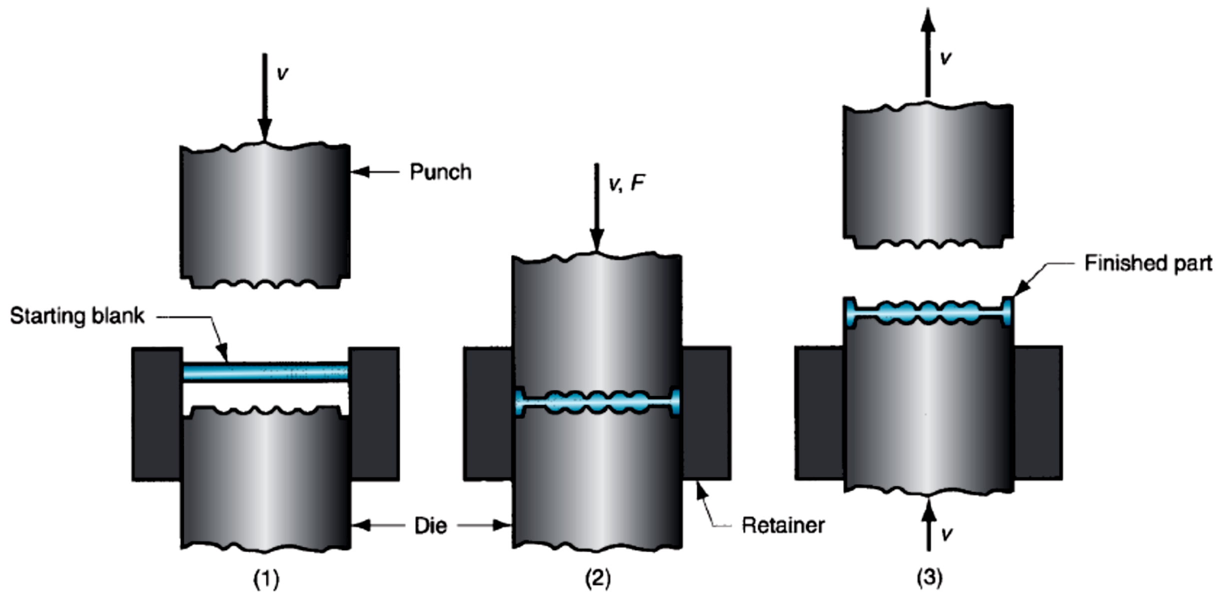

Figure (3-45) coining operation (1) start of cycle (2) compression stroke (3) ejection of final product

Other Deformation Processes Related to Forging:

The following processes are closely associated with forging:

Upsetting and Heading:

- Also called upset forging.
- It is used to increase diameter of w.p. and reduce its length.
- It is used in fastener industry to form heads on nails, bolts and similar products
- Maximum length that can be upset in one blow is three times the diameter of starting stock, otherwise, metal bends or buckles instead of compressing.
- Figures (3-46) and (3-47) illustrate this process.

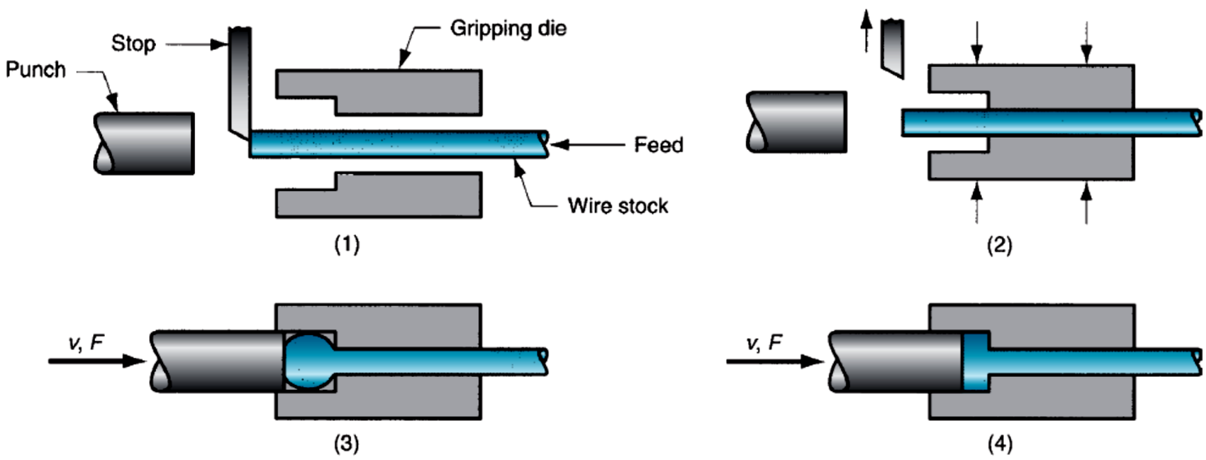

Figure (3-46) upset forging to form a head on a bolt (1) wire stock is fed to the stop (2) gripping dies close on the stock and stop is retracted (3) punch moves forward (4) bottoms to form the head

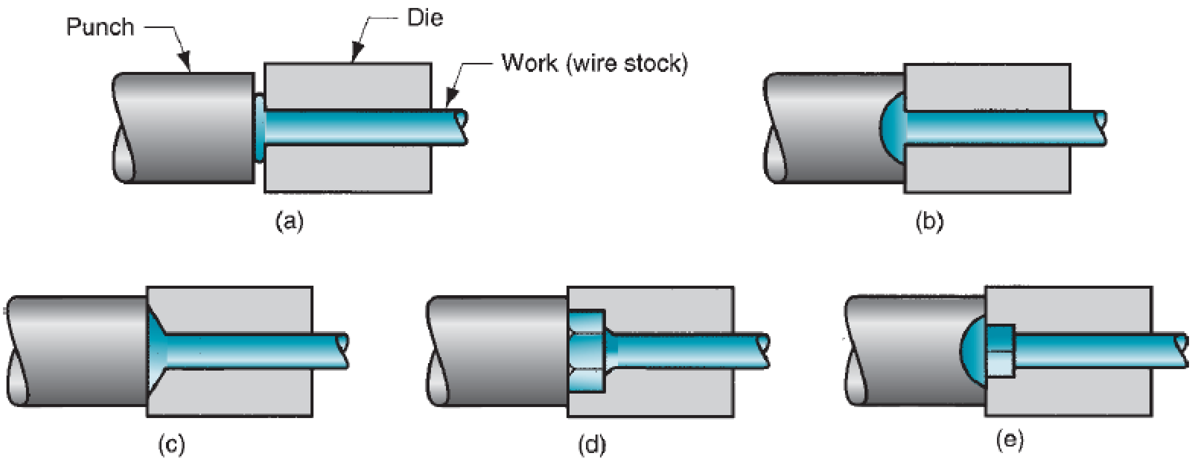

Figure (3-47) examples of heading (upset forging) operations: (a) heading a nail using open-dies (b) round head formed by punch (c) and (d) heads formed by die (e) carriage bolt head formed by punch and die

Swaging and Radial Forging:

- Swaging and radial forging are used to reduce diameter of a tube or solid rod.
- Swaging is often performed on end of w.p. to create tapered section.
- In swaging, the dies are rotated and hammer a w.p. radially inward to taper it.
- Swaging process is shown in figure (3-48).

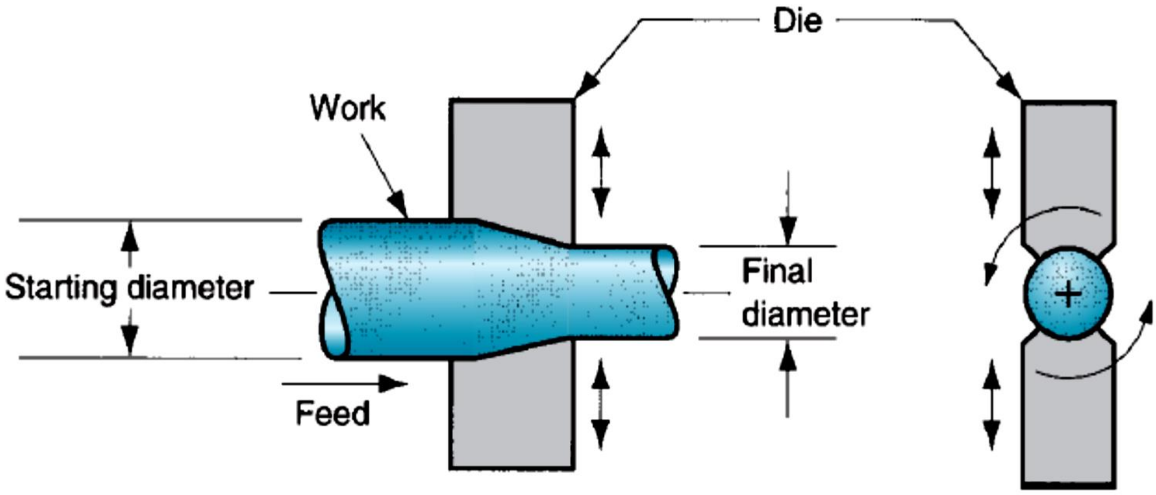

Figure (3-48) swaging process; the dies rotate as they hammer the w.p.

- The mandrel is required to control the shape and size of tubular products that are swaged.

- Radial forging is similar to swaging except, in radial forging, the w.p. rotates while the dies remain in a fixed orientation as they hammer the w.p. as in figure (3-49).

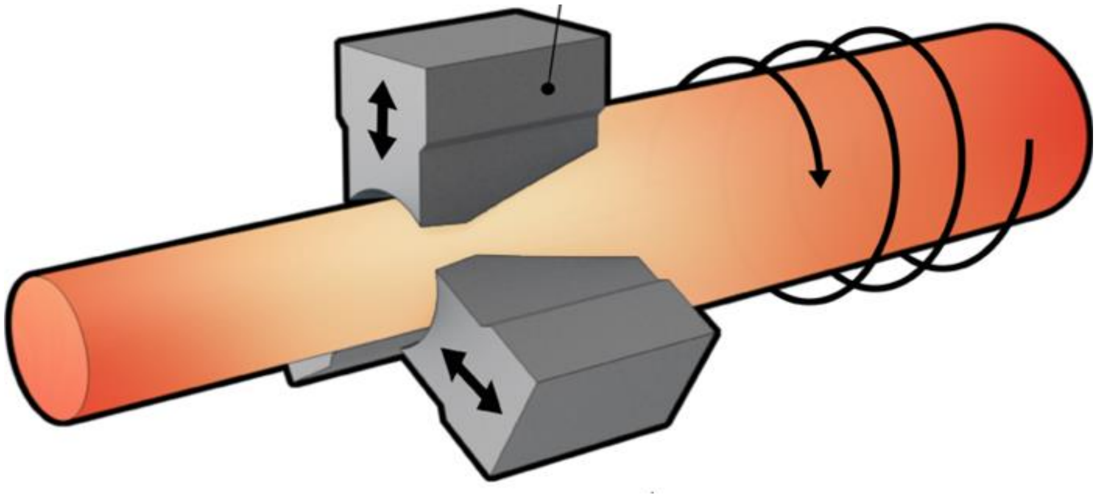

Figure (3-49) radial forging

- Figure (3-50) explains some of products that are made by swaging.

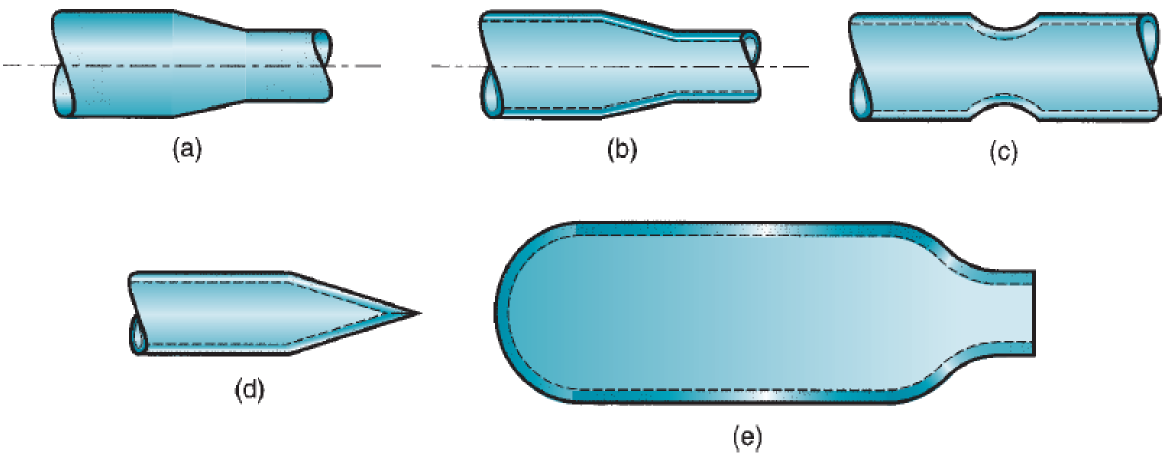

Figure (3-50) examples of products made by swaging (a) reduction of a solid stock (b) tapering a tube (c) swaging to form a groove on a tube (d) pointing of a tube (e) swaging of neck on a gas cylinder.

<u>Roll Forging:</u>

- It is used to reduce cross-section of cylindrical (or rectangular) w.p. by using an opposing rolls that have grooves matching the desired shape of final part.
- Figure (3-51) states this process.
- Roll forged products are stronger and possess favorable grain structure compared to machined parts.

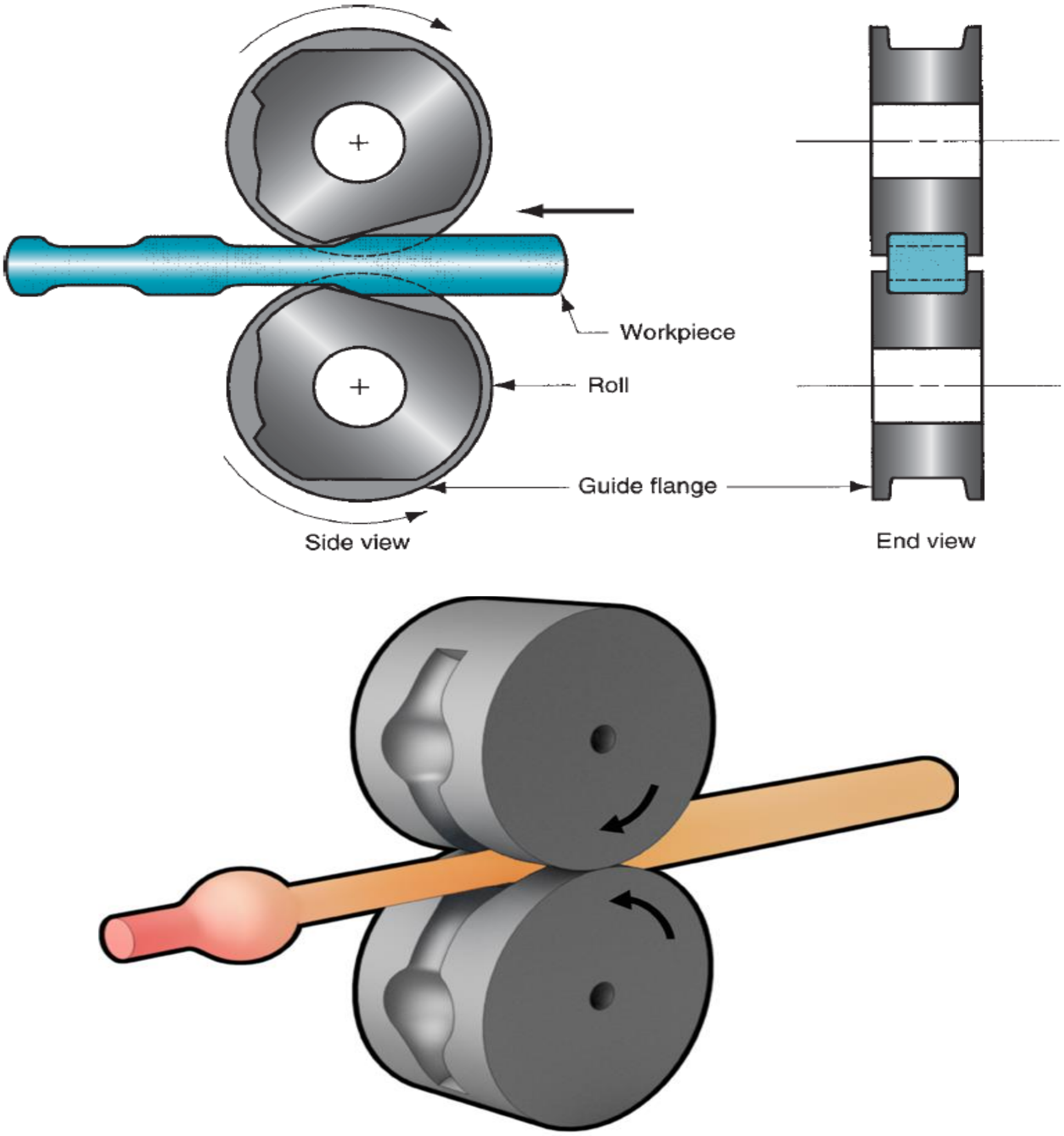

Figure (3-51) Roll Forging

Orbital Forging:

- In this process, the deformation occurs by using a cone-shaped upper die that simultaneously rolls and presses the w.p. which is supported by lower die.
- The press load (or force) required is lowered substantially because only small area of w.p. is compressed at any moment during rotation of cone die.
- Figure (3-52) explains this process.

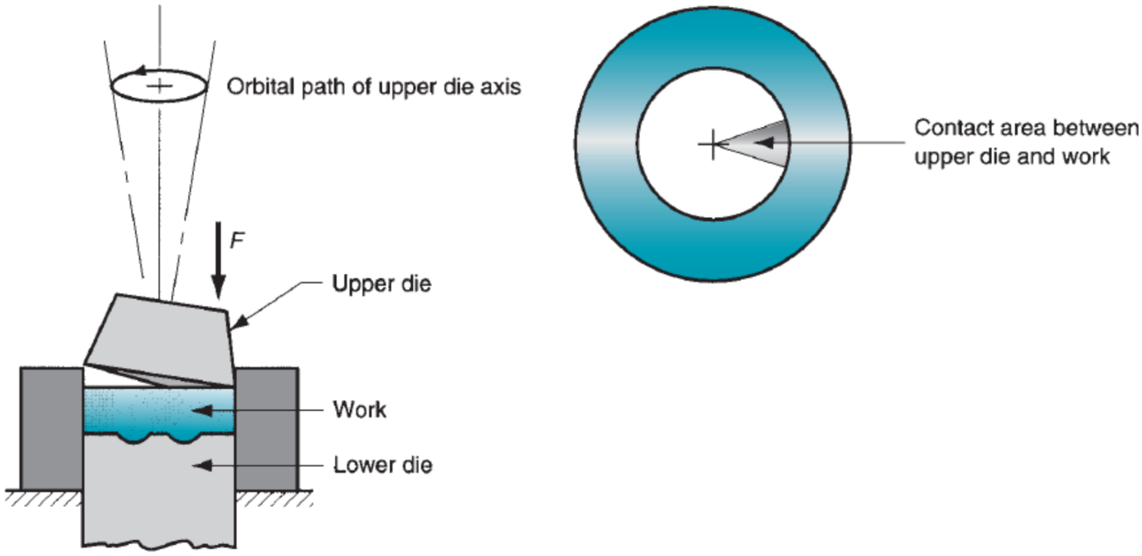

Figure (3-52) orbital forging. At end of cycle, lower die lifts to eject part.

Hubbing Forging:

- In this process, a hardened steel die is pressed into a soft metal block to make mold cavities for plastic molding and die casting.
- The hardened steel die, called the ***hub***, is machined to the part geometry to be molded.
- Figure (3-53) shows this process.

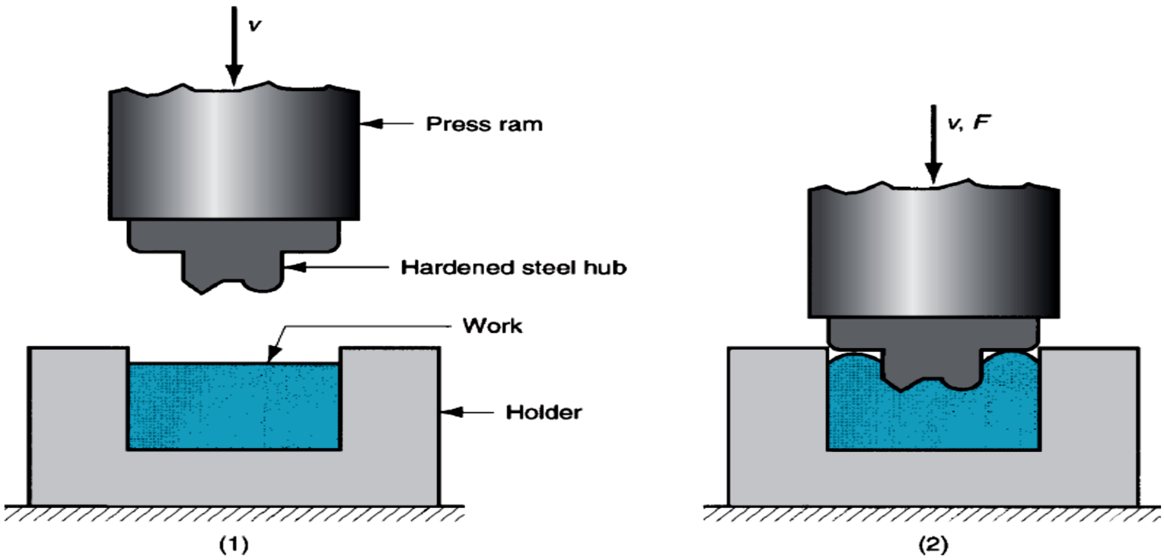

Figure (3-53) hubbing process (1) before deformation (2) the process is completed. Note that the excess material formed by the penetration of the hub must be machined away.

Isothermal Forging:

- It is a hot-forging operation in which the w.p. is maintained at or near its starting elevated temperature during deformation.
- This is usually accomplished by heating the forging dies to the same temperature of w.p.
- It is applied for difficult-to-forge metals such as titanium and superalloys and for complex shapes.
- This process is sometimes carried out in a vacuum to avoid rapid oxidation of the die material.

Trimming Operation:

- It is used to remove flash on w.p. in impression-die forging.
- In most cases, trimming is carried out by shearing.
- In cases the w.p. might be damaged by the cutting (shearing process), trimming may be done by another methods, such as grinding or sawing.
- Trimming is usually carried out while w.p. is still hot.
- Figure (3-54) illustrates this operation.

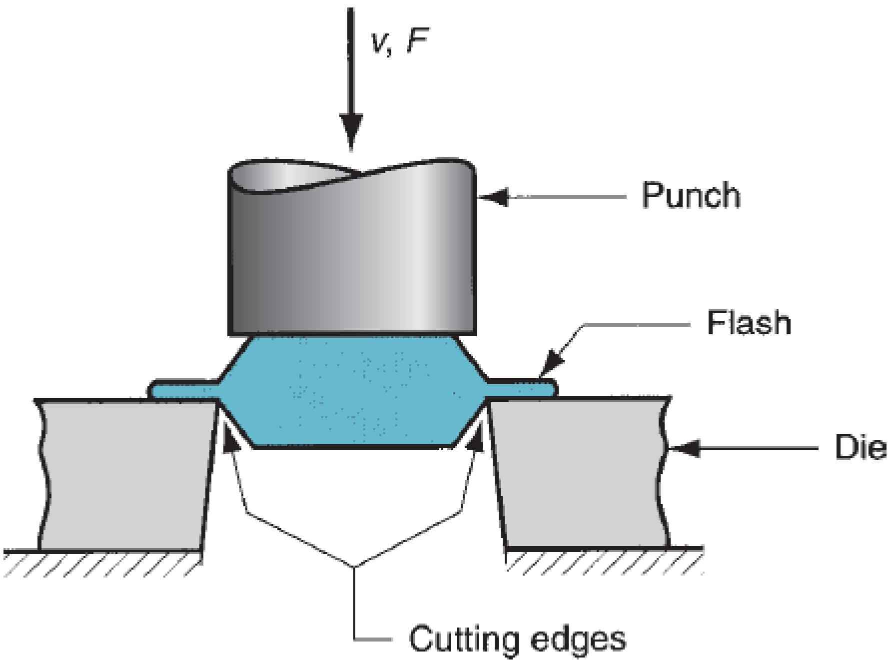

Figure (3-54) trimming operation