


## ENR212 Lecture 6 Slides and Notes

Slide 1



Manufacturing Processes  
Lecture 6

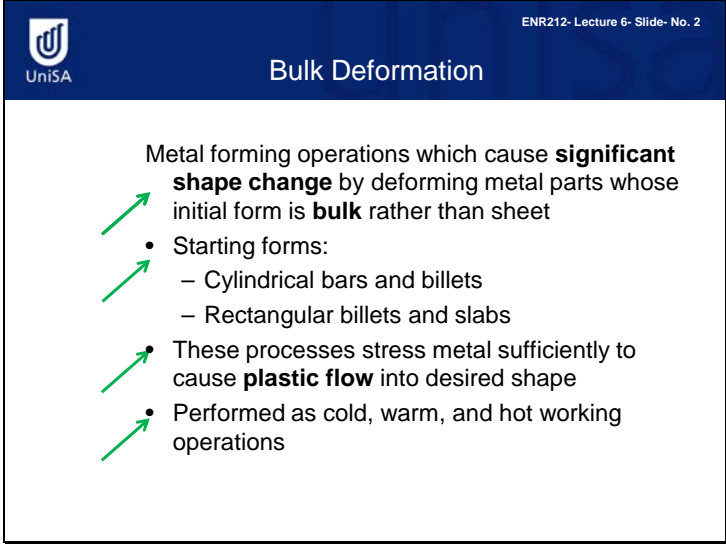
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### BULK FORMING

Dr Jun Ma

1. Rolling
2. Forging
3. Extrusion
4. Wire and Bar Drawing

Hello everyone, and welcome to Lecture 6 of Manufacturing Processes. (This lecture works through material covered in Chapter 19 of the textbook.) In this lecture, we introduce major bulk forming processes, including rolling, forging extrusion and wire and bar drawing.



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### Bulk Deformation

Metal forming operations which cause **significant shape change** by deforming metal parts whose initial form is **bulk** rather than sheet

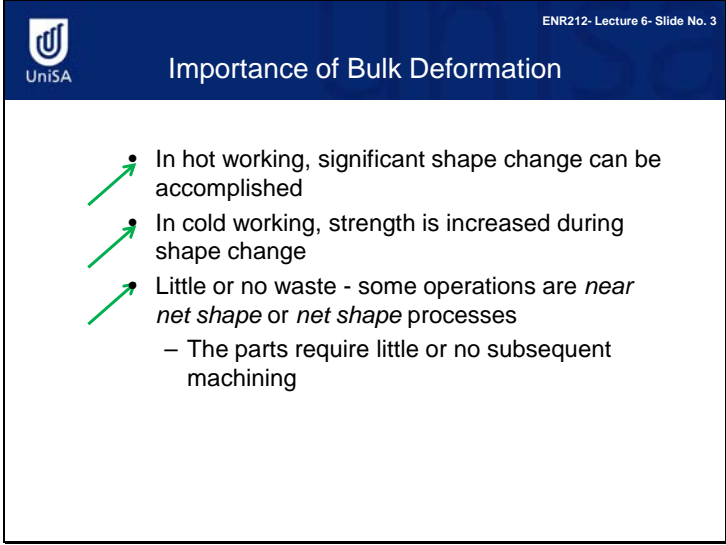
- Starting forms:
  - Cylindrical bars and billets
  - Rectangular billets and slabs
- These processes stress metal sufficiently to cause **plastic flow** into desired shape
- Performed as cold, warm, and hot working operations

Bulk deforming is a metal forming operation which causes significant shape change by deforming metal parts whose initial form is bulk rather than sheet. The starting forms include cylindrical bars and billets, and rectangular billets and slabs. A slab is rolled from an ingot or a bloom, and has a rectangular cross section of about 250 mm by 40 mm. A billet is rolled from a bloom and has a square cross section of about 40 mm by 40 mm. A bloom is a rolled steel workpiece with a square cross section of about 150 mm by 150 mm.

These processes work by stressing the metal sufficiently to cause plastic flow into the desired shape. Bulk deformation processes are performed at cold, warm, and hot working temperatures.

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### Importance of Bulk Deformation

- In hot working, significant shape change can be accomplished
- In cold working, strength is increased during shape change
- Little or no waste - some operations are *near net shape* or *net shape* processes
  - The parts require little or no subsequent machining

The bulk deformation processes are important for the following reasons:

In hot working, bulk deformation can achieve significant shape change in the shape of the workpiece.

In cold working, the workpiece is strengthened. Strengthening is caused by strain-hardening.

These operations produce little or no waste, allowing them to be classified as near net shape or net shape processes. They also require little or no subsequent machining.

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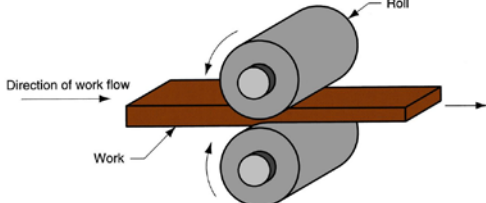
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### Rolling

- Deformation process in which work thickness is reduced by compressive forces exerted by two opposing rolls



The rolling process (specifically, flat rolling).

**Rolling is a metal forming process in which metal stock is passed through a pair of rolls. The function of the rolls is to pull the work into the gap between them by using friction. At the same time, they squeeze the work to reduce its cross section.**

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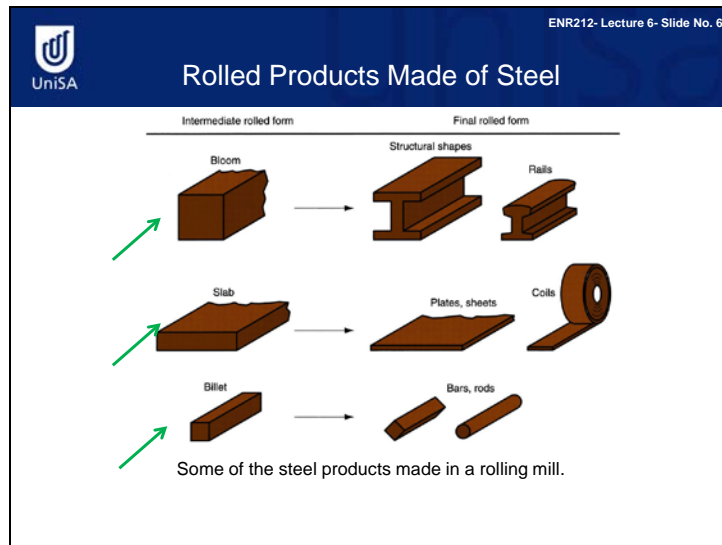
### Types of Rolling

- Based on workpiece geometry :
  - – Flat rolling - used to reduce thickness of a rectangular cross section
  - – Shape rolling - square cross section is formed into a shape such as an I-beam
- Based on work temperature :
  - – Hot Rolling – most common due to the large amount of deformation required
  - – Cold rolling – produces finished sheet and plate stock

Based on workpiece geometry, there are two types of rolling: flat rolling and shape rolling. Flat rolling is the most basic process, and it is used to reduce the thickness of a rectangular cross section. Shape rolling is closely related to flat rolling. In shape rolling, a square cross section is formed into a shape such as an I-beam. Rolling can be classified according to work temperature. Hot rolling is the most common type, due to the large amount of deformation required. Cold rolling produces a finished sheet and plate stock.

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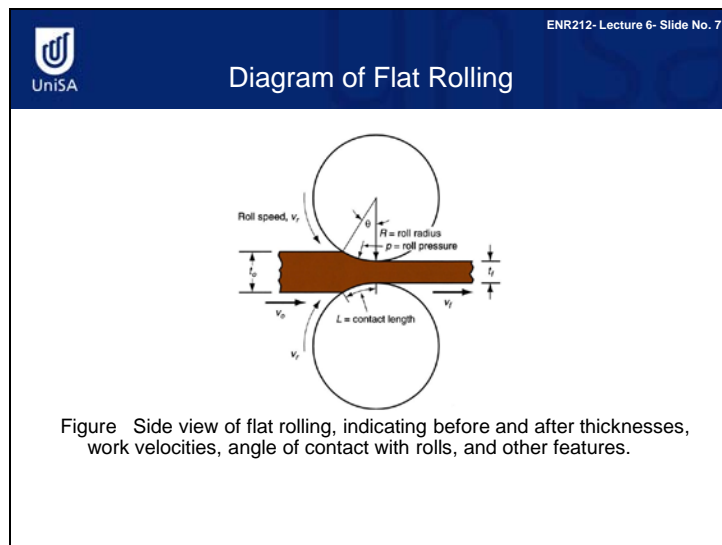


So what are some examples of rolling? In bulk deformation processes, blooms are rolled into structure shapes and rails for railroad tracks. Slabs are rolled into plates, sheets, and strips. Billets are rolled into bars and rods. Most of these processes are performed hot or warm, because hot and warming conditions can produce significant shape change. These shapes are the raw materials for machining, wire drawing, forging, and other metalworking processes.

Further flattening of hot-rolled plates and sheets is often accomplished by cold rolling. Cold rolling strengthens the metal and permits a tighter tolerance on thickness.

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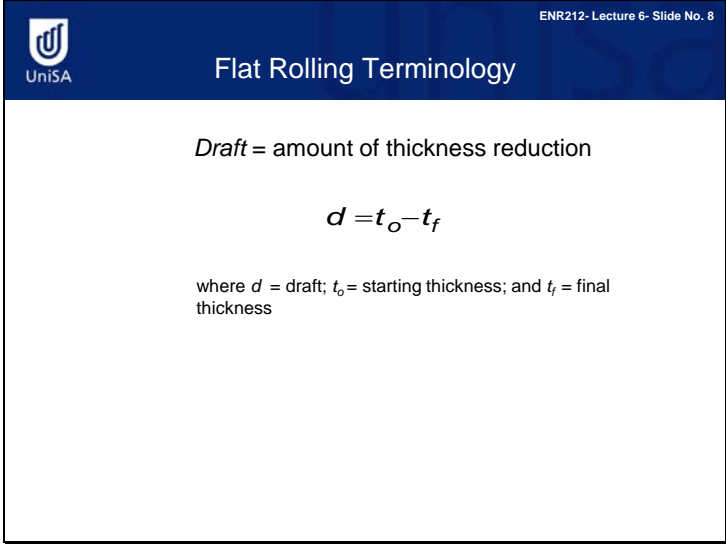
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Flat rolling is illustrated in this figure. When a work piece passes through the two rolls from left to right, its thickness is reduced.

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### Flat Rolling Terminology

*Draft* = amount of thickness reduction

$$d = t_o - t_f$$

where  $d$  = draft;  $t_o$  = starting thickness; and  $t_f$  = final thickness

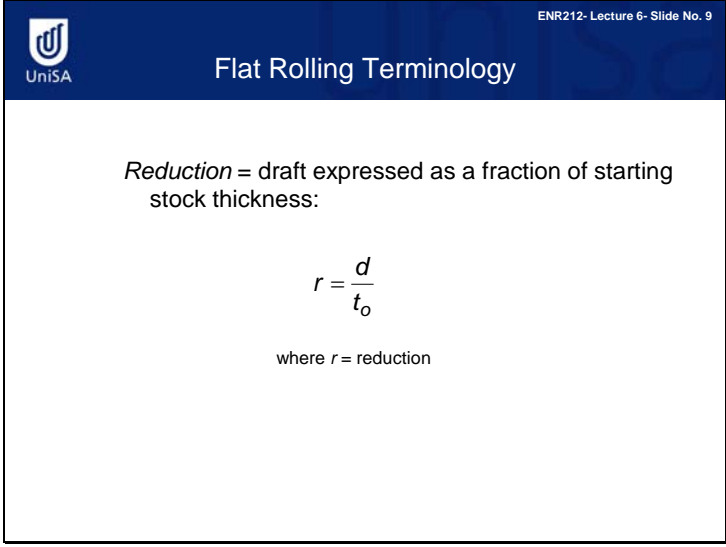
This amount of the reduced thickness is called a draft.

The maximum possible draft in a rolling operation depends on the following parameters : (a) coefficient of friction between roll and work, (b) roll diameter



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### Flat Rolling Terminology

*Reduction* = draft expressed as a fraction of starting stock thickness:


$$r = \frac{d}{t_0}$$

where  $r$  = reduction

Reduction is the ratio of draft (or the change of thickness) to starting thickness

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### Shape Rolling

Work is deformed into a **contoured cross section** rather than flat (rectangular)

- Accomplished by passing work through rolls that have the reverse of desired shape
- Products include:
  - Construction shapes such as I-beams, L-beams, and U-channels
  - Rails for railroad tracks
  - Round and square bars and rods

In shape rolling, a workpiece is deformed into a contoured cross section. Shape rolling products include I-beams, Rails for railroad tracks, round and square bars and rods.

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### Thread Rolling

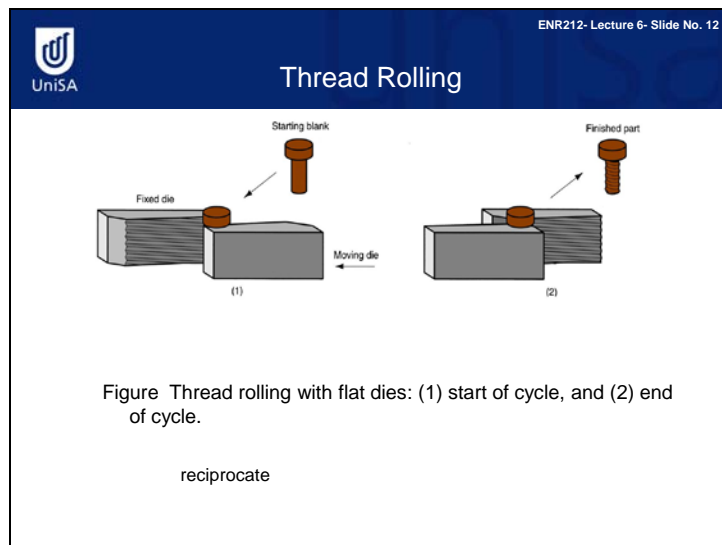
Bulk deformation process used to form threads on cylindrical parts by rolling them between two dies

- Important commercial process for mass producing bolts and screws
- Performed by cold working in thread rolling machines
- Advantages over thread cutting (machining):
  - Higher production rates
  - Better material utilization
  - Stronger threads and better fatigue resistance due to work hardening

Thread rolling is used to form threads on cylindrical parts by rolling them between two dies. Is thread rolling a cold working or a warm working process? The answer is cold working.

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In thread rolling, the two dies reciprocate relative to each other to produce thread.

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### Ring Rolling

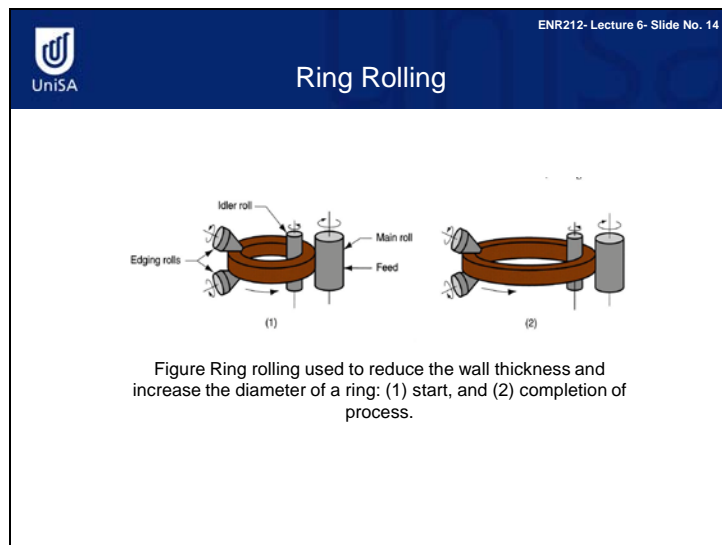
Deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter

- As thick-walled ring is compressed, deformed metal elongates, causing diameter of ring to be enlarged
- Hot working process for large rings and cold working process for smaller rings
- Applications: ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery
- Advantages: material savings, ideal grain orientation, strengthening through cold working

Ring rolling is a deformation process in which a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter.

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As the thick-walled ring is compressed, the deformed metal elongates, causing the diameter of the ring to be enlarged.

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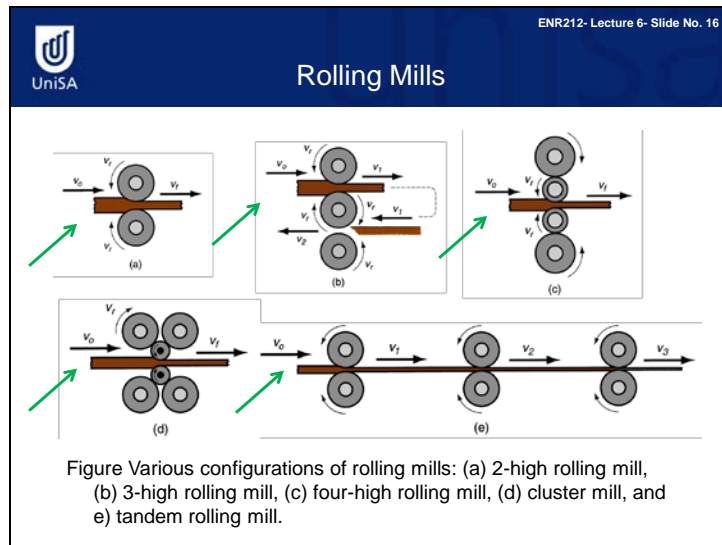
### Rolling Mills

- Equipment is massive and expensive
- Rolling mill configurations:
  - Two-high – two opposing rolls
  - Three-high – work passes through rolls in both directions
  - Four-high – backing rolls support smaller work rolls
  - Cluster mill – multiple backing rolls on smaller rolls
  - Tandem rolling mill – sequence of two-high mills

In rolling, equipment is massive and expensive. Mills are designed in different types of configurations, as you can see above.

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The two-high rolling mill is the basic type, consisting of two opposing rolls.

In the three-high configuration, there are three rolls in a vertical column, and the direction of rotation of each roll remains unchanged. An elevator mechanism is needed to raise or lower the workpiece.

The four-high rolling mill uses two smaller-diameter rolls to contact the workpiece with two backup rolls.

In a cluster rolling mill, more than two backup rolls support smaller-diameter rolls.

To achieve high production rates, a tandem rolling mill is often used. It consists of a number of rolling stands. With each rolling step, workpiece velocity increases.



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### Forging

Deformation process in which work is compressed between two dies



• Oldest of the metal forming operations, dating from about 5000 B C


• Components: engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts

• Also, basic metals industries use forging to establish basic form of large parts that are subsequently machined to final shape and size

In forging, a workpiece is compressed between two opposing dies, so that the die shapes are imparted to the work.

It is the oldest of the metal forming operations, dating from about 5000 B.C.

The basic metals industries use forging to establish basic form of large parts; the large parts are subsequently machined to final shape and size, such as engine crankshafts, connecting rods, gears, aircraft structural components, and jet engine turbine parts.

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### Classification of Forging Operations

- Cold vs. hot forging:
  - Hot or warm forging – most common, due to the significant deformation and the need to reduce strength and increase ductility of work metal
  - Cold forging – advantage: increased strength that results from strain hardening
- Impact vs. press forging:
  - Forge hammer - applies an impact load
  - Forge press - applies gradual pressure
- Open-die forging, impression-die forging and flashless forging.

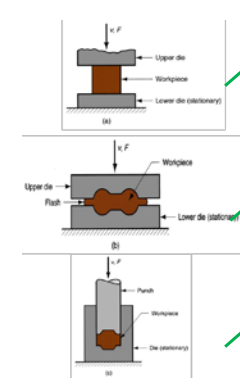
Forging is carried out in many different ways. One way to classify it is by working temperature. Hot or warm forging is most common. This is due to the significant deformation and the need to reduce strength and increase ductility of work metal. Cold forging is also commonly used. The advantage is the increased strength that results from strain hardening of the component.

According to the way load is applied, forging can use a hammer or a press. In some forging operations, forge hammers are used, which apply an impact load, while in others forging presses are used, which apply gradual pressure. Based upon the cavities that the die and punch form, forging operations are classified into open-die forging, impression-die forging and flashless forging.

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### Classification of Forging Operations



(a) Open-die forging - work is compressed between two flat dies, allowing metal to flow laterally without constraint

(b) Impression-die forging - die contains cavity or impression that is imparted to workpiece  
Metal flow is constrained so that flash is created

(c) Flashless forging - workpiece is completely constrained in die  
No excess flash is created

In open-die forging, a work is compressed between two flat dies, so that the metal flows without constraint in a lateral direction relative to the die surfaces. In impression-die forging, the die contains cavities or impressions that are imparted to the workpiece, thus constraining metal flow to a significant degree. Metal flow is constrained so that flash is created. In flashless forging, the workpiece is completely constrained within the die and no excess flash is created.

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### Open-Die Forging

Compression of workpiece between two flat dies

- Similar to compression test when workpiece has cylindrical cross section and is compressed along its axis
  - Deformation operation reduces height and increases diameter of work


Assuming no friction between workpiece and die

(1) (2) (3)

In open-die forging, a work is compressed between two flat dies. Assuming there is no friction between workpiece and die, metal flows laterally without constraint. This is similar to compression testing. Remember back to when we covered the stress-strain curve and the true stress-strain curve. The true stress-strain curve obtained from tensile testing for a given material can be used to predict stress-strain value for compression testing.

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### Open-Die Forging with NO Friction

If no friction occurs between work and die surfaces, then homogeneous deformation occurs, so that radial flow is uniform throughout workpiece height and true strain is given by:

$$\longrightarrow \quad \varepsilon = \ln \frac{h_o}{h}$$


where  $h_o$  = starting height; and  $h$  = height at some point during compression

- At  $h$  = final value  $h_f$ , true strain is maximum value

If no friction occurs between work and die surfaces, then metal flows freely between die and metal. The true strain is given by this equation; note that this equation of true strain is slightly different to the equation of true strain we covered in lecture three.


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### Theoretical Forging Force with NO Friction

- Estimate of force to perform forging can be calculated



- $F = Y_f A_i$

Where:

- $F$  = Force (N),
- $A_i$  = instantaneous cross-sectional area of the part ( $\text{mm}^2$ ),
- $Y_f$  = flow stress corresponding the strain given in previous equation (MPa)

The forging force is given by this equation, which is just another format of true stress.

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### Open-Die Forging with Friction

- Friction between work and die surfaces constrains lateral flow of work, resulting in barrelling effect
- In hot open-die forging, effect is even more pronounced due to heat transfer at and near die surfaces, which cools the metal and increases its resistance to deformation

The diagram illustrates the barrelling effect in open-die forging through three stages:

- (1) Initial cylindrical workpiece with diameter  $D_0$  and height  $h_0$ .
- (2) Workpiece under force  $F$  with height  $h$  and diameter  $D$ .
- (3) Workpiece under force  $F$  with height  $h_r$  and diameter  $D_1$ , showing a barrel-shaped profile.

As explained, open-die forging is similar to compression testing in that they both assume the condition that no friction exists between workpiece and die. Of course, in the real world, there is always friction between the work piece and the die surfaces, which constrains the lateral flow of the piece. This results in a barrelling effect, so the cross section is not uniform. Therefore, we need to modify the equation.

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### Theoretical Forging Force with Friction

- As an approximation, we can apply a shape factor to the previous equation to account for effects of the  $D/h$  ratio and friction:


$$F = K_f Y_f A_i$$

Where:

- $F$  = Force (N),
- $A_i$  = instantaneous cross-sectional area of the part (mm<sup>2</sup>),
- $Y_f$  = flow stress (MPa)
- $K_f$  = forging shape factor

To take into account the barrelling effect, a shape factor was applied to the above equation.



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### Forging Shape Factor

- Forging shape factor  $K_f$ , defined as:

$$K_f = 1 + \frac{0.4\mu D}{h}$$

Where:

- $\mu$  = coefficient of friction,
- $h$  = workpiece height, mm,
- $D$  = workpiece diameter or other dimension representing contact surface with die, mm,

The forging shape factor is defined by this equation.

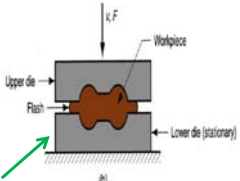
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### Impression-Die Forging

Compression of workpiece by dies with inverse of desired part shape

- Flash is formed by metal that flows beyond die cavity into small gap between die plates
- Flash must be later trimmed, but it serves an important function during compression:
  - As flash forms, friction resists continued metal flow into gap, constraining material to fill die cavity
  - In hot forging, metal flow is further restricted by cooling against die plates




The diagram illustrates the impression die forging process. A workpiece is placed between an upper die and a lower die. A force  $F$  is applied to the upper die, compressing the workpiece. The lower die is stationary. As the workpiece is compressed, metal flows into the gap between the die plates, forming a flash. The flash is shown as a small piece of metal protruding from the parting line. The workpiece is shown in a cross-section, and the flash is shown as a small piece of metal protruding from the parting line. The diagram is labeled (b).

Impression die forging is performed with dies that contain the inverse of the desired shape of the part, so that the die contains the cavity or impression that is imparted to the workpiece. In impression die forging, the metal under high pressure is squeezed into the small space between the die halves at the parting line, so that a flash is created. A flash is the formation of a small piece of metal. As the flash forms, friction resists the metal flowing into the gap. This constrains the material, making it fill the die cavity.

Impression-die forging is followed by trimming, which is a shearing operation used to remove the flash on the workpiece after impression die forging.

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### Impression-Die Forging Practice

- Several forming steps often required, with separate die cavities for each step
  - Beginning steps redistribute metal for more uniform deformation and desired metallurgical structure in subsequent steps
  - Final steps bring the part to final geometry
- Impression-die forging is often performed manually by skilled operator under adverse conditions

In impression-die forging, a number of steps are required. The initial steps redistribute metal for more uniform deformation and the final steps bring the part to final geometry. This sort of forging needs skilled labor.

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### Flashless Forging

Compression of work in punch and die tooling whose cavity does not allow for flash

- Starting workpiece volume must equal die cavity volume within very close tolerance
- Process control more demanding than impression-die forging
- Best suited to part geometries that are simple and symmetrical

The diagram illustrates the three stages of flashless forging. Stage (1) shows a 'Starting workpiece' (a cylindrical rod) being placed into a 'Die' cavity. Stage (2) shows the 'Punch' moving down, compressing the workpiece. Stage (3) shows the 'Finished part' (a shorter, wider cylinder) being ejected from the die. Labels include 'Starting workpiece', 'Punch', 'Finished part', and 'Die'. The stages are labeled (1), (2), and (3) respectively. Arrows labeled  $v_1, F$  indicate the direction of the punch and the force applied.

In flashless forging, the workpiece is completely constrained within the die and no excess flash is created. This is often classified as a precision forging process. The starting workpiece volume must equal the die cavity volume within a very close tolerance. This is best suited to part geometries that are simple and symmetrical.

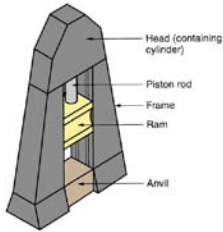
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### Forging Hammers (Drop Hammers)

Apply impact load against workpiece

- Two types:
  - Gravity drop hammers - impact energy from falling weight of a heavy ram
  - Power drop hammers - accelerate the ram by pressurized air or steam
- Disadvantage: impact energy transmitted through anvil into floor of building
- Commonly used for impression-die forging




The diagram shows a cross-section of a drop hammer. It consists of a large, heavy, grey metal head at the top, which contains a yellow cylinder. A piston rod connects the cylinder to a yellow ram. The ram is supported by a frame. Below the ram is a brown anvil. Labels with arrows point to the Head (containing cylinder), Piston rod, Frame, Ram, and Anvil.

Forging hammers operate by applying an impact loading against the workpiece.

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### Forging Presses

- Apply gradual pressure to accomplish compression operation
- Types:
  - Mechanical press - converts rotation of drive motor into linear motion of ram
  - Hydraulic press - hydraulic piston actuates ram
  - Screw press - screw mechanism drives ram

Forging presses apply gradual pressure, rather than sudden impact, to accomplish the forging operation.

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### Upsetting (Heading)

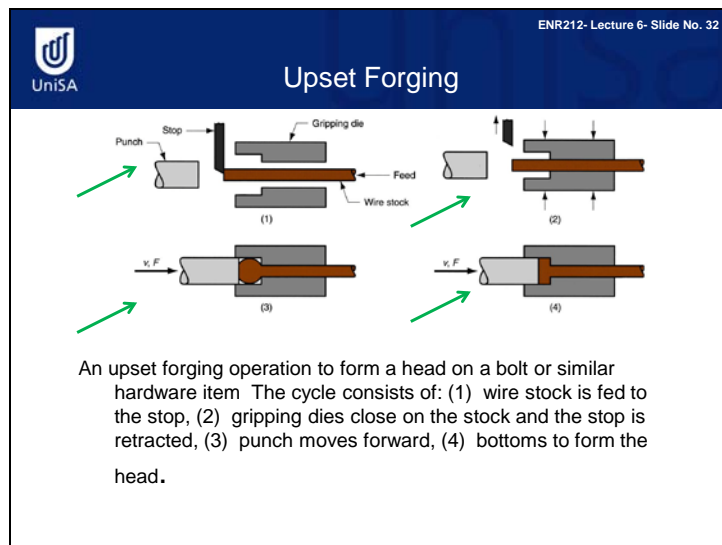
Forging process used to form heads on nails, bolts, and similar hardware products

- More parts produced by upsetting than any other forging operation
- Performed cold, warm, or hot on machines called *headers* or *formers*
- Wire or bar stock is fed into machine, end is headed, then piece is cut to length
- For bolts and screws, thread rolling is then used to form threads

Upsetting is a deformation operation in which a cylindrical workpiece is increased in diameter and reduced in length. This is a very popular form of forging.

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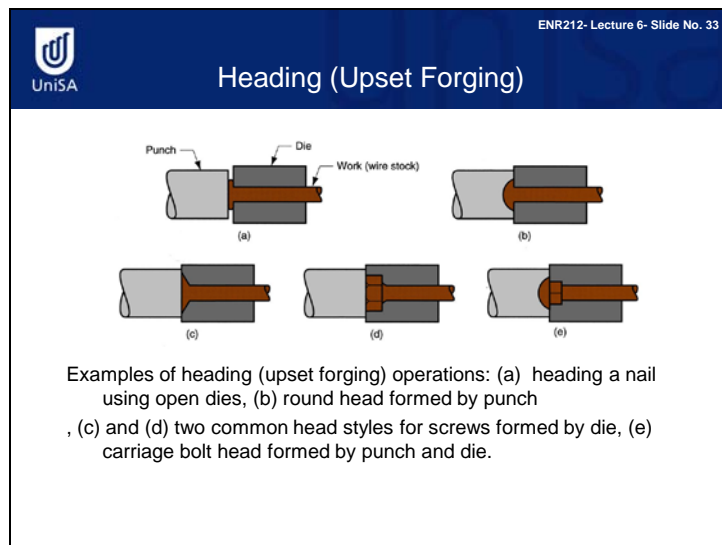


An upset forging is shown in this figure. (1) a wire stock is fed into a die and stopped by a stop, (2) the die closes on the stock and the stop is retracted, (3) the punch moves forward, (4) a head is produced.



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By changing the geometries of punch and die, upset forging is able to produce a variety of heads.

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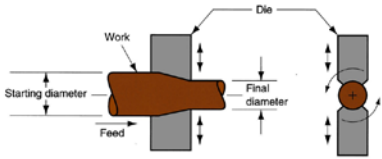
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### Swaging

Accomplished by rotating dies that hammer a workpiece radially inward to taper it as the piece is fed into the dies

- Used to reduce diameter of tube or solid rod stock



Swaging is accomplished by means of rotating dies. The dies hammer a work piece radially inward to taper it as the piece is fed into the dies. The swaging process is used to reduce diameter of solid rod stock; the dies rotate as they hammer the work.

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### Extrusion

Compression forming process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross section

- Process is similar to squeezing toothpaste out of a toothpaste tube
- In general, extrusion is used to produce long parts of uniform cross sections
- Two basic types:
  - Direct extrusion
  - Indirect extrusion

Extrusion is a compression process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross section. There are two basic types: direct extrusion and indirect extrusion.

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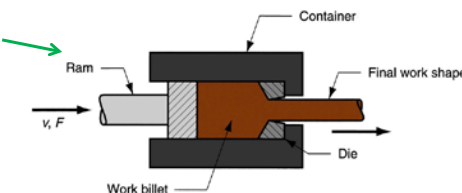
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### Direct Extrusion

- Also called forward extrusion
- As ram approaches die opening, a small portion of billet remains that cannot be forced through die opening
- This extra portion, called the *butt*, must be separated from *extrudate* by cutting it just beyond the die exit

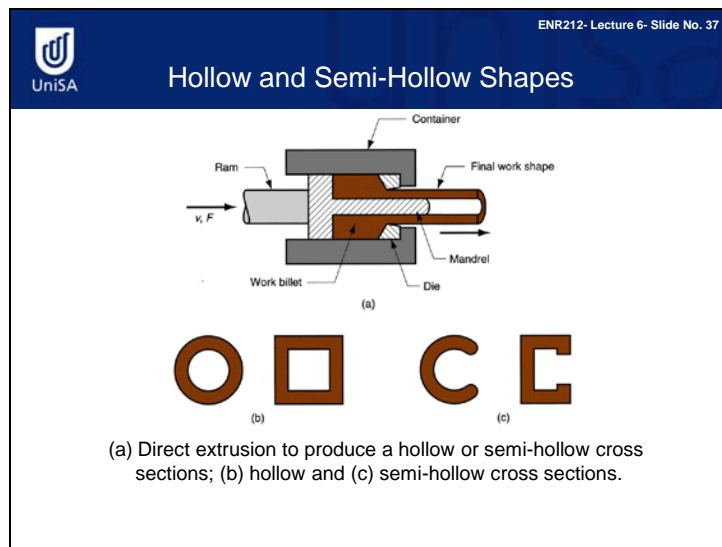


The diagram illustrates the direct extrusion process. A cylindrical work billet is placed inside a container. A ram is pushed into the container from the left, compressing the work billet. The ram is labeled with a green arrow and the force  $v, F$ . The work billet is being forced through a die opening, which is labeled 'Die'. The material being pushed through the die is labeled 'Final work shape'. The container is labeled 'Container'. The work billet is labeled 'Work billet'.

Direct extrusion is also called forward extrusion. As shown in this figure, a metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container.

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A variety of cross sections can be made in direct extrusion, by using various die openings, as you can see in figure b.

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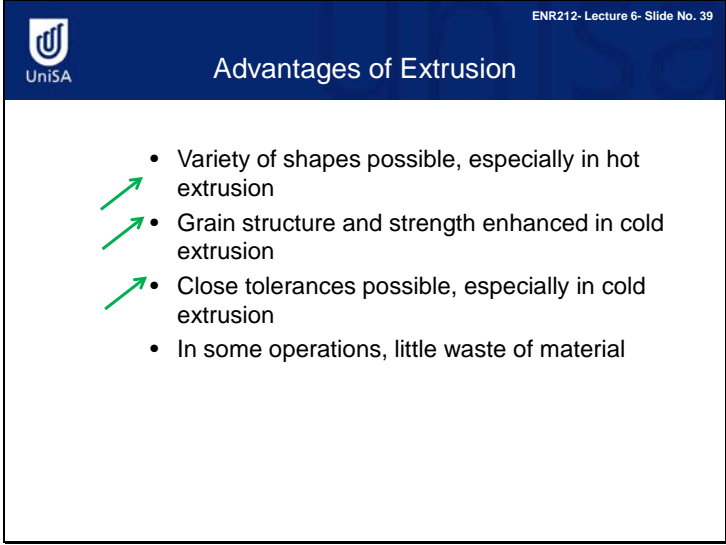
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### Indirect Extrusion

- Also called backward extrusion and reverse extrusion
- Limitations of indirect extrusion are imposed by
  - Lower rigidity of hollow ram
  - Difficulty in supporting extruded product as it exits die

Figure Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

Indirect extrusion is also called backward extrusion and reverse extrusion. In indirect extrusion, the die is mounted to the ram rather than at the end of the container. As the ram penetrates in to the workpiece, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram.



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### Advantages of Extrusion

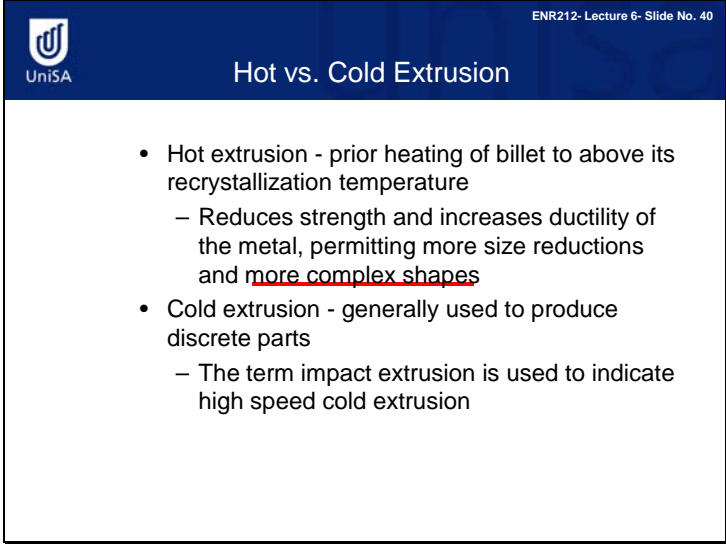
- Variety of shapes possible, especially in hot extrusion
- Grain structure and strength enhanced in cold extrusion
- Close tolerances possible, especially in cold extrusion
- In some operations, little waste of material

Advantages of extrusion include the following:

- 1 A variety of shapes can be made by changing dies, especially in hot extrusion.
2. It produces desired grain structure, and strength is enhanced in cold extrusion.
3. Because metal is extruded through a die, the extrusion produces close tolerances and there is little waste.

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### Hot vs. Cold Extrusion


- Hot extrusion - prior heating of billet to above its recrystallization temperature
  - Reduces strength and increases ductility of the metal, permitting more size reductions and more complex shapes
- Cold extrusion - generally used to produce discrete parts
  - The term impact extrusion is used to indicate high speed cold extrusion

So how are hot extrusion and cold extrusion different? Hot extrusion needs prior heating. It is able to produce more complex shapes, due to the high ductility of metal at high temperatures.



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### Extrusion Ratio

Also called the *reduction ratio*, it is defined as

$$r_x = \frac{A_o}{A_f}$$

where  $r_x$  = extrusion ratio;  $A_o$  = cross-sectional area of the starting billet; and  $A_f$  = final cross-sectional area of the extruded section

- Applies to both direct and indirect extrusion

The extrusion ratio is the ratio of the starting cross section area to the final area.

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### Complex Cross Section

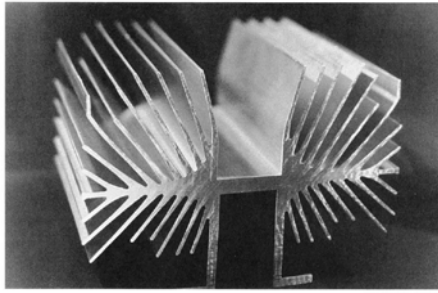


Figure A complex extruded cross section for a heat sink  
(photo courtesy of Aluminum Company of America)

The image shows a highly complex, multi-fingered extruded cross-section of an aluminum heat sink. The structure consists of a central vertical stem from which numerous thin, flat, fan-like fingers radiate outwards, forming a symmetrical, butterfly-like shape. The fingers are closely spaced and have a slightly curved, tapered profile. The overall appearance is that of a precision-machined or extruded metal component designed for efficient heat dissipation.

This photo shows you a heat sink. Do you think that this was produced using cold extrusion or hot extrusion? The answer is hot extrusion.

## ENR212 Lecture 6 Slides and Notes

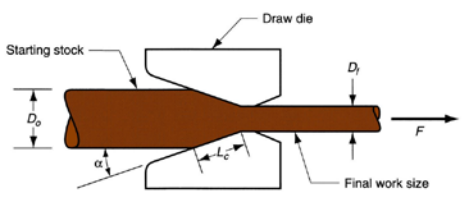
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### Wire and Bar Drawing

- Drawing is a forming process in which the diameter of a round wire or bar is reduced by pulling it through a die opening.
- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it passes through die opening




The diagram illustrates the wire and bar drawing process. A brown cylindrical starting stock with diameter  $D_o$  is being pulled through a draw die with diameter  $D_d$ . The final work size has diameter  $D_f$ . The die has a length  $L_d$  and a taper angle  $\alpha_d$ . A force  $F$  is applied to the right, pulling the work through the die.

Wire and bar drawing is a forming process in which the diameter of a round wire or bar is reduced by pulling it through a die opening.

It is similar to extrusion, but the work is pulled through a die in drawing, where it is pushed through in extrusion.

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### Wire Drawing vs. Bar Drawing

- Difference between bar drawing and wire drawing is ~~stock size~~
  - Bar drawing - large diameter bar and rod stock
  - Wire drawing - small diameter stock - wire sizes down to 0.03 mm (0.001 in.) are possible
- Although the mechanics are the same, the methods, equipment, and even terminology are different

The basic difference between bar drawing and wire drawing is the stock size that is processed. Bar drawing is used for large diameter bar and rod stock. Wire drawing is applied to small diameter stock, with wire sizes down to 0.03 mm (0.001 inch) being possible.

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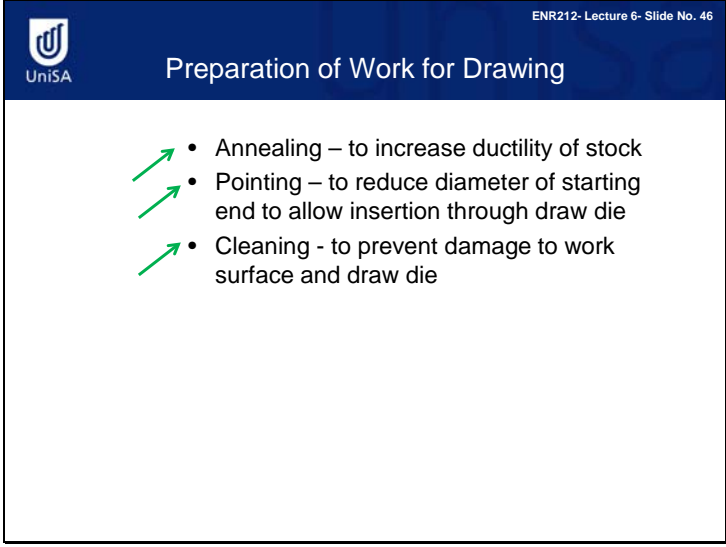
### Drawing Practice and Products

- Drawing practice:
  - Usually performed as cold working
  - Most frequently used for round cross sections
- Products:
  - Wire drawing: electrical wire; wire stock for fences, coat hangers, and shopping carts
  - Bar drawing: metal bars for machining, forging, and other processes

Drawing practice is usually performed as a cold working operation. It is usually used to produce round cross sections, but squares and other shapes are also drawn. Wire drawing is an important industrial process, providing commercial products such as electrical wire and cable, wire stock for fences, coat hangers, and shopping carts, and rod stock to produce nails, screws, rivets, and springs. Bar drawing is used to produce metal bars for machining, forging, and other processes.

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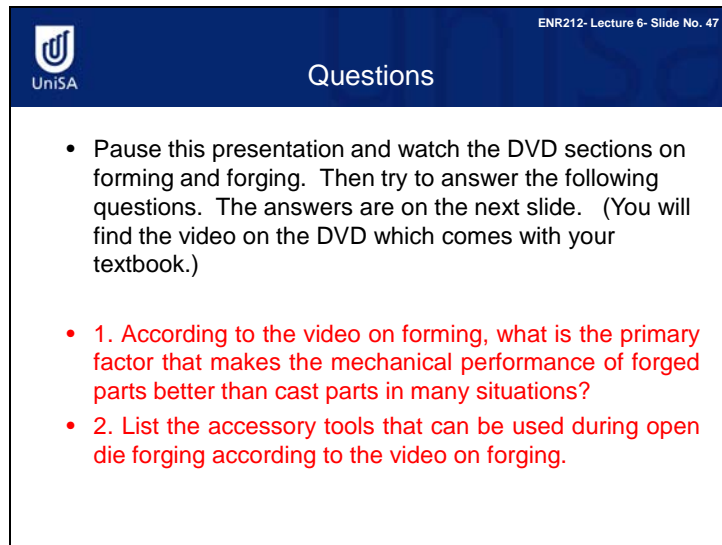
### Preparation of Work for Drawing

- Annealing – to increase ductility of stock
- Pointing – to reduce diameter of starting end to allow insertion through draw die
- Cleaning - to prevent damage to work surface and draw die

Three steps of work are needed to prepare a workpiece for drawing.

## ENR212 Lecture 6 Slides and Notes

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The slide features a dark blue header with the UniSA logo on the left and the text 'ENR212- Lecture 6- Slide No. 47' on the right. The word 'Questions' is centered in the header. The main content area is white and contains a list of instructions and two questions. The first question is in red text.

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### Questions

- Pause this presentation and watch the DVD sections on forming and forging. Then try to answer the following questions. The answers are on the next slide. (You will find the video on the DVD which comes with your textbook.)
- 1. According to the video on forming, what is the primary factor that makes the mechanical performance of forged parts better than cast parts in many situations?
- 2. List the accessory tools that can be used during open die forging according to the video on forging.

Now pause this presentation and watch the DVD sections on forming and forging. Then try to answer the following questions. The answers are on the next slide. (You will find these videos on the DVD which comes with your textbook.)

## ENR212 Lecture 6 Slides and Notes

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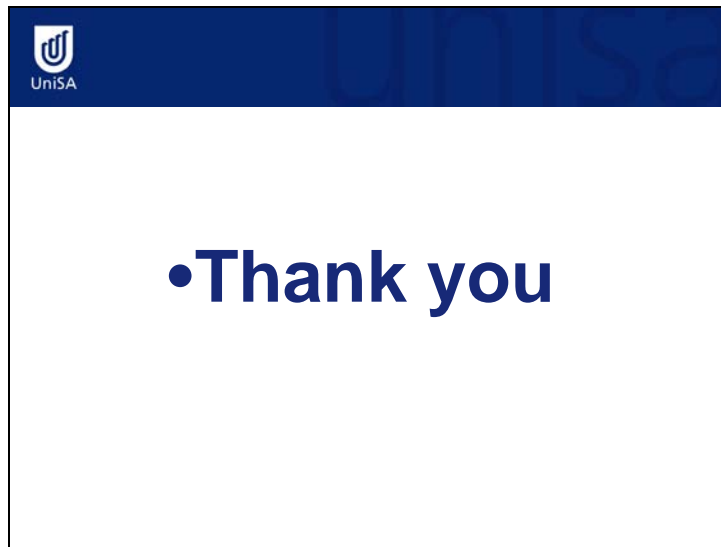
### Answers

- Answer 1: The mechanical performance of forged or wrought parts is usually better because of the microstructure changes and the directional grain flow imparted during the forging process.
- Answer 2: Accessory tools that can be used during open die forging are (1) saddles, (2) blocks, (3) rings, (4) mandrels, and (5) punches.



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Thanks for your attention.