

ENR212 Lecture 5 Slides and Notes

Slide 1



Manufacturing Processes
Lecture 5


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FUNDAMENTALS OF METAL FORMING

Dr Jun Ma

- ✓ 1. Overview of Metal Forming
- ✓ 2. Material Behavior in Metal Forming
- ✓ 3. Temperature in Metal Forming
- ✓ 4. Strain Rate Sensitivity
- ✓ 5. Friction and Lubrication in Metal Forming

Welcome to lecture summary 5. (This lecture works through material covered in Chapter 18 of the textbook.) In this lecture, we will introduce the fundamentals of metal forming. We will look at the following questions:

First, what is metal forming, and what are the categories of metal forming?

Second, how do we describe material behaviour when forming metals? Material behaviour can be understood as material deformation, so material behaviour can be described by the stress-strain curve.

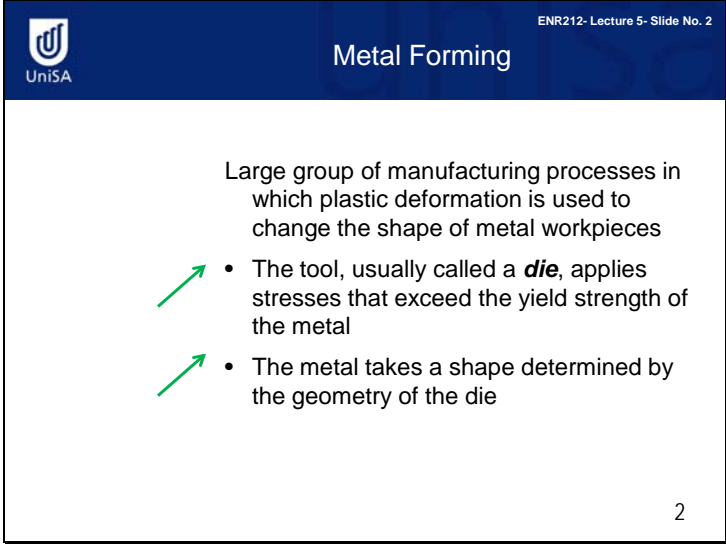
Third, what is the effect of temperature on metal forming. When temperature increases, strength reduces, but ductility increases.

Fourth, does strain rate matter much in metal forming?

Fifth, is friction desirable, and how can we control it?

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Metal Forming

Large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces

- The tool, usually called a **die**, applies stresses that exceed the yield strength of the metal
- The metal takes a shape determined by the geometry of the die

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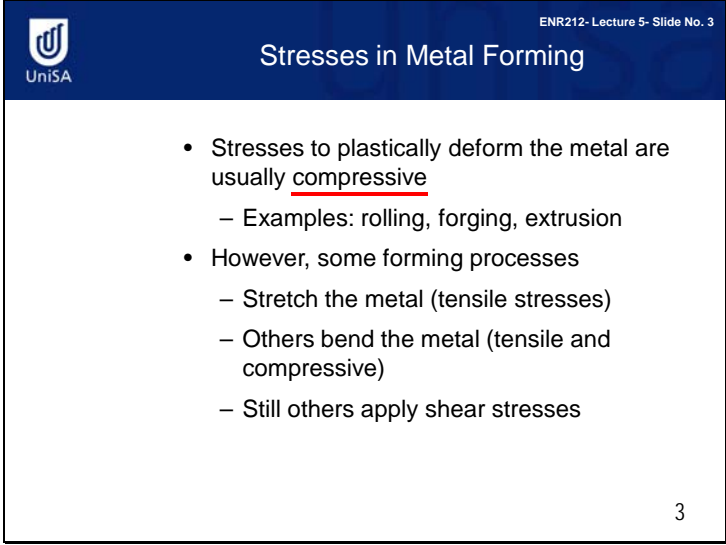
Metal forming is also called metal deformation. In metal forming, the shape of a metal piece is changed by plastic deformation, so the plastic region in the true Stress-Strain curve is important here. Metal flow is the nature of metal forming; the flow is caused by the stress applied.

The metal deformation is caused by using a tool. The tool, usually called a die, applies stresses that exceed the yield strength of the metal.

The shape of the metal product is determined by the geometry of the die.

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The slide features a dark blue header with the UniSA logo on the left and the text 'ENR212- Lecture 5- Slide No. 3' on the right. The main content area is white with a black border. It contains a bulleted list of points about stresses in metal forming. The word 'compressive' is underlined in red. A small number '3' is located in the bottom right corner of the slide frame.

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Stresses in Metal Forming

- Stresses to plastically deform the metal are usually compressive
 - Examples: rolling, forging, extrusion
- However, some forming processes
 - Stretch the metal (tensile stresses)
 - Others bend the metal (tensile and compressive)
 - Still others apply shear stresses

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We have learnt about three types of static stresses: tension, compression and shearing. In metal forming, compression is commonly applied to plastically deform the metal. However, tension and shearing are also used in metal forming.

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Material Properties in Metal Forming

- Desirable material properties:
 - Low yield strength
 - High ductility
- These properties are affected by temperature:
 - Ductility increases and yield strength decreases when work temperature is raised
- Other factors:
 - Strain rate and friction

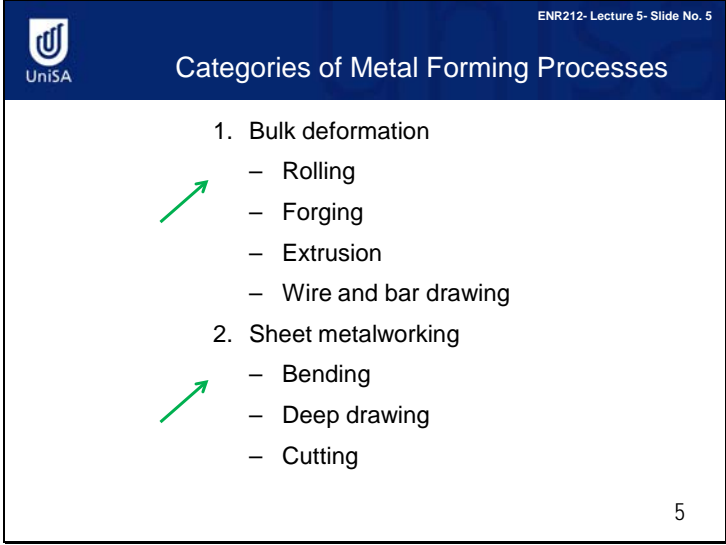
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To be successfully formed, a metal must possess certain properties. Desirable material properties for metal forming include a low yield strength and high ductility. High ductility means high strain value at break. These properties are affected by temperature. When the work temperature is raised, ductility increases and yield strength decreases. Strain rate and friction are additional factors that affect performance in metal forming.

So we can sum up the three factors which affect metal forming: temperature, strain rate and friction.

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Categories of Metal Forming Processes

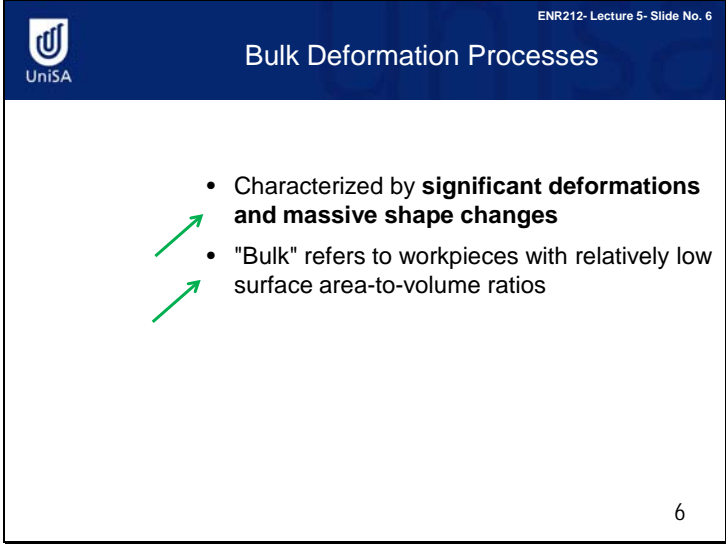
1. Bulk deformation
 - Rolling
 - Forging
 - Extrusion
 - Wire and bar drawing
2. Sheet metalworking
 - Bending
 - Deep drawing
 - Cutting

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Metal forming processes can be classified into two basic categories: bulking deformation and sheet metalworking. This classification is based on the volume to surface ratio of the starting materials. Bulking deformation includes rolling, forging, extrusion, and wire and bar drawing. Sheet metalworking consists mainly of bending, deep drawing and cutting.

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Bulk Deformation Processes

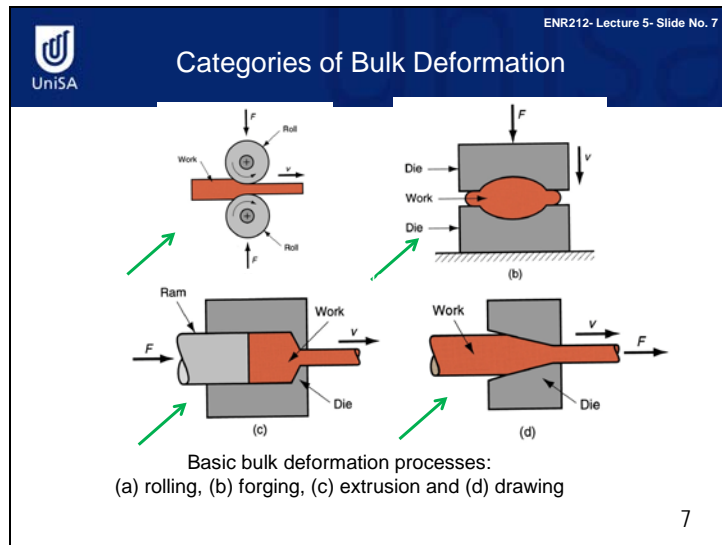
- Characterized by **significant deformations and massive shape changes**
- "Bulk" refers to workpieces with relatively low surface area-to-volume ratios

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Bulk forming is a metal forming operation which causes significant shape change by deforming a metal part; the initial form of the metal part is bulk rather than sheet. Bulk deformation processes are generally characterized by significant deformations and massive shape changes. The term "Bulk" describes the workpieces that have a low area-to-volume ratio.

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Bulk deformation includes rolling, forging, extrusion and drawing.

One. Rolling is a compressive deformation process in which the thickness of a slab or plate is reduced by two opposing cylindrical tools called rolls. The rolls rotate so as to draw the work into the gap between them, and squeeze it.

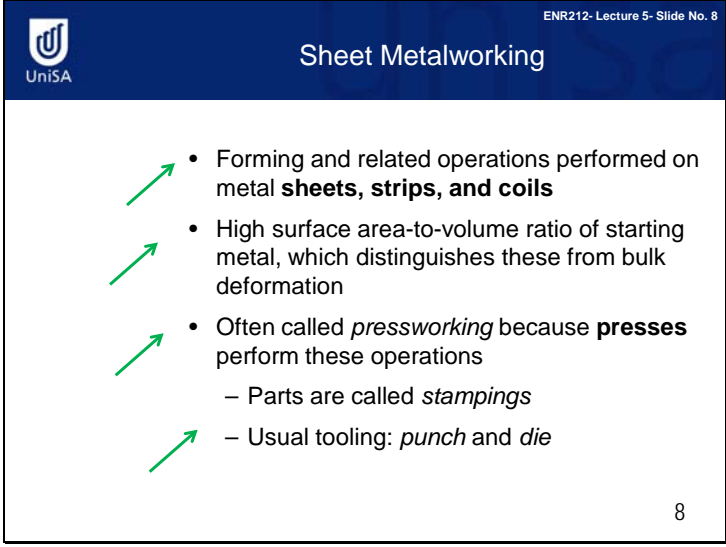
Two. In forging, a workpiece is compressed between two opposing dies, so that the die shapes are imparted to the work. Forging is traditionally a hot working process, but nowadays many types of forging are performed cold.

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

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

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Sheet Metalworking

- Forming and related operations performed on metal **sheets, strips, and coils**
- High surface area-to-volume ratio of starting metal, which distinguishes these from bulk deformation
- Often called *pressworking* because **presses** perform these operations
 - Parts are called *stampings*
 - Usual tooling: *punch* and *die*

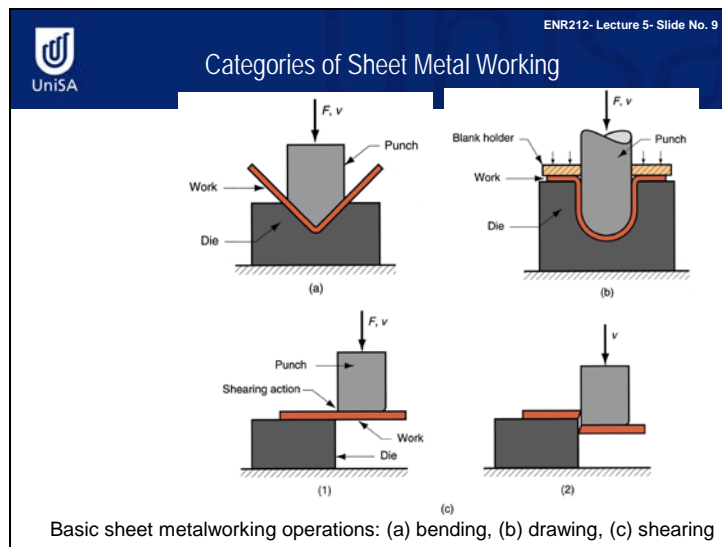
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Sheet metalworking processes are deformation operations performed on metal sheets, strips, and coils. They are characterized by the high surface area-to-volume ratio of starting metal. Sheet metalworking is often called pressworking because the machines used to perform these operations are presses.

Sheet metal operations are accomplished using a set of tools called punch and die.

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Sheet metal working includes bending, drawing and shearing. In Bending (figure a), a metal sheet or plate takes an angle along a straight axis by straining. Deep or cup drawing (figure b) refers to the forming of a flat metal sheet into a hollow or concave shape, such as a cup, by stretching the metal. A blankholder is used to hold down the blank while the punch pushes into the sheet metal. A shearing operation (figure c 1 and 2) cuts the work using a punch and a die. Although it is not a forming process, it is included here because it is a necessary and very common operation in sheet metal working.

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Material Behavior in Metal Forming


- Plastic region of stress-strain curve is of primary interest because material is plastically deformed
- In plastic region, metal's behavior is expressed by the flow curve:
$$\sigma = K\varepsilon^n$$
where K = strength coefficient; and n = strain hardening exponent
- Flow curve based on true stress and true strain

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In metal forming, the plastic region of true stress-strain curve is of primary interest because material is plastically and permanently deformed in this region. The true stress-strain relation in the plastic region is given in the equation on this slide, where K equals the strength coefficient and n equals the strain hardening exponent.

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Flow Stress

- For most metals at room temperature, strength increases when deformed due to strain hardening
- *Flow stress* = instantaneous value of stress required to continue deforming the material

$$Y_f = K\varepsilon^n$$

where Y_f = flow stress, that is, the deformation strength as a function of strain

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Since metal flow is the nature of metal forming, true stress in the plastic region is called flow stress in metal forming.

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Temperature in Metal Forming


- Any deformation operation can be accomplished with lower forces and power at elevated temperature
- Three temperature ranges in metal forming:
 - Cold working
 - Warm working
 - Hot working

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We have learnt about the effect of temperature on the mechanical properties of materials. With increases in temperature, strength reduces but ductility increases. Therefore, there are three temperature ranges used in metal forming: cold working, warm working and hot working.

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Cold Working

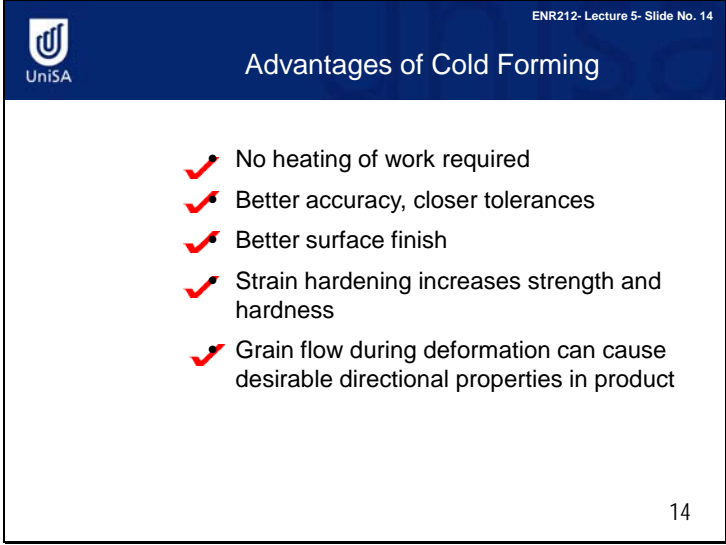
- Performed at room temperature or slightly above
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required
 - These operations are *near net shape* or *net shape* processes

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Cold working is metal forming performed at room temperature. Many cold forming processes have developed into important mass production operations. They provide close tolerances and good surfaces, minimizing the amount of machining required. Therefore, these operations are classified as near net shape or net shape processes.

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Advantages of Cold Forming

- ✓ No heating of work required
- ✓ Better accuracy, closer tolerances
- ✓ Better surface finish
- ✓ Strain hardening increases strength and hardness
- ✓ Grain flow during deformation can cause desirable directional properties in product

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Cold forming has the following advantages:

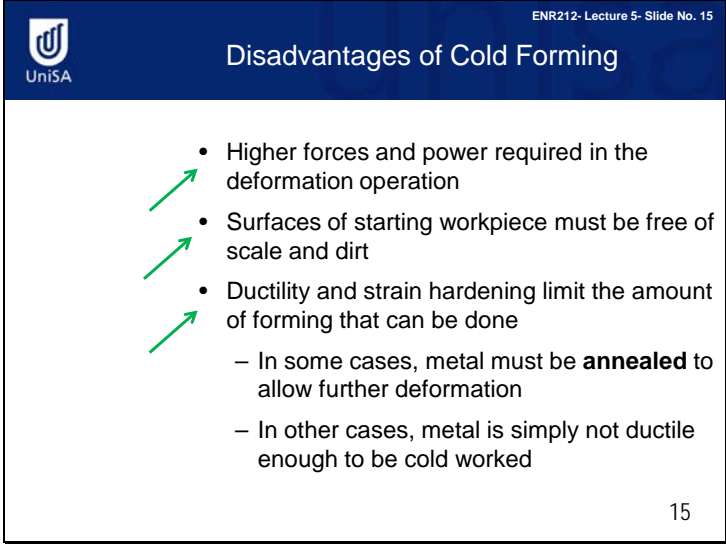
No heating of the work piece is required.

It has better accuracy, and closer tolerances.

It gives a better surface finish.

The strain hardening increases the strength and hardness.

The grain flow during deformation can cause desirable directional properties in the product.



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Disadvantages of Cold Forming

- Higher forces and power required in the deformation operation
- Surfaces of starting workpiece must be free of scale and dirt
- Ductility and strain hardening limit the amount of forming that can be done
 - In some cases, metal must be **annealed** to allow further deformation
 - In other cases, metal is simply not ductile enough to be cold worked

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There are certain disadvantages or limitations associated with cold forming operations, as follows:

1. Higher forces and power are required in the deformation operation.
2. The surfaces of the starting workpiece must be free of scale and dirt.
3. The ductility and strain hardening limit the amount of forming that can be done. In some cases, metal must be annealed to allow further deformation. In other cases, metal is simply not ductile enough to be cold worked.

Note: Annealing consists of heating the metal to a suitable temperature, holding at that temperature for a certain time (soaking), and slowly cooling. This process reduces hardness and brittleness.

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Warm Working


- Performed at temperatures above room temperature but below recrystallization temperature
- Dividing line between cold working and warm working often expressed in terms of melting point:
 - $0.3T_m$ where T_m = melting point (absolute temperature) for metal

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Because increasing the workpiece temperature reduces the yield strength and increases the ductility of metals, forming operations are sometimes performed at temperatures above room temperature but below recrystallization temperature. This is called warm working. The dividing line between cold working and warm working is often expressed in terms of melting point: $0.3T_m$, where T_m equals melting point (absolute temperature) for metal.

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Hot Working

- Deformation at temperatures above the *recrystallization temperature*
- Recrystallization temperature = about one-half of melting point (absolute temperature)
 - In practice, hot working usually performed somewhat above $0.5T_m$
 - Metal continues to soften as temperature increases above $0.5T_m$ enhancing advantage of hot working

T---thermodynamic temperature

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Hot working (hot forming) involves deformation at temperatures above the recrystallization temperature. The Recrystallization temperature for a given metal is about one-half of melting point. The work metal softens further as the temperature is increased beyond $0.5T_m$, thus enhancing the advantage of hot working.

Thermodynamic temperature is an "absolute" scale because it is the measure of the fundamental property underlying temperature: its zero point, absolute zero, is the temperature at which the particle constituents of matter have minimal motion and can be no colder. Absolute zero is defined as 0 K on the Kelvin scale and as minus 273.15°C on the Celsius scale

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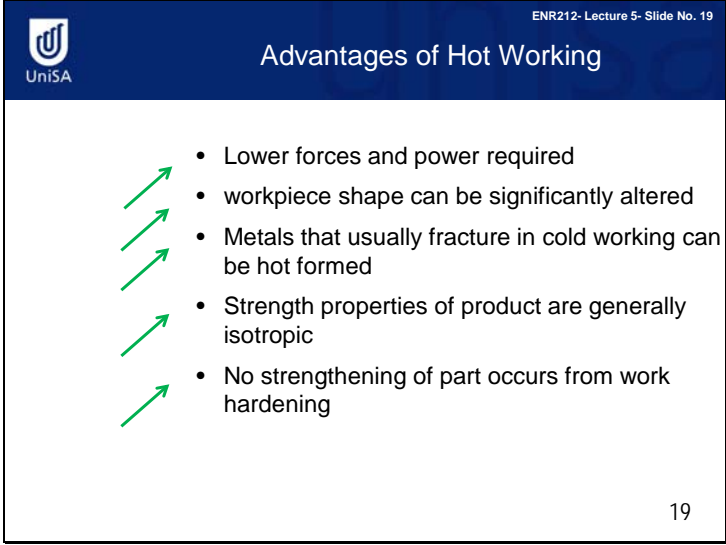
Why Hot Working?

Capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working

- Why?
 - Strength coefficient (K) is substantially less than at room temperature
 - Strain hardening exponent (n) is zero (theoretically)
 - Ductility is significantly increased

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The most significant advantage of hot working is the capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working. This is because the Strength coefficient (K) is substantially less than at room temperature, the Strain hardening exponent (n) is close to zero and the Ductility is significantly increased.



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Advantages of Hot Working

- Lower forces and power required
- workpiece shape can be significantly altered
- Metals that usually fracture in cold working can be hot formed
- Strength properties of product are generally isotropic
- No strengthening of part occurs from work hardening

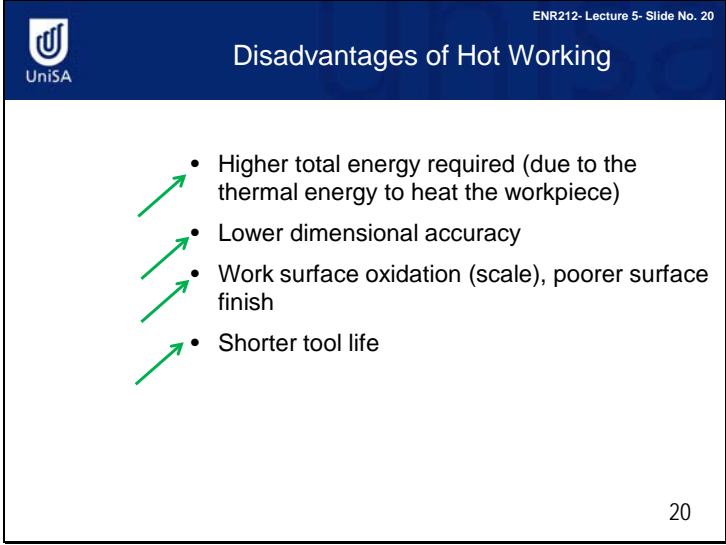
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The advantages of hot working are as follows:

1. Lower forces and power are required to deform the metal.
2. The shape of the workpiece can be significantly altered.
3. Metals that usually fracture in cold working can be hot formed.
4. The strength properties are generally isotropic because of the absence of the oriented grain structure typically created in cold working.
5. No strengthening of the part occurs from work hardening.

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Disadvantages of Hot Working

- Higher total energy required (due to the thermal energy to heat the workpiece)
- Lower dimensional accuracy
- Work surface oxidation (scale), poorer surface finish
- Shorter tool life


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The disadvantages of hot working are as follows:

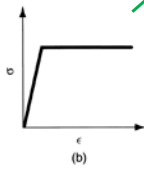
1. Higher total energy is required (due to the thermal energy to heat the workpiece).
2. The dimensional accuracy is not good.
3. It produces work surface oxidation (scale), resulting in poorer surface finish.
4. Tool life is reduced.

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Strain Rate Sensitivity




- Theoretically, a metal in hot working behaves like a perfectly plastic material, with strain hardening exponent $n = 0$
 - The metal should continue to flow at the same flow stress, once that stress is reached
 - However, an additional phenomenon occurs during deformation, especially at elevated temperatures: Strain rate sensitivity

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Let's review and compare the three types of Stress-Strain curves. Theoretically, a metal in hot working behaves like a perfectly plastic material, with strain hardening exponent $n = 0$. This means that the metal should continue to flow under the same level of flow stress, once that stress is reached. However, the flow stress increases with strain in the plastic region, especially at elevated temperatures. That phenomenon is called strain rate sensitivity.

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What is Strain Rate?

- Strain rate in forming is directly related to speed of deformation v
- Deformation speed v = velocity of the ram or other movement of the equipment
- *Strain rate* is defined:
$$\dot{\epsilon} = \frac{v}{h}$$


where $\dot{\epsilon}$ = true strain rate; and h = instantaneous height of workpiece being deformed

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Strain rate is the rate at which a metal is strained in a forming process. The rate is directly related to speed of deformation v . In many forming operations, the deformation speed v is equal to the velocity of the ram or other moving parts .

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Effect of Strain Rate on Flow Stress

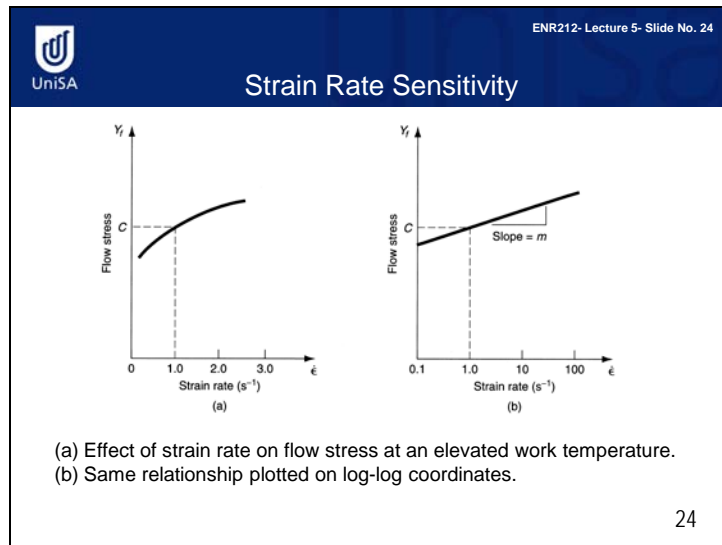
- Flow stress is a function of temperature
- At hot working temperatures, flow stress also depends on strain rate
 - As strain rate increases, resistance to deformation increases
 - This effect is known as strain-rate sensitivity

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Flow stress of a metal is a function of temperature. At hot working temperatures, flow stress also depends on strain rate. This effect of strain rate on strength properties is known as strain-rate sensitivity.

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This effect can be seen in the figure. As the strain rate is increased, flow stress increases. This usually plots approximately as a straight line on a log-log graph. So there is a linear relation between log flow stress and log strain rate.

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Strain Rate Sensitivity Equation

$$Y_f = C\dot{\epsilon}^m$$

where C = strength constant (similar but not equal to strength coefficient in flow curve equation), and m = strain-rate sensitivity exponent

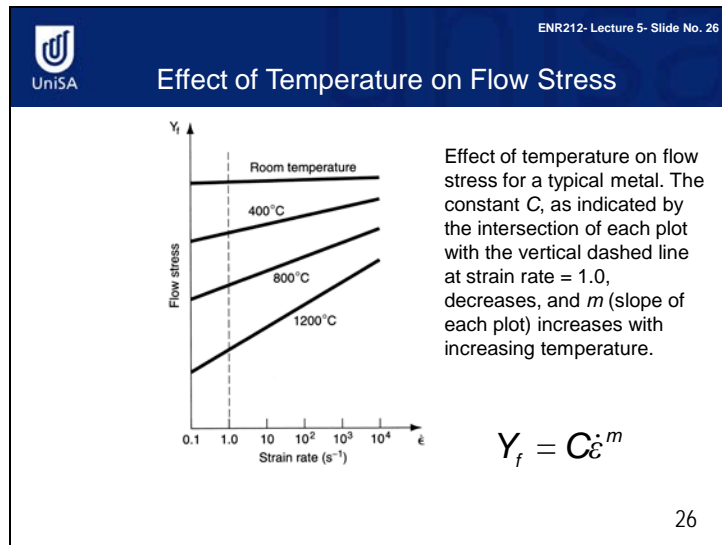
$$\sigma = K\epsilon^n$$

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The strength constant is the flow stress when strain rate equals 1, while the strain rate sensitivity exponent is the slope of the straight portion.

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This plot indicates the effect of temperature on flow stress. With increasing temperature, these lines become steeper.

So we conclude the following:

Increasing temperature decreases strength constant C and increases strain-rate sensitivity exponent m .

At room temperature, therefore, the effect of strain-rate sensitivity exponent is almost negligible.

As temperature is increased, strain rate plays a more important role in determining flow stress.

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Friction in Metal Forming


- In most metal forming processes, friction is undesirable:
 - Metal flow is retarded
 - Forces and power are increased
 - Tooling wears faster
- Friction and tool wear are more severe in hot working

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Friction in metal forming arises because of the close contact under high pressures between the tool and work surfaces. In most metal forming processes, friction is undesirable for the following reasons:

Firstly, metal flow is retarded, causing residual stresses and sometimes defects in the product. Forces and power needed to perform the operation are increased. Tooling wears faster, which leads to loss of dimensional accuracy, resulting in defective parts and requiring replacement of the tooling.

Secondly, friction and tool wear are more severe in hot working because of the much harsher environment.

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Lubrication in Metal Forming

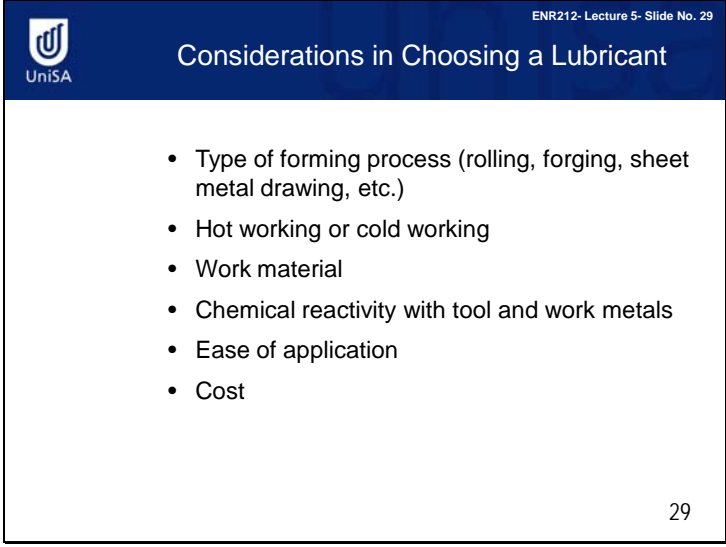
- Metalworking lubricants are applied to tool-work interface in many forming operations to reduce harmful effects of friction
- Benefits:
 - Reduces sticking, forces, power, tool wear
 - Better surface finish
 - Removes heat from the tooling

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Metalworking lubricants are applied to tool-work interface in many forming operations to reduce the harmful effects of friction. Using lubricates reduces sticking, forces, power, and tool wear. It gives a better surface finish and removes heat from the tooling.

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Considerations in Choosing a Lubricant

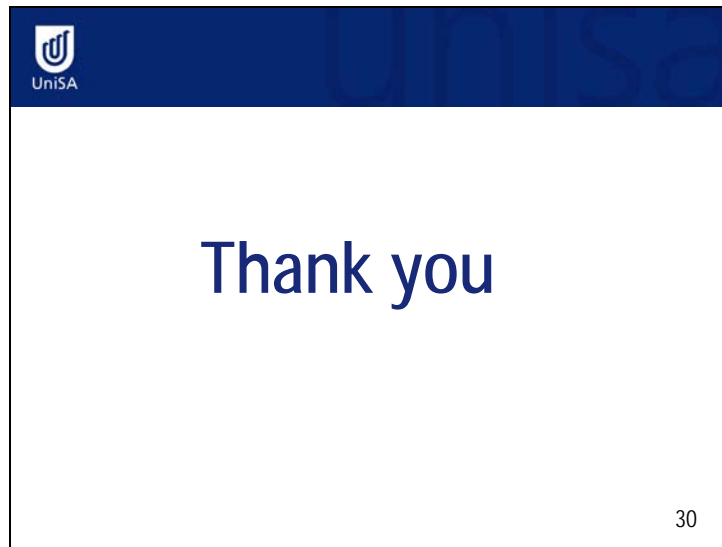
- Type of forming process (rolling, forging, sheet metal drawing, etc.)
- Hot working or cold working
- Work material
- Chemical reactivity with tool and work metals
- Ease of application
- Cost

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When choosing an appropriate metalworking lubricant, consider the points on this slide.

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Thanks for your attention.