

ENR212 Lecture 4 Slides and Notes

Slide 1



The slide features a dark blue background with a white UniSA logo on the left. The title 'Manufacturing Processes Lecture 4' is in the top right. A white-bordered box contains the text 'INTRODUCTION OF METAL CASTING'. Below this, the name 'Dr Jun Ma' is written in yellow. A numbered list of four items is centered on the slide.

Manufacturing Processes
Lecture 4

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INTRODUCTION OF METAL CASTING

Dr Jun Ma

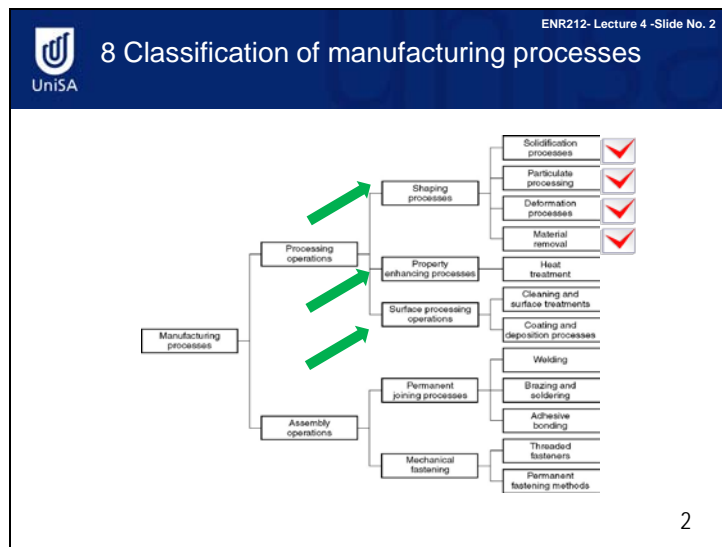
1. Casting Overview
2. Heating and Pouring
3. Solidification and Cooling
4. Casting Design

Hello, everyone, and welcome to lecture summary 4 of Manufacturing Processes. (This lecture works through material covered in Chapter 10 of the textbook.)

In this lecture summary, we will introduce the fundamentals of metal casting, including the pros and cons of metal casting, classifications, mould structure, casting processes, and the intrinsic problems of metal casting design.

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First, let's review the classification of manufacturing processes. Manufacturing processes comprise processing operations and assembly operations. In processing operations, making a part shape is essential. Once the part shape is made, the properties and surface finish can be improved. So processing operations include shaping processes, property enhancing processes, and surface processing operations. Shaping processes comprise solidification processes (where the starting material is liquid or a metal melt), particulate processes (where the starting material is particles), deformation processes (where the starting material is a solid piece of material) and material removal processes (whose purpose is to remove extra material to achieve the desired accurate geometry).

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Solidification Processes

Starting work material is either a liquid or is in a highly plastic condition, and a part is created through solidification of the material

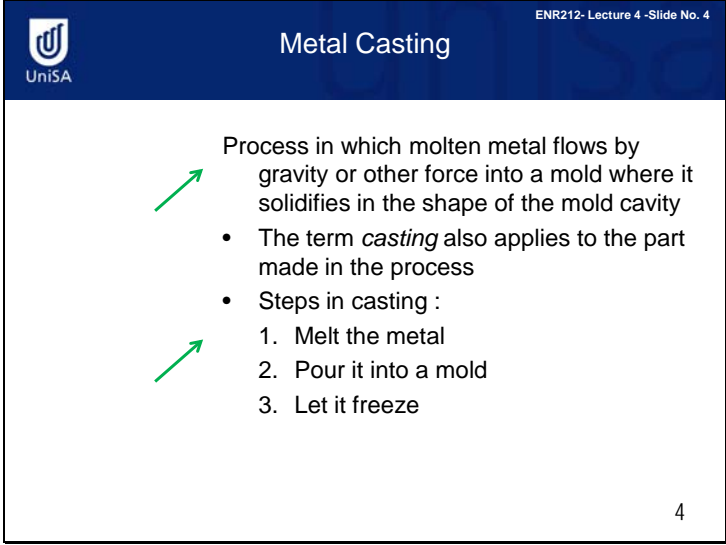
- Solidification processes can be classified according to engineering material processed:
 - Metals
 - Ceramics, specifically glasses
 - Polymers and polymer matrix composites (PMCs)

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In a solidification process, the starting work material is either a liquid or is in a highly plastic condition, and a part is created through solidification of the material. According to the materials processed, the solidification processes can be classified into: metal casting for metals, ceramics solidification processes, and thermal plastic moulding for polymers.

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Metal Casting

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Process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity

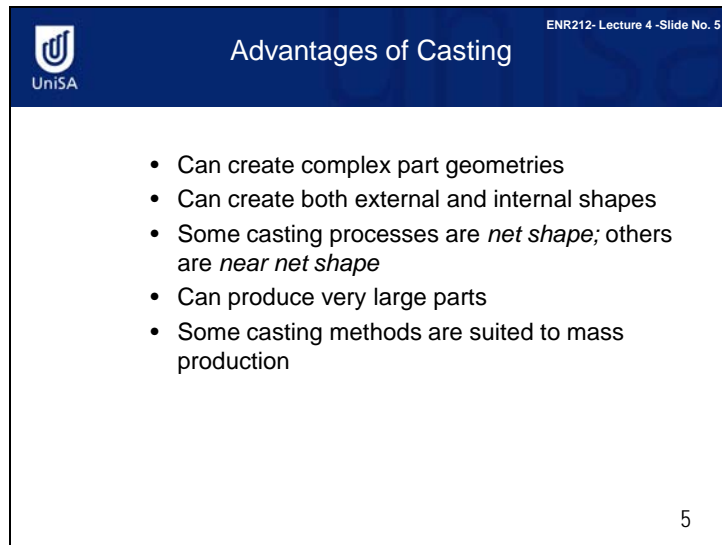
- The term *casting* also applies to the part made in the process
- Steps in casting :
 1. Melt the metal
 2. Pour it into a mold
 3. Let it freeze

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Casting is a process in which molten metal flows by gravity or by other types of force into a mould, where it solidifies in the shape of the mould cavity. The term casting is also applied to the part that is made by this process. The principle of casting seems simple: just melt the metal, pour it into a mould, and let it cool and solidify. However, there are many factors and variables that must be considered in order to accomplish a successful casting operation.

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The slide features a dark blue header with the UniSA logo on the left and the title 'Advantages of Casting' in the center. The text 'ENR212- Lecture 4 -Slide No. 5' is visible in the top right corner of the header. The main content area is white and contains a bulleted list of five advantages. A small number '5' is located in the bottom right corner of the slide frame.

- Can create complex part geometries
- Can create both external and internal shapes
- Some casting processes are *net shape*; others are *near net shape*
- Can produce very large parts
- Some casting methods are suited to mass production

Casting can be used to create complex part geometries, including both external and internal shapes.

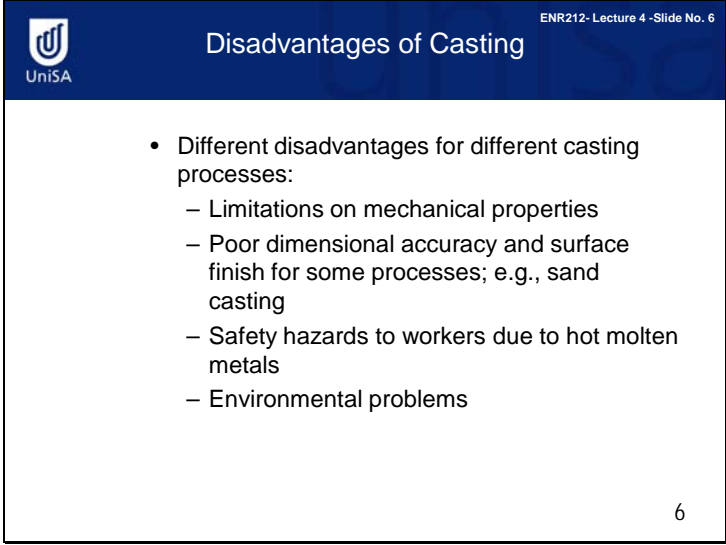
Some casting processes are capable of producing parts to net shape. No further manufacturing operations are required to achieve the required geometry and dimensions of the parts. Other casting processes are near net shape, for which some additional shape processing is required in order to achieve accurate dimensions and details.

Casting can be used to produce very large parts, such as castings weighing more than 100 tons. The list of large parts made through casting includes engine blocks and heads for automotive vehicles, machine frames, railway wheels, pipes, pump housings, etc. Small parts include dental crowns, jewellery, statues, frying pans, etc.

Some casting methods are quite suited to mass production.

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Disadvantages of Casting

- Different disadvantages for different casting processes:
 - Limitations on mechanical properties
 - Poor dimensional accuracy and surface finish for some processes; e.g., sand casting
 - Safety hazards to workers due to hot molten metals
 - Environmental problems

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There are disadvantages associated with casting. These include limitations on mechanical properties, porosity, poor dimensional accuracy and surface finish for some casting processes, safety hazards to humans when processing hot molten metals, and environmental problems.

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Foundry

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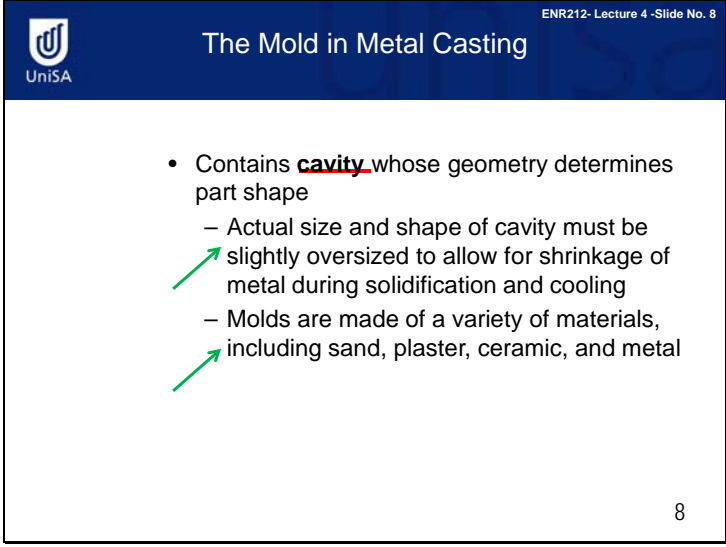
- Casting is usually performed in a foundry

Foundry = factory equipped for making molds, melting and handling molten metal, performing the casting process, and cleaning the finished casting

- Workers who perform casting are called ***foundrymen***

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Casting is usually carried out in a foundry. A foundry is a factory equipped for making moulds, melting and handling metal in molten form, performing the casting process, and cleaning the finished casting. The workers who perform the casting operations in these factories are called foundry men.



The Mold in Metal Casting

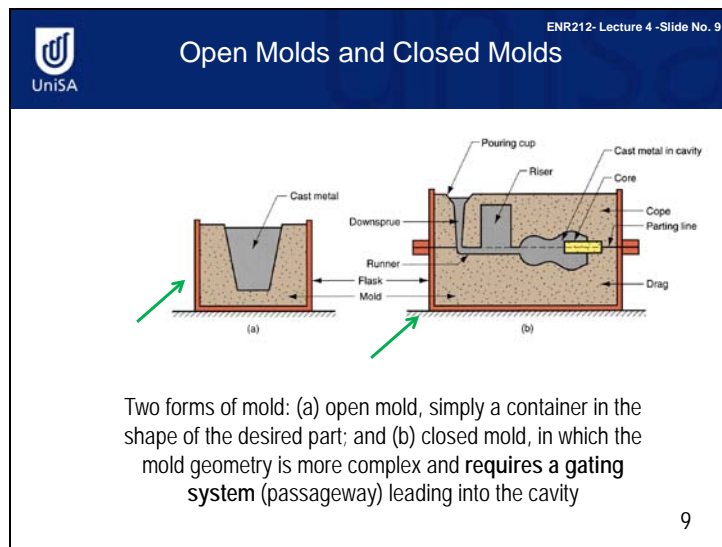
- Contains **cavity** whose geometry determines part shape
 - Actual size and shape of cavity must be slightly oversized to allow for shrinkage of metal during solidification and cooling
 - Molds are made of a variety of materials, including sand, plaster, ceramic, and metal

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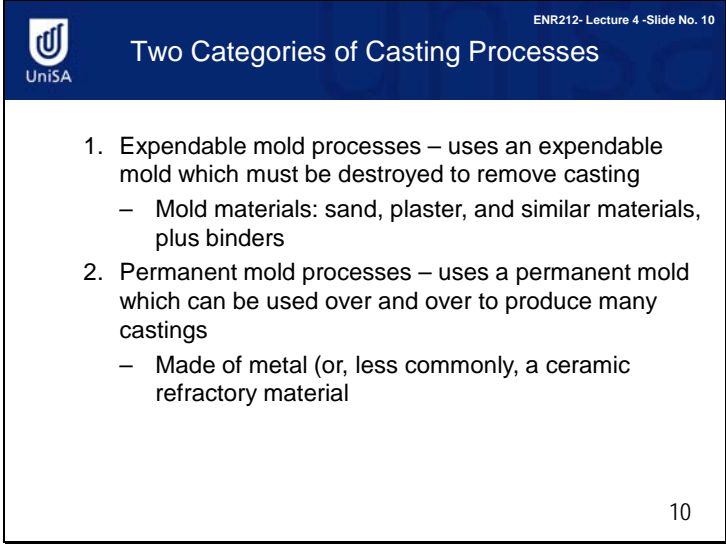
The mould in metal casting contains a cavity whose geometry determines the shape of the cast part. Since the density for a given metal in a solid state is higher than its density in a molten state, the actual size and shape of the cavity must be slightly oversized to allow for the shrinkage that occurs in the metal during solidification and cooling. Different metals undergo different amounts of shrinkage, so the mould cavity must be designed for the particular metal to be cast if dimensional accuracy is critical. The moulds are made from a variety of materials, including sand, plaster, ceramic, and metal.

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To accomplish a casting operation, the metal is first heated to a temperature which is high enough to completely transform it into a liquid state. It is then poured, or otherwise directed, into the cavity of the mould. In an open mould, the liquid metal is simply poured in until it fills the cavity. In a closed mould, a passageway, called the gating system, lets the molten metal flow from outside the mould into the cavity.



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Two Categories of Casting Processes

1. Expendable mold processes – uses an expendable mold which must be destroyed to remove casting
 - Mold materials: sand, plaster, and similar materials, plus binders
2. Permanent mold processes – uses a permanent mold which can be used over and over to produce many castings
 - Made of metal (or, less commonly, a ceramic refractory material)

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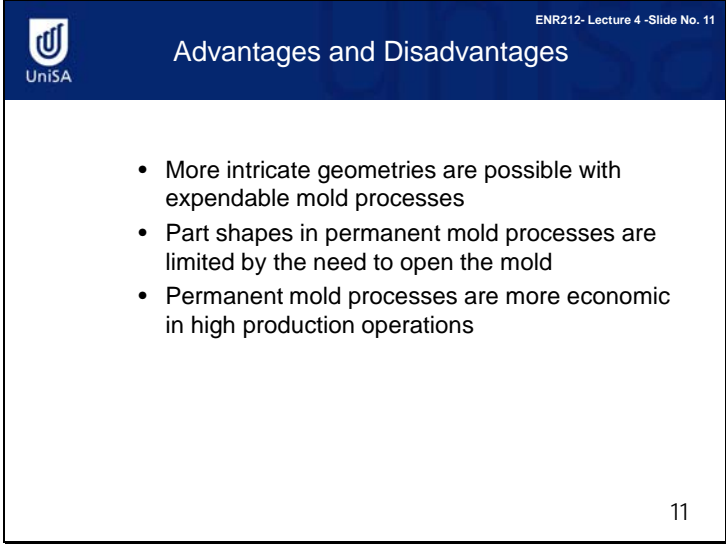
There are two categories of casting processes: expendable mould processes and permanent mould processes.

An expendable mould means that the mould in which the molten metal solidifies must be destroyed in order to remove the casting. These moulds are made out of sand, plaster, or similar materials. They maintain their form by binders of various kinds.

By contrast, a permanent mould is one that can be used over and over again to produce many castings. It is made of metal that can withstand the high temperatures of the casting operation.

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Advantages and Disadvantages

- More intricate geometries are possible with expendable mold processes
- Part shapes in permanent mold processes are limited by the need to open the mold
- Permanent mold processes are more economic in high production operations


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If we compare expendable processes with permanent mould processes, we can see that more sophisticated casting geometries are generally made with the expendable mould processes.

Casting part shapes by using permanent mould processes is made more difficult because of the need to open the mould. On the other hand, some of the permanent mould processes have certain economic advantages in high production operations.

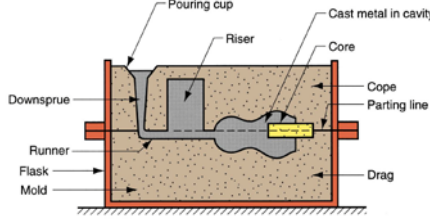
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Mold Structure

- Mold consists of two halves:
 - Cope = upper half of mold
 - Drag = bottom half
- Mold halves are contained in a box, called a flask
- The two halves separate at the parting line




(b)

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A mould consists of two halves: the cope and the drag. The cope is the upper half of the mould, and the drag is the bottom half.

These two mould parts are contained in a box, called a flask, which is also divided into two halves, one for the cope and the other for the drag.

The two halves of the mould separate at the parting line. This figure is one of the final exam topics. You will be given this figure and will be asked to give the names of some of the parts.

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Forming the Mold Cavity

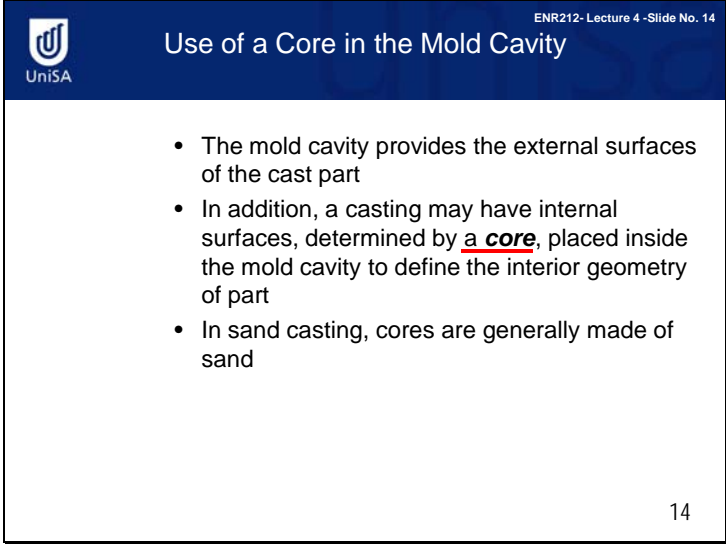
- Mold cavity is formed by packing sand around **a pattern**, which has the shape of the part
- When the pattern is removed, the remaining cavity of the packed sand has desired shape of cast part
- The pattern is usually oversized to allow for shrinkage of metal during solidification and cooling
- Sand for the mold is moist and contains a binder to maintain its shape

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In metal casting, the mould cavity is formed by means of a pattern, which is made of wood, metal, plastic, or other material which has the shape of the casting. The cavity is formed by packing sand around the pattern, so that when the pattern is removed, the remaining void has the desired shape of the cast part. The pattern is usually made oversized to allow for shrinkage of the metal as it solidifies and cools. The mould is usually made of sand, which is moist and contains a binder to maintain its shape.

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Use of a Core in the Mold Cavity

- The mold cavity provides the external surfaces of the cast part
- In addition, a casting may have internal surfaces, determined by a core, placed inside the mold cavity to define the interior geometry of part
- In sand casting, cores are generally made of sand

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The cavity in the mould provides the external surfaces of the cast part. In addition, a casting may have internal surfaces. These surfaces are determined by means of a core, which is placed inside the mould cavity to define the interior geometry of the part. In sand casting, cores are generally made of sand, although other materials can be used, such as metals, plaster, and ceramics.

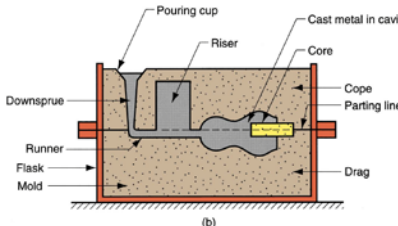
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Gating System

Channel through which molten metal flows into cavity from outside of mold

- Consists of a *downsprue*, through which metal enters a *runner* leading to the main cavity
- At the top of downsprue, a *pouring cup* is often used to minimize splash and turbulence as the metal flows into downsprue



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The gating system in a casting mold is the channel, or network of channels, by which molten metal flows into the cavity from outside the mould.

As shown in the figure, the gating system typically consists of pouring cup, downsprue and runner. In this system, the metal enters a runner that leads into the main cavity. A pouring cup is often used to minimize splash and turbulence as the metal flows into the downsprue.

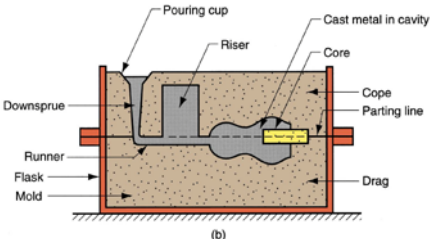
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Riser

Reservoir in the mold which is a source of liquid metal to compensate for shrinkage of the part during solidification

- The riser must be designed to freeze after the main casting in order to satisfy its function



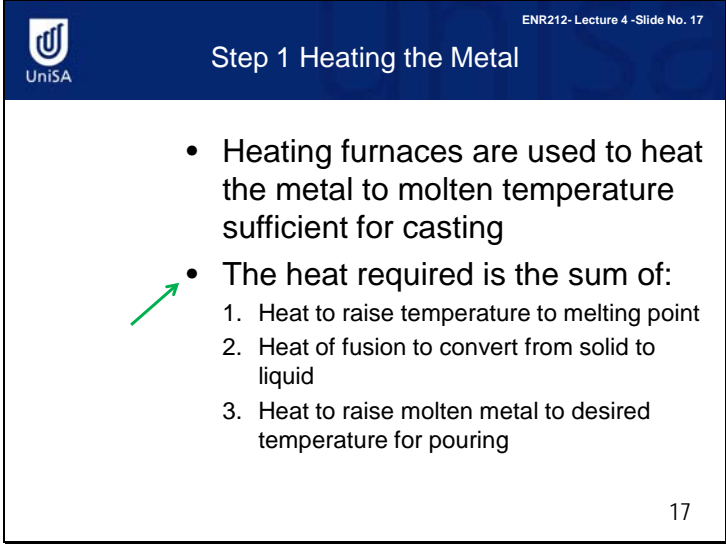
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Now, as we have discussed, shrinkage can be a serious problem. Any casting in which shrinkage is significant requires a riser connected to the main cavity, in addition to the gating system. The riser is a reservoir in the mould that serves as a source of liquid metal for the casting, to compensate for shrinkage during solidification. Here are three questions to research for interest:

One. Is a riser a metal piece that is not a part of the casting?

Two. Is a riser a source of molten metal to feed the casting and compensate for shrinkage during solidification?

Three. Is a riser waste metal that is usually recycled?



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Step 1 Heating the Metal

- Heating furnaces are used to heat the metal to molten temperature sufficient for casting
- The heat required is the sum of:
 1. Heat to raise temperature to melting point
 2. Heat of fusion to convert from solid to liquid
 3. Heat to raise molten metal to desired temperature for pouring

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Heating furnaces of various kinds are used to heat the metal to a molten temperature sufficient for casting. The heat energy required is the sum of the following three energies: first, the heat to raise the temperature to the melting point, second, the heat of fusion to convert it from solid to liquid, and third, the heat to raise the molten metal to the desired temperature for pouring.

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Step 2 Pouring the Molten Metal

- For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, before solidifying
- Factors that determine success
 - ✓ – Pouring temperature
 - ✓ – Pouring rate--turbulence

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After heating, the metal is ready for pouring. The introduction of molten metal into the mould, including its flow through the gating system and into the cavity, is a critical step in the casting process. For this step to be successful, the metal must flow into all regions of the mould before solidifying. The factors which affect the pouring operation include the pouring temperature, the pouring rate, and the turbulence.

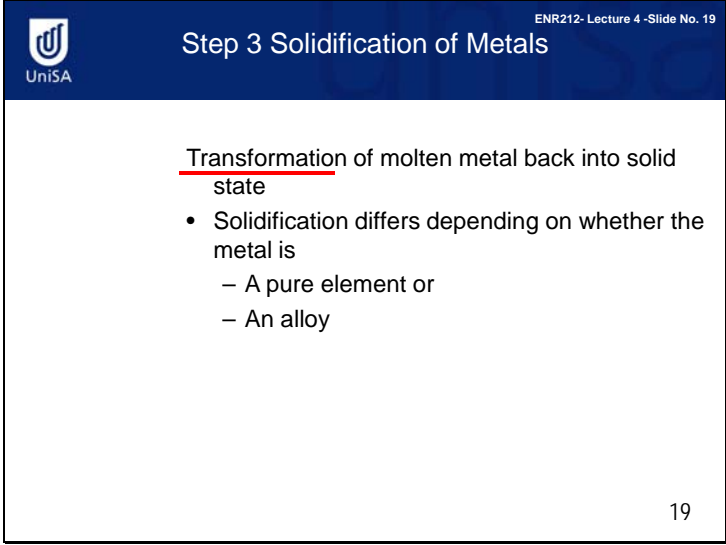
The pouring temperature is the temperature of the molten metal as it is introduced into the mould. There is a difference between the temperature at pouring and the temperature at which freezing begins.

The pouring rate refers to the volumetric rate at which the molten metal is poured into the mould. If the rate is too slow, the metal will chill and freeze before filling the cavity. If the pouring rate is excessive, turbulence can become a serious problem.

The turbulence in the fluid flow is characterized by erratic variation in the magnitude and direction of the velocity throughout the fluid. Turbulence must be avoided because it increases the erosion of the mould surfaces, and it increases the formation of metallic oxides that can become entrapped during solidification.

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Transformation of molten metal back into solid state


- Solidification differs depending on whether the metal is
 - A pure element or
 - An alloy

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Solidification involves the transformation of the molten metal back into the solid state. The solidification process differs depending on whether the metal is a pure element or an alloy.

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Solidification of Pure Metals


- Due to chilling action of mold wall, a thin skin of solid metal is formed at the interface immediately after pouring
- Skin thickness increases to form a shell around the molten metal as solidification progresses
- Rate of freezing depends on heat transfer into mold, as well as thermal properties of the metal

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When molten metal is chilled, a thin skin of solid metal is initially formed at the interface immediately after pouring.

The thickness of the skin increases to form a shell around the molten metal as solidification progresses inward toward the centre of the cavity.

The rate at which freezing proceeds depends on heat transfer into the mould, as well as the thermal properties of the metal.

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Solidification Time

- Solidification takes time
- Total solidification time T_{TS} = time required for casting to solidify after pouring
- T_{TS} depends on size and shape of casting by relationship known as *Chvorinov's Rule*

$$TST = C_m \left(\frac{V}{A} \right)^n$$

where TST = total solidification time; V = volume of the casting; A = surface area of casting; n = exponent with typical value = 2; and C_m is *mold constant*.

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The total solidification time is the time required for the casting to solidify after pouring. This time is dependent on the size and shape of the casting by an empirical relationship known as Chvorinov's rule.

The mould constant C_m depends on the particular conditions of the casting operations, including mould materials, thermal properties of the cast metal and pouring temperature.

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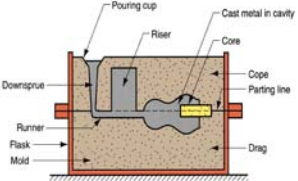
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What Chvorinov's Rule Tells Us

- A casting with a higher volume-to-surface area ratio cools and solidifies more slowly than one with a lower ratio
 - To feed molten metal to main cavity, TST for riser must greater than TST for main casting
 - Since mold constants of riser and casting will be equal, design the riser to have a **larger volume-to-area ratio** so that the main casting solidifies first
 - This minimizes the effects of shrinkage


$$TST = C_m \left(\frac{V}{A} \right)^n$$

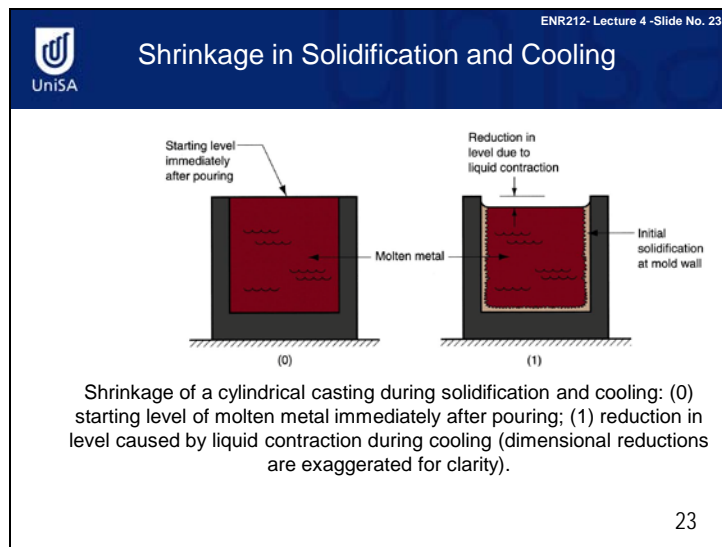
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What does Chvorinov's Rule Tell Us ?

It tells us that a casting with a higher volume-to-surface area ratio cools and solidifies more slowly than one with a lower ratio. So, using this rule, how do we design a riser? A riser should be designed to have a possibly larger volume-to-area ratio so that the main casting solidifies first.

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Shrinkage occurs in three steps:

First, when the liquid contracts during cooling, prior to solidification.

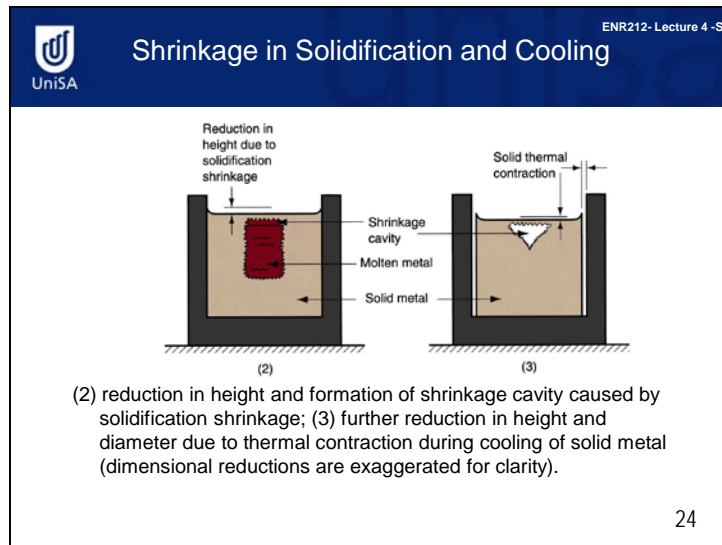
Second, the solid contracts during the phase change from liquid to solid.

Third, in thermal contraction of the solidified casting during cooling to room temperature.

Above here you can see the temperature-time plot for the three steps. These steps can be explained with reference to a cylindrical casting made in an open mould, as you can see on this slide and the next. Figure 0 shows the molten metal immediately after pouring. Liquid contraction occurs from figure 0 to figure 1, and this causes the height of the liquid to be reduced from its starting level, as you can see in figure 1. A thin metal wall is formed between the mould and the molten metal.

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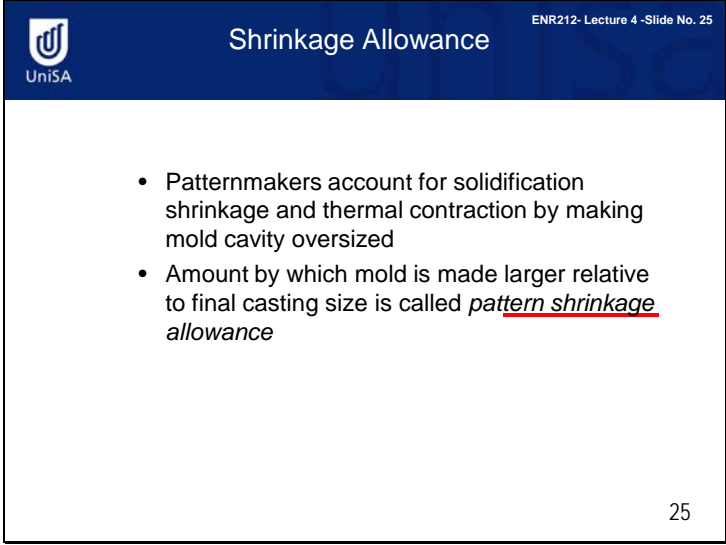
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Solidification contraction occurs from figure 1 to figure 2. Because the molten metal solidifies inward towards the top centre, with obvious shrinkage, metal flows from the top centre towards the surround region. Therefore, there is always a void in the final region to freeze, as shown in Figure 3. This void is created by the absence of metal, and is called a pipe. Once solidified, the casting experiences further contraction in height and diameter.

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The slide features a dark blue header with the UniSA logo on the left and the title 'Shrinkage Allowance' in the center. The slide number '25' is in the top right corner. The main content area is white with two bullet points. The second bullet point includes the term 'pattern shrinkage allowance' in italics, with 'shrinkage' underlined in red.

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Shrinkage Allowance


- Patternmakers account for solidification shrinkage and thermal contraction by making mold cavity oversized
- Amount by which mold is made larger relative to final casting size is called *pattern shrinkage allowance*

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Pattern-makers account for solidification shrinkage and thermal contraction by making the mould cavities oversized. The amount by which the mould must be made larger relative to the final casting size is called the pattern shrinkage allowance.

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Directional Solidification


- To minimize damaging effects of shrinkage, it is desirable for regions of the casting most distant from the liquid metal supply to freeze first and for solidification to progress from these remote regions toward the riser(s)
 - Thus, molten metal is continually available from risers to prevent shrinkage voids
 - The term *directional solidification* describes this aspect of freezing and methods by which it is controlled

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In simple words, directional solidification is a metal solidification in which the molten metal is controlled to solidify from the remote regions toward the risers.

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Achieving Directional Solidification

- Desired directional solidification is achieved using Chvorinov's Rule to design the casting itself, its orientation in the mold, and the riser system that feeds it
- Locate sections of the casting with lower V/A ratios away from riser, so freezing occurs first in these regions, and the liquid metal supply for the rest of the casting remains open
- Chills - internal or external heat sinks that cause rapid freezing in certain regions of the casting

$$TST = C_m \left(\frac{V}{A} \right)^n$$

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Chvorinov's rule can be used to achieve directional solidification by mould design. For example, we can locate parts of the casting with lower ratios away from the riser, so solidification occurs first in these regions, and there is still molten metal supply for the rest of the parts. We use chills to achieve rapid freezing.

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Riser Design

- Riser is waste metal that is separated from the casting and remelted to make more castings
- To minimize waste in the unit operation, it is desirable for the volume of metal in the riser to be a minimum
- Since the geometry of the riser is normally selected to maximize the V/A ratio, this allows riser volume to be reduced to the minimum possible value

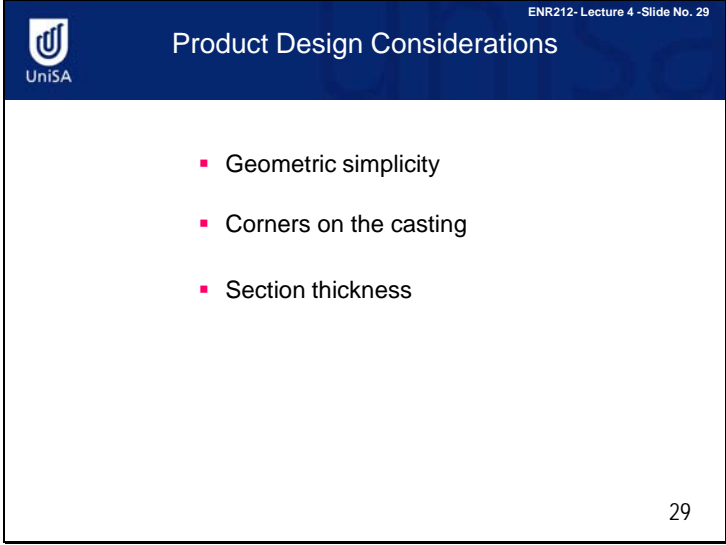
$$TST = C_m \left(\frac{V}{A} \right)^n$$

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The riser is waste metal that is separated from the casting and remelted to make more castings. To minimize waste in the unit operation, it is desirable for there to be a minimum volume of metal in the riser. Since the geometry of the riser is normally selected to maximize the V over A ratio, this allows riser volume to be reduced to the minimum possible value.

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Product Design Considerations

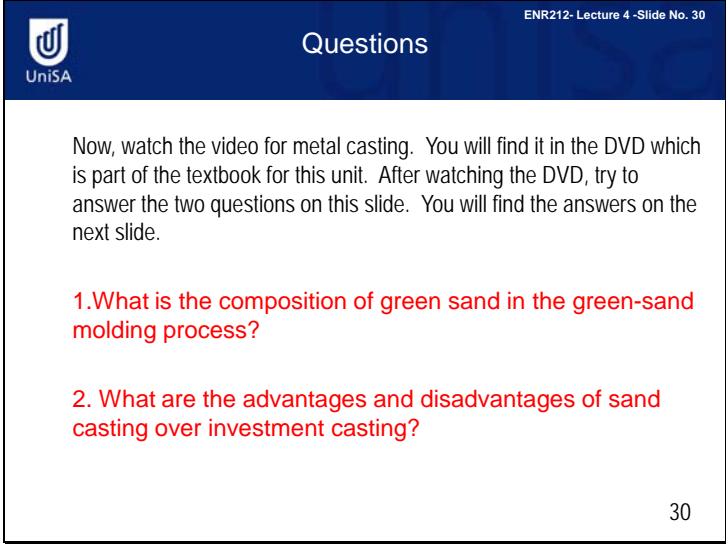
- Geometric simplicity
- Corners on the casting
- Section thickness

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Although casting can be used to produce complex part geometries, simplifying the part design usually improves castability. Sharp corners and angles should be avoided, since they are sources of stress concentrations and may cause hot tearing and cracks. Section thicknesses should be uniform in order to avoid shrinkage cavities.

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Questions

Now, watch the video for metal casting. You will find it in the DVD which is part of the textbook for this unit. After watching the DVD, try to answer the two questions on this slide. You will find the answers on the next slide.


1. What is the composition of green sand in the green-sand molding process?
2. What are the advantages and disadvantages of sand casting over investment casting?

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Now, watch the video for metal casting. You will find it in the DVD which is part of the textbook for this unit. After watching the DVD, try to answer the two questions on this slide. You will find the answers on the last slide of the presentation. Thank you for your attention.

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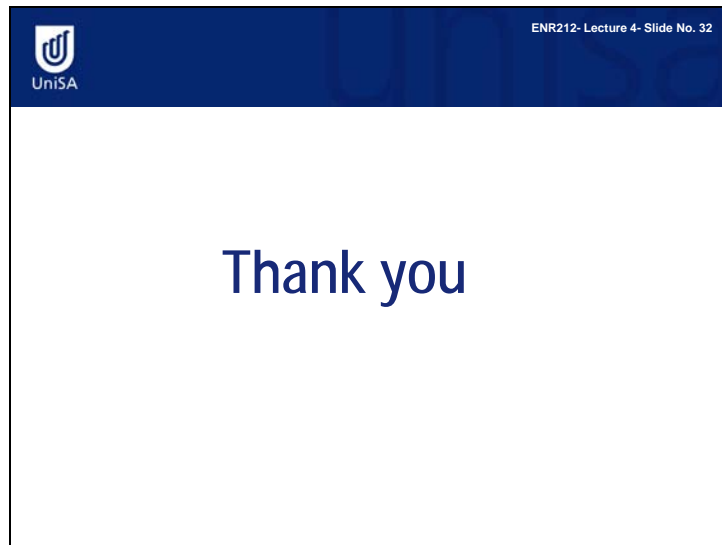
Answers

1. What is the composition of green sand in the green-sand moulding process?
Answer: The sand is composed of silica sand, clay, and water.
2. What are the advantages and disadvantages of sand casting over investment casting?
Answer: Sand casting provides low production cost for a wide variety of metals, shapes and sizes. The size of the casting is unlimited. The disadvantage is that the surface finish and dimensional control are not very good.

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Thank you for your attention.