

## ENR212 Lecture 10 Slides and Notes


Slide 1



Hello everyone, and welcome to Lecture Summary 10. (This lecture covers material from chapters 24 and 25 of the textbook.) This lecture is in two parts. In this first part, we will introduce the seven design guidelines for conventional machining operations.

## ENR212 Lecture 10 Slides and Notes

Slide 2




University of  
South Australia

ENR212-Lecture 10- Slide No. 2

### Machinability

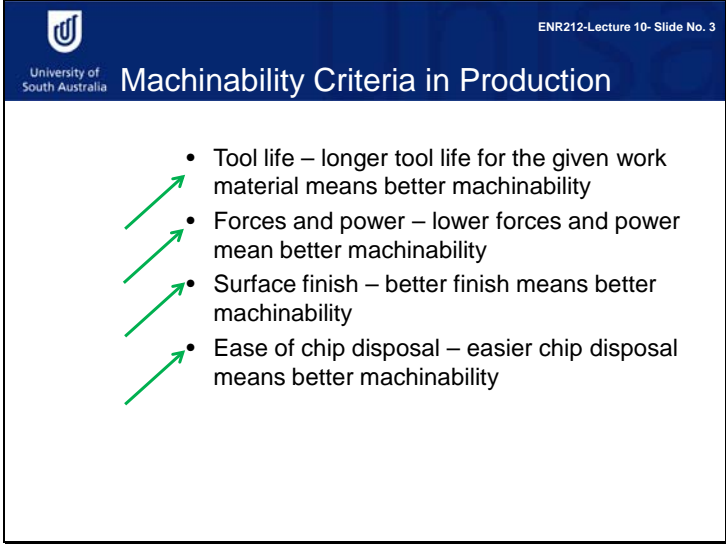
- A measure of how economically it can be machined into a finished part using appropriate tooling and cutting conditions.
- Various criteria used to evaluate machinability:
  - Tool life
  - Forces and power
  - Surface finish
  - Ease of chip disposal



The properties of a work material have a significant influence on the machining operation of that material. These properties and other characteristics of the work material are often summarized in the term “machinability”. The machinability of a material is a measure of how economically it can be machined into a part. Machinability is evaluated by the four criteria: tool life, forces and power, surface finish and ease of chip disposal.

## ENR212 Lecture 10 Slides and Notes

Slide 3



ENR212-Lecture 10- Slide No. 3

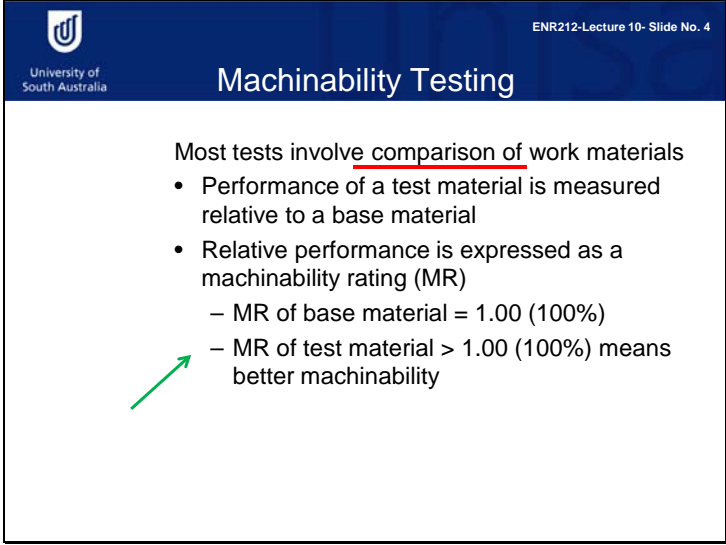
University of South Australia

### Machinability Criteria in Production

- Tool life – longer tool life for the given work material means better machinability
- Forces and power – lower forces and power mean better machinability
- Surface finish – better finish means better machinability
- Ease of chip disposal – easier chip disposal means better machinability

This slide shows how the four criteria affect machinability. Firstly, longer tool life and lower forces and power mean better machinability. For example, let's look at aluminium and copper. Aluminium has a lower modulus and a lower yield strength than copper, so it has a longer tool life and uses lower forces and power than copper. This means that aluminium has a higher and better machinability than copper. Therefore, if we have two parts, one aluminium and one copper, and both have an identical geometry, and are processed with the same forces and power, which will have a better surface finish? The aluminium part will have a better surface finish, because the material has a lower modulus and lower yield strength. Better surface finish means better machinability. Finally, easier chip disposal means better machinability.

Of all these characteristics, tool life is the most important.



ENR212-Lecture 10- Slide No. 4

### Machinability Testing

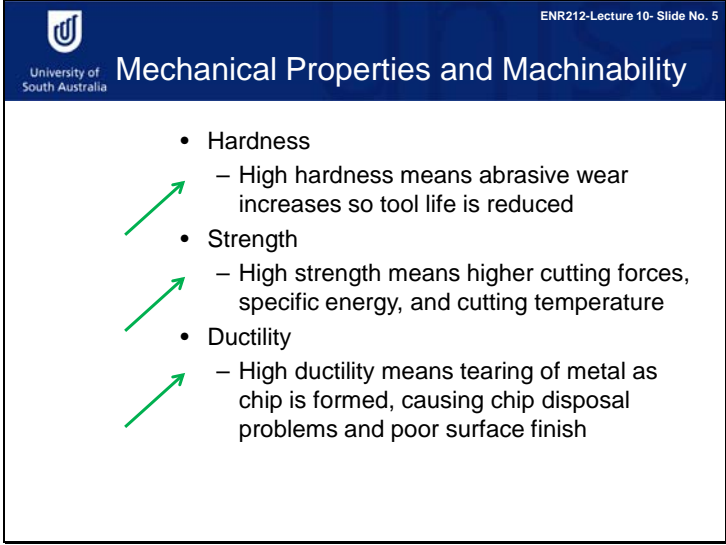
Most tests involve comparison of work materials

- Performance of a test material is measured relative to a base material
- Relative performance is expressed as a machinability rating (MR)
  - MR of base material = 1.00 (100%)
  - MR of test material > 1.00 (100%) means better machinability

The machinability of a material is expressed relative to a base material, so selecting a base material is very important in determining machinability. For example, let's look at three materials: aluminium, copper and steel. Of these three materials, which one has the highest machinability? The answer is aluminium, because it has the lowest modulus and strength. The steel has the lowest machinability, because steel has the highest modulus and strength. If aluminium is set as the base material, then the copper and steel should have machinability lower than 1.0. If copper is set as the base material, aluminium should have a machinability higher than 1.0. Steel has a machinability lower than 1.0.

## ENR212 Lecture 10 Slides and Notes

Slide 5



ENR212-Lecture 10- Slide No. 5

University of South Australia

### Mechanical Properties and Machinability

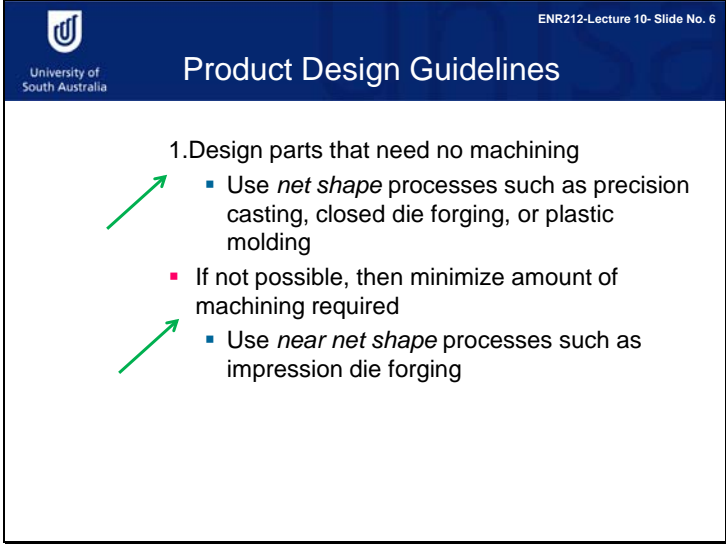
- Hardness
  - High hardness means abrasive wear increases so tool life is reduced
- Strength
  - High strength means higher cutting forces, specific energy, and cutting temperature
- Ductility
  - High ductility means tearing of metal as chip is formed, causing chip disposal problems and poor surface finish

We know that the machinability of a material is determined by the mechanical properties of this material. To demonstrate good machinability, a material must possess moderate mechanical properties.

First, it must have moderate hardness. If it is too hard (for example, diamond), then the processing will be extremely difficult. For example, a diamond knife, can be used to cut polymer nanocomposites samples, costs \$5000 dollars. If the knife becomes blunt, it costs \$2500 to sharpen it – which is quite expensive! The reason is that diamond is just too hard to sharpen easily.

Second, it should have moderate strength. High strength requires higher cutting forces, specific energy, and cutting temperature. Some alloys, such as titanium alloy, are very difficult to machine.

Third, it must be ductile. If the material is brittle, like epoxy, it is hard to machine, because brittleness often causes catastrophic failure. Material which is too ductile (for example, rubber) is also difficult to machine.



The slide is titled "Product Design Guidelines" and is from the University of South Australia. It contains a list of guidelines for designing parts that require no machining. The first guideline is "1. Design parts that need no machining". This guideline is further broken down into three bullet points: "Use *net shape* processes such as precision casting, closed die forging, or plastic molding", "If not possible, then minimize amount of machining required", and "Use *near net shape* processes such as impression die forging". Two green arrows point to the first and second bullet points.

ENR212-Lecture 10- Slide No. 6

University of South Australia

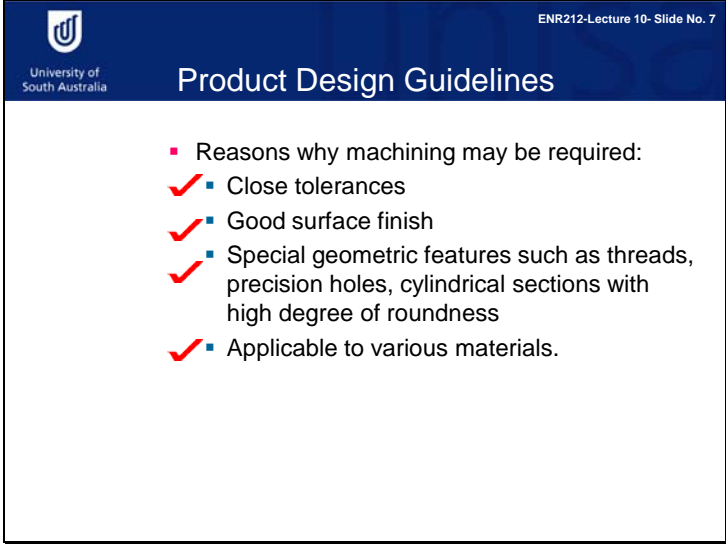
### Product Design Guidelines

1. Design parts that need no machining
  - Use *net shape* processes such as precision casting, closed die forging, or plastic molding
  - If not possible, then minimize amount of machining required
  - Use *near net shape* processes such as impression die forging

There are seven product design guidelines for conventional machining operations. First guideline. If possible, parts should be designed in a way that doesn't need machining. In general, products produced by using net shape processes such as precision casting, closed die forging, etc, cost less to produce. If machining cannot be avoided, then minimize the amount of machining required on the parts.

## ENR212 Lecture 10 Slides and Notes

Slide 7



The slide is titled "Product Design Guidelines" and is part of a presentation from the University of South Australia. It lists four reasons why machining may be required, each preceded by a red checkmark icon. The slide also includes the university logo and the text "ENR212-Lecture 10- Slide No. 7" in the top right corner.

ENR212-Lecture 10- Slide No. 7

University of South Australia

### Product Design Guidelines

- Reasons why machining may be required:
  - ✓ ▪ Close tolerances
  - ✓ ▪ Good surface finish
  - ✓ ▪ Special geometric features such as threads, precision holes, cylindrical sections with high degree of roundness
  - ✓ ▪ Applicable to various materials.

In fact, machining is desirable in a great many manufacturing operations because it can produce close tolerances and a good surface finish, and it can produce a variety of geometries. Machining is also applicable to various materials.

ENR212-Lecture 10- Slide No. 8

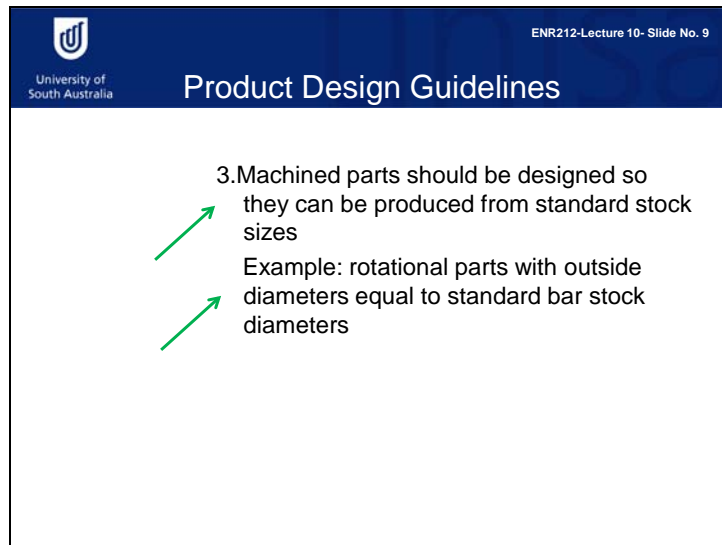
University of South Australia

### Product Design Guidelines

2. Select materials with good machinability
  - As a rough guide, allowable tooling & cutting speed and production rate correlates with machinability rating of a material
  - Thus, parts made of materials with low machinability take longer and cost more to produce

Second guideline. Select materials with good machinability, because the tooling and cutting conditions and production rate of a material correlate with the material's machinability. Parts made of materials with low machinability take longer and cost more to produce.





The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 9' on the right. Below the header, the title 'Product Design Guidelines' is centered. The main content area is white and contains the following text: '3. Machined parts should be designed so they can be produced from standard stock sizes' followed by 'Example: rotational parts with outside diameters equal to standard bar stock diameters'. Two green arrows point from the left towards the text.

ENR212-Lecture 10- Slide No. 9

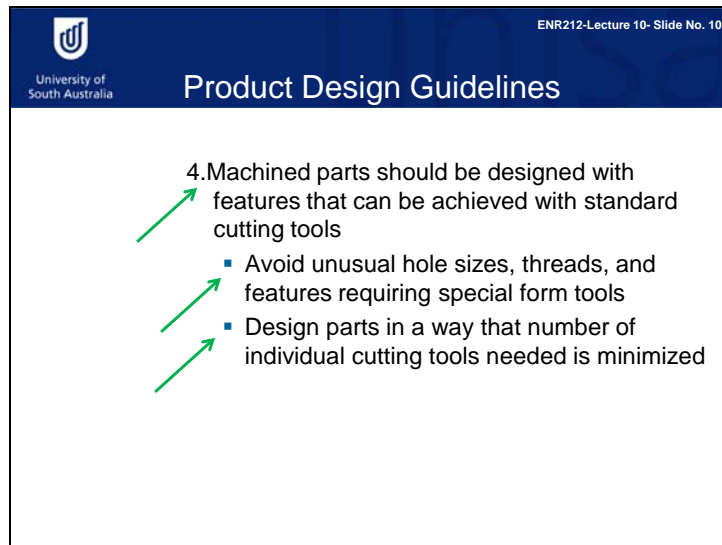
University of South Australia

### Product Design Guidelines

3. Machined parts should be designed so they can be produced from standard stock sizes

Example: rotational parts with outside diameters equal to standard bar stock diameters

Third guideline. In order to minimize the amount of machining, the exterior dimensions of a part should be chosen to equal the standard stock size. For example, choose rotational parts with outside diameters that are equal to standard bar stock diameters.



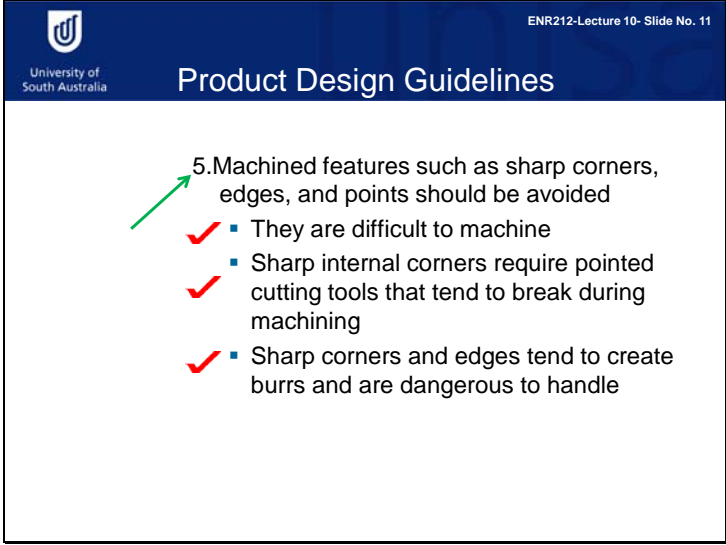
The slide is titled "Product Design Guidelines" and is from the University of South Australia. It contains a fourth guideline about machined parts. The text is as follows:

4. Machined parts should be designed with features that can be achieved with standard cutting tools

- Avoid unusual hole sizes, threads, and features requiring special form tools
- Design parts in a way that number of individual cutting tools needed is minimized

Three green arrows point from the left towards the main guideline and the two bullet points.

Fourth guideline. Machined parts should be designed with features that can be achieved with standard cutting tools. This means avoiding unusual hole sizes, threads, and features requiring special form tools. It is helpful to design a part in a way that minimizes the number of individual cutting tools. This often allows the part to be completed in one setup on a machining center with limited tool storage capacity.

The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 11' on the right. Below the header, the title 'Product Design Guidelines' is centered. The main content area is white and contains a numbered list item '5. Machined features such as sharp corners, edges, and points should be avoided'. A green arrow points to this item. To the right of the main text are three bullet points, each preceded by a red checkmark: 'They are difficult to machine', 'Sharp internal corners require pointed cutting tools that tend to break during machining', and 'Sharp corners and edges tend to create burrs and are dangerous to handle'.

ENR212-Lecture 10- Slide No. 11

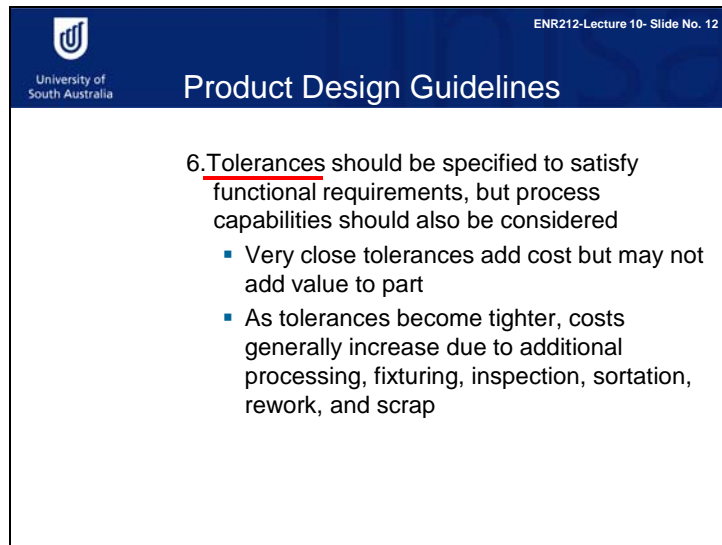
University of South Australia

### Product Design Guidelines

5. Machined features such as sharp corners, edges, and points should be avoided

- ✓ They are difficult to machine
- ✓ Sharp internal corners require pointed cutting tools that tend to break during machining
- ✓ Sharp corners and edges tend to create burrs and are dangerous to handle

Fifth guideline. Machined features such as sharp corners, edges, and points should be avoided. There are three reasons for this: they are difficult to machine, they tend to break during machining, and they are a safety hazard.



ENR212-Lecture 10- Slide No. 12

University of South Australia

### Product Design Guidelines

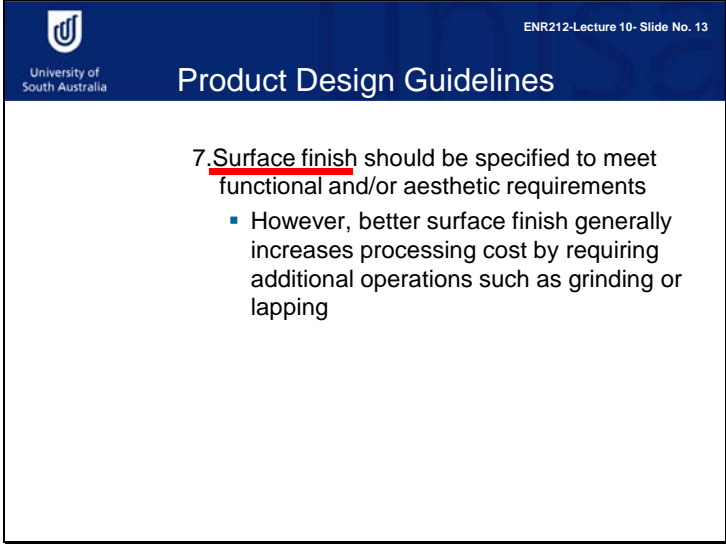
6. Tolerances should be specified to satisfy functional requirements, but process capabilities should also be considered

- Very close tolerances add cost but may not add value to part
- As tolerances become tighter, costs generally increase due to additional processing, fixturing, inspection, sortation, rework, and scrap

Sixth guideline. Machining is time consuming, but it provides good surface finish and close tolerances. We know that good surface finish and close tolerances are desirable in design, but that means a high manufacturing cost. Therefore, we need to evaluate the level of tolerance and surface finish needed by taking into account the end application of the product, the machining time and tool life.

## ENR212 Lecture 10 Slides and Notes

Slide 13



ENR212-Lecture 10- Slide No. 13

University of South Australia

### Product Design Guidelines

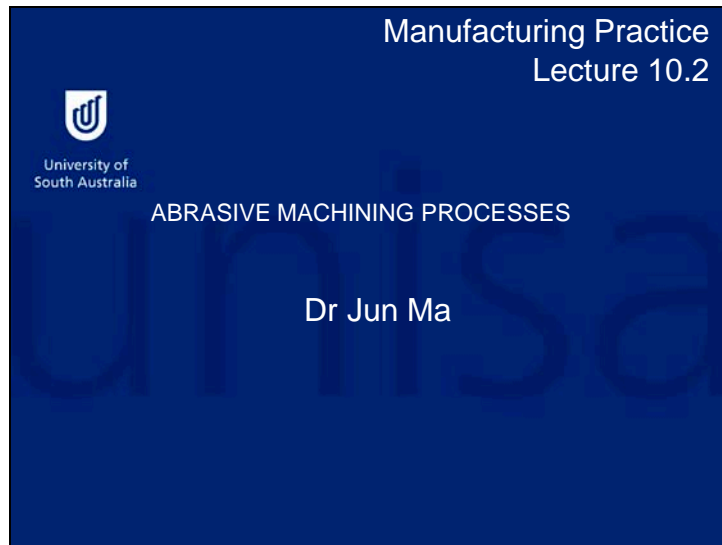
7. Surface finish should be specified to meet functional and/or aesthetic requirements

- However, better surface finish generally increases processing cost by requiring additional operations such as grinding or lapping

Seventh guideline. As we discussed in the previous guideline, surface finish should be specified to meet functional or aesthetic requirements.

## ENR212 Lecture 10 Slides and Notes

Slide 14



In the second part of this lecture summary, we will introduce abrasive machining processes. Let's start by reviewing the classifications of manufacturing processes. Manufacturing processes include processing operations and assembling operations. Processing operations consist of shaping processes, property enhancing processes, and surface treatment processes. There are four categories of shaping processes: solidification processes, particulate processes, deformation processes and material removal processes. The topic we are going to talk about now, abrasive machining processes, is one of the material removal processes.

ENR212-Lecture 10- Slide No. 15

University of South Australia

### Abrasive Machining


Material removal by action of hard, abrasive particles usually in the form of a bonded wheel

- Grinding is most important abrasive process
- Other abrasive processes: honing, lapping, superfinishing, polishing, and buffing
- Generally used as finishing operations after part geometry has been established by conventional machining

Abrasive machining processes use hard, abrasive particles (usually in the form of a bonded wheel) for material removal operations. Abrasive machining processes are generally used as finishing operations after the part geometry has been established by conventional machining operations.

## ENR212 Lecture 10 Slides and Notes

Slide 16

ENR212-Lecture 10- Slide No. 16

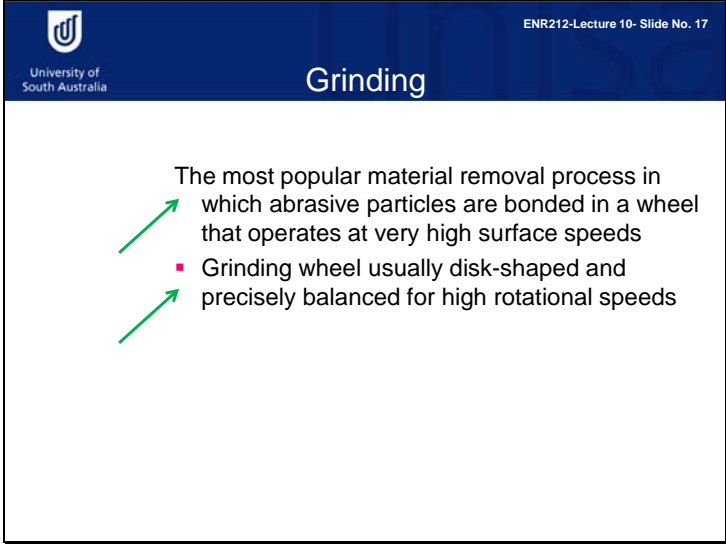
### Why Abrasive Processes are Important

- Can be used on all types of materials
- Some can produce extremely fine surface finishes, to  $0.025\ \mu\text{m}$  ( $1\ \mu\text{-in}$ )
- Some can hold dimensions to extremely close tolerances

Process	Tolerance (mm)	Surface Roughness ( $\mu\text{m}$ )
Sand Casting	$\pm 0.5\text{-}2.0$	6
Milling/turning	$\pm 0.025$	0.4/0.8
Grinding	$\pm 0.008$	0.025

Conventional machining operations can produce close tolerances and good surface finish. However, abrasive processes can produce even closer tolerances and better surface finishes. This table compares the tolerance and surface finish produced by conventional machining processes and abrasive processes.





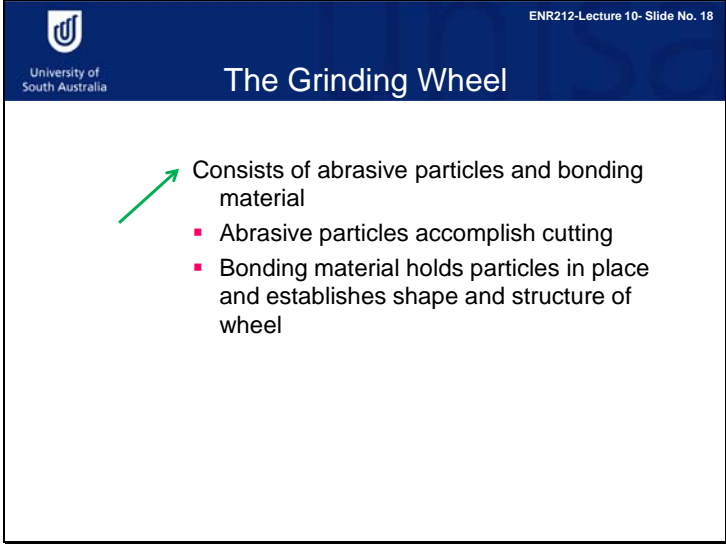
ENR212-Lecture 10- Slide No. 17

### Grinding

The most popular material removal process in which abrasive particles are bonded in a wheel that operates at very high surface speeds

- Grinding wheel usually disk-shaped and precisely balanced for high rotational speeds

Grinding is the most popular abrasive machining process. In grinding, abrasive particles are bonded in a wheel that operates at very high surface speeds. Most grinding wheels have a disk-like shape and are precisely balanced for high rotational speed.



ENR212-Lecture 10- Slide No. 18

University of South Australia

### The Grinding Wheel

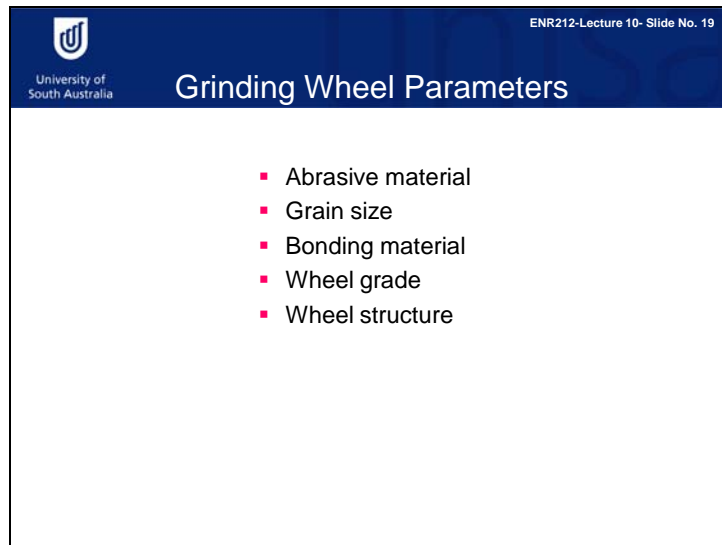
Consists of abrasive particles and bonding material

- Abrasive particles accomplish cutting
- Bonding material holds particles in place and establishes shape and structure of wheel

A grinding wheel consists of abrasive particles and bonding material. The role of the abrasive particles is to accomplish cutting, and the role of the bonding material is to hold the particles in place and to establish the shape and structure of the wheel.

## ENR212 Lecture 10 Slides and Notes

Slide 19



The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 19' on the right. The main title 'Grinding Wheel Parameters' is centered in the header. Below the header, a white box contains a bulleted list of five parameters.

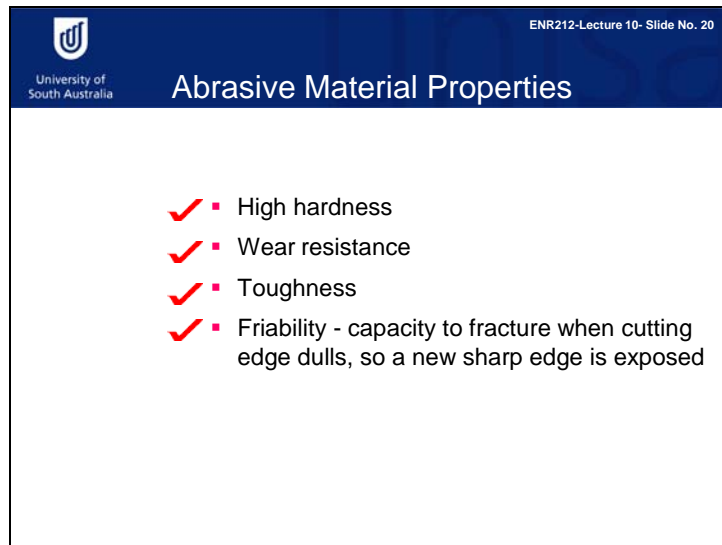
ENR212-Lecture 10- Slide No. 19

University of South Australia

### Grinding Wheel Parameters

- Abrasive material
- Grain size
- Bonding material
- Wheel grade
- Wheel structure

These abrasive particles and bonding material are the two ingredients, and the way they are fabricated determines the five basic parameters of a grinding wheel: abrasive material, grain size, bonding material, wheel grade, and wheel structure. Each of the parameters must be carefully selected to achieve the desired performance in an application.



The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 20' on the right. Below the header, the title 'Abrasive Material Properties' is centered. The main content area is white and contains a bulleted list of four properties, each preceded by a red checkmark icon.

ENR212-Lecture 10- Slide No. 20

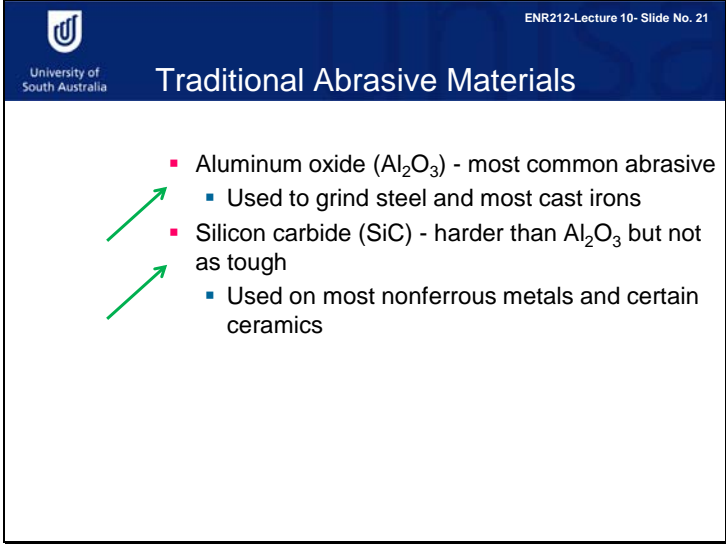
University of South Australia

### Abrasive Material Properties

- ✓ ▪ High hardness
- ✓ ▪ Wear resistance
- ✓ ▪ Toughness
- ✓ ▪ Friability - capacity to fracture when cutting edge dulls, so a new sharp edge is exposed

A grinding wheel consists of abrasive particles and bonding material. The desirable properties of the abrasive materials include high hardness, wear resistance, toughness and friability.

Hardness refers to the resistance of a material to permanent deformation. Stiffness is the resistance of an elastic material to deformation. (In solid mechanics, Young's modulus is a measure of the stiffness of a material.) The wear resistance refers to how resistant the material is to wear. The toughness refers to how resistant the material is to the propagation of a sufficiently sharp crack. Finally, friability refers to the capacity of the abrasive particles to fracture when the cutting edge of the grain becomes dull, thereby exposing a new sharp edge.



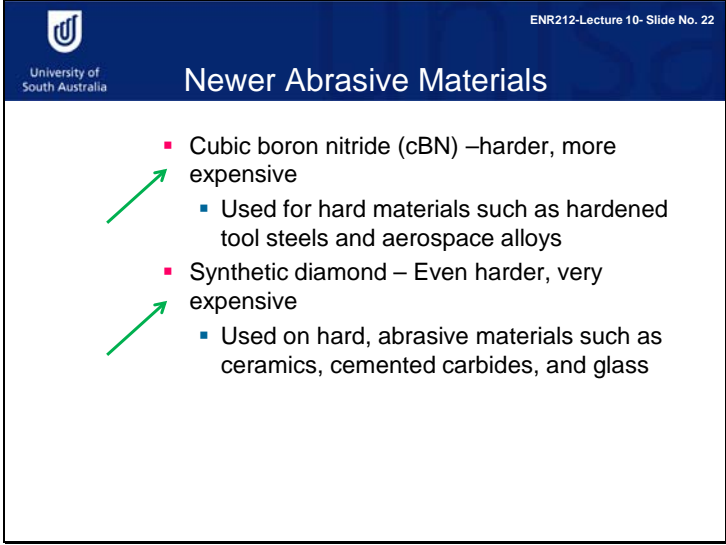
ENR212-Lecture 10- Slide No. 21

University of South Australia

### Traditional Abrasive Materials

- Aluminum oxide ( $\text{Al}_2\text{O}_3$ ) - most common abrasive
  - Used to grind steel and most cast irons
- Silicon carbide ( $\text{SiC}$ ) - harder than  $\text{Al}_2\text{O}_3$  but not as tough
  - Used on most nonferrous metals and certain ceramics

There are four important materials used for abrasion. The two traditional materials are aluminium oxide and silicon carbide. Aluminium oxide is the most commonly used. It is used for grinding steel and for most cast irons. Silicon carbide is harder than aluminium oxide but not as tough. Silicon carbide is used on most nonferrous metals and certain ceramics.



ENR212-Lecture 10- Slide No. 22

University of South Australia


### Newer Abrasive Materials

- Cubic boron nitride (cBN) –harder, more expensive
  - Used for hard materials such as hardened tool steels and aerospace alloys
- Synthetic diamond – Even harder, very expensive
  - Used on hard, abrasive materials such as ceramics, cemented carbides, and glass

Cubic boron nitride is harder and more expensive than the first two materials. It is used for hard materials, such as hardened tool steels and aerospace alloys. The last abrasion material is synthetic diamond. It is the hardest and the most expensive of the four materials. It is used on hard, abrasive materials such as ceramics, cemented carbides, and glass.

## ENR212 Lecture 10 Slides and Notes

Slide 23

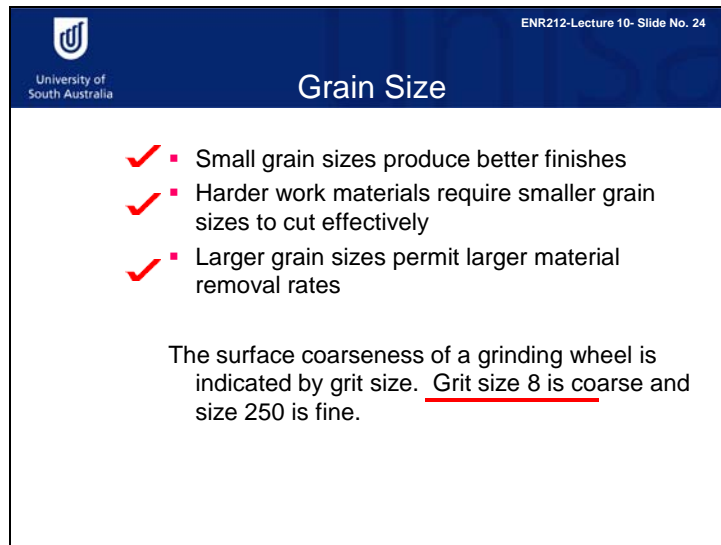


ENR212-Lecture 10- Slide No. 23

### Hardness of Abrasive Materials

<u>Abrasive material</u>	<u>Knoop hardness</u>
Aluminum oxide	2100
Silicon carbide	2500
Cubic boron nitride	5000
Diamond (synthetic)	7000

This table shows you the hardness of these four commonly used abrasive materials.



ENR212-Lecture 10- Slide No. 24

University of South Australia

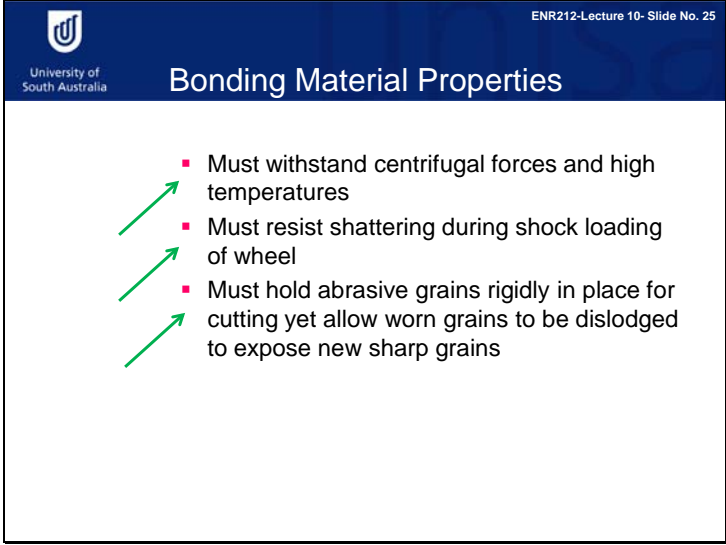
### Grain Size

- ✓ ▪ Small grain sizes produce better finishes
- ✓ ▪ Harder work materials require smaller grain sizes to cut effectively
- ✓ ▪ Larger grain sizes permit larger material removal rates

The surface coarseness of a grinding wheel is indicated by grit size. Grit size 8 is coarse and size 250 is fine.

These materials are in the form of particles, and the grain size is the actual size of the materials. A smaller grain size produces better finish, and is more suitable for harder material, when it corresponds to lower removal rates. Grit size is a grinding product indicator. It is the opposite to grain size.





ENR212-Lecture 10- Slide No. 25

University of South Australia

### Bonding Material Properties

- Must withstand centrifugal forces and high temperatures
- Must resist shattering during shock loading of wheel
- Must hold abrasive grains rigidly in place for cutting yet allow worn grains to be dislodged to expose new sharp grains

The bonding material holds the abrasive grains and establishes the shape and structural integrity of the grinding wheel. The bonding material must be able to withstand the centrifugal forces and high temperatures experienced by the grinding wheel. It must resist shattering in shock loading of the wheel. It must hold the abrasive grains rigidly in place to accomplish the cutting action while allowing worn grains to be dislodged so that new grains can be exposed. That is what we called friability.

There are three types of bonding materials: ceramics, metal(bronze), and rubber or resin.

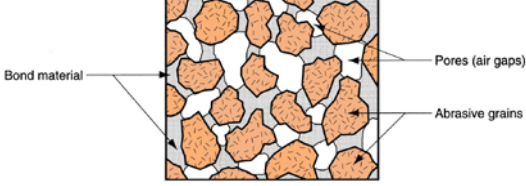
University of South Australia

ENR212-Lecture 10- Slide No. 26

### Wheel Structure


Refers to the relative spacing of abrasive grains in wheel

- In addition to abrasive grains and bond material, grinding wheels contain air gaps or pores



The diagram illustrates the internal structure of a grinding wheel. It consists of three main components: abrasive grains, bond material, and pores (air gaps). The abrasive grains are represented by irregular, orange-colored shapes. The bond material is the grey matrix that holds the grains together. The pores are the white, irregular spaces between the grains and the bond material. Labels with arrows point to each of these components: 'Bond material' on the left, 'Pores (air gaps)' on the right, and 'Abrasive grains' on the right. A green arrow points from the text 'In addition to abrasive grains and bond material, grinding wheels contain air gaps or pores' to the pores in the diagram.

Wheel structure refers to the relative spacing of the abrasive grains in the wheel. This figure shows that a wheel structure includes bond material, pores and abrasive grains.

ENR212-Lecture 10- Slide No. 27

### Wheel Structure

▪ Volumetric proportions of grains, bond material, and pores can be expressed as:

$$P_g + P_b + P_p = 1.0$$

*P<sub>g</sub>* = proportion of abrasive grains in the total wheel volume, *P<sub>b</sub>* = proportion of bond material, and *P<sub>p</sub>* = proportion of pores

The volumetric proportions of grains, bond material, and pores can be expressed in this equation.

ENR212-Lecture 10- Slide No. 28

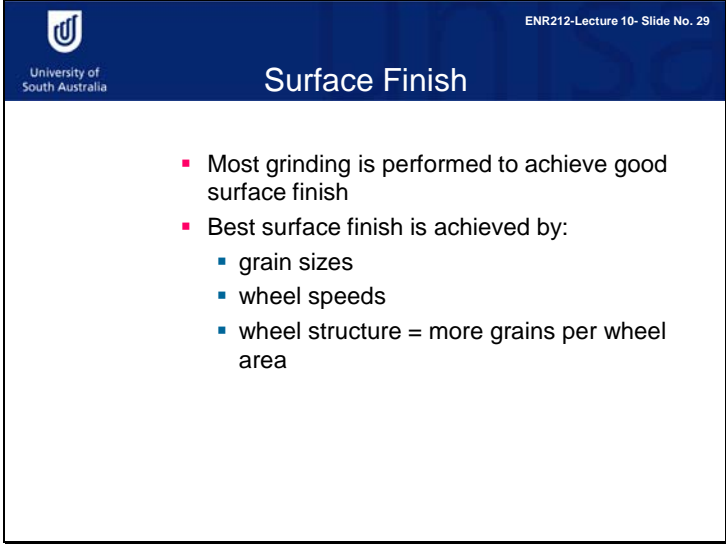
University of South Australia

### Wheel Grade

Indicates bond strength in retaining abrasive grains during cutting

- Measured on a scale ranging between soft and hard
  - Soft wheels lose grains readily - used for low material removal rates and hard work materials
  - Hard wheels retain grains - used for high stock removal rates and soft work materials

Wheel grade indicates the grinding wheel's bond strength in retaining the abrasive grains during cutting. The grade is measured on a scale that ranges between soft and hard. Soft wheels lose grains readily and are used for low material removal rates and hard work materials. Hard wheels retain grains and are used for high stock removal rates and soft work materials.



The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 29' on the right. The main title 'Surface Finish' is centered in the header. The content area is white with a black border and contains a bulleted list.

ENR212-Lecture 10- Slide No. 29

### Surface Finish

- Most grinding is performed to achieve good surface finish
- Best surface finish is achieved by:
  - grain sizes
  - wheel speeds
  - wheel structure = more grains per wheel area

Most grinding is performed to achieve a surface finish that is superior to what can be accomplished with conventional machining.

ENR212-Lecture 10- Slide No. 30

University of South Australia

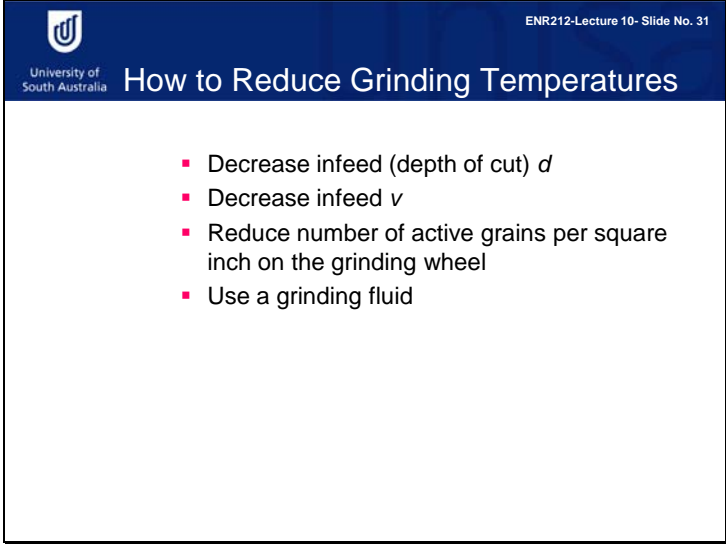
### Temperatures at Work Surface

- Grinding is characterized by high temperatures and high friction, and most of the energy remains in the ground surface, resulting in high work surface temperatures
- Damaging effects include:
  - Surface burns and cracks
  - Softening of the work surface
  - Residual stresses in the work surface

The grinding process is characterized by high temperatures and high friction. The high surface temperatures have several damaging effects: surface burns and cracks, softening of the work surface (like a polymer sample) and residual stresses in the work surface.

## ENR212 Lecture 10 Slides and Notes

Slide 31



The slide features a dark blue header with the University of South Australia logo on the left and the text 'ENR212-Lecture 10- Slide No. 31' on the right. Below the logo is the text 'University of South Australia'. The main title 'How to Reduce Grinding Temperatures' is centered in the header. The body of the slide is white and contains a bulleted list of four methods to reduce grinding temperatures.

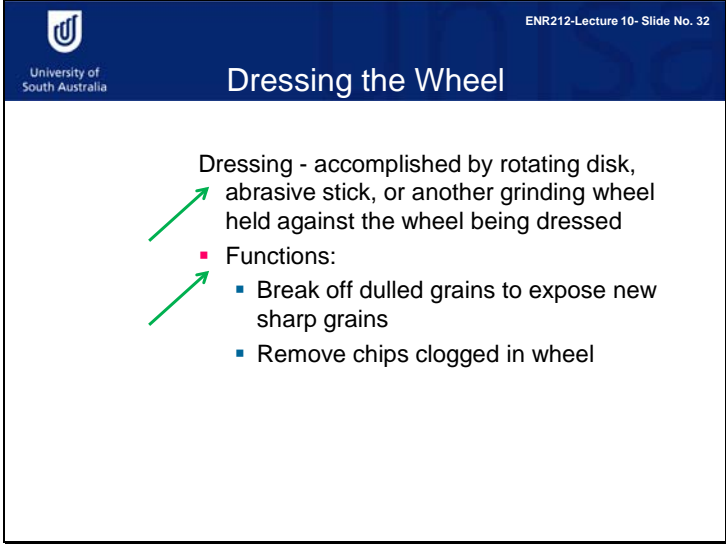
ENR212-Lecture 10- Slide No. 31

University of South Australia

### How to Reduce Grinding Temperatures

- Decrease infeed (depth of cut)  $d$
- Decrease infeed  $v$
- Reduce number of active grains per square inch on the grinding wheel
- Use a grinding fluid

High grinding temperatures are harmful, but can be reduced. There are four ways to do this: decrease the infeed depth of cut, decrease the infeed, reduce the number of active grains per square inch on the grinding wheel, and use a grinding fluid. Of these methods, the most effective is using grinding fluid.



ENR212-Lecture 10- Slide No. 32

University of South Australia

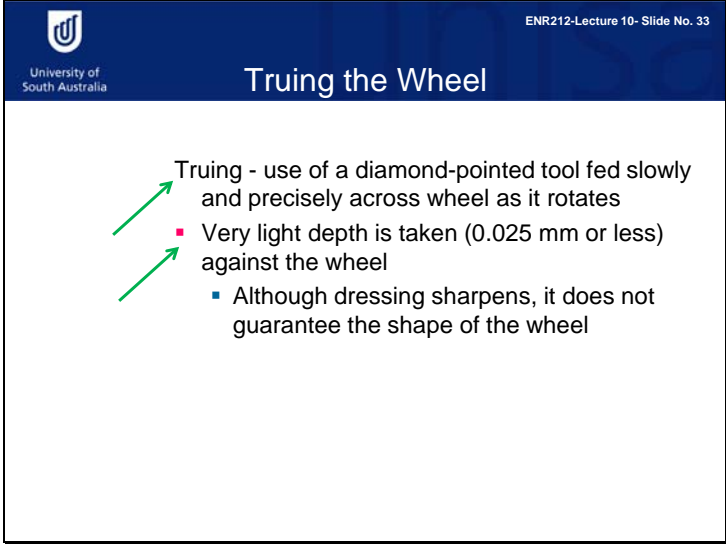
### Dressing the Wheel

Dressing - accomplished by rotating disk, abrasive stick, or another grinding wheel held against the wheel being dressed

- Functions:
  - Break off dulled grains to expose new sharp grains
  - Remove chips clogged in wheel

When a grinding wheel is worn, it is resharpened by dressing and truing. Dressing is accomplished by using a dressing tool. The tool can be a rotating disk or an abrasive stick, or another grinding wheel. Operating at high speed, the tool is held against the wheel to be dressed. The dressing breaks off dulled grains to expose new sharp grains and removes chips clogged in the wheel.





ENR212-Lecture 10- Slide No. 33

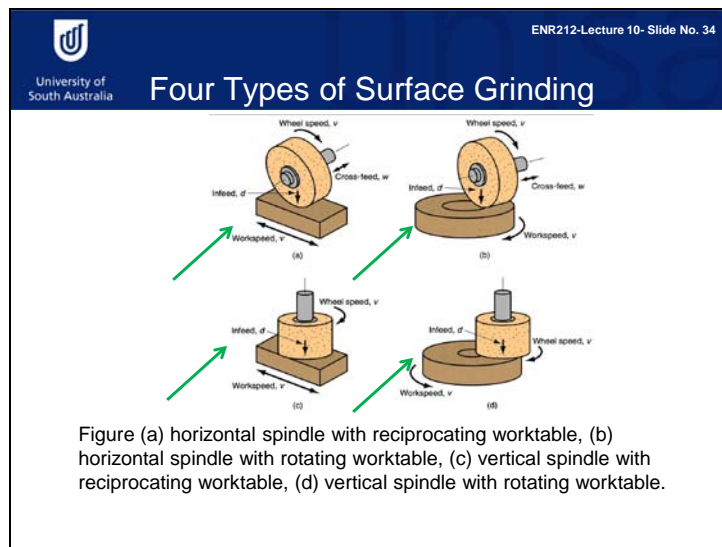
University of South Australia

### Truing the Wheel

Truing - use of a diamond-pointed tool fed slowly and precisely across wheel as it rotates

- Very light depth is taken (0.025 mm or less) against the wheel
- Although dressing sharpens, it does not guarantee the shape of the wheel

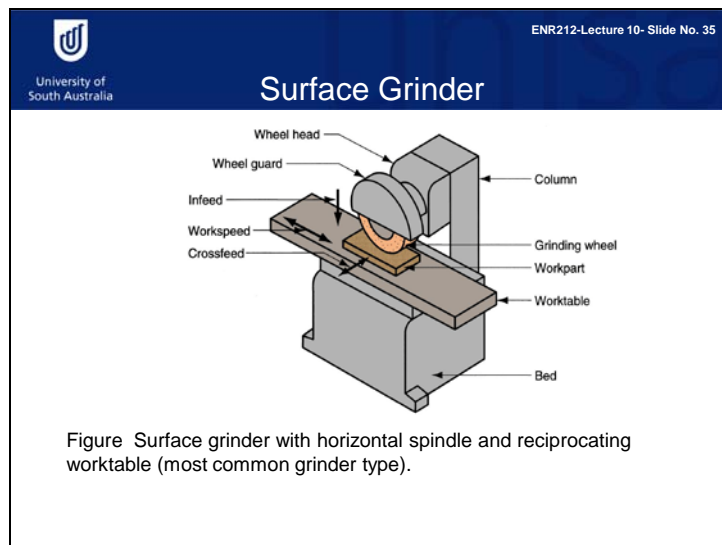
Dressing is a procedure to resharpen a worn grinding wheel. Truing is an alternative procedure. The procedure involves feeding a diamond-pointed tool slowly and precisely across the wheel as it rotates. Truing makes a very light depth (25um) against the wheel.



There are four types of surface grinding, depending on the relative motion between the worktable and the spindle of the grinding wheel. As you can see in figure a, this surface grinding machine has a horizontal spindle with a reciprocating worktable. In figure b, the grinding facility has a horizontal spindle with a rotating worktable. In figure c, the grinder has a vertical spindle with a reciprocating worktable. In figure d, the grinder has a vertical spindle with a rotating worktable.

## ENR212 Lecture 10 Slides and Notes

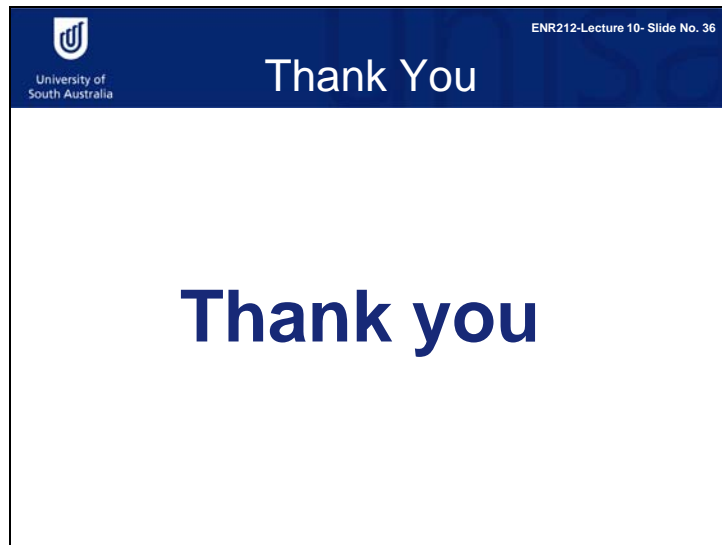
Slide 35



This figure shows you a surface grinder which has a reciprocating worktable and a horizontal spindle in the grinding wheel.

## ENR212 Lecture 10 Slides and Notes

Slide 36



Thank you for your attention.