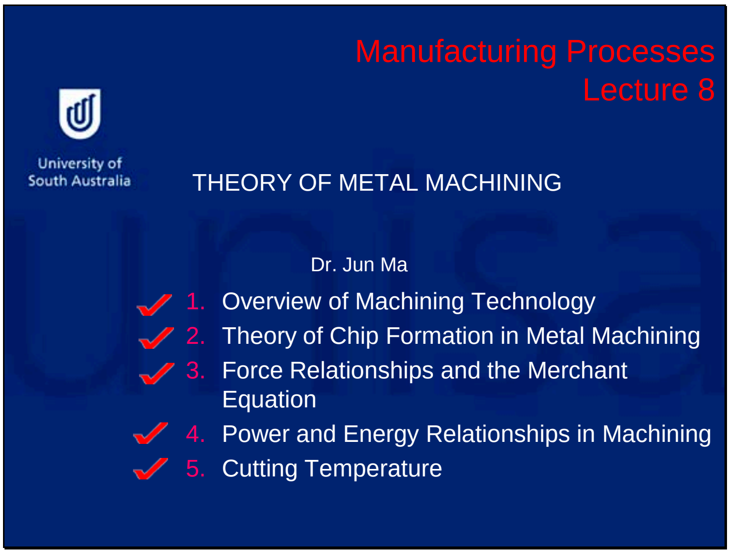
ENR212 Lecture 8 Slides and Notes

Slide 1



Hello everyone, and welcome to Lecture Summary 8 for Manufacturing Processes. (This lecture works through material covered in Chap 21 of the textbook.)

In this lecture, we will introduce the theory of metal machining, and address the following topics:
Overview of Machining Technology.
Theory of Chip Formation in Metal Machining.
Force Relationships and the Merchant Equation.
Power and Energy Relationships in Machining.
Cutting Temperature.

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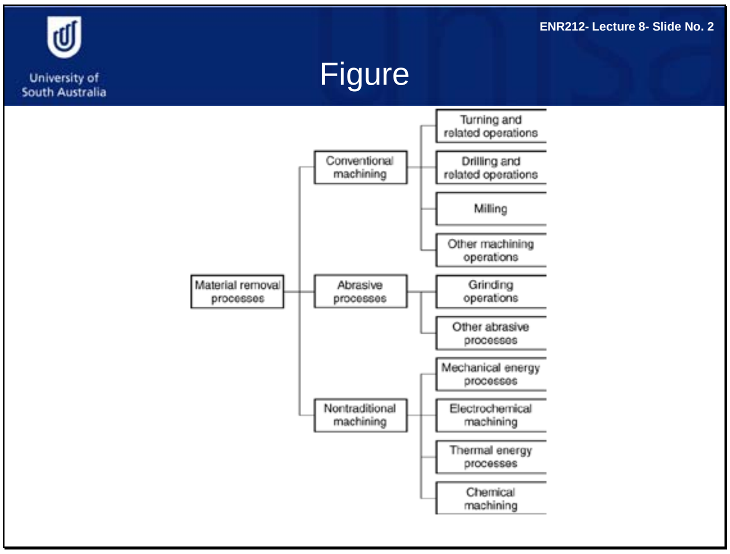
Slide 2



The Shaping operations include material removal processes. The common feature of these processes is that they remove material from a starting workpiece so that the remaining part has the desired geometry. Material removal processes include machining processes, abrasive processes and nontraditional machining processes.

*In machining processes, materials are removed by a sharp cutting tool (for example, through turning, milling and drilling).

*In abrasive processes, materials are removed by hard, abrasive particles (for example, through grinding).

* Nontraditional processes use various energy forms other than sharp cutting tools to remove materials, such as high velocity streams of abrasives or fluids.

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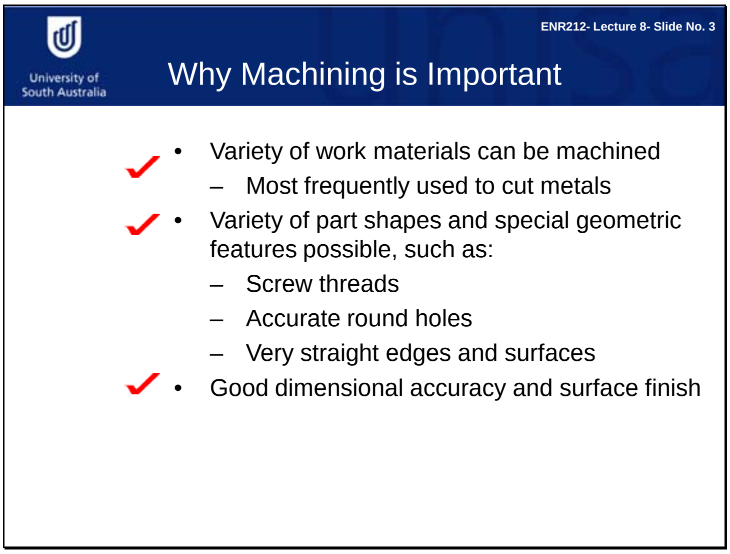
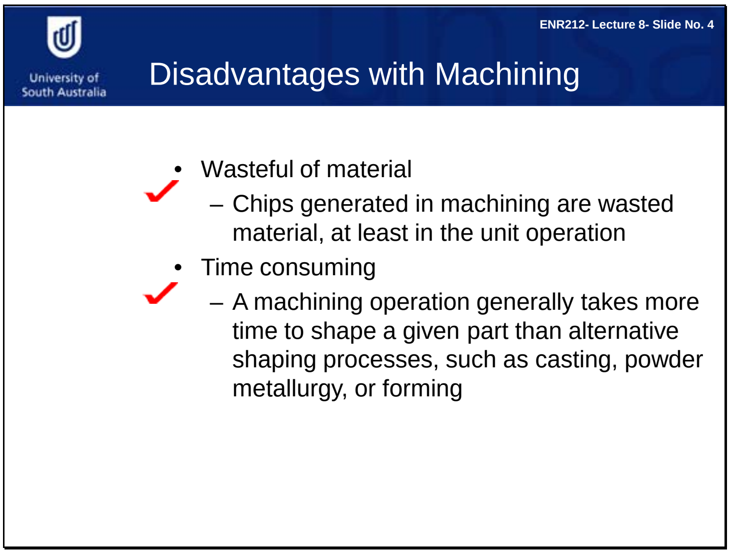


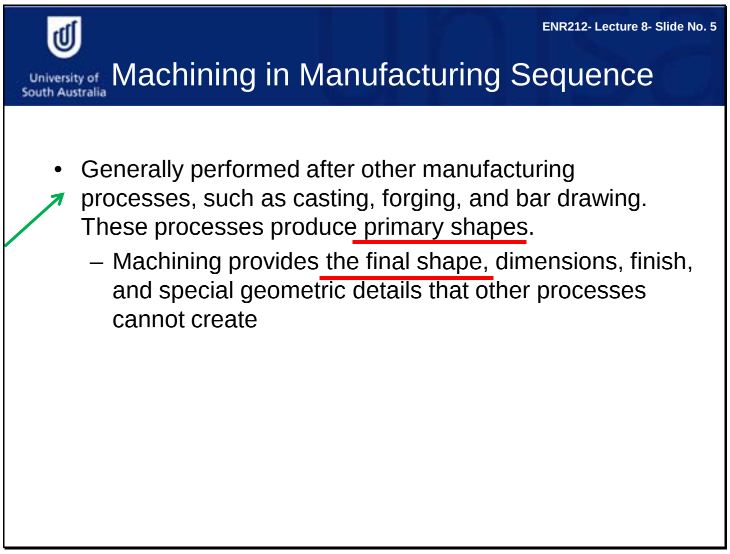
Machining is important because it has three main strengths. It can be applied to a wide variety of work materials, including metals, plastics, thermosets, composites and even ceramics. In fact, it is the most frequently used method to cut materials. It can be used to create any special geometries, such as screw threads. Finally, it can produce good dimensional accuracy and surface finish.

Slide 4



However, machining has two weaknesses. First, it is inherently wasteful of materials, because it removes materials from a starting workpiece. Second, a machining operation generally takes more time to shape a given part than alternative shaping processes such as casting or moulding.

Slide 5



The weaknesses of machining can be overcome to some extent if the machining is performed after other manufacturing processes, such as casting or bulk deformation. These processes create the primary shapes of the starting workpiece, and these primary shapes are subsequently machined to produce the final geometry, dimensions, and finish.

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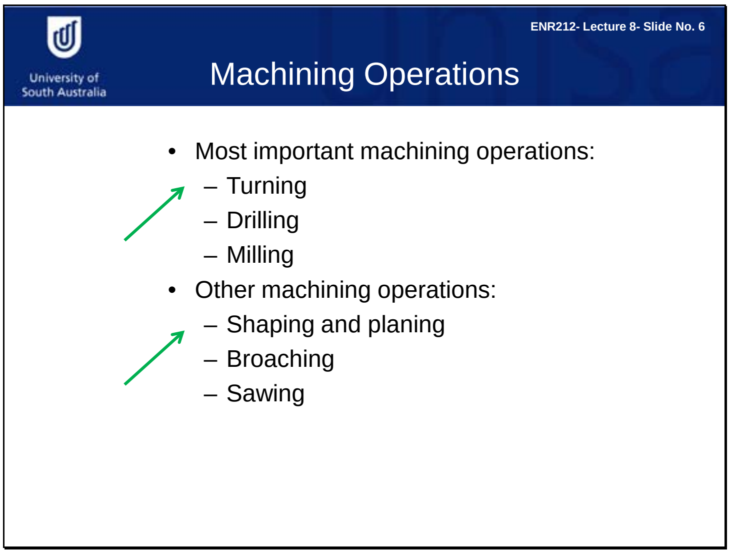

There are three most commonly used machining operations. They are turning, drilling and milling. However, other machining operations include shaping and planing, broaching, and sawing.

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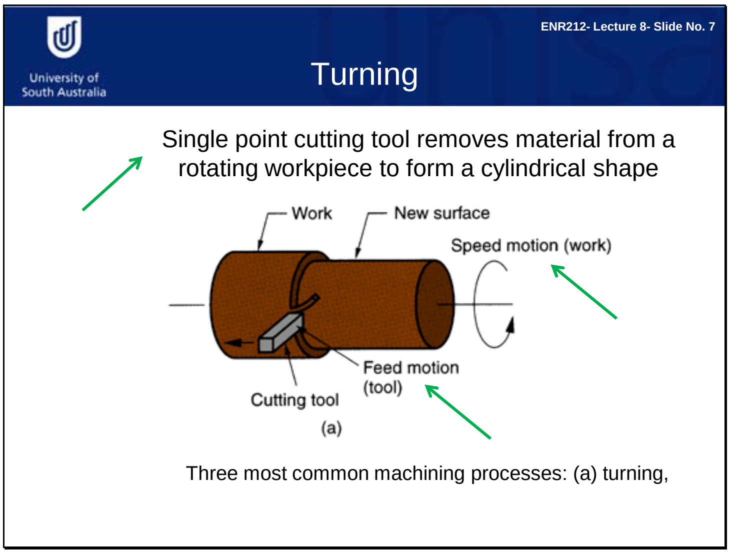

In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. There are two types of relative motion. The first is speed motion provided by the rotating workpiece, and the second is feed motion, achieved by moving the cutting tool slowly in a direction parallel to the axis of rotation of the workpiece.

This figure shows you a typical turning operation.

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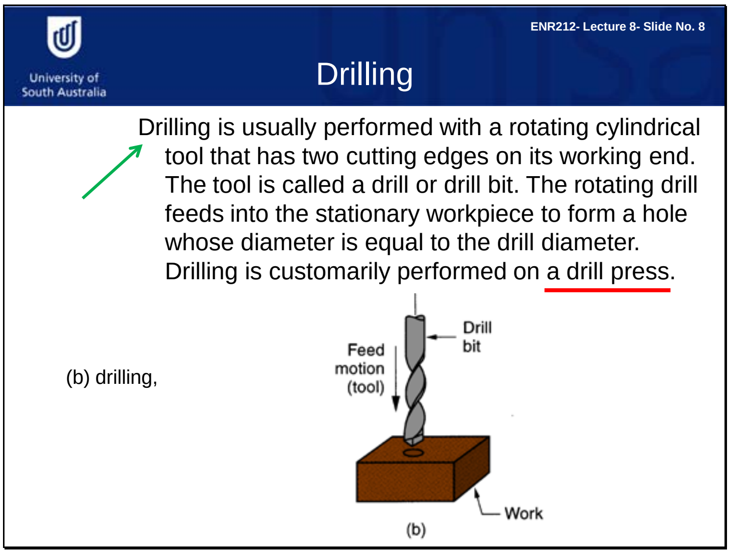
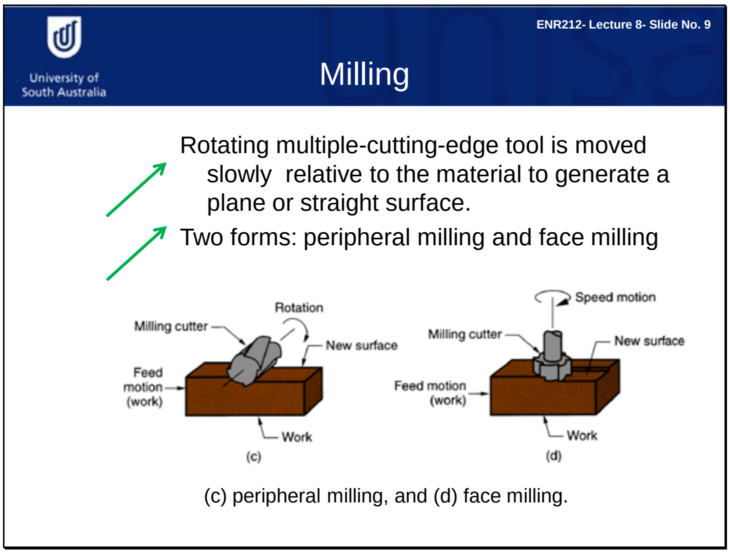


Drilling is a machining process which is usually performed with a rotating cylindrical tool that has two cutting edges on its working end. The tool is called a drill or drill bit. The rotating drill feeds into the stationary workpiece to form a hole whose diameter is equal to the drill diameter. Drilling is customarily performed on a drill press. This figure shows you a drilling process.

Slide 9



In milling, a rotating tool with multiple cutting edges is moved slowly across the material to generate a plane or straight surface. There are two forms of milling, peripheral milling and face milling.

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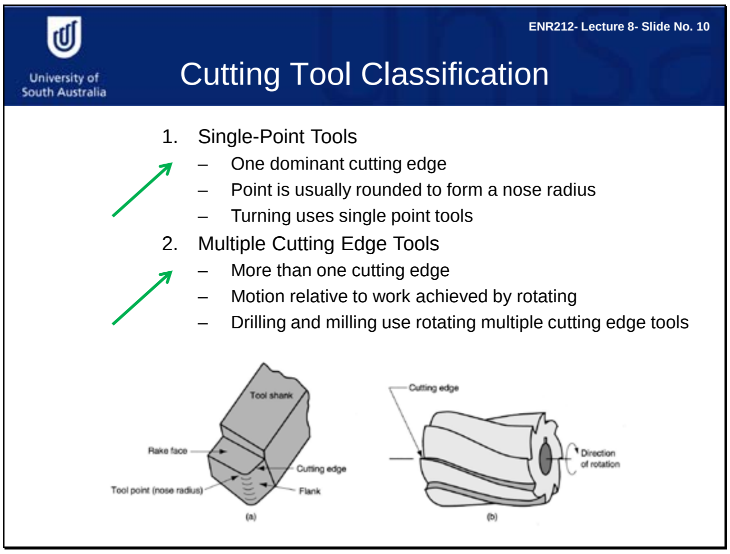

There are two basic classifications of cutting tools, single-point and multiple-cutting-edge. A single-point tool has one cutting edge and is used for operations such as turning. A multiple-cutting-edge tool has more than one cutting edge and usually achieves its motion relative to the workpiece by rotating. These tools are used for drilling and milling operations.

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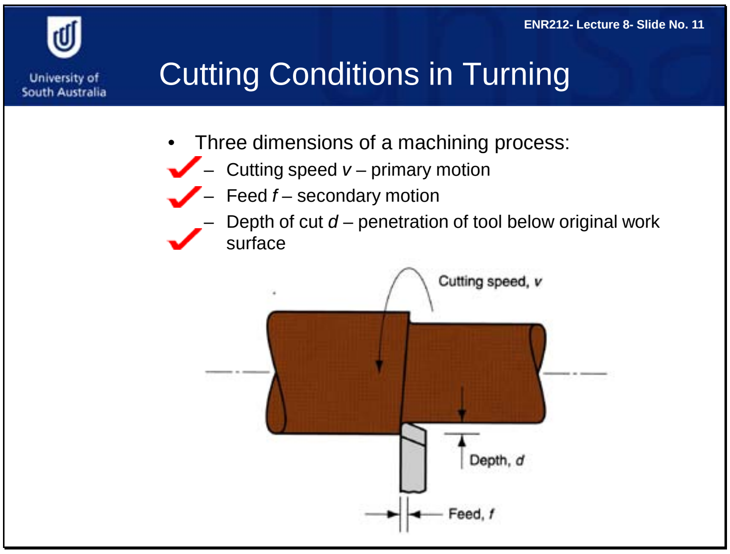
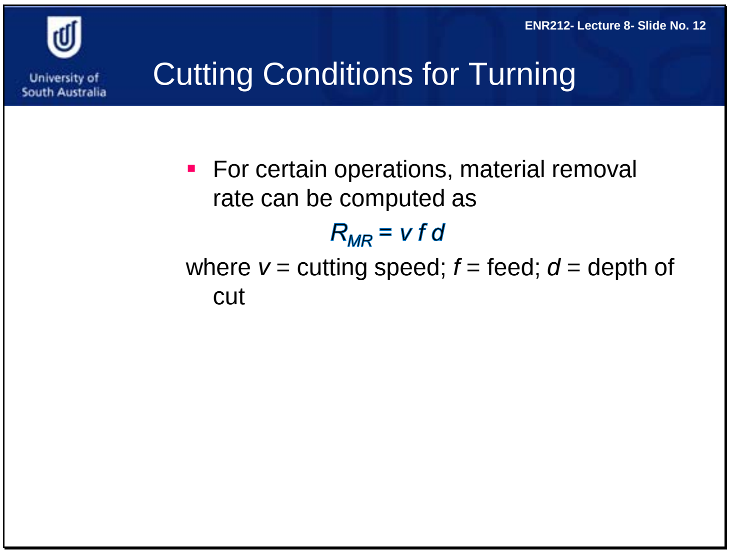


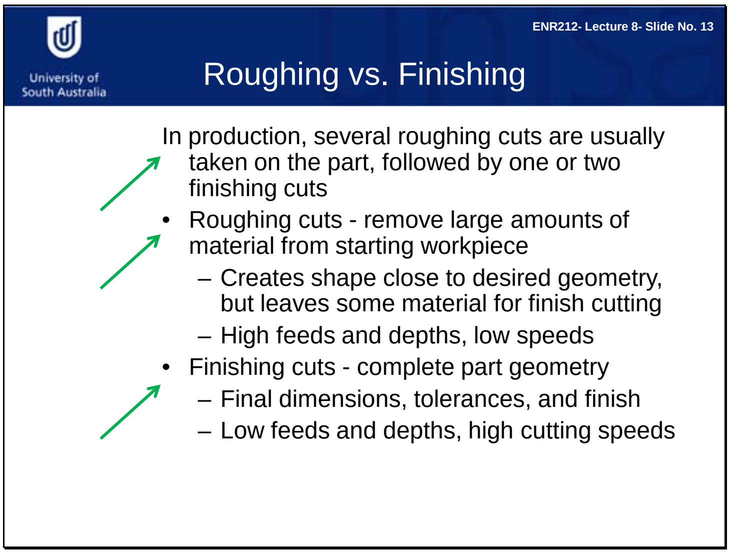
We have looked at two types of relative motions in a turning operation, speed motion and feed motion. This slide shows you the three dimensions which must be considered in a machining process. They are the cutting motion, the feed motion and the depth of the cut.

Slide 12



For most single-point tool operations, the material removal rate can be calculated using this equation. The Material Removal Rate is equal to the cutting speed multiplied by the feed multiplied by the depth of the cut.

Slide 13



Machining operations are usually divided into two categories, depending on their purpose and the cutting conditions. Roughing cuts remove large amounts of material from the starting workpiece as rapidly as possible, in order to produce a shape close to the desired form, but they leave some material on the piece for a subsequent finishing operation. Roughing cuts are characterised by low speeds, high feed and large depth. Finishing cuts are used to complete the part and achieve the final dimensions, tolerances, and surface finish. They are characterised by low feeds and depth, and high cutting speeds.

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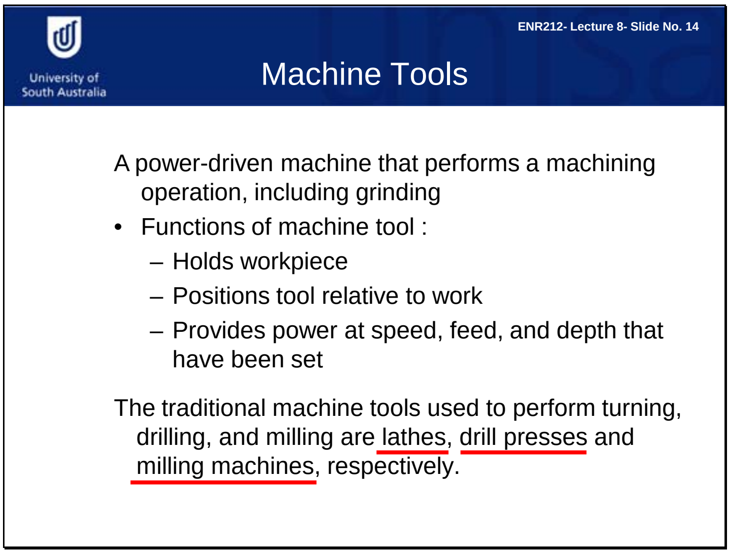
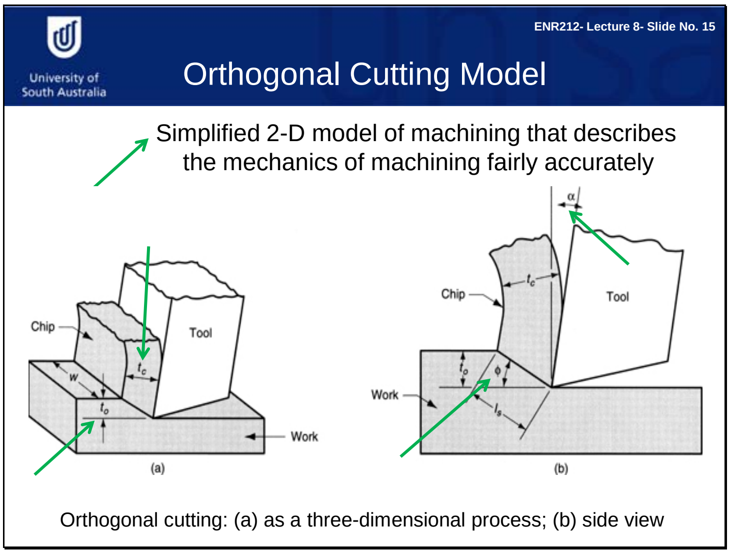


Machine tools are just the machines that accomplish the material removal processes. The machine tool for turning is called a lathe, and the machine tool for drilling is called a drill press. The machine tool for milling is called a milling machine.

Slide 15



The geometry of most workpieces in machining is complex. To describe the mechanics of the process, a simple two-dimensional orthogonal cutting model has been introduced. This model has only two dimensions which play an active role in the analysis. The cutting edge is perpendicular to the direction of the cutting speed, and the two elements of tool geometry are rake and shear plane angle. In this figure, as the tool is forced into the material, a chip is formed by shear deformation along a plane called the shear plane. In this case, the shear angle is an angle between the shear plane and the horizontal plane. The rake angle is an angle between the tool front plane and the vertical plane.

Chips are produced in machining operations. The T-o represents the original chip thickness, and the T-c represents the thickness of a cut chip.

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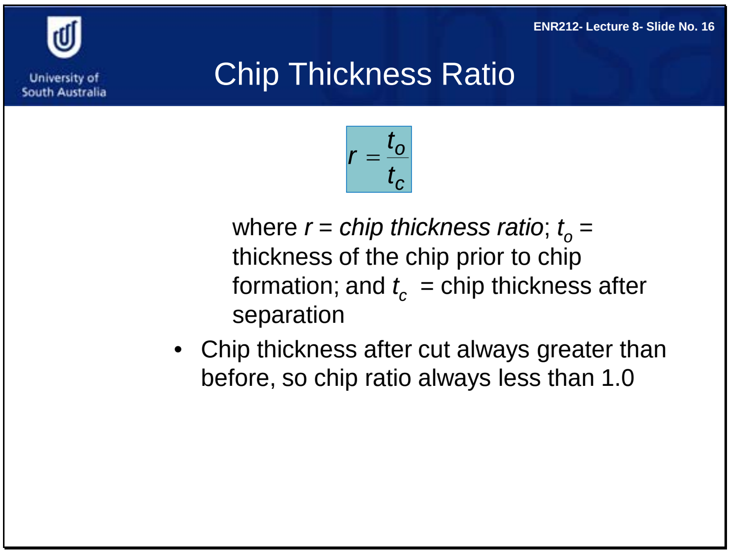

To calculate the chip thickness ratio, divide the chip thickness before chip formation by the chip thickness after separation. The thickness after the cutting is always greater than the thickness before, so the chip ratio is always less than 1.0.

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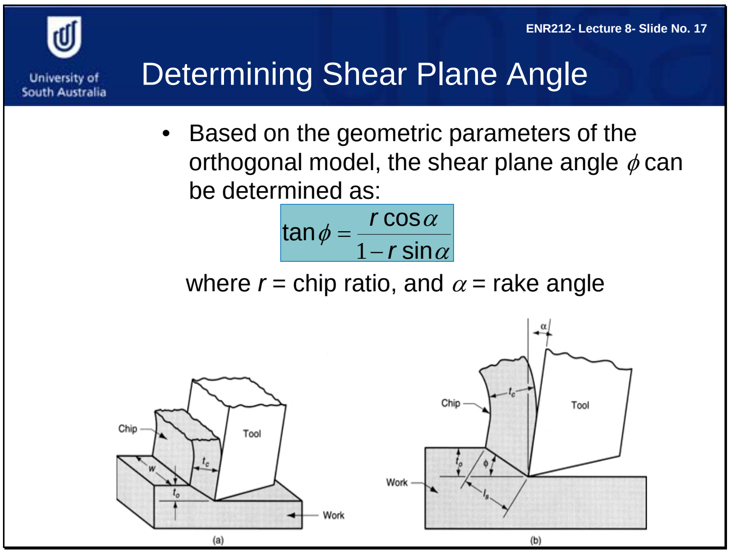
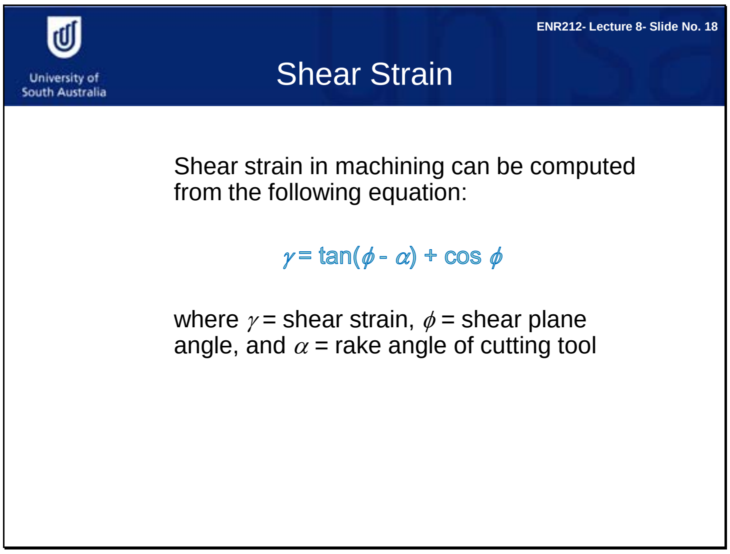


In a chip formation process, the shear plane angle is the angle between the horizontal plane and the shear plane. It is calculated by this equation: Tan angle is equal to chip ratio cosine rake angle divided by 1 minus chip ratio sine rake angle.

Slide 18



We have looked at strain in previous lectures. Strain is relative to the deformation of a material. Shear strain is relative to the deformation of material in shearing. The shear strain in machining is calculated by tan shear plane angle minus rake angle, plus cos shear plane angle.

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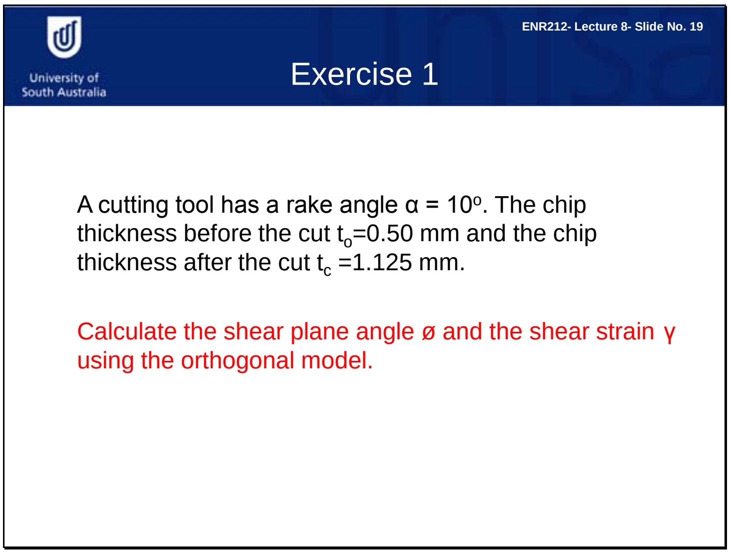

Now it is the time to use the equations you have learnt to solve a practical problem. Pause the presentation here and work out this problem.
An important task in manufacturing is to use theories to estimate and predict cutting forces, so that you can choose appropriate facilities and tools for your manufacturing processes. Suppose a cutting tool has a rake angle of 10o. The chip thickness before the cut is 0.50 mm and the chip thickness after the cut is 1.125 mm. Calculate the shear plane angle ø and the shear strain γ using the orthogonal model. The solution is on the next slide. (Note this kind of question will appear in the assessment activities for this unit.)

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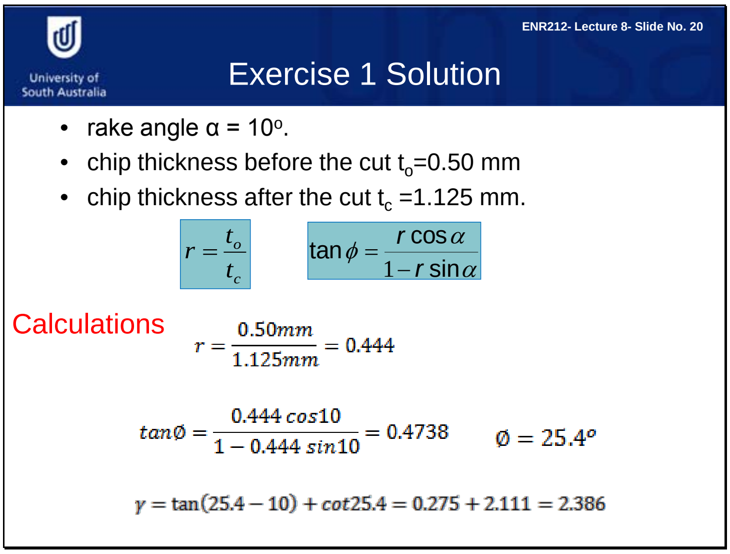

First of all, you need to find the chip thickness ratio, by dividing the chip thickness before chip formation by the chip thickness after separation, which gives you a chip thickness ratio of 0.444. Now let's look at the shear plane angle. You should have worked this out by using the equation Tan angle is equal to chip ratio cosine rake angle divided by 1 minus chip ratio sine rake angle. The answer for this scenario is that Tan angle is 0.4738, which means that the shear plane angle is 25.4 degrees. Finally, calculate the shear strain using the formula tan shear plane angle minus rake angle, plus cosine shear plane angle. The answer is 2.386.

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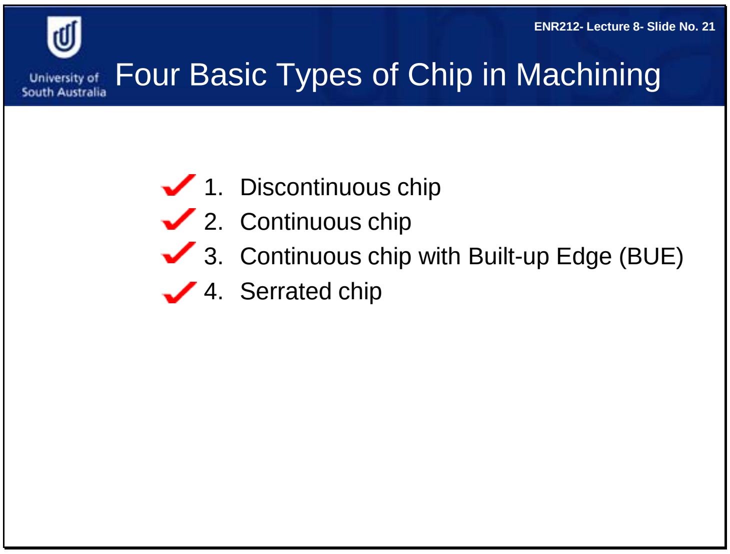

A chip is produced by shear deformation when a single-edge cutting tool is forced into a rotating part. Depending on the type of material being machined and the cutting conditions of the operation, four basic types of chips can be distinguished: discontinuous chip, continuous chip, continuous chip with a built-up edge, and serrated chip.

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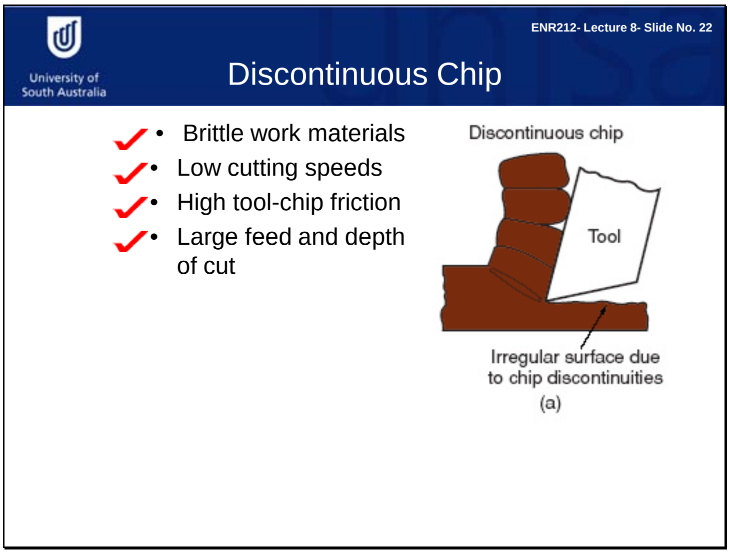

Discontinuous chips are produced by brittle materials, such as cast iron, at low cutting speeds.   High tool-chip friction and large feed and depth of cut can cause this type of chip to form.

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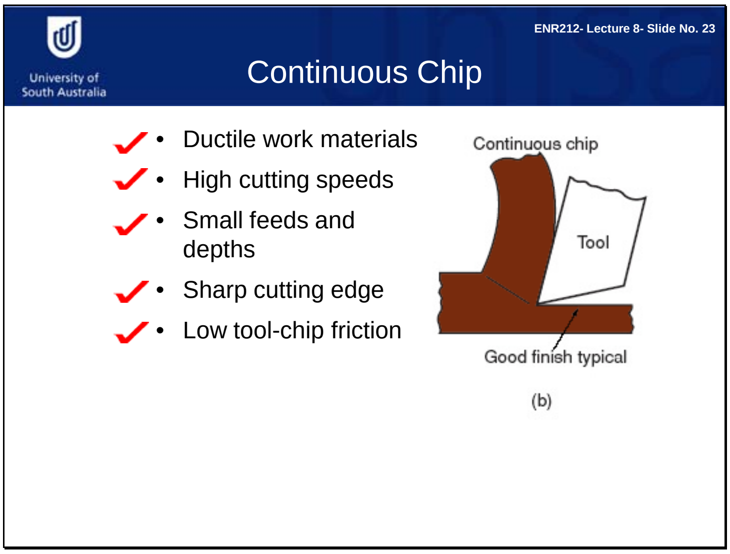

Continuous chips are formed by ductile materials at high speeds with relatively small feeds and depth. They are caused by sharp cutting edges on the tools and low tool-chip friction.

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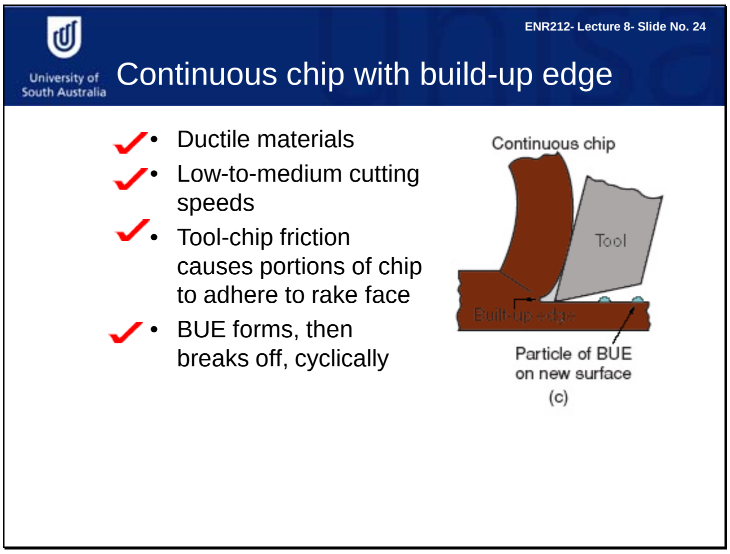

When ductile materials are being machined at low-to-medium cutting speeds, friction between the tool and the chip tends to cause portions of the work material to adhere to the rake face of the tool near the cutting edge. This can form a continuous chip with a built up edge (BUE). The formation of a BUE is cyclical; it forms and grows, then becomes unstable and breaks off.

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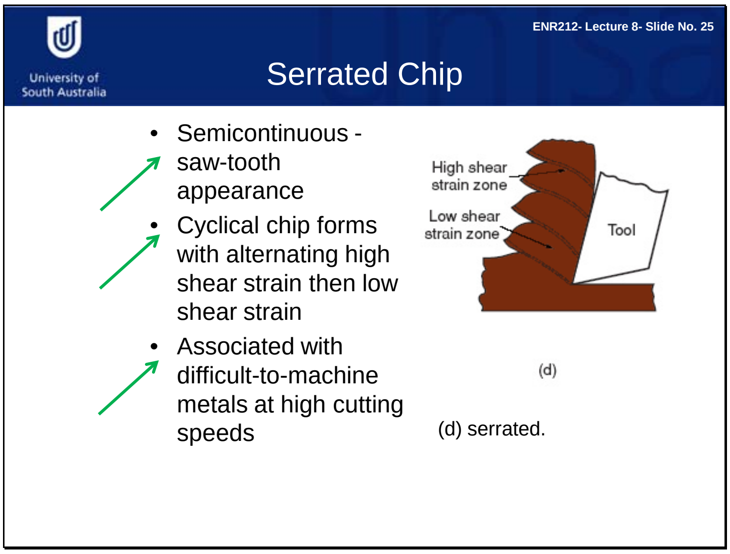

Serrated chips possess a saw-tooth appearance. They are the result of alternating high shear strain and then low shear strain. This type of chip is most closely associated with certain difficult-to-machine metals being machined at high cutting speeds, such as titanium alloys.

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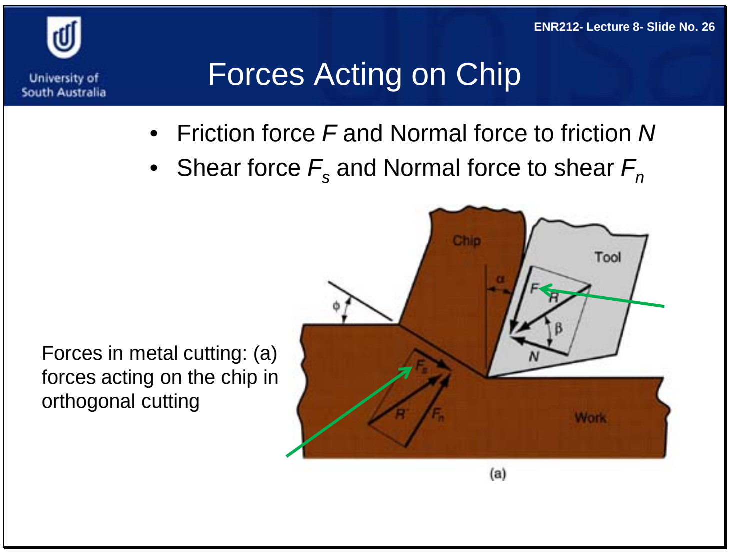

As shown in this figure, there are four forces in total in a typical machining process. The friction force is the frictional force which resists the flow of the chip along the rake face of the tool. The normal force to friction is perpendicular to the friction force. The shear force is the force that causes shear deformation to occur in the shear plane, and the normal force to shear is perpendicular to the shear force.

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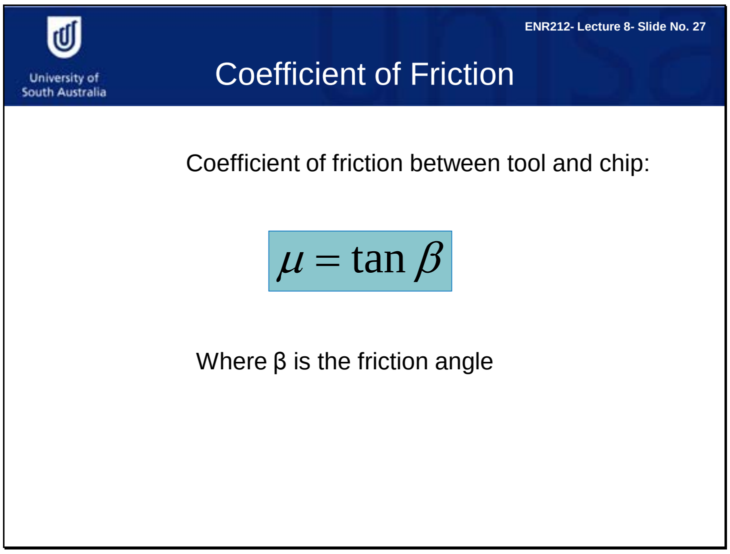

The friction between tool and chip is important. The coefficient of friction between the tool and chip is tan friction angle.

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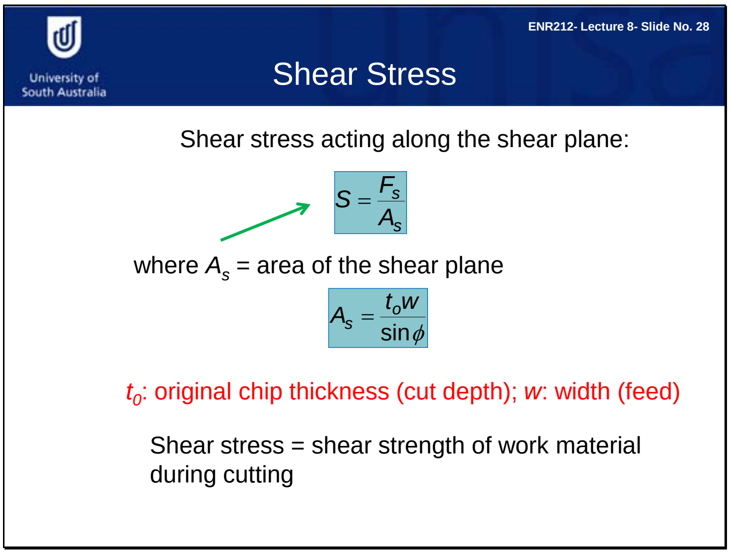

In past lectures, we have looked at what stress and engineering stress are. Stress is equal to the load divided by the original cross-sectional area. So, what is shear stress? Shear stress is defined as a stress acting along the shear plane. Shear stress is equal to the load divided by the area of the shear plane.

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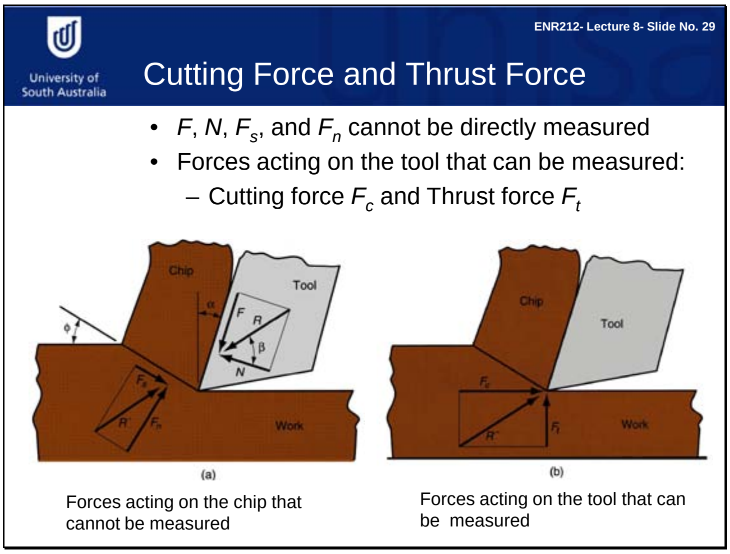

When a cutting tool is forced into a working material, two forces are needed, and these are measurable. The cutting force is in the direction of cutting, the same direction as the cutting speed. The thrust force is perpendicular to the cutting force and is associated with the chip thickness before the cut.

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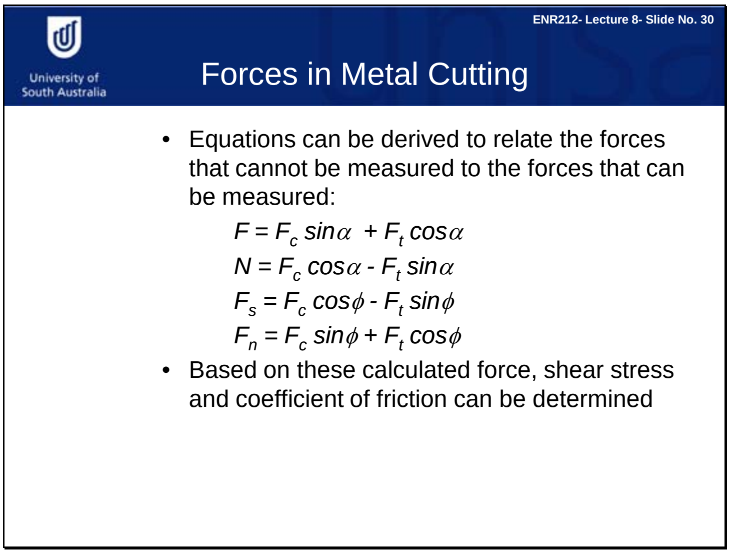

Cutting force and thrust force are used to calculate shear force, friction force, and normal force to friction, by these four equations.

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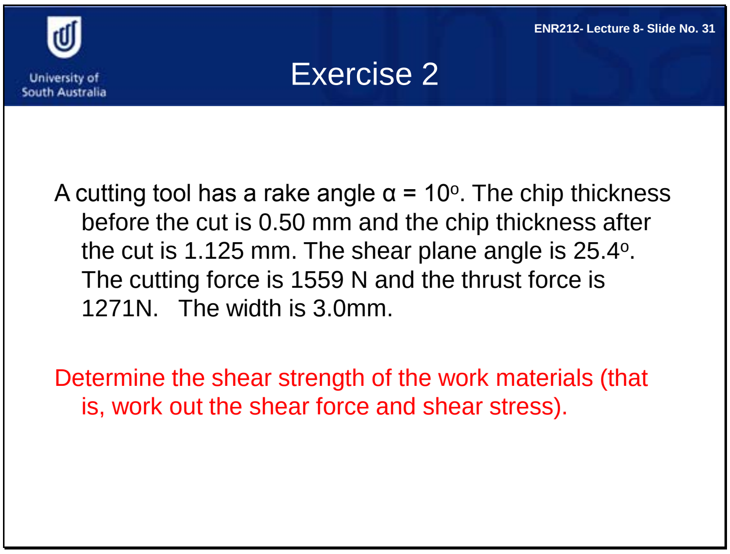
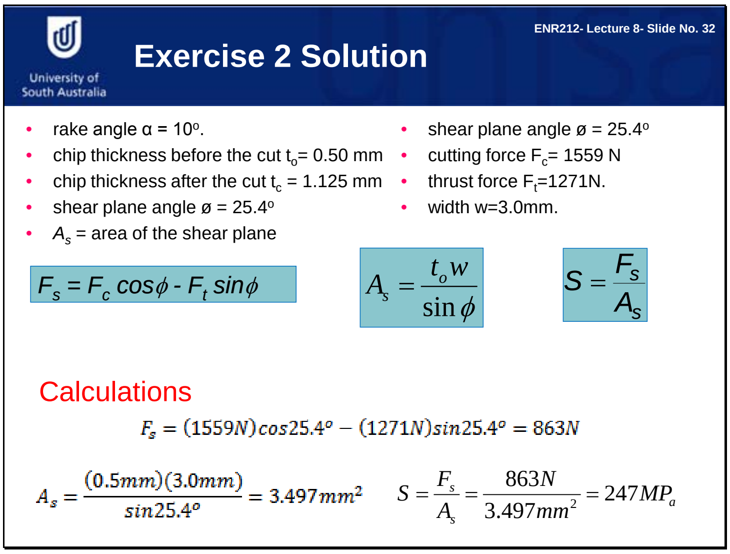


Now pause this presentation and use what you have learnt from the last few slides to solve this question. The solution is on the next slide.

Slide 32



To do this, we need to determine the shear force Fs and the shear stress S. You can see the three equations which you need, and the actual calculations, in this slide.

The shear force Fs equals the cutting force cos shear plane angle minus the thrust force sine shear plane angle, which equals 863 Newtons. To work out the shear stress, we need to know the shear plane area, which is the chip thickness prior to cutting multiplied by the width, all divided by sine shear plane angle. The area is 3.497 square mm. Now we find the shear stress by dividing the the shear force by the shear plane area, which is 247 MPa.

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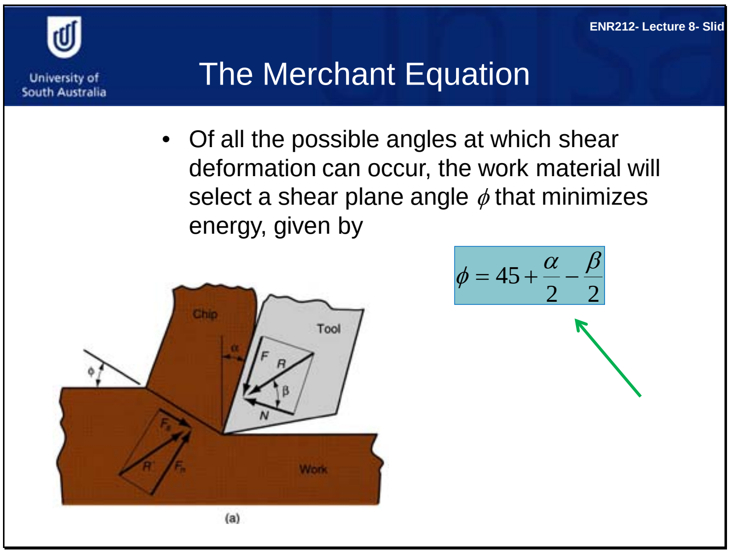

One of the most important equations in metal cutting is the merchant equation. This equation states that the shear plane angle is 45 plus rake angle divided by 2 minus friction angle divided by 2.

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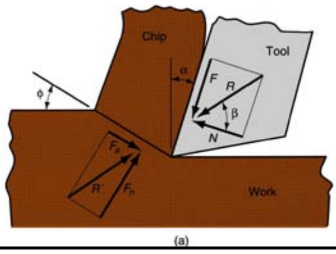
University of South Australia

What the Merchant Equation Tells Us

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

- To increase shear plane angle
  - Increase the rake angle
  - Reduce the friction angle (or coefficient of friction)



Based on orthogonal cutting, but validity extends to 3-D machining

What does the merchant equation tell us? It tells us that to increase shear plane angle, we need to increase the rake angle, while reducing the friction angle.

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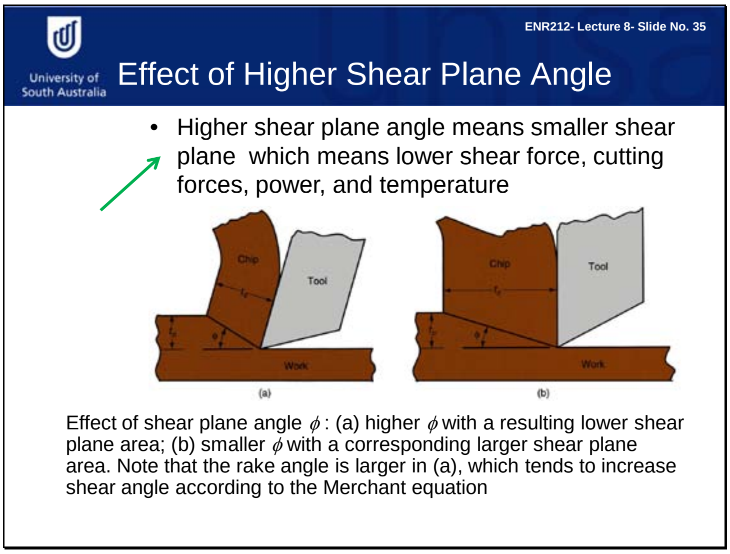

This slide shows you the relationship between the shear plane angle and the cutting force. A higher shear plane angle means a smaller shear plane, which means lower shear force, cutting forces, power, and temperature.

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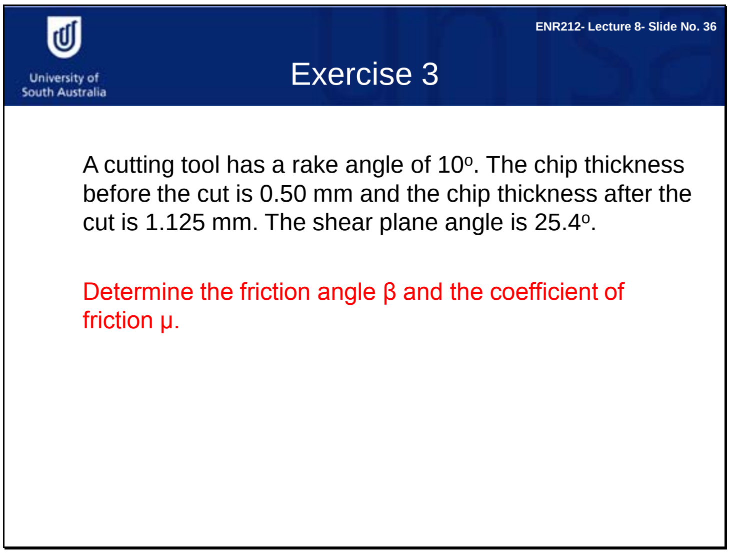
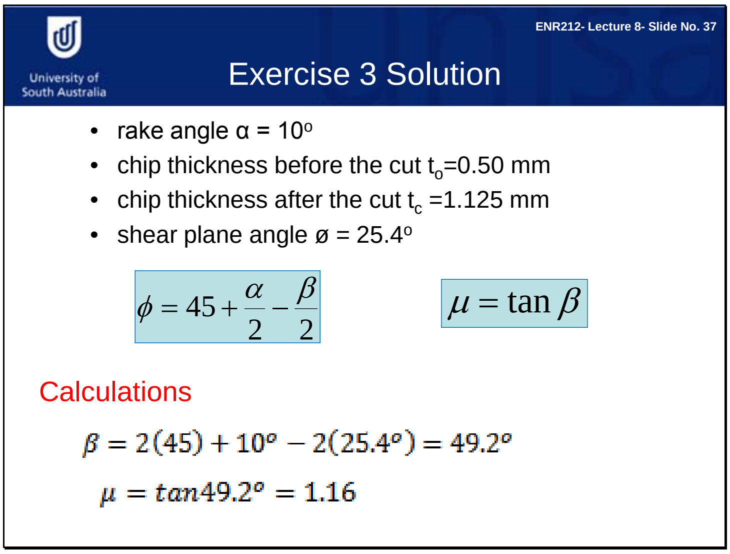


Now, pause the presentation and use the Merchant equation to try to work out this problem. The solution is on the next slide.

Slide 37



You can see the two equations which you need for this problem in this slide. The coefficient of friction between the tool and chip is tan friction angle. The friction angle can be derived by rearranging the Merchant equation, because you know the shear plane angle and the rake angle. The solution is that the friction angle is 49.2 degrees and the coefficient of friction is 1.16.

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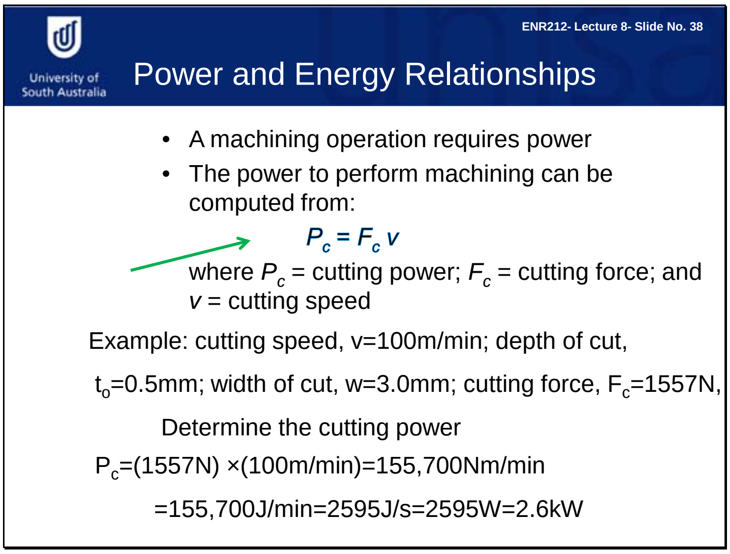

A machining operation requires power, and you will need to work out the amount of power you require for specific operations. The equation for this is cutting power equals cutting force multiplied by cutting speed. For example, if we have an operation with a cutting speed of 100 meters per minute, and a cutting force of 1557 Newtons, then the power needed is 155, 700 Newton meters per minute, which equals 2.6 kilo Watts.

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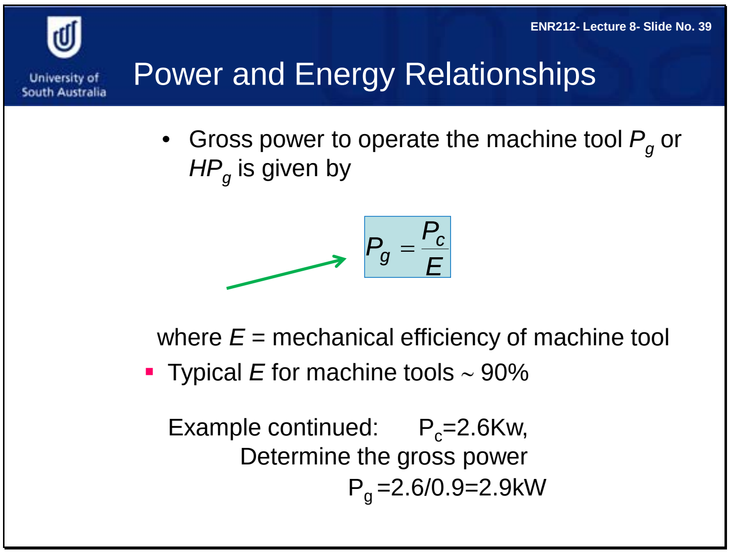

The gross power needed to operate the machine tool is calculated by dividing cutting power by the mechanical efficiency of the machine tool, which is typically 90%. So, to continue the last example, if we divide the cutting power by 90%, we get a gross power of 2.9 kilo Watts.

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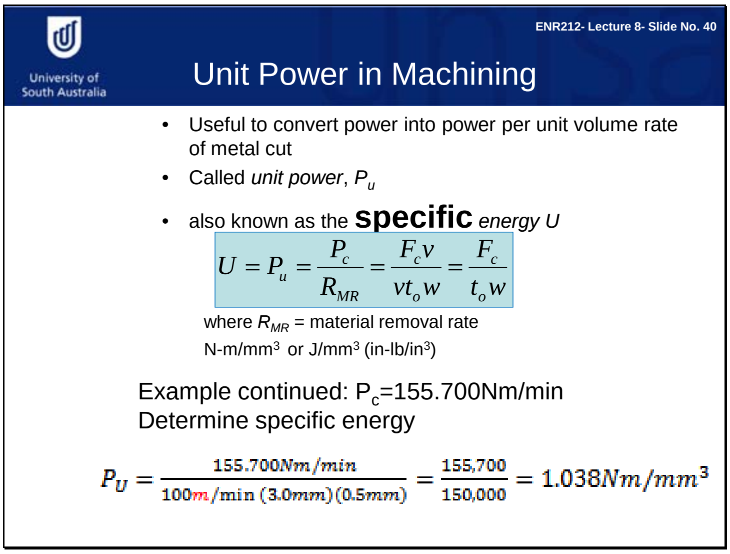

The unit power is the amount of power required to remove per unit volume of cut metal. It is calculated by dividing the cutting power by the material removal rate. To continue the previous example, if the cutting power is 155.7 Nm per minute, and the material removal rate is 100 meters per minute, then the Unit power is 1.038 Nm per cubic mm.

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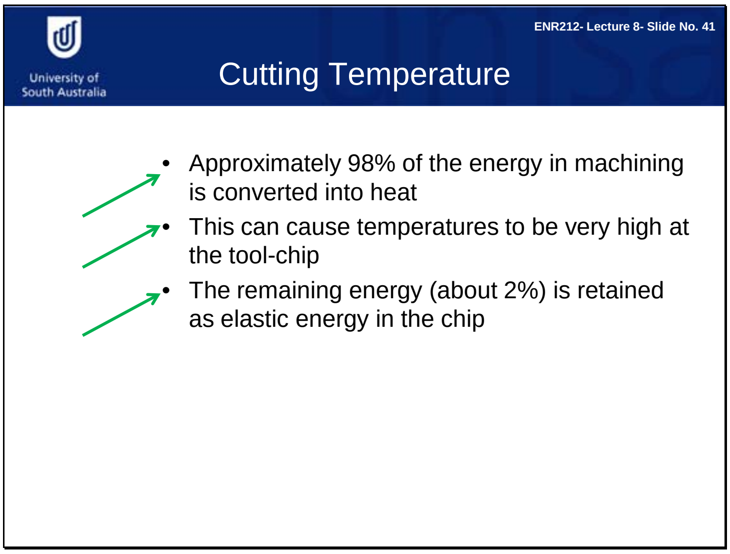

Approximately 98% of the energy in machining is converted into heat. This can cause very high temperatures at the tool-chip. The remaining energy (about 2%) is retained as elastic energy in the chip.

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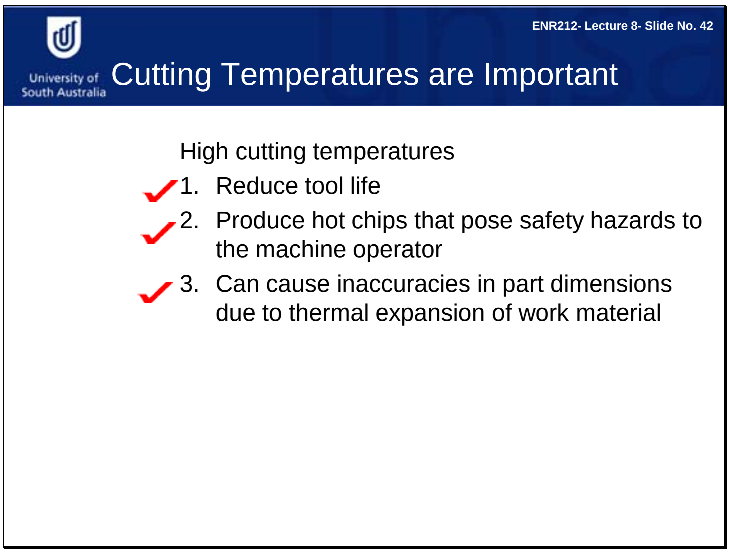

High cutting temperatures are not good at all, for a number of reasons. They reduce tool life, they produce hot chips that pose safety hazards to the machine operator, and they can cause inaccuracies in part dimensions, due to the thermal expansion of work material.

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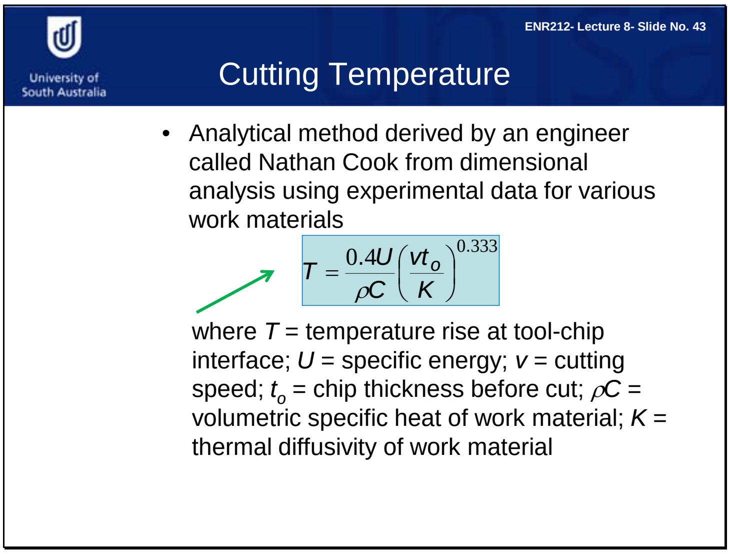

It is important to control the cutting temperature. Nathan Cook developed an equation for predicting cutting temperature.

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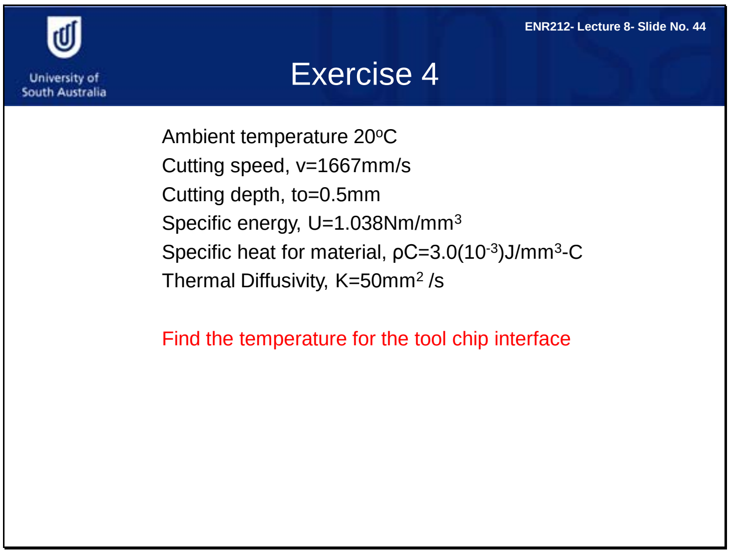

Now, you can use the Nathan's equation to predict the cutting temperature in this example. You have been given the ambient temperature, the cutting speed and depth, the specific energy, the specific heat for the material and the thermal diffusivity. Find the temperature rise for the tool chip interface. The solution is on the next slide.

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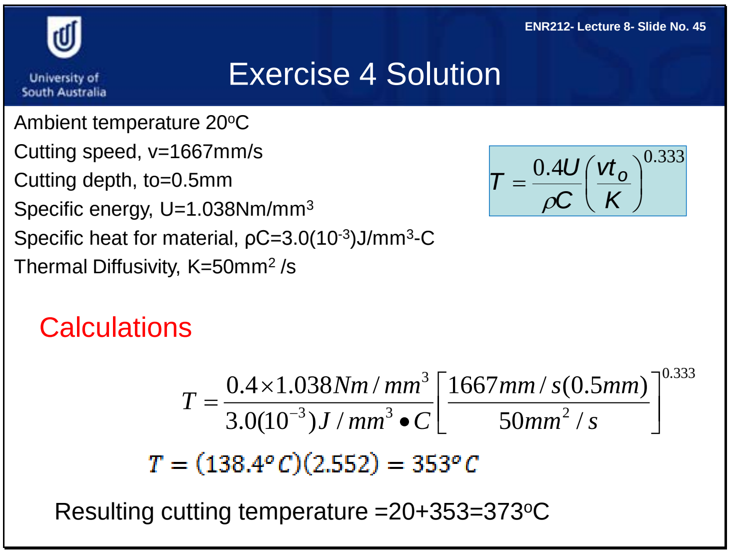
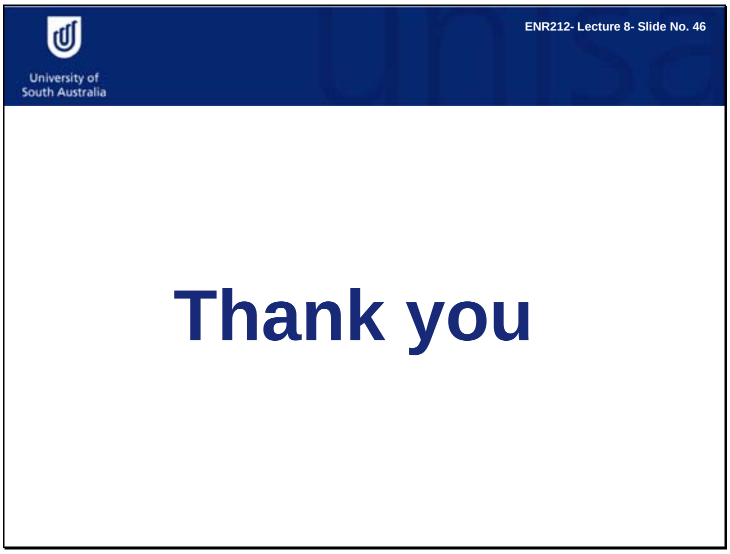


Nathan Cook's equation is given here. You should have used this equation to work out that the cutting temperature rise is 353 degrees Celsius. Given the ambient temperature of 20 degrees, this means that the resultant cutting temperature is 373 degrees Celsius.

ENR212 Lecture 8 Slides and Notes

Slide 46



Thank you for your attention.