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ENR116 Engineering Materials

Module 4 Non-metals and Corrosion

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Structural composites

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Intended Learning Outcomes

At the end of this section, students will be able to:

- Describe the function of matrix materials
- Identify the typical composite fabrication processes

•The intended learning outcomes from this presentation are for students to be able to describe the function of composite matrix material and the fabrication processes typically used in composite manufacture.

ENR116 – Mod. 4- Slide No. 5

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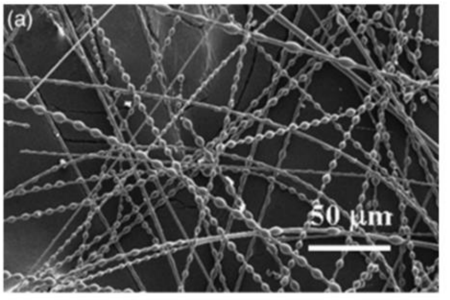
Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

Fibres

High strength under axial loading

- **Whiskers**
  Thin single crystals - large length to diameter ratio.
- **Fibers**
  Diameter 3 – 20 μm.
- **Wires**
  Diameter ~0.5 mm



From J. Am. Ceram. Soc., 93 [10] 3499–3503 (2010)

•In this lecture summary we explore in somewhat more detail the properties of the individual phases within composites.

•For the reinforcing phase we will concentrate on fibres and there are a wide range of fibres available.

•The defining feature is the high strength under axial loading of this phase.

•We will consider different matrix materials, highlighting common features between different matrix materials.

•It is important to appreciate how the properties of each phase contribute to the overall performance of the composite and moreover how each phase can complement the other.

•For example, if we consider the fibre phase this phase comprises materials that, on their own, are usually very brittle.

•Glass fibres contain many surface flaws that act as sites for crack propagation. Surface flaws arise from mechanical damage from handling. When glass fibres are embedded within a ductile matrix material, the matrix “protects” the fibre from surface damage.

•Fibre materials are grouped according to diameter; whiskers such as silicon carbide and fibres and wires such as carbon and aluminium oxide.

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Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

Fibre Materials

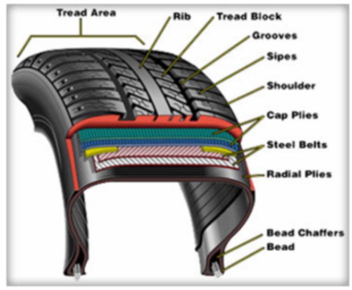
Fibres, polycrystalline or amorphous.

Generally polymers:

Carbon, UHMWPE, Aramid

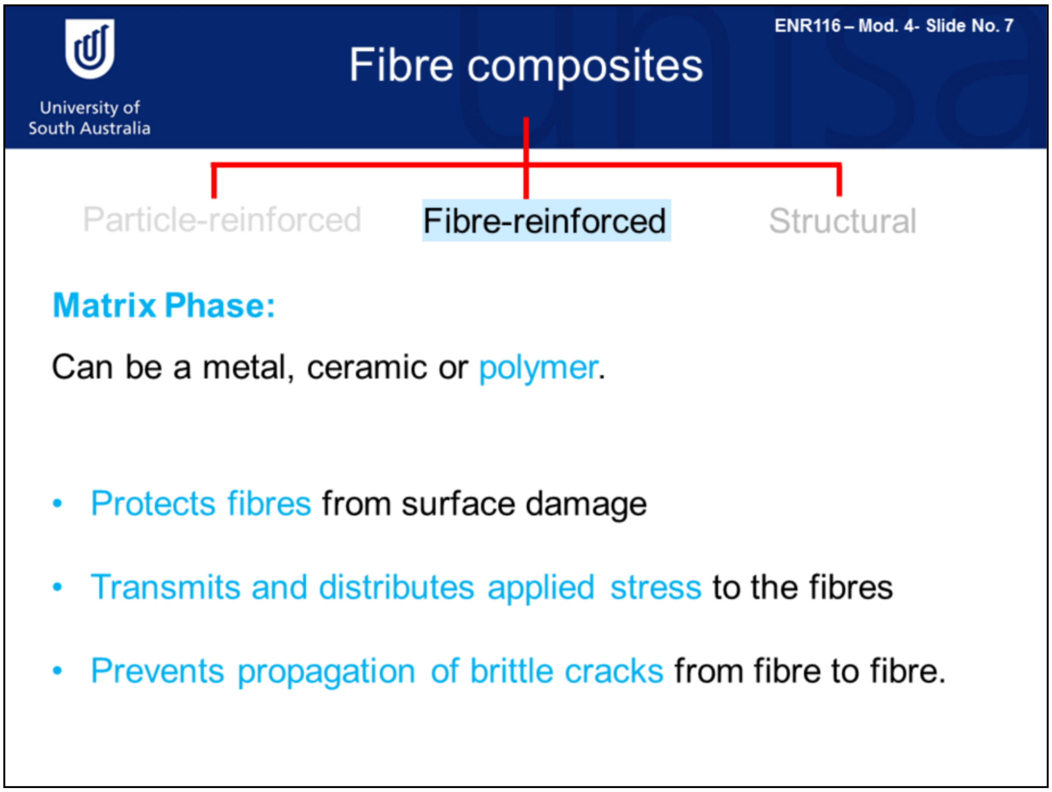
Or ceramics:

E-glass, Boron



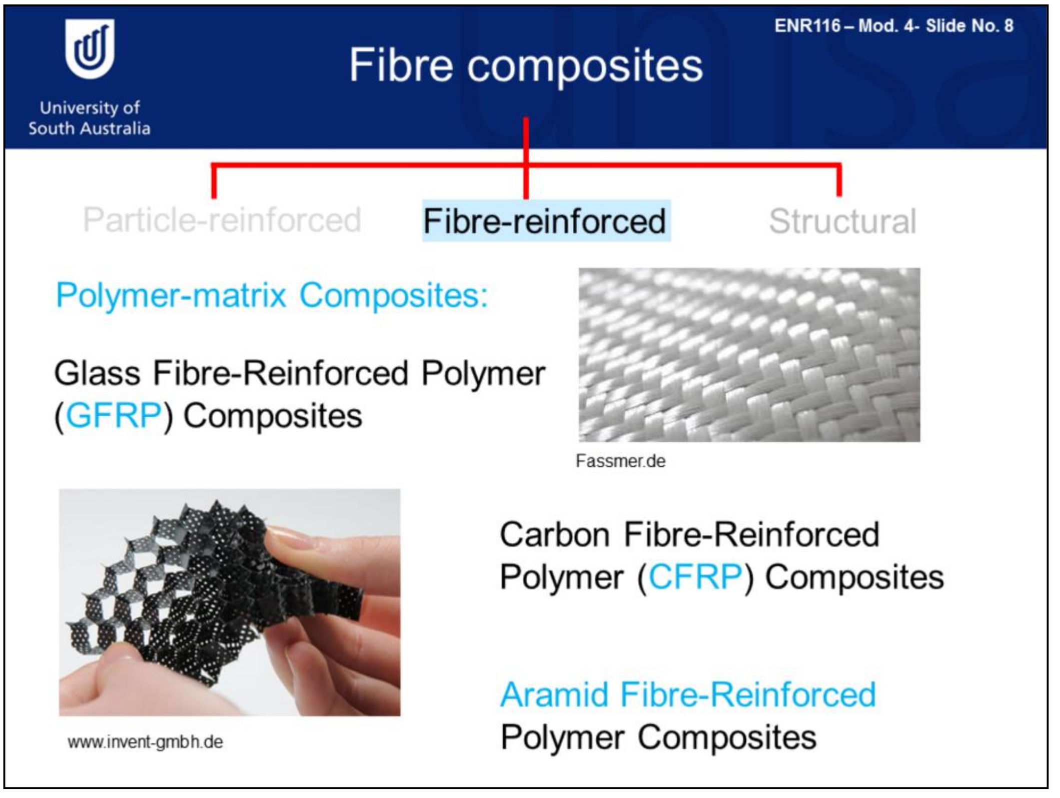
metals

- Here we can appreciate the range of material types used as the reinforcing fibre in the composite material.
- Whilst most are polymers such as carbon, ultra high molecular weight polyethylene and aramid, aromatic polyamides or ceramics, such as E-glass pictured her metals such as steel and tungsten can also be used in composite fabrication i.e. automotive tyres.



•For fibre-reinforced composites the matrix phase can be any of the traditional materials types; metal, ceramic or polymer but generally by far the most common are those with a polymeric matrix.

•Here the matrix phase is ductile protecting the brittle glass- or polymer-based dispersed reinforcing phase added to improve strength (all materials) but fibres can also improve fracture toughness.



•The three typical fibre-reinforced polymer matrix composites then are GFRP, CFRP and the aramid fibre-reinforced polymer composites.

Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

GFRP Composites:

Consist of glass fibres within a polymer matrix.

Either continuous or discontinuous.

GFRP Drawbacks:

- Not very stiff
- Low service temperatures (< 200°C).
- Adhesion between the fibre and resin often poor

•Glass Fibre Reinforced Composites are the most widely employed.

•GFRP or ‘fibreglass’ composites are the traditional composite material used where strength and toughness are required in a lightweight material.

•Many examples have been developed over the years such as the classic fibreglass boat pictured and these have used both continuous and discontinuous fibres.

•Whilst widely utilised there are drawbacks that can arise including the following:

•These composites are not very stiff and are unsuitable for use in applications where some flexibility (give) in the structure is required.

•Most polymer resins are restricted to low service temperatures below 200 degrees C.

•Adhesion between the fibre and resin is often poor and the interface can be susceptible to environmental attack.

ENR116 – Mod. 4- Slide No. 10

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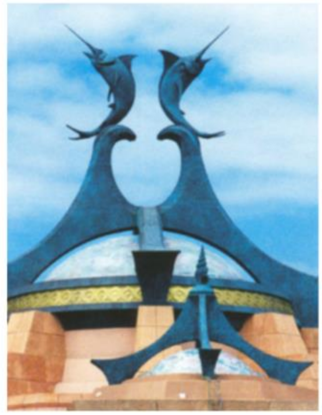
Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

GFRP Advantages

- Easy to draw glass fibres
- Broad range of applications
- Very high specific strength.
- Can be used in corrosive environments (ie. high UV)
- Adhesion promoters offer some control over failure modes



www.strombergarchitectural.com

•There are several advantages to glass-fibre reinforced composites.

•It’s easy to draw glass fibres from the molten charge using processing that is widespread and economical and these can have very high strengths.

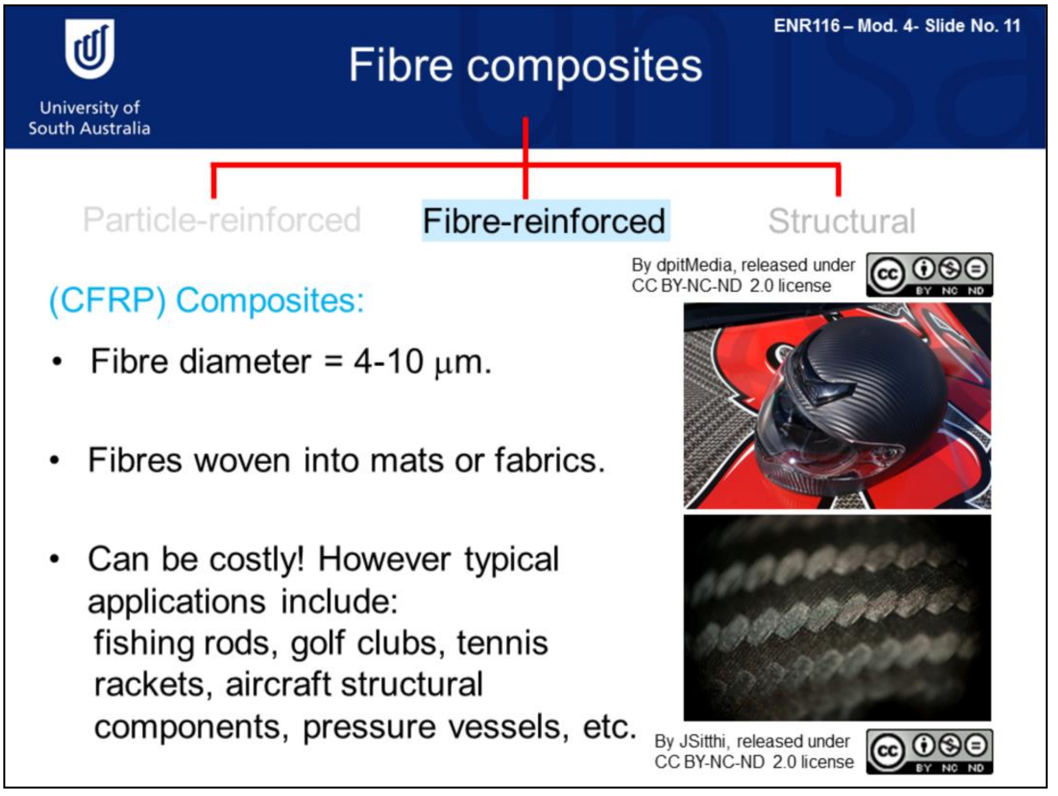
•In more recent times these polymer matrix composites have found a broader range of applications such as the construction of lightweight ornamental features as pictured here.

•In this example not only has the composite a comparatively high strength to weight ratio it also withstands environmental weathering well. The colouration, being incorporated into the polymer matrix, helps offset UV-initiated degradation and is low maintenance in that it does not required regular repainting.

•It is necessary to treat freshly prepared fibre surfaces with a coating known as a sizing to protect the fibres during handling; this reduces the surface damage to the fibres.

•Prior to bonding with the resin the sizing is removed and the fibres coated with an adhesion promoter.

•This allows tailoring the strength of the bond between the fibre and resin and can be used to control failure modes with GFRP’s.

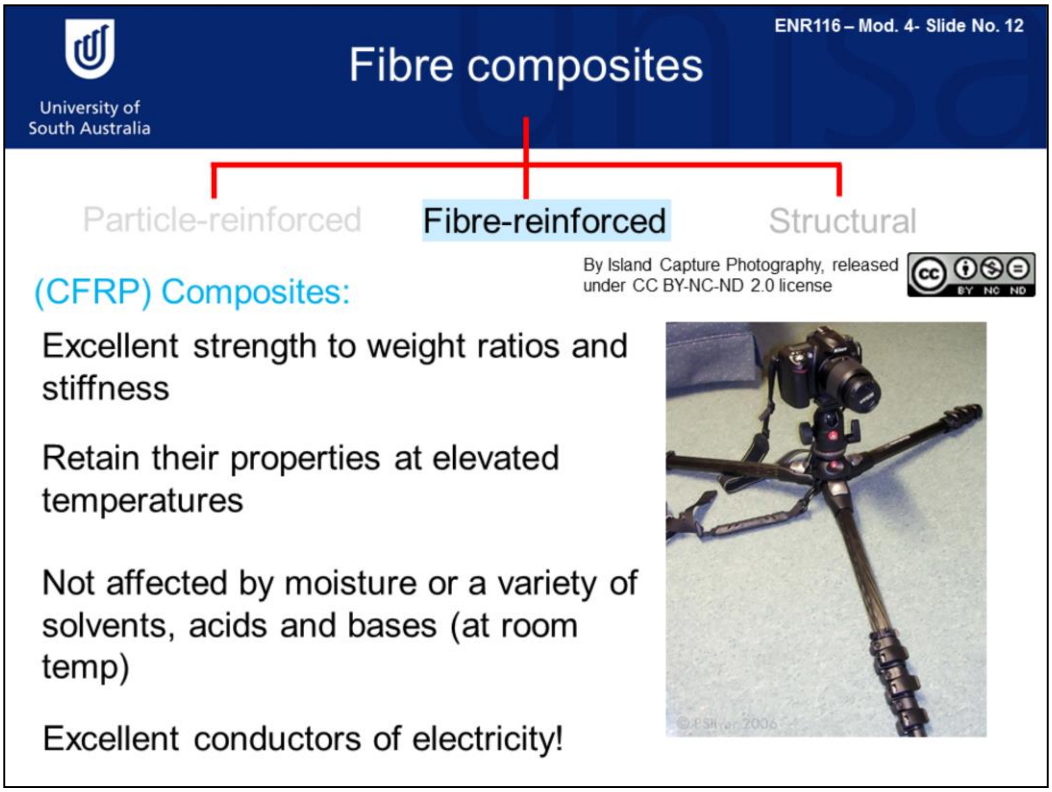


•In more recent times carbon fibre composites have been developed.

•These carbon fibres, manufactured from a number of different precursors have fibre diameters of a few micrometres.

•The fibres are woven into threads to form mats and fabrics similar to woven clothing. The threads can comprise of many thousands of fibres.

•The fabrication and processing costs are generally more expensive than the corresponding glass-fibre composites although the differences are continually being reduced.



•Given the price premium carbon fibre composites initially found applications in high performance situations where the excellent strength to weight ratios and stiffness overcame issues of cost.

•The applications are now more widespread as processing costs have fallen; particularly in the manufacture of sporting goods.

•As an aside, one of the popular uses has been in the fabrication of fishing rods where greater lengths of rod can be made without a corresponding increase in weight compared to other materials. Certainly an excellent advantage but with an unexpected and unwelcome disadvantage; carbon fibres are excellent conductors of electricity and care should be taken when using them close to power lines.

ENR116 – Mod. 4- Slide No. 13

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Fibre composites

Particle-reinforced | **Fibre-reinforced** | Structural

(AFRP) Composites:

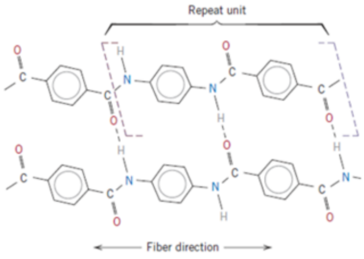
Outstanding strength to weight ratios

Retain their properties between –200˚C and +200˚C

Chains aligned in the fibre direction

Matrix materials are polyesters and vinyl esters

poly(paraphenylene terephthalamide)



Adapted from Fig. 16.10, *Callister & Rethwisch 8e.*

- •Aramid fibres were first introduced in the 1970's.
- •There are several tradenames now on the market.
- •Routes of production differ and in fact in the 1980's these were the subject of expensive court cases between chemical giants that had their own proprietary methods of production but in all cases the repeat unit is parphenylene terephthalamide.
- •These composites have outstanding strength to weight ratios (superior to metals).
- •They retain their high mechanical properties is between minus 200 to plus 200 degrees C.
- •Individual molecular chains are aligned in the fibre direction and there is strong interchain hydrogen bonding.
- •For polymers the most widely employed resins are polyesters and vinyl esters; these are cheap and have relatively low upper-ceiling service temperatures.
- •For high temperature application, polyimides can be used (up to 230 deg C). Epoxies are also used with an often enhanced performance but these are more expensive.
- •The most noteworthy applications are the bullet proof Kevlar vests. Kevlar being a registered trademark of the Du Pont company.

ENR116 – Mod. 4- Slide No. 14

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Metal-Matrix composites

Matrix metals:

www.metpreg.com

- High operating temperatures
- Not flammable, resistant to chemicals
- Applications in engine components and the aerospace industry.
- Used with continuous fibre materials (B, C, SiC, Al_2O_3) and discontinuous reinforcements (SiC whiskers, chopped fibres of Al_2O_3 and C, and particulates of SiC and Al_2O_3)

•Metal matrix composites are not as common as polymer matrix composites. However, they offer advantages of high operating temperature, are not flammable and are more resistant to chemicals.

•Therefore, despite the greater cost these find application in high performance engineering applications.

•The general principle of reinforcement is the same as polymers with continuous and discontinuous fibres and whiskers being used as the filler materials.

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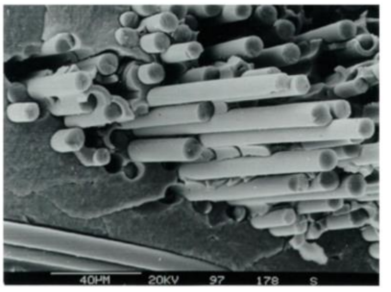
Ceramic-Matrix composites

Ceramic composites:

- High temperature resistance
- Resist oxidation and/or corrosion
- Ceramic-matrix composite materials have improved fracture properties over traditional ceramics

SiC fibres in a SiC matrix



https://commons.wikimedia.org

- Ceramic particles (fibres or whiskers) arrest crack propagation
- Expensive due to relatively complex processing

•Ceramic materials are not temperature sensitive compared with the polymer and some metal matrix materials.

•Neither are they prone to oxidation and/or corrosion.

•If it were not for their inherent brittleness they would be much more widely employed in advanced engineering applications.

•Where the high temperature resistance of a ceramic is required, for example in automotive or aerospace engines, inherent brittleness is mitigated by addition of a filler (fibre or particulate) that impacts on the fracture toughness.

•Generally, the reinforcing material is another ceramic as there are the only materials that have a like temp resistance!

•Ceramic-matrix composite materials have improved fracture properties. The embedded ceramic particles, in the form of fibres or whiskers, serve to arrest crack propagation.

•Whilst increasing the fibre volume fraction will gain greater improvements in strength and toughness the fibres and the composite fabrication costs are high. For this reason these materials find application in high value products within the automotive and aerospace industries.

ENR116 – Mod. 4- Slide No. 16

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Hybrid composites

Hybrid composites have two or more different particulate are dispersed throughout the matrix.

Matrix can be metal, ceramic or polymer

Example: Carbon and glass fibres incorporated in a polymeric resin

•An interesting variation on composites are those termed hybrid. Here two or more types of particulate are dispersed throughout the matrix.

•This matrix can be a metal, ceramic or polymer but we will generally just consider the case of a polymer matrix with two fibre types as the dispersed phase.

•Here the matrix phase is ductile and the carbon and glass fibres act as a reinforcing phase to improve the strength. Two fibre types are selected based on economic considerations since, although the carbon fibres have superior strength and stiffness to the glass fibres they are significantly more expensive.

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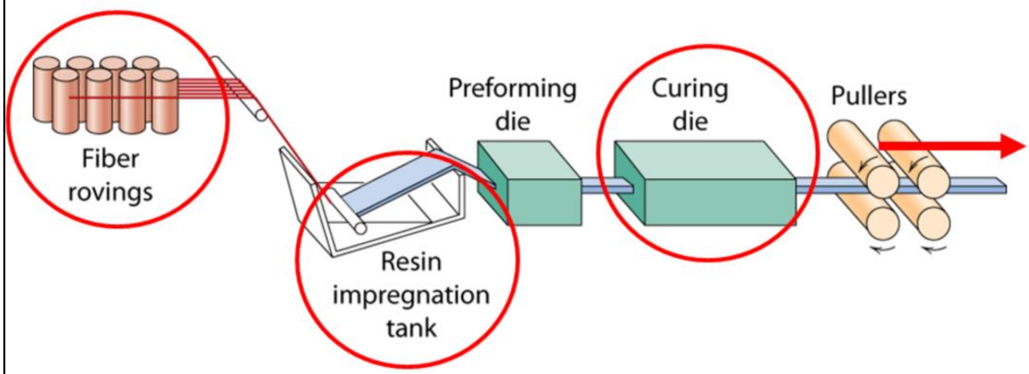
Composite production methods

Pultrusion:



Rods, tubes, beams, etc.

Adapted from Fig. 16.13, *Callister & Rethwisch 8e.*

•It is outside the scope of this introduction to cover all the methods by which the various classes of composites i.e. polymer-, metal- and ceramic-matrix can be fabricated.

•Therefore we will focus on the most widely employed composite material the continuous fibre-reinforced plastic and explore 3 ways in which these composites are manufactured and in support there are a number of web-based resources showing these fabrication techniques in greater detail for you to view at the completion of this lecture summary.

•The first fabrication technique is that of pultrusion. Here the continuous fibres are pulled through a resin tank containing a liquid form of the matrix.

•From here the material passes through a die to shape the composite before passing through an oven to cure and set the matrix.

•Pultrusion is a highly automated fabrication process used for components such as rods and beams.

ENR116 – Mod. 4- Slide No. 18

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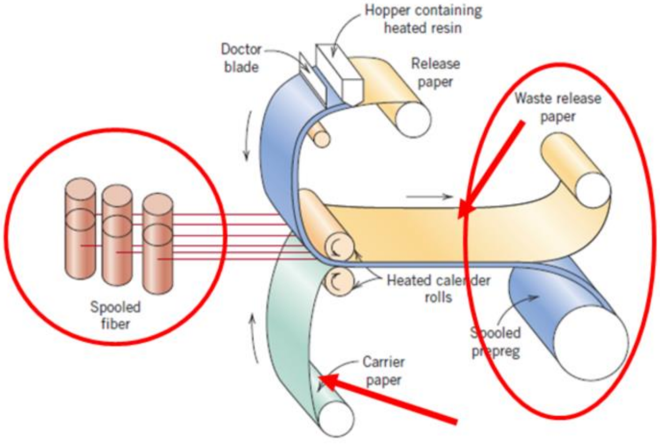
Composite production methods

Prepreg:

Industry term for continuous fibre reinforcement pre-impregnated with a polymer resin



Adapted from Fig. 16.14, *Callister & Rethwisch 8e.*

•The key points here are that prepreg is industry’s terminology for the continuous fibre reinforcement pre-impregnated with a polymer resin.

•This polymer resin is only partially cured and can be formed as a flat shape during production.

•Customers can then form more complex shapes which are then final cured, generally with additional heat.

•The processes starts with spool wound continuous fibre tows. The tows are pulled and sandwiched sheets of release and carrier paper pinched between hot rollers.

•The release paper carries a thin film of heated resin which is used to impregnate the fibre tow.

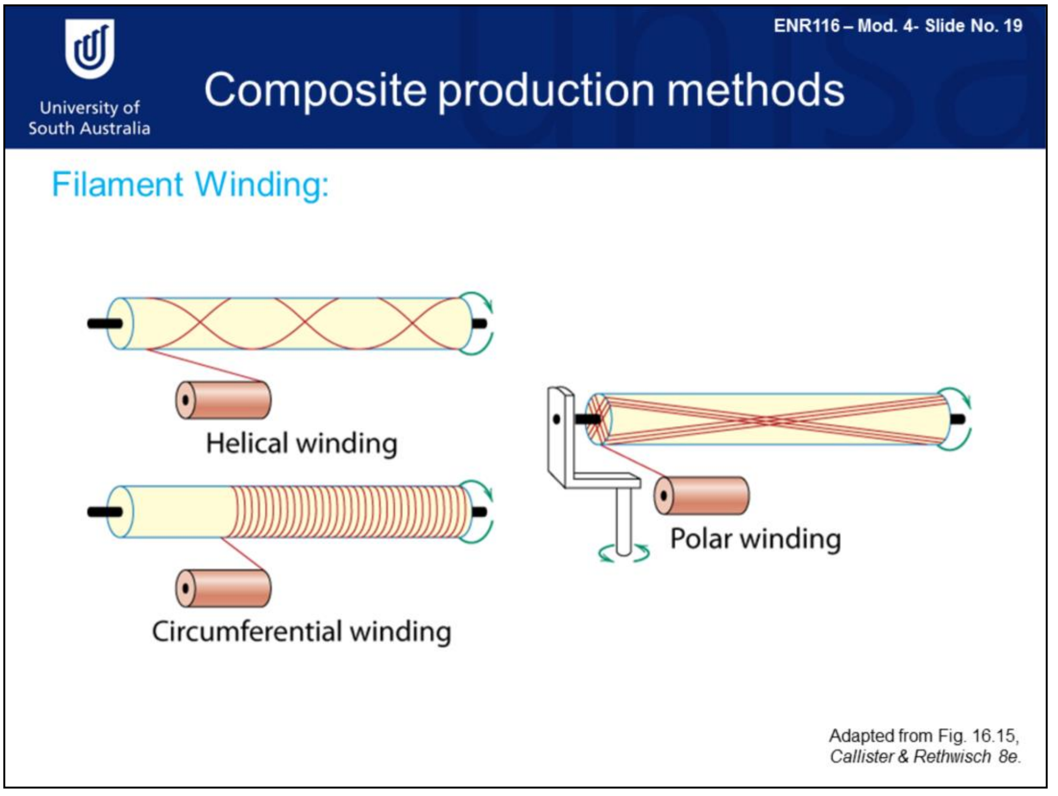
•The carrier paper forms part of the sandwich and ensures that the resin is forced in between individual fibres of the tow.

•The carrier paper and tow are then wound onto a spool with the (waste) release paper being separated.

•One problem is the temp at which resin cures, which is room temp. Therefore after production the prepreg is stored under refrigeration.

•The prepreg method is used with glass-, carbon- and aramid fibres.

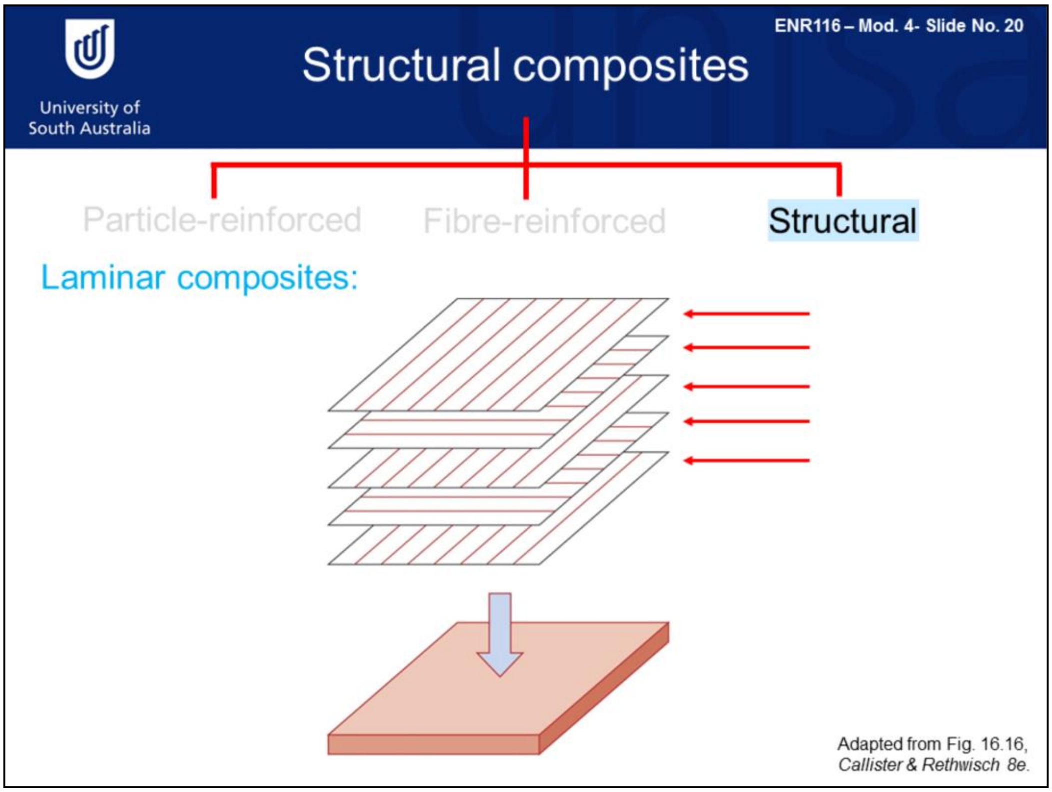
•Composites are fabricated by the lay up method; the simple laying up of the prepregs sheet by sheet having first removed the carrier paper before curing using heat and pressure.



•The final fabrication method we will consider in this lecture summary is that of filament winding.

•This is the method whereby hollow cylindrical components are manufactured.

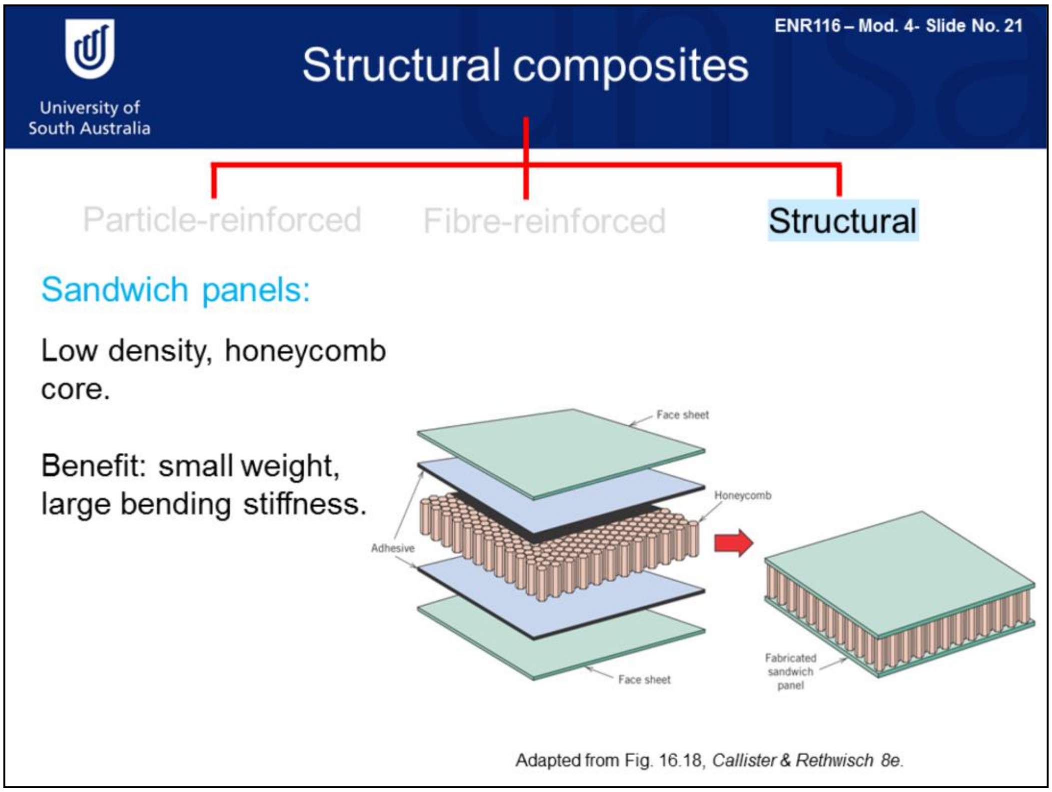
•Certainly in the early days of carbon fibre the applications were high performance and expensive yet today carbon fibre products are becoming more ubiquitous from tripods for video and photography to purely decorative pieces for the home.



•In concluding this lecture summary there is one application for composite materials that remains to be considered; that of structural composites.

•We have already considered these when discussing cement and reinforced concrete however there are a number of laminate composites that are applied in industries such as construction and transportation.

•Laminate composites address the uniaxial mechanical properties of composites; particularly those with continuous fibre fillers by assembling and bonding a layered, laminate structure of sheets serially orientated at right angles to each other.

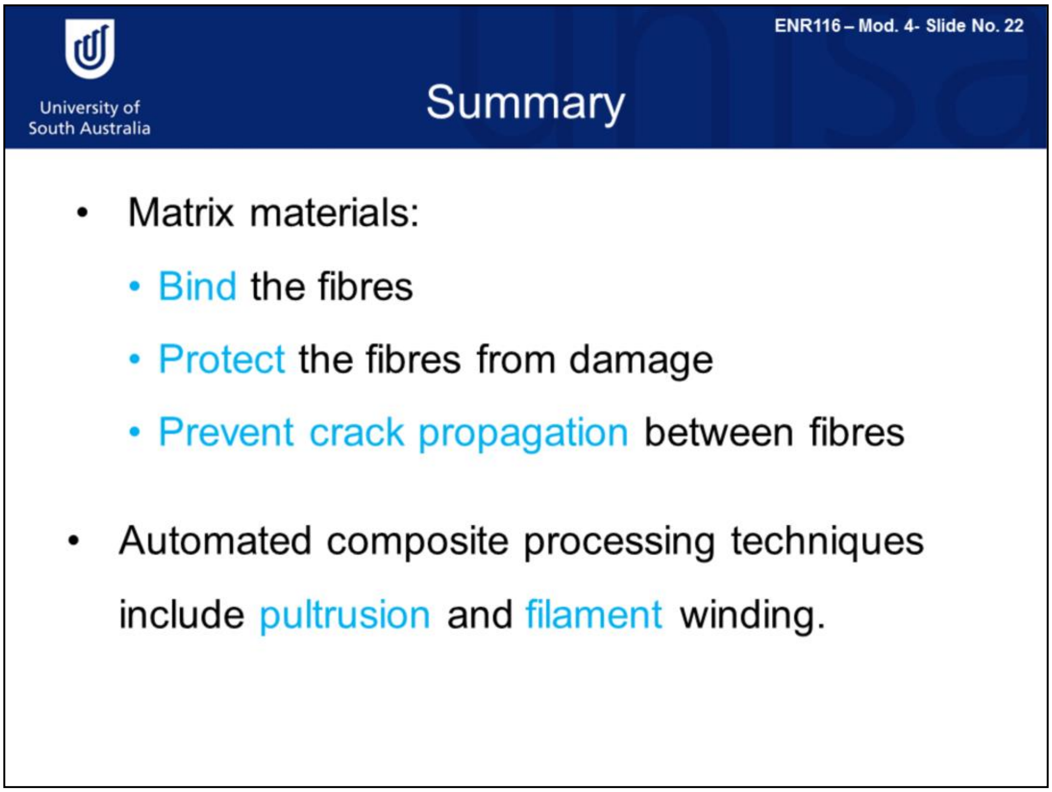


•Since the laminate sheets when assembled are dense an alternative approach is to construct sandwich panels of the composite sheets.

•The sheets face-off a core of lower density material arranged in a honeycomb structure.

•These sheets can then be used in construction for features such as floors and wall cladding.

•The reduced weight of the composites decreasing the buildings structural engineering requirements.



•In summary we can now appreciate that, in composite materials, the role of the matrix material is often one of protection; binding the fibres together, providing a protective coating from damaging environmental conditions and arresting or slowing crack propagation between the brittle fibres.

•As manufacturing methods become more automated the cost of advanced composites such as carbon and aramid fibre based materials is reduced.

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Thank you

If you have any questions or desire further clarification please post a question or comment on the Engineering Materials Discussion Forum.