Module 1: Introduction to Composites

Lecture 2: Reinforcement: Materials and Forms

The Lecture Contains:

Introduction

In the previous lecture we have introduced the composite. Then we have seen the constituents of a typical composite material. Further, based on the reinforcement, the classification of the composite was presented.

In the present lecture we will introduce natural fibres and some advanced fibres. We will see, in brief, the key features of these advanced fibres.

What are the functions of a reinforcing agent?

The functions of a reinforcing agent are:

1. These are the main load carrying constituents.
2. The reinforcing materials, in general, have significantly higher desired properties. Hence, they contribute the desired properties to the composite.
3. It transfers the strength and stiffness to the matrix material.

What are the functions of a matrix material?

The matrix performs various functions. These functions are listed below:

1. The matrix material holds the fibres together.
2. The matrix plays an important role to keep the fibres at desired positions. The desired distribution of the fibres is very important from micromechanical point of view.
3. The matrix keeps the fibres separate from each other so that the mechanical abrasion between them does not occur.
4. It transfers the load uniformly between fibers. Further, in case a fibre is broken or fibre is discontinuous, then it helps to redistribute the load in the vicinity of the break site.
5. It provides protection to fibers from environmental effects.
6. It provides better finish to the final product.
7. The matrix material enhances some of the properties of the resulting material and structural component (that fibre alone is not able to impart). For example, such properties are: transverse strength of a lamina, impact resistance

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What are the types of fibres?

The fibres that are used in the fabrication of a composite can be divided into two broad categories as follows:

A. **Natural fibres** and

B. **Advanced fibres**

A. **Natural fibres**

The natural fibres are divided into following three sub categories.

- ***Animal fibers***: silk, wool, spider silk, sinew, camel hair, etc.
- ***Plant/vegetable fibers***: cotton (seed), jute (stem), hemp (stem), sisal (leaf), ramie, bamboo, maze, sugarcane, banana, kapok, coir, abaca, kenaf, flax, raffia palm, etc.
- ***Mineral fibers***: asbestos, basalt, mineral wool, glass wool.

B. **Natural fibresAdvanced fibers**:

An advanced fibre is defined as a fibre which has a high specific stiffness (that is, ratio of Young's modulus to the density of the material, E/ρ) and a high specific strength (that is the ratio of ultimate strength to the density of the material, σ_{ult}/ρ).

What are the advanced fibres?

The fibres made from following materials are the advanced fibres.

1. Carbon and/or Graphite
2. Glass fibers
3. Alumina
4. Aramid
5. Silicon carbide
6. Sapphire

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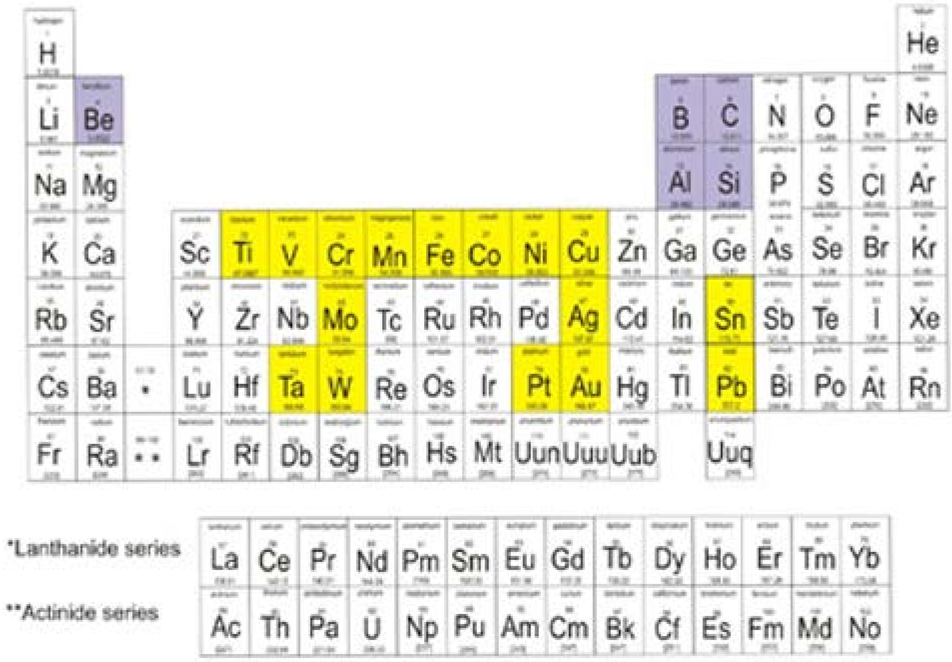

Figure 1.6: Periodic Table showing the materials used in advanced composites (blue blocks) and conventinal metals (yellow blocks)

Figure 1.6 shows the periodic table. The conventional metals are shown in yellow colour whereas the materials of the advanced fibres are shown in blue colour. It can be seen that the materials of the advanced fibres are lighter than the conventional metals. These materials occupy higher position as compared to metals in the periodic table. Thus, one can easily deduce that, in general, these materials have higher specific properties (property per unit weight) than that of metals.

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Boron Fiber

This fibre was first introduced by Talley in 1959 [15]. In commercial production of boron fibres, the method of Chemical Vapour Deposition (CVD) is used. The CVD is a process in which one material is deposited onto a substrate to produce near theoretical density and small grain size for the deposited material. In CVD the material is deposited on a thin filament. The material grows on this substrate and produces a thicker filament. The size of the final filament is such that it could not be produced by drawing or other conventional methods of producing fibres. It is the fine and dense structure of the deposited material which determines the strength and modulus of the fibre.

In the fabrication of boron fibre by CVD, the boron trichloride is mixed with hydrogen and boron is deposited according to the reaction

$$2BCl_3(g) + 3H_2(g) \rightarrow 2B(s) + 6HCl(g)$$

In the process, the passage takes place for couple of minutes. During this process, the atoms diffuse into tungsten core to produce the complete boridization and the production of WB_4 and W_2B_5. In the beginning the tungsten fibre of 12 μm diameter is used, which increases to 12 μm. This step induces significant residual stresses in the fibre. The core is subjected to compression and the neighbouring boron mantle is subjected to tension.

The CVD method for boron fibres is shown in Figure 1.7.

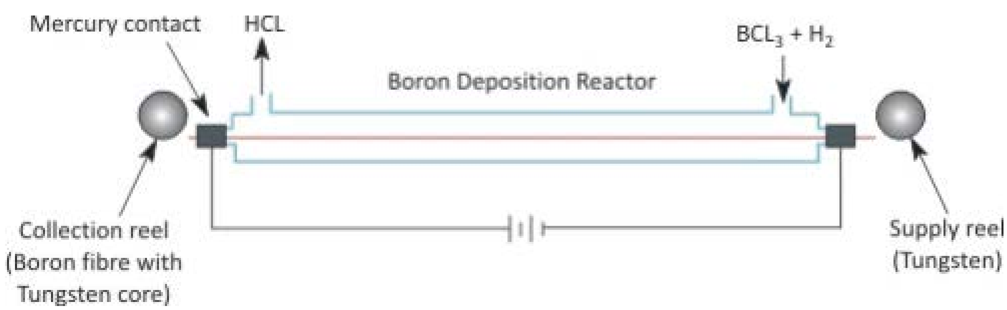

Figure 1.7: Schematic of reactors for silicon carbide fibres by Chemical Vapour Deposition

The key features of this fibre are listed below:

- These are ceramic monofilament fiber.
- Fiber itself is a composite.
- Circular cross section.
- Fiber diameter ranges between 33-400 μm and typical diameter is 140 μm.
- Boron is brittle hence large diameter results in lower flexibility.
- Thermal coefficient mismatch between boron and tungsten results in thermal residual stresses during fabrication cool down to room temperature.
- Boron fibres are usually coated with SiC or B_4C so that it protects the surface during contact with molten metal when it is used to reinforce light alloys. Further, it avoids the chemical reaction between the molten metal and fibre.
- Strong in both tension and compression.

- Exhibits linear axial stress-strain relationship up to 650°C.
- Since this fibre requires a specialized procedure for fabrication, the cost of production is relatively high.

The boron fibre structure and its composite is elucidated in Figure 1.8.

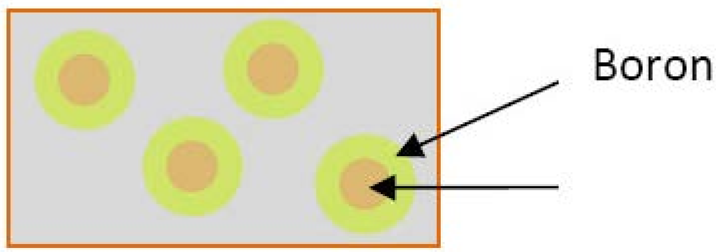

Figure 1.8: Boron fibre structure and its composite

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Carbon Fiber:

The first carbon fibre for commercial use was fabricated by Thomas Edison.

- Sixth lightest element and carbon - carbon covalent bond is the strongest in nature.
- Edison made carbon fiber from bamboo fibers.
- Bamboo fiber is made up of cellulose.
- Precursor fiber is carbonized rather than melting.
- Filaments are made by controlled pyrolysis (chemical deposition by heat) of a precursor material in fiber form by heat treatment at temperature of 1000-3000 $^{\circ}C$
- The carbon content in carbon fibers is about 80-90 % and in Graphite fibers the carbon content is in excess of 99%. Carbon fibre is produced at about 1300$^{\circ}C$ while the graphite fibre is produced in excess of 1900 $^{\circ}C$.
- The carbon fibers become graphitized by heat treatment at temperature above 1800 $^{\circ}C$.
- “Carbon fibers” term is used for both carbon fibers and graphite fibers.
- Different fibers have different morphology, origin, size and shape.
- The size of individual filament ranges from 3 to 147 μm .
- Maximum use of temperature of the fibers ranges from 250$^{\circ}C$ to 2000 $^{\circ}C$.
- The use temperature of a composite is controlled by the use temperature of the matrix.
- Precursor materials: There are two types of precursor materials (i) Polyacrylonitrile (PAN) and (ii) rayon pitch, that is, the residue of petroleum refining.
- Fiber properties vary with varying temperature.
- Fiber diameter ranges from 4 to10 μm.
- A tow consists of about 3000 to 30000 filaments.
- Small diameter results in very flexible fiber and can actually be tied in to a knot without breaking the fiber.
- Modulus and strength is controlled by the process. The procedure involves the thermal decomposition of the organic precursor under well controlled conditions of temperature and stress.
- Cross section of fiber is non-circular, in general, it is kidney bean shape.
- Heterogeneous microstructure consisting of numerous lamellar ribbons.
- Morphology is very dependent on the manufacturing process.
- PAN based carbon fibers typically have an onion skin appearance with the basal planes in more or less circular arcs, whereas the morphology of pitch-based fiber is such that the basal planes lie along radial planes. Thus, carbon fibers are anisotropic.

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Glass Fibre

- Fibers of glass are produced by extruding molten glass, at a temperature around 1200$^\circ C$ through holes in a spinneret with diameter of 1 or 2 *mm* and then drawing the filaments to produce fibers having diameters usually between 5 to15 μm.
- The fibres have low modulus but significantly higher stiffness.
- Individual filaments are small in diameters, isotropic and very flexible as the diameter is small.
- The glass fibres come in variety of forms based on silica (SiO_2) which is combined with other elements to create speciality glass.

What are the different types of glass fibres? What are their key features?

The types of glass fibres and their key features are as follows:

- ***E glass*** - high strength and high resistivity.
- ***S_2 glass*** - high strength, modulus and stability under extreme temperature and corrosive environment.
- ***R glass*** – enhanced mechanical properties.
- ***C glass*** - resists corrosion in an acid environment.
- ***D glass*** – good dielectric properties.

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