Module 1: Introduction to Composites

Lecture 3: Reinforcement: Materials

The Lecture Contains:

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Introduction

In this lecture we are going see some more advanced fibres. Further, we will see their key features, applications and fabrication processes.

Alumina Fibre

- These are ceramics fabricated by spinning a slurry mix of alumina particles and additives to form a yarn which is then subjected to controlled heating.
- Fibers retain strength at high temperature.
- It also shows good electrical insulation at high temperatures.
- It has good wear resistance and high hardness.
- The upper continuous use temperature is about 1700 °C .
- Fibers of glass, carbon and alumina are supplied in the form of tows (also called rovings or strands) consisting of many individual continuous fiber filaments.
- Du Pont has developed a commercial grade alumina fibre, known as Alumina FP (polycrystalline alumina) fibre. Alumina FP fibres are compatible with both metal and resin matrices. These fibres have a very high melting point of 2100 °C. They can withstand temperatures up to 1000°C without any loss of strength and stiffness properties at this elevated temperature. They exhibit high compressive strengths, when they are set in a matrix.
- The Alumina whiskers are available and they exhibit excellent properties. Alumina whiskers can have the tensile strength of 20700 MPa and the tensile modulus of 427 GPa.

What are the applications of Alumina fibres?

- The Alumina has a unique combination of low thermal expansion, high thermal conductivity and high compressive strength. The combination of these properties gives good thermal shock resistance. These properties make Alumina suitable for applications in furnace use as crucibles, tubes and thermocouple sheaths.
- The good wear resistance and high hardness properties are harnessed in making the components such as ball valves, piston pumps and deep drawing tools.

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Aramid Fibre

- These fibres are from Aromatic polyamide, that is, nylons family.
- Aramid is derived from “Ar” of Aromatic and “amid” of polyamide.
- Examples of fibres from nylon family: Polyamide 6, that is, nylon 6 and Polyamide 6.6, that is, nylon 6.6
- These are organic fibers.
- Melt-spun from a liquid solution.
- Du Pont developed these fibers under the trade name Kevlar. From poly (p-phenylene terephthalamide (PPTA) polymer.
- Morphology – radially arranged crystalline sheets resulting into anisotropic properties.
- Filament diameter about 12 μm and partially flexible.
- High tensile strength.
- Intermediate modulus.
- Significantly lower strength in compression.
- 5 grades of Kevlar with varying engineering properties are available. Kevlar-29, Kevlar-49, Kevlar-100, Kevlar-119 and Kevlar-129.

Silicon Carbide Fibre (SiC)

Silicon carbide fibres are ceramic fibers. These fibres are produced in similar fashion as boron fibres are produced. The fibres are produced by two methods as follows:

- ***CVD on Tungsten or Carbon Core***
- ***NICALON™ by NIPPON Carbon Japan***

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CVD on Tungsten or Carbon Core:

- This fiber is similar in size and microstructure to boron.
- The fibres are produced on both tungsten and carbon cores.
- These fibres are relativity stiff due to thicker diameter of the fibres. The diameter of the fibres is about 140 μm .
- The fibres have strength in the range of 3.4 – 4.0 GPa.
- Failure strain is in the range of 0.8 - 1%.
- The Young's modulus is about 430 GPa.
- The fibres show high structural stability and strength retention even at temperatures above 1000 $^{\circ}C$.

The CVD with CH_3SiCl_3 as the reactant, SiC is deposited on the core as follows:

$$CH_3SiCl_3(g) \rightarrow SiC(s) + 3HCl(g)$$

- The SiC fibres produced on a tungsten core with a diameter about 12 μm . It shows a thin interfacial layer between the SiC mantle and the tungsten core. In case, when carbon fibre is used the fibre diameter of the carbon fibres is about 33 μm.
- Both type of SiC fibre have smoother surfaces than a boron fibre. This is because there is a deposition of small columnar grains as compared to conical nodules in boron fibres.
- The SiC fibres produced with carbon core are used in light reinforced alloys. These fibres are produced with a surface coating. The composition of this coating varies from carbon rich from inner surface to silicon carbide at the outer surface.
- The fibres that are used to reinforce the titanium have a protective layer which varies from a carbon rich to silicon rich and again to a composition which is rich in carbon at the surface. The outer surface acts as a protective surface and when it comes in contact with molten and highly reactive titanium. The fibres are made by Specialty Materials Inc. under the trade name SCS-6. The coating increases the fibres diameter by 6 μm.
- The fibre has low failure stresses due to surface flaws.
- The higher strength of fibre is due to the controlled defects at the core-mantle interface.
- The strength of SiC fibres produced using CVD is seen to be anisotropic. The radial strength is significantly lower than longitudinal tensile strength.
- When the fibres are heated to above 800 ºC in air for a long period, they lose their strength due to oxidation of the carbon rich outer layers.

The CVD for SiC fibres is shown in Figure 1.9.

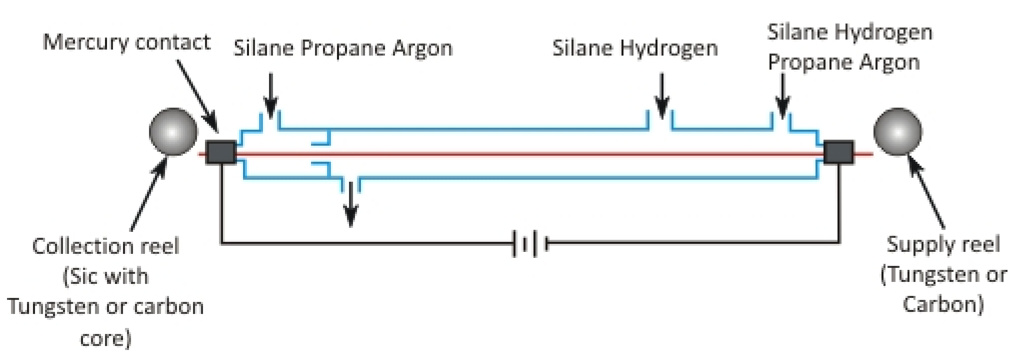

Figure 1.9: Schematic of reactors for silicon carbide fibres by Chemical Vapour Deposition

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NICALON™ by NIPPON Carbon Japan

- The fibres are manufactured by the process of controlled pyrolysis (chemical deposition by heat) of a polymeric precursor.
- The fiber is homogeneously composed of ultrafine beta-SiC crystallites and carbon.
- The filament is similar to carbon fiber in size.
- The diameter of the fibre is about 14 μm
- The fibres more flexible due to small diameter.
- The fibres are arranged in tows of 250 to 500 filaments per tow.
- These fibres come in two grades:
    a. Ceramic Grade: provides good high temperature performance and mechanical properties
    b. High Volume Resistivity Grade: It is a low dielectric fibre. It has good electrical and mechanical properties. These are used in dielectric structures.

Uses of the NICALON™ Fibres

These fibres are used to form fibrous products such as high temperature insulation, filters, etc. These fibres have high resistance to chemical attack. Hence, these can be used in harsh environments.

These are also used as a reinforcement in plastic, ceramic and metal matrix composites.

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Cross Sectional Shapes of Fibres

The cross sectional shapes of fibre of various types we have studied above are different. The cross sectional shape of the fibres, although is assumed to be circular, is not circular in general. The various cross sectional shapes of the fibre are shown in Figure 1.10.

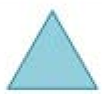
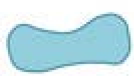
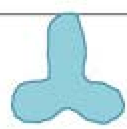
Cross Sectional Shape		Types of fibres
Circular		Glass, Carbon, Organic fibres, Alumina, Silicon Carbide
Elliptical		Alumina, Mulite
Triangular		Silk, Silicon Carbide Whiskers
Hexagonal		Sapphire (Al_2O_3) Whiskers
Rounded triangular		Sapphire (Al_2O_3) single crystal fibre
Kidney bean		Carbon
Trilobal		Carbon, Rayon

Figure 1.10: Cross sectional shapes of fibres

Fiber Properties

The following are the important points regarding the fibre properties.

- Density, axial modulus, axial Poisson's ratio, axial tensile strength and coefficient of thermal expansion are some of the important properties.
- Advanced fibers exhibit a broad range of properties.
- Properties of carbon fiber can vary significantly depending upon fabrication process.
- For the advanced fibres studied above one can attain either ***high modulus*** (> 700 GPa) or ***high strength*** (> 5 GPa) but not both attainable simultaneously.
- SCS-6, IM8, boron and sapphire fibers offer the best combination of stiffness and strength but have large diameters and thus limited flexibility. However, IM8 fibers are exception for flexibility.

- The specific stiffness of some of these fibres is almost 13 times of structural metals.
- Similarly, the specific strength of some of these fibres is almost 16 times of structural metals.
- Weight saving, when the composites of these fibres are used, is tremendous due to high specific stiffness and strength.
- Actual properties of composite (fiber + matrix) are reduced.
- Specific properties are reduced even further when the loading is in a direction other than the length direction of fibers.
- Tailorable properties.
- One can get the desired heat transfer or electrical conductivity with proper designing.
- The increased fatigue resistance is attainable with the use of these fibre composites.
- Aging effect can be significantly lowered.

Note: The fibres are classified based on their values of modulus as follows:

1. Ultra-high-modulus, type UHM (modulus > 450 GPa)
2. High-modulus, type HM (modulus between 350-450 GPa)
3. Intermediate-modulus, type IM (modulus between 200-350 GPa)
4. Low modulus and high-tensile, type HT (modulus < 100 GPa, tensile strength > 3.0 GPa)

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