Module 1: Introduction to Composites

Lecture 4: Matrix Materials

The Lecture Contains:

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Introduction

In the previous lecture we have introduced various advanced fibres along with their fabrication processes, precursor materials and key features. In the present lecture we will introduce some matrix materials, their key features and applications.

What are the matrix materials used in composites?

The matrix materials used in composites can be broadly categorized as: Polymers, Metals, Ceramics and Carbon and Graphite.

The polymeric matrix materials are further divided into:

1. Thermoplastic – which soften upon heating and can be reshaped with heat and pressure.
2. Thermoset – which become cross linked during fabrication and does not soften upon reheating.

The metal matrix materials are: Aluminum, Copper and Titanium.

The ceramic materials are: Carbon, Silicon carbide, Silicon nitride.

The classification of matrix materials is shown in Figure 1.11.

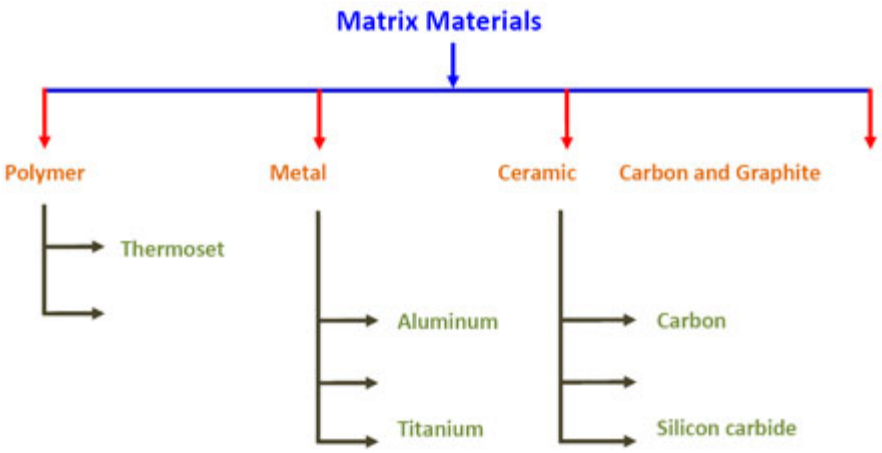

Figure 1.11: Matrix materials

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What are the thermoplastic matrix materials? What are their key features?

The following are the thermoplastic materials:

1. polypropylene,
2. polyvinyl chloride,
3. nylon,
4. polyurethane,
5. poly-ether-ether ketone (PEEK),
6. polyphenylene sulfide (PPS),
7. polysulpone.

The key features of the thermoplastic matrix materials are:

1. higher toughness
2. high volume
3. low cost processing
4. The use temperature range is upto 225 ^{o}C .

What are the thermoset matrix materials? What are their key features?

The thermoset matrix materials are:

1. polyesters,
2. epoxies,
3. polyimides

The key features of these materials are given for individual material in the following.

Polyesters

1. Used extensively with glass fibers
2. Inexpensive
3. Light weight
4. Temperature range upto 100 ^{o}C.
5. Resistant to environmental exposures

Epoxy

1. Expensive
2. Better moisture resistance
3. Lower shrinkage on curing
4. Use temperature is about 175 ^{o}C

Polyimide

1. Higher use temperature about 300 ^{o}C
2. Difficult to fabricate

What are the problems with the use of polymer matrix materials?

1. Limited temperature range.
2. Susceptibility to environmental degradation due to moisture, radiation, atomic oxygen (in space)
3. Low transverse strength.
4. High residual stress due to large mismatch in coefficients of thermal expansion between fiber and matrix.
5. Polymer matrix cannot be used near or above the glass transition temperature.

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Comparison between Thermoplastics and Thermosets:

The comparison between the thermoplastic and thermoset matrix materials is given in Table 1 below:

Table 1.1: Comparison between thermoplastics and thermosets.

Thermoplastics	Thermosets
Soften upon heat and pressure	Decompose upon heating
Hence, can be repaired	Difficult to repair
High strains are required for failure	Low strains are required for failure
Can be re-processed	Can not be re-processed
Indefinite shelf life	Limited shelf life
Short curing cycles	Long curing cycles
Non tacky and easy to handle	Tacky and therefore, difficult to handle
Excellent resistance to solvents	Fair resistance to solvents
Higher processing temperature is required. Hence, viscosities make the processing difficult.	Lower processing temperature is required.

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What are the common metals used as matrix materials? What are their advantages and disadvantages?

The common metals used as matrix materials are aluminum, titanium and copper.

Advantages:

1. Higher transfer strength,
2. High toughness (in contrast with brittle behavior of polymers and ceramics)
3. The absence of moisture and
4. High thermal conductivity (copper and aluminum).

Dis-advantages:

1. Heavier
2. More susceptible to interface degradation at the fiber/matrix interface and
3. Corrosion is a major problem for the metals

The attractive feature of the metal matrix composites is the higher temperature use. The aluminum matrix composite can be used in the temperature range upward of 300ºC while the titanium matrix composites can be used above 800 ºC.

What are the ceramic matrix materials? What are their advantages and disadvantages?

The carbon, silicon carbide and silicon nitride are ceramics and used as matrix materials.

***Ceramic*:**

The advantages of the ceramic matrix materials are:

1. The ceramic composites have very high temperature range of above 2000 ºC .
2. High elastic modulus
3. Low density

The disadvantages of the ceramic matrix materials are:

1. The ceramics are very brittle in nature.
2. Hence, they are susceptible to flows.

Carbon

The advantages of the carbon matrix materials are:

1. High temperature at 2200 ºC.
2. Carbon/carbon bond is stronger at elevated temperature than room temperature.

The disadvantages of the carbon matrix materials are:

1. The fabrication is expensive.

2. The multistage processing results in complexity and higher additional cost.

It should be noted that a composite with carbon fibres as reinforcement as well as matrix material is known as ***carbon-carbon composite***. The application of carbon-carbon composite is seen in leading edge of the space shuttle where the high temperature resistance is required. The carbon-carbon composites can resist the temperatures upto 3000°C .

The advantages of these composites are:

1. Very strong and light as compared to graphite fibre alone.
2. Low density.
3. Excellent tensile and compressive strength.
4. Low thermal conductivity.
5. High fatigue resistance.
6. High coefficient of friction.

The disadvantages include:

1. Susceptible to oxidation at elevated temperatures.
2. High material and production cost.
3. Low shear strength.

Figure 1.12 depicts the range of use temperature for matrix material in composites. It should be noted that for the structural applications the maximum use temperature is a critical parameter. This maximum temperature depends upon the maximum use temperature of the matrix materials.

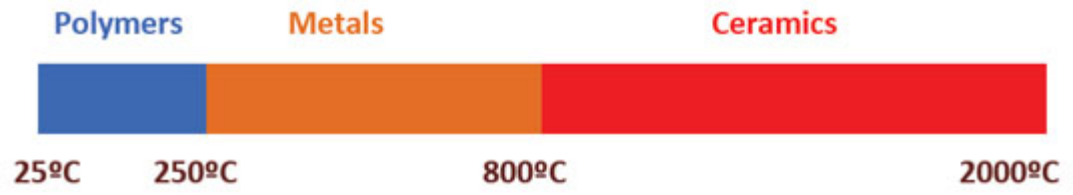

Figure 1.12: Range of use temperature for matrix materials in composites

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What are the different forms of composites?

1. ***Unidirectional lamina***:
   - It is basic form of continuous fiber composites.
   - A lamina is also called by *ply* or *layer*.
   - Fibers are in same direction.
   - Orthotropic in nature with different properties in principal material directions.
   - For sufficient number of filaments (or layers) in the thickness direction, the effective properties in the transverse plane (perpendicular to the fibers) may be isotropic. Such a composite is called as transversely isotropic.
2. ***Woven fabrics***:
   - Examples of woven fabric are clothes, baskets, hats, etc.
   - Flexible fibers such as glass, carbon, aramid can be woven in to cloth fabric, can be impregnated with a matrix material.
   - Different patterns of weaving are shown in Figure 1.13.

   Typical weaving patterns are shown in Figure 1.13.

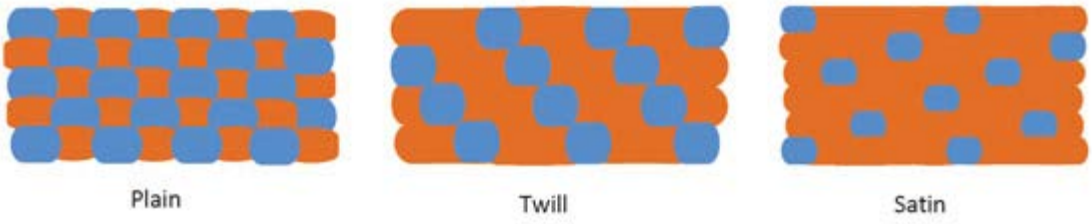

Figure 1.13: Types of weave

3. ***Laminate***:
   1. Stacking of unidirectional or woven fabric layers at different fiber orientations.
   2. Effective properties vary with:
      1. orientation
      2. thickness
      3. stacking sequence

   A symmetric laminate is shown in Figure 1.14.

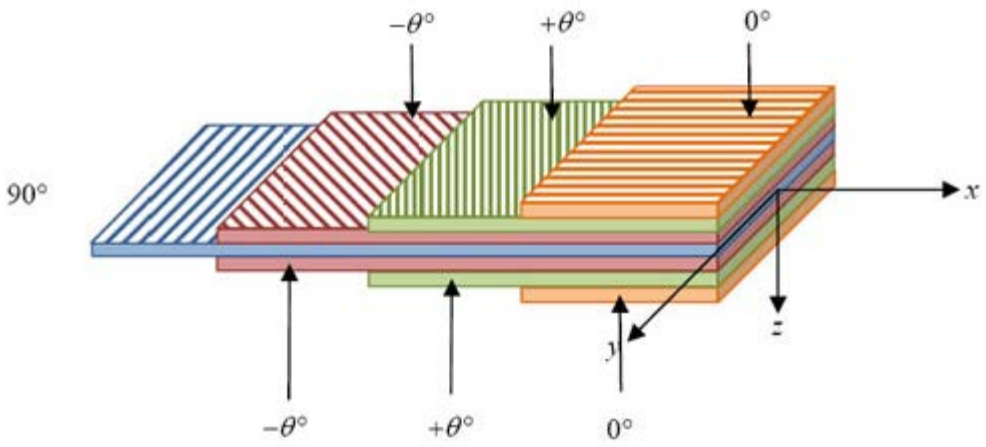

Figure 1.14: A symmetric laminate

4. ***Hybrid composites***:

The hybrid composite are composites in which two or more types of fibres are used. Collectively, these are called as *hybrids*. The use of two or more fibres allows the combination of desired properties from the fibres. For example, combination of aramid and carbon fibres gives excellent tensile properties of aramid and compressive properties of carbon fibers. Further, the aramid fibres are less expensive as compared to carbon fibres.

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What are the factors that affect the composite properties?

There are various factors upon which the properties of the composite depend. Following are the various factors:

1. Properties of the constituent materials. Apart from this, the properties of other phases present, like additives, fillers and other reaction phases also affect the properties of the composite.
2. Length of the fibre.
3. Orientation of the fibres (with respect to the loading direction).
4. Cross sectional shape of the fibre.
5. Distribution and arrangement of the fibres in the matrix material.
6. Proportions of the fibre and matrix material, that is, volume fractions of the constituent materials.

Notation for Composite Designation:

The composites are designated by the combination of the fibre and matrix system. The fibre and matrix materials are separated by a slash $(/)$, that is, ***fibre material/matrix material*.** Further, one needs to specify the volume fractions of the constituents. In general, the fibre volume fraction is specified. For example: AS4/PEEK, $v_f = 45\%$, that is, a carbon composite with AS4 fibres and PEEK as the matrix material with fibre volume fraction of 45%. Other examples are: T300/5208, T700/M21, Kevlar/Epoxy, Boron/Al, SCS-6/Ti-15-3, S_2 Glass/Epoxy.

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