Chapter 5
Micromechanical and Finite Element Modeling for Composites

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ABSTRACT

The major areas of applications of the composite materials today encompass fields as wide as wind energy to marine to construction to aerospace to strategic areas. Apart from such specialized fields the major composite market blooms out of their extensive exploitations in the automotive, sporting goods, pipes, tanks, chemicals, fertilizers and many other industries. As compared to the conventional materials, the composites offer several unique advantages. The list of such advantages may include as a typical example the higher tensile strength, the lighter weight, the greater corrosion resistance, the better surface finish and the easier processability. It is interesting to note that in 2011, the global composite materials market size was $19.6 billion and the same is estimated now to reach approximately $34.1 billion in 2018. This amounts to a Compounded Annual Growth Rate (CAGR) of about 10.5% percent. This huge market growth of composites will require a thorough knowledge of the mechanics and mechanical properties of a wide variety of composites under a still wider variety of application dependent constraints. That is why, just to make an humble beginning in this direction, the basics of the composite materials and it's varieties, are briefly described in this Chapter. In addition, the analytical methods of continuum micromechanics have been touched upon. Keeping in view the complex microstructure of most of the composites, and the effect that such complexities can have in the resultant properties, the numerical approaches to continuum micromechanics has been highlighted with emphasis on the fundamentals of the Finite Element Analysis (FEA) based methods. Further, the concepts involved in modelling of the "Failure of composites" have been elucidated with some interesting case studies.

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1. MICROMECHANICS OF COMPOSITES

1.1 Basics of Composite Materials

A composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. The most obvious question that comes to the mind in this context is what the typical kinds of man-made composites are. Today, the most common man-made composites can be divided into three main categories:

1. **Metal Matrix Composites (MMC's):** These composites are being increasingly used in the automotive industry. For instance these materials can use a light metal such as aluminium as the matrix, and reinforce it with fibres or particulates such as silicon carbide particles or fibers.
2. **Ceramic Matrix Composites (CMC's):** These materials are meant for use in very high hrash environments e.g., highly corrosive atmosphere, high or very high temperature, high strain rate impact resistant applications, ultra high load, ultra high temperature oxidative environments etc. These materials use a ceramic as the matrix and reinforce it with particles such as aluminium nitride or silicon carbide or zirconia or short/long fibres, or whiskers such as those of alumina, silicon carbide and boron nitride.
3. **Polymer Matrix Composites (PMC's):** These materials represent the most common type of composites. These materials are also known as FRP - Fibre Reinforced Polymers. Contrary to the case of MMCs and CMCs, these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon, aramid and natural fibres as the reinforcement. The major reason for use of FMC is weight saving. They offer high relative stiffness and strength. For instance, it may be noted that the carbon fibre reinforced polymer composite (CFRP) may be five times as strong as the SS1020 while it has weight one fifth that of the weight of SS1020. Similarly, CFRP has modulus twice as high and strength seven times as high as that of Al6061.

1.2 Basics of Micromechanics

Taken literally, micromechanics refer to mechanics of materials effects at the micrometer scale length. Usually however the term is used more broadly as representing effects at scales somewhat larger than the nano-scale size but much smaller than the macroscopic size. They may center on the micron scale but they can also reach up and down considerably from that size. Micromechanics certainly offer an appealing look at basic effects at intermediate length scales.

Thus, the basic aim of the subject field of "Micromechanics of Composites" is to determine the unknown properties of the composite based on the known properties of the reinforcement phase and the matrix phase. Many of the problems of special interest in the micromechanics domain are related to inclusions that are dispersed into an otherwise continuous phase. Doing this mixing at or near the micron scale affords an enormous variety of materials combinations that can yield a huge array of enhanced properties. When done properly, the combinations can achieve the best attributes of the constituents. When done casually or carelessly it almost always degenerates to the worst from each or all. The properties that are to be improved include stiffness, strength, toughness, processability, stability, durability and

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