A review on Micro and Macro mechanic Analysis of Fiber Reinforced Composites

Prof D. P. Kamble[1], Prof Dr M.M. Bhoomkar[2]

[1] Assistant Professor, Mechanical Department, APCOER , Savitribai Phule Pune University, Pune
[1] dattatraykamble5705@gmail.com
[2] Professor, Mechanical Department, PVG's COET Pune Savitribai Phule Pune University, Pune
[2] manmohan_bhoomkar@yahoo.co.in

Abstract: A review on the micromechanical analysis of the different orientation of fiber reinforced composites. Translational symmetric transformation has been applied to make the simplest model for the analysis which can save the time for the analysis. Unit cell obtained from this section can be subjected to arbitrary combination of the macroscopic strains and the response of the unit cell is observed to take out the effective material properties using the simple elasticity approach. Mathematical models are presented to obtain the values of the effective material properties so that they can compared with the numerical model. Further parametric study has been carried out to check the dependency of fiber and matrix on the overall effective material properties. More significant analysis has been done on effective material properties to make it useful for the selection of the appropriate material for the specific application

Keywords-macro, micro analysis Effective material properties, analytical modelling,

I. Introduction

Composite materials are nothing but mixing of two or more materials together to form new material for better mechanical properties. There are three types of composites- Polymer Matrix Composite (PMC) and Ceramic Matrix Composite (CMC) and Metal Matrix Composite (MMC). Mostly they are light weight and with good mechanical strength.

Now days natural fibers are used to prepare fiber reinforced composite materials. Such materials are called biocomposite materials. There are different natural fibers like banana, kenaf, coir, bamboo, jute, hemp, sisal, etc. natural fibers are biodegradable, ecofriendly, non-toxic, harmless to skin, renewability, recyclability. These composites materials are used in space flight, building constructions, packaging and automobile industries.

Composites are defined as a multiphase material which consists of different materials in order to obtain desired properties that the individual constituent by themselves cannot attain. Composite materials can be tailored for various properties by appropriately choosing their components, their proportions, their distributions, their morphologies, their degrees of crystalline, their crystallographic textures, as well as the structure and composition of the interface between components (Deborah 2009). Due to this strong tailor ability, they are capable for different applications like automobiles, aerospace, construction, electronics, energy, biomedical and other industries. Composites are popular for their high strength to weight ratio and stiffness to weight ratio. Composites are broadly classified as fibrous, laminated, particulate, and hybrid composites. Present study aims on review on micro and macro analysis for different orientations on fiber reinforced composites.

Micromechanics

Micromechanics have become an important means of understanding the mechanical behaviour of the composite material. Certain assumptions are taken into account like idealized packing of the fiber in the matrix. Micromechanics is an increasing trend in order to understand the behavior of modern material with sophisticated microstructures, e.g. fibre or particulate reinforced composites, textile composites, etc. (Li 2007).

The mechanics of fiber-reinforced composite materials are studied at
Two levels:

1. The micromechanics level, in which the interaction of the constituent materials is examined on a microscopic scale. Equations describing the elastic and thermal characteristics of a lamina are, in general, based on micromechanics formulations. An understanding of the interaction between various constituents is also useful in delineating the failure modes in a fiber-reinforced composite material.
2. The macro mechanics level, in which the response of a fiber-reinforced composite material to mechanical and thermal loads is examined on a macroscopic scale. The material is assumed to be homogeneous. Equations of orthotropic elasticity are used to calculate stresses, strains, and deflections. [8]

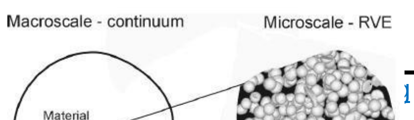
A physical property of the composites depends upon the microstructure, which is design during its manufacturing. Volume fraction of the reinforcing material must be known before its processing. However, final design of composite is limited to some extent, which results in complex and micromechanical interaction. This develops dilemma in modeling the relation between microstructure and the characteristics of the material. In many studies assumption has been taken that the dispersion of the reinforcing element is regular within the matrix material. Due to this assumption it significantly simplifies the calculations and gives acceptable results. It also helps to simplify the finite element model to some extent but in case of crack propagation and plastic zones this assumption leads to seriously incorrect results (Pyrz 2008). So, it is required to mention the dispersion characteristics of microstructure if one analyzes the micro cracks and plastic zones.

If the material is statistically homogeneous, which means that the local material properties are constant when averaged over a representative volume element, then it is possible to replace the real disordered material by a homogeneous one in which the local material properties are the averages over the representative volume element in the real material. Modern technology has found extensive use for unidirectional fiber-reinforced composite materials. To make effective use of these materials, knowledge of their properties and performances when subjected to loads is essential. Many aspects of their behavior are directly associated with the microscopic structure of these materials. The desire to understand these materials drives the research in this field into the micromechanics of this type of materials (Hashin 1983).
Unidirectionally fiber reinforced composites has been considered in this dissertation, by assuming idealized fiber-matrix arrangement in square packing and hexagonal packing. In previous study square packing is analysed in(Adam S, Crane and Donar 1984), and for hexagonal packing

and (Zou and Li 2000). The superiority of the hexagonal packing to the square packing is that it preserves this characteristic while the effective properties obtained from square packing show significant transverse anisotropy. The transverse isotropy achieved through a hexagonal packing, however, is at a price, i.e. the unit cell from it is substantially more sophisticated than that from a square packing (Li 2000). Apart from the square and hexagonal many author have tried different symmetries like cylindrical unit cell, used in literature of (Rosen and Hashin 1964) and (McCartney 1992). This model showed good results for the material properties.

II. LITERATURE REVIEW

In (Xia, et al. 2006), the macrostructure was considered as a periodic array of a repeated unit cell (RUC). RUC was constructed assuming a uniform distribution and the same geometry for the reinforcing phase. The uniqueness of solution by applying unified displacement difference periodic boundary conditions on the repeating unit cell models (RUCs) was proved. Illustrative examples were presented and advantages of applying this type of boundary conditions were discussed. Uniqueness was proved by analyzed the RUCs in displacement based FEM analysis. By applying enough sets of global strains in the unified periodic boundary condition, entire stiffness or a flexibility matrix for a periodic composite structure was predicted. Further it was suggested that the proposed unified boundary conditions can also be applied to non-linear micro mechanical analysis of composites under any combination of multi axial load.



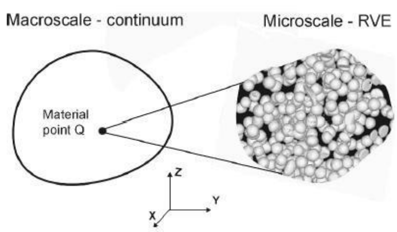
The mechanical behavior of the composites was derived from the use of the micromechanics modeling method which provide the whole behavior by using the known properties of the constituents. Nature of the composites was predicted using the repeating volume element or unit cell model in (Aboudi 1991).A mathematical presentation of periodic composites, called asymptotic homogenization theory, can be found, e.g. (Moorthy, et al. 2001) in among others.

(Aboudi 1991) Has developed a unified micro- mechanical theory based on the study of interacting periodic cells, and it was used to predict the overall behavior of composite materials both for the elastic and inelastic constituents. In his work and many other references, homogeneous displacement boundary conditions equivalent to the „„plane-remains-plane"" conditions were applied to the RVE or unit cell models. In fact, the „„plane-remains-plane"" is only valid for the symmetric RUC subjected to normal tractions. Many researchers, e.g., (Needleman and Overgaard 1993), have indicated that the "plane-remains-plane" boundary conditions are over-constrained boundary conditions.

(Li 2008) Has devoted his study to the generation of such an account, where boundary conditions were derived entirely based on the symmetries which present in the microstructure. The implication of the boundary condition was discussed. Also, it was demonstrated that unit cell of same appearance but subject to boundary condition derived based on the different symmetry consideration may behave rather differently. It also depicted to inform the user of unit cell that to introduce a unit cell one needs not only the mechanically correct boundary condition but also a clear sense of microstructure under consideration.

(Paley and Aboudi 1992) Has analyzed fibrous composites with periodic structure, the repeating volume element consists of four interacting sub-cells. It also offers generalization of method to an arbitrary number of sub-cells for the modeling of multiphase periodic composites. Effective constitutive laws that govern overall behavior of the elastic- visco-plastic composite material were established. Comparison between the response of boron/aluminum composite obtained and finite element solution were given.

Finite element method is very useful in analyzing the RUCs. It determines the mechanical and damage mechanisms of composites. Many authors have done the finite element analysis on different types of composites like unidirectional laminates (Allen and Boyd 1993), cross ply laminates (Bigelow 1993), woven and braided textile composites (Dasgupta, Agrawal and Bhandarkar 1996). High computer performance in combination with easy-to-use commercial model-creation software (Pro/Engineer, AutoCAD, etc.) and FEM software has contributed to this development. Thus it has become relatively easy to apply FEM to solid RUCs with all levels of complexity.



III. MODELLING AND ANALYSIS

A. Type of analysis

In previous sections the boundary conditions and mesh are derived for the square unit cell. Macroscopic strains are introduced for the derivation of the boundary conditions. Nodes of the edges and corners are extracted from the meshed model and then applied each node an individual degree of freedom. Concentrated force was applied as a loading condition for the unit cell. Longitudinal, transverse and shear load was applied to derive the effective material properties of the fiber reinforced composites.

B. Effective material properties

The two basic approaches to the micromechanics of composite material are mechanics of material and elasticity embodies the vastly simplifying assumptions regarding hypothesized behavior of mechanical system. The properties of the composites can be defined in terms of its constituent properties and also in terms of relative volume fraction.

Many mathematical models have been found to determine the effective material properties of the composites. Several authors have devoted their study to develop the mathematical model to determine longitudinal young's modulus, Transverse young's modulus, Shear modulus, and poison's ratio and elastic constants (Charmis D Rajput 2015)

C. Material selection

Isotropic materials were selected for the micromechanical analysis of the unit cell. Both matrix and fiber are isotropic, and homogeneous in nature. The input file is independent for the material selection. One can change the Young's modulus and Poisson's ratio of the matrix and fiber according to their need for the analysis. By just editing the input file the analysis can be done for various materials. For the analysis one particular Material is chosen whose material properties are shown in the below table which was also used by the result obtained for the numerical model can be validated.

D. Analytical Model

Mathematical models are based on translational symmetry in y-z direction are described below

1. Rule of mixure

If V_f,ρ_f, and W_f be the volume, density and weight of fiber respectively.

If V_m, ρ_m, and W_m be the volume, density and weight of matrix respectively then,

$$\text{Volume fraction} = \frac{Vf}{Vf+Vm} \ldots \quad (1)$$

$$\text{Weight fraction} = \frac{Wf}{Wf+Wm} = \frac{Vf\times \rho f}{(Vf \times \rho f)+(Vm \times \rho m)} \quad \ldots (2)$$

2. Calculations for Elastic constant of composite materials

Composite materials can be considered as orthotropic material. Theoretically we can calculate elastic constants in X and Y directions. (E_1 and E_2) by considering this as plain stress case. For simplicity we can assume $E_2 = E_3$

Elastic Property of Composite

In One direction $E_1 = E_f V_f + E_m V_m = \frac{\text{Ef Em)}}{\text{VmEf+VfEm}} \ldots$

In Two directions $E_2 = (E_f E_{m)} / V_m E_f + V_f E_m)$

Transverse Compression

$F_{2c=}(F_{mc}+\square_{rm)}/K_6$ Where, $F_{mc=}$ compressive strength of matrix

In Plane Shear

The in-plane shear strength of the composite based on matrix shear failure can be predicted as

$F_6 = F_{mS/}K_t$

$K_{t=}[1-Vf(1-Gm/Gf)]/[1-(4V_f/\pi)^{1/2}(1-Gm/G_f)]$

(Shear Stress concentration factor) And Gm, G_f = Moduli of rigidity for matrix and fibers respectively

CONCLUSIONS

This paper reviewed for micro and macro analysis for composite material evaluation to obtain the values of the effective material properties so that they can compare with the numerical model. Further parametric study has been carried out to check the dependency of fiber and matrix on the overall effective material properties. More significant analysis has been done on effective material properties to make it useful for the selection of the appropriate material for the specific application

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