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Thermal Analysis of A6061-Boron/Silicon Carbide Composite for In-plane Transverse Loading

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Abstract*— A structural composite is a material system consisting of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of constituent materials acting independently. FRP composites are slowly emerging from the realm of advanced materials and are replacing conventional materials in a variety of applications. However, the mechanics of fiber-reinforced composites is complex owing to their anisotropic and heterogeneous characteristics. In this paper, the micromechanical behavior of the square unit cell of a fiber reinforced composite lamina consisting of boron and Silicon Carbide fibers embedded in Alumina matrix, has been studied. A three-dimensional finite element model with governing boundary conditions has been developed from the unit cells of square pattern of the composite to predict the Thermal Gradient and Thermal Flux of A6061-Boron / Silicon Carbide fiber reinforced lamina for various volume Fraction . A finite element model incorporating the necessary boundary conditions is developed and is solved using commercially available FEA package to evaluate the Thermal properties. The variations of the Temperature at the fiber- matrix interface with respect to the Thermal Gradient & Thermal Flux are studied. This may result in the separation of fiber and matrix leading to deboning. This analysis is useful to realize the advantages of A6061-Boron / Silicon Carbide composites in structural applications, and to identify the locations with reasons where the Temperature is critical to damage the interface. The present analysis is useful to identify the composite effect in selecting the materials for reasonable properties.

***Index Terms*—Finite element method, FRP, Micro-mechanics, Model, Temperature.**

I. INTRODUCTION

A Composite is a material system consisting of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of constituent materials acting independently. One of the phases is discontinuous, stiffer, and stronger and is called reinforcement. Where the less stiff and weaker phase is continuous and is called matrix. The low density, high strength, high stiffness to weight ratio, excellent durability and design flexibility of fiber-reinforced composite materials are the primary reasons for their extended use. The properties of a fiber reinforced plastics can be controlled by the appropriate selection of the substrata parameters such as volume fraction, fiber spacing, and layer sequence. The required directional properties can be achieved in the case of fiber reinforced composites by properly selecting fiber volume fraction, fiber spacing, and fiber distribution in the matrix and layer sequence.

As a result of this, the designer can have a tailor-made material with the desired properties. Such a material design reduces the weight and improves the performance of the composite. For example, the carbon-carbon composites are strong in the direction of the fiber reinforcement but weak in the other direction. A great number of micromechanical models have been proposed in the literature [1] for predicting various mechanical properties of composite materials. Several other models have been proposed such as numerical homogenization [2], FEM [3] among others. The longitudinal Young's modulus E1 and transverse Young's modulus E2 increases linearly with increase in fiber volume fraction & Poisson's ratio υ12 increases linearly [4]. In the present study the finite element method is adopted for predicting various engineering Thermal properties of composites and the results of Thermal Gradient & Thermal Flux are plotted and compared with each other.

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II. METHODOLOGY

The present research work deals with the evaluation of engineering Thermal properties by the elasticity theory based finite element analysis of representative volume elements of fiber-reinforced composites (square unit cell).

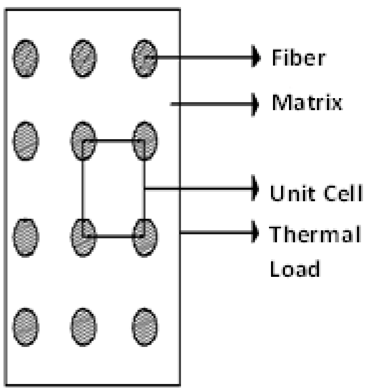

Fig. 1. Concept of unit cells

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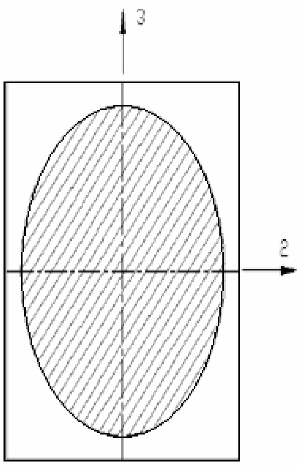

Fig. 2. Isolated unit cell.

A. Numerical Solution

Finite element method is an approximate numerical method which has been successfully used for solutions of problems in various fields, including solid mechanics, fluid mechanics and heat transfer. In the present work, the computational numerical analysis is done using ANSYS 10.
Assumptions made for the present analysis were

- Fibers are uniformly distributed in the matrix.
- Fibers are perfectly aligned.
- There is perfect bonding between fibers and matrix.
- The composite lamina is free of voids and other irregularities.
- The load is within the linear elastic limit.

The dimensions of the finite element model are symmetric boundary conditions are used taken as

a) X=100 units (in-plane Transverse direction)
b) Y=100 units (out-of-plane transverse at direction)
c) Z=10 units (fiber direction).

The radius of fiber is varied corresponding to the at volume fraction. For example, the radius of the fiber is calculated as 61.8 units, so that the fiber volume fraction becomes 0.30.

B. Finite Element Model

The 1-2-3 coordinate system shown in Fig. 2 is used to study the behavior of a unit cell (The direction 1 is along the fiber axis and normal to the plane of the 2D plane given in (Fig. 1 and 2). It is assumed that the geometry, material and loading of the unit cell are symmetrical with respect to 1-2-3 coordinate system. Therefore, a one fourth portion of the unit cell is modeled Fig. 3 for the prediction of Thermal properties. The 3D Finite Element mesh on one fourth portion of the unit cell is shown in Fig. 4.

C. Element Type

The element SOLID95 of ANSYS V10 used for the present analysis is based on a general 3D state of stress and is suited for modeling 3D solid structure under 3D loading. The element has 20 nodes with three degrees of freedom per node.

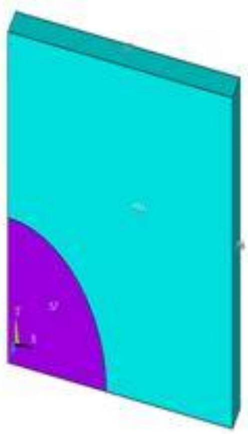

Fig. 3. One-fourth portion of unit cell model.

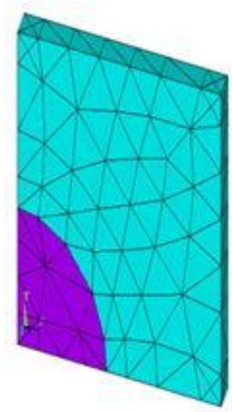

Fig. 4. Meshed model.

D. Boundary Conditions

Due to the symmetry of the problem the following symmetric boundary conditions are used and initial temperature taken as 100 ^{0}C.

a) At x = 0, Ux = 0
b) At y = 0, Uy = 0
c) At z = 0, Uz = 0

E. Materials

Two different types of composite materials are taken for the analysis.

TABLE I
TYPICAL THERMAL PROPERTIES

Material	ρ kg/m^3	Coefficient of thermal expansion 10^{-6}m/mk	Thermal conductivity W/(mk)	Heat capacity KJ/(kg.k)
AA6061	2800	23.4	171	0.96
Boron	2200	5	38	1.30
Silicon Carbide	2800	4.3	16	1.2

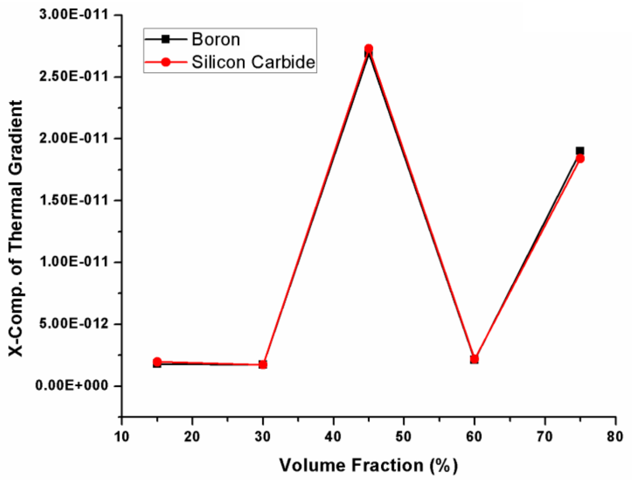

Fig. 5. Variation of Thermal Gradient in X-Direction with volume Fraction

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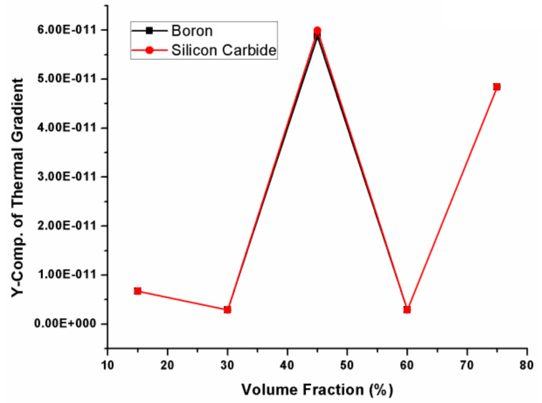

Fig. 6. Variation of Thermal Gradient in Y-Direction with volume Fraction

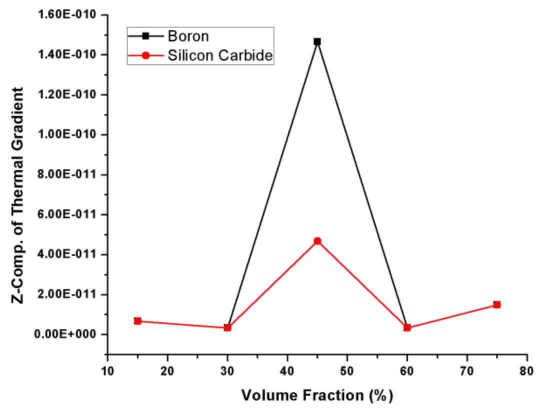

Fig. 7. Variation of Thermal Gradient in Z-Direction with volume Fraction

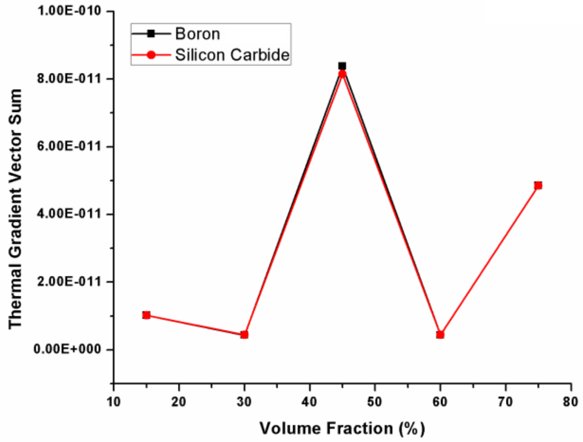

Fig. 8. Variation of Thermal Gradient Vector Sum with volume Fraction

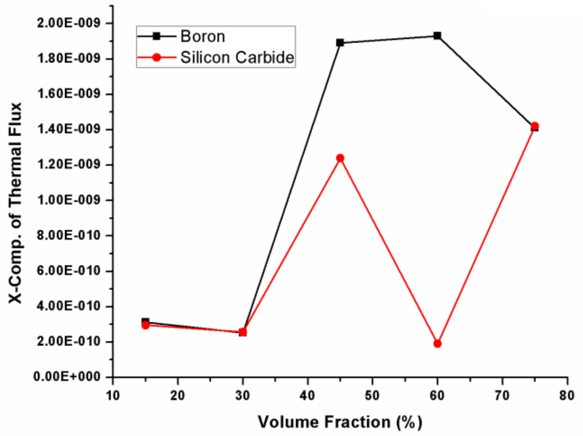

Fig. 9. Variation of Thermal Flux in X-Direction with volume Fraction

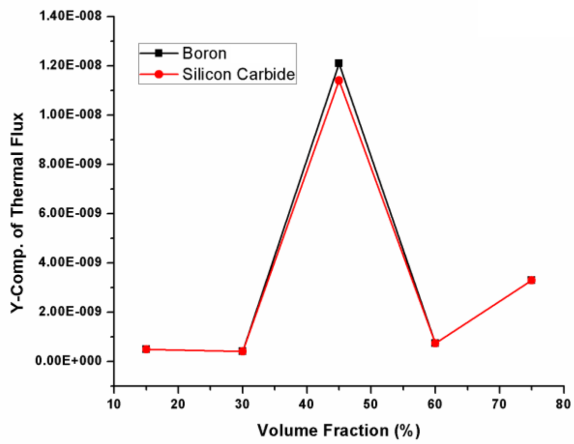

Fig. 10. Variation of Thermal Flux in Y-Direction with volume Fraction

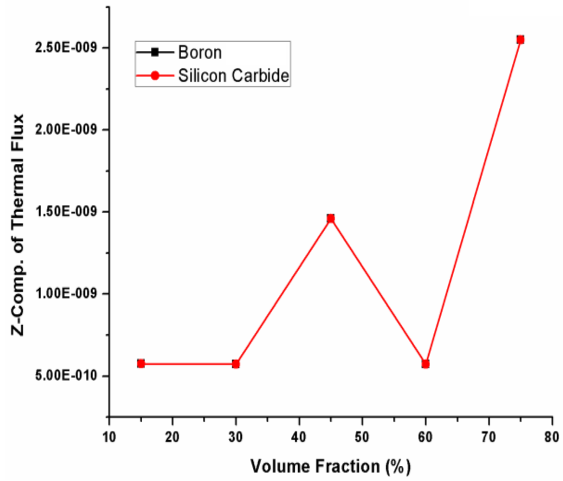

Fig. 11. Variation of Thermal Flux in Z-Direction with volume Fraction

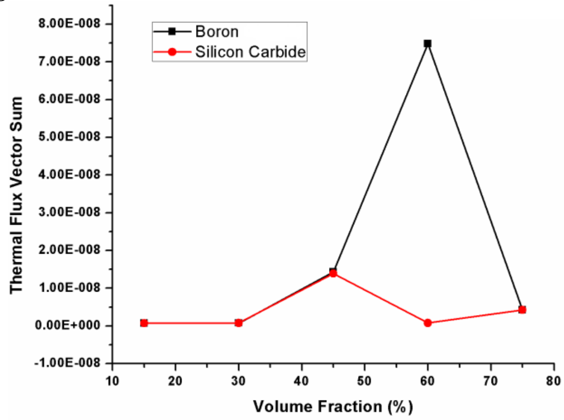

Fig. 12. Variation of Thermal Flux Vector Sum with volume Fraction

III. RESULTS AND DISCUSSION

Fig. 5-12 shows the variation of various behaviors of materials with the fiber volume fraction. The observations made from the plots are:

a) Variation of thermal gradient of both materials are linear in both x and y directions along volume fraction. It shows good agreement between the materials. But in z direction thermal gradient of boron is maximum at 45% of volume fraction compared to silicon carbide.

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b) In case of thermal flux in x-direction the thermal flux with volume fraction are different. Variation of thermal flux vector sum with volume fraction of both materials are linear up to 45% of volume fraction then the thermal flux of boron increases with volume fraction.

c) Comparisons of both materials reveal that silicon carbide stronger than boron.

IV. CONCLUSION

Several characteristics of two different composite materials have been evaluated for various fiber volume fractions with the help of FEA. The results of thermal gradient and thermal flux of both materials are compared and discussed. It is seen that the results from the finite element simulation are little bit deviating with both materials at 45% of volume fraction. Hence finite element method provides with a large property set to perform better analysis for FRP composite materials.

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