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Title **INVESTIGATION OF ELLIPTICAL AND SQUARE UNIT CELL FOR THE PREDICTION OF EFFECTIVE THERMAL CONDUCTIVITY**

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INVESTIGATION OF ELLIPTICAL AND SQUARE UNIT CELL FOR THE PREDICTION OF EFFECTIVE THERMAL CONDUCTIVITY

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Abstract: This paper focuses upon using the Numerical Simulation Method for determining the appropriate heat conductivities (K_{eff}) of unidirectional Composite Materials (FRCs) (FEM). The K_{eff} along transverse (K_2) and through thickness (K_3) directions for different types of fibers and matrix arrangements with and without deboned for both elliptical and square fibre mechanical models through FEM put into Representative Volume Element (RVE)were evaluated. The results indicated that the random fiber distribution and the voids in the matrix can trigger the enhancement of K_{eff} in FRCs.

Index terms: Fibre reinforced composites, Heat transfer, Finite Element Method, Thermal Conductivity.

1. Introduction

The composite materials were extensively used in structural applications since of the higher specific strength, tremendous strength to weight ratio, and stiffness. So, the researchers were exploring the properties of different fibers and matrix configurations. In recent A.Shirisha et al [1] have examined the composite with glass fiber as reinforcements and polyester as matrix material. Similarly, the mechanical properties of polymer composite reinforced with natural glass fibers were characterized by M.R.Sanjay et al [2]. Xiaomin Deng [3] has investigated the consequences at interfaces with the theories of fracture mechanics and the influence on debonding and delamination imperfections of composites. Recently, the composites were being used in the thermal conductivity enhancements as well. However, the specific fibers and their matrix materials, as well as their proportions used in the composites will determine the heat conductivity of FRCs. Many researchers have adopted several numerical and the analytical methods to predict the thermal conductivities in the composites. Based on shear loading, Springer and Tsai [4]"have provided a numerical approach for estimating the Transverse thermal conductivity of the composites". Through FEM, G. Sambasivarao et al [5]have used the square unit cell and the hexagonal unit cell used for diverse range of volume fractions considering imperfections for prediction of effective thermal conductivity. Also, Tsai et al have considered circular filaments utilizing the square unit cells and obtained the transverse direction thermal conductivities. Similarly, in transverse direction for ideal FRCs, the thermal conductivities were determined by Islam and Pramila [6] also considering the composites having cracks and also

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interfacial barrier resistances.T.J.Lu and J.W.Hutchinson[7]"have introduced the cracks in matrix and investigated the heat transmission mechanism across the cracks and deboned interfaces for unidirectional FRCs". Yaun Lu [8] computed the thermal conductivity in transverse direction using the boundary collection method, having the circular and square cylinders with square and hexagonal array distribution. Kamala Priya B [9]discussed the prediction on Thermal Conductivities of Fibre Reinforced Composites using Finite Element Method applied to Representative Volume Element in shape of elliptical Model. Examination has been done by Kamala Priya B[10] to find out the effect of fibre type and fibre arrangements of effective thermal conductivities in transverse and through thickness directions. The result shown that from Kamala Priya B[11] , enhancement of effective thermal conductivities of composites can be done with voids and random arrangement of fibres in a matrix.

In this study, the comparison of K_{eff} (K_2 and K_3), for the unidirectional FRC's having Elliptical and Square models with and without deboned for staggered arrangements are discussed on insertion of third phase material between the composites.

2. Problem Statement

The present paper is mainly externalized to measure and predict the K_{eff} for FRC's which is of uni-directional that was made by inserting the thin phased material in between matrix and fiber.

2.1 Methodology

The current analysis is done for both the models square and elliptical one having fibres of staggered arrangement either they are with deboning or without deboning. It was proved that for the cases where the boundary conditions are aligned in the same direction of heat flow, the fiber volume fractions range between 0.1 to 0.6. The composite's periodic Fibres, which is generally and acceptable to get the output of the entire structure by only considering the unit cell hence known as the RVE which can be seen in Fig. 1,2,3, and 4 are useful for the analysis.

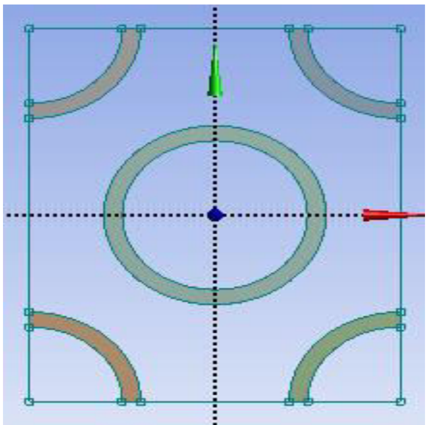

Fig1 Isolated Square Unit cell having Fiber Matrix Interface for Staggered arrangement

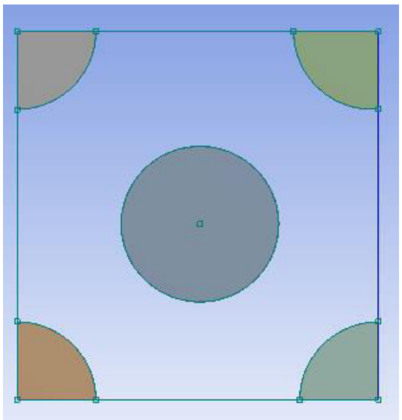

Fig2 Isolated Square Unit cell not having Fiber Matrix Interface for Staggered arrangement

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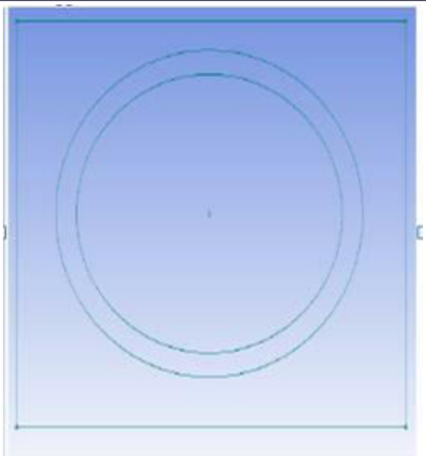

Fig3 Isolated Elliptical Unit cell having Fiber Matrix boundary for staggered arrangement

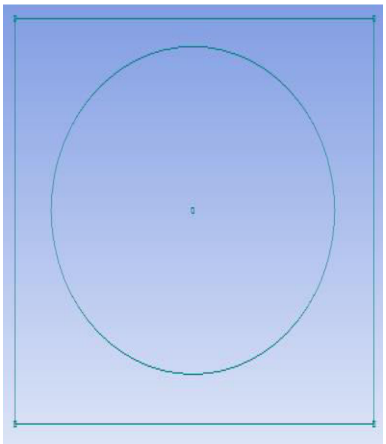

Fig4 Isolated Elliptical Unit cell not having Fiber Matrix boundary for staggered arrangement

Geometry

The measurement of fibre volume, which refers to overall volume for composite and is known as fibre-volume-fraction, is the area of the fibre's, fibre's cross-section of a fibre that is relative to the surface of a cross-section of the single cell (v_f).

Here, $V_f = \frac{\frac{\pi}{4} * r^2}{a^2}$

r is known as fibre radius; a is the unit cell edge length; v_f is the volume fraction for fibre.

3.1 Finite Element Models

The Unit cells quarter portion of Elliptical and Square are designed using Ansys as shown in figure and the RVE for the whole structure of those models are designed as shown in figure 5,6,7 and 8 is selected for the analysis.

The flow of heat that acquired from ANSYS was substituted in the Equation q = -K dt/dx and the Conductivity in similar direction will be evaluated in W/m-k. Likewise, the fibre volume fraction will be constantly varied in between 0.1 to 0.6 by varying single parameter 'r' i.e., fiber radius.

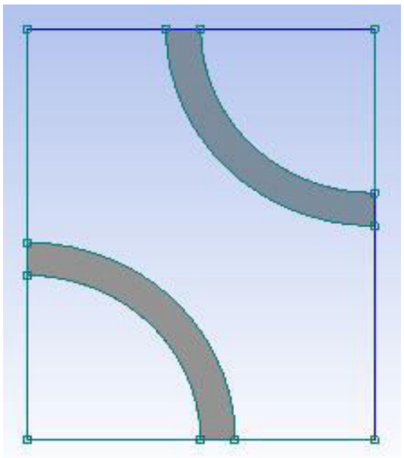

Fig5 Quarter portion of Square unit cell with Fiber Matrix boundary for staggered arrangement

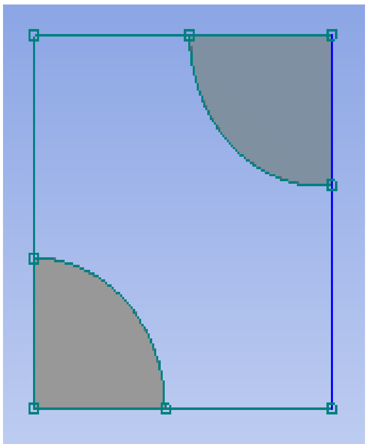

Fig6 Quarter portion of Square unit cell without Fiber Matrix boundary for staggered arrangement

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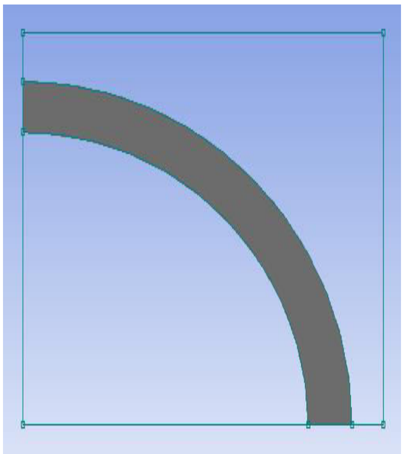

Fig7 Quarter portion of Elliptical unit cell with Fiber Matrix boundary for staggered arrangement

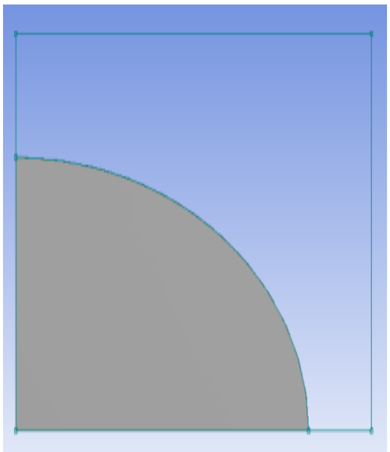

Fig8Quarter portion of Elliptical unit cell without Fiber Matrix boundary for staggered arrangement

3.2Boundary conditions of temperature for quarterly model are as mentioned below:

These adiabatic boundary conditions are applied to all the other faces.

Where,

To predictK_1: T (0, y)

To predictK_2:T (0, y) =T_1; T (a, y) = T_2

To predict K_3:T(x, 0) =T_1; T(x, a) = T_2

3.3 Material Properties

Fibre Conductivity

The thermal conductivity values in the analysis are typically in the range of 5 to 100. Carbon and glass fibres are the materials in this typical range.

Conductivity of the Matrix

Polymer is recommended for this analysis. The calculated matrix thermal conductivity value is used to compare the effective thermal conductivity of the Fibre Matrix interfaces with and without deboned.

4. Analysis of Results

The following figures 9,10,11,12,13,14,15 & 16 shows the analytical results of Elliptical and Square unit cell for staggered fibres in the transverse and thickness directions respectively.

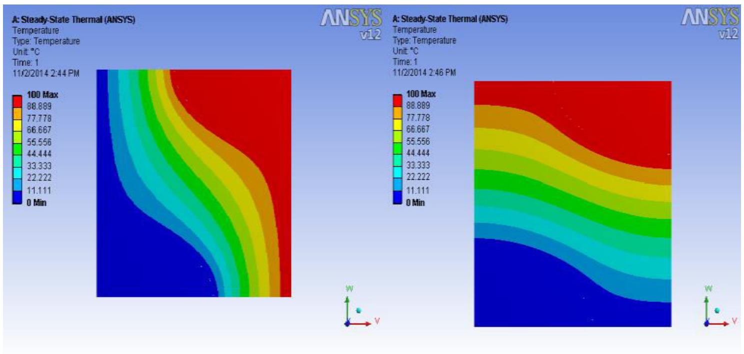

Fig 9 represents the temperature variation in Elliptical of the Unit Cell with Fiber Matrix interface for Staggered Fibers in Transverse Direction.	Fig10 represents the temperature variation in Elliptical of the Unit Cell with Fiber Matrix interface for Staggered Fibers through thickness Direction arrangement

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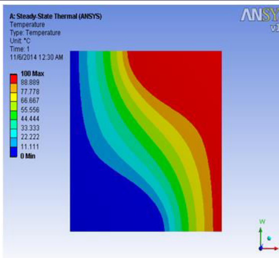
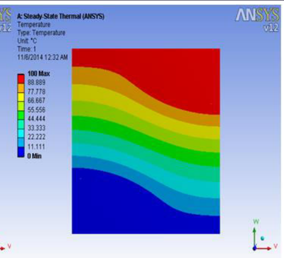



Fig 11 represents the disparity of temperature in Elliptical Unit Cell of Staggered Fibers at Transverse direction thickness.	Fig 12 represents the disparity of temperature in Elliptical Unit Cell of Staggered Fibers along direction.

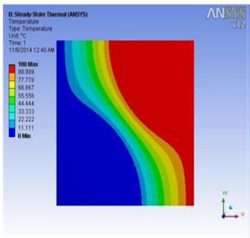
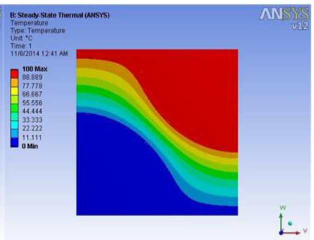



Fig 13represents the disparity of temperature in Square Unit Cell of Fiber Matrix interfaces in Staggered Fibers in Transverse direction.	Fig14 represents the disparity of temperature in Square Unit Cell of Fiber Matrix interfaces in Staggered Fibers along Thickness direction

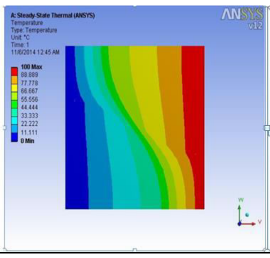
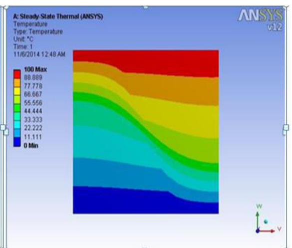
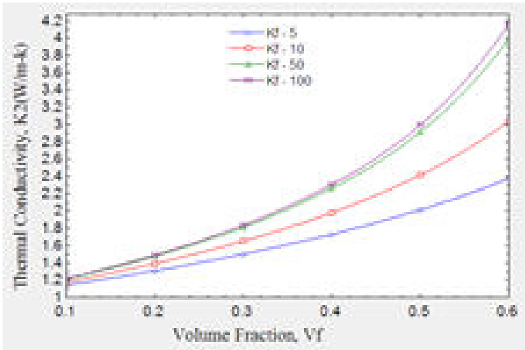



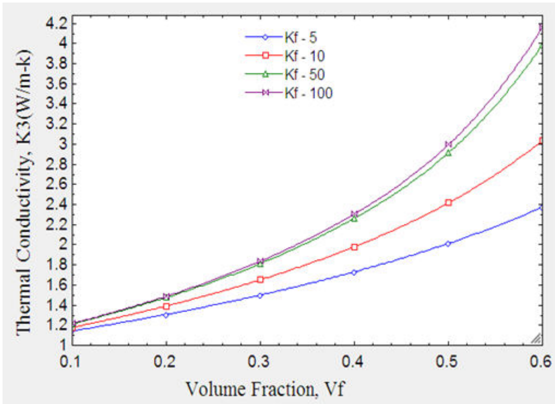
Fig15 represents the disparity of temperature in Square Unit Cell of Staggered Fibers in Transverse direction	Fig16 represents the disparity of temperature in Square Unit Cell of Staggered Fibers in Thickness direction.

4.1 Staggered square unit cell

A comparable fluctuation around Thermal Conductivity was found to increase with the increase in the volume percentage of up to 20% in both Transverse (K2) direction and Thickness (K3) direction. A wide range of Thermal Conductivity is observed, ranging from 20% to 60%. Fiber conductivities of 50W/m-k and 100W/m-k have lower Transverse Thermal Conductivity values.



GRAPH 1.K2 (W/m-k) V_s the Volume Fraction V_f plot for Staggered Square Unit Cell.



GRAPH 2.K3 (W/m-k) V_s the Volume Fraction V_f plot for Staggered Square Unit Cell.

4.2 Staggered Square Unit Cell with Fiber Matrix Deboned

A comparable fluctuation in Thermal Conductivity is reflected with a rise in volume fraction up to 0. 2 in both the Transverse (K2) as well as the Thickness (K3) directions. The Thermal

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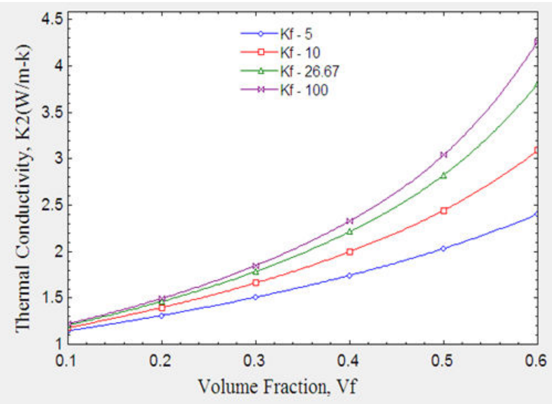
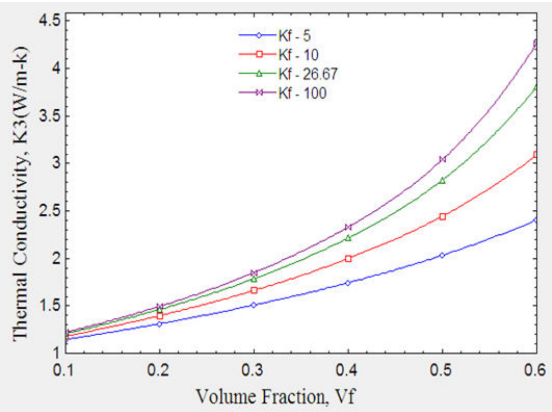
Conductivity range of values from 0.2 to 0.6, indicating a wide range.



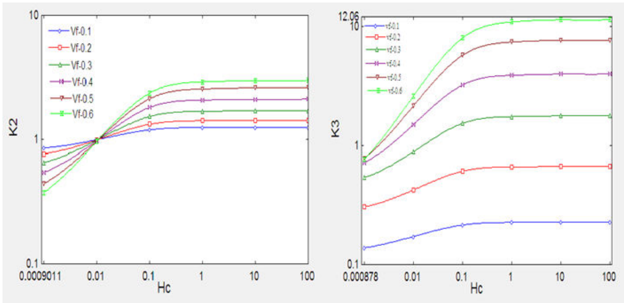
GRAPH 3.K_2 (W/m-k) Vsthe VolumeFraction$V_{f\ plot}$ for Staggered Square Unit Cell



GRAPH4 K_3(W/m-k) V_S the Volume Fraction $V_f$plot for Staggered Square Unit Cell.

4.3Elliptical Unit Cell for Staggered Fibers at Fiber Matrix Interface via Transverse and Thickness Thermal Conductivities

Elliptical Unit Cell at Interface of Fiber Matrix for Staggered Fibers, from graph 5, with an increase in K_c, the K_{eff} of the staggered fibres with the elliptical unit cell in transverse direction was shown to be equivalent0.01 W/m^{2}k. The conductivities of the third phase fall beneath this value due to a minimal Interface of the Fiber Matrix.In the Transverse direction effective conductivity is just the sum of the matrix and conductivities of third phase that triggers K_2 value to be lesser than the matrix value, with the impact being more pronounced at increasing fibre volume fractions. Conductivity of third phase (Kc) is chosen range 0.001 to 100 W/m-k for the evaluation through the thickness direction, which includes almost gap to greatest conductivity materials. As shown in graph 6, thermal conductance levels are varying from 1W/m2k to a maximum level of conductance to show low or no fluctuation for 100 percent deboning. This is evident so as the V_f increase, so does the area that resisting the heat flow.



GRAPH 5K_2(W/m-k)V_s K_c(W/m^{2}k)plot for K_f=5to100 GRAPH 6K_3(W/m-k)V_s K_c(W/m^{2}k) plot for K_f=5to100

4.4 The transverse and thickness thermal conductivities of staggered patterned fibres with Elliptical unit cell

Graph7 indicates that a rise in the volume fraction up to 0.2 causes a similar fluctuation in Thermal Conductivity. K2 values range from 0.2 to 0.6, indicating a significant difference.Graph8 indicates that a rise in the volume fraction up to 0.3 causes a similar fluctuation in Thermal Conductivity. Thermal Conductivity readings range from 0.3 to 0.6, indicating a significant difference.

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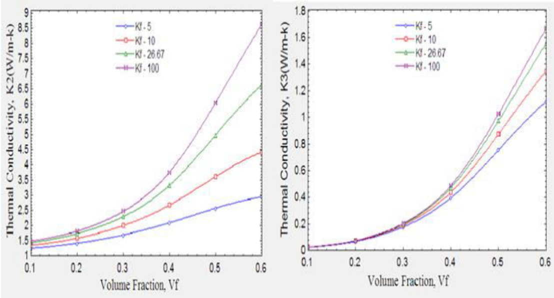

GRAPH7.K_2(W/m-k)V_s K_c (W/m^2k) plot for K_f=5 to 100 **GRAPH8.**K_3(W/m-k)$V_s$$K_c$ (W/m^2k) plot for K_f=5 to 100

5. Conclusions:

- The K_{eff} of the staggered fibers with the elliptical unit cell in the transverse direction was observed to be equivalent with such an increment in thermal conductivity. The conductivities of the third phase are lower than the value predicted for a minimal Fiber Matrix Interface.
- For the thickness direction, the third stage conductivity (Kc) is specified in the range from 0.001 to 100 W/m-k, which covers almost the entire gap to the high conductivity materials but is neither trivial nor variable for 100 percent bonded.
- A comparable change in Thermal Conductivity is found to increase with the increase in volume percentage of up to 20% in a square unit cell containing matrix interface of fibers for staggered fibres, including Transverse (K_2) and across Thickness (K_3) directions.Closer Transverse Thermal Conductivity values are observedforFiberConductivities50W/m-k,100W/m-k.
- Thermal conductivity varies similarly in the transverse and thickness directions for circular and square models by increase in volume fraction up to 20%.
- Thermal conductivity values differ widely in both elliptical and square models, ranging from 20% to 60% and 20% to 30%, respectively.

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