International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 5
May 2018

# Transverse Thermal Conductivity of Hollow Fiber Composites

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**ABSTRACT:**

*Present investigation deals with the prediction of transverse thermal conductivity of a hollow fiber reinforced composite. Three dimensional finite element models have been developed and validated for thermal conductivity in longitudinal direction using rule of mixtures. Later the analysis is extended to determine thermal conductivity in transverse direction. Effect of fiber hollowness and conductivity ratio on transverse thermal conductivity is studied for a constant volume fraction of fiber ($V_f = 0.5$). It is realized that effect is to increase the transverse thermal conductivity in fiber dominated cases and to decrease this property in matrix dominated cases. The present analysis will be useful in the design of thermal systems with required transverse thermal conductivity.*

***KEYWORDS: Fiber hollowness, Conductivity Ratio, Transverse conductivity, FEM.***

## 1.0 INTRODUCTION

Transverse thermal conductivity of a fiber reinforced composite depends on the resistance offered by the constituent materials due to their geometrical arrangements and conductivities. Some of the contributions on analysis of hollow fiber composites are reviewed. Huang, Z.M. [1] has implemented a micromechanics model called as 'bridging model' to simulate the overall thermal – mechanical properties of a fibrous composite out of an elastic deformation range. HWAN-BOH SHIM et al. [2] investigated thermal conductivity and mechanical properties for carbon fiber-reinforced composites with different fiber cross-section types, such as round, C, and hollow-shape. It was found that cross-section type of the reinforcing fibers influence the thermal conductivity.

Liang, J.Z. & Li, F.H [3] measured the effective thermal conductivity (keff) of hollow glass-bead (HGB)-filled polypropylene (PP) composites by means of a thermal conductivity instrument to identify the effects of the content and size of HGBs on the effective thermal conductivity for these filled systems. The results showed that the measured keff decreased roughly linearly with increase of the volume fraction (φf) of HGB. In addition, keff decreased slightly with increase of the particle diameter when φf was constant.

Ryosuke Osugi et al. [4] examine thermal conductivity of natural fiber-reinforced composites with an attention on hollow portion of natural fiber. They concluded that natural fiber-reinforced composite has an excellent thermal insulation property and the thermal conductivity of Manila hemp fiber reinforced composites decreases with increasing fiber content.Hande C. [5] investigated tensile properties and thermal conductivities of hollow glass microspheres (HGM) filled polypropylene composites with and without surface treatment. It was shown that the tensile properties were improved but no considerable effect on thermal conductivity due to surface treatment. Mohamed Zakriya et al. [6] developed sandwich structure of non-woven composite considering 50–70% weight of jute fibre content with 30–50% weight of hollow conjugated

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polyester fibre, ideal thickness of the composites is maintained in the range from 4 to 5 mm. Thermal properties such as thermal conductivity, thermal resistance, thermal transmittance and thermal diffusivity were evaluated by considering three factors: weight of jute (A), weight of hollow conjugated polyester (B) and thickness of the composite (C). The thermal conductivity of the composite material is determined by heat flow meter method ASTM C518. Experiment result will help to make a suitable standardized panel composite for thermal insulation. It requires 3600 gsm 51/49 parts of contribution of jute/hollow conjugated polyester fibre with 5.0 mm thickness and 3200 gsm 76.5/23.5 parts of contribution of jute/hollow conjugated polyester fibre with 4.5 mm thickness of the composites. The composite weight of 3280 gsm shown optimized thermal responses, it was predicted from response surface method graph. Contribution of jute/hollow conjugated polyester fibre of 54/46 parts with 5.0 mm thickness would be considered to make standardized composite panel. Mostly air conditioning process reduces the energy cost spent for the thermal stability in indoor climate of dwellings.

Considering the variation of thermal properties of hollow fibers, finite element analysis is applied to investigate the transverse thermal conductivity of hollow fiber composites in this paper.

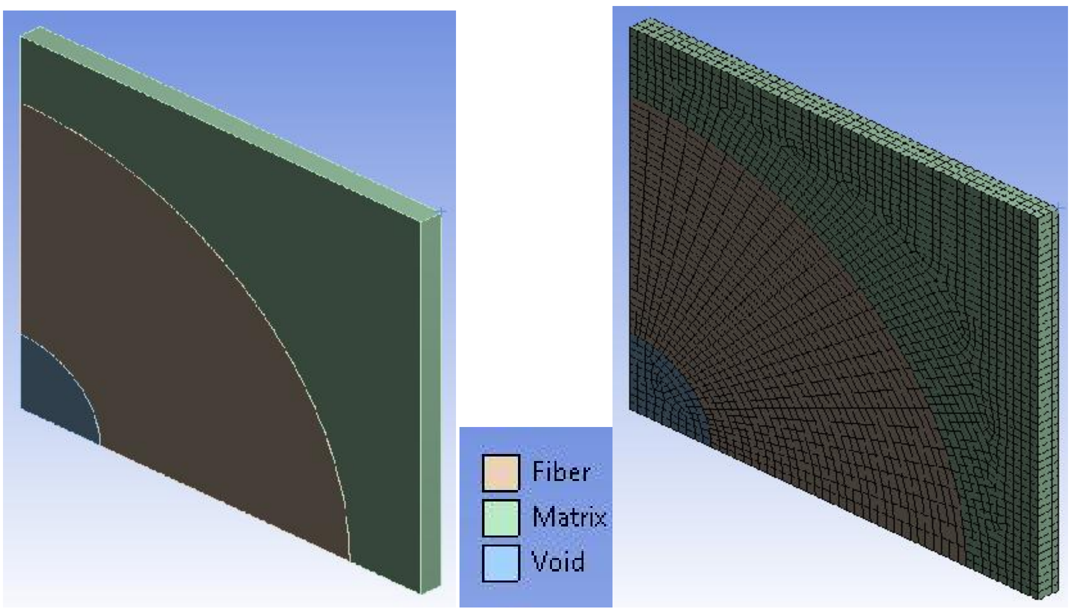
## 2.0 PROBLEM DESCRIPTION

The aim of the current work is to predict the transverse thermal conductivity of a Hollow Fiber Reinforced Plastic Lamina using micromechanics approach. Three dimensional finite element models with appropriate boundary conditions were developed. These models were validated for longitudinal thermal conductivity using rule of mixtures and later extended to predicted transverse thermal conductivity for a possible range of conductivity ratios and fiber hollowness. For the present analysis the following assumptions are made. (i) Fibers are uniformly distributed in the matrix, (ii) Fibers are perfectly aligned, (iii) There is perfect bonding between fibers and matrix and (iv) The composite lamina is free of voids and other irregularities.

### 2.1 Material properties

Thermal conductivities of fiber and matrix are chosen to cover the conductivity ratios of 2, 5, 10, 25, 50, 100 and 200 in fiber dominated cases and 1/200, 1/100, 1/50, 1/25, 1/10, 1/5 and 1/2 in matrix dominated cases.

### 2.2 Geometry and FE mesh




(a) Geometry (b) Finite Element Mesh

Fig. 1. Finite element mesh on one-fourth portion of the unit cell

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The dimensions of the finite element model are taken as: side of the unit cell 2a=200mm, thickness of the unit cell = 5mm. The inner radius ($R_i$) of fiber is varied as 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 mm. The outer radius (Ro) of the fiber is calculated corresponding to the fiber volume fraction ($V_f$ =50). Fig.1 shows the geometry and finite element mesh on one-eighth portion of the unit cell having $R_i$=20mm, Ro=82.257mm, $V_f$=0.5, Vm=0.4686 and $V_v$ =0.0314. A three dimensional quadratic brick element having 20 nodes, available in ANSYS software, is used with an element edge length of 2mm.

### 2.3 Loading and boundary conditions

Temperatures along the sides of FE model are applied to allow a unidirectional flow of heat in the required direction with a temperature gradient equal to unity.

## 3.0 SOLUTION

The finite element model is validated for longitudinal thermal conductivity using rule of mixtures. Fig. 2 shows the temperature contour and reaction solution for longitudinal heat flow in the model as illustrated in Fig.1 with the ratio $K_f$ / Km = 25.

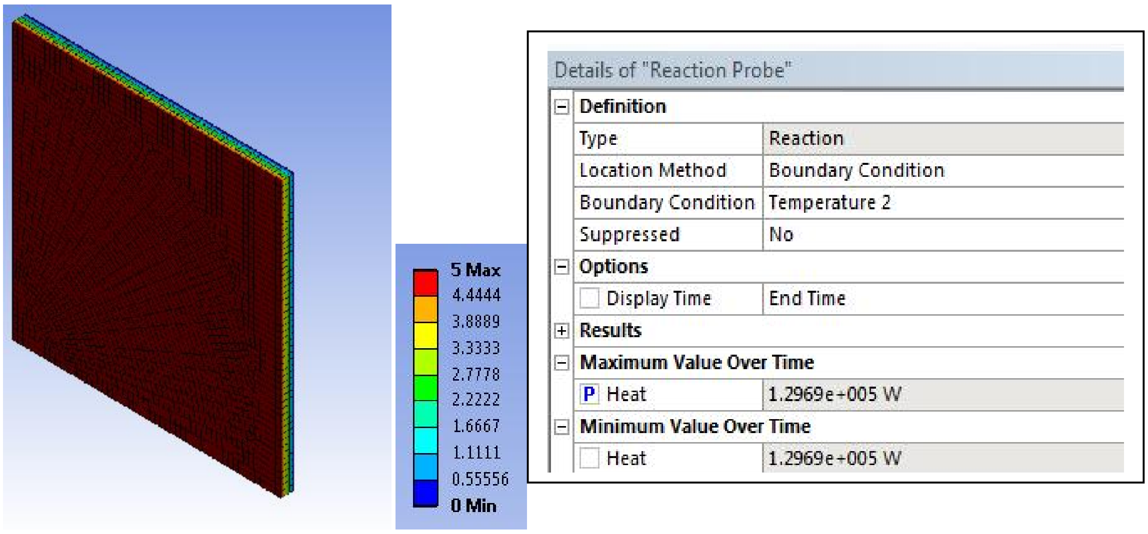


Fig. 2. Temperature contour and reaction solution for longitudinal heat flow.

### 3.1 Validation of FE model

The longitudinal thermal conductivity of the developed finite element model is validated with the rule of mixtures equation given by $K_L = K_f*V_f + Km*Vm+Kv*Vv$.

$K_L$- Theoretical = 25*0.5+1*0.4686 +0*0.0314 = 12.9686 W/mm K

$K_L$-FEM = Reaction heat / (100*100) = 1.2969e5/10000 = 12.969 W/mm K

## 4.0 DISCUSSION OF RESULTS

Fig. 3 shows the temperature contour and reaction solution for transverse heat flow in the model as illustrated in Fig.1 with the ratio Kf / Km = 25. The transverse thermal conductivity was calculated using the formula,

$K_T$-FEM = Reaction heat / (5*100) = 1483.9/500 = 2.9678 W/mm K

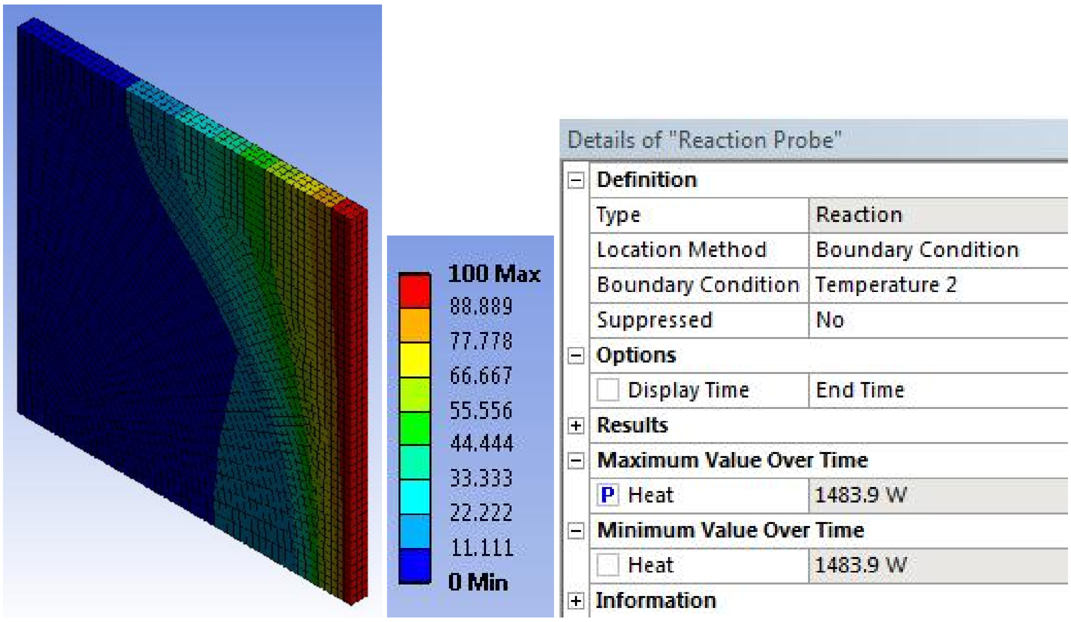


Fig. 3. Temperature contour and reaction solution for transverse heat flow.

The effect of Conductivity ratio and Hollowness of fiber on Transverse conductivity of the composite are shown in figures 4 and 5 for fiber dominated composites and in figures 5 and 6 for matrix dominated composites.

From figure 4, it can be observed that an increase in transverse conductivity with an increase in conductivity ratio which is obvious and also an increase in $K_T$ is observed with an increase in hollowness of the fiber. The effect of hollowness of the fiber can be clearly observed in figure 5. As the hollowness increases from 0 (solid fiber) to 0.5, the $K_T$ increase becomes dominant at higher conductivity ratios. The variation is very little up to a conductivity ratio of 10. At higher conductivity ratios (~100), the $K_T$ becomes double the value compared to a solid fiber. For this entire variation of $K_T$ with respect to fiber hollowness and conductivity ratio, the thermal resistance in the path of heat flow is the main reason.

Similar analysis is carried out to find the effect for the matrix dominated composites and the results are plotted in figures 6 and 7. From these two figures it can be observed that the effect of hollowness is to decrease $K_T$ in case of matrix dominated composites. The decrease of transverse conductivity with respect to conductivity ratio is linear and with respect to fiber hollowness is non linear. Also in the normal range of conductivity ratio of composites used in practical applications, a considerable change in $K_T$ (of the order of 2 times) is observed which can be an important factor to be considered in the design of composites in thermal applications.

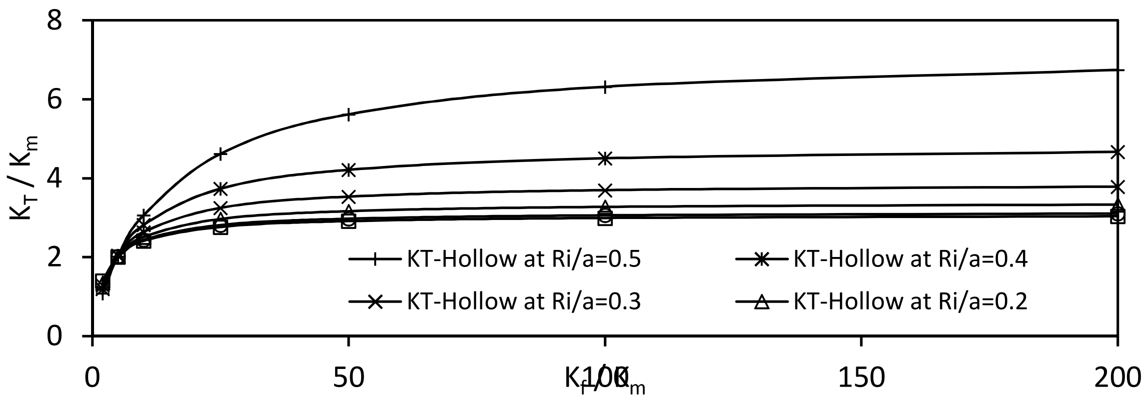


Fig.4. Effect of Conductivity ratio on Transverse conductivity of Fiber dominated Composite

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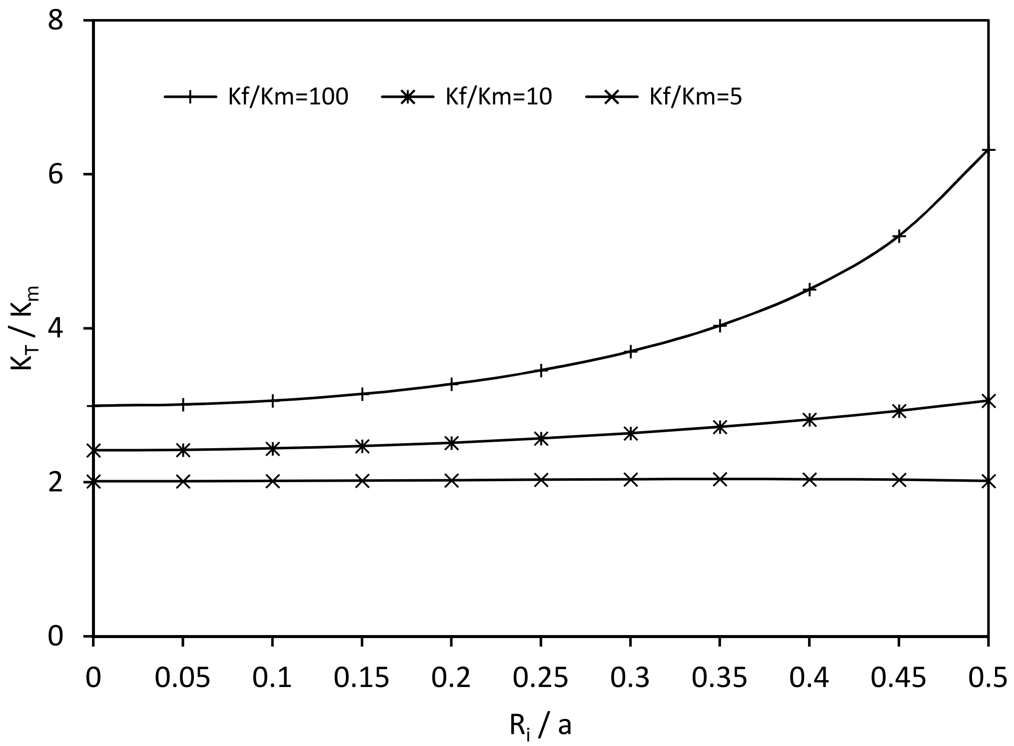


Fig.5. Effect of Hollowness of fiber on Transverse conductivity of Fiber dominated Composite

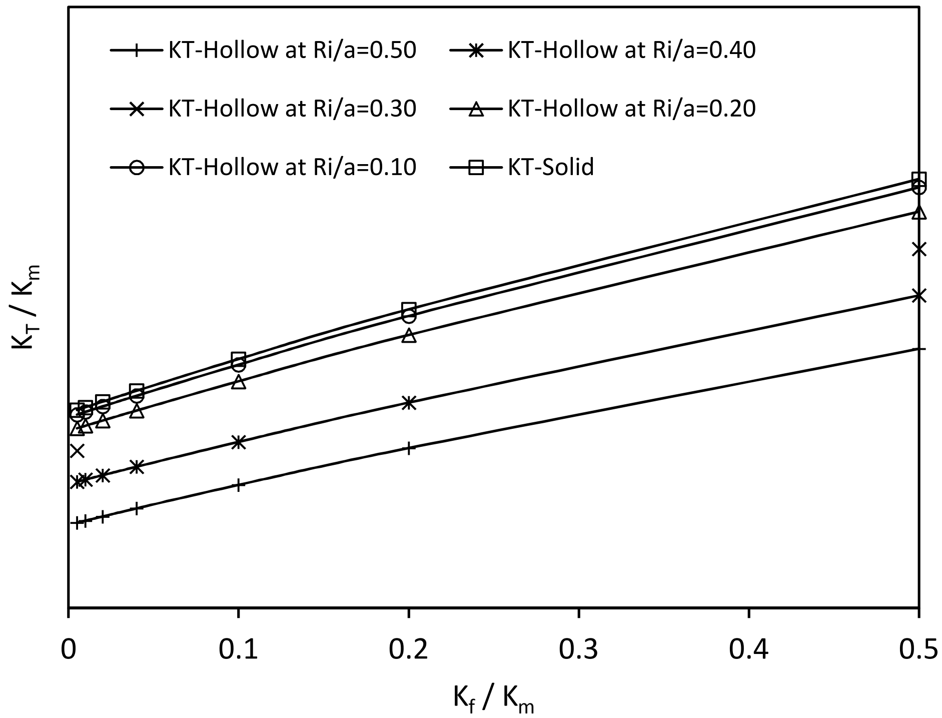


Fig.6. Effect of Conductivity ratio on Transverse conductivity of Matrix dominated Composite

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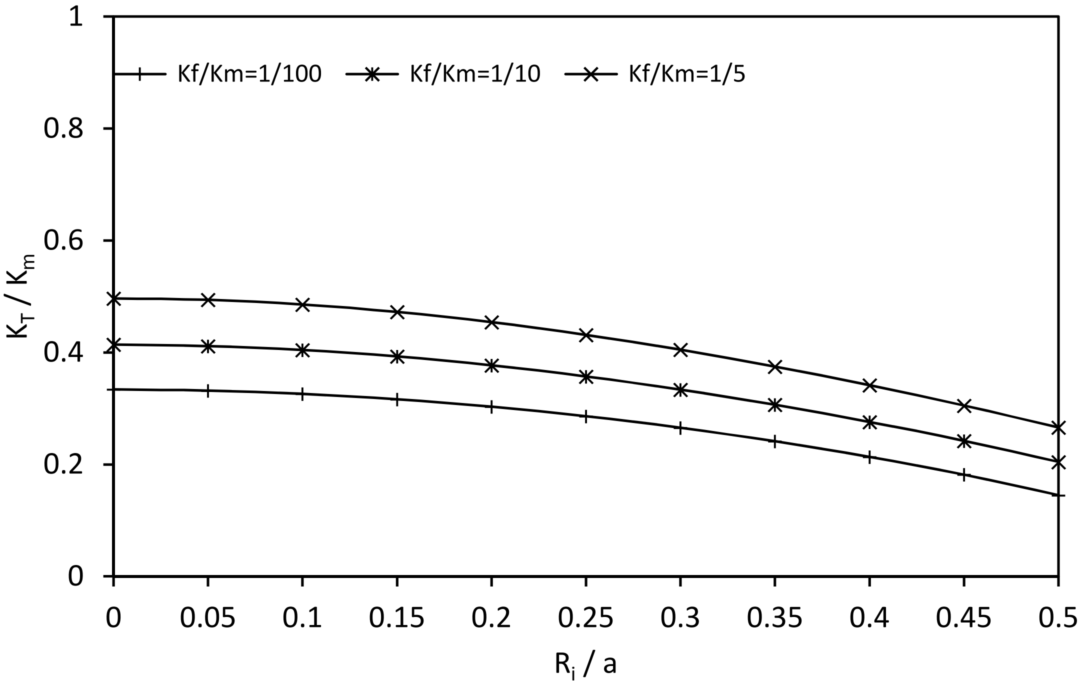


Fig.7. Effect of Hollowness of fiber on Transverse conductivity of Matrix dominated Composite

## 5.0 CONCLUSIONS

Transverse thermal conductivity plays an important role in the heat transport applications in fiber reinforced composite materials. This property depends on many factors like fiber volume fraction, properties of constituents, shape of the fiber, and distribution of fiber in matrix and debonds between fiber and matrix. In addition fiber hollowness also influences the property which is the study of the present work. It can be concluded from the analysis that fiber hollowness increases the transverse conductivity considerably in case of fiber dominated composites and has a decreasing effect in case of matrix dominated composites. This variation in the property can be better utilized in the heat transport applications where rate of heat flow is to be increased or decreased.

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