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Research Paper

EFFECT OF FIBER ORIENTATION ON HEAT TRANSFER FOR FRP COMPOSITE

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Influence of different fiber orientations in representative volume element has been shown over the Heat transfer analysis in the fiber reinforced polymer composites. Finite Element Method (FEM) simulations have been performed to model and visualize 2D microstructures of fiber reinforced matrix composites with Heat Transfer boundary conditions. The results indicate that micro structural heterogeneity has an influence on Heat Transfer rate and hence overall conduction of composite is effected by rotating fibers in matrix.

Keywords: Finite Element Method (FEM), Heat transfer analysis, Polymer matrix composites, ABAQUS

INTRODUCTION

To study the behavior of composites, nowadays it has been widely accepted that it can be attained by accurate and precise study of Representative Volume Element (RVE), i.e., we differentiate whole composites into no. of small and periodically repeating parts (Vaughan and McCarthy, 2011; and Jain *et al.*, 2012). The whole purpose of modeling of RVE is to study the composite at micro structural level and consider the effects of topological arrangements of fibers in matrix. Jain *et al.* (2012) modeled the effect of uniformly and randomly spaced clustered fiber arrangements to know their diffusion response. Which can be used to design the several machine parts used in moisture conditions as it was found that the randomly clustered fiber arrangement opposes the moisture absorption more as compared to uniformly clustered fibers. Jia-Lin Tsai and Yang-Kai Chi (2008) worked to find effect of thermal residual stress on mechanical behavior of composite with three different fiber orientations, i.e., irregular, square edge and square diagonal. Thermal residual stresses are generated in composite due to mismatch of coefficient of thermal expansion during cooling. It was found that composite with square edge packing fibers is more sensitive to the thermal stresses as comparative to others.

All of them studied the effect of fibers in mechanical and physical properties of

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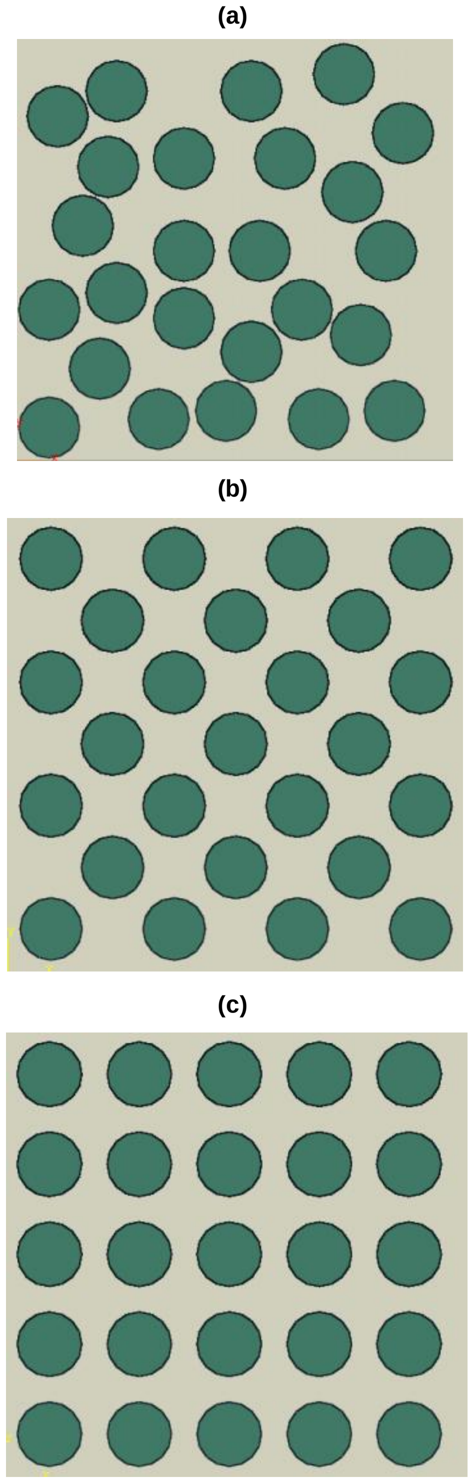
composites. Also Ene (ABAQUS/ STANDARD, 1998) has studied the heat transfer on five different models at interfacial thermal barrier between fiber and matrix. Also influence of interfacial barrier on thermal conductivity and heat transfer rate in composites. It was concluded that the heat transfer from component with interfacial thermal barrier resistance depends strongly on the value of resistance of thermal barrier between interface and component. In order to utilize the full potential of composite materials their response to different environments and effect of fibers on heat transfer must be fully known. Hence, the aim of this paper is to present a concise study of different 2D fiber polymer microstructures to assess heat transfer in fiber HTA reinforced in Matrix6376 polymers composites regimes under transient conditions.

MODELLING AND SIMULATION

The basic modeling of any fiber reinforced composite is governed by the factors such as fiber volume fraction, fiber diameter, no. of fibers. By considering the factors into account the model of a fiber is generated and afterwards for the simulation purpose different boundary conditions are implemented on the model according to the requirement.

The micro structural arrangement of fiber is generally random but RVE's considered for the current study are 2D square cell containing Random Array (RA), Square Edge Array (SEA), Square Diagonal Array (SDA) of fiber HTA in matrix 6376 phase with the fiber volume fraction (V_f) of 0.35. Different types of RVE's, although each statistically identical were

Figure 1: Different Micro Architectures Considered for the Study (a) Random Array (RA), (b) Square Edge Array (SEA) and (c) Square Diagonal Array (SDA)



generated each measuring 133 x 133 m containing 25 complete fibers with 18m diameter as shown in Figure 1.

Finite element software ABAQUS/ STANDARD (1998) will be used for simulation of heat transfer through the composite material and effects of fiber orientation on heat transfer in 2-D. In the heat transfer analysis, every node has one degree of freedom and temperature saturation is directly specified as a nodal value. In our finite element model, the heat transfer into material occurs across the left surface exposed to temperature of 973 K. Thus, it is possible to specify the maximum temperature attained under given environmental conditions as the boundary condition on these surfaces. At time t = 0, the entire RVE is at 0K temperature. Model was meshed using 4-node element (DCC2D4). Conduction properties used in the analysis are listed in Table 1.

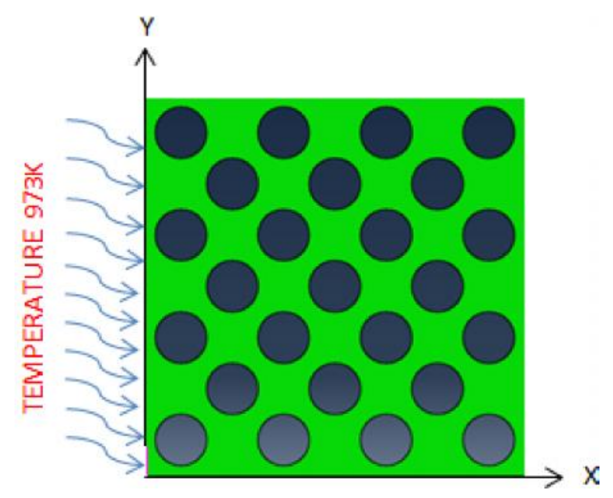
Table 1: Conduction Properties of Fiber, Epoxy and Interfacial Barrier

Property	Fiber	Epoxy	Interfacial Barrier
Conductivity (W/mK)	17	5	5000
Specific Heat (J/Kg K)	710	800	–
Density (Kg/m^3)	1760	1700	–

The computations were carried out for 1000, 1400, 1800, 2200, 2600, 3280 sec exposures and transient state accomplishment. As diameter of fibers are in micro meters (µ) which was 10^{-6} meters, but dimension in ABAQUS cannot be reduced more than 0.01 m therefore we have taken the meter-scale but a relation has been concluded between the time, dimensions and the conductivity of fiber and matrix.

For most of the fiber-reinforced polymer composites, conductivity of the fibers is near 1000 times compared to that of the epoxy matrix. ABAQUS employs the Fourier's law and its finite element formulation to perform the steady state and transient heat transfer analysis. Fourier's law is an empirical law based on observation. It states that the rate of heat flow, dQ/dt, through a homogeneous solid is directly proportional to the area, A, of the section at right angles to the direction of heat flow, and to the temperature difference along the path of heat flow, dT/dx.

Figure 2: Representation of Studied One-Dimensional Heat Transfer Problem



The heat transfer process follows the Fourier law of conduction that can be stated by heat conduction equation in differential form as:

$$Q = -kA\frac{dT}{dx} \quad ...(1)$$

k = Thermal Conductivity, W/mK

A = Cross-sectional Area, m^2

T = Temperature, K or °C

x = Heat flow path, m

q = heat flux

Q = heat flow rate

(Negative sign denotes heat transfer in the direction of decreasing temperature).

RESULTS

It has been found that the conductivity and time taken for saturation has inverse relation. To prove above statement a simulation has been carried out on a neat resin and a single fiber reinforced composite with 5 W/mK and 17 W/mK respective conductivities of matrix (resin) and fiber. For these models the time of saturation are 9×10^9 sec for neat resin and 8×10^9 sec for single fiber composite. But if the respective conductivity of matrix and fiber is increased to by 10^6 factor the time is reduced by 10^6 times, i.e., new conductivity is 5×10^6 W/mK and 17×10^6 W/mK then time of saturation is 890 sec and 798 sec. Also the dimensions of RVE are in meters not in micro-meters.

To investigate the response of different RVE architectures provided with 973 K temperature, finite element simulations were carried out for different exposure durations of 1000, 1400, 1800, 2200, 2600, 3280 sec and transient state achieved using Fourier Law of conduction.

Figure 3: Contours of Transient Heat Transfer Within Epoxy at Different Time Intervals Row 1: RA (1000, 1400, 1800, 2200, 2600, 3280 sec Saturation), Row 2: Type SDA (1000, 1400, 1800, 2200, 2600, 3280, 3495 sec Saturation), Row 3: Type SEA (1000, 1400, 1800, 2200, 2600, 3280, 3340 sec Saturation)

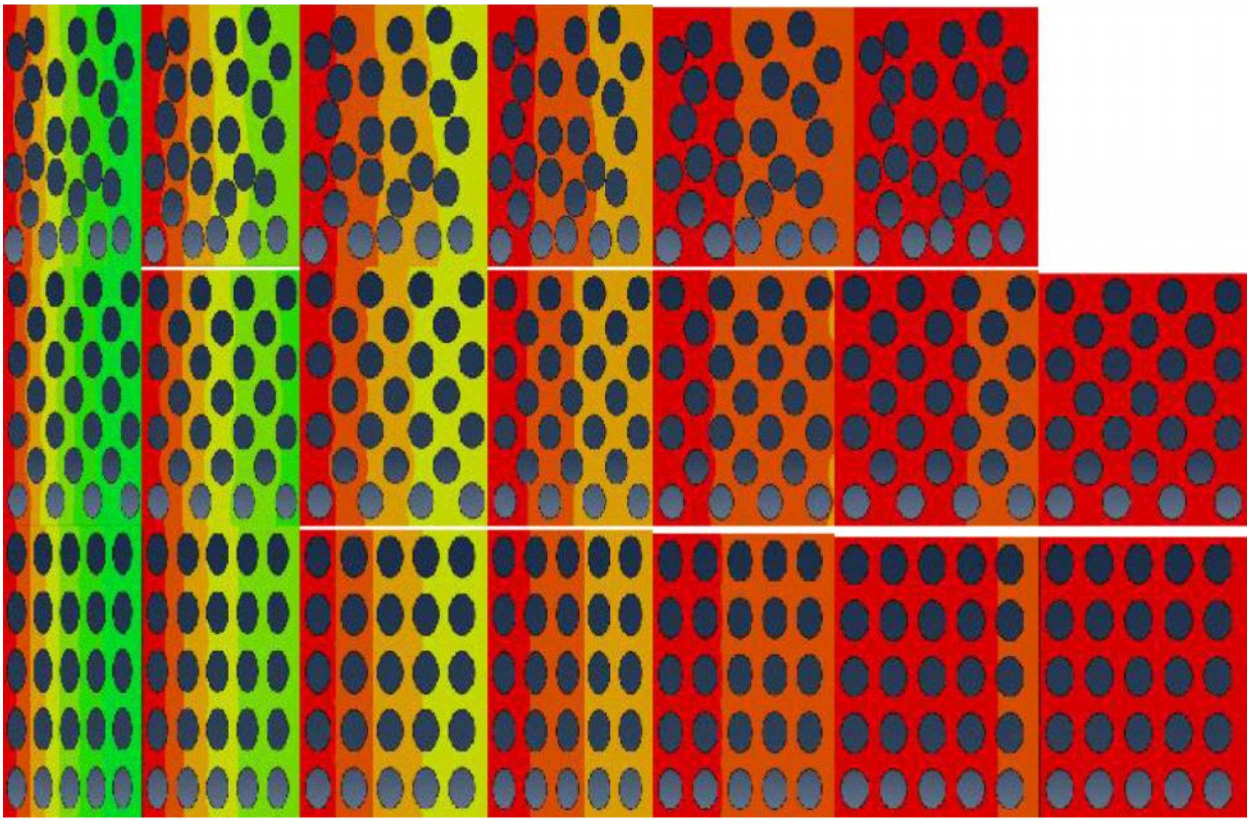
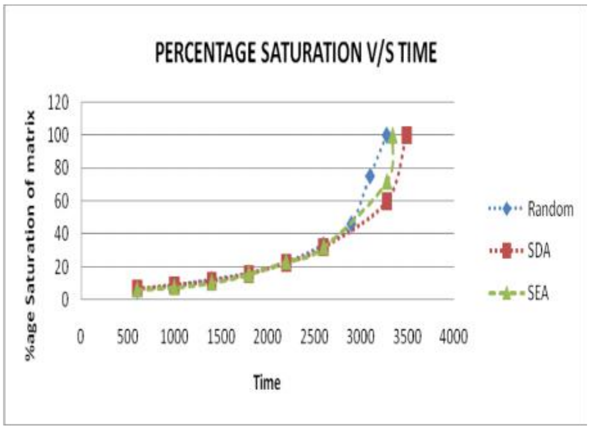


Figure 4: Saturated Epoxy Phase Fractions at Different Exposure Times for Different Topologies



Time taken for entire epoxy to fully saturate was 3280, 3495, 3340 sec for RA, SDA and SEA arrangements respectively. The rate of heat transfer through different fiber topologies have been shown in Figure 4 which gives a comparison between differences in rate of heat transfer.

A few important observations can be made based on this plot. Firstly, heat transfer rate is lower in random models than other two for around 5% saturation achieved, whereas it shows a reverse behavior during the later time intervals where heat transfer is much lower in Square diagonal and Square edge models than the random counterpart. Finally, there is considerable difference between the time taken for full saturation in random, square edge and square diagonal models. This shows that the square diagonal fiber arrangement is more resistant to the heat transfer than other two models.

CONCLUSION

Firstly, time for saturation is inversely related to the conductivity of the FRP composite, i.e., if we are taking the dimensions in meters and conductivity is increased by some factor then the time is reduced by same factor as conductivity is increased.

Secondly, Heat transfer is greatly influenced by the micro structural topology with the objectives in hand; the heat transfer analysis has been performed for various micro structural topologies by creating different arrangements of fibre insertion within matrix and their heat transfer response using finite element software. The fibre arrangements with square diagonal arrayes give more resistance to heat transfer, as time of saturation is more from other two cases.

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