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Influence of Thermal Conductivity on Stacking Sequence of Hybrid Composites

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Abstract**:** ***Hybrid Composites comprising of two or more reinforcement materials are finding increase in demand in diverse field of applications such as building panels, automotive components and aero parts. There is a need to study the thermal properties to find the suitability of hybrid laminates as insulating materials. In this research article an attempt is made to find the thermal conductivity of laminate materials having varying stacking sequence of its reinforcement fibers. The said laminate is produced using hand layup method. It contain seven layers of reinforcement fibers stacked one over other in three different configurations. First the reinforcements kevlar (K49) and basalt fibers are stacked in alternating layers. Second configuration contain bilayers of kevlar or basalt sandwiching the inner three alternative layers. Third configuration contain tri layer of one of the reinforcement fibers sandwiched between bilayers of another reinforcement fibers. Epoxy resin is used as binding cum matrix element in all the hybrid laminates. The produced hybrid laminates are tested for its thermal conductivity and coefficient of thermal expansion. It is found that increasing the number of layers of basalt fibers increased the thermal conductivity of the hybrid laminate. On the other hand, kevlar fibers contributed in reducing the thermal conductivity of the hybrid laminates. Thermal expansion coefficient depended on the presence of basalt fibers as the outermost layers in the hybrid laminates. The hybrid laminates having kevlar fibers contributed in lowering thermal conductivity and also the coefficient of thermal expansion.***

Keywords**:** ***hybrid laminates, basalt fibers, kevlar fibers, thermal conductivity, coefficient of thermal expansion***

I. INTRODUCTION

Laminate materials having different compositions as reinforcement among its various layers is classified under hybrid composite materials. Such laminates are finding increase in demand for various applications that extend from domestic items to high end industrial and scientific equipment. Some of the materials such as building panels, automotive parts, aeronautical components and marine structures require materials that have tailored properties. Hybrid composite materials are more suited for afore mentioned specific applications.

Very few literatures have focused on finding the thermal properties of composite materials. The influence of material characteristics on thermal conductivity of composite materials are highlighted. A strong influence between carbon fiber volume concentration and thermal conductivity was determined, in which the correlation was exponential for transverse thermal conductivity and linear along the fiber direction [1]. Thermal conductivity of hemp fiber reinforced polymer composite was compared between two theoretical models and an experimental results. There was good agreement between the results [2], [3]. Evaluation of thermos-physical properties of granite, sandstone and basalt in the temperature range of 25-1000 ^{o}C revealed that phase transition influenced the texture and stability of the materials [4].

Since laminate materials are made using different materials having different properties, there can be varying thermal properties between the interfaces. This can lead to widely varying effective thermal conductance because of the influence of interfacial thermal barrier resistance [5]. Comparison between in-plane conductivity and through thickness conductivity in carbon-epoxy laminate revealed that the former is four times greater than the latter because of directional dependence of thermal properties in fiber laminates [6]. Increase the volume of reinforcement material in fiber laminates can contribute to increase in thermal conductivity of the composite. This raise in thermal conductivity is exceptionally high if the fibers are not clustered but oriented in a definite direction [7].

The change in thermal conductivity depends on the thermal properties of reinforcement and matrix element used in the composite. While using unidirectional arranged Manila hemp as reinforcement in Poly-Lactic Acid (PLA) and epoxy resin as matrix element, the thermal conductivity is noted to reduce by 33.33 % with an increase in weight fraction from 40 to 69 wt. % [8]. Thermal conductivity reduced by 8 % while using 15.7 vol. % of glass fiber as reinforcement material and by 12 % while using same volume of banana fibers [9].

Reinforcement materials such as glass, carbon and kevlar has the ability to affect the weight loss during Thermal Gravimetric Analysis (TGA) and alter the thermal degradation temperature [10]. Thermal properties of fiber reinforcement composites depends on factors such as composition, size of fibers, length of fibers, its orientation and presence of defects within the composite [11]. This article studies the changes in thermal conductivity and coefficient of thermal expansion of hybrid laminates under the influence of reinforcement composition and stacking sequences.

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II. EXPERIMENTAL WORK

A. Material Selection

The materials chosen to make the laminate material are fibers of kevlar (K49) and basalt as the reinforcements. Both these materials were purchased as woven roving form with cross-ply fibers arrangement. The binding element was made up of epoxy resin LY556 and hardener HY951 in the ratio of 10:1. The thermal conductivities of individual components of the hybrid laminate is given the table below [12]–[14].

Table- I: Thermal properties of selected materials

Material	Thermal conductivity (W/mK)	Coefficient of thermal expansion 10^{-6} /°C
Kevlar (K49) fibers	0.04	--
Basalt fibers	0.031 – 0.038	6.5
Epoxy resin	2.8	--

B. Fabrication of Laminate

The hybrid laminate materials were produced using hand layup technique by stacking the reinforcement one over the other with intermediate epoxy acting as binding and matrix element. The layers of matrix and reinforcement materials were allowed to set under a mass of 15 kg for a duration of 24 h to allow sufficient time for curing. A total of six hybrid composites having varying stacking sequences with each having seven layers of reinforcement fibers were produced. The hybrid laminates are grouped into three configuration with the first having alternate layers of kevlar (K49) and basalt fibers. The second configuration contain bilayers of kevlar or basalt sandwiching the inner three alternative layers. Third configuration contain tri layer of one of the reinforcement fibers sandwiched between bilayers of another reinforcement fibers. Fig. 1 shows the image of the produced hybrid laminate.

Table- I: Codes of six different stacking sequences in hybrid laminate material

[B for basalt fibers; K for kevlar (K49) fibers]

Code for unidirectional basalt fibers	U	V	W	X	Y	Z
Stacking sequence of each hybrid laminate material	B	K	B	K	B	K
	K	B	B	K	B	K
	B	K	K	B	K	B
	K	B	B	K	K	B
	B	K	K	B	K	B
	K	B	B	K	B	K
	B	K	B	K	B	K

Fig. 1.Hybrid laminate reinforced with K49 and basalt fibers

C. Testing of Laminate

The produced laminate materials is tested to determine its effective thermal conductivity and also its coefficient if thermal expansion. Specimen for the test were cut to ASTM E-1530 standards. The test were carried out using Unitherm Model 2022 testing machine.

III. NUMERICAL APPROXIMATION

The thermal conductivity of the produced hybrid composite material is calculated using Fourier's law of heat conduction as in (1).

$$k = \frac{ql}{\Delta T} \quad (1)$$

where k is the thermal conductivity of the hybrid composite material (W/mK), q is the heat flux along the stacked layers of the hybrid composites, l is thickness of the hybrid composite and ΔT is the difference in temperature between the top and bottom of the stack. In this case, q is found in using equation as in (2)

$$q = \frac{Q}{A} \quad (2)$$

where Q is the heat transfer rate through the hybrid composite and A is the cross sectional area of the produced laminate.

IV. RESULT AND DISCUSSION

A. Thermal Conductivity of Laminate Materials

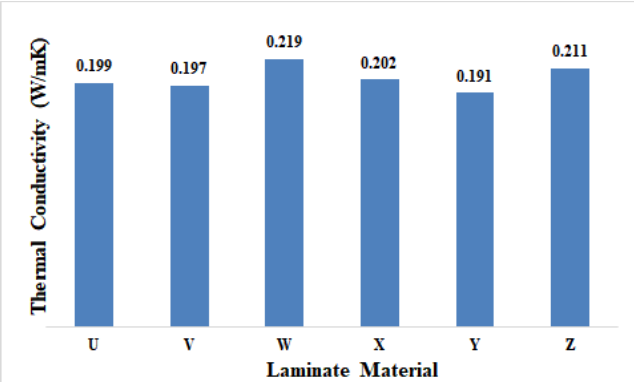

Fig. 2.Thermal conductivity of the produced laminates

Fig. 2 shows the variation in thermal conductivity of the six hybrid composites produced for this research work. The intended purpose of producing the hybrid laminates were to lower the thermal conductivity to use it as an insulating material. The highest thermal conductivity of 0.219 W/mK is exhibited by the hybrid laminate coded W. This has the stacking sequence of a central basalt fiber sandwiched between kevlar fibers which are in turn sandwiched between dual layers of basalt fibers. This was followed by the hybrid composite Z having tri layers of basalt fibers sandwiched between dual layers of kevlar fibers with thermal conductivity of 0.211 W/mK. Another hybrid laminate X which had mirror image of W maintained thermal conductivity of 0.202 W/mK.

B. Coefficient of Linear Thermal Expansion

Fig. 3 shows the variation in coefficient of linear thermal expansion of the six hybrid laminates produced for this research work. It is noted that the hybrid composites V, X and Z having kevlar fibers along the outer layers had the lower thermal expansion of 8.24, 9.26 and 8.93 x $10^{-6}/^{o}C$.

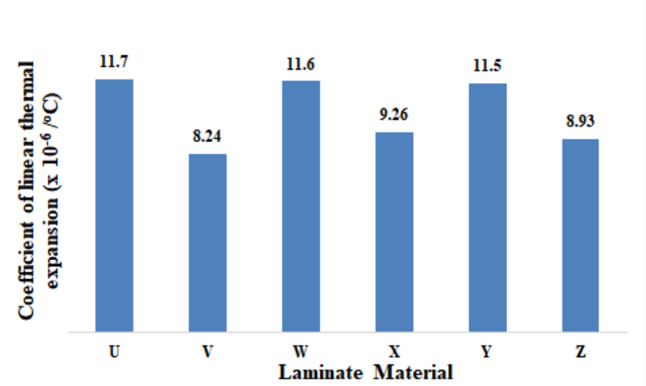

Fig. 3.Thermal expansion coefficient of the produced laminates

C. Inference on Findings

It is noted that the thermal conductivity of the hybrid laminates depended on the order in which the reinforcement fibers were arranged. In case of alternating layers, the thermal conductivity were 0.199 W/mK and 0.197 W/mK for the hybrid laminates U and V respectively. In the latter of the two hybrid laminates, there was one less layers of basalt fibers. Likewise, the hybrid laminates having bilayers of basalt exhibited 7.76 % greater thermal conductivity compared to its counterpart that had bilayers of kevlar fibers. Likewise, among the composites having tri layer of same reinforcement among its stacking sequence, the one having basalt fibers showed 9.5 % greater thermal conductivity than its counterparts.

Since both the reinforcement has cross-ply arrangement of its fibers, the distribution of thermal conductivity is isotropic in nature. The increase in thermal conductivity in the hybrid laminates is associated with the contribution of epoxy resin that has greater thermal conductivity. Basalt fibers has affinity towards epoxy resin that permits the binding material to seep in through the pores the woven fibers. As a result, the binding material could get distributed evenly into the layers of the hybrid laminate. During the heat transfer, the epoxy resin allowed proper diffusion of heat giving raise to increase in thermal conductivity.

Thermal expansion coefficient graph revealed that every hybrid laminates having kevlar in its out layer had 20 % to 29.6 % lower expansion coefficient compared to its counterparts having basalt fibers as the out layers. Interestingly, adding layers of same composition increased the thermal expansion coefficient. This is because of increase in the thermal conductivity backed by epoxy resin.

V. CONCLUSION

Thermal conductivity of the hybrid laminates increased under the influence of epoxy resin. The affinity between basalt fibers and epoxy resin, enhanced the effective thermal conductivity through the various layers of the laminates. Presence of kevlar interfered the direct contact between the epoxy resin, thus interfering the transfer thermal properties between the subsequent layers. Presence of kevlar is beneficial in reducing the thermal conductivity and also coefficient of linear thermal expansion. Addition of kevlar layers enhanced the insulating property of the hybrid laminates.

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