

Investigation on Moisture Absorption and Fire Retardant Behaviour of Glass Fiber, Jute Fiber and Hybrid Glass/Jute Fiber Reinforced with Epoxy/Polyester Resin made by Hand Layup and Vartm Technique

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Abstract

CO_2 and other toxic emissions from vehicles cause global warming and climate change. This is a serious problem the world is facing right now. One of the best solutions to reduce this effect is to replace the use of existing sheet metal with lightweight composite parts in automobiles. Fiber Reinforced Polymer (FRP) composites can rectify drawbacks of conventional metal such as High Strength Steel (HSS) and aluminum due to their high strength and stiffness-to-weight ratio. In this work, investigation was conducted for synthetic glass fiber, hazard-free natural jute fiber, highly stable epoxy resin, and low-cost isophthalic polyester resin. In addition, the composite is developed using traditional hand layup and advance VARTM methods. In addition, hybrid glass/jute isophthalic composite was also fabricated. Glass Fiber Reinforced Polymer (GFRP) made by VARTM shows excellent properties due to its low void and high bonding nature. The sustainability of the material under high environment impact was tested by water absorption, change of Barcol hardness, and fire-retardant test. The result shows that, higher moisture absorption and poor fire safety for (natural) jute fiber composites. The GFRP showed negligible water absorption and safety material whereas isophthalic resin showed negligible change in burning property compare to epoxy.

Keywords: *GFRP, Environmental Impact, Hand Layup, VARTM, Fire safe*

Introduction

The increase in automobile is responsible for 65% of air pollution (Joshi and Swami 2007). Automobiles emit significant quantity of hydrocarbons, Sulphur dioxide (SO2), nitrogen oxide (NO& NO2), large amount of carbon monoxide (CO), and carbon dioxide (CO2). This rapid increase in the air pollution has resulted in the air quality deteriorated in developing countries (Helmut Mayer 1999). Automobiles account for 26% of global CO2 emission, which leads to major climate change (Chapman 2007). All over the world different methods are followed to reduce air pollution. From the automobile perspective, replacing conventional metal with a lightweight material is highly preferable to reduce greenhouse gas and increase fuel economy (Dhingra & Das 2014). To overcome the limitation of monolithic metal, alternative light weight synthetic and natural fiber-based reinforced polymer (FRP) composites are in demand from the engineering sector (Jagadeesh *et al*. 2022). The main purpose of this study is to overcome limitations of the composite such as high cost, low binding properties and high environmental damage.

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The lightweight composite material increases fuel economy and are required by the automobile industry to replace the conventional metals such as HSS and aluminum (Witik *et al.* 2011). The carbon, Kevlar and fiberglass are widely used in favor of strength and stiffness with respect to weight ratio, but their application is not widespread due to limitations such as high cost, recycling failure, damage environment, and uneven bonding and fiber peeling. The selection of the FRP material (fiber and resin) is important to satisfy all properties with respect to existing sheet metal body structure.

The selected material should be low cost and flexible in order to be considered for different production technique. They must be fire safe and of high quality and to withstand moisture abortion property (Sreadha, AR & Pany 2020). Natural fiber jute and glass fiber with matrix epoxy and isophthalic is preferred in this study mainly due to its low cost, availability, high degradable quality, and the characteristics should be satisfied with respect to the environmental impact resistance.

In this research, a change of production technique and *Vf*% with respect to quality of material is considered (Ferrara & Meda 2006). Although many studies are conducted on composite materials to understand their ability to withstand environmental impact, it should be noted that the material must withstand fire and resist moisture. Kootsookos and Mouritz (2004) studied the seawater moisture absorption rate at 30°C for 2 years using CFRP and GFRP with polymer resin. The material shows noticeable degradation and flexural strength and modulus are reduced (Yan & Chouw 2015). This degradation is mainly due to poor bonding of fiber and matrix. Liu *et al.* (2015) reported that mechanical and the physical properties of the composites are based not only on fiber but also on the resin or matrix. By varying the resin it is found that there is no significant effect on moisture absorption property (Pandian *et al.* 2014). The experimental result showed that, moisture absorption is one of the major drawbacks in Natural finer composites (NFC) material and this can be remedied by hybridizing natural fiber with synthetic fiber, and change of resin had negligible impact on the differences in the properties of composite laminates. The author suggested the change of resin does not make significant effect on the environmental impact property. Arao *et al*. (2008) reported the FRP material should maintain a moisture absorption of 0–1.8% for aerospace application, and an increase in the performance of the material was found at the reduced moisture content. Suzanne *et al.* (2014) measured the flammability properties, the chemical kinetics of composite materials is complex to determine the limited oxygen index (LOI).

The LOI is effective method and is widely used in industries to find fire prevention property (Liu et al. 2021). Xu *et al*. (2021) reported the. In addition, the increased use of curing agents in the preparation of (FRP) composites reduced the thermal conductivity, decreases the exo-thermicity, and natural fiber composite production shows combustible carbon in the material. In most cases, FRP is classified based on the fire retardation testing and calculations of LOI value (Ramadan *et al*. 2021). In standard, the percentage of O2 is fixed as 20.95%, and it is used to categorize the material based on its flammability nature, as shown in Table 2.4. Zakaria *et al.* (2016) reported jute fiber is the best fiber compared to other natural fiber to withstand environmental impact. But the drawback is that, 20 wt% of jute fiber with unsaturated polyester has a LOI of 33 and it shows self-extinguishing nature. Also the water or moisture absorption is high (2.7%) and it randomly reduces the micro hardness.

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Materials and manufacturing methods

In this study, two type of fiber such as synthetic E-glass fiber 300 GSM (grams per square meter) and jute plant (*Corchorus olitorius*) 20 yarns (248 Tex) with density of 1.42 g/cm3 and 2.52 g/cm3, respectively. The two different matrices such as epoxy and isophthalic polyester were used in this study. The epoxy resin (Araldite LY 556) with density 1.17 g/cm3 and catalyst XB 3403 are used at 1 : 0.25 ratio. The isophthalic polyester (NRC 220) with density 1.1 g/cm3 and catalyst MEKP (methyl ethyl ketone peroxide) addition with cobalt naphthenate accelerator re used at 1 : 0.025 : 0.015 ratio. In this study, two different composite manufacturing techniques such as hand layup and VARTM technique is used.

In hand layup process, the fabrics where cut and placed manually by layer by layer on clean mold or paten by applying matrix in-between them. But in VARTM, multiple layers of fabrics were covered with vacuum bag and tightly sealed by silicon tape and the resin catalyst mixture of ratio 1 : 0.45 is injection with pressure 25 psi (0.17 MPa) using vacuum pump . In both technique, after 2 hours of pre-curing, the specimen was removed from the mold and stored for 24 hour at room temperature. VARTM process failed for jute fiber composite due to uneven resin flow. Fiber volume fraction and percentage of void is calculated using Equations (1 - 5):

$$V_f = v_f / v_m \quad (1)$$

$$V_f + V_m = 1 \quad (2)$$

$$V_f = \frac{M_f/\rho_f}{M_f/\rho_f + M_m/\rho_m} \quad (3)$$

$$\mathrm{V_f} = \frac{\left(M_{fj}/\rho_{fj}\right) + \left(M_{fg}/\rho_{fg}\right)}{\left(M_{fj}/\rho_{fj}\right) + \left(M_{fg}/\rho_{fg}\right) + \left(M_m/\rho_m\right)} \quad (4)$$

$$\mathrm{V_{void}}\ \% = \frac{\rho_t - \rho_a}{\rho_t} \times 100 \quad (5)$$

where: Vf – fiber volume fraction, Vm – matrix volume fraction, vf and vm – volume of fiber and matrix, respectively.
Seven groups of composite specimens such as synthetic fiber, NFCs and hybrids were manufactured by hand layup and VARTM method as shown in Table 1.

Table 1: Composite specimens for investigation

Configuration code	Stacking sequence	Making process	Fiber orientation	Thickness (mm)	Fiber volume fraction (Vf%)	Density (kg/m3)	V_{void}(%)
A	Glass fiber/ epoxy composite	HL	[45g/0g/90g/-45g]8	5	45	2500	1.51
B	Glass fiber/ polyester composite	HL	[45g/0g/90g/-45g]8	5	45	2500	1.50
C	Glass – jute/polyester composite	HL	[0g/45g/0j5/-45g/0g]2	5	32	1700	1.62

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D	Glass – jute/polyester composite	HL	[0g/45g/0j/-45g/0g]2	3	22	1700	1.53
E	Glass fiber/ polyester composite	HL	[45g/0g/90g/-45g]6	3	45	2500	1.45
F	Jute fiber/ polyester	HL	[0j/45j/90j/-45j/0j]2	3	29	1900	1.81
G	Glass fiber/ polyester composite	VARTM	[45g/0g/90g/-45g]6	3	52	2500	0.21

Experimental setup

Moisture absorption test

The moisture absorption test is carried out as per ASTM D570, The specimens were subjected to water with a period of 7 days and the Borcol hardness test was conducted at various 2-6 hours time intervals according to ASTM D2583-07. The hardness value is calculated using the formula HBa=100-(h/0.0076), were *HBa* represents Barcol hardness value and *h* indicates the indentation depth (mm). The percentage of water absorption was calculated by the weight difference using equation (6),

$$M = \left(\frac{W_t - W_o}{W_o}\right) \times 100\% \qquad (6)$$

where *W0* and *Wt* denote the original dry weight of the sample and weight of moisture absorbed specimen after specific time and *M%* is the water absorption percentage. The effect of moisture absorption property and changes in composite hardness were recorded and moisture absorption and weight measurement setup as in figure 1 and hardness measured by Barcol hardness tester as shown in figure 2.

Figure 1 Moisture absorption and weight measurement setup

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Figure 2 Hardness measured by Barcol hardness tester

Fire retardant Test

Fire retardant property was investigated for specimens by varying O2 and N levels and the limiting oxygen index was calculated to identify the burning property of fiber and matrix combination as per ASTM D2863 standard. During the test, top surface of the specimen is ignited by the fire and is placed inside the tube. By applying the flame from the top to the bottom edge of the specimen, the top of the burner remains 10 mm below the point of the lower end of the specimen, and that distance is maintained for 60 seconds. The LOI was calculated by equation (7) and the burning ratio was calculated using equation (8). The Fire-retardant test setup as shown in figure 3 and the fire-retardant test and burned composite specimens as shown in figure 4.

$$\text{LOI} = \frac{O_2}{O_2+N_2} \times 100 \quad (7)$$

$$\text{Burn ratio} = \left(\frac{60 \times Distance}{Time}\right)(\text{mm/min}) \quad (8)$$

Figure 3 Fire-retardant test setup

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Figure 4 Fire-retardant test and burned composite specimens

Result and discussion

Effect of moisture absorption property

Moisture absorption is measured by the increase in weight by absorbing water relative to the dry weight of the samples. It shows that, water absorption increased during the first 2 days for all speciments, and comparing with synthetic fiber, NFCs and hybrids showed a sharp linear increase in the moisture absorption and decrease in the hardness value. The water absorption with respect to Barcol hardness value is shown in Figures 5 and 6**.** The result of water absorption for specimens C and D during the first 2 days was 13% and 12%, respectively, and it was found that the increase in volume of natural fiber (by increasing the thickness of the specimen) increases the moisture absorption property.

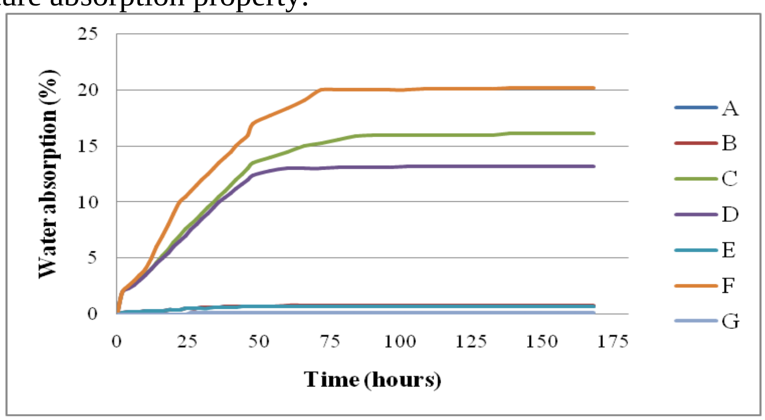

Figure 5 Water absorption of composite

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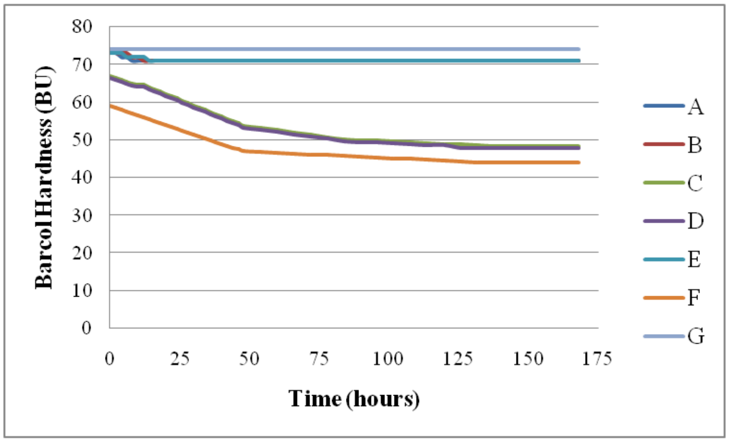

Figure 6 Barcol hardness of composite specimens with respect to water absorption

The final moisture absorption percentage of C and D hybrids was 16.1% and 13.2% with the hardness value being 48.4 and 48BU. The pure jute specimen F shows high moisture absorption (20.2%) with very low hardness of 44BU. The continuous increase in water absorption in jute fiber-based pure jute and hybrid specimens showed continuous decrease in the hardness value. Moisture absorption property of specimens A and B shows similar and negligible changes with 0.7% and 0.8%, and the hardness value of 71BU was similar for both specimens. This suggests that the change of resin does not make a major influence on the moisture absorption and hardness values.

Comparing specimens E and G, the result showed improvement in specimen G with water absorption of 0.7% and 0.1% and hardness of 71 and 74BU, respectively. This change in the value of similar material specimen was mainly due to the change in manufacturing technique and change in the *Vf*%. The low *Vf*% in specimen E showed more void compared to specimen G, and this void was filled by water molecules during the moisture absorption test and increased the overall weight of the specimen. The effect of high hardness on G specimen was mainly due to high *Vf*% where as low moisture absorption was owing to low void (0.5%) in the specimen prepared using the VARTM process.

In comparison of natural and synthetic fibers, synthetic fiber is superior in terms of moisture absorption property, where as the hardness value remains same. Although hybrid shows better moisture absorption, it does not exert influence compared to hardness value. The high *Vf*% synthetic material specimen G shows excellent results for both moisture absorption and material hardness.

Effect of LOI on fire retardant test

The flammability test conducted at UL-94 by considering standard O2 average range at atmospheric air as 20.95% to identify composite material combustion nature. The three important factors considered for fire test are fuel, O2, and heat. In the fire-retardant test, one of the factors controlled is O2 and N by varying these levels, burning property can be calculated. In this study, initial O2, N and atmospheric air values were fixed at 40%, 40%, and 20% as standard and supply to a glass tube. At ignition, O2 distribution value was 17%, N supply value as 69% and 14% atmospheric air is maintained at open atmospheric inside a glass tube with standard room temperature of 25^{o}C. The fire-retardant test and burned specimens are shown in Figure 6.7 and results are given in Table 2.

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The result of the flammability test showed that in both epoxy and polyester resins, burning time increases gradually when ignition starts. The LOI of glass fiber specimens (A, B, E & G) showed better result compared to natural fiber–based specimens (C, D & F). The LOI of specimens A and B was 39 and 38 with burning ratio of 80 and 87 mm min–1 with uniform fast burning.

The result showed higher LOI value of epoxy, which represents higher stability compared to polyester resin. Moreover, the presence of glass fiber in specimens A, B, E, and G showed high LOI value and this result was mainly because glass fiber was basically acting as physical barrier against flame. Although epoxy is thermally stable, it has a similar response to isophthalic resin material with a negligible difference in burning time. Comparing specimens E and G, specimen G showed a better result with low burning time, low burning ratio, and high LOI value. This high LOI shows low heat flux and high flammable resistance. Hybrid specimens C and D showed better LOI value compared to specimen F, but they had very low LOI and fiber burning. This shows that the natural jute fiber–based composite is not safe and is not an environmentally suitable material for high heat application.

Table 2: Fire retardant test with burning ratio and LOI value

Sample	LOI	Burning time/sec	Burning length/mm	Burning rate/mm min^{-1}	Notes
A	39	80	107	80	Fast burning of resin
B	38	79	115	87	Fast burning of resin
C	31	61	109	107	Readily burning and glass fiber not burn
D	32	60	110	108	Readily burning and glass fiber not burn
E	37	75	112	89	Fast burning of resin
F	28	55	105	114	Readily burning and fiber char formation is high
G	41	79	102	77	Slow burning

Conclusions

The following conclusions are made based on the moisture absorption and fire retardant test to identify an environmentally stability of the material.

i. The water absorption is high in the first 24–36 hours in all specimens. Natural fiber–based composites and hybrids result shows increase in the jute fiber volume, which increases the moisture absorption. The hybrid specimens C and D shows moisture absorption of 16.1% and 13.2% with hardness values of 48.4 and 48BU, but the pure jute specimen F has a high moisture absorption (20.2%) with a very low hardness value of 44BU.

ii. Moisture absorption properties of specimens A and B show almost identical value and low moisture absorption (0.7% and 0.8%). The same amount of moisture absorption and hardness is achieved in specimen E (0.7% and 71BU), which shows that the thickness does not affect the moisture and hardness properties, but specimen G shows negligible moisture absorption of 0.1% with a high hardness value of 74BU. The excellent hardness and moisture

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resistance are mainly due to the negligible amount of void in specimen G prepared by the VARTM process.

iii. LOI values of glass fiber specimens show better result compared to natural fiber specimens. Jute fiber composite is an unsafe material because jute fiber burns with resin and shows a low LOI value of 28. The LOI values for specimen A and B are 39 and 38, and this difference is minimum but compared to polyester resin, epoxy resin shows higher thermal stability with respect to burning time.

Considering these results, glass fiber is selected as the appropriate material for the auto component product. The isophthalic resin modification does not cause any significant changes in environmental impact damage, that is, the property is simpler to the result of expensive epoxy resin. This result satisfied the engineering requirements for automobile part manufacturing with high-strength to weight ratio. From the above conclusion, it has been decided that glass fiber/ isophthalic reinforced composite, made by this VARTM process, is the best material for making composite automobile component.

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