Mechanical and thermal behavior of hybrid glass/jute fiber reinforced composites with epoxy/polyester resin

P. Manuneethi Arasu [1), *)], A. Karthikayan[1)], R. Venkatachalam[2)]

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Abstract: The hybrid glass/jute fiber composites were fabricated by hand layup (HL) and vacuum assisted resin transfer molding (VARTM) method using epoxy and isophthalic polyester resins as matrices. The effects of fiber and matrix type as well as fabrication method on the tensile and flexural mechanical strength of resulting composites were investigated. The morphological fracture was analyzed based on scanning electron microscopy (SEM) images. Also, the curing characteristics of two matrix resins was studied by using differential scanning calorimetry (DSC). For glass fiber composite, the curing rate of polyester resin is faster at 100 °C than that of composite with epoxy matrix. Using VARTM process, the composite with high fiber volume fraction (V_f) of 52% was obtained.

Keywords: GFRP composite, hybrid composite, VARTM process, DSC analysis.

Mechaniczne i termiczne właściwości hybrydowych kompozytów na bazie żywicy epoksydowej/poliestrowej wzmocnionych włóknem szklanym i jutowym

Streszczenie: Hybrydowe kompozyty z włóknem szklanym i jutowym otrzymano metodami laminowania ręcznego (HL) oraz wspomaganego próżniowo formowania polimeryzacyjnego (VARTM**)** na osnowie żywicy epoksydowej lub izoftalowej poliestrowej. Badano wpływ rodzaju wzmocnienia i osnowy oraz metody wytwarzania kompozytów na ich wytrzymałość w testach rozciągania i zginania. Morfologię przełomów kompozytów analizowano za pomocą skaningowej mikroskopii elektronowej (SEM). Metodą skaningowej kalorymetrii różnicowej (DSC) określono charakterystykę utwardzania kompozytów na różnych osnowach żywicznych. Szybkość utwardzania w temperaturze 100 °C kompozytów żywicy poliestrowej z włóknem szklanym jest większa niż kompozytów z osnową żywicy epoksydowej. Metodą VARTM uzyskano kompozyt z dużym udziałem objętościowym włókna (V_f) równym 52%.

Słowa kluczowe: kompozyty GFRP, kompozyty hybrydowe, proces VARTM, analiza DSC.

Carbon, kevlar and glass fiber composites, due to their light weight and high tensile strength, are increasingly being used in various applications replacing metals like steel and aluminum [1]. Glass fiber reinforced polymers (GFRP) as low cost and robust materials are used in aerospace and military applications [2, 3] as well as in automobile industry [4]. However, being non-degradable and non-recyclable materials, they contribute to worldwide environmental pollution. Consequently, much of the research is focused on high quality composite materials, which are biodegradable or able to be recycled. Natural fibers offer environmentally friendly solution having the advantages of low density, low cost, biodegradability, good thermal properties and low energy consumption during processing [5–7].

As reported in the study of Vijaya Ramnath *et al*. [8], in case of the usage of natural fibers in curved pipes a cost reduction of 20% can be achieved compared to synthetic fibers. These "green" components provide environmental advantages in low mechanical strength applications [9–11].

Other studies demonstrated that hybrid fiber system such as glass/jute composite is a superior solution compared to that containing only jute fibers, moderately cheaper and easy to use [12, 13].

As it was shown in the work of Mirmiran *et al*. [14] the properties of composite material depend not only on the type of fiber but also on the matrix properties such as interface bonding, curing time, density and viscosity. Epoxy resins are widely used in the manufacture of composite parts due to high thermal stability, however these resins are expensive [15–17]. In this study, low cost isophthalic polyester resin is used as an

[1)] KSR College of Engineering, Department of Mechanical Engineering, Tiruchengode-636 403, Tamil Nadu, India.

[2)] Department of Automobile Engineering, KSR College of Engineering, Tiruchengode, Tamil Nadu, India.

[*)] Author for correspondence;

e-mail: manuneethi222@gmail.com

alternative matrix. Various modifications of matrices and processing methods can change the properties of composite materials [18–20]. To increase the curing time and maintain dimensional stability, nowadays advanced manufacturing methods replace traditional hand layup (HL) method. Markicevic *et al.* [21] analyzed a vacuum assisted processing method, which allow for reducing resin percentage and thickness of composite parts [22] by increasing fiber volume fraction (V_f).

In this paper, vacuum assisted resin transfer manufacturing (VARTM) method, in which vacuum is used for transferring the resin in between fiber laminates, was employed for the composite fabrication [23]. Alms *et al.* carried out experiment on VARTM method in order to eliminate volatile organic component and improve the cost efficiency and composite strength [24]. This paper shows how the properties of glass fiber/jute composites are influenced by changing the type of fiber and matrix and manufacturing method.

EXPERIMENTAL PART

Materials

Synthetic E-glass fiber 300 GSM (grams per square meter) and jute plant (*Corchorus olitorius*) 20 yarns (248 Tex) with total surface mass density of 315.8 g/m^2 were used in this study. The density of E-glass and jute fibers are determined by water displacement method and found to be 1.42 g/cm^3 and 2.52 g/cm^3, respectively.

Two different matrices were used:

– epoxy resin (Araldite LY 556) with density 1.17 g/cm^3 and catalyst XB 3403 at 1 : 0.25 ratio;

– isophthalic polyester (NRC 220) with density 1.1 g/cm^3, catalyst MEKP (methyl ethyl ketone peroxide) and cobalt naphthenate accelerator at 1 : 0.025 : 0.015 ratio.

Samples preparation

Seven groups of composite specimens were manufactured using hand layup and VARTM method as shown in Table 1.

The process was preceded by cleaning the mold surface using acetone and applying PVA [poly(vinyl alcohol)] as release agent on the surface of the mold. The laminate orientation was fixed in a mold with dimensions 30 × 30 cm. For hand layup process, fabrics where cut and pre-impregnated with matrix system, then manually placed layer by layer. For VARTM, multiple layers of fabrics were covered with vacuum bag and tightly sealed by silicon tape. Fabric and resin with catalyst were taken in the ratio of 1 : 0.45 and filled inside the mold by injection pressure 25 psi (0.17 MPa) using vacuum pump controller. 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 is calculated using Equations (1) and (2):

$$V_f = (v_f/v_m) \tag{1}$$

$$V_f + V_m = 1 \tag{2}$$

where: V_f – fiber volume fraction, V_m – matrix volume fraction, v_f and v_m – volume of fiber and matrix, respectively.

Methods of testing

Mechanical tests

Tensile and three-point flexural test were conducted on Zwick Roell testing machine with pre-load 5 MPa and 1 MPa at the speed of 2 mm/min. Tensile test ASTM D 3039 for specimens with dimensions 200 × 25 × actual thickness (3 or 5) (mm^3) and tensile stress *vs.* tensile strain graph were recorded until the break of the specimens with tensile modulus. For three-point flexural test ASTM D790 the specimens with dimensions 60 × 15 × actual thickness (3 or 5) (mm^3) were used and flexural stress *vs.* flexural strain were recorded with flexural modulus to determine stiffness and interference bonding strength. Broken specimens were cut to the dimensions 10 × 10 × actual thickness (3 or 5) (mm^3) for morphological failure analysis using scanning electron microscope (SEM) by ZEISS-3400N machine.

Thermal test

Chopped powder specimens A and G were analyzed using differential scanning calorimeter (DSC) on STA449F3

T a b l e 1. Composite specimens

Configuration code	Stacking sequence	Manufacturing process	Fiber orientation	Fiber volume fraction, %	Thickness mm
A	Glass fiber/epoxy composite	HL	$[45/0/90/-45]_8$	45	5
B	Glass fiber/polyester composite	HL	$[45/0/90/-45]_8$	45	5
C	Glass-jute/polyester composite	HL	$[0g/45g/0j_5/-45g/0g]_2$	32	5
D	Glass-jute/polyester composite	HL	$[0g/45g/0j/-45g/0g]_2$	22	3
E	Glass fiber/polyester composite	HL	$[45/0/90/-45]_6$	45	3
F	Jute fiber/polyester composite	HL	$[0/45/90/-45/0]_2$	29	3
G	Glass fiber/polyester composite	VARTM	$[45/0/90/-45]_6$	52	3

Jupiter machine. The specimens of 6–8 mg weight were heated in a closed aluminum crucible at 0–427 °C at a heat rate of 10 °C/min while supplying N_2 gas. The scanner baseline was adjusted as per the heat flow and the thermograms were recorded as heat flow *vs*. temperature with glass transition temperature as quasi-static linear response by melting the resin for 1 h time intervals.

RESULTS AND DISCUSSION

Tensile properties

Tensile graph and ultimate tensile strength with tensile modulus bar chart are shown in Fig. 1 and Fig. 2 indicating the brittleness and ductile nature of the composites.

The specimens containing only glass fiber reinforcement show the highest values of elongation at break in the range of 4 to 5. Specimens A (epoxy matrix) and B (polyester matrix) show maximum tensile values of 340 MPa and 351 MPa with tensile modulus 13.8 GPa and 12.6 GPa, respectively. Therefore, the change of resin type results in a negligible change in tensile properties. Tensile strength values for the samples E and G are 245 MPa and 268 MPa, while tensile modulus values are 8.91 GPa and 9.30 GPa, respectively, showing an increase with increasing fiber volume fraction V_f. Specimen F containing only jute fiber shows low elongation at break and low tensile strength 81 MPa with tensile modulus of 6.5 GPa. Hybrid specimens C and D show tensile strength values of 165 MPa and 105 MPa with tensile modulus 5.7 GPa and 8.6 GPa, respectively. SEM micrograph of specimen G (Fig. 3) demonstrates strong bonding between fiber and matrix due to high V_f in comparison with specimen E (Fig. 4).

Flexural properties

Flexural strength graph and flexural modulus bar chart are shown in Figs. 5 and 6.

Specimens B and E (glass fiber/polyester composite) show very low offset yield. GFRP specimens A, B, E and G show high flexural strength 56 MPa, 58 MPa, 39 MPa and 54 MPa and high flexural modulus of 3.6 GPa, 3.7 GPa, 2.7 GPa and 3.4 GPa, respectively, but more failure in compressive side. Natural fiber composites C, D

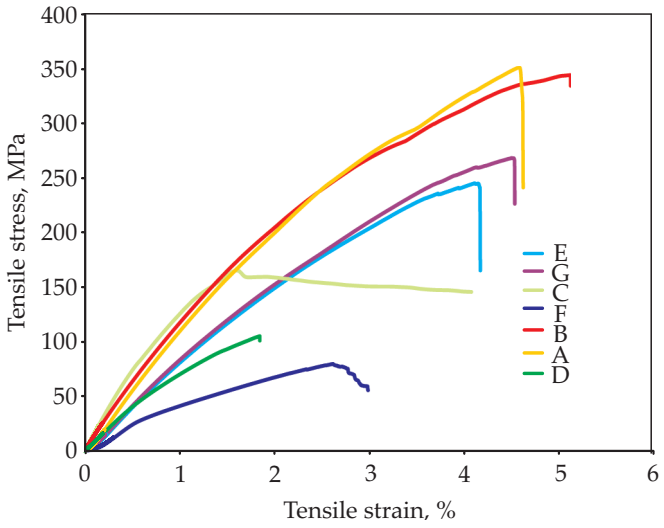

Fig. 1. Tensile graph

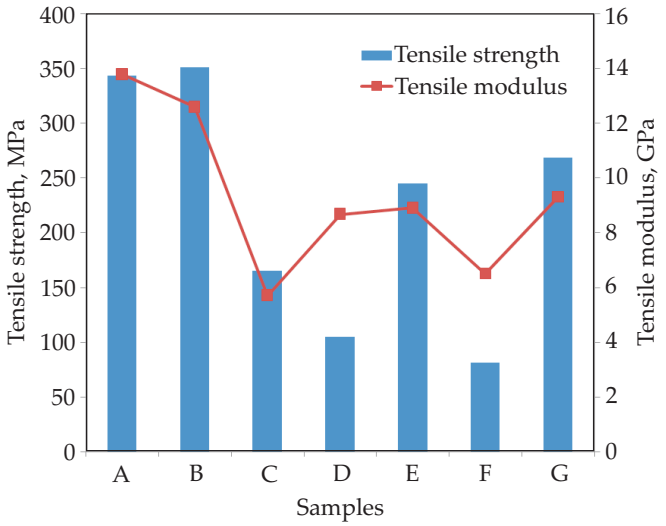

Fig. 2. Ultimate tensile strength and tensile modulus

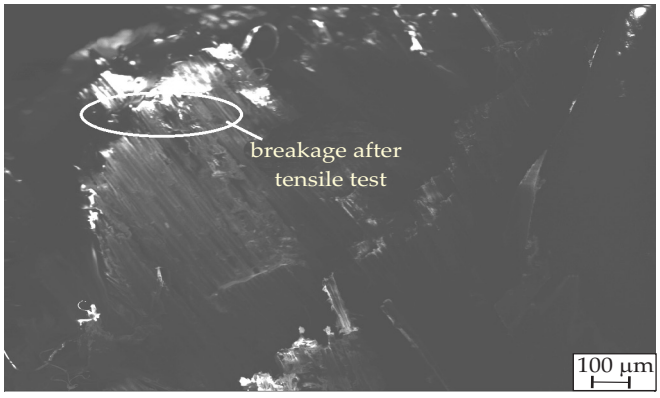

Fig. 3. SEM image of specimen G showing tight fiber bonding and fiber breakage

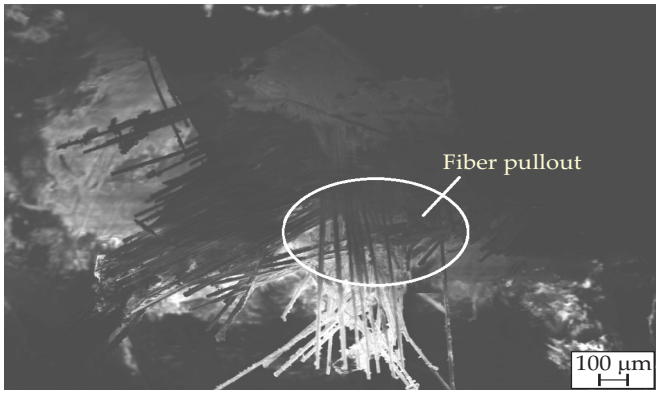

Fig. 4. SEM image of specimen E showing fiber pullout

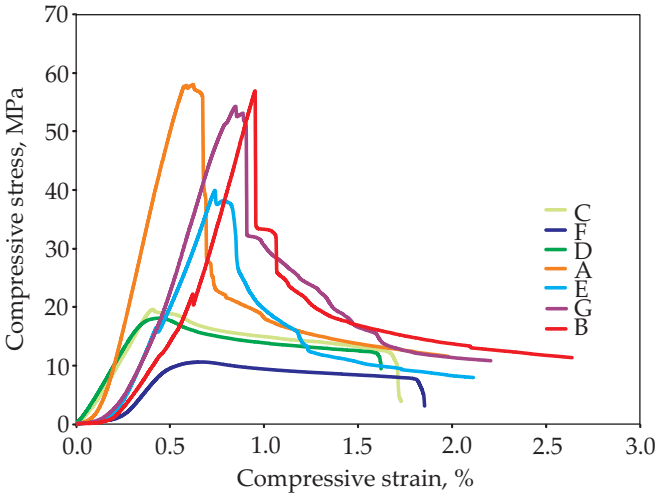

Fig. 5. Flexural graph

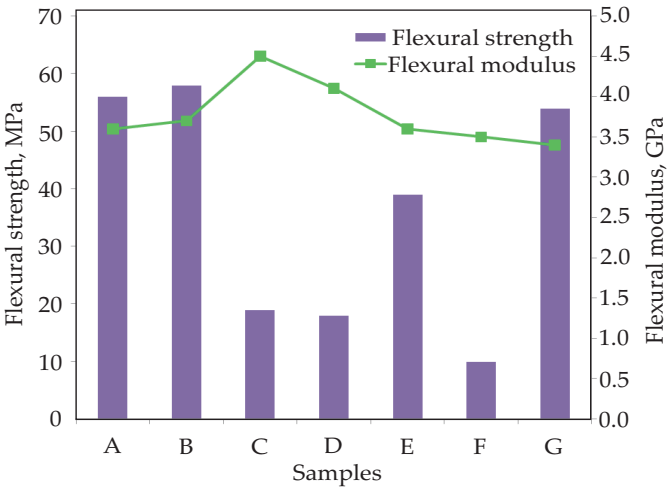

Fig. 6. Ultimate flexural strength and flexural modulus

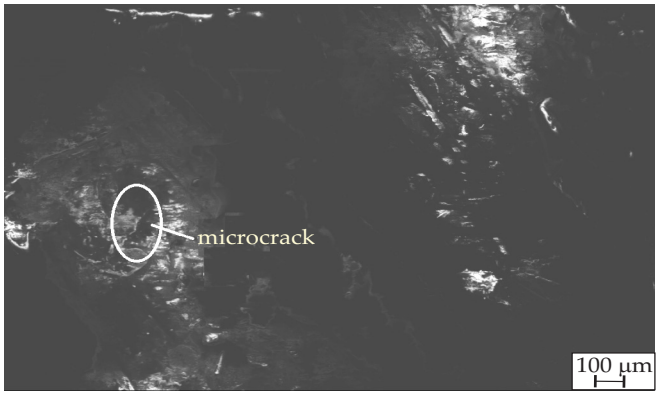

Fig. 7. SEM image of specimen F showing microcrack

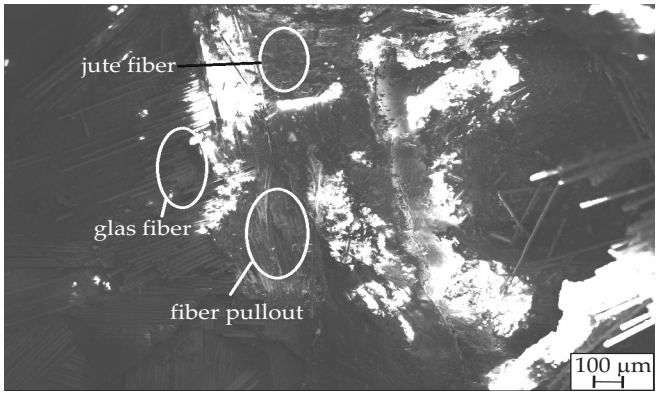

Fig. 8. SEM image of specimen D showing microcrack

and F show very high stiffness in compressive side and high flexural modulus 4.5 GPa, 4.0 GPa and 3.5 GPa, with very low flexural strength of 19 MPa, 18 MPa and 10 MPa, respectively. SEM images of the specimens F and D show the presence of voids and microcracks (Figs. 7 and 8).

Thermal stability and curing rate DSC test

Figures 9 and 10 show DSC curves of quantitative heat flow of epoxy and isophthalic polyester composites as a direct function of time. For epoxy composite, glass transition temperature T_g starts from 80–85 °C and quasi--static linear response up to 223 °C is observed. Epoxy composite is more stable than polyester in this temperature range. DSC thermogram of epoxy composite in Fig. 9 shows three peak values in the upper region, first peak at 270–300 °C exhibits endothermic reaction. The second peak at temperatures of 300 to 336 °C corresponds to exothermic reaction of epoxy resin.

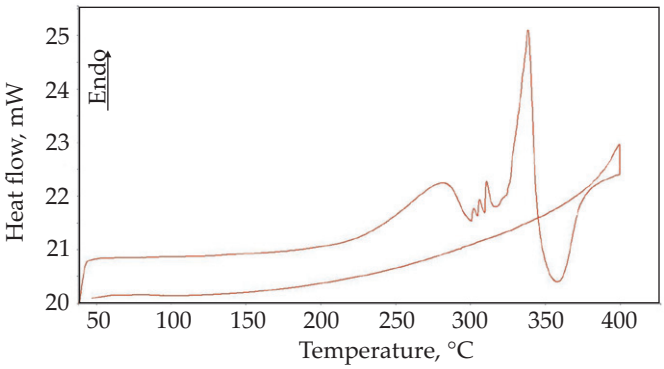

Fig. 9. DSC graph of epoxy composite

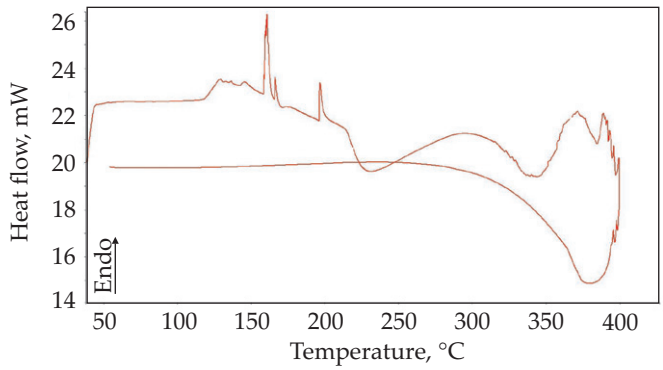

Fig. 10. DSC graph of isophthalic polyester composite

The thermogram in Fig. 10 shows T_g at 100 °C and endothermic reaction is started at 125 °C and ended up 220 °C with three different upper peaks at 162 °C, 173 °C and 192 °C. At 200–220 °C crosslinking process begins. The two exothermic peaks at bottom of the curve can combine when increasing percentage of catalyst and accelerator, which results in increased curing percentage. These high curing percentages for VARTM process are beneficial in mass production but high heat emission affects the natural fibers.

CONCLUSIONS

In this paper, glass fiber reinforced composites were made by VARTM method with high V_f of 52%. VARTM process failed for jute fiber due to uneven resin flow. The following conclusions can be made based on the mechanical and thermal study:

– Resistance to failure in tensile test shows a minor change with respect to the resin type. The polyester resin GFRP shows high tensile strength of 351 MPa but the stability of the epoxy composite is high by quasi-static linear expansion.

– Composites with natural fibers show much lower tensile and flexural strengths of 81 MPa and 10 MPa than glass fiber reinforced specimens. However, the stiffness determined by flexural test shows high value for natural fiber composite. An improvement in tensile strength (165 MPa and 105 MPa) is observed for hybrid composites with added glass fiber.

– DSC result shows a faster curing rate at 100 °C for composites with polyester matrix.

– GFRP composite with isophthalic polyester resin fabricated by VARTM shows the highest fiber volume fraction V_f and is suitable for automobile mass production due to tight package of fibers with very low content of voids.

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