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Research Article

# Effect of Stacking Sequence on Flexural and Dynamic Mechanical Properties of Hybrid Sisal/Glass Polyester Composite

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**Abstract**

In present study, flexural properties in terms of break load, percentage elongation, flexural strength and flexural modulus, and dynamic mechanical analysis (DMA) in terms of storage modulus ( $E'$ ), loss modulus ( $E''$ ), damping $(Tan\delta)$, glass transition temperature $(T_g)$ and effectiveness constant of reinforcement $(\in)$ of hybrid sisal/glass fibre reinforced polyester composite are investigated. Polyester based hybrid composites are prepared by Hand lay-up technique followed by static compression having constant 25 wt.% of fibre content with various stacking sequences. A significant improvement in flexural properties of sisal fibre reinforced polyester composite is observed by incorporation of glass fibre. In addition, the stacking sequence has great influences on flexural and dynamic mechanical properties of hybrid composites.

**Keywords:** Hybrid; Polyester; Flexural properties; Dynamic Mechanical Analysis

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**Competing Interests**: The authors have declared that no competing interests exist.

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# 1. Introduction

Since last three decades, natural fibres have been subject of tremendous interest by the researchers and scientist as reinforcement for polymer based composite materials because of its advantages i.e. low density and cost, high specific strength and modulus, less wear and tear, easy processing, recyclability, extensive availability and biodegradability [1-8]. On other hands these fibre have some limitations also such as poor compatibility, low impact strength, high moisture absorption and poor durability [9-12]. These limitations of natural fibres can be overcome by using various types of chemical treatments, hybridization of synthetic fibres and addition of nano-particles as additives.

Many studies have been reported in which glass fibre was commonly hybridized with different natural fibres to increase its properties, and obtained the positive effect of hybridization. The performance of hybrid composites depends upon many factors such as nature of matrix, isotropic/anisotropic nature of fibres reinforcement, fibres loading, and interfacial adhesion between fibres and matrix. Junior et al. [13] studied the mechanical, thermal and dynamic mechanical properties of hybrid curaua/glass composite, and Ahmed and Vijayarangann [14] studied the tensile, flexural and interlaminate shear properties of jute/glass/ polyester composites and reported that performance of jute composite was improve by incorporation of glass fibres. Gupta et al. [15] studied the mechanical and water absorption properties of hybrid sisal/glass reinforced epoxy composite and got positive effect of hybridization. Moreover, Ramnath et al. [16] investigated the effect of glass fibre loading on mechanical properties of abaca and jute composite. It was reported that hybrid composite had the better performance than pure jute and abaca composite.

DMA has become a far used technique which combines the both mechanical and viscoelastic properties of polymer based composite materials. Gupta and Srivastava [17] studied the dynamic mechanical and thermal properties of hybrid jute/sisal epoxy composite and reported that hybrid composite had the better storage modulus and glass transition temperature than both jute and sisal composite. Shanmugam and Thiruchitrambalam [18] carried out the DMA of hybrid palm leaf stalk/jute fibre polyester composite. It was reported that hybridization had its positive effect as increase in dynamic mechanical properties. In addition, Ray et al. [19] studied the dynamic mechanical analysis of jute fibre reinforced vinylester composite and Idicula et al. [20] investigated the dynamic mechanical properties of hybrid banana/sisal polyester composite.

In present communication, the aim of present study is to investigate the effect of stacking sequence on flexural and dynamic mechanical properties of hybrid sisal/glass reinforced polyester composite. Hybridization has increased the properties hence prepared composite has increasing scope of application in area of automobile, construction and packaging.

# 2. Materials and methods

### 2.1. Materials

Sisal fibres were purchased from Uttarakhand Bamboo and Fibre Development Board, Dehradun whereas glass fibres were purchased from Kolkata. Unsaturated polyester resin with ketone peroxide as catalyst and cobalt naphthalate as accelerator were purchased from Local resource.

### 2.2. Fabrication method

Sisal/glass polyester hybrid composites contain unidirectional continuous aligned sisal fibres and woven glass fibres as a reinforcement and unsaturated polyester as matrix. The hybrid composites were fabricated by hand lay- up technique followed by static compression with varying stacking sequences, and keeping constant 25 wt.% of total fibre content in each composite. Polyester resin was mixed with 2 wt.% catalyst and accelerator to prepare the matrix. The mixture was stirred thoroughly to ensure consistent mixing. A stainless steel mould having dimensions of 300 mm × 200 mm × 3 mm was used to make the 3 mm thickness of laminate. Silicon spray was used to facilitate easy removal of the composite from the mould after curing. The cast of each composite was cured under a load of 50 kg for 24 hours before it was removed from the mould. Specimens were cut in proper dimension as per ASTM standard using a diamond cutter subjected to analysis of flexural and dynamic mechanical properties. The composites manufactured with varying stacking sequences are designated as shown in Table 1.

**Table 1** Designations of composites

| Symbol | Composites | Stacking Sequences |
|---|---|---|
| S1 | Sisal composite | S/S/S |
| HI | Hybrid composite | G/S |
| H2 | Hybrid composite | G/S/G |
| H3 | Hybrid composite | G/S/G/S/G |

# 3. Characterization

### 3.1 Flexural test

Flexural test of the composite was carried out using a three point bending test on Tinius Olsen H10 K-L (Bi-axial testing machine). The samples were prepared for the test of dimensions 80 mm × 12.7 mm × 3 mm with a recommended span to depth ratio of 16:1 as per ASTM D790. The flexural test was carried out at room temperature with the crosshead speed of 2 mm/min. Calculation of flexural strength and flexural modulus are done using following equation [27].

$$\text{Flexural strength} = \frac{3FL}{2bd^2} \quad \text{and} \quad \text{Flexural modulus} = \frac{mL^3}{4bd^3} \tag{1}$$

where $F$ is ultimate failure load (N), $L$ is span length (mm), $b$ and $d$ are width and thickness of specimen in (mm) respectively and $m$ is slope of the tangent to initial line portion of the load-displacement curve. Five specimens of each composite are tested and average values are reported.

### 3.2 Dynamic mechanical analysis

The dynamic mechanical properties of polyester and hybrid composites were studied using the dynamic mechanical analyzer (Seiko instruments DMA 6100). The dynamic mechanical properties were determined in 3 point bending test as a function of temperature. The laminates were cut into samples having dimensions of 50 mm × 13 mm × 3 mm as per ASTM D 5023 subjected to DMA. Experiments were carried out at 1Hz frequency and within temperature range of 30-200 °C.

# 4. Results and discussion

### 4.1 Flexural properties

The flexural properties of polyester and sisal/glass hybrid composites in terms of break load, maximum displacement, elongation % , flexural strength and flexural modulus are tabulated in Table 2 and corresponding data are plotted in Fig. 1. Each composite has better flexural performance than polyester which shows positive effect of reinforcement of fibres. Positive effect of hybridization is also observed because each hybrid composite has better flexural properties than sisal composite S1. The maximum flexural properties is shown by hybrid composite H2 due to uniform distribution of fibres and better adhesion between fibres and matrix than other composites. Flexural strength and flexural modulus of hybrid composite H2 are found to be 122.57 MPa and 3.989 GPa respectively which is 49% and 27% more as compared to those of sisal composite S1. Flexural strength of hybrid composite H2 is 9% and 2% more than those of composites H1 and H3 respectively. Similarly flexural modulus of hybrid composite H2 is 9% and 6% more than those of composites H1 and H3 respectively. In addition, polyester has higher percentage of elongation as compared to all composites because of its lower stiffness.

**Table 2** Flexural properties of hybrid sisal/glass composites

| Composite | Break Load (N) | Maximum Displacement (mm) | Elongation (%)) | Flexural strength (MPa) | Flexural modulus (GPa) |
|---|---|---|---|---|---|
| Polyester | 98.66±6.57 | 12.56±0.98 | 15.8±1.18 | 49.33±2.67 | 1.266±0.10 |
| S1 | 164.23±10.91 | 10.12±0.78 | 10.47±0.95 | 82.12±5.98 | 2.989±0.22 |
| HI | 223.32±10.90 | 11.15±0.65 | 13.85±1.07 | 111.66±7.85 | 3.652±0.21 |
| H2 | 245.14±15.76 | 12.67±1.07 | 14.56±1.15 | 122.57±6.98 | 3.989±0.19 |
| H3 | 239.87±15.98 | 12.36±1.05 | 14.23±1.18 | 119.93±8.16 | 3.776±0.20 |

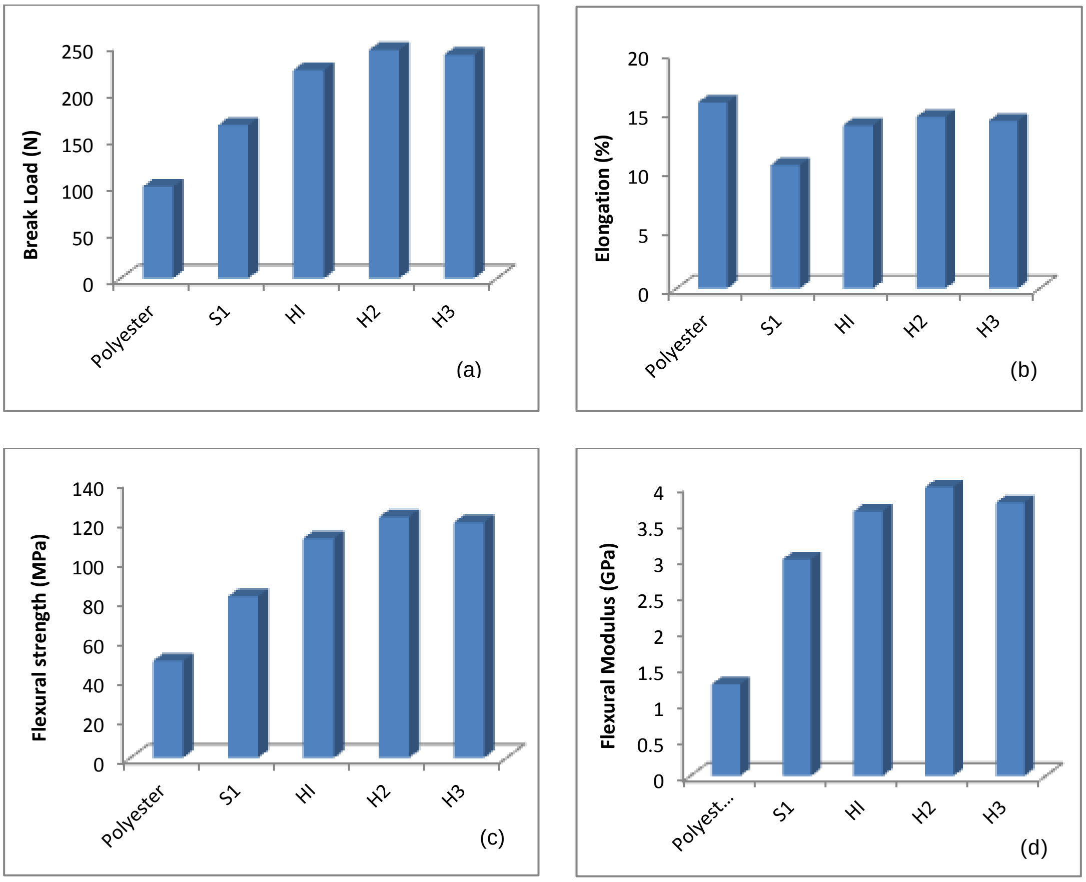


**Fig.1** Flexural properties of polyester and hybrid sisal/glass composites: (a) Break load, (b) Elongation (%), (c) Flexural strength and (d) Flexural modulus

The flexural properties of various hybrid composites from already published work are compared with flexural properties of present sisal/glass hybrid polyester composite as shown in Table 3. The properties are observed to be comparable with those of Palmyra/glass/Rooflite resin [22], Sisal/glass/Polypropylene [23], Coir/jute/Polypropylene [24], Banana/sisal/Polyester [25], Banana/glass/Polystyrene [26], PALF/glass/Polyester [27], Jute/glass/Polyester [28] and Hemp/glass/Epoxy [29].

**Table 3** Comparison of flexural properties of some hybrid composites from published work

| Reinforcement | Matrix | Fabrication method | Fibre orientation | Flexural Strength (MPa) | Flexural Modulus (GPa) | Ref. |
|---|---|---|---|---|---|---|
| Palmyra/glass | Rooflite resin | Compression method | Non woven Mat | ~170 | 9.35 | [22] |
| Sisal/glass | Polypropylene | Injection moulding | Randomly distributed | ~70 | 4.5 | [23] |
| Coir/jute | Polypropylene | Compression method | Randomly distributed | ~40 | 0.78 | [24] |
| Banana/sisal | Polyester | Hand lay up | Randomly distributed | ~65 | 2.99 | [25] |
| Banana/glass | Polystyrene | Injection moulding | Randomly distributed | 11.3 | 0.79 | [26] |
| PALF/glass | Polyester | Hand lay up | Non woven Mat | ~100 | - | [27] |
| Jute/glass | Polyester | Hand lay up | Fabric | ~160 | 12.5 | [28] |
| Hemp/glass | Epoxy | Hand lay up | Fibre mat | ~37 | ~2.5 | [29] |
| **Sisal/glass** | **Polyester** | **Hand lay up** | **Woven** | **122** | **3.98** | **Present work** |

### 4.2 Storage modulus

The variation of storage modulus of polyester and sisal/glass hybrid composites as a function of temperature at 1 Hz frequency is shown in Fig. 2. Mainly three significant region i.e. glassy, transition and rubbery can be observed in storage modulus versus temperature curve. In the glassy region, it can be observed that $E'$ of composites are close to each other. This observation may be explained as at lower temperature stiffness is not much affected by fibres content. The hybrid composite H2 has the higher value of $E'$ due to good interfacial adhesion between fibres and matrix cause uniform transfer of stress. In glassy region, the values of $E'$ of polyester and hybrid composite follow the order: H2 > H1 > S1 > H3 > polyester. In transition region, it is observed that all composites have a gradual fall in value of $E'$ with increase in temperature whereas polyester resin has a sudden fall. It is due to increase in molecular mobility as temperature reached above to $T_g$ [22]. In all cases, the $E'$ of polyester and composites are found to decrease with increase in temperature due to loss in stiffness of fibres at high temperature [23]. In rubbery region, sisal composite S1 shows the higher value of $E'$ whereas its lower value is given by polyester. Polyester resin has the lowest value of $E'$ due to increase in molecular mobility at higher temperature [24]. It can be also observed that $E'$

of hybrid composites are separated to each other because at high temperature the fibres control the stiffness of composite materials. The $\in$ is calculated using following equation [22]:

$$\in = \frac{\left(\frac{E'_g}{E'_r}\right)_{Composite}}{\left(\frac{E'_g}{E'_r}\right)_{Resin}} \quad (2)$$

where $E'_g$ and $E'_r$ are the storage modulus in glassy region and rubbery region respectively. The higher value of $\in$ shows the lower efficiency of the reinforcement and its lower value shows the higher efficiency of reinforcement. The calculated values of $\in$ for sisal/glass hybrid composites are given in Table 4. The sisal composite S1 has the lowest value (0.176) of $\in$ whereas the hybrid composite H1 has its highest value (0.462). The lowest value of $\in$ for composite S1 shows the high efficiency of reinforcement than other all composites.

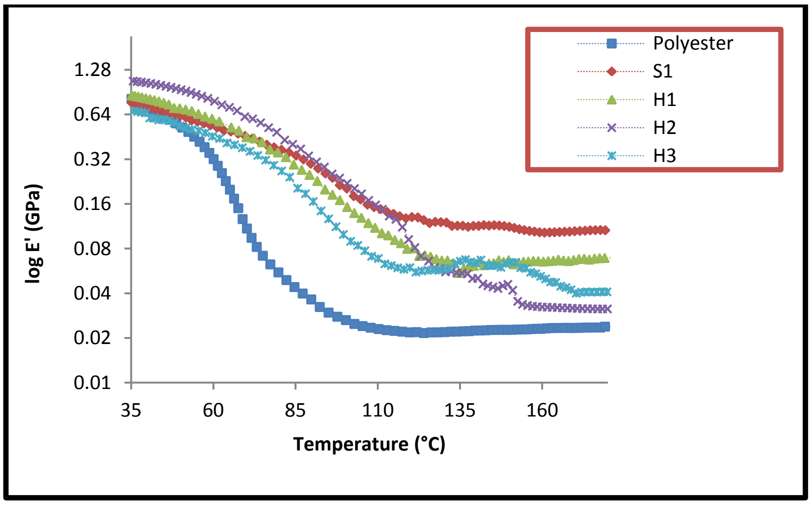


**Fig. 2** Variation in storage modulus with temperature for polyester and hybrid sisal/glass composites

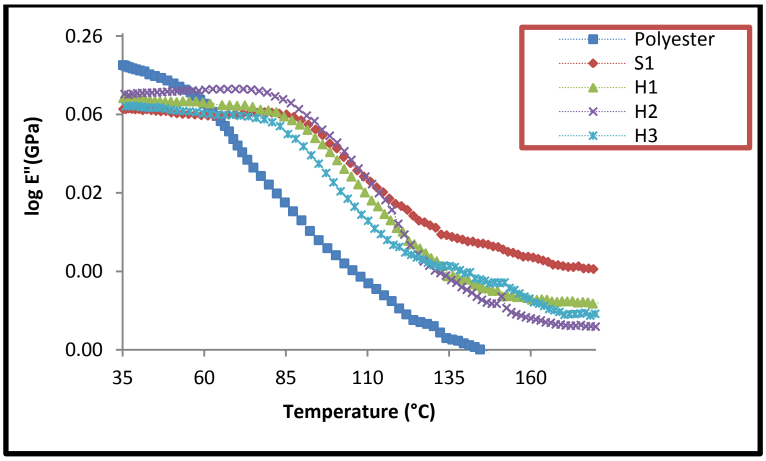


**Fig.3** Variation in loss modulus with temperature for polyester and hybrid sisal/glass composites

### 4.3 Loss modulus

Loss modulus is explain as loss of energy in form of heat from the sample during one cycle of oscillation. It shows the viscous response of the materials which mainly depends upon molecular motion with increase in temperature. The variation in loss modulus for polyester and sisal/glass hybrid composites as a function of temperature at 1 Hz frequency is shown in Fig. 3. The highest peak of loss modulus is found for hybrid composite H2 whereas polyester has the lowest peak due to increase in molecular mobility. It is also observed that the value of $E''$ increased up to $T_g$ and then decreased with increase in temperature. The value of $T_g$ obtained from loss modulus is more realistic than those of obtained from $Tan\delta$ curve [23]. The value of $T_g$ for polyester and hybrid composites obtained from loss modulus curve is given in Table 4. The highest value of $T_g$ is observed for sisal composite S1 which reflects better thermal stability than polyester and other all composites. The highest value of $T_g$ is due to strong adhesion between fibres and matrix cause proper stress transfer.

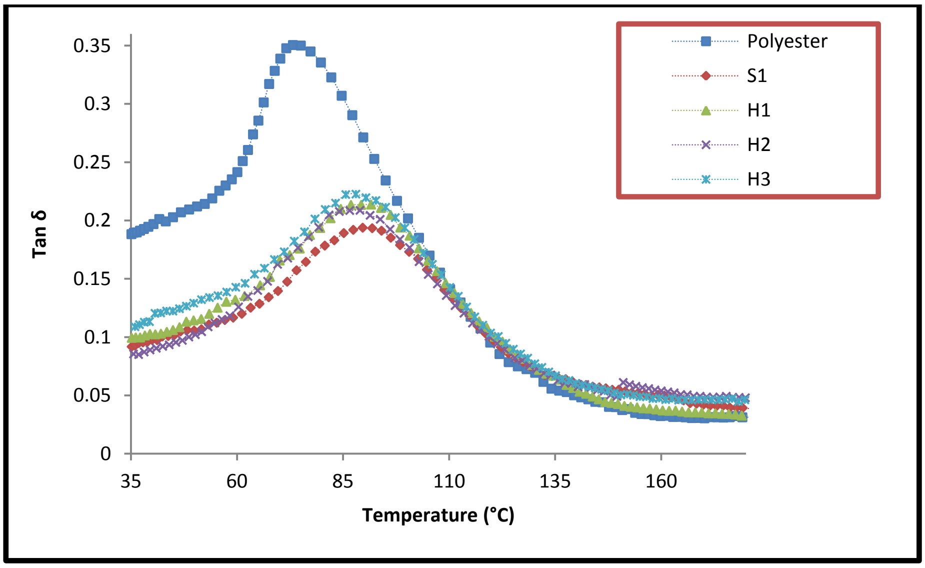


**Fig.4** Variation in Tan δ with temperature for polyester and hybrid sisal/glass composites

**Table 4** Values of $\in$ and $T_g$ of hybrid sisal/glass composites

| **Composites** | $\in$ | **Peak height of $Tan\delta$ curve** | **$T_g$ from loss modulus curve $(^0C)$** | **$T_g$ from $Tan\delta$ curve $(^0C)$** |
|---|---|---|---|---|
| Polyester | - | 0.350 | 65.60 | 73.20 |
| S1 | 0.198 | 0.193 | 80.70 | 91.88 |
| H1 | 0.462 | 0.213 | 79.05 | 91.63 |
| H2 | 0.393 | 0.208 | 76.83 | 88.99 |
| H3 | 0.352 | 0.222 | 78.37 | 88.03 |

### 4.4. Damping

During one cycle of oscillation the ratio of loss modulus and storage modulus is damping or $Tan\delta$. The variation in $Tan\delta$ for polyester and sisal/glass hybrid composite as a function of temperature is shown in the Fig. 4. The peak values of $Tan\delta$ curve for polyester and hybrid composites are given in Table 4. The peak of $Tan\delta$ curve follows the order: Polyester > H3 > H1 > H2 > S1 as shown in Table 4. Polyester resin has the highest value of $Tan\delta$ curve as expected due to no restriction of molecular motion at higher temperature. The higher value of $Tan\delta$ for polyester shows better damping than all composites. The lowest value of $Tan\delta$ is found for sisal composite S1 due to strong interface between fibres and matrix which reflects good load bearing capacity. This fact can be explained as fibre-matrix adhesion increase, mobility of molecular chain at fibre matrix interface decease as results reduction in value of $Tan\delta$ takes place. The value of $T_g$ obtained from peak of $Tan\delta$ curve are given in Table 4. Shifting of $T_g$ towards higher temperature is found for sisal composite S1 which shows the better thermal stability than polyester and other composites.

# 5. Conclusions

Flexural and Dynamic mechanical properties of hybrid sisal/glass polyester composite are studied and following conclusions are drawn.

- Stacking sequence has significantly affected the flexural and dynamic mechanical properties of sisal/glass hybrid polyester composite.
- Hybrid composite H2 has the better flexural performance, maximum value of storage modulus in glassy region, and higher value of loss modulus as compared to polyester and other composites.
- Sisal composite S1 has the higher value of $T_g$, and higher values of $E'$ and $E''$ in rubbery region as compared to polyester and hybrid composites.
- The lower value of $Tan\delta$ and $\in$ is shown by sisal composite S1 which shows good load bearing capacity and higher efficiency of reinforcement.
- Dynamic mechanical properties of sisal composite is found better than hybrid sisal/glass composites. On basis of this fact it can be concluded that sisal fibre may be consider as better replacement of glass fibre.

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