Mechanical Performance and Vibration Characteristics of Glass/Jute Fibre-Reinforced Polyester Hybrid Composites

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Abstract-- **Hybrid synthetic-natural polymer matrix composites (HSNPMCs) are becoming more important and attractive for many structural applications. Partial replacement of synthetic fibres (SFs) with natural fibres (NFs) are an interesting subject for engineers considering the environmental awareness and cost reduction. In this study, the glass/jute fibre-reinforced polyester composites were fabricated with different jute-to-glass content ratios while keeping the same fibre weight fractions that equal to about 18% for all composites. The mechanical tests like tensile, flexural, and absorbed energy (Charpy impact test) were conducted for glass, jute, and hybrid composite specimens and compared among each other. Free vibration analysis was carried out to these composite specimens to find their fundamental natural frequencies and damping ratios. The results indicated that hybrid composites with a stacking sequence of G-J-G exhibited promising tensile and flexural properties and good absorbed energy. Concerning the free vibrational characteristics, the G-J-J-G composite type offered the highest fundamental frequency with good dampening characteristics. Higher benefits could be obtained when using specific mechanical properties and vibrational characteristics of hybrid composites when compared with glass composites. It can be suggested that the incorporation of jute fibres into the glass fibre composite in hybrid structure, as presented in this study, can improve the dynamic characteristics of the composites with encouraging mechanical performance.**

Index Term-- **Mechanical properties, dynamic characteristics, glass fibre, jute fibre, hybrid composites**

1. INTRODUCTION

In the recent years, cellulosic natural fibres have been used widely in the reinforcement of composites mainly due to their lower cost, abundant, renewable, eco-friendly and biodegradable. These fibres have reduced the detrimental impact on the environment due to using synthetic fibres (SFs) in the composite structures. However, using of natural fibres (NFs) alone as reinforcements in the composites could not provide mechanical properties better than SFs did. Therefore, many researchers tried hybridising natural and synthetic fibres to reduce the detrimental aspects that could yield due to using individual fibres. Recent studies revealed that some applications of using hybrid natural/synthetic fibres reinforced composites could be potentially applied in some industry fields. Cicala et al. [1] utilised hybrid glass/natural (flax, hemp, and kenaf) fibre composites to fabricate curved pipes and got a weight saving of 23% and a cost reduction of 20% compared with the commercial pipe construction. Davoodi et al. [2] fabricated kenaf/glass hybrid fibres embedded epoxy composites to be used as car bumper beam. Automotive designers explored the hybrid glass/natural fibre composites for sound dampening characteristics [3].

The main issues of using NFs instead of SFs in composite structures are their low stiffness, low strength, poor wettability, weak adhesion with polymer matrix and high moisture absorption [4–8]. Previous studies have shown that glass fibres are humidity resistant (hydrophobic nature); whereas, natural fibres have hydrophilic nature which can be considered a great issue when they are competing with glass fibres [9]. Therefore, using of individual natural fibres embedded in polymeric matrix composites (PMCs) might not satisfy the application requirements or they have little or no mechanical avail. Previous studies showed that composites reinforced with SFs such as glass, carbon, or Kevlar are stronger than composites reinforced with NFs such as sugar palm, jute, sisal, flax, kenaf, bamboo, or hemp [9]. This led many researchers trying to partially replace SFs by NFs to fabricate HSNPMCs. This seems to be the best method available nowadays to exploit the incorporation of two different kinds of reinforcing fibres in the composite structures subjected to static or dynamic loadings.

The incorporation of SF with NF for producing hybrid polymer-matrix composites (HPMCs) was successfully applied by several researchers [8,10–13]. HPMCs consist from at least two different reinforcements within a single matrix to get the best balance between positive and negative aspects in the composite products [14,15]. However, SF reinforced composites are more expensive and have negative effects on the environment. Therefore, combining SF with NF may satisfy the requirements of the composite structure with lower cost. The incorporation of glass fibres into untreated jute/polyester composite increased its mechanical properties, as glass fibre has higher tensile strength than jute fibre [16]. Glass fibres were successfully hybridised with several NF such as jute [17], bamboo [18], kenaf [19], flax and sisal [20]. The hybridisation of sisal-jute fibres with glass fibre reinforced polyester composites could improve the mechanical properties of the hybrid composite such as tensile, flexural and impact strengths [21]. Jute fibre was successfully hybridised with carbon fibre-reinforced/epoxy composites as well. The tensile properties of the hybrid composite were lower than carbon fibre-reinforced composite (about one-third), but the cost of the former was relatively lower [14]. Gujjala et al. [17] examined the tensile, flexural and interlaminar shear properties of woven untreated jute/glass hybrid-reinforced/epoxy composites prepared with different stacking sequences. The study showed that hybrid composites with jute-glass-jute-glass stacking sequence has the maximum flexural strength, while glass-jute-jute-glass stacking sequence exhibited the maximum tensile strength. The absorbed energy by carbon-flax/epoxy hybrid composite was improved when using a stacking sequence of flax-carbon-flax in comparison with carbon-flax-carbon stacking sequence with approximately the same overall fibre volume fraction [22]. Ahmed et al. [16] evaluated the physical and mechanical properties of woven untreated jute/glass fibre hybrid-polyester composites such as tensile, flexural, interlaminar shear strength, and water absorption. The incorporation of 16.5 wt% glass fibre could improve the tensile, flexural, interlaminar shear strength by 37, 31, and 18%, respectively. Concerning the water absorption, jute/glass hybrid composites showed higher resistance to water absorption. However, there was no information about the stacking sequence of the glass and untreated jute fabrics within the composites. Mohan and Kishore [23] studied the flexural properties and moisture absorption of unidirectional jute-glass sandwich/epoxy composites with jute volume fractions ranged from 16 to 40%. The study showed that flexural properties increased substantially when the thickness of the surface glass lamina to the thickness of core jute lamina was less than 0.3. Jute fibres exhibited less moisture absorption attributable to hybridisation with glass fibres.

The physical and mechanical properties of the NFs were improved by treating these fibres with NaOH solution using suitable concentration and immersing time [6,24,25]. For example, the external surface of jute fibres could be improved by removing pectin, lignin, natural oils, and waxy substances when they were treated with 25% solution of sodium hydroxide (NaOH) for 20 min [6]. Another study achieved by Roy et al. [25] showed 82% enhancement in the tensile strength of the jute fibre when treating jute fibres with 0.5% NaOH solution for 24 h. The tensile, flexural and impact strength of kenaf-glass/unsaturated polyester hybrid composites were enhanced by treating the kenaf fibres with 6% NaOH [26].

Vibration characteristics (natural frequency and damping behaviour) of composite structures are important in several fields such as aerospace, automotive and construction [27]. Therefore, the dynamic performance of HPMCs needs to be investigated before deciding to use them in different structural applications. Dynamic characteristics of NFPMC and HPMCs were extensively reported by Saba et al. [27]. It was stated that polymer alone has damping factor much greater than fibres-reinforced polymer matrix composites, as the polymers have lowered elasticity and higher viscosity [27,28]. A comparative study on the mechanical and damping properties of the flax fibre reinforced composites with composites reinforced with carbon or glass fibre reinforced composites was achieved by Duc et al. [29] and Assarar et al. [30]. These studies showed that flax composites exhibited higher damping behaviour than composites reinforced with carbon or glass fibres. Moreover, the hybridisation of ramie/glass fibre reinforced polyester composite showed an increase in the damping factor with increasing the fibre content [31,32]. Another study revealed that increasing jute fibre content could increase the damping behaviour of hybrid jute/palm leaf stalk fibres reinforced polyester composites [33]. Ghosh et al. [34] found out that the presence of glass fibres could decrease the damping behaviour of jute/glass fibres reinforced epoxy composite. The study of dynamic mechanical characteristics of phenol formaldehyde reinforced with oil palm/glass hybrid fibres showed that the highest damping could be obtained for the hybrid composite with maximum fibre volume fraction of oil palm (96% palm fibre:4% glass fibre) and it decreased with increasing glass fibre content [35]. Ashworth et al. [14] showed that the dissipated energy defined by the so-called loss factor of jute-carbon fibre hybrid composite was double than carbon fibre-reinforced composite. In contrast, the energy dissipation of hybrid curaua/glass fibres reinforced polyester composites increased with increasing glass content due to increasing the interfacial area and adhesion strength at the interface [36]. In summary, there have been relatively few studies reported potential static and dynamic mechanical advantages and disadvantages of using HSNPMCs.

Studying structural properties of natural/synthetic HPMCs is without doubt an interesting subject nowadays as these types of composites have promising properties and need to be investigated. Therefore, jute was hybridised with glass fibres at different ratios within the composite, while the fibre weight fraction was kept approximately constant. Mechanical properties (tensile, flexural and impact) and vibration characteristics (fundamental natural frequency and damping ratio) of different composite types were investigated.

2. METHODOLOGY

Materials

Plain-weave jute fibre was obtained from Surat, Gujarat, India. The areal density of jute fabric is approximately equal to 300 g/m^2. The glass fibre is plain-weave type-E with areal density equal to 425 g/m^2. The unsaturated polyester resin was used in this work as a matrix phase. The methyl ethyl ketone peroxide (MEKP) was used as catalyst with mixing ratio with the polyester equal to 1.6% (volume ratio). Tensile test of the neat unsaturated polyester specimens was conducted using INSTRON 3382 machine. The speed of the machine cross-head was 2 mm/min. The gauge length of the tensile composite sample was 50 mm as recommended by ASTM D638 [37]. Six samples were tested at environment conditions (22 ºC and 38% RH) and the mean value was considered. Tensile tests of glass and jute yarns were carried out at environment conditions of 24 ºC and 46% RH, following the ASTM D2256 [38] and using INSTRON 5542A testing machine with a load cell of 50 N. The used gauge length of the yarn was equal to 0.25 m and the testing speed of the machine cross-head was 250 mm/min. Five replicants were conducted for both glass and jute yarns and mean values were considered. Densities of polyester matrix, glass and jute fibres were determined using the water displacement method and sensitive digital balance. Mechanical and some physical properties of the composite constituent's materials are listed in Table I.

Table I
Mechanical and physical properties of the unsaturated polyester

Property	E-glass	Jute	Polyester
Tensile strength (MPa)	2218±134	512±31	48.8±2.71
Strain to failure %	3.01±0.13	1.72±0.08	2.01±0.04
Elastic modulus (GPa)	69.82±2.0	25.7±1.96	2.10±0.02
Density (g/cm^3)	2.51±0.02	1.51±0.04	1.18±0.01
Areal density (g/m^2)	425±6.92	304±8.33	-

Alkalisation

The untreated jute fibre was washed three times using distilled deionised water to remove the dust if any and then immersed in 25% NaOH solution for 20 minute [6], filtered and washed with distilled water several times till the pH of rinsing water become neutral (i.e. pH equal to 7) [39]. The treated fibres were then dried into an oven at 60 ºC for six hours. The alkalisation treating process is necessary for natural fibres as it can improve their adhesion with polymeric matrix and reduce the density of lumens that naturally existed in the plant fibres.

Sample Preparations

There were three different composite types or configurations prepared in this work: glass/polyester composites with four layers, secondly, jute/polyester composites with three layers, and glass/jute/polyester hybrid composites with layer sequences of glass/jute/glass (38% jute and 62% glass fibre volume fraction) and glass/jute/jute/glass (55% jute and 45% glass fibre volume fraction). In Table II, symbols G and J represent the glass and jute fibre layers, respectively. The hand lay-up combined with cold press method was used to fabricate the composite sheet at ambient temperature of 27 ºC. The weight fraction of the fibres within the composites were kept constant (about 18 wt%) for the reason of comparison and evaluation among different types of composites. The dimensions of the mould were 20 cm × 30 cm and the thickness of the different composite sheets were variable according to the number of layers and material type (i.e. glass and/or jute woven fabric). The composite sheets were left to cure at ambient temperature for 72 h and then post-cured inside the oven at 90 ºC for two hours. Table II lists the four types of composites that were prepared in this study along with their physical properties.

Table II
Specifications and physical properties of different prepared composites

Type of composite* (Stacking sequence)	Glass volume fraction %	Composite density (g/cm^3)	Total fibre weight fraction (%)	Thickness of composite sheet, t (mm)
G-G-G-G	100	1.58	18.20	2.62
J-J-J	0	1.20	17.81	3.80
G-J-G	62	1.39	17.87	2.34
G-J-J-G	45	1.36	17.79	3.85

* G: glass-ply, J: jute-ply

Tensile testing

Tensile test was conducted for the composite samples according to ASTM D3039 [40]. The size of the sample was 250 mm × 25 mm × t mm. The thickness (t) of each composite type was listed in Table II. INSTRON 3382 machine was used to perform the tensile testing at a constant machine head speed of 2 mm/min. All samples were tested at lab conditions equal to 22 ºC and 43% RH. Elastic modulus, tensile strength and strain-to-failure were obtained from this test. For each composite's type, five samples were used and the mean results have been considered.

Flexural testing

Flexural test (three-point bend tests) was performed according to ASTM D790 [41] for estimating the flexural modulus and strength of composite samples. The span length (L) of the sample was thirty times the specimen thickness, while the total length was 1.2L. The span to thickness ratio of 22 was considered. According to ASTM D790, the recommended width of the composite samples was equal to 12.7 mm for G-G-G-G and G-J-G samples, while for J-J-J and G-J-J-G samples it was equal to 25 mm due to using different thicknesses of composite samples. The crosshead speed during the test was kept constant at 3 mm/min with strain rate 0.01 mm/mm/min. The final results were taken from the average of five replications.

Impact testing

Charpy impact test with impactor weight of 2.05 kg and impact velocity equal to 3.8 m/s was used to estimate the impact absorbed energy of the fibre-reinforced composites. The size of the unnotched sample was 55 mm (length) × 10 mm (width) × t mm (thickness). Five samples from each composite type defined in Table II were tested and the mean values were considered. The impact strength in kJ/m^2 was calculated using the equation (1);

$$S = \frac{\bar{E}}{t\,b} \times 10^3 \quad (1)$$

where

$\bar{E}$ is the breaking absorbed energy in (J)

t is the sample thickness in (mm)

b is the sample width in (mm)

Fundamental natural frequency and damping ratio (factor)

Vibration characteristics such as the natural frequency and damping factor were measured using ceramic shear accelerometer model 352C22 from PCB Piezotronics. The accelerometer dynamic signal was acquired using National Instruments (NI) Data Acquisition (DAQ). These characteristics were measured by attaching an accelerometer at the free end of a cantilever composite beam as shown in Fig. 1. The length of the cantilever was 220 mm. The free end of the cantilever was displaced downward 20 mm and then released to undergoes free vibration. The acceleration data was analysed using LabVIEW software. The acceleration-time domain was transferred to the amplitude-frequency domain using FFT algorithm for calculating the natural frequency (f_n) of the composite samples. Damping ratio (ζ) and quality factor (Q) were determined from the frequency domain using the half-power bandwidth method [42,43] as shown in Fig. 2. The maximum peak in the amplitude-frequency domain represents the fundamental resonant frequency. The damping ratio corresponding to this peak could be determined using equation (2);

$$\zeta = \frac{f_2 - f_1}{2\,f_n} \quad (2)$$

The quality factor (Q) indicates the rate of energy loss relative to stored energy which is equal to:

$$Q = \frac{1}{2\zeta} \quad (3)$$

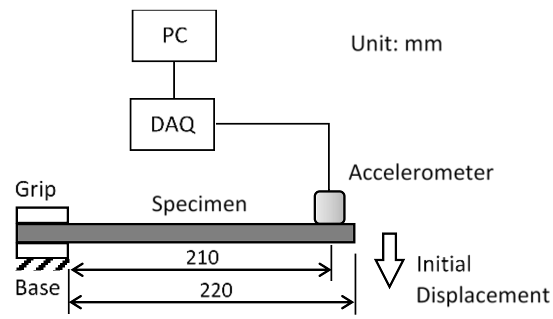

Fig. 1. The specimen and testing setup of dynamic properties.

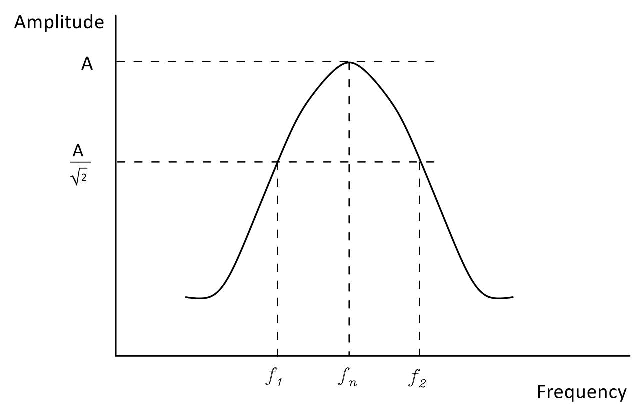

Fig. 2. Half-power bandwidth method.

RESULTS AND DISCUSSION

Tensile properties

Fig. 3 shows the tensile stress-strain curves of all composites that were prepared in this work. Table III lists the tensile strength and tensile elastic modulus of different types of composites such as glass, jute and hybrid composites. It is clear that composites reinforced with 100% glass fibres have the highest tensile strength and elastic modulus than other types of composites used in this work which is consistent with the results obtained by Gujjala et al. [17]. In Gujjala's study, jute fibres were not chemically treated. The tensile properties increased as glass fibre content has been increased within the epoxy reinforced with jute/glass fibres. The results of their study showed that incorporation of 50 wt% glass fibres jute/epoxy composites (17.5 % total fibre volume fraction) had increase the tensile strength and elastic modulus from 52 MPa to 87 MPa, and from 2 GPa to 4.8 GPa, respectively. Hybrid glass/jute fibre reinforced composites displayed better tensile properties than composite reinforced with jute fibres alone; this observation was in agreement with the study achieved by Ahmed et al. [16]. Ahmed and co-workers indicated that inclusion of glass fibre with untreated jute fibres into polyester matrix had higher tensile properties than untreated jute/polyester composites. They found that hybridising 25.2 wt% of glass fibres with 17.1 wt% of untreated jute fibres had improved the tensile strength and elastic modulus by 53.7% and 30.3% (compared with untreated jute/polyester composites), respectively.

In this work, increasing glass fibres content into treated jute fibres/polyester composites showed the same trend. Therefore, it could be concluded the hybridisation of glass (skin)-treated jute (core) fibres in the polyester matrix had been successfully implemented. The main reason is that tensile properties of reinforcement phase (glass fibre) are higher than jute fibres. Another reason is that the percentage crimp (waviness) of jute fibre yarns within the woven textile is relatively higher when compared with glass yarn within the woven fabric. The loosen jute yarns embedded in the polyester matrix cannot carry the load transferred from the polyester matrix instantly [44]. Therefore, the microcracks within the matrix phase were developed early when the jute fibre reinforced composite was subjected to tensile loading [45].

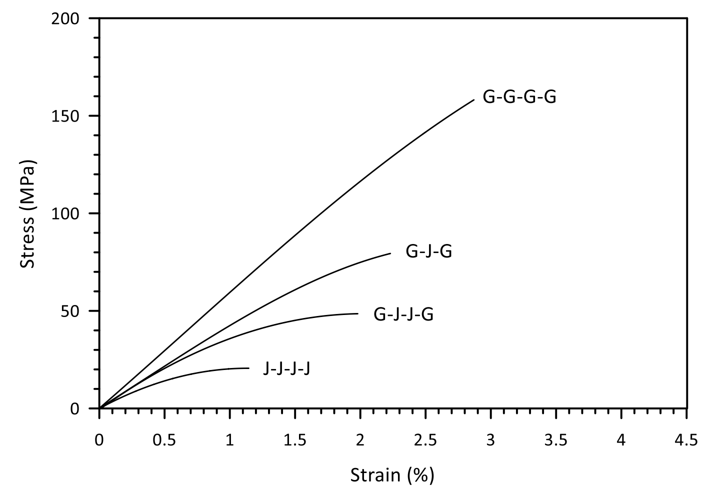

Fig. 3. Tensile stress-strain relationships of different composite types.

Table III
Tensile properties of different types of composites

Symbol	Composite designation	Tensile strength MPa	Tensile modulus GPa	Strain-to-failure mm/mm
A	G-G-G-G	157.71±7.33	5.51±0.16	2.73±0.16
B	J-J-J	21.30±1.32	3.12±0.15	1.14±0.07
C	G-J-G	78.61±3.54	4.26±0.13	2.23±0.13
D	G-J-J-G	48.72±1.80	3.82±0.18	1.98±0.12

As the strength and stiffness-to-weight ratios are the most important characteristics of composite materials [21,46], the specific tensile properties of the different composites listed in Table III were investigated. Consequently, the specific tensile properties of the composite were calculated by dividing the composite's tensile property by its density in order to compare the composite properties taking into consideration its weight and volume. The specific tensile properties of the different composite types listed in Table III are shown in Fig. 4. Although the trend of the specific properties looks at the first instant similar to what have been found in Table III, some additional improvement or benefits in the tensile performance could be obtained. For example, the tensile strength of the G-J-G composite gives 50% of glass fibre reinforced composite (G-G-G-G) having the same fibre weight fraction, the specific tensile strength of this hybrid composite type was improved up to 57%. Concerning the tensile modulus, the incorporation of 62% glass fibre within the G-J-G hybrid composite gives tensile modulus about 77% of glass composite counterparts; however, this value reached up to 88% when using the specific values of elastic modulus. The same behaviour of G-J-J-G hybrid composite was obtained when compared with glass composites. The tensile properties (strength and elastic modulus) of G-J-J-G hybrid composite were 31 and 69% of glass composite counterparts, respectively. However; the corresponding specific tensile properties give 36 and 80% of glass composite specimens. This gives approximately 14 and 16% specific tensile properties advantage for G-J-G and G-J-J-G composites, respectively. The improvement in the specific tensile properties of the hybrid composites was more significant owing to using heavier and more compacted fibres content (i.e. glass fibres) instead of jute fibres for the same piece dimensions of the fabric. The appropriate combination between these dissimilar physical properties tends to increase the specific strength and stiffness of the glass/jute hybrid composites. The failure patterns of different composites under tensile load are shown in Fig. 5.

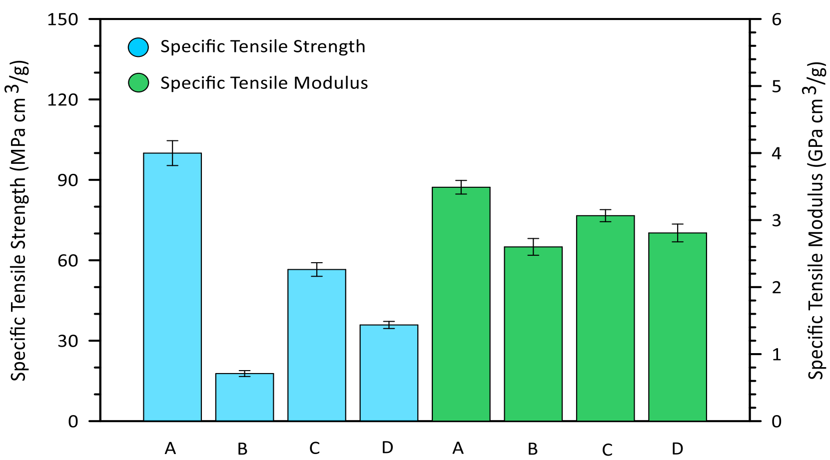

Fig. 4. Specific tensile properties of different types of composites.

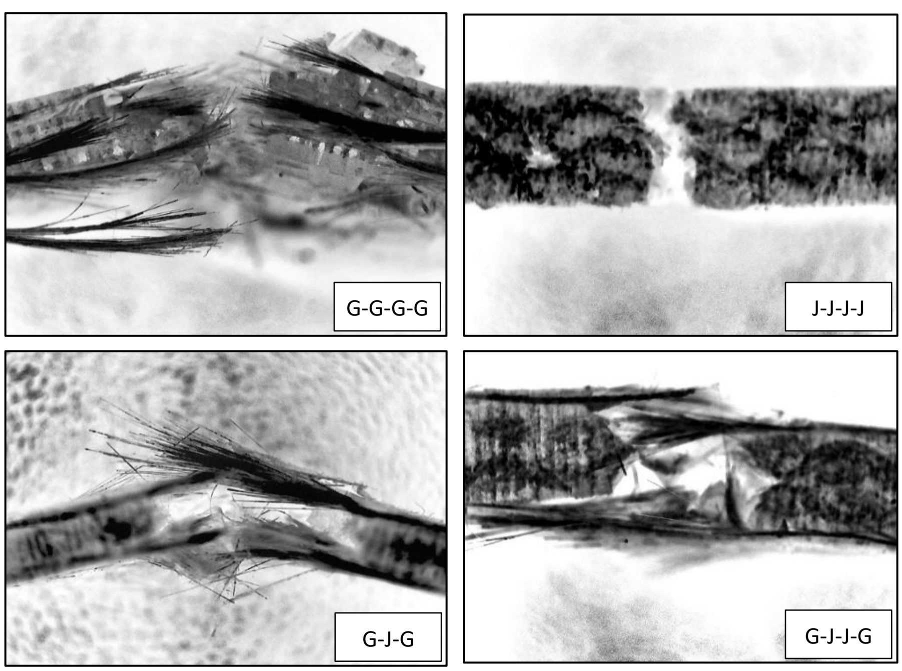

Fig. 5. Images of different composites failure after tensile test

Flexural properties

The changes in the flexural strength and flexural modulus for different types of the fabricated composites are listed in Table IV. The treated jute composite gives 12% flexural strength and 55% flexural modulus of the glass composite counterparts. Meanwhile, the flexural strength and modulus of G-J-G composites (74 wt% Glass + 26 wt% treated Jute of total fibres) is 58% and 92% of glass composites, respectively. The same trend was found in the literature; incorporation of glass fibres (50 wt%) with untreated jute fibres (50 wt%) gave 71.7% flexural strength and 93.3% flexural modulus of the glass composites counterparts [17]. The higher flexural strength of the glass/untreated jute reinforced epoxy composites obtained by Gujjala et al. [17] could be attributed to the higher adhesion strength between glass/jute fibres with epoxy matrix than with polyester matrix used in the current work.

Table IV
Flexural properties of different types of composites

	Composite designation	Flexural strength MPa	Flexural modulus GPa
A	G-G-G-G	251.20±8.91	6.39±0.28
B	J-J-J	29.82±3.62	3.67±0.27
C	G-J-G	146.33±5.66	5.85±0.28
D	G-J-J-G	94.03±4.51	5.16±0.22

It is well known when the specimen is subjected to flexural loading, the outer surfaces of the specimen are exposed to greater lateral strain than its core. Therefore, flexural properties are mostly controlled by the properties of the external fibres [47,48]. On the other hand, the semi-brittle nature of jute fibres make them breaking earlier than the semi-ductile glass fibres when they are stretching under the flexural loading [17,49]. Therefore, the improvement obtained in flexural properties of the hybrid composites is expected to be higher than the improvement in the tensile properties for the same composite type. Fig. 6 shows the specific flexural properties for different composite types.

The improvement in the specific flexural properties follows the same trend of flexural properties listed in Table IV, but they are higher. For instance, G-J-G specimen gives 66% specific flexural strength and 104% flexural modulus of glass composite counterparts, respectively. Meanwhile, the flexural strength and modulus of G-J-J-G hybrid composite specimens were equal to 38 and 81% of glass composite counterparts. The specific flexural strength and modulus give 44 and 94% of glass composite specimens, respectively. The failure modes of the four composite types after three-point bending test are shown in Fig.7.

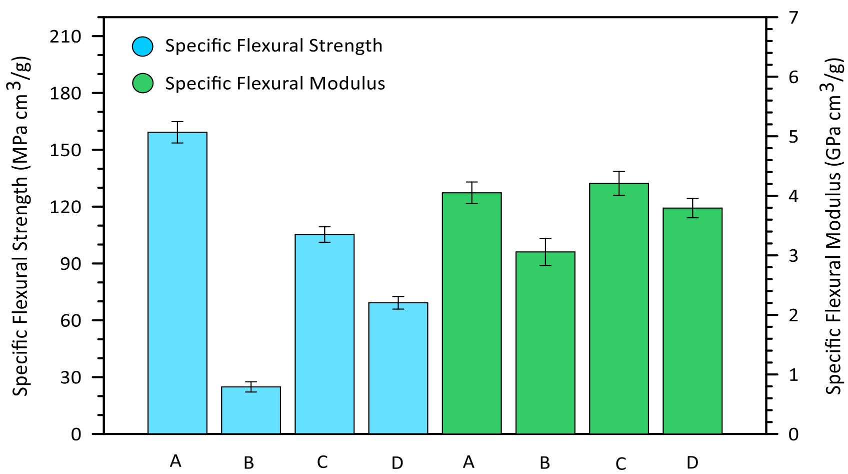

Fig. 6. Specific flexural properties of different types of composites.

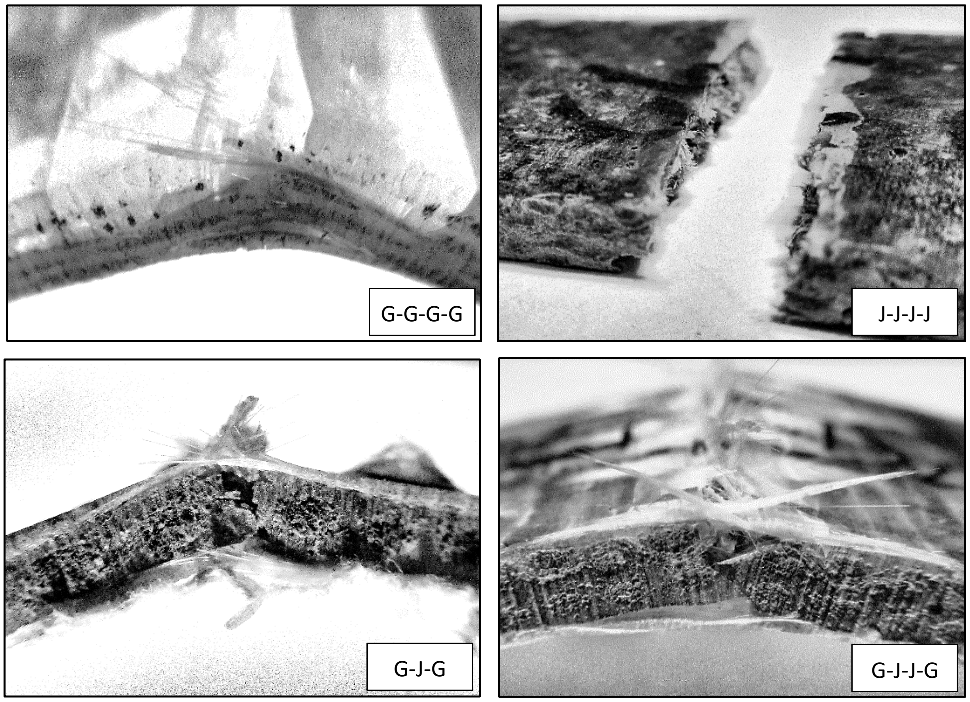

Fig. 7. Images of different composites failure after flexural test.

Impact properties

The reinforcing phase plays an important role in impact properties of the PMCs, as it absorbs part of the energy during the impact event and distribute some of the impact energy within the composite as well. Delamination, matrix cracking and fibre breakage failure modes of impacted composite specimens can be induced due to the excess energy [12]. It can be observed from Table V, that non-hybrid jute composites have lowest impact strength followed by G-J-J-G hybrid composites. Increasing of impact strength with increasing glass fibre content can be attributed to the higher tensile strength that provided by glass fibres and the higher energy dissipation at the fibre/matrix interface required to separate the fibres from the polyester matrix. Therefore, glass fibre reinforced composites have highest impact strength among all composites used in this work as listed in Table V. In addition to the relatively weak properties of jute fibres compared with glass fibres, the twisted jute tows shown in Fig. 8 are approximately taking circular cross-section shape which would weaken the interfacial binding strength and reduce the interfacial contact surface area between the reinforcement and matrix [50]. Accordingly, the applied impact load would not transfer effectively between any adjacent yarns throughout the interfacial matrix. Again, the specific impact strength of different composite types used in this study showed generally the same trend that impact strength data did. For example, Fig. 9 shows that the impact strength of G-J-G hybrid composite gives about 60% of the glass composite, while it gives 68% if they are compared regarding their specific impact strengths. The second configuration of hybrid composites (G-J-J-G) offers 42% impact strength of glass composites with similar fibre weight fraction. This proportion increased up to 49% when using specific impact strengths. Fig. 10 shows the failed specimens of different composites used in this study after the impact test.

Table V
Charpy's impact strength of different types of composites

Symbol	Composite designation	Impact strength kJ/m^2
A	G-G-G-G	102.96±5.06
B	J-J-J	7.33±1.28
C	G-J-G	61.63±3.30
D	G-J-J-G	43.13±3.16

Fig. 8. Twisted jute tow.

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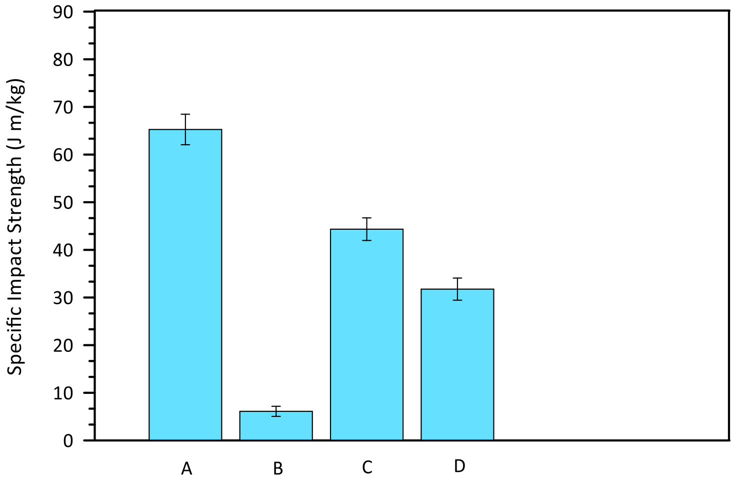

Fig. 9. Specific impact strength of different types of composites.

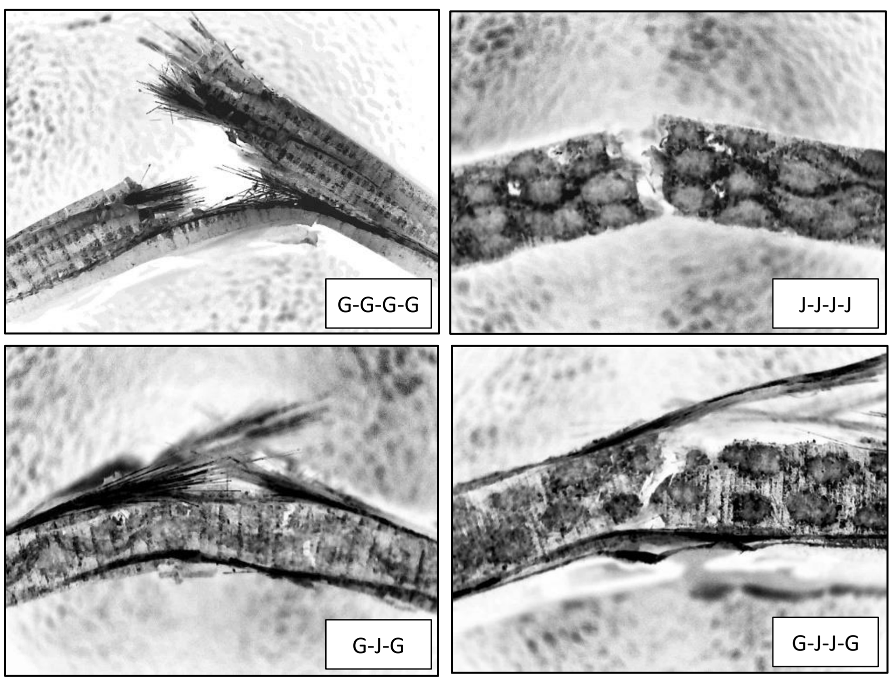

Fig. 10. Images of different composites failure after Charpy impact test.

Vibration characteristics

The dynamic acceleration responses of the various types of the composites prepared in this study are shown in Fig. 11. The fundamental natural frequencies and damping ratios are listed in Table VI. Hybrid composite (G-J-J-G) offers the highest natural frequency and the specific natural frequency among other composites' types since jute fibres within the composite have lighter weight than glass fibres. Another reason is that the G-J-J-G hybrid composite specimens have the greater thickness among other composite types. Subsequently, the transverse stiffness of the G-J-J-G contributes to increase the frequency. Fig. 12 shows that specific natural frequency of the G-J-J-G hybrid composite specimens is double than the frequency of glass specimens. However, damping ratio decreases with decreasing the jute content, i.e. J-J-J > G-J-J-G > G-J-G > G-G-G-G. The incorporation of glass fibre contributes to decreasing the damping of hybrid composites as also confirmed previously in the literature [31,33,34]. The higher inherent stiffness (directly related to the modulus) of E-glass fibres produces a lower damping effect than jute fibres do. On the other hand, the relatively higher damping characteristic of jute fibres is attributed to the presence of voids, fibre entanglement, fibre crimp and twist, and the friction between the heterogenous cell walls [14]. The same general behaviour was obtained by inclusion of flax with carbon fibres reinforced epoxy matrix due to the higher damping behaviour of flax fibres [30].

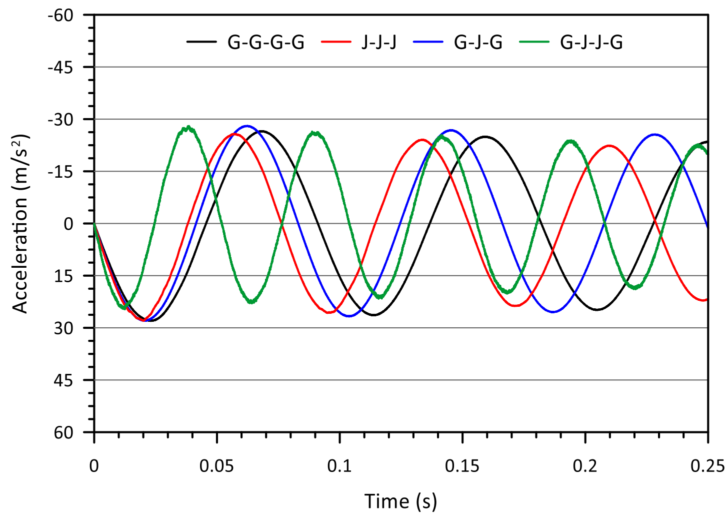

Fig. 11. Acceleration response of different types of composites.

Table VI
Charpy's impact strength of different composites' types

Symbol	Composite designation	Fundamental natural frequency (Hz)	Damping ratio $*10^{-3}$	Quality factor
A	G-G-G-G	11.03±0.51	32.53±1.76	15.37
B	J-J-J	13.31±0.60	46.65±2.20	10.78
C	G-J-G	11.08±0.46	39.56±1.51	12.64
D	G-J-J-G	19.17±0.64	43.34±1.41	11.54

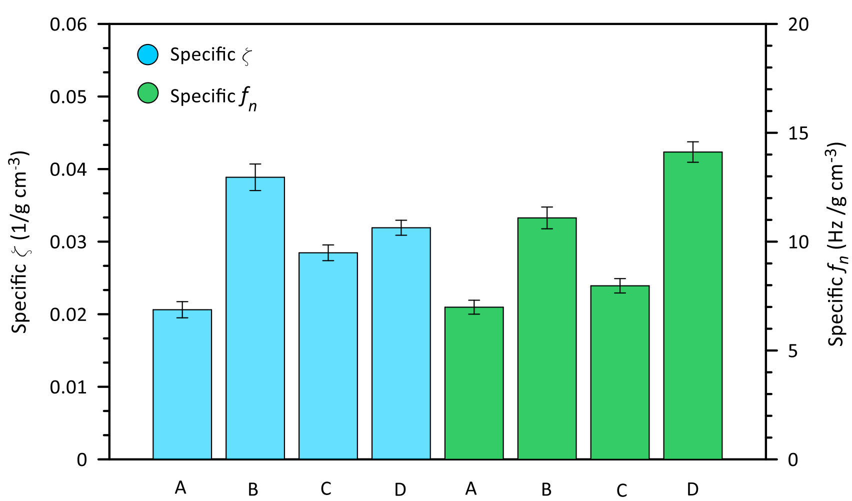

Fig. 12. Specific vibration properties of different types of composites.

CONCLUSIONS

In this work, the mechanical properties and vibrational characteristics of the glass, jute, and hybrid glass/jute fibres/polyester composites are investigated. By keeping the total fibre weight loading of the composites constant (i.e. about 18 wt%), the relative weight fractions of the individual fibres were changed. The tensile, flexural and impact properties were enhanced by incorporation of glass with jute fibres in the hybrid composites when compared with jute composites. The presence of jute fibres within the composite led to increase the damping factor of the composite and its fundamental natural frequency. In this work, higher mechanical properties and vibrational characteristics of the hybrid composites have been obtained when they were related to their densities. This means that there is a weight reduction gain when using the glass/jute hybrid composites. However, increasing the numbers of jute ply should be limited because it would contribute to overall composite weight and volume. The key conclusion suggests that hybrid composites with lower jute fibre fraction have the higher tensile, flexural and impact properties, while hybrid composites with higher jute fibre fraction have the higher vibration characteristics.

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