ISSN : 2028-2508
CODEN: JMESCN

Mechanical Behavior of Banana Fiber Based Hybrid Bio Composites

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Received in 26 July 2011, Revised 13 Aug 2011, Accepted 18 Aug 2011.
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Abstract
With growing environmental awareness, ecological concerns and new legislations, bio-fiber-reinforced plastic composites have received increasing attention during the recent decades. The composites have many advantages over traditional glass fiber or inorganic mineral-filled materials, including lower cost, lighter weight, environmental friendliness, and recyclability. In the present work a banana fiber and silica powder reinforced composite material is developed. Scanning electron microscopy shows that banana fibers are well dispersed in the resin matrix. Addition of fiber increases the modulus of elasticity and decreases the ultimate tensile strength of the epoxy. And further addition of silica also increases the modulus of elasticity reduces the ultimate tensile strength. Addition of banana highly reduces yield strength and addition of silica gives better results than banana reinforced composites but still having yield strength highly reduced. Banana reinforced improve the impact strength of epoxy materials. Addition of fibers increases the capacity of water absorption. This test is necessary where the composites are used in moisture affected areas. Addition of banana fiber reduces bending strength and addition of silica with banana has not given better bending strength than banana fiber reinforced composites.

Key Words: Composite Material, banana fiber, polymer and environment

Symbol used:	1) BaF	Banana Fiber
	2) Si	Silica Particle
	3) wt%	Weight percentage

1. Introduction

With growing environmental awareness, ecological concerns and new legislations, bio-fiber-reinforced plastic composites have received increasing attention during the recent decades. The composites have many advantages over traditional glass fiber or inorganic mineral filled materials, including lower cost, lighter weight, environmental friendliness, and recyclables. Because wood and other bio-fibers easily undergo thermal degradation beyond 200°C, thermoplastic matrix used in the composites is mainly limited to low-melting-temperature commodity thermoplastic resins, like polyethylene (PE), and polypropylene (PP) [1]. However, the inherently unfavorable thermo mechanical and creep properties of the polyolefin matrix limit some structural applications of the materials.

In order to overcome the above drawbacks, effort has been recently made to utilize high-performance thermoplastics as matrix materials. A low temperature compounding (LTC) technique developed by [2] was successfully used to produce cellulose fibers reinforced engineering plastics such as Nylon-6, poly(butylenes terephthalate), and ethylene-carbon monoxide [3]. It was shown that cellulose fiber-reinforced Nylon-6 composites were approximately twice as strong and twice as stiff as wood flour filled polypropylene. At the same time, the composites had better notched and unnotched Izod toughness than wood flour composites [2]**.**

The dynamic mechanical analysis of banana fiber reinforced polyester composites was carried out with special reference to the effect of fiber loading, frequency and temperature. The intrinsic properties of the components, morphology of the system and the nature of interface between the phases determine the dynamic mechanical properties of the composite. At lower temperatures (in the glassy region), the modulus of elasticity values are maximum for the neat polyester whereas at temperatures above higher temperature the modulus of elasticity's are found to be maximum for composites with 40% fiber loading, indicating that the incorporation of banana fiber in polyester matrix induces reinforcing effects appreciably at higher temperatures. The loss modulus and damping peaks were found to be lowered by the incorporation of fiber [4].

In recent times, increasing attention has been paid to the use of renewable resources particularly of plant origin keeping in view the ecological concerns, renew-ability and many governments passing laws for the use of such materials. On the other hand, despite abundant availability of lignocellulosic materials in Brazil, very few attempts have been made about their utilization, probably due to lack of sufficient structure/property data. Systematic studies to know their properties and morphology may bridge this gap while leading to value addition to these natural materials. Chemical composition, X-ray powder diffraction, and morphological studies and thermal behavior aspects in respect of banana, sugarcane bagasse sponge gourd fibers of Brazilian origin are presented. Chemical compositions of the three fibers are found to be different than those reported earlier. X-ray diffraction patterns of these three fibers exhibit mainly cellulose type I structure with the crystallinity indices of 39%, 48% and 50% respectively for these fibers. Morphological studies of the fibers revealed different sizes and arrangement of cells. Thermal stability of all the fibers is found to be around 200 °C. Decomposition of both cellulose and hemicelluloses in the fibers takes place at 300 °C and above, while the degradation of fibers takes place above 400 °C. These data may help finding new uses for these fibers.

2. Materials and Methods

2.1 Matrix Material

2.1.1 Epoxy Resin (CY 230)

Epoxy resin is widely used in industrial application because of their high strength and mechanical adhesiveness characteristic. Araldite CY 230 is a liquid solvent free epoxy resin. It has versatile applications in technical and industrial applications. Curing takes place at room temperature and atmospheric pressure after addition of hardener. Araldite CY 230 purchased from M/s Petro Aradite Pvt. Limited, Chennai, India is used in the present investigation.

2.1.2 Hardener (HY 951)

Hardener HY-951 is a yellowish-green liquid. Hardener HY 951 purchased from M/s Petro Aradite Pvt. Limited, Chennai, India has been used as curing agent. In the present investigation 8 % by wt has been used in all material developed. The weight percentage of hardener used in the present investigation is as per recommendation of [5].

2.2 Reinforcing Element

Reinforcing agents are added to the resin to improve the mechanical strength and wear properties.

2.2.1 Banana fiber

Banana fiber (figure 1) is extracted from the waste product of banana cultivation. Due to high cellulose content, it has superior mechanical properties, especially tensile strength and modulus [6]**.** It is thus considered as a promising candidate for replacing conventional glass fibers in the fiber-reinforced composites. Earlier studies showed that BaF (maximum 10 wt%) provided good reinforcement for various thermosetting resins such as unsaturated polyester [7, 8, 9, 10].

Figure 1: Banana fibers

2.2.2 Silica

It is reported [11] that silica partials (maximum 2 wt%) are uniformly dispersed in to the matrix of parent material and there is no chemical reaction between silica and resin matrix. Addition of silica particles improves the mechanical and wears properties significantly. Properties of Silica particle are given in table 1.

Table 1: Physical properties of reinforcing element

Material	Density (kg/m^3)	Form
Silica	2.33	Powder form

2.3 Methods

Epoxy resin (CY 230), hardener (HY 951), silica particle (2 wt%) and banana fiber (10 wt%) with different weight percentage were used. Commercial epoxy resin CY 230 and hardener HY 951 were supplied by M/s Petro Araldite Pvt. Limited, Chennai, India and silica particle was supplied by M/s Insilco Limited, Gajraula, (Degussa Group) and M/s Taj Resins Pvt. Limited, New Delhi, India, respectively. Different mixtures of silica particles, banana fiber epoxy resin were prepared by mechanical stirring at 3000 rpm. The curing curve of epoxy CY 230 is shown in Figure2. Based on the curing curve, the solution obtained by mixing silica particle and banana fiber in resin is kept in the furnace at a temperature of 90 ± 10 °C for two hours**.** At each interval of 30 minutes the solution is taken out from the electric furnace and remixed by mechanical stirrer at same speed. After two hours the whole solution is taken out and allowed to cool to a temperature of 45°C. When a temperature of 45°C has been attained the hardener HY 951 (8% wt) is mixed immediately. Due to addition of hardener high viscous solution is obtained which is remixed mechanically at high speed by the mechanical stirrer. The viscous solution so obtained is poured into different moulds for sample preparation for tensile, compression and fracture toughness testing. All tensile, compression and fracture tests are conducted on 100 kN servo hydraulic universal testing machine (ADMET, USA). A flat specimen for tensile test, Circular specimens with aspect ratio (length to diameter) of 2.0 for compression test are tested under displacement mode of control of 0.1 mm/sec. Silicon grease is used to lubricate two interfaces between the specimen and grips, to eliminate the interfacial friction influence as much as possible. The results are presented and discussed in subsequent sections.

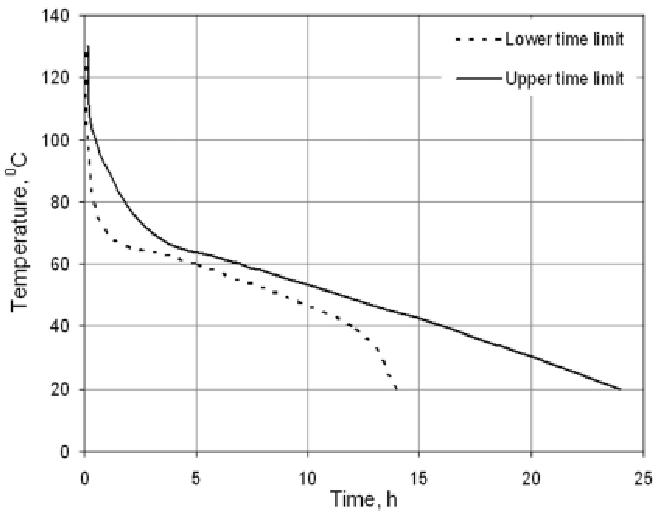

Figure 2: Curing curve of CY 230 epoxy based composite [12]

3. Results and Discussion

3.1 Density

Density is one of the most important mechanical properties of the material. The density of banana reinforced composite, banana-silica reinforced composite and banana-bagasse reinforced composite along with density of epoxy resin are presented in Table 2.

Table 2: Density of epoxy resin, banana reinforced composite and banana-silica reinforced composite

S.No	BaF (gm/cm³)	BaF+Si (gm/cm³)	Epoxy (gm/cm³)
1	1.11	1.13	1.159
2	1.1	1.19	1.184
3	1.08	1.12	1.186
Mean	1.097	1.147	1.176
S D	0.015	0.038	0.015

Table 2 reveals that increase in wt% of reinforced particles, i.e. the banana fiber in the resin solution decreases the density. The decrease in density can be related to the fact that the fibers are light in weight but occupy substantial amount of space. Hence there is a general decrease in the density of all the composite materials with regards to the epoxy resin.

In the present investigation density of banana filled composite is found be 1.097 gm/cm³ for 10wt% banana filled composites, 1.147 gm/cm³ and for 10%banana-2%silica wt% reinforced composite. This is lower than the pure epoxy resin which is 1.176gm/cm³. Hence, it can be concluded that proper combination of the banana-silica hybrid composite material may have a varieties of industrial application when weight and strength would be the critical parameter in the design.

3.2 Water Absorption Capacity

Water absorption capacity is another crucial factor to be taken into account when considering the effect of water on the composite material developed. The effect is presented in Table 3.

ISSN : 2028-2508
CODEN: JMESCN

Table 3: Water Absorption capacity

S.No	BaF	BaF+Si	Epoxy
1	2.63%	2.19%	0.633%
2	3.08%	3.43%	0.699%
3	2.66%	2.55%	0.609%
Mean	2.79%	2.72%	0.647%
S D	0.252	0.638	0.0466

The effect of water absorption is important incase the material that has been developed when used for applications comes in contact of water. This substantial increase with regards to the epoxy resin can be due to the fact that here the present banana fibers have maximum capacity of water absorption in comparison to the silica and the resin particles.

3.3 Scanning Electron Microscope (SEM)

The state of dispersion of banana fiber into the resin matrix plays a significant role on the mechanical properties of the composite. Various methods such as SEM, TEM etc can be used to evaluate the fiber dispersion in the composite. In the present investigation SEM has been carried out for hybrid composite containing 10 wt% Banana fiber the epoxy resin matrix. Figure 3(a) to 3(b) shows the SEM photographs of hybrid composite material investigated in the present work. In the both photographs, good dispersion of banana fiber in the resin matrix has been observed. Hence, from the above micrographs it is can be concluded that due to uniform dispersion of banana fiber is the epoxy resin, a remarkably effect on the mechanical properties may be obtained.

Figure 3(a) shows the vertical cut section of SEM photographs of 10 wt% banana fiber composite material. In this case, good dispersion of banana fiber in the resin matrix has been observed. It is seen from the figures that fibers are well dispersed in the epoxy resin matrix in a preferred orientation. The absence of any voids around the fibers indicates a good adhesion between fibers and epoxy matrix. From the Figure 3(b) it can be concluded that the vertical fracture section of SEM photographs of 10 wt% banana fiber composite material is well bonded as the picture clearly shows that there is no stretching of fibers, rather fibers are broken uniformly. From the above figures it is also evident that there is no chemical reaction between fibers and epoxy resin.

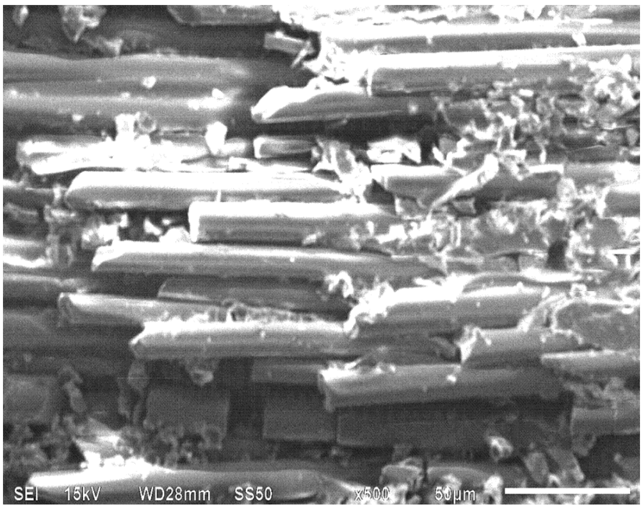

Figure 3(a): Scanning electron micrograph for 10 wt% banana fiber of vertical cut section

ISSN : 2028-2508
CODEN: JMESCN

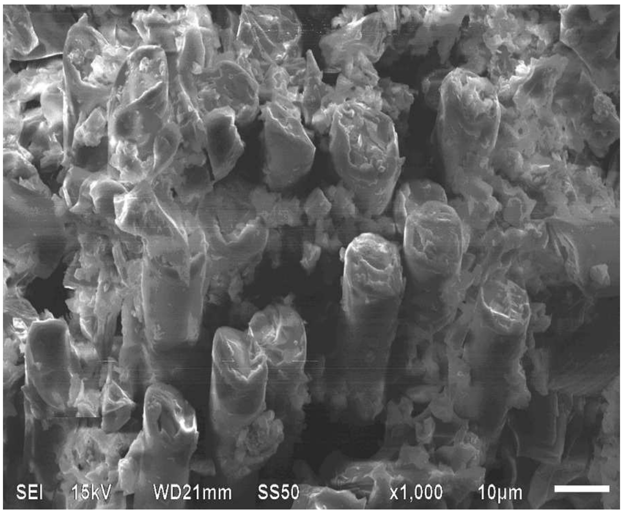

Figure 3(b): Scanning electron micrograph for 10 wt% banana fiber of horizontal cut section

3.4 Mechanical Properties

3.4.1 Tensile strength

The mechanical properties of the banana and banana-silica filled epoxy resin hybrid composite materials were determined by 100 kN ADMET make servo controlled universal testing machine at 1mm/min strain rate under displacement control mode. The results are presented in figures 4.

3.4.2 Tensile stress-strain curve

The tensile stress-strain curve for unfilled epoxy resin (8 wt% HY-951 hardener and rest CY-230 resin) and hybrid composite materials containing 10 wt% banana fiber and 10 wt% banana and 2 wt% silica. All tests are conducted as per ISO in 100 kN servo hydraulic Universal Testing. Remarkable differences can be seen in the stress-strain behavior due to addition of silica and banana fibers in epoxy resin matrix.

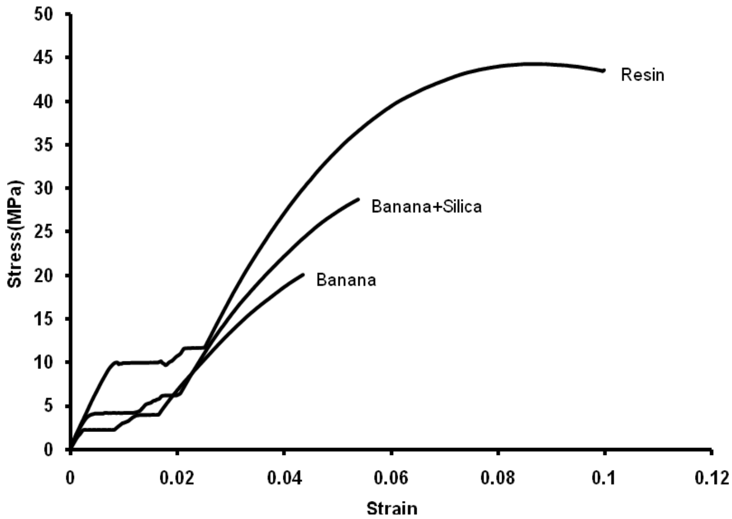

Figure 4: Stress-strain diagram for different composite materials

3.4.3 Tensile Properties

Tensile tests were carried out at strain rates of 0.1 mm/sec. The properties of the banana reinforced composite and banana-silica reinforced composite along with that of epoxy resin are presented in Table 4.

Table 4: Tensile properties of the composite materials and epoxy resin.

Property	BaF	BaF+Si	Epoxy
E,(GPa)	1.340 ± 0.142	1.460 ± 0.173	1.359±0.124
Ultimate stress, (MPa)	22.258 ± 5.55	27.618 ± 4.94	43.790±7.767
Yield stress, (MPa)	4.15 ± 2.99	4.43 ± 1.36	9.82±0.629
Strain energy, (Nm)	23.792 ± 10.277	37.405 ± 8.452	597.54±42.48

The results of modulus of elasticity, the ultimate tensile strength, yield stress and strain energy are shown in the table 3 for strain rate of 0.1 mm/sec. Remarkable differences can be seen on the ultimate tensile strength of the hybrid composite material having different reinforcing materials. It can be noticed that for all specimens the ultimate tensile strength is highest for the banana-silica composite and is 27.618 MPa though it is still less than that of the epoxy resin, which has a ultimate tensile strength of 43.790 MPa, as found out by the experiments conducted. It is seen that addition of silica and fibers significantly affects the modulus of elasticity. About 12% increase in modulus of elasticity has been seen due to addition of 10wt% of banana fibers and load applied at 0.1 mm/sec. strain rate. Yield strength has decreased with addition of silica and fibers content in the composite material. Even the strain energy considerably decreased due to addition of the banana fiber. This would have had an impact on the mechanical properties of the composite material.

From the above observation it can be concluded that modulus of elasticity can be increased with appropriate combination of silica and banana content for different application environment. This indicates that decrease in yield strength due to addition of reinforcing fibers in silica hybrid composite material, the material is expected to behave less elastically throughout practically.

3.4.4 Compressive Strength

The Compressive Strength properties of the banana and banana-silica filled epoxy resin hybrid composite materials were determined by 100 kN ADMET make servo controlled universal testing machine at 0.1mm/sec. strain rate under displacement control mode. The results are presented in figure 5. The results of the compressive test are shown in table 4.4. All tests are conducted under displacement control mode. The variation of compression strength with wt% of silica and banana fibers is shown in figure 5. The compressive properties of the composite material are shown in table 5.

Table 5: Compressive properties of the composite materials and epoxy resin

Property	BaF	BaF+Si	Epoxy
Modulus of Easticity, (GPa)	0.504± 0.248	1.669 ± 0.027	0.736±0.136
Ultimate stress (MPa)	49.853 ± 4.230	63.202 ± 15.746	185.283±37.679
Yield stress (MPa)	10.167 ± 2.021	13.067 ± 6.278	13.5±2.18
Strain energy (Nm)	31.253 ± 9.029	11.302 ± 1.574	50.899±27.581

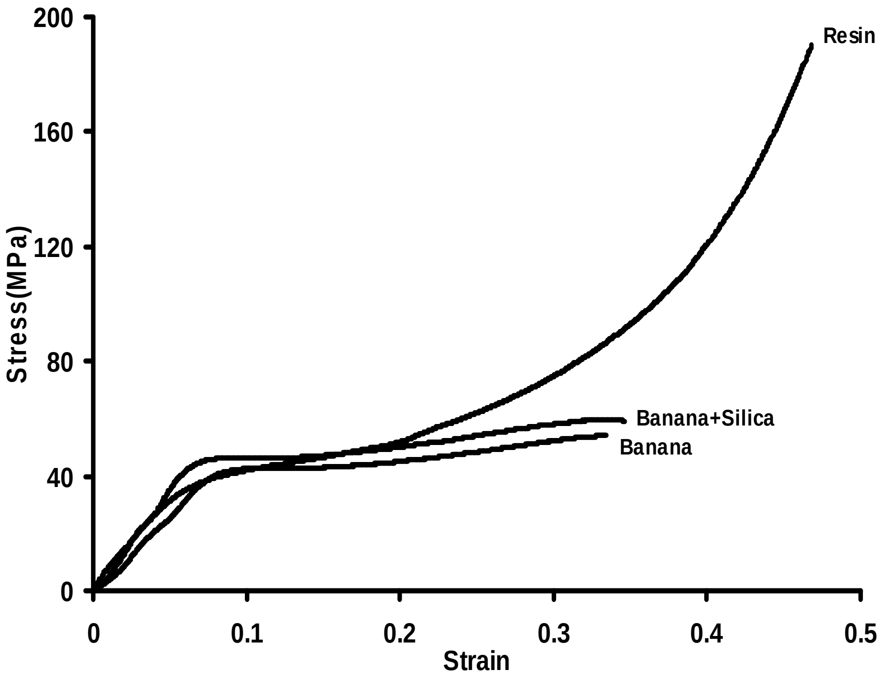

Figure 5: Stress-strain diagram for different composite materials

A remarkable difference can be noticed in the value of the compressive strength with different wt% composition of silica and banana fibers. It can be noticed that addition of silica to the banana fibers improves the ultimate compressive strength of the hybrid composite materials. It is found that ultimate compressive strength of 2wt% of silica and 10 wt% of banana fiber is about 63.2 MPa. As depicted by the test conducted the most favorable combination is that of banana and silica reinforced composite material for good ultimate compressive strength.

3.4.5 Impact Strength

The results obtained from Charpy test are presented in table 6. Charpy impact strength of banana reinforced composite banana and banana-silica reinforced composite are depicted in table 6. The effects of silica and banana fibers as individual filler as well as hybrid fillers on the impact strength are studies and discussed in this section.

Table 6: Impact strength

S.No	BaF , (Nm)	BaF+S, (Nm)	Epoxy, (Nm)
1	22.05	22.05	24.524
2	22.05	24.50	22.0725
3	17.15	24.50	19.62
Mean	20.416	23.683	22.072
S D	2.829	1.414	2.452

Table 5 shows that composite containing banana fiber and silica shows maximum impact strength amongst all hybrids composite studied. Addition of 2 wt% of silica to 10 wt% banana increased its impact strength which was more than that of the pure epoxy.

An increase of impact strength from 22.07 Nm to 23.683 Nm has been noticed due to addition of 10 wt% of banana and 2 wt% of silica to the epoxy composite. Addition of silica particle as filler material probably fill the small voids the regions of particle corners and would, therefore improve the impact strength.

3.4.6 Hardness Test

As known, hardness implies a resistance to indentation, permanent or plastic deformation of material. In a hybrid composite material, filler weight fraction significantly affects the hardness value of the hybrid composite material. Hardness values measured on the Rockwell M-Scale showing the effect of weight percentage of silica and banana and bagasse fibers on the hardness values of hybrid composite are presented in Table 7.

Table 7: Rockwell Hardness values on M-Scale for various filled hybrid composite

S.No	BaF(Rm)	BaF+Si	Epoxy
1	53	57	60
2	48	54	55
3	54	63	58
4	65	64	61
5	57	64	55
Mean	55.4	60.4	57.8
S D	6.269	4.616	2.775

It is found that hardness of neat epoxy resin (CY-230+ 8 wt% of HY-951) is 57.8. The hardness of the fabricated composite made of epoxy resin and 10 wt% of banana fiber and 2 wt% of silica is maximum and is 60.4.

The hardness increases with the amount of silica and the presence of banana with the banana fibers reflecting the reinforcement formed in the hybrid composite.

3.4.7 Bending Test

The Bending strength properties of the banana and banana-silica filled epoxy resin hybrid composite materials were determined by 100 kN ADMET make servo controlled universal testing machine at 0.1mm/sec. strain rate under displacement control mode. The results are presented in Table 8.

Table 8: bending strength properties for resin and composite materials

Property	BaF	BaF+Si	Epoxy
E,(GPa)	1.252 $\pm$ 0.414	0.697 $\pm$ 0.298	0.801$\pm$0.254
Flexural Stress, (MPa)	32.618 $\pm$ 5.775	29.670 $\pm$ 5.835	51.254$\pm$7.171
Flexural Strain	0.04 $\pm$ 0.006	0.043 $\pm$ 0.005	0.0906$\pm$0.0257

As depicted by the test data, amongst the composite materials developed the 10 wt% banana reinforced composite shows the best results with regards to the modulus of elasticity (1.252 GPa w.r.t. 0.801 GPa of epoxy resin) and the Flexure Stress having a value of 32.618 MPa w.r.t. other reinforcing materials.

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