Glass/Biofibers/Epoxy Methacrylate of Bisphenol-C Sandwich Composites: Comparative Mechanical and Electrical Properties and Chemical Resistance

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ABSTRACT

Glass/Biofibers/Epoxy methacrylate of bisphenol-C (G/BF/EBCMAS) sandwich composites was prepared by compression molding. G/BF/EBCMAS showed good mechanical and good to excellent electrical properties and excellent chemical resistance. Studied properties are compared with EBCMAS and G/EBCMAS. In comparison with G/EBCMAS, G/BF/EBCMAS showed considerable decline of tensile strength (18-63.4%), flexural strength (18.8-38.7%), flexural modulus (12.8-50.7%), Izod impact strength (17.4-43.5%), Barcol hardness (2.1-16.7%) and dielectric strength (23.8-76.8%) except flexural strength of G/BM/EBCMAS. G/WC/EBCMAS (96.7%), G/B/EBCMAS (79.2%), G/GN/EBCMAS (83.3%) and G/RH/EBCMAS (97.9%) showed decline of volume resistivity, whereas other sandwich composites showed 1150-58233% improvement. The decrease in mechanical properties and dielectric strength of G/BF/EBCMAS sandwich composites is mainly due to poor interfacial adhesion and randomly oriented fibers. Water absorption trend in different environments is H_2SO4 (10.9-12.7%) > HCl (10.5-12.3%) > NaOH (9.5-11.7%) > H_2O (8.3-11.0%) > NaCl (7.9-10.1%). Saturation time for G/BF/ EBCMAS in different environments is 336-384 h (H_2O), 228-360 h (NaCl), 336-360 h (NaOH and HCl) and 312-360h (H_2SO4), which is comparable with G/EBCMAS (336-384) except G/BC/EBCMAS (288 h, NaCl), G/B/EBCMAS (312 h, H_2O) and G/GN/ EBCMAS (228 h, NaCl). Sandwich composites may be useful for low-cost housing and other specific applications.

KEYWORDS: *Epoxy methacrylate, Sandwich composites, Mechanical and electrical properties, Chemical resistance, Water absorption.*

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INTRODUCTION

Nowadays demand for imperishable materials is rapidly growing in different fields such as construction, packaging, engineering, aerospace and automotive, agriculture, etc. Glass, carbon, and aramid filaments are synthetic filaments, economically costlier, nonrenewable, nonbiodegradable. Products composed from them are imperishable and used for special purposes. On the other side, bio-fibers are bountiful, easily available, biodegradable, and economically low priced. Biofibers can be extracted from various parts of the plant materials and can be modified by chemical and physical methods[1-4]. Biofibers are mainly used for making low-priced and economically viable biocomposites, which can be handled easily and non-hazardous, biodegradable, and lightweight with low density, high characteristic strength, and modulus, good sound-absorbing property[5-11]. Biofibers contain varying amounts of cellulose, hemicellulose, lignin, and pectin[1-3]. They are highly hygroscopic due to a large number of hydroxyl groups and are responsible for poor wettability with hydrophobic matrix resulting in poor adhesion[10,11].

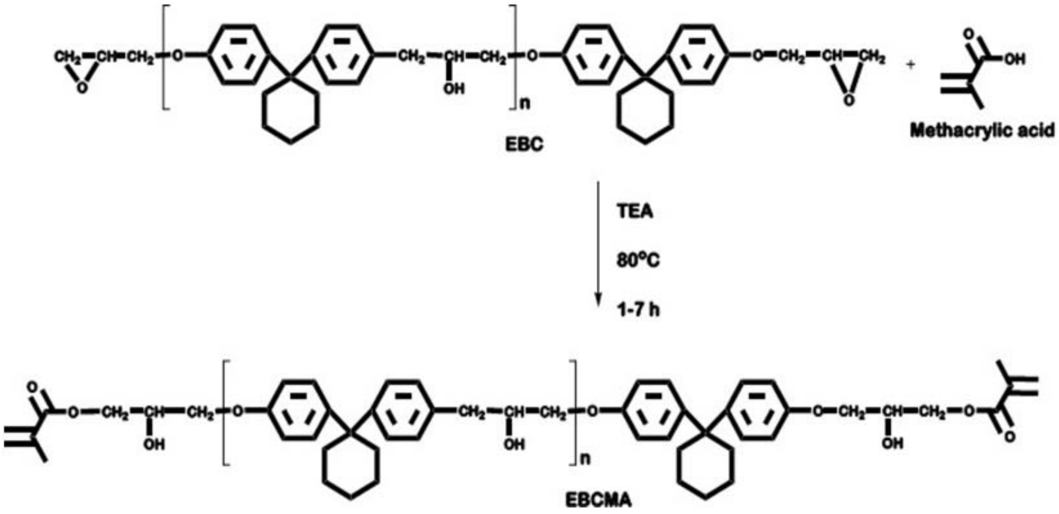
Acrylated polymers with a different structure based on epoxy resin, polyurethane, polyester, polyether, and oils are extensively used as coating material.[12,13] Because of excellent chemical and solvent resistance, good durability, good stickiness, tenacity, versatility in cross-linking, and nonyellowing of epoxy acrylates and epoxy methacrylates make them useful for manufacturing products as per their end uses. Epoxy backbone imparts toughness property, whereas carbon- carbon and ether bonds enhance chemical resistance. Hydroxyl groups of epoxy backbone increase the polarity and thereby improve the wettability of adhesive[14]. A wide range of viscosities, design flexibility, and room temperature curing of such reactive materials make them useful for many manufacturing sectors[12,15-17].

Many researchers as well as we have reported preparation and evaluation of physicochemical properties of different biocomposites but not glass/bio-fibers/ epoxy methacrylate sandwich composites[18-23]. Since glass filaments are economically costlier, nonrenewable, nonbiodegradable, and are used for high-performance industrial applications. Our main objective of the present work was to prepare low-cost sandwich composites based on some agricultural waste biomasses, which partially protect the environment and producers can get financial support in earning their bread and butter. Such sandwich composites may be alternate of plywood for specific applications especially at the time of natural calamities like floods, earthquakes, cyclones, etc. Keeping in mind the usefulness of bio-fibers in combination with glass fibers, we had collected several bio-fibers from different natural resources and utilized them in making sandwich composites, and evaluated their characteristic mechanical and electrical properties as well as chemical resistance against different reagents.

EXPERIMENTAL

Materials

Laboratory grade solvents and chemicals were used as received or purified by the appropriate method. Epoxy methacrylate of bisphenol-C (EBCMA) **(Scheme 1)** was synthesized and purified according to our reported method[19,24] and its 40% styrene solution (EBCMAS)



Scheme 1. Synthesis of epoxy methacrylate of bisphenol-C (EBCMA)

was prepared at room temperature. EBCMAS used in the present study had 1.12gcm^{-3} density, 300 cP viscosity; 20 min gel time, and 135°C peak exotherm temperature[24]. Methylethylketoneperoxide (MEKP), 6% cobalt octoate, woven silane treated E-glass fabric (450 gsm) and mylar were supplied by EPP Composites, Rajkot as free samples and was used as received. Various bio- fibers(BFs) such as white coir (WC) (Cocus Nucifera), brown coir (BC)(Cocus Nucifera), banana fibers (B)(Musa acuminate), groundnut fibers (GN)(Arachis hypogaea), cane sugar fibers (CS) (Blue agave), pineapple leaf fibers (PA)(Pina), rice husk (RH) (Oryza sativa L) and wheat husk (WH) (Triticum) were collected from the local market (Rajkot). Wild almond fruits were purchased from Junagadh and fibers (WA) (Sterculia foetida) were extracted manually[4]. Bamboo fibers (BM)(Phyllostachys aurea) were purchased from Kolkata. Betel nut fibers (BN) (Areca catechu) and palmyra fibers (PM) (Borassus flabellate) were purchased from Calicut. Collected bio-fibers were cleaned, washed several times with distilled water, and dried in an oven at 50°C for 48 h. Dry and clean bio-fibers were chopped into 1-2mm size and stored in airtight containers. Chemical compositions and physical properties of some of the bio-fibers are presented in Table 1[1-3], from which it is observed that bio-fibers possess quite variable percentages of cellulose (31-83%), hemicellulose (18-33%) except coir (0.1-0.2%) and lignin (14-30 %); and water absorption tendency (9-16%). Similarly, some of the physical properties are also found variable.

Preparation of Glass/Biofiber/EBCMAS Sandwich Composites

Required quantity of EBCMAS ((40% of reinforcement) (Table 2), 1% MEKP (initiator), 1.5% cobalt octoate (accelerator), and 1.5% dimethylaniline (promoter) of EBCMAS were transferred into a 500 mL beaker at room temperature and mixed thoroughly with a glass rod to prevent air bubble formation. The resin solution was applied to 5 plies of glass fabric (20cm x 20cm) with a smooth brush and kept at room temperature for 15-20 min. Chopped bio-fibers (about 33% of glass fabric) were divided into 4 equal portions and spread uniformly on five impregnated glass plies. The impregnated plies were stacked one over the other between two mylar films and pressed between two mold platen under 5 MPa pressure at room temperature for 3 h and post cured in an oven at 150°C for 30 min, cooled to room temperature, peeled off mylar films and machined the edges. Samples were machined according to standard test methods. For the water absorption study, 2cmx 2cm size samples were cut from the sheets, and their edges were sealed by using

TABLE 1. Chemical compositions and physical properties of some bio-fibers

Biofiber	Cellulose %	Hemicellulose %	Lignin, %	Density, gcm^{-3}	Tensile Strength MPa	Tensile Modulus, GPa	Elongaction %	Moisture Absorption %
Jute	61-71	12-20	12-13	1.39-1.52	307-1000	13-70	1.2-1.8	8.5-17
Coir	32-43	0.1-0.2	40-45	1.15-1.25	140-800	11-34	-	10-13
Banana	65	19	5	0.75-1.35	1.7-7.9	11-32	1.5-9	9-15
Groundnut	35.7	18.7	30.2	-	-	-	-	-
Betel nut	53.2	33	7.2	-	-	-	-	-
Palmyra	37	31.5	18.54	0.4-0.6	110-280	-	-	-
Cane sugar	32-55	20-25	18-24	0.5-1.2	170-290	15-19	3-7	-
Pineapple leaf	70-83	-	5-12.7	1.44	100-170	10-50	-	10-13
Bamboo	26-43	15-26	21-31	0.6-1.5	140-800	11-34	-	-
Rice husk	31.3	24.3	14.3	-	-	-	-	-
Wheat husk	36	18	16	0.75	-	-	-	16

TABLE 2. The experimental details for the fabrication of G/BF/EBCMAS sandwich composites

Composite	EBCMAS, g	Glass fabric, g	Biofiber, g	Total wt, g
G/EBCMAS	62	90	-	152
G/WC/EBCMAS	81	90	30	201
G/BC/EBCMAS	82	92	31	205
G/B/EBCMAS	80	90	30	200
G/GN/EBCMAS	82	92	31	205
G/BN/EBCMAS	81	90	30	201
G/PM/EBCMAS	80	90	30	200
G/CS/EBCMAS	82	90	30	202
G/PA/EBCMAS	82	92	31	205
G/WA/EBCMAS	82	92	31	205
G/BM/EBCMAS	80	90	30	200
G/RH/EBCMAS	80	90	30	200
G/WH/EBCMAS	80	90	30	200

resin solution and cured at room temperature, and post cured in an oven. The control sample (EBCMAS) was prepared according to our recent publication[24].

Testing Methods

Tensile strength (ASTM-D-638-01) and flexural strength (ASTM-D-790-03) measurements were carried out at a speed of 10 mm min^{-1} on a W & T Avery Ltd. Type 1010 Model No E- 46234 (Birmingham, England). Izod impact strength (ASTM-D-256-06) tests were carried out on an Izod Impact Tester Model No.E-46204 Type A-1300 (Birmingham, England). Electric strength (IEC-60243-Pt-1-1998) quantifications were carried out in the air using 25/75 mm brass electrodes on a high voltage tester (Automatic Electric-Mumbai). Volume resistivity (ASTM-D- 257-2007) measurements were carried out in the air at 25°C after 60 s charging at 500 V DC applied voltage on a Hewlett Packard high resistance meter. Replicate tests were carried out 3-5 times, and average values were considered. Water absorption (ASTM-D-570-98) testing was carried out at 30±2°C by the change in mass method. For that, the samples were weighed and dipped in water, 10% aq. NaCl, 10% aq. NaOH, 10% aq. HCl and 10% aq. H_2SO4 solutions at 30±2°C. The samples were withdrawn at the interval of 24 h; the samples' surfaces were cleaned with tissue papers, reweighed, and immediately dipped in the respective solutions. The testing was carried out till the saturation equilibrium was established.

RESULTS AND DISCUSSION

Mechanical Properties

Tensile strength, flexural strength, flexural modulus, Izod impact strength, Barcol hardness, dielectric strength, and volume resistivity of G/EBCMAS and G/BF/EBCMAS are shown in Figures 1-7, respectively.

EBCMAS showed 55MPa tensile strength, 50 MPa flexural strength, 85MPa flexural

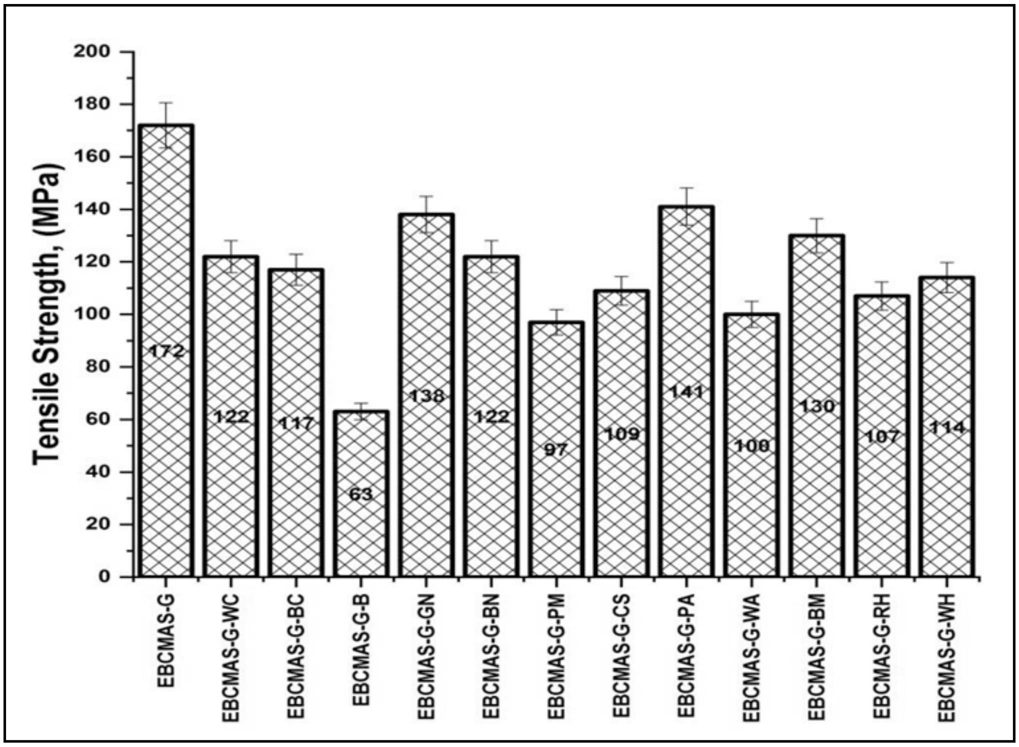


Figure 1. Comparative tensile strength of G/EBCMAS and G/BF/EBCMAS sandwich composites.

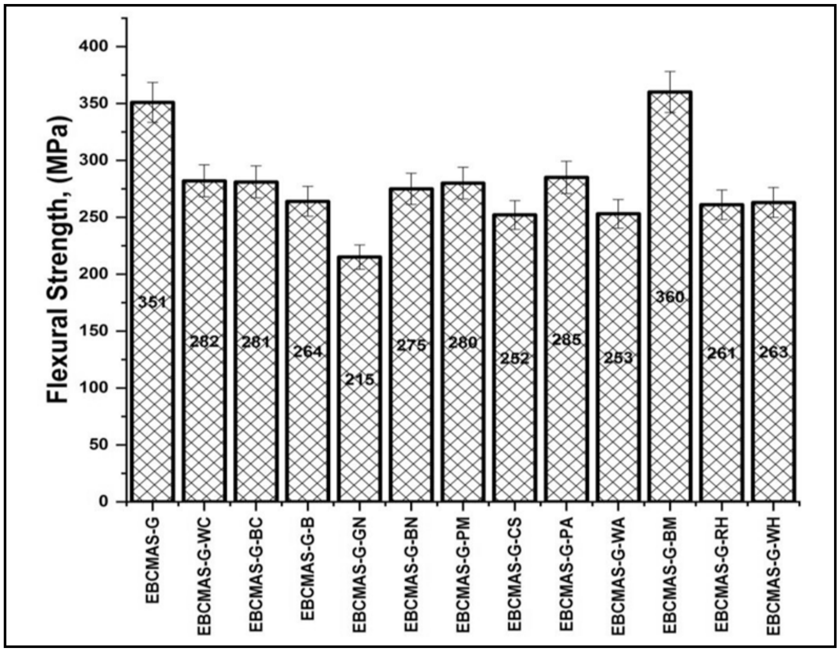


Figure 2. Comparative flexural strength of G/EBCMAS and G/BF/EBCMAS sandwich composites.

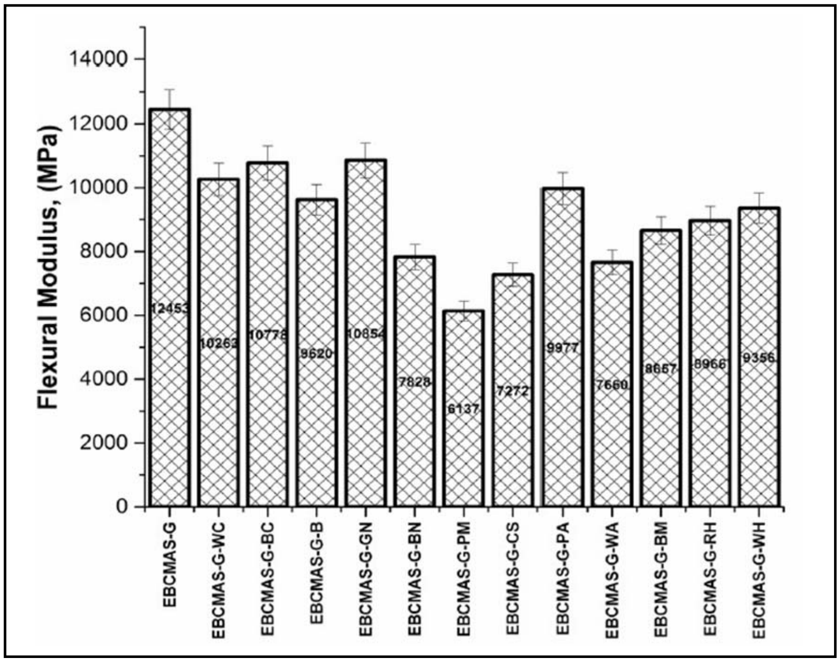


Figure 3. Comparative flexural modulus of G/ EBCMAS and G/BF/EBCMAS sandwich composites.

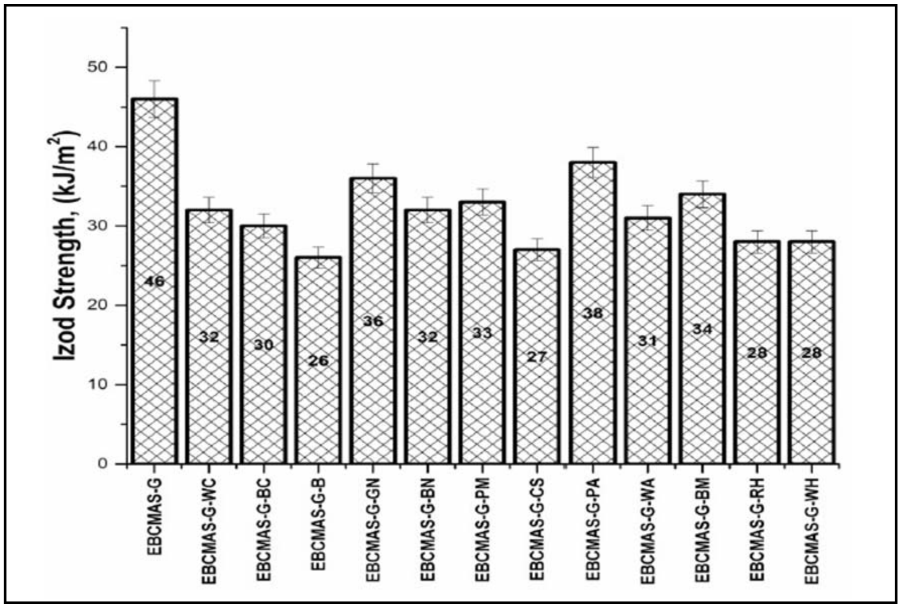


Figure 4. Comparative Izod impact strength of G/EBCMAS and G/BF/EBCMAS sandwich composites.

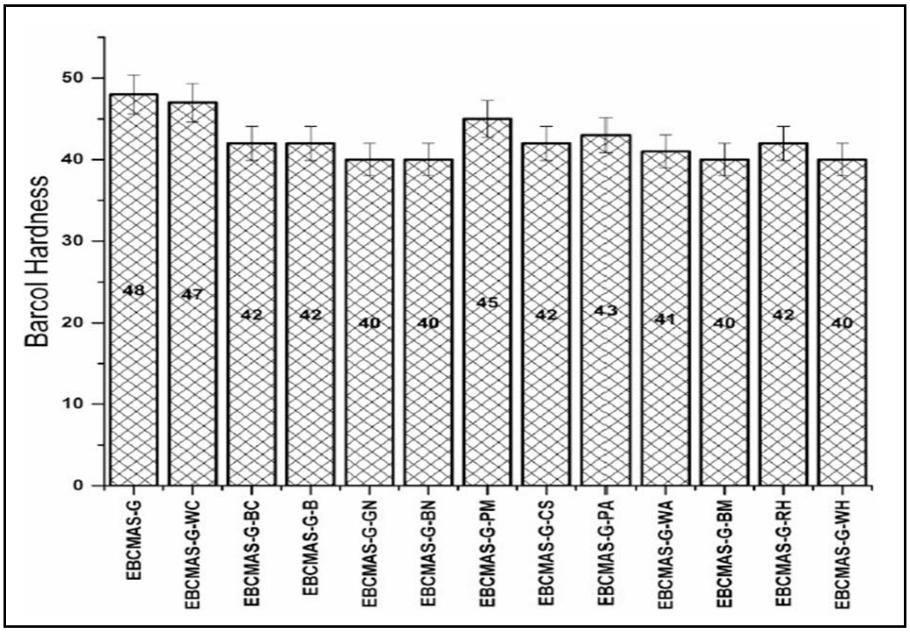


Figure 5. Comparative Barcol hardness of G/EBCMAS and G/BF/EBCMAS sandwich composites.

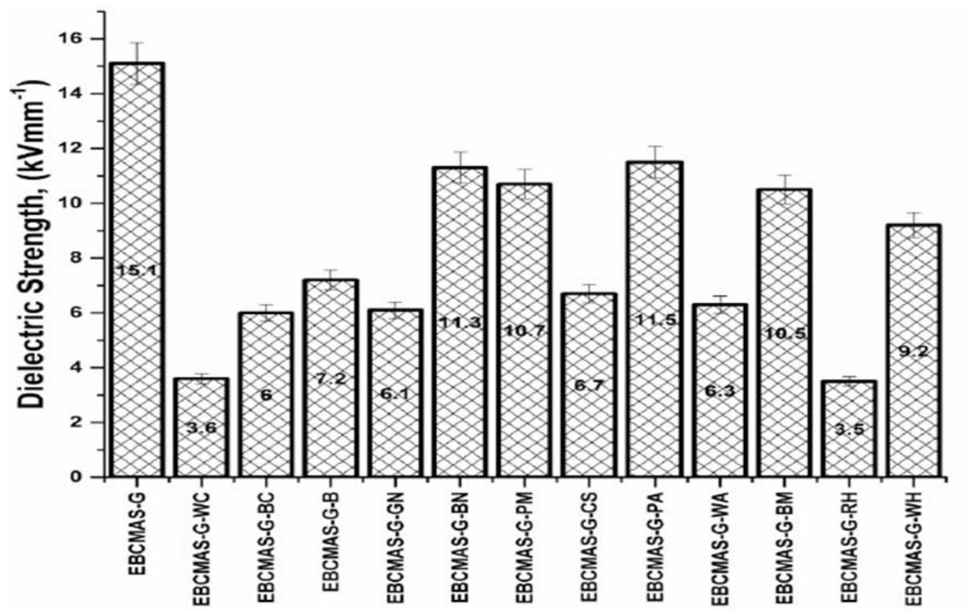


Figure 6. Comparative dielectric strength of G/EBCMAS and G/BF/EBCMAS sandwich composites.

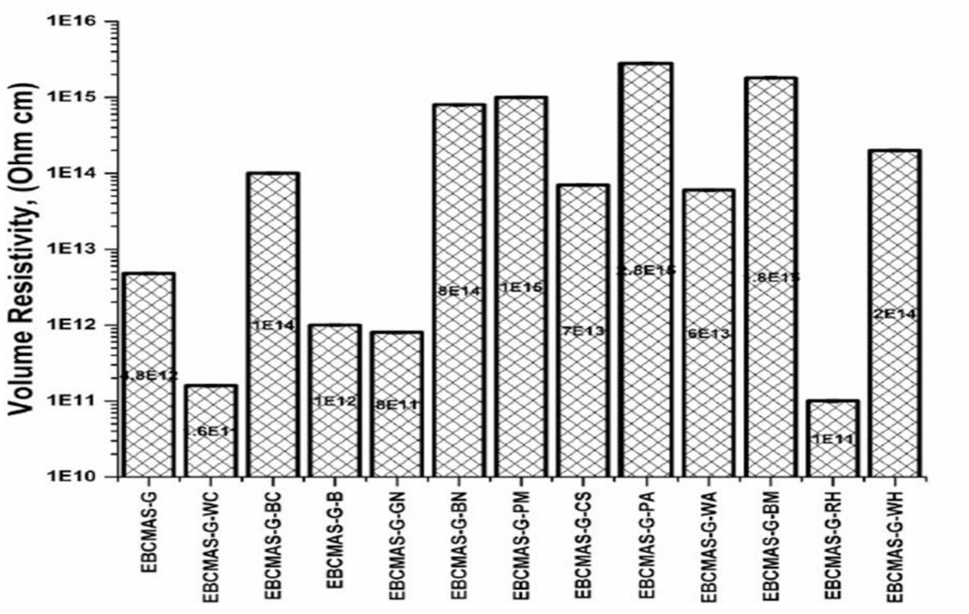


Figure 7. Comparative volume resistivity of G/EBCMAS and G/BF/EBCMAS sandwich composites.

modulus, 23kJm^{-2} Izod impact strength, 37 Barcol hardness, 10.7 kVmm^{-1} dielectric strength, and 5.2x10^{16} ohmcm volume resistivity.[24]

The % changes in the above mentioned mechanical and electrical properties of G/BF/EBCMAS with respect to EBCMAS and G/EBCMAS are reported in Table 3. In comparison with G/EBCMAS, the tensile strength (18-63.4%), flexural strength (18.8-38.7%), flexural modulus (12.8-50.7%), izod impact strength (17.4-43.5%), Barcol hardness (2.1-16.7%) and dielectric strength (23.8-76.8%) of G/BF/EBCMAS are declined considerably except flexural strength of G/BM/EBCMAS, which showed 2.6% improvement. Similarly in comparison to EBCMAS, tensile strength(14.5-156.4%), flexural strength (330-620%), flexural modulus (7120-12669%), Izod impact strength (13-85.2%), and Barcol hardness(8.1-27%) of G/BF/EBCMAS are improved considerably, while dielectric strength (19-67.3%) declined considerably except G/BN/EBCMAS (5.6%), G/PA/EBCMAS (7.5%) and G/WA/EBCMAS (41.1%) is improved to some extent, while no change is observed for G/PM/EBCMAS.

G/B/EBCMAS (63MPa) and G/PM/EBCMAS (97MPa) showed comparatively lower tensile strength as compared to other G/BF/EBCMAS (107-141MPa). Amongst selected fibers, G/GN/EBCMAS (138MPa), G/PA/EBCMAS (141MPa), and G/BM/EBCMAS (130MPa) showed better tensile strength than other sandwich composites (107-122MPa). G/BM/EBCMAS (360 MPa) showed somewhat better stiffness than other sandwich composites (215-285MPa).

All the sandwich composites showed relatively better Izod impact strength (26-38 kJ m^{-2}) and Barcol hardness(40-47) and they are somewhat better than EBCMAS(23 kJ m^{-2} and 37) but comparable with G/EBCMAS (46 kJ m^{-2} and 48). International Cast Polymer Alliance (ICPA)[25] has recommended Barcol hardness between 45 and 65 for scratch and wears resistance-proof materials. G/WC/EBCMAS (47) and G/PM/EBCMAS (45) showed Barcol hardness in the suggested range so they can be useful for the said application.

Electrical properties

G/BN/EBCMAS (11.3kVmm^{-1}), G/PM/EBCMAS (10.7kVmm^{-1}), G/PA/EBCMAS (11.5 kV mm^{-1}), G/BM/EBCMAS (10.5kV mm^{-1}) and G/WH/EBCMAS (9.2kV mm^{-1}) showed good dielectric strength and found intermediate of EBCMAS (10.7kVmm^{-1}) and G/EBCMAS (15.1 kV mm^{-1}), whereas other G/BF/EBCMAS (3.5-7.2kV mm^{-1}) showed fairly good dielectric property except G/WC/EBCMAS (3.6kV mm^{-1}) and G/RH/EBCMAS (3.5kV mm^{-1}). In comparison with G/EBCMAS, volume resistivity of G/WC/EBCMAS (96.7%), G/B/EBCMAS (79.2%), G/GN/EBCMAS (83.3%) and G/RH/EBCMAS (97.9%) is declined considerably, whereas for other sandwich composites, it is improved (1150-58233%) to a greater extent. As compared to EBCMAS (5.2x10^{16} ohm cm), G/BF/EBCMAS displayed drastic reduction in volume resistivity (1x10^{11} -8x10^{14} ohm cm) except G/PM/EBCMAS (1x10^{15} ohmcm),G/PA/EBCMAS (2.8x10^{15} ohm cm) and G/BMEBCMAS (1.8x10^{15}ohm cm), which showed relatively small decrement. G/WC/EBCMAS (1.6x10^{11} ohm cm), G/B/EBCMAS (1x10^{12} ohm cm), G/GN/EBCMAS

($8x10^{11}$ ohm cm) and G/RH/EBCMAS ($1x10^{11}$ ohm cm) showed fairly good volume resistivity, where as other G/BF/EBCMAS showed good to excellent volume resistivity ($6x10^{13}$-$2.8x10^{15}$ ohm cm). Sandwich composites showed better volume resistivity than G/EBCMAS ($4.8x10^{12}$ ohm cm) and considerably lower than that of EBCMAS ($5.2x10^{16}$ ohm cm) except G/WC/EBCMAS ($1.6x10^{11}$ ohm cm), G/B/EBCMAS ($1x10^{12}$ ohmcm), G/GN/EBCMAS ($8x10^{11}$ ohm cm) and G/RH/EBCMAS ($1x10^{11}$ ohmcm).

G/BF/EBCMAS sandwich composites showed good mechanical properties and fairly good to excellent electrical properties. The observed variation in derived properties concerning G/ EBCMAS and EBCMAS is mainly due to variable chemical compositions (Table 1) of fibers i.e. 31-83% cellulose, 18-33% hemicellulose except for coir (0.1-0.2%), and 5-45% lignin content; variable physical

TABLE 3. Changes in mechanical and electrical properties of G/BF/EBCMAS sandwich composites for EBCMAS and G/EBCMAS

Composite	**TS, MPa**	**FS, MPa**	**FM,MPa**	**IS, kJ/m²**	**BH**	**Dielectric strength, kVmm⁻¹**	**Volume resistivity, Ω.cm**
G/WC/EBCMAS	121.8 -29.1	464 -19.6	11974 -17.6	85.2 -30.4	27.0 -2.1	-66.4 -76.1	-96.7
G/BC/EBCMAS	112.7 -32	462 -19.9	12580 -13.5	30.4 -34.8	13.5 -12.5	-43.9 -60.3	1983.3
G/B/GEBCMAS	14.5 -63.4	428 -24.8	10041 -22.7	13.0 -43.5	13.5 -12.5	-32.7 -52.3	-79.2
G/GN/EBCMAS	150.9 -19.8	330 -38.7	12669 -12.8	56.5 -21.7	8.1 -16.7	-43.0 -59.6	-83.3
G/BN/EBCMAS	121.8 -29.1	450 -21.6	9109 -37.1	39.1 -30.4	8.1 -16.7	5.6 -25.2	16566.7
G/PM/EBCMAS	76.4 -43.6	460 -20.2	7120 -50.7	43.5 -28.3	21.6 -6.3	0.0 -29.1	20733.3
G/CS/EBCMAS	98.2 -36.6	404 -28.2	8455 -41.6	17.4 -41.3	13.5 -12.5	-37.4 -55.6	1358.3
G/PA/EBCMAS	156.4 -18	470 -18.8	11638 -19.9	65.2 -17.4	16.2 -10.4	7.5 -23.8	58233.3
G/WA/EBCMAS	96.4 -41.9	406 -27.9	8912 -38.5	34.8 -32.6	10.8 -14.6	41.1 -58.3	1150
G/BM/EBCMAS	136.4 -24.4	620 +2.6	10096 -30.5	47.8 -26.1	8.1 -16.7	-1.9 -30.5	37400
G/RH/EBCMAS	94.5 -37.8	422 -25.6	10448 -28	21.7 -39.1	13.5 -12.5	-67.3 -76.8	-97.9
G/WH/EBCMAS	107.3 -33.7	426 -25.1	10907 -24.9	21.7 -39.1	8.1 -16.7	-14 -39.1	4066.7

properties[1-3] and interface adhesion and fiber orientation. Poor interfacial adhesion is due to the hydrophobic nature of EBCMAS and its poor wettability with a large number of hydrophilic hydroxyl groups present in cellulose, hemicellulose, and lignin in biofiber[1,3,26]. For the judgment of interfacial bond strength, the SEM technique is powerful. Due to personal limitations, SEM images of the sandwich composites were not scanned. Relatively poor interface bonding was judged only based on studied properties and comparing them with G/EBCMAS and EBCMAS.

Nature of reinforcements and matrices, fiber loading, fiber strength, fiber orientation as well as interfacial adhesion play an important role in the properties of the composites materials. Observed increase in stiffness i.e. flexural strength and declined tensile strength of sandwich composites is mainly due to random orientations of bio-fibers and relatively poor interfacial bonding, respectively. Glass fibers are stronger and stiffer than bio-fibers so sandwich composites showed declined mechanical properties as compared to G/EBCMAS. Opposite partial charges present on matrix and reinforcement leads to stronger interfacial adhesion and hence good mechanical properties of the composites. In the present case, there are likely more partial positive charges over negative charges resulting in an overall increase in the polarity of the sandwich composites, and that is reflected in volume resistivity measurements. Improved volume resistivity of some of the sandwich composites in comparison with G/EBCMAS is due to the neutralization of partial charges present in glass fabric, bio-fibers, and EBCMAS. Similarly, the decrease in volume resistivity of some of the sandwich composites had confirmed an overall increase in polarity of the sandwich composites. In the present case, we had achieved promising results by using economically cheaper bio-fibers in combination with synthetic glass fibers. The sandwich composites may be useful for some specific applications especially for low load bearing housing and other electrical and electronic industries.

Chemical Resistance

During service, composite materials undergo interaction with different chemicals and affect their properties. Chemical interactions with the composites may be a chemical reaction, absorption, solvation, stress cracking, plasticization, etc. can occur with different rates and degrees[27]. Bond strength, branching, polarity, degree of crystallinity, and temperature are very important factors in determining the chemical resistance of the composites. Composite materials absorb water in a humid environment depending upon the nature of the constituting component materials. It is a well-known fact that chemical compositions and physical properties, as well as water absorption tendency (9-16%) of various bio-fibers, are quite variable (Table 1)[1-3] and are highly hygroscopic because of a large number of hydrophilic hydroxyl groups present in them. The hygroscopic nature of bio-fibers shows poor wettability with hydrophobic resin[26-31].

In the present case, we have assumed uni-dimensional Fickian type diffusivity in the sandwich composites[27]. Water absorption in G/BF/EBCMAS was carried out by the change in mass method at the interval of 24h at 30

±2°C in different environments namely water, 10% aq. NaCl, 10% aq. NaOH, 10% aq. HCl and 10% aq. H_2SO4. % Water absorbed (M) by G/BF/EBCMAS in a given environment was determined according to Eqn.1:

$$M = \frac{W_m - W_d}{W_d} \text{ x } 100 \quad \dots 1$$

Where M = % water absorbed, Wm = weight of the moist sample, and Wd = weight of the dry sample. Representative % Weight gain against Time for G/EBCMAS and G/WC/EBCMAS are shown in Figures 8 and 9, respectively. Weight gained by G/BF/EBCMAS was found to increase with time till saturation limit was achieved. For different environmental conditions, equilibrium time and equilibrium water content in G/BF/EBCMAS are presented in Table 4. Water absorption trend in different environments is H_2SO4 (10.9-12.7%) > HCl (10.5-12.3%) > NaOH (9.5-11.7%) > H_2O (8.3-11.0%) > NaCl (7.9-10.1%). G/BF/EBCMAS composites showed a somewhat more water absorption tendency than that of G/BF/EBCMAS (7.9-10.2%) due to the presence of additional hydrophilic hydroxyl groups present in bio-fibers. No systematic saturation time trend is observed in different environments due to the characteristic nature of bio-fibers. Saturation time for G/BF/EBCMAS in different environments is 336-384h (H_2O), 228-360h (NaCl), 336-360h (NaOH and HCl) and 312-360h (H_2SO4), which is comparable with G/EBCMAS (336-384) except G/BC/EBCMAS (288h, NaCl),G/B/EBCMAS (312h, H_2O), G/GN/EBCMAS (228h, NaCl). Obtained data on saturation time and saturation water absorption tendency of G/BF/EBCMAS sandwich composites in different environments revealed high water absorption tendency and excellent chemical resistance against water, salt, alkali, and acids.

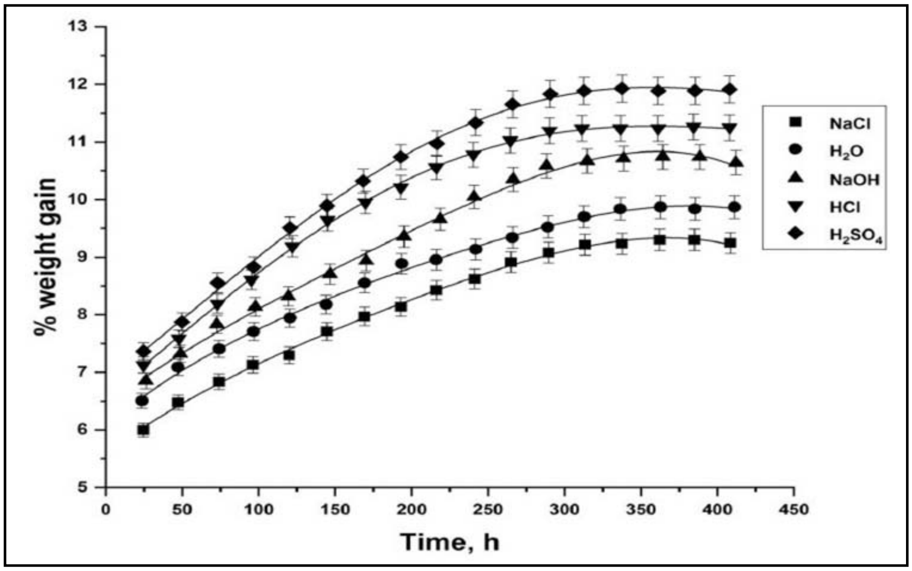


Figure 8. The plots of % weight gain against time for G/EBCMAS in various environments at 30°C

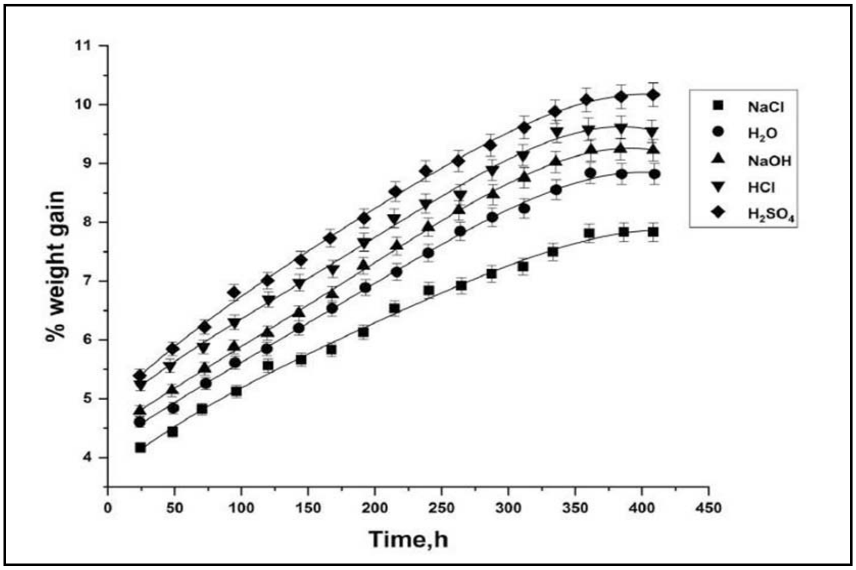


Figure 9. The plots of % weight gain against time for G/WC/EBCMAS in various environments at 30°C.

TABLE 4. Equilibrium time and water content data of G/BF/ EBCMAS sandwich composites

Composite	Equilibrium water content,%					Equilibrium time, h				
	H_2O	10 % NaCl	10 % NaOH	10 % HCl	10 % H_2SO_4	H_2O	10 % NaCl	10 % NaOH	10 % HCl	10 % H_2SO_4
G/EBCMAS	8.9	7.9	9.3	9.6	10.2	360	360	360	336	384
G/WC/EBCMAS	9.1	8.7	9.9	10.6	10.9	360	360	336	360	360
G/BC/EBCMAS	8.7	7.9	9.5	10.6	11.1	336	288	336	336	312
G/B/EBCMAS	10.5	9.4	10.9	11.2	11.9	312	360	360	336	360
G/GN/EBCMAS	10.6	10.1	11.2	11.5	12.4	360	228	360	360	360
G/BN/EBCMAS	10.5	9.6	10.9	11.4	12.1	336	336	336	360	360
G/PM/EBCMAS	9.6	8.9	10.4	11.3	11.7	360	360	336	360	360
G/CS/EBCMAS	11.0	9.7	11.7	12.3	12.7	360	336	360	360	360
G/PA/EBCMAS	9.5	8.6	10.5	10.9	11.3	360	360	360	360	360
G/WA/EBCMAS	10.1	9.6	10.5	11.5	12.1	336	360	360	360	360
G/BM/EBCMAS	8.3	9.9	10.4	11.5	12.4	336	360	336	336	360
G/RH/EBCMAS	9.6	8.7	10.0	10.6	10.9	360	360	360	360	336
G/WH/EBCMAS	9.6	8.7	10.0	10.5	10.9	384	360	360	360	360

Lignin-rich fiber composites showed better resistance to weathering as compared to cellulose fiber composites. Lignin has a lower affinity towards moisture and acts as a protective barrier for cellulose microfibrils from moisture absorption. The nature of electrolytes with the same concentration and different chemical compositions of bio-fibers affected saturation time and equilibrium water absorption behavior.

Diffusivity

Diffusivity in the G/BF/EBCMAS at 30°C and in a given environment was determined by determining initial slopes of the M against $\sqrt{t}$ curves (Eqns.2 and 3):

$$\mathbf{M} = \frac{4M_m}{h}\sqrt{\frac{\mathbf{t}}{\boldsymbol{\pi}}}\sqrt{\mathbf{D_x}} \quad \ldots\ 2$$

$$\mathbf{D}_x = \boldsymbol{\pi}\left(\frac{h}{4M_m}\right)^2 (Slop)^2 \quad \ldots\ 3$$

Where Dx = diffusivity, t = time (second), h = sample thickness (m) and Mm = equilibrium water content. Diffusivity in different sandwich composites is reported in Table 5. Diffusivity in the composites depends upon temperature, environmental conditions, type, and nature of the constituents of the composite. The nature of the strong electrolytes also affects water structure differently and as a consequence different diffusivity is observed in different environments and different sandwich composites. The smaller is the size of the solvated ions higher is the diffusivity[18,23,31]. Water absorption in the composites occurs through the capillary mechanism and leads to swelling, blistering, cracking, and plasticization of the polymers and fibers. This phenomenon continues up to saturation point and after that point, free water occupies voids if any. Free water may interact with constituent components of the composite and may cause delamination, degradation, void formation[32]. Absorbed water causes swelling and plasticization of resin, weakening of interface increases delamination rate and thereby deterioration of the mechanical properties of the composite[33-40]. Cracking and blistering lead to high water absorption, while the leaching of small molecules results in a decrease in weight[41]. Thus, G/BF/EBCMAS sandwich composites showed a high water absorption tendency and excellent chemical resistance against water, acids, alkali, and salt solutions. The sandwich composites may be useful in harsh environmental conditions.

CONCLUSIONS

Sandwich composites of glass/bio-fibers/epoxy methacrylate of bisphenol-C (G/BF/EBCMAS) were prepared by compression molding method. Sandwich composites showed good mechanical and fairly good to excellent electrical properties. Derived properties are compared with EBCMAS and G/EBCMAS. In comparison to G/EBCMAS, G/BF/EBCMAS showed a considerable decline in mechanical properties and dielectric strength. Volume resistivity of G/WC/EBCMAS, G/B/EBCMAS, G/GN/EBCMAS, and G/RH/EBCMAS is declined whereas other G/BF/EBCMAS showed improvement. Observed changes in the mechanical and electrical properties are mainly due to the nature of EBCMAS and reinforcement, their chemical compositions and physical properties, interfacial adhesion, and random orientation of sandwiched bio-fibers. Sandwich composites showed a high water

TABLE 5. Diffusivity data of G/BF/EBCMAS sandwich composites

Composite	**Diffusivity (Dx), 10^{-13}, m^2s^{-1}**				
	H_2O	**10 % NaCl**	**10 % NaOH**	**10 % HCl**	**10 % H_2SO_4**
G/EBCMAS	6	5.8	5.7	4	6.3
G/WC/EBCMAS	4.3	4.3	4	7.9	7.3
G/BC/EBCMAS	8.0	5.9	5.6	5.7	5.0
G/B/EBCMAS	3.7	2.9	2.2	1.9	2.9
G/GN/EBCMAS	5.8	5.5	6.6	5.3	4.9
G/BN/EBCMAS	2.4	4.9	3.6	4.5	4.8
G/PM/EBCMAS	4.9	4.7	3.2	1.1	1.2
G/CS/EBCMAS	2.6	3.6	2.3	3.4	3.7
G/PA/EBCMAS	3.1	4.1	3.2	4.3	3.0
G/WA/EBCMAS	3.6	1.9	2.6	1.9	2.2
G/BM/EBCMAS	3.7	2.9	2.2	1.9	2.9
G/RH/EBCMAS	4.0	3.5	1.8	3.3	3.9
G/WH/EBCMAS	3.9	7.1	1.6	3.2	2.3

absorption tendency and excellent chemical resistance against water, acids, alkali, and salt solutions. Sandwich composites may be useful for low-cost housing and other specific applications.

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