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Improved mechanical properties of natural-synthetic hybrid composites

Marwa A. Abd El-baky*, Mona Megahed, Hend H. El-saqqa, Amal E. Alshorbagy

Mechanical Design and Production Engineering Department, Zagazig University, Zagazig 44519, Egypt

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ABSTRACT

This study is an attempt to utilize sugarcane bagasse (natural fiber) with glass fiber (synthetic fiber) to fabricate new types of hybrid composites. To explore the best mechanical properties, six composites with different layering sequence and different fibers amounts were fabricated via hand lay-up method. The tensile, impact, flexural and hardness properties were compared. Scanning electron microscopy was used to adapt to analyze the hybrid natural composite specimens' damage. Results revealed that the tensile, impact, flexural and hardness properties of sugarcane bagasse/polyester composites can be enhanced by its hybridization with glass fiber reinforcement. Different Layering configurations and the relative fiber amounts have noticeable impacts on the mechanical properties. Ultimate tensile strength and strain to failure of [G/SCB/G_4/SCB/G] are about 1.10 and 1.24 times those of [G_2/SCB/G_2/SCB/G_2]. Flexural strength and flexural strain of [G3/SCB2/G3] are about 1.88 and 1.63 times those of [G2/SCB/G2/SCB/G2]. Moreover, flexural strength and flexural strain of [G3/SCB2/G3] are about 2.19 and 1.13 times those of [G/SCB/G4/SCB/G]. Edgewise impact strength of [G3/SCB2/G3] is about 1.08 and 1.17 that of [G2/SCB/G2/SCB/G2] and [G/SCB/G4/SCB/G]. Flatwise impact strength of [G3/SCB2/G3] is about 1.06 and 1.10 that of [G2/SCB/G2/SCB/G2] and [G/SCB/G4/SCB/G]. Hardness values of [G3/SCB2/G3], [G2/SCB/G2/SCB/G2] and [G/SCB/G4/SCB/G] are, respectively, 1.11, 1.03, 0.98 that of [G2/SCB4/G2]. The advantages of the hybridization of reinforcements in this work are the low price besides the light weight with comparable mechanical properties. Consequently, the recommended hybrid composites can be utilized in moderate load applications. Moreover, the suitable selection of the amounts of fibers and stacking sequence produces fabricated hybrid composites attaining property profiles which are close to glass fiber/polyester composites in terms of specific properties.

1. INTRODUCTION

Lately, natural fibers are broadly utilized as reinforcing constituents in polymeric matrix composites owing to their light weight, biodegradability, low price, and recyclability [1-3]. Numerous kinds of natural reinforcement are considered to be available as sisal, rice straw, jute, and cotton [4,5]. However, the main problems concerned utilizing these natural fibers as a reinforcement are the high moisture uptake, the poor wettability and also, the environmental degradation. To use natural fibres lonely in polymeric matrix composite is inadequate. Hybridization can be

* Corresponding author. Tel: +201273831106, +201095613501.
E-mail address: dr.marwa2013@yahoo.com .

attained by adding synthetic fibres as glass fiber (G) or carbon reinforcement to natural fibres. Hybrid polymeric composites are produced to keep the merits of both fibre reinforcement constituents. As a result, a balance in the mechanical behavior and proper price will be achieved [6].

Sugarcane bagasse (SCB) is considered as a one of the promising reinforcing materials [7,8,9]. SCB can be utilized as a reinforcement in polymer composites due to its abundant availability, low density, low pre-treatment costs and acceptable mechanical properties. It also satisfies the greening requirements by being biodegradable, recyclable and reusable [8-10]. SCB reinforced composites can be used in applications such as furniture, interior panels, wall lining, doors, toys, building and construction industry (panels, false ceilings, partition boards etc.) packaging, automobile and railway coach interiors and storage devices with the advantage of lower cost and good quality [11, 13].

Diverse studies have been carried out to understand the structure, mechanical properties, and the effect of chemical modification on SCB and its usage in reinforcing composite materials [14-16]. Literature review demonstrates the influence of the hybridization process of reinforcement on the mechanical performance of SCB reinforced polymeric composites. It was reported by Saw et al. [17] that SCB /coir composite exhibits the highest flexural strength, however, SCB /coir/SCB composite exhibits the highest tensile strength and modulus. Later, the same authors [18] proved that, the addition of jute to SCB improves the tensile properties and decreases the moisture uptake of the fabricated hybrid composite. The existence of jute fibre at the composite external layers enhances the tensile properties.

Tewari et al. [19] studied the effect of adding SCB with different weight fractions (15, 20, 25 and 30 wt. %) on the mechanical properties of sugar cane/G fibers reinforced polymeric composites. The results revealed that the optimum tensile strength, Young's modulus, and the flexural strength were reported for hybrid polymeric composites filled with 15 wt. % sugar cane bagasse reinforcement but the optimum elongation was recorded for hybrid one filled with 30 wt % sugar cane bagasse reinforcement. Otto et al. [20] studied the physical and mechanical properties of ployurethan (PU) reinforced with SCB, rice husk, or sisal fibers hybrid polymeric composites. The hybrid polymeric composite based on 82% rice husk and 18% SCB increases all the physical and mechanical properties of ployurethan. As reported by Attia et al. [21], the mechanical performance of hybrid composites are influenced by different parameters as the fibers amounts, fibers configuration, type and layering sequence.

The main objective of this article is to investigate the impact of essential parameters, namely fibers amounts and stacking sequence on the mechanical performance of SCB/G hybrid polymeric composites. Sugar cane bagasse reinforcement was chemically treated with sodium hydroxide (NaOH) to make SCB more compatible with polyester matrix and thus the mechanical performance of the fabricated composites will be increased. To obtain the optimum mechanical properties, 6 different hybrid composites with different fibers amounts and stacking sequence were manufactured. Their tensile, impact, flexural and hardness properties were compared. In all previous studies, SCB was used in the chopped form. This form has no regular distribution in each ply. In this study, SCB sheets was initially produced and utilized as a reinforcement mat to ensure the regular distribution of SCB in each ply.

2. MATERIALS AND METHODS

2.1. Materials

E-glass fiber mat and sugarcane bagasse were used as synthetic and natural reinforcements, Fig. 1. The mechanical properties of glass fiber and sugar cane bagasse reinforcement are shown in Table 1. Unsaturated polyester was selected as a polymeric matrix. The mechanical properties of polyester resin are presented in Table 2.

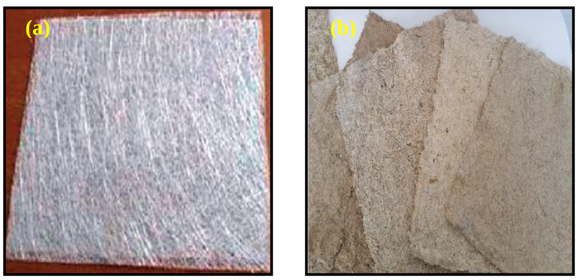


Fig.1. (a) E-glass mat and (b) sugarcane bagasse.

2.2. Chemical treatment using sodium hydroxide

Soft inner pulp of sugar cane bagasse reinforcement was washed with running water to get rid of any excess sugar and dirty particles. SCB were sundried for four weeks before chopping into small fibers of 30 mm in length. Afterwards, SCB was immersed in 5 wt. % NaOH solution for 48 hours. Hence, fibrillation ocuured thus improving fibre/polyester interfacial adhesion and enhanced mechanical properties can be attained [24].

Table 1. Properties of sugarcane bagasse and glass fabrics [22].

Property	E–glass fiber	Sugarcane bagasse
Average diameter, µm	13	279
Areal density, g/m^2	300	300
Density, g/cm^3	2.5	1.1-1.6
Young’s modulus, GPa	76	5.1–6.2
Elongation, %	1.8-3.2	6.3–7.9
Tensile strength, MPa	2000–3500	170–350

Table 2. Properties of polyester resin [23].

Property	Polyester
Apperance	Yellow liquid
Proportion of accelerator, cobalt naphthenate	1.0 – 1.5 % of resin vol.
Density, g/cm^3	1.09
Elongation, %	3.0
Tensile modulus, GPa	3.1
Tensile strength, MPa	65
Flexural strength, MPa	100
Flexural modulus, GPa	3.5

This blend was boiled for two hrs until sugar cane bagasse reinforcement became soft. Sugar cane bagasse reinforcement was cleaned and crushed with a mallet. The crushed sugar cane bagasse reinforcement was regular distributed in a mold (40×40 cm^2) then was left in air for 24 hrs to get dry. SCB mat was separated from the mold then dried in a hot oven to remove the moisture.

2.3. Fabrication of composite laminates

Hand lay-up method used to fabricate six SCB/G/polyester composites presented in Table 3 can be summarized as follows:

Polyester resin and catalyst were mixed and manually stirred, using a stir rod, for 5 minutes. The blend was applied to the reinforcement utilizing a brush and a metallic roller. Afterwards, the mold was compacted at a pressure of 1.2 bar. The constructed laminates were completely cured at ambient temperature after seven days. Then, the hybrid composite samples were cut into the requested dimensions corresponding to the test standards.

Table 3. Details of the fabricated SCB-G/polyester composites.

Composite	Fiber volume fraction, %		Relative fabric volume fraction, %	
	G	SCB	G	SCB
[G_2/SCB_4/G_2]	3. 82	8.68	30.56	69.44
[G]$_8$	15.89	0.0	100	0.0
[G_3/SCB_2/G_3]	7.96	6.03	56.9	43.1
[SCB]$_8$	0.0	11.64	0.0	100
[G_2/SCB/G_2/SCB/G_2]	7.55	5.72	56.9	43.1
[G/SCB/G_4/SCB/G]	7.94	6.01	56.9	43.1

2.4. Measurement and characterization

2.4.1. Fiber volume fraction

The relative and overall fiber volume fractions were determined as follows, [25]:

$$\mathrm{v}_{f,i} = \frac{m_{fi}\, n_{fi}}{\rho_{fi}\, h} \qquad (1)$$

$$V_f = \sum_{i=1}^{N_f} \mathrm{v}_{fi} \qquad (2)$$

where, m_{fi}, ρ_{fi} , n_{fi}, and $\mathrm{v}_{f,i}$ are, respectively, the areal density, volumetric density, number of plies, and volume fraction of fiber “i”. V_f denotes the total fiber volume fraction. h is the measured thickness of the laminate. N_f refers to the number of the used fabrics, i.e. sugarcane bagasse (SCB) and glass (G).

2.4.1. Density

The density of the fabricated hybrid natural composites were determined using Archimedes (buoyancy) method according to [26]. Soybean oil with density of 0.907 provided from Sigma Aldrich was utilized.

2.4.2. Mechanical testing

Tensile and flexural tests were conducted on Jinan Testing Machine WDW 100 kN according to [27,28]. Impact tests were conducted on Izod impact testing machine (type Avery Denison) according to [29]. Hardness was measured using PCE-1000N Hardness Tester Instrument according to [30].

2.4.3. Specific properties

Specific property is the experimental quantity was divided by the composite density. Specific properties concept can be utilized when comparing different composite materials.

2.4.4. Scanning electron microscopy (SEM)

Morphological analysis was conducted to investigate the failure of the polymeric composite coupons. The failed surface was coated with gold and kept in an ionizer. Images were taken by subjecting the failed surface to 20 kV.

3. RESULTS AND DISCUSSIONS

3.1. Tensile properties

It is clear from Figs. 2 and 3 that $[SCB]_8$ exhibits the lowest ultimate tensile strength and strain to failure. Whilst, $[G]_8$ has the highest ones.

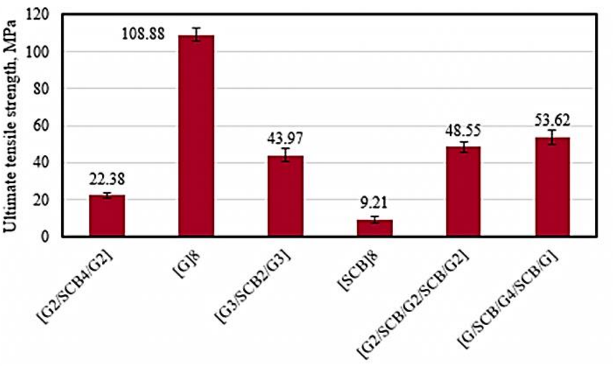


Fig. 2. Ultimate tensile strength of natural hybrid composites.

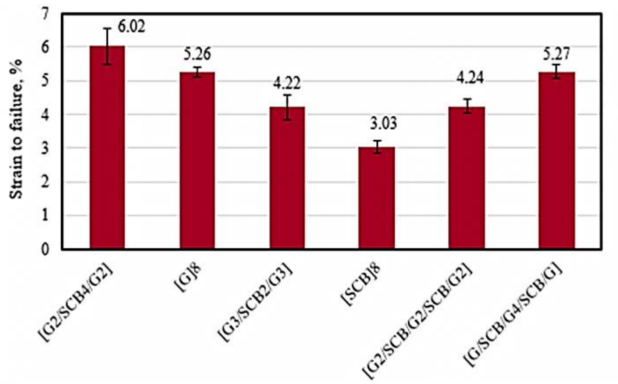


Fig. 3. Strain to failure % of natural hybrid composites.

For hybrid composites, the tensile strength and strain to failure of $[G_2/SCB_4/G_2]$ are about 2.43 and 1.99 times those of $[SCB]_8$. Which means that hybridizing SCB reinforced composite with G-fiber improves the tensile properties. The tensile strength and strain to failure of $[G_3/SCB_2/G_3]$ are, respectively, 4.77 and 1.39 times those of $[SCB]_8$. It was observed that as G-fiber weight content increases, the tensile behaviour are enhanced.

Stacking sequence slightly affects the tensile performance of natural hybrid composites. The ultimate tensile strength and strain to failure of [G/SCB/G4/SCB/G] are about 1.10 and 1.24 times those of $[G_2/SCB/G_2/SCB/G_2]$. This is owing to the good load transfer that obtained from the weak skin plies, thus improving the crack growth by the strong inner plies. This is consistent with that recorded by Selmy et al. [31] for unidirectional glass/random glass hybrid composites.

3.2. Flexural properties

It was noticed from Figs. 4 and 5 that the flexural strength and strain of $[SCB]_8$ are, respectively, 0.1 and 1.7 times those of $[G]_8$. The combination of G-fiber with sugar cane bagasse reinforcement increases the flexural strength but reduces the flexural strain.

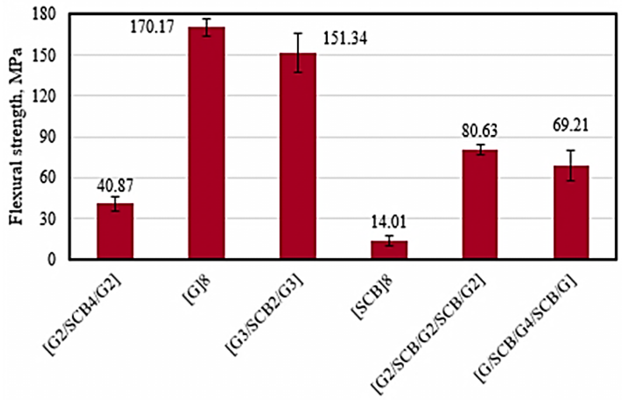


Fig. 4. Flexural strength of SCB-G reinforced composites.

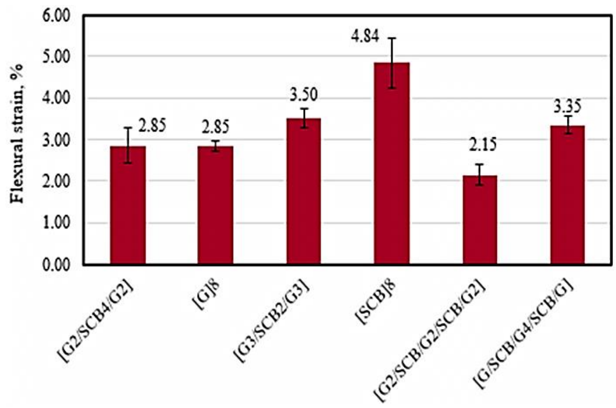


Fig. 5. Flexural strain of SCB-G reinforced composites.

The flexural performance of hybrid composites mainly relies on the reinforcement type presented on the compressive and tensile sides of the specimen. Flexural strength and strain of $[G_3/SCB_2/G_3]$ are 1.88 and 1.63 times those of $[G_2/SCB/G_2/SCB/G_2]$. Moreover, flexural strength and strain of $[G_3/SCB_2/G_3]$ are about 2 and 1.14 times those of

[G/SCB/G_4/SCB/G]. This means that placing glass reinforcement at the coupon outer sides and sugar cane bagasse in the middle cause a significant enhancement in the flexural strength which is owing to flexural strength that is controlled by the outer plies. This result agrees with that obtained by [32,33].

3.3. Impact properties

It is clear from Fig. 6 that edgewise and flatwise impact strengths of $[SCB]_8$ are about, 0.36 and 0.29 times those of $[G]_8$. This is due to the greater elongation of G-fiber at break compared to SCB-fiber. Elongation at break and impact strength are directly correlated as reported by [34].

The addition of G-fiber to SCB increases the impact strength of hybrid composites, compared to that of $[SCB]_8$. This result agrees with that obtained by Rahmanian et al. [35]. Hybrids have intermediate impact strengths between the parent materials. As G-fiber amount increases, impact strengths increase. The existence of G-fiber at the external layers increases impact strengths. Edgewise impact strength of [G_3/SCB_2/G_3] is about 1.08 and 1.17 that of [G_2/SCB/G_2/SCB/G_2] and [G/SCB/G_4/SCB/G]. Flatwise impact strength of [G_3/SCB_2/G_3] is 1.06 and 1.10, respectively, that of [G_2/SCB/G_2/SCB/G_2] and [G/SCB/G_4/SCB/G]. This happens by the fact that the flexible layer at the impacted surface experiences larger deformation. This result agrees with that obtained by Park and Jang [36].

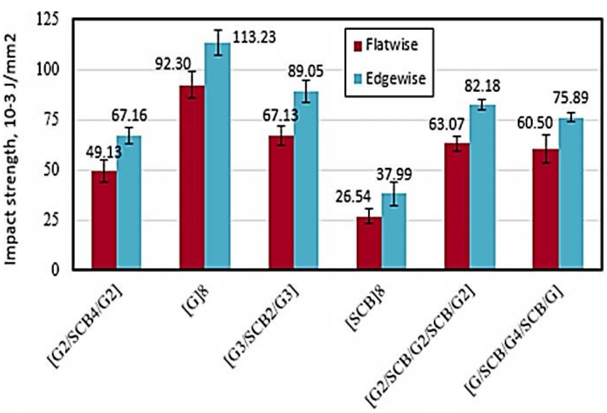
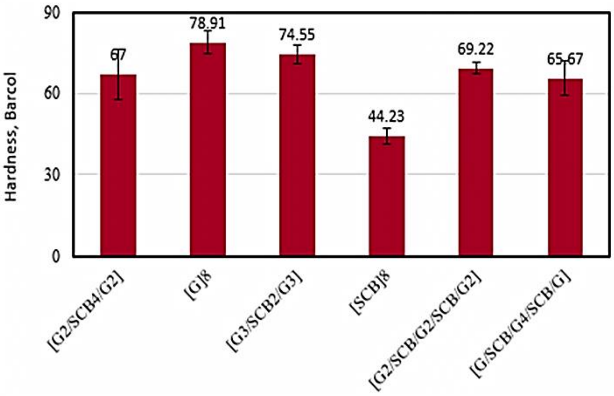


Fig. 6. Impact strengths of SCB-G reinforced composites.

3.4. Hardness

It is obvious from Fig. 7 that the hardness of $[G]_8$ is about 1.79 times that of $[SCB]_8$. As G-fiber amount at the specimen surface increases, the hardness increases. Hardness values of [G_3/SCB_2/G_3], [G_2/SCB/G_2/SCB/ G_2] and [G/SCB/G_4/SCB/G] are, respectively, 1.11, 1.03, 0.98 that of [G_2/SCB_4/G_2]. This is in consistent with that obtained by Megahed et al. [37].

Fig. 7. Barcol hardness of SCB-G reinforced composites.



3.5. Specific properties

Table 4 shows the specific properties of sugar cane bagasse-G/polyester composites. It can be noticed that, $[G]_8$ followed by [G/SCB/G_4/SCB/G] show the highest specific tensile strength. $[G]_8$ and [G_3/SCB_2/G_3] exhibit the highest specific flexural strength, specific flatwise impact strength and specific edgewise impact strength. These results agree qualitatively with those obtained for rice straw-glass fiber-reinforced polyester composites [35].

Table 4. Specific mechanical properties of SCB-G composites.

Composite	Specific tensile strength, MPa.cm^3/g	Specific flexural strength, MPa.cm^3/g	Specific flatwise impact strength, J.cm/g	Specific edgewise impact strength, J.cm/g
[G_2/SCB_4/G_2]	20.48	37.41	4.51	6.16
$[G]_8$	84.19	131.58	7.16	8.78
[G_3/SCB_2/G_3]	37.65	129.59	5.74	7.61
$[SCB]_8$	9.03	13.73	2.60	3.72
[G_2/SCB/G_2/SCB/G_2]	42.13	69.97	5.48	7.15
[G/SCB/G4/SCB/G]	45.69	58.97	5.17	6.49

3.6. SEM

SEM for sugar cane bagasse-G/polyester composite coupons under different loadings is shown in Fig. 8. Failure signs can be summarized as polyester matrix cracking, delamination, glass fiber reinforcement breakage and sugar cane bagasse pull-out.

4. CONCLUSIONS

The mechanical properties, tensile, flexural, impact, and hardness of SCB reinforced polyester composites have been enhanced by the incorporation of G-fiber. [G/SCB/G_4/SCB/G] has the best tensile strength whilst [$G_3/SCB_2/G_3$] shows the highest flexural strength, flatwise impact strength, edgewise impact strength and hardness. Stacking sequence and relative fiber amounts have noticeable impacts on mechanical properties. The merits of the reinforcement hybridization process in this study are combining low price and light weight together with comparable mechanical properties. Consequently, the recommended hybrid composites can be utilized in moderate load applications. The suitable selection of the amounts of fibers and stacking sequence produces fabricated hybrid natural composites attaining property profiles which are close to glass fiber/polyester composites in terms of specific properties.

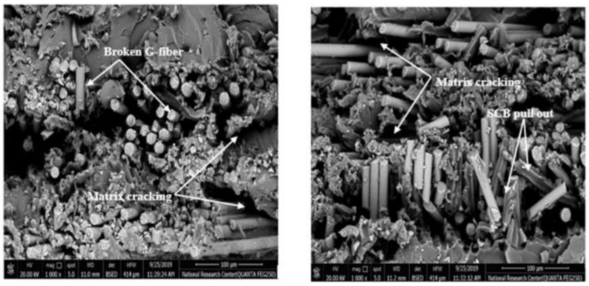


Fig. 8. SEM for failed surfaces of SCB-G reinforced composites.

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