Hybrid composites based on textile hard waste: use as sunshades

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ABSTRACT – REZUMAT

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Hybrid composites have gained exceptional interest from researchers and industry sectors in the last couple of decades with an aim to improve existing and/or develop new composites to cater for a wide variety of applications. In this research, hybrid composites utilizing glass fibre combined with textile hard waste were fabricated. A control sample and 7 hybrid composite samples including glass-polyester hard waste, glass-mercerized cotton hard waste and glass-cotton hard waste were developed as part of this study. Density, tensile strength and thermal conductivity of all developed samples and that of a commercial composite (purchased from the market) were measured. The results revealed that the control sample developed at the lab scale showed similar or higher values of density, tensile properties and thermal conductivity. Hybrid composites based on unmercerized and mercerized cotton showed very low tensile properties and similar conductivity, so they are not suitable for sunshade application. On the other hand, a composite made from polyester provided with highest tensile properties amongst all the hybrid composites but was still quite lower than a commercial sample. Polyester hybrid composite has enhanced thermal insulation properties suggesting that it has the potential to replace the existing composite, but a compromise needs to be made between the physical and thermal properties of the sunshade.

Keywords: *hybrid composites, textile reinforcement, thermal conductivity, tensile strength, tensile modulus*

Compozite hibride pe bază de deșeuri textile dure: utilizare ca parasolare

Compozitele hibride au câștigat un interes excepțional din partea cercetătorilor și a sectoarelor industriale în ultimele două decenii, cu scopul de a îmbunătăți compozitele existente și/sau de a dezvolta noi compozite pentru o mare varietate de aplicații. În această cercetare, au fost fabricate compozite hibride care utilizează fibră de sticlă combinată cu deșeuri textile dure. În cadrul acestui studiu au fost dezvoltate o probă martor și 7 probe compozite hibride, inclusiv deșeuri dure din sticlă-poliester, deșeuri dure din bumbac mercerizat cu sticlă și deșeuri dure din sticlă-bumbac. Au fost determinate densitatea, rezistența la tracțiune și conductivitatea termică a tuturor probelor dezvoltate și a unui compozit comercial (achiziționat de pe piață). Rezultatele au arătat că proba martor dezvoltată la scară de laborator a prezentat valori similare sau superioare ale densității, rezistenței la tracțiune și conductivității termice. Compozitele hibride pe bază de bumbac nemercerizat și mercerizat au prezentat o rezistență la tracțiune foarte scăzută și o conductivitate similară, deci nu sunt potrivite pentru a fi aplicate la realizarea parasolarelor. Pe de altă parte, compozitul realizat din poliester a avut cea mai bună rezistență la tracțiune dintre toate compozitele hibride, dar au fost mai scăzută în comparație cu proba comercială. Compozitul hibrid din poliester are proprietăți de izolare termică îmbunătățite, ceea ce sugerează că are potențialul de a înlocui compozitul existent, dar trebuie făcut un compromis între proprietățile fizice și termice ale parasolarului.

Cuvinte-cheie*: compozite hibride, armătură textilă, conductivitate termică, rezistență la tracțiune, modul de tracțiune*

INTRODUCTION

Hybrid composites are getting important consideration in recent years because they possess reasonable physical and mechanical properties for some applications and they are more cost-effective [1, 2]. Hybrid composites are manufactured by mixing two or more different fibres in the reinforcement. The composites are also considered hybrid if two different resins are blended or some filler material is added to the resin [3, 4]. It is a common practice in the industry to manufacture composites using glass, carbon and Kevlar fibres as reinforcement [5, 6]. However, to overcome some inherent disadvantages of these fibres being used as reinforcement, these fibres are blended in the reinforcement to manufacture hybrid composites [4, 7]. Hybrid composites are also being manufactured by blending lingo-cellulosic fibres with glass fibres as reinforcement. These composites are getting attention from the researchers because the used natural fibres are bio-degradable, renewable and less expensive as compared to glass fibres [8–11].

The textile industry generates a lot of waste; this waste is also being used by some researchers to manufacture hybrid composite materials [12, 13]. Recycling waste produced by the textile industry is always a challenge. Composites manufactured using the aforementioned fibres and their hybrid configurations have been utilized in a variety of applications in different industries including automobile, building and packaging [14–17]. Sunshades are one key application area where cost reduction in addition to improved mechanical and thermal properties is the primary consideration.

Several researchers have reported improved thermal and mechanical properties of hybrid composites that were made by utilizing a blend of natural and synthetic fibres [18–21]. Idicula suggested that the thermal properties of glass composites were enhanced when a mixture of glass fibre with natural fibre was utilized [18]. Osugi's research focused on the thermal conductivity of composite when Manila hemp was used as reinforcing fibre. In the research composites, samples were fabricated at different fibre content levels. Results suggested that thermal insulation was greatly improved when higher fibre content levels were used [19]. Karthik developed composites using banana and glass fibre with epoxy. Different length of banana fibres was used to evaluate the effect of fibre length on the mechanical behaviour of fibres. It was concluded that tensile properties improved when fibre length increases up to a certain level but then started decreasing gradually [20]. Atiqah investigated the thermal behaviour of sugar palm/glass fibre thermoplastic hybrid composites. Samples were made at different weight fractions of sugar palm/glass fibre. The results of the study emphasized that thermal properties were enhanced in the case of hybrid configuration [21].

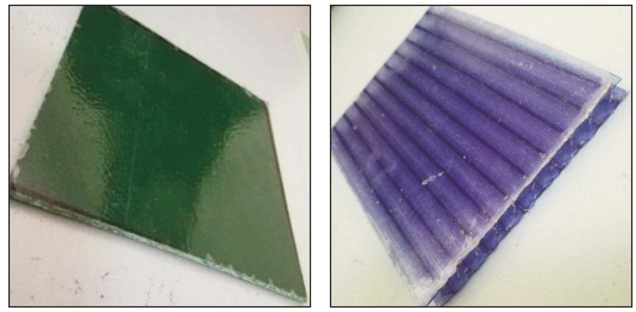
The sunshades could be used in the gardens to provide protection from heat and UV rays. The buildings are designed to become energy efficient based on the ratios of windows and walls. If sunshades are provided at the windows, they will increase the energy efficiency of the building [22, 23]. In general, the sunshades will provide coolness and protection from the radiation of the sun and help to design buildings with better ventilations. However, they will have a disadvantage for additional installation cost and they could also be a possible fire hazard, the shades will also affect the light transmission from the sun to the building rooms [24, 25]

The above-mentioned literature study suggests that a lot of work has been carried out on hybrid composites made using a combination of natural and synthetic fibres, but very few studies have been carried out to evaluate the performance and characterization of hybrid composites made using a combination of textile hard waste along with glass fibre [26, 27]. In this research work, the hard waste produced from the yarn manufacturing industry has been utilized to manufacture hybrid composite material. The composite material based on the textile hard waste will be tested for its mechanical and thermal properties, it is hoped that this material could be used to replace the existing sunshade in the market.

MATERIALS AND METHODS

Materials

Based on the thickness the commercially available sun shades are divided into four categories i.e. 1 mm, 1.5 mm, 4 mm and 2.5 mm. The commercial sample of 1.5 mm was chosen for comparison because these are commonly used as garden sunshades. These sunshades are also shown as an example in figure 1.



a *b*

Fig. 1. Types of sunshades: *a* – 1.5 mm; *b* – 2.5 mm

For this research work, Glass fibre mats having the GSM 300 g/m^2 were purchased from the local supplier i.e. Al Khair Industries, Karachi, while the hard waste was obtained from Soorty Enterprises, Karachi. Two types of hard waste were used i.e. cotton and polyester. The hard waste was obtained from the cone winding section of the spinning mill. The hard waste was also used as reinforcement to manufacture hybrid composites.

Some of the cotton hard waste was treated with Caustic Soda to make a category of mercerized cotton hard waste. It is a common practice in the composite industry to treat cellulosic fibres with NaOH so that the interaction i.e. adhesion between the resin and the fibres is improved [28, 29]. Cotton hard waste was immersed in the solution of caustic soda (27 Baume) for 60 seconds at 20°C. The cotton hard waste sample is hot-washed and cold-washed simultaneously. Finally, it was dried in an oven at 100°C for 30 minutes.

Unsaturated polyester thermoset resin, Malikens GP was used as a matrix, MEEK 50 Methyl ethyl ketone peroxide was used as a hardener and Cobalt octoate was used as an accelerator to accelerate the reaction and harden the polyester quickly. These chemicals were purchased from Al Khair Industries Private Limited, Karachi, Pakistan.

Composites development

The characterization results of the developed samples were compared against a commercially available glass fibre-reinforced composite of thickness 1.5 mm. To find out the percentage of reinforcement i.e. glass fibre in the selected commercially available composite, the ISO 1172 method was used [30].

The sample obtained from the market was considered a standard sample, this sample was replicated by using a 30% glass fibre mat and 70% polyester resin was considered as a control sample. Different combinations for manufacturing hybrid composites were considered for this research work and are shown in table 1.

Table 1

DIFFERENT TYPES OF COMPOSITE SAMPLES MANUFACTURED			
S. No.	**Type of composite**	**Abbreviation**	**Thickness (mm)**
1	Glass fibre composite sample purchased from market	Standard (M)	1.5
2	Glass fibre composite sample manufactured in the lab (30% glass fibre mat and 70% polyester resin)	Controlled (C)	1.55
3	Cotton hard waste and glass fibre hybrid composite (10% C and 10% G)	GC 10-10	4.28
4	Cotton hard waste and glass fibre hybrid composite (15% C and 15% G)	GC 15-15	2.37
5	Mercerized cotton and glass fibre hybrid composite (10% MC and 10% G)	GMC 10-10	3.13
6	Mercerized cotton and glass fibre hybrid composite (15% MC and 15% G)	GMC 15-15	3.75
7	Polyester and glass fibre hybrid composites (10% P and 10% G)	GP 10-10	2.86
8	Polyester and glass fibre hybrid composites (15% P and 15% G)	GP 15-15	2.47

The hand layup technique is commonly used to manufacture composite material. In this study, this technique was utilized. It involved using of a glass plate as a tool; some wax was spread on the glass plate to avoid sticking of sample on the plate. We wanted to manufacture a composite sample of A4 size i.e. 10 by 7 inches, therefore A4 size plastic sheet was placed on the glass plate. Some resin was spread on the sheet. The glass fibre mat was placed on the A4 sheet, the hard waste was spread and the reinforcement was covered by another glass fibre mat. A resin coat was spread on the top of the glass fibre mat; it was covered by an A4-size plastic sheet. A roller was used to ensure the proper spreading of resin in the composite sample. The A4 plastic sheet was covered with a glass plate. A marble piece of 5 kg was placed on the top glass plate to provide enough pressure. The resin was allowed to cure for 24 hours and finally, the composite sample was obtained. The composite sample was placed in an oven for post-curing at 100°C for two hours. The schematic process for making composite samples is shown in figure 2.

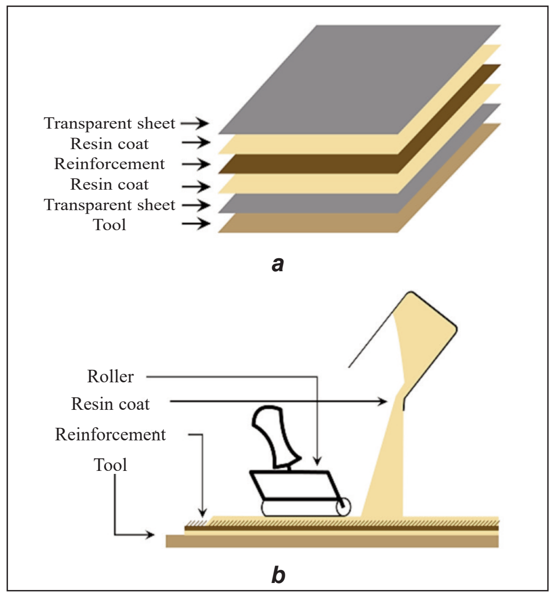


Fig. 2. Schematic process for making composite samples: *a* – layering of different layers and resin during composite manufacturing; *b* – hand layup (reinforcement means; glass fibre mats or the combination of glass fibre mat and hard waste)

Determination of density

The density of composite samples was determined using Archimedes' principle, using the standard method ISO 1183 [31]. Five specimens of 2 by 2 inches were used for each category to measure the density of composites.

Testing of Tensile Properties

The tensile tests were performed at 2mm/min by using a universal tensile testing machine (Zewick/Roell Z005 with 5 KN load cell) using ISO-527-4,1997 standard [32]. The gage length was fixed at 150 mm. Tensile strength, strain and modulus were determined for all types of composites mentioned in table 1. Five specimens of 10 × 1 in^2 were selected for each category.

Evaluation of Thermal conductivity

In the context of the present study, it was considered important to calculate the thermal conductivity of the composite material to be used as a sunshade. For this purpose, two plate method was used (ASTM 1530 2016) [33]. A circular specimen with a diameter of 50 mm is positioned such that it separates the two metal plates (hot plate and cold plate respectively). Heat travels from the hot plate to the cold because of the longitudinal temperature difference. Once the steady-state condition is attained, temperature sensors mounted on the metal plates measure temperature at both ends of the composite specimen. An additional measurement of heat flux is obtained with the help of a heat flux sensor. Thermal conductivity is then calculated by using these three measurements. The test was carried out for all types of composite materials.

RESULTS AND DISCUSSION

From figure 3, it is evident that the density of the control sample manufactured in the lab was very close to the standard sample. The density of hybrid composites with mercerized cotton hard waste as reinforcement was the lowest. This was perhaps due to the action of the caustic soda which might have removed the waxes on the fibre surface thus slightly reducing the density. The density of hybrid composites in all categories was lower than the composites reinforced with only the glass fibre strand mats. This was because glass fibre has higher density as compared to cotton and polyester. In the case of hybrid composites, the difference in the densities was not significant; therefore this matter was not investigated further.

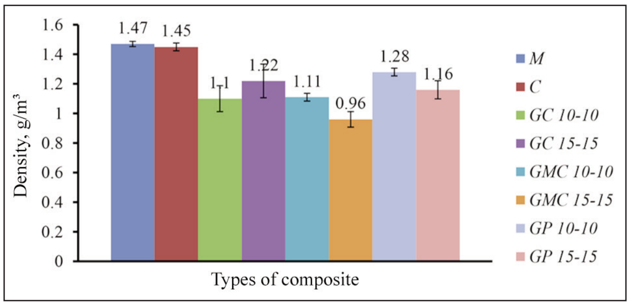


Fig. 3. Density of the composite samples

The force-strain curves for the Market sample as well as the samples manufactured in our lab were obtained from the software of the testing machines (figure 4).

From figure 4, it was observed that the samples obtained from the market are brittle in nature, and the standard samples manufactured in the lab with 30% glass fibre content are also brittle in nature. By adding the hard waste along with the glass fibres i.e. the hybrid composites show brittleness as well.

The tensile properties of different types of composites were determined by using the method explained in the last section. The results are shown in figures 5, 6 and 7.

From figure 5, it can be observed that the tensile strength of the controlled sample was slightly higher than the standard sample. Hybrid composite samples with mercerized cotton have shown the minimum strength, this might be because of the lower interaction of resin and cotton hard waste. It is a common belief that caustic soda is used to remove waxes, hemicellulose and other vegetable substances from lingo-cellulosic fibres to improve the interaction of resin and the fibres, by making the surface of fibres rough [11]. In the case of cotton hard waste used during this research work did not contain any impurities, so when the hard waste was treated with caustic soda, it resulted in swelling of fibres, thus causing shrinkage of small pieces of yarn, the caustic soda also makes the smooth surface of cotton fibre, resulting in less interaction of yarn pieces with the resin and minimum strength. The strength of hybrid

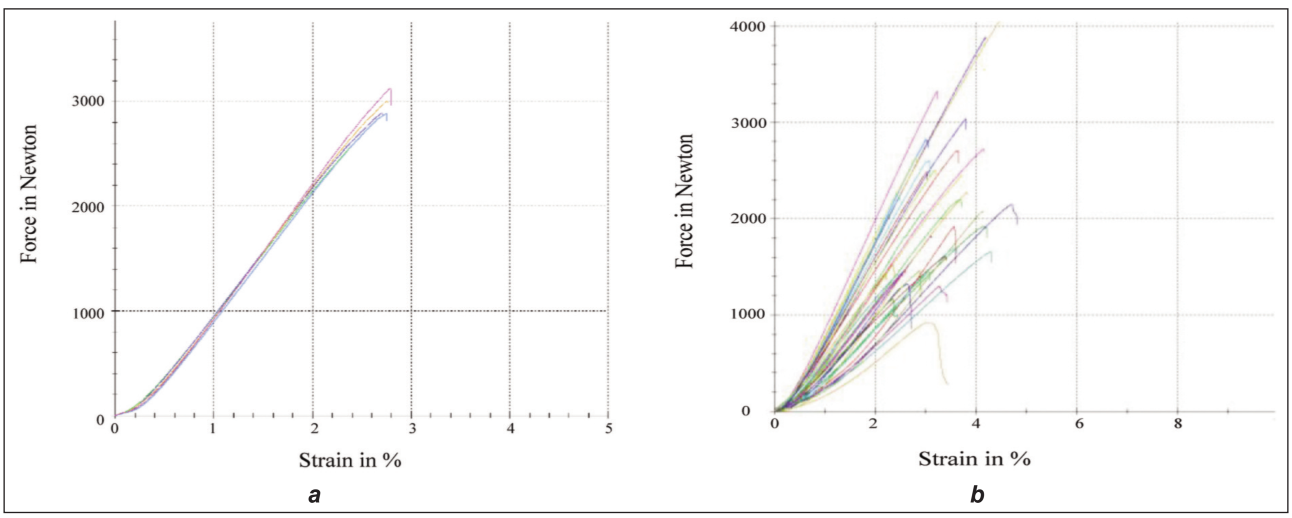


Fig. 4. Force-strain curves for: *a* – market samples; *b* – standard and hybrid composite samples

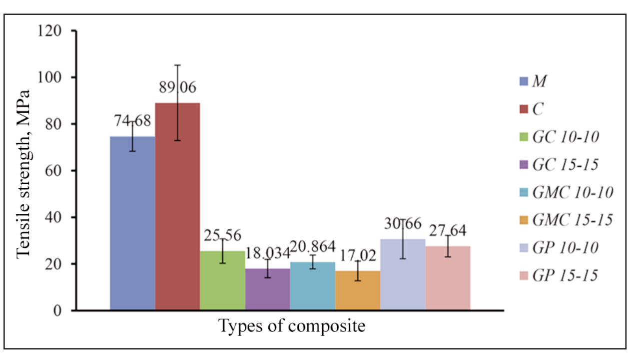


Fig. 5. Tensile strength of the composite samples

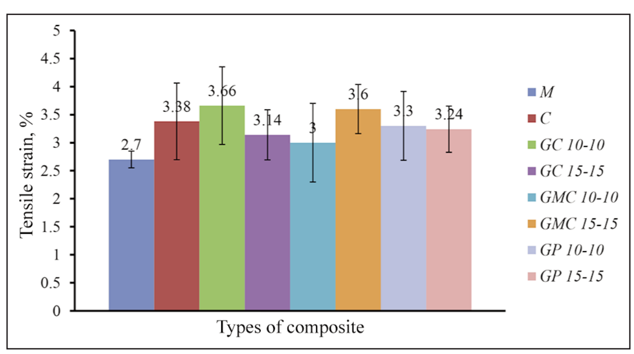


Fig. 6. Tensile strain of the composite samples

polyester composites is slightly higher than the composites manufactured with cotton hard waste. This is perhaps because polyester has high strength as compared to cotton.
Figure 6 shows that the tensile strain of the controlled sample is slightly higher than the commercial sample obtained from the market. In the commercial sample, the fibres might not be distributed properly, when we manufacture the control sample in our lab, the fibre distribution in the resin was proper showing more resistance to the load, resulting in higher elongation. For hybrid samples, the even distribution of fibres and hard waste also resulted in higher strain values.

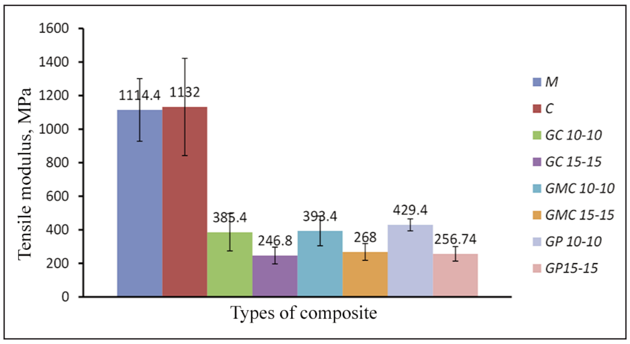


Fig. 7. Tensile modulus of the composite samples

There is not much difference in the tensile modulus of standard and controlled samples, presented in figure 7. Hybrid composites have lower modulus as compared to composites manufactured only from glass fibre mats as reinforcement. All the hybrid composites have shown a mixed trend, so this phenomenon was not discussed further.
The tensile properties i.e. tensile strength of the controlled sample was 19.25% higher, and the tensile stain for the controlled sample was 25% higher than the market sample. This was perhaps because of the hand layup method adopted in the lab resulted in the proper distribution of fibres in the resin. However the tensile modulus of the commercial and controlled samples is similar, so we were able to successfully replicate the samples in the lab.
In the case of hybrid composites, the samples manufactured with 10% polyester and 10% glass have shown better results. For example: the tensile strength of 10% polyester and 10% glass composite was 19.95% higher as compared to 10% cotton and 10% glass composites; it was also 10.93% higher as compared to 15% polyester and 15% glass hybrid composites.
When these samples were compared with the commercial samples the tensile strength was 58.94% lower, and when they were compared with controlled samples, the strength was 65.57% lower. If we consider sun shade as a non-structural product, then this hybrid composite material has the chance to replace the commercial sunshade.
The thermal conductivity of different types of composites was assessed by using the two-plate method explained in the last section (figures 8).

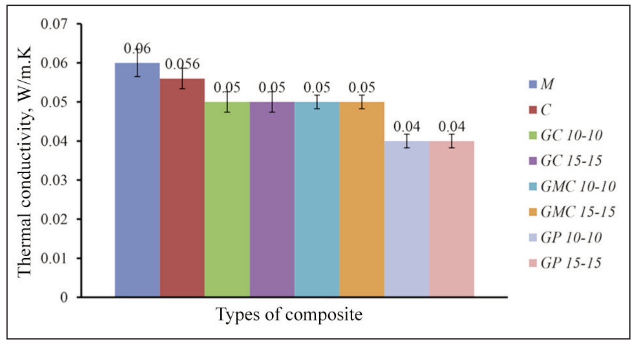


Fig. 8. Thermal conductivity of the composite samples

From figure 8, it can be observed that the thermal conductivity of composites reinforced with glass fibre strand mats is the highest. This means it will allow more heat to pass the shade thus it has a less insulating effect.
Hybrid composites reinforced with glass and polyester hard waste resulted in lower thermal conductivity as compared to glass fibre composites. Because the presence of hard waste as reinforcement resulted in more gaps within the fibre networks in the composite material. In the case of polyester hard waste, thermal conductivity is further reduced, this might be because most of the heat is trapped in the layer of polyester hard waste, and a very small quantity of heat passed the layer of glass fibres and resin.
The combination of glass fibre mats (10%) and polyester hard waste (10%) in the reinforcement has a great potential to replace commercial sunshades having 30% glass fibre mats as reinforcement. These samples developed as a result of this research work have reasonable strength (30.66 MPa) and modulus (429.4 MPa), lower density (1.28) i.e., the samples will be lighter in weight and lower thermal conductivity (0.04) as compared to the commercial market sample.
The tensile properties of polyester hybrid composites are much lower as compared to glass mat composites, but the application of sunshades could come in the category of non-structural application, so the tensile properties will be considered less important.

CONCLUSIONS

From the above discussion, the following conclusions can be made: the commercial samples of sunshades can be replicated by our successfully developed composites at a lab scale that have slightly higher tensile properties, similar density and slightly lower thermal conductivity. The hybrid composites based on un-mercerized and mercerized cotton had shown lower tensile properties and similar thermal conductivity, so these composite materials are not considered to be used as sunshades. The hybrid composites based on polyester fibre as reinforcement had lower tensile properties, but they have lower thermal conductivity as compared to glass fibre composites. The hybrid composites based on polyester hard waste have the potential to be used as sunshades if we consider this application as a non-structural one. However, in future research, these composite materials will be tested further to prove their performance in actual environmental conditions for the sunshades.

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