Scientific Research Journal,
Vol 18, No 1 (2021) 119 - 130
https://doi.org/10.24191/srj.v18i1.11390

Tensile and Impact Properties of Hybrid Composites from Textile Waste

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Received: 3 December 2020
Accepted: 16 December 2020
Online first: 28 February 2021

ABSTRACT

The rise of the textile industry in global fashion has caused a high level of post-consumer textile waste generation. Every year, million tons of textile waste has been sent to landfills that consequently leading to environmental pollution. This study aimed to use the textile waste for the development of hybrid composite laminate, together with the existing commercially available fibreglass. This research investigated the tensile properties and impact strength of textile waste hybrid composites. Three textile variants were used in this study, which is lycra, polyester and cotton, and they were either chopped or used as a full fabric. Hand lay-up and hot press technique were used to produce the sample materials, using epoxy resin as the binder. A total of 9 samples were prepared and their tensile and impact properties were assessed. Tensile test results showed that all hybrid composites have a better ultimate tensile strength and tensile modulus compared to their original raw fabrics, but not on the elongation property. It can be seen that the arrangement of fabrics has a distinctive eJect on tensile and impact strength. All raw fabrics were greatly punctured during the failure, but all hybrid composites have barely visible impact damage on the front surface, and no penetration was observed. This study reveals that the reuse of textile waste and fibreglass for the development of hybrid composites has a huge potential to be used as substitutes in other composite materials. In the future, this will contribute to improving the sustainability of textile materials.

***Keywords**: textile waste, fibreglass, hybrid composites, tensile properties, impact strength*

INTRODUCTION

Globally, an estimated 92 million tonnes of textile waste are created each year. According to Discover Natural Fibre Initiative (DNFI), global production of all apparel and textile fibres have amounted to 110 million tons in 2018 [1]. In the US alone, roughly 13 million tonnes are thrown away in landfill or burned. By 2030, it is expected that textile waste will be disposed of more than 30 million tonnes a year [2]. This happened due to the rising of world population and living standard, from both production and consumption of the textile goods. The average consumer now buys 60% more clothing than they did a decade ago [2]. Although, all textile waste can be recycled, unfortunately, only a small amount is recycled [4]. If the current global trends persist, the textile waste will reach more than 300 million tonnes and the amount of microplastic released into oceans will increase too, which leads to global environmental pollution [5]. It is important to note here that the textile waste that is resulting from overconsumption should be properly managed or recycled. Therefore, developing innovative recycling solutions to deal with this textile waste problem is important. However, for textile waste, the recycling of textile products is not as common as the material groups such as plastic, paper and glass. Recycling textile waste becomes problematic when it comes to the process of separation of different types of fabrics [6]. In the global market, polyester and cotton are the most widely used fibres in the textile industry. There are many other types of fabrics such as lycra, nylon, rayon, denim, and many more [7]. But in this study, three types of textile waste are used: lycra, polyester and cotton.

Lycra fabric is derived from polymer, composed of long chains of monomers that are connected with a special type of acid [8]. Lycra is a highly elastic synthetic fibre, and it can stretch to five to eight times its usual size and it is highly resistant to heat. Cotton is chemically organic, derived from fibres surrounding the seeds of cotton plants [9]. It has a porous structure, small fibre diameter and spiral in shape. Polyester is a synthetic fabric that is usually derived from petroleum, ester functional polymer [10]. It has low shrinkage ability and high durability properties. They are highly resistant to environmental changes, which makes them ideal for long-term application. Some forms of polyester are biodegradable, but most of them are not, and this contributes to the global pollution caused by plastics and textile wastes from this polymer group.

In this study, the objective is to recycle this textile waste and mix with commercial fibreglass sheets for development of a hybrid composite material that can be used in domestic applications such as sound barriers or road safety barrier. Fibreglass is a type of fiber-reinforced polymers. It has good properties such as low density, high strength, and easy processing, that it is widely used in aerospace, automotive, and construction materials [10,11]. Combining the fibreglass with other fibres into a single polymer matrix could result in the development of hybrid fibreglass composites, which will raise new opportunities to explore new ideas and applications in the future [12,13]. One example, a novel and sustainable method of producing sound insulation materials using cotton/polyester mixed textile waste is presented in [14] by employing a compression moulding technique under heat. The use of textile waste together with the fiberglass in this study could become an innovative recycling solution instead of dumping them in landfills. This study could improvise the material properties of existing fibreglass and could reduce the usage volume of fibre glass by incorporating textile waste in the fibreglass hybrid composites. Quality and profitability may be achieved by careful design and study of the material properties of the hybrid composite. To achieve that, a simple processing route is used and the following section explains the details.

METHODOLOGY

Sample Preparation

Figure 1 shows the three types of raw textile wastes used in this study; Lycra, Polyester and Cotton, mark as L, P and C respectively. A total of nine samples were fabricated. The conditions of the textile fabric were arranged either in a chopped condition or in one-piece full fabric. For the chopped fabric, the raw fabrics were cut into small pieces then weighted for 50g before stacking up together with layers of fibreglass. These textiles were then mixed with fibreglass (marks as FG) fabric and epoxy resin for the fabrication of the laminate composite samples in the ratio of 5:1:4 (textile: fibreglass: epoxy). The epoxy and hardener (by Miracon) are mixed in the ratio of 3:1 by mass. In this work, the fabrication of the composite plates employed a hand lay-up technique, where the laminates were laid up in a stainless-steel mold and were placed in a hot press hydraulic machine. Parchment papers were used as a mold release surface. The composite laminates were pressed at a temperature of 140^{o}C and a pressure of 40 bars for the duration of 2 hours. The final thickness of the laminates was 3mm ±0.5mm, as required in the standard ASTM testing. The fabrication of the raw textile specimens without fibreglass followed a similar procedure purposely used for a comparison between raw and composite specimens. Then, all samples were cut to the specific dimensions using a vertical band saw machine.

Figure 1:a) Lycra Fabric, b) Polyester Fabric, c) Cotton Fabric, d) Fibreglass e) Samples for Tensile Testing f) Samples for Impact Testing

Mechanical Testing

In this study, two mechanical testings were performed on all specimens: Tensile test and Drop-weight impact test. To conduct the tensile test, the specimens were made according to the ASTM D3039 standard, with the dimension of 250 mm length x 25 mm width x 3 mm thickness, as shown in Figure 1. The tensile test was conducted at room temperature with a speed rate of 2mm/min using INSTRON 3382 universal testing machine. The tensile test was the method to obtain the elastic modulus. To study the behavior of impact resistance of the hybrid composite plates, impact test was performed on the specimens. The dimension of the specimens was set to 50 mm x 50 mm x 3 mm, and was impacted by a drop-weight impact tester, equipped with a hemispherical nose impactor made from hardened steel with a diameter of 11.7 mm and a mass of 6.5kg. All specimens were impacted at the same low impact energy of 5J to investigate the effect of different textiles on the impact resistance. A visual inspection was conducted on all impacted specimens right after the impact. The relationships between time and displacement were computed by a data acquisition system to obtain the absorbed impact energy. All results are presented in Fig. 2 and Fig.3, and are discussed in terms of the effects of different textile types (lycra vs polyester vs cotton) and different fabric arrangements (raw fabric vs chopped vs full fabric)

RESULTS AND DISCUSSIONS

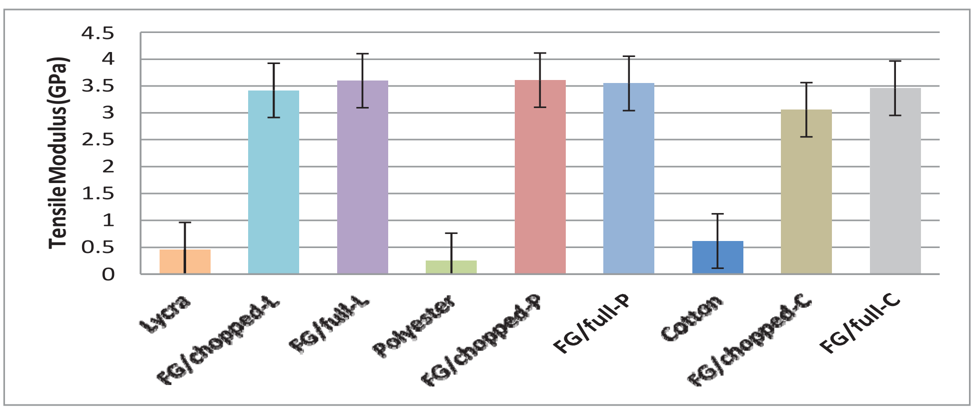
Tensile Properties

Tensile test was performed to determine the behaviour of the samples under tension load. In the test, the samples are pulled to its breaking point to determine the ultimate tensile strength (UTS) of the material. InFigure 2a, 2b and 2c, the ultimate tensile strength, tensile modulus and elongation percentage of nine samples (three raw fabrics and six hybrid composites) are presented.

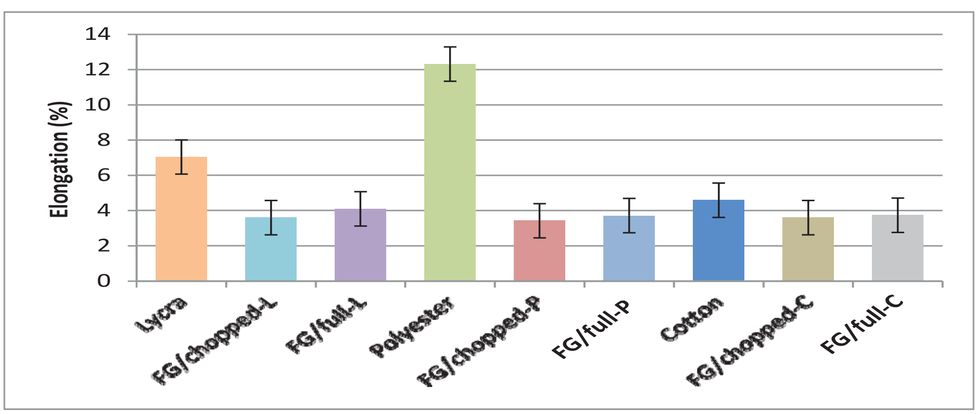
Comparing the first three raw fabrics, lcyra and polyester fabrics have almost similar UTS values, while the cotton fabric having the lowest value with a percentage difference of 15% between them. The tensile modulus on the other hand, is the highest (0.62 GPa) for cotton, compared to the other raw fabrics, 0.46 GPa and 0.26 GPa, respectively for the lycra and polyester fabrics. Meanwhile, the polyester fabric has the highest elongation percentage (12%), followed by lycra (7%) and then cotton (5%). From these results, three general observations can be made about all three raw fabrics. First, the Polyester fabric can withstand a higher amount of stress before failure and has the ability to stretch longer before fail. Second, the cotton fabric has the highest modulus, which means it has the highest ability to return to its original shape after stress is removed, but it has a shorter plastic deformation. The final fabric, lycra, has mid-range tensile values compared to the other two fabrics.

Moving now to a comparison between the hybrid composites, where the raw fabrics were mixed with fibreglass and stacked together either with the chopped or full sheet fabrics. It can be seen in Figure 2 that the FG/chopped cotton has the lowest UTS value (112 MPa), and the FG/chopped lycra has the highest UTS value (142 MPa). For the tensile modulus, FG/chopped cotton has the lowest modulus (3.1 GPa), and the FG/chopped polyester has the highest modulus (3.6 GPa), meanwhile, the other hybrids are having a modulus in a range of 3.4 GPa to 3.5 GPa. For the elongation percentage, the FG/chopped polyester has the lowest elongation percentage (3.4%), compared to the FG/full lcyra that has the highest percentage of elongation, which is 4%. It is quite obvious that all hybrid composites have a better UTS and tensile modulus compared to their original raw fabrics (more than 80%), but not on the elongation property. This means that the hybrid composite has a low ability to resist changes in shape without cracking, but they have a better stiffness and toughness, compared to their raw fabrics. It is apparent that variation in the arrangement of fabric types in the hybrid composites can have a profound effect on the tensile properties. It can be seen that a particular shape or arrangement (chopped or full sheet) has a distinctive effect on the strength values of the composite. So, careful consideration to select the suitable reinforcement and matrix formulation should be given for producing a better hybrid composite using textile wastes for commercial applications.

a.



b.



c.

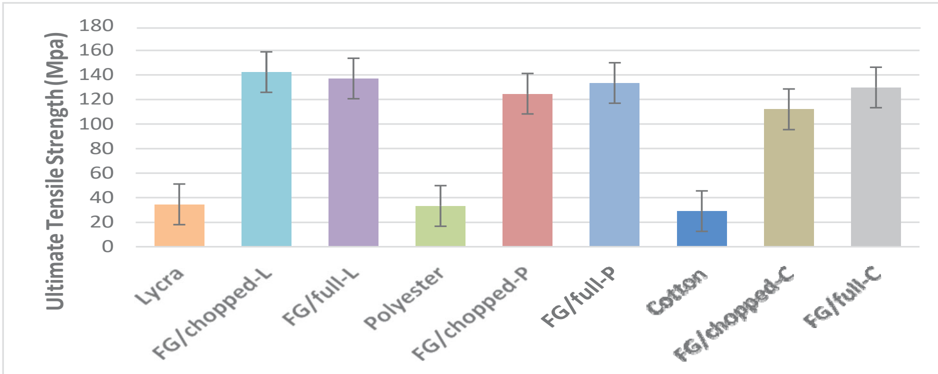


Figure 2: Comparison of Tensile Properties: a) Ultimate Tensile Strength, b) Tensile Modulus and c) Percentage of Elongation

Impact Properties

In this section, the effect of different raw textile types (lycra vs polyester vs cotton) and different fabric arrangements (raw fabric vs chopped vs full fabric) on the impact strength are discussed. All specimens were impacted at the same energy level of 5J. Figure 3 displays the visual images of all nine samples after being impacted by a drop-weight impact tester, and Figure 4 presents the absorbed impact energy, peak load and deflection at peak load. Generally, the combination and the arrangement of the fabrics and matrix provide a better characteristic superior to their original materials, in this case, has caused the impact resistance to be better. As can be observed in Figure 4, all hybrid composites have a better impact strength compared to their raw fabrics, where the evidence can be seen in the visual images in Figure 3. The extent of the damage was more significant for the raw fabrics, where the penetration of the impactor can be clearly seen. All raw fabrics were greatly punctured during the failure, and the absorbed impact energy varied between 3 to 6 J. Meanwhile, all the hybrid composites have barely visible impact damage on the front surface and no penetration through the sample thickness. This is consistent to the results obtained in Figure 4c, where all raw fabrics have higher deflection at peak load compared to their hybrid composites, about 30% to 40% differences.

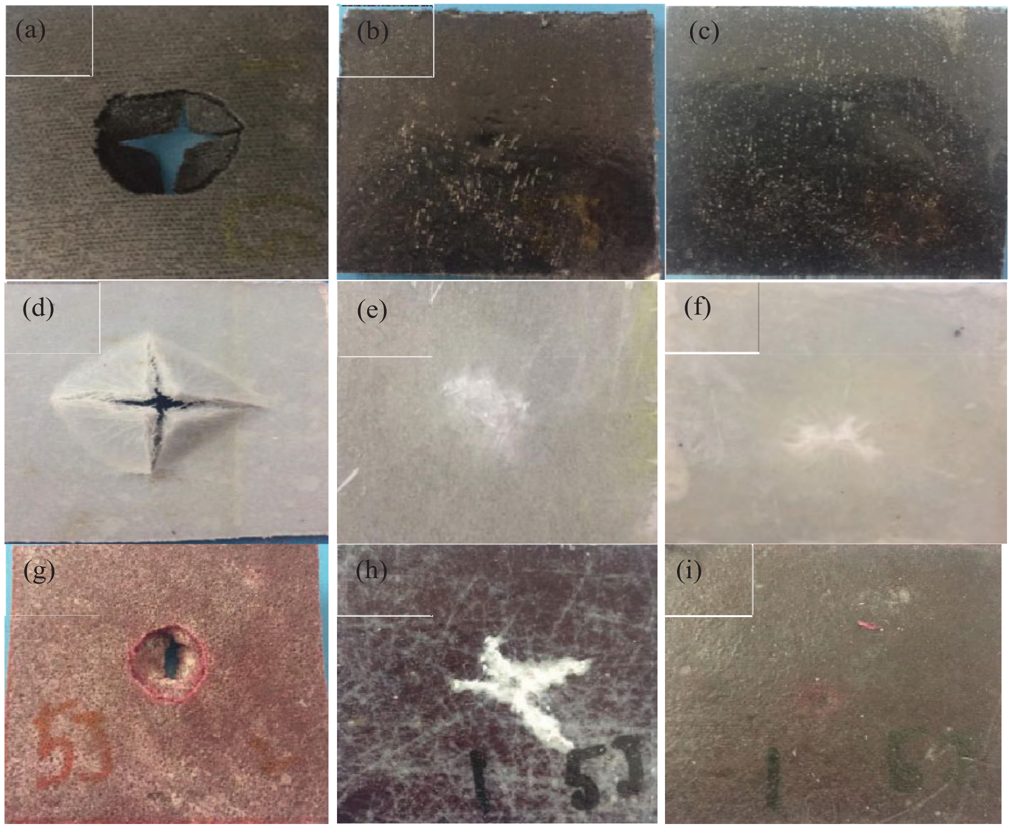
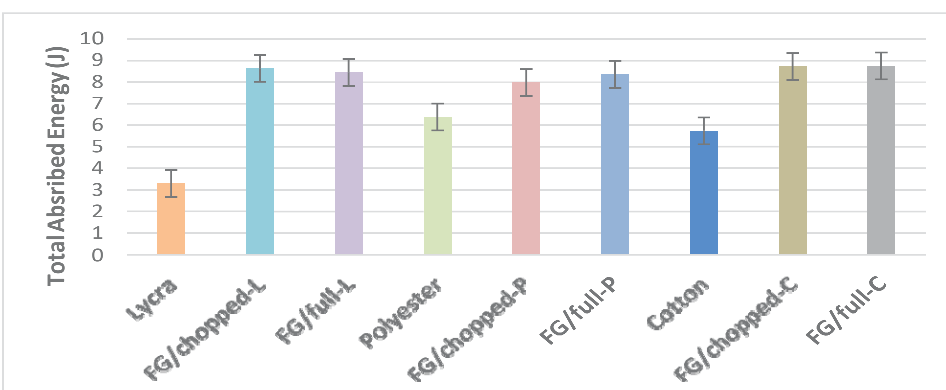
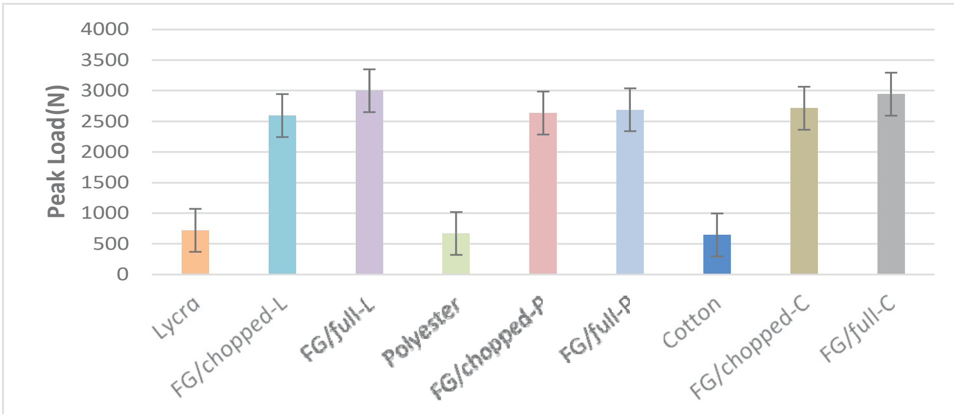


Figure 3: Visual Images of the Front Surface of the Impacted Samples. a) Lycra, b) FGIChopped Lycra, c) FGIFull Lycra, d) Polyester, e) FGIChopped Polyester, f) FGIFull Polyester, g) Cotton, h) FGIChopped Cotton and i) FGI Full Cotton

a.



b.



c.

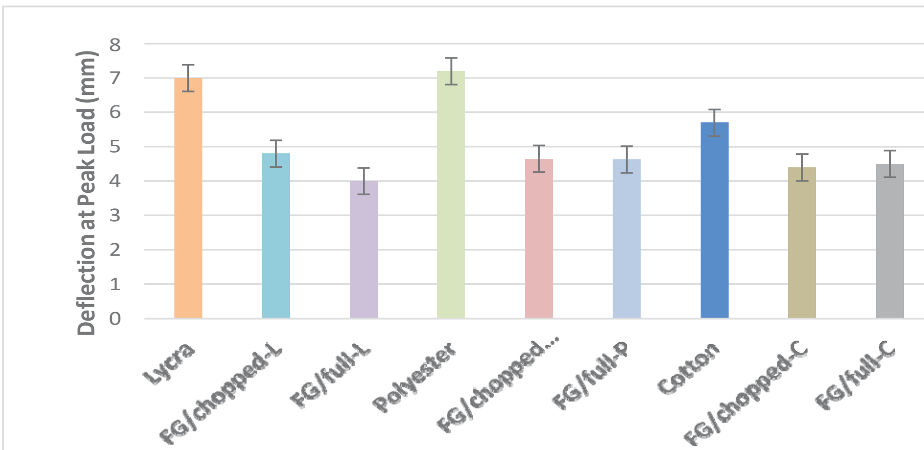


Figure 4: Comparison of a) Total Absorbed Energy b) Peak Load and c) Deflection at Peak Load During Impact Testing

Figure 4a and 4b show that all hybrid samples have a better total absorbed energy and peak load, as opposed to their raw fabrics. This shows that the addition of fibreglass provides dimensional advantages that improved the impact resistance ability, but the level of impact damage severity is different in each hybrid samples. Referring to Figure 4c, all hybrid samples have a comparable deflection at their peak load, ranging from 4.5 mm to 4.8 mm, except the FG/full lycra fabric has the lowest deflection of 4 mm and this sample able to withstand a higher load of 3002 N, as can be seen in Figure 4b. From Figure 4a, it can be observed that both cotton hybrid composites have the highest total absorbed energy (8.7J), followed by the hybrid FG/lycra, then hybrid FG/chopped polyester. Both hybrid FG/polyester specimens have the highest deflection and the evidence can be seen in Figure 3d and 3f. Comparing between chopped and full fabric arrangement in the hybrid composites, there are no significant trends on the impact properties, but they have a difference of 10%-20% between the two types of fibre arrangement. From this study, generally, it can be concluded that by modifying the fabric laminate arrangement, it improves the energy transfer between the laminates that upgrade the impact resistance of the textile fabrics.

CONCLUSION

In general, the tensile properties and the impact resistance of the hybrid composite samples are greater than their original fabrics. It was found that the arrangement of fibre in all hybrid composite either in chopped or used as a full fabric trigger an increase of elastic modulus and impact resistance, but not to the elongation percentage in tensile test. This means that the hybrid composite has a low ability to resist changes in shape without cracking, but they have a better stiffness and toughness, compared to their raw fabrics. Generally, the combination and the arrangement of textile fabrics, fibreglass and epoxy binder provide a better characteristic superior to their original materials. As summary, the characterisation of the recycled hybrid composite samples conducted in this study has provided critical insight in finding their recyclability potential and their suitability to be used in domestic applications such as sound barrier, road safety barrier, or many other applications. By recycling these textile wastes, global textile pollution can be reduced that will bring benefits to everyone for a green and sustainable future.

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