Development and Characterization of Hybrid Green Composites from Textile Waste

Mehmet Karahan[1(✉)], Zaid Masood[2], Yasir Nawab[2], and Nevin Karahan[1]

[1] Uludag University Vocational School of Technical Sciences, Gorukle, 16059 Bursa, Turkey
mkarahan@uludag.edu.tr

[2] Textile Composite Materials Research Group, Faculty of Engineering and Technology, National Textile University, Sheikhupura Road, Faisalabad 37610, Pakistan

Abstract. The current study focused on the use of textile industry waste (cotton and jute) and glass fabric for the development of hybrid composites. Composites were fabricated using either a single reinforcement or different fractions of cotton, jute and glass fabric. A good fibre-matrix interface was observed using Scanning Electronic Microscopy (SEM). The mechanical performance of the developed composites was analyzed under certain loads. The tensile and flexural properties of the composites developed from waste material was found lower as compared to the glass fiber composites, while hybrid composites had comparable properties. Regression equations were also developed to predict the mechanical properties of the hybrid composites. The results revealed that, after some pre-treatment (mercerization and desizing) textile waste materials can be used with virgin material in reinforcement part of composite to decrease the cost but with optimum mechanical properties. This usage of textile waste will be helpful for its value addition and solving the waste disposal problems.

Keywords: Hybrid composite · Textile waste · Dynamic mechanical analysis · Mechanical properties

1 Introduction

The fiber reinforced composites (FRC) are used for a wide range of applications from water storage tanks to high tech aircraft parts. The mechanical performance of FRC is mainly a function of the reinforcing material, i.e. natural or manmade fibers [1]. Glass fibers are the most commonly used reinforcement material, occupying 87% market share of the FRC [2]. However, the production, usage and disposal of these composite structures (reinforced with glass fibers) is declining due to increased environmental concerns. It motivated the researchers to look for alternative materials, and the natural fibers appeared as a potential substitute [3]. The advantages offered by natural fibers over glass fiber include sustainability, low cost, ease of availability, low density, biodegradation and low health hazards [4, 5]. Among the various plant based fibers, flax, bamboo, sisal, hemp, ramie, jute, and wood fibers are of particular interest [6]. Animal-based fibers e.g. wool and silk are also used as reinforcements for FRC [7]. The silk fiber reinforced

S. Trzcielinski (ed.), *Advances in Ergonomics of Manufacturing: Managing the Enterprise of the Future*, Advances in Intelligent Systems and Computing 606,
DOI 10.1007/978-3-319-60474-9_4

composites have been investigated in view of bioengineering applications such as scaffolds for tissue engineering and bone fixators [8]. The current research interest is towards recycling and value addition to low cost materials. In view of better land saving, for example, perennial grasses such as Indian-grass or switch-grass have been investigated as reinforcing agents [9]. Composite materials reinforced with switch-grass stems were used for automotive interiors and showed higher modulus, flexural strength and impact resistance as compared to jute- PP composite of the same density [10].

The tailored properties in a single piece of composite material may be achieved using more than one reinforcement or matrix [11]. Such composites are termed as hybrid composites. They can be manufactured by using synthetic fibers, natural fibers or with a combination of both synthetic and natural fibers [12].

Another approach to value addition is the extraction of fibers from agricultural or industrial waste. Attempts have been made to use sunflower stalk, bagasse [13], rice husk, cornhusk [14], wheat straw [15], and soy stalk [16] as sources of cellulosic fibers to serve as reinforcement in FRC. Cellulose fibers having properties intermediate between those of cotton and flax were successfully extracted from cornhusk, a by-product of corn production that is worldwide available and has limited commercial value [17]. This approach also contributes to solve the problem of agricultural waste disposal [18].

Other potential waste fiber sources include animal-derived protein wastes, such as by-products from the wool textile industry (poor quality raw wools not suitable for spinning), hair, and feather. The hollow structure of keratin fibers leads to an extremely low fiber density that can be used to obtain light-weight materials for automotive applications [19]. Overall, the use of fibers from waste (either agricultural or animal) as reinforcement in bio-composites offers a low cost and environmentally friendly solution to waste disposal [20].

However, lack of good interfacial adhesion, susceptibility to bacterial attacks and poor resistance towards moisture make the use of natural fiber reinforced composites less attractive [21]. Pretreatments (mercerization, scouring, etc.) of the natural fiber clean the fiber surface and chemically modify the surface to reduce the moisture absorption and enhance surface roughness [22]. The bacterial attacks may be avoided by the addition of some fillers having antibacterial activity [23].

Generally, 16–17% cotton fibers are wasted due to their short length that makes them unsuitable for making fine and high strength yarn. The price of finished yarn is increased due to this 17% waste [24, 25]. These waste fibers can be used for making low strength yarn that can be used for making composite reinforcement [26]. But the mechanical performance of these composites is less as compared to glass fiber composites [27]. This problem can be overcome by using the waste fibre reinforcement along with virgin reinforcement producing hybrid composites, which will be low cost.

The aim of this study was to minimize the use of synthetic fibers by developing hybrid composites reinforced by waste natural fibers (textile industry waste) and virgin synthetic fibers and to find best combination of waste and virgin fiber based reinforcement with optimum mechanical properties. This study will also increase the value of textile waste and keep the environment hygiene by minimizing waste.

2 Materials and Methods

Three types of yarn were used to fabricate reinforcement for the manufacturing of composites structures i.e. cotton, jute, and glass. The areal density of woven cotton, jute and glass fabric was 200, 270 and 250 g/m^2.

Thermosetting unsaturated polyester resin was used due to easy handling, curing at room temperature and its low cost [28]. Cobalt naphthalene was used as hardener while poly-ethyl-ether ketone as accelerator for thermoset unsaturated polyester. Hardener and accelerator were used 0.2% and 1.0% of the resin amount respectively.

The methods involve the steps including manufacturing and treatment of reinforcement, fabrication and characterization of the composites. The reinforcements were prepared on weaving machine, and subsequently enzymatic de-sizing and scouring was done as pretreatment of cotton and jute respectively. The desizing was performed using enzyme Beisol (2 g/l) for 30 min and temperature was maintained at 70–80 °C. Scouring of the jute fabric was done for 40 min at a temperature of 80–90 °C to remove the impurities. The recipe used for scouring was:

- NaOH: 10 g/l
- Wetting agent: 2 g/l
- Sequesting agent: 2 g/l
- Detergent: 2 g/l

Seven samples were fabricated having different percentage of cotton, jute, and glass. Out of seven, three samples were fabricated with single type of reinforcements while four with hybrid reinforcements. Reinforcements were placed at [0] stacking sequence.

Vacuum bag molding technique was used to manufacture composite samples. This method helps to produce a more uniform composite part by removing the air bubbles and hence better consolidation of layers is achieved [29]. A negative pressure of −1 bar was applied by vacuum. The fiber volume fraction was maintained at 30%. The initial curing was performed at room temperature for four hours and then post curing was done at 120 °C for two hours in oven.

The tensile properties of these composite materials were tested using ASTM D3039, while flexural properties were tested according to the test method ASTM D7264.

3 Results and Discussion

The developed composite materials were characterized for mechanical performance under certain loads, as discussed in the previous section.

The scanning electron microscopy images of hybrid composite sample having equal fractions of cotton, jute and glass reinforcement is given in the Fig. 1. The figure shows a good interphase developed between the different reinforcements with the matrix and also at the point where plies of two materials make a contact. Hence, the matrix can transfer the load easily to the reinforcement, without any possibility of delamination and the fibers fully contribute to the mechanical properties of the composites.

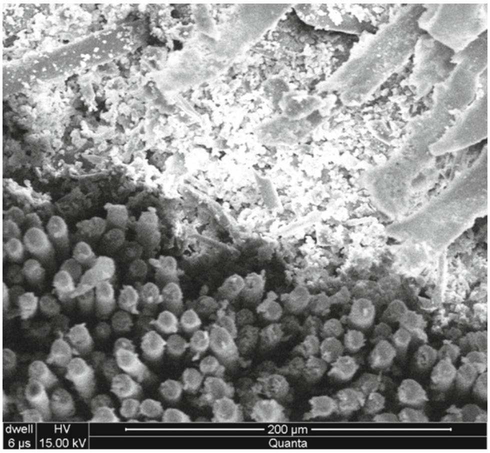

Fig. 1. SEM image of hybrid composite sample

3.1 Tensile Strength

The tensile properties of composite samples were analyzed on Testomeric tensile strength machine, and the contour plot between tensile strength and different percentages of cotton, jute and glass reinforcement in composite samples is given in Fig. 2. It can be observed that the plot is divided into four colored segments, each representing a specific range of tensile strength from <30 MPa to >60 MPa. Highest range of tensile strength (>60 MPa) is represented by darkest colored segment. Tensile strength of composite is effected by the percentage of reinforcing materials (cotton, jute and glass) that are showed by each corner of graph.

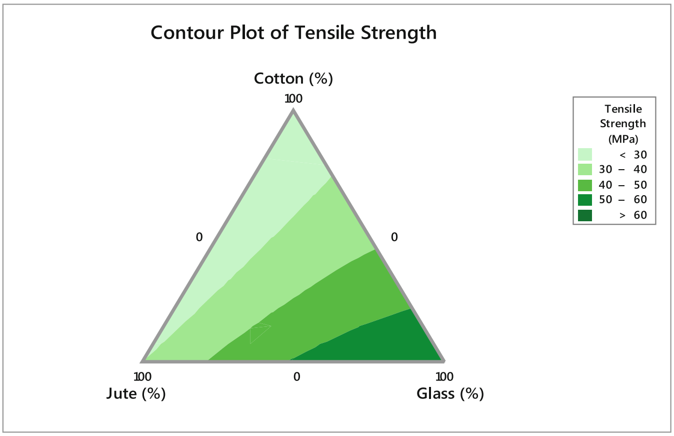

Fig. 2. Contour plot of tensile strength

It is obvious from the Fig. 2 that composite having 100% cotton as reinforcing material has tensile strength in a range of 20 MPa because mechanical properties of cotton are lower than jute and glass [26]. A large change in tensile strength of composite is not observed by using both natural fibers i.e. jute and cotton as reinforcing materials because mechanical properties of natural fibers are lower than glass fibers [30]. Tensile strength of hybrid composites having different percentages of cotton, jute and glass fibers is laid between 40–60 MPa. Composite having 100% glass fibers as reinforcing material has tensile strength more than 60 MPa because mechanical properties of glass are higher than cotton and jute fibers [11].

Figure 3 shows a main effect plot between percentages of reinforcing materials (Cotton, jute and glass) and tensile strength of composite samples. In main effect plot, the factor (reinforcing material) whose slop is steeper than others, imparted a large effect on response variable (tensile strength).

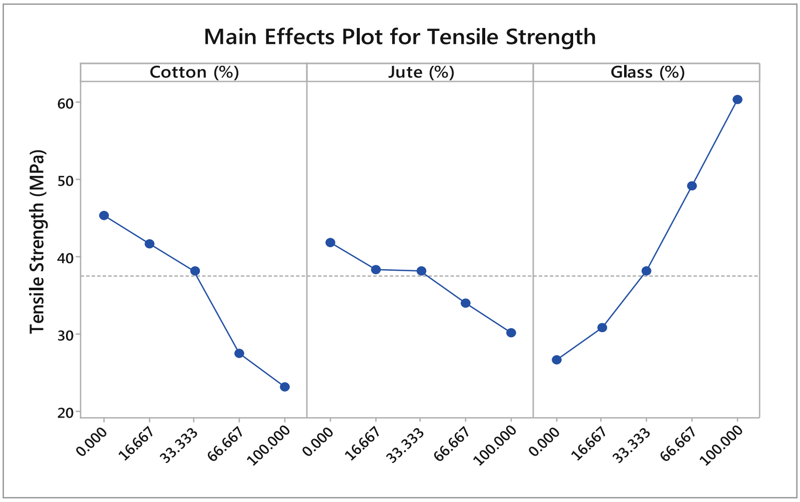

Fig. 3. Main effect plot tensile strength

It is obvious from the graph that slop of glass and cotton are steeper than jute. But the relation is inversed. Tensile strength of composite samples is decreased by increasing the percentage of cotton. While strength is increased by increasing the percentage of glass, because tensile strength of glass fibers are greater than cotton [31].

Slope of jute showed that tensile strength is not changed abruptly by increasing the percentage of jute because tensile strength of jute are intermediate between cotton and glass [32].

$$\text{Tensile Strength (MPa)} = 23.10\,X_1 + 30.19\,X_2 + 60.27\,X_3 - 13.87\,X_1X_2 - 13.85\,X_1X_3 + 22.09\,X_2X_3$$

$$R^2 = 99.84 \tag{1}$$

This regression equation showed a mathematical relationship between response (tensile strength) and factors (percentages of reinforcing materials) where X_1, X_2, and X_3 are percentage of cotton, jute and glass respectively. Coefficient of determination (R^2) showed that X_1, X_2, and X_3 satisfied the given equation by 99.84%. Response (tensile strength) is largely effected by the factor (reinforcing material) whose coefficient is more than other. So it is cleared from the equation that tensile strength is largely effected by the factors X_3 and $X_2 \times X_3$.

3.2 Tensile Modulus

Figure 4 showed a contour plot between tensile modulus and percentages of cotton, jute and glass in composite samples. This graph is divided into six colored segments. Each segment is represented by a specific range of tensile strength from <2 GPa to >4 GPa. The highest range of tensile modulus (>4 GPa) is represented by the darkest colored segment. Tensile modulus of composite is effected by the percentage of reinforcing materials (cotton, jute and glass) that are showed by each corner of graph.

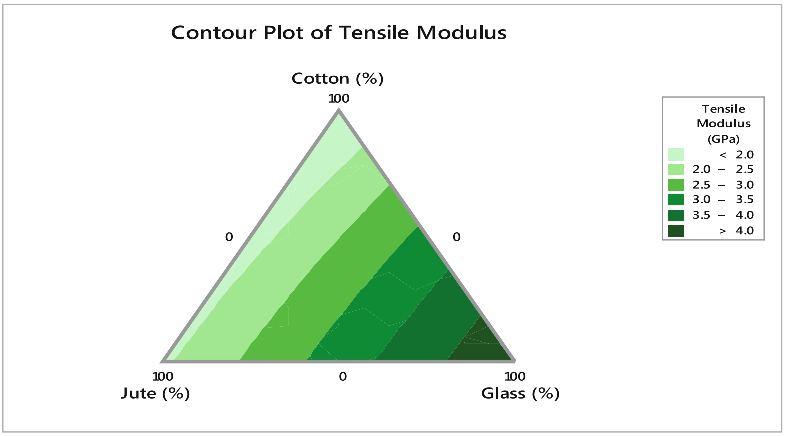

Fig. 4. Contour plot of tensile modulus

It is clear from graph that composite having 100% cotton as reinforcing material has tensile modulus in a range of 2 GPa because mechanical properties of cotton are lower than jute and glass [26]. A large change in tensile modulus is not observed by using both natural fibers i.e. jute and cotton as reinforcing materials because mechanical properties of natural fibers are lower than glass fibers [30]. Tensile modulus of hybrid composites having different percentages of cotton, jute and glass fibers is laid between 2.6 GPa to 4 GPa. Composite having 100% glass fibers as reinforcing material has tensile modulus more than 4 GPa because mechanical properties of glass are higher than cotton and jute fibers [11].

Figure 5 showed a main effect plot between percentages of reinforcing materials (Cotton, jute and glass) and tensile modulus of composite samples. In main effect plot, the factor (reinforcing material) whose slope is steeper than others, imparted a large effect on response variable (tensile modulus).

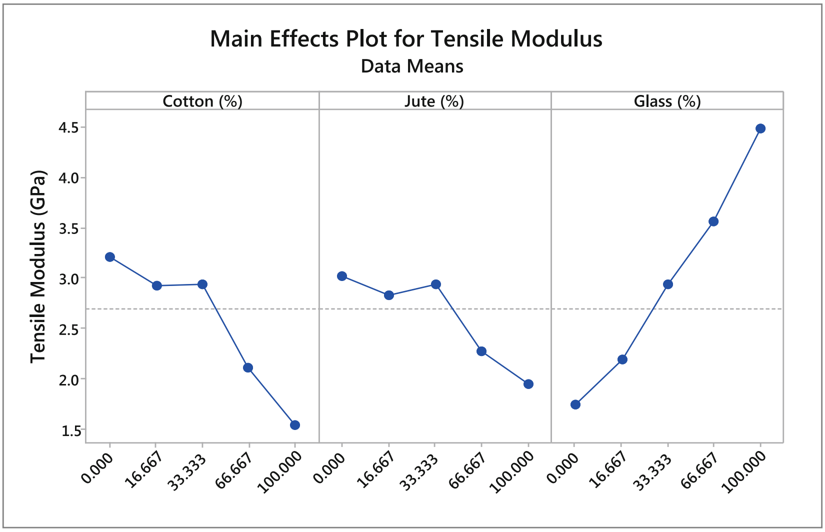

Fig. 5. Main effect plot tensile modulus

It is cleared from graph that slope of glass and cotton are steeper than jute. But the relation is inversed. Tensile modulus of composite samples is decreased by increasing the percentage of cotton. While modulus is increased by increasing the percentage of glass, because tensile strength of glass fibers are greater than cotton [31].

$$\text{Tensile Modulus (GPa)} = 1.52\,X_1 + 1.93\,X_2 + 4.46\,X_3 + 0.36\,X_1X_2 + 0.54\,X_1X_3 + 0.18\,X_2X_3$$

$$R^2 = 99.20\% \quad (2)$$

This regression equation showed a mathematical relationship between response (tensile modulus) and factors (percentages of reinforcing materials) where X_1, X_2, and X_3 are percentage of cotton, jute and glass respectively. Coefficient of determination (R^2) showed that X_1, X_2, and X_3 satisfied the given equation by 99.20%. Response (tensile modulus) is largely effected by the factor (reinforcing material) whose coefficient is more than other. So it is cleared from the equation that tensile modulus is largely effected by the factors X_3 and $X_1 \times X_3$.

3.3 Flexural Strength

Figure 6 showed a contour plot between flexural strength and different percentages of cotton, jute and glass in composite samples. This graph is divided into seven colored segments. Each segment is represented by a specific range of flexural strength from <20 MPa to >90 MPa. The highest range of flexural strength (>90 MPa) is represented by the darkest colored segment. Flexural strength of composite is effected by the percentage of reinforcing materials (cotton, jute and glass) that are showed by each corner of graph.

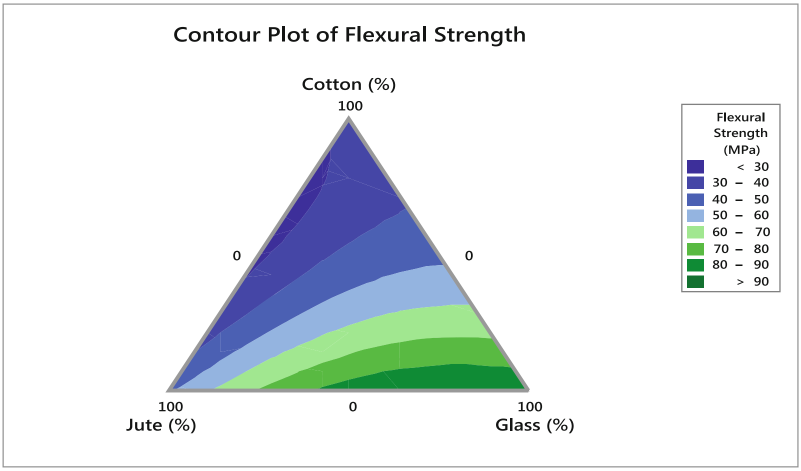

Fig. 6. Contour plot of flexural strength

It is clear from graph that composite having 100% cotton as reinforcing material, the flexural strength is laid in a range of 20 MPa because mechanical properties of cotton are lower than jute and glass [26]. A large change in flexural strength is not observed by using both natural fibers i.e. jute and cotton as reinforcing materials because mechanical properties of natural fibers are lower than glass fibers [30]. Flexural strength of hybrid composites having different percentages of cotton, jute and glass fibers is laid between 40–90 MPa. Composite having 100% glass fibers as reinforcing material has flexural strength more than 90 MPa because mechanical properties of glass are higher than cotton and jute fibers [11].

Figure 7 showed a main effect plot between percentages of reinforcing materials (Cotton, jute and glass) and flexural strength of composite samples. In main effect plot, the factor (reinforcing material) whose slope is steeper than others, imparted a large effect on response variable (flexural strength).

It is cleared from graph that slope of glass and cotton are steeper than jute. But the relation is inversed. Flexural strength of composite samples is decreased by increasing the percentage of cotton. While strength is increased by increasing the percentage of glass, because flexural strength of glass fibers are greater than cotton [31].

$$\text{Flexural Strength (MPa)} = 33.01\,X_1 + 48.93\,X_2 + 88.72\,X_3 - 51.37\,X_1X_2 - 51.07\,X_1X_3 + 64.25\,X_2X_3$$

$$R^2 = 99.77\% \qquad (3)$$

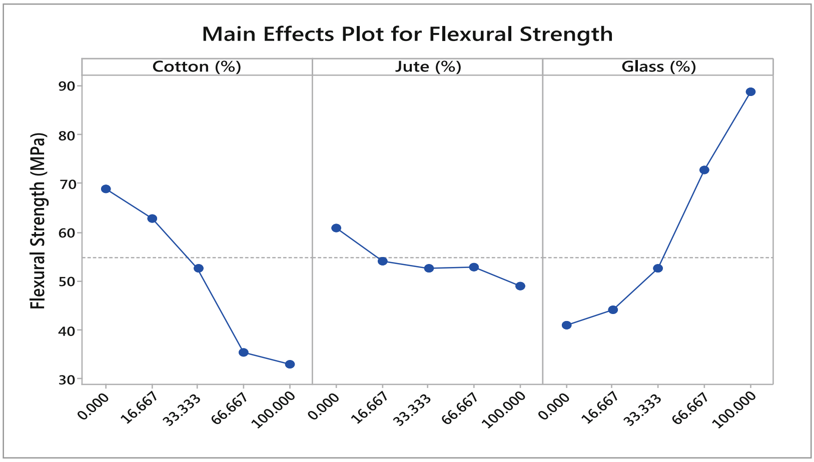

Fig. 7. Main effect plot flexural strength

This regression equation showed a mathematical relationship between response (flexural strength) and factors (percentages of reinforcing materials) where X_1, X_2, and X_3 are percentage of cotton, jute and glass respectively. Coefficient of determination (R^2) showed that X_1, X_2, and X_3 satisfied the given equation by 99.77%. Response (flexural strength) is largely effected by the factor (reinforcing material) whose coefficient is more than other. So it is cleared from the equation that flexural strength is largely effected by the factors X_3 and $X_2 \times X_3$.

3.4 Flexural Modulus

Figure 8 showed a contour plot between flexural modulus and different percentages of cotton, jute and glass in composite samples. This graph is divided into six colored segments. Each segment is represented by a specific range of flexural modulus from <1 GPa to >2 GPa. The highest range of flexural modulus (>2 GPa) is represented by the darkest colored segment. Flexural modulus of composite is effected by the percentage of reinforcing materials (cotton, jute and glass) that are showed by each corner of graph.

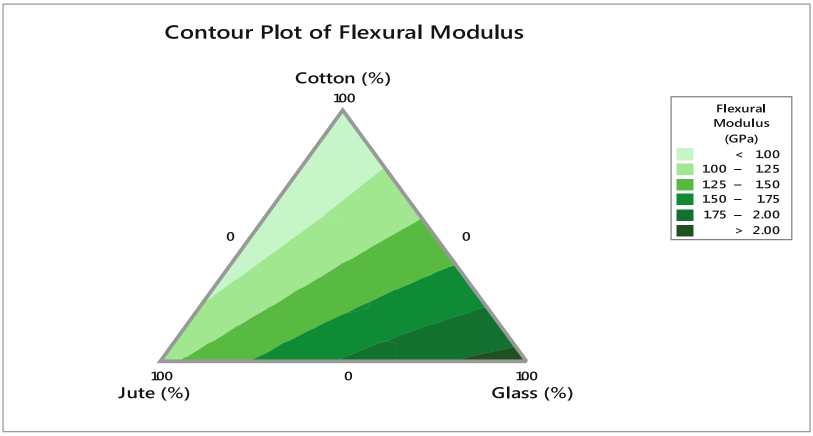

Fig. 8. Contour plot of flexural modulus

It is cleared from graph that composite having 100% cotton as reinforcing material has flexural modulus in a range of 1 GPa because mechanical properties of cotton are lower than jute and glass [26]. A large change in flexural modulus is not observed by using both natural fibers i.e. jute and cotton as reinforcing materials because mechanical properties of natural fibers are lower than glass fibers [30]. Flexural modulus of hybrid composites having different percentages of cotton, jute and glass fibers is laid between 1.5 to 2.0 GPa. Composite having 100% glass fibers as reinforcing material has flexural modulus more than 2 GPa because mechanical properties of glass are higher than cotton and jute fibers [11].

Figure 9 showed a main effect plot between percentages of reinforcing materials (Cotton, jute and glass) and flexural modulus of composite samples. In main effect plot, the factor (reinforcing material) whose slope is steeper than others, imparted a large effect on response variable (flexural modulus).

Flexural Modulus (GPa) = $0.76\,X_1 + 1.18\,X_2 + 2.10\,X_3 - 0.45\,X_1\,X_2 - 0.35\,X_1\,X_3 + 0.53\,X_2\,X_3$

$$R^2 = 99.98\% \tag{4}$$

This regression equation showed a mathematical relationship between response (flexural modulus) and factors (percentages of reinforcing materials) where X_1, X_2, and X_3 are percentage of cotton, jute and glass respectively. Coefficient of determination $\left(R^2\right)$ showed that X_1, X_2, and X_3 satisfied the given equation by 99.98%. Response (flexural modulus) is largely effected by the factor (reinforcing material) whose coefficient is more than other. So it is cleared from the equation that flexural modulus is highly effected by the factors X_3 and $X_2\,X_3$.

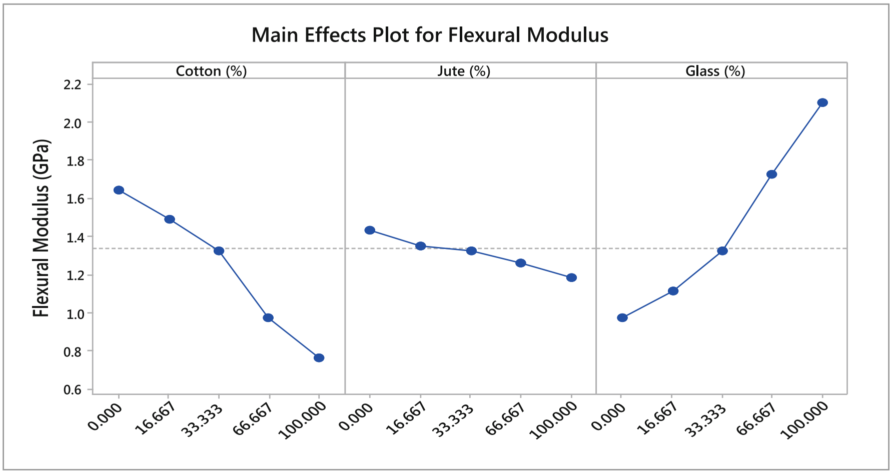

Fig. 9. Main effect plot flexural modulus

4 Conclusions

The study concluded that the tensile and flexural properties of the composites developed from waste material was found lower as compared to the glass fiber composites, while hybrid composites had comparable properties. Regression equations were also developed to predict the mechanical properties of the hybrid composites. The results revealed that, after some pre-treatment (mercerization and desizing) textile waste materials can be used with virgin material in reinforcement part of composite to decrease the cost but with optimum mechanical properties. This usage of textile waste will be helpful for its value addition and solving the waste disposal problems.

References

1. Mouritz, A.P., Bannister, M.K., Falzon, P.J., et al.: Review of applications for advanced three-dimensional fibre textile composites. Compos. Part A Appl. Sci. Manuf. **30**, 1445–1461 (1999)
2. Shah, D.U.: Developing plant fibre composites for structural applications by optimising composite parameters: a critical review. J. Mater. Sci. **48**, 6083–6107 (2013)
3. Taylor, P., Bhowmick, M., Mukhopadhyay, S., et al.: Mechanical properties of natural fibre-reinforced composites. Text. Prog. **44**, 85–140 (2012)
4. Abedin, M.Z., Beg, M.D.H., Pickering, K.L., et al.: Study on the mechanical properties of Jute/Glass fiber-reinforced unsaturated polyester hybrid composites: effect of surface modification by ultraviolet radiation. J. Reinf. Plast. Compos. **25**, 575–588 (2006)
5. John, M.J., Anandjiwala, R.D., Pothan, L.A., et al.: Cellulosic fibre-reinforced green composites. Compos. Interfaces, **14**(7–9), 37–41 (2012)
6. Chabba, S.: Composites get greener. Mater. Today **6**(4), 22–29 (2003)
7. Blicblau, A.S., Coutts, R.S., Sims, A.: Novel composites utilizing raw wool and polyester resin. J. Mater. Sci. Lett. **16**, 1417–1419 (1997)

8. Cheung, H., Ho, M., Lau, K., et al.: Natural fibre-reinforced composites for bioengineering and environmental engineering applications. Compos. Part B Eng. **40**, 655–663 (2009)
9. La Mantia, F.P., Morreale, M.: Green composites: a brief review. Compos. Part A Appl. Sci. Manuf. **42**, 579–588 (2011)
10. Zou, Y., Xu, H., Yang, Y.: Lightweight polypropylene composites reinforced by long switchgrass stems. J. Polym. Environ. **18**, 464–473 (2010)
11. Clark, R.A., Ansell, M.P.: Jute and glass fibre hybrid laminates. J. Mater. Sci. **21**, 269–276 (1986)
12. Short, D., Summerscales, J.: Hybrids—a review: Part 2. Physical properties. Composites **11**(1), 33–38 (1980)
13. Ashori, A., Nourbakhsh, A.: Bio-based composites from waste agricultural residues. Waste Manag. **30**, 680–684 (2010)
14. Fávaro, S.L., Lopes, M.S., de Carvalho Neto, A.G.V., et al.: Chemical, morphological, and mechanical analysis of rice husk/post-consumer polyethylene composites. Compos. Part A Appl. Sci. Manuf. **41**, 154–160 (2010)
15. Pfister, D.P., Larock, R.C.: Green composites from a conjugated linseed oil-based resin and wheat straw. Compos. Part A Appl. Sci. Manuf. **41**, 1279–1288 (2010)
16. Ahankari, S.S., Mohanty, A.K., Misra, M.: Mechanical behaviour of agro-residue reinforced poly(3-hydroxybutyrate-co-3-hydroxyvalerate), (PHBV) green composites: a comparison with traditional polypropylene composites. Compos. Sci. Technol. **71**, 653–657 (2011)
17. Reddy, N., Yang, Y.: Structure and properties of high quality natural cellulose fibers from cornstalks. Polymer (Guildf) **46**, 5494–5500 (2005)
18. Habibi, Y., El-Zawawy, W.K., Ibrahim, M.M., et al.: Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibers from Egyptian agro-industrial residues. Compos. Sci. Technol. **68**, 1877–1885 (2008)
19. Barone, J., Schmidt, W., Liebner, C.: Compounding and molding of polyethylene composites reinforced with keratin feather fiber. Compos. Sci. Technol. **65**, 683–692 (2005)
20. Lee, S., Cho, D., Park, W., et al.: Novel silk/poly(butylene succinate) biocomposites: the effect of short fibre content on their mechanical and thermal properties. Compos. Sci. Technol. **65**, 647–657 (2005)
21. Thakur, V., Singha, A., Thakur, M.: Biopolymers based green composites: mechanical, thermal and physico-chemical characterization. J. Polym. Environ. **20**, 412–421 (2012)
22. Kalia, S., Kaith, B.S., Kaur, I.: Pretreatments of natural fibers and their application as reinforcing material in polymer composites—a review. Polym. Eng. Sci. **49**, 1253–1272 (2009)
23. Shaker, K., Ashraf, M., Jabbar, M., et al.: Bioactive woven flax-based composites: development and characterisation. J. Ind. Text. **46**, 549–561 (2016)
24. Drennan, R.T.: Pakistan Cotton and Products Annual 2013 (2013)
25. Nazir, M.U., Shaker, K., Nawab, Y., Khan, M.I. Fazal, Z., Umair, M.: Investigating the effect of material and weave design on the comfort properties of bilayer woevn fabrics. J. Text. Inst. **108**(8), 1319–1326 (2017)
26. Mishra, R., Behera, B.K., Militky, J.: 3D woven green composites from textile waste: mechanical performance. J. Text. Inst. **105**, 460–466 (2014)
27. Nazir, M.U., Shaker, K., Ahmad, S., et al.: Investigating the mechanical behavior of composites made from textile industry waste. J. Text. Inst. **108**, 835–839 (2016). doi: 10.1080/00405000.2016.1193982. Epub. ahead of print 2016
28. Mandhakini, M., Devaraju, S., Venkatesan, M.R., et al.: Linseed vinyl ester fatty amide toughened unsaturated polyester-bismaleimide composites. High Perform. Polym. **24**, 237–244 (2012)

29. Hoto, R., Furundarena, G., Torres, J.P., et al.: Flexural behavior and water absorption of asymmetrical sandwich composites from natural fibers and cork agglomerate core. Mater. Lett. **127**, 48–52 (2014)
30. Thakur, V.K., Singha, A.S., Thakur, M.K.: Green composites from natural fibers: mechanical and chemical aging properties. Int. J. Polym. Anal. Charact. **17**, 401–407 (2012)
31. Husić, S., Javni, I., Petrović, Z.S.: Thermal and mechanical properties of glass reinforced soy-based polyurethane composites. Compos. Sci. Technol. **65**, 19–25 (2005)
32. Wang, S., Masoodi, R., Brady, J., et al.: Tensile strength and water absorption behavior of recycled Jute-Epoxy composites. J. Renew. Mater. **1**, 279–288 (2013)