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Investigation on Impact and Flexural Behavior of Polymer Composite Developed from Discarded Carpet

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ABSTRACT

In the 21st century, waste becomes the primary concern for the manufacturing sector and industries. The carpet and textile industry products are increasing in view of customer varying needs. This article highlights the development of polymer composites from waste carpets (Nylon). The Vacuum-assisted resin transfer molding method (VARTM) is used to infuse epoxy and hardener into the waste nylon carpet. The mixture is properly fused into the fibrous material without any blow holes and entrapping of air in a vacuum environment. It enhances the mechanical strength of the developed composites. The impact and flexural performance of the proposed polymer composites is investigated in this work. The outcomes of the developed carpet waste composites show the feasibility of lightweight structural applications. It can exhibit better shock load resistance and flexural than some conventional synthetic fiber polymer composites. This technique utilizes the carpet fiber sheets waste to manufacture composites with improved mechanical properties (Impact and flexural), ensuring recycling the waste carpet to overcome the environmental hazards.

Keywords: carpet, VARTM, composite, shock load, flexural strength

1. Introduction

Nowadays, waste becomes a severe issue for manufacturing industries. The carpet sector is proliferating due to varying requirements of comfort conditions and applications. The average life of the carpet is a maximum of five-seven years (Miraftab, Horrocks, & Woods, 1999; Singh & Dwivedi, 2020). After that, it converts into massive solid waste. A new method is required to develop for carpet recycling to reduce the problems generated through conventional techniques. Therefore, various studies and approaches toward recycling carpet waste were conducted, which is quite different. Numerous studies focus on composite fabrication by utilizing the waste carpet, which can be used in low structural applications. Besides, the different carpet waste processing options are explored, including waste to energy through Incineration, fiber reprocessing, carpet re-use, and plastics reprocessing. In recent studies, the development of composites using fabric waste has been explored for sound and heat applications (Pan, Zhao, Xu, Ma, &

Yang, 2016; Partha, G., Rathinamoorthy, & Ramachandran, 2000). There are various types of carpet waste, such as backing sheets, fibers, available in the garbage piles. Industries and environmental expertise are anxious about the decomposition of such kinds of carpet wastes. Various pioneer scholars are working on recycling carpet waste and its utilization in the development of some products. In this series, Yang et al. (Xuan, Chen, Yang, Dai, & Chen, 2018) analyzed the effect of various parts of carpet waste by adding to the cement mortar. The findings reported that the addition of carpet face fibers was more feasible for improving mortar impact behavior. It was also found that the reinforcing effect of face fibers was more prominent at higher temperature or higher impact pressure. Some parts of the carpet revealed a negative effect on the impact resistance irrespective of the temperature variation. The microstructure and the pore distribution of mortar were significantly improved, which favors a change in residual strength. Wang et al.(Ucar & Wang, 2011) carried out a comparative examination of the impact strength between GFRP and sisal fiber composite. They were analyzed that developed composite can be utilized as an alternate material over the traditional materials. This work suggests that the polymer composites required features could be altered using jute fibers and explored the possibility of using carpet waste jute yarn to enhance the physical and mechanical properties of fiber-reinforced composites. Jute yarn was treated with 25 wt.% NaOH solution to enhance the fiber-matrix interface. Carvalho et al. (Laranjeira, De Carvalho, Silva, & D'Almeida, 2006) examined the compression behavior of wool and acrylic hand-tufted tapestries using varying compressive load. Wool tapestries demonstrate higher compression and recovery than similarly crafted acrylic tapestries. It diminishes the compression and mates with a rise in pile density. Due to the improved compression period, the percentage of the recovery of the tapestries has improved. The efficiency, aesthetics, and durability of the carpet are highly affected by the repeated loads. The efficiency of the cyclic compression load is evaluated in terms of decrease, restoration, and matting. The composition of the stack yarns and the tapestry building parameters significantly influence the carpet quality. Based on the outcomes, the wool carpet is more efficient the acrylic for compression behavior. Mishra et. al.(Mishra & Vaidyanathan, 2019) developed the lightweight components for tooling material from post-consumer carpet waste. A little addition of 5. % by weight of graphene nanoplatelets is used as filler material to improve the strength features. The proposed composite validates consistent hardness and compression results based on the number of cure cycles. The fabrication costs in this method are about the same as those of instruments made from the critical cost estimates of epoxy and polyurethane resins. Sotayo et.al. (Sotayo, Green, & Turvey, 2018)discussed an exhaustive literature survey on the recycling of waste carpets. The study summarized that the re-use of carpets could be the most cost-efficient and environmentally friendly approach. It is related to substantial savings in raw materials and energy consumption; however, it is viable for certain types of carpet waste and necessitates proper processing centers. Mohit et al. (Mohit et al., 2021) explore the several advantages to natural fibers: low density, low cost, ecological, biodegradable, and high mechanical efficiency. The study fabricated the epoxy composites modified by randomly oriented short jute fiber to boost the bending and impact properties. The findings conclude that the flexural and impact characteristics are improved by jute fiber and tensile were remain constant.

The exhaustive literature review demonstrates the feasibility of the carpet waste application to develop composites and other manufacturing products. It has been remarked that the waste generated from the carpet industry is very harmful to the environment and its decomposition is very costly and detrimental for ecology. It can be reutilized or recycle for the development of products. But, a very limited study is available on the fabrication of polymer composites from carpet waste. This work targets the lightweight structural application through carpet waste composites. The impact and flexural performance of the developed composites is estimated in this work. A modified manufacturing method is used in a vacuum environment for the development of samples. (Mohammadhosseini, Abdul Awal, & Mohd Yatim, 2017)The sample was tested using ASTM standards to evaluate the application potential for end-use. An attempt has been used to utilize recycled carpet waste.

2. Materials and Methods

The waste carpet pieces changed into the size of $30\, mm \times 30\, mm$ to use in the VARTM setup. The carpet pieces' backing is combined to obtain the back fiber to fiber back (BFFB) configuration. At the starting step, a release agent (silica gel) is spread over the surface to remove the developed specimen firmly from the bottom surface. This configuration is placed into the vacuum bagging at the silica gel surface of the glass table. A vacuum mold is created with the help of a porous sheet and tacky tape. The inlet at atmospheric pressure and the outlet at the compressor side were offered in the mold setup. First, the air inside the mold was expelled out by running a vacuum pump to make the mold air-free or perfect vacuum. The resin was then allowed to infuse into the preform prepared. The driving force and suction force were formed by 1 atm pressure created by the vacuum pump for proper infusion of resin motion into the mold. After this, the samples inside the bagging are under the mixture flow and completely spread the mixture into the mold. Both ends of the suction and outlet pipe are remained clamped for proper curing in 24 hours. The polymerization time of the mixture for Diglycidyl ether of bisphenol A, Lapox (L-12) resin with Tri-ethylene-tetra-amine, K-6 hardener was used as described in Figs. 1. (a-c). For preparing a $30\, mm \times 30\, mm$ size composite sample, a blend of 400 ml epoxy with a 40 ml hardener is well mixed through the manual stirring process.

Figure 1. (a) Mold release agent, (b) Tacky tape, and (c) VARTM Setup

2.1 Charpy Test for Specimen

The impact performance of developed samples was investigated using the Charpy test. These samples were tested destructively with the Charpy Impact tester, as displayed in Fig. 2 (a). The Charpy test is used to measure the amount of energy that the sample absorbs until fracture—one of the most common tests used in evaluating relative toughness in a fast. Depending upon the sample shape and size, a notch is made to increase the sample's stress concentration. Afterward, the sample is breaks, and the failure mode is presented in Fig. 2 (b). It is generally avoided to make a notch for the pieces having very low strength.

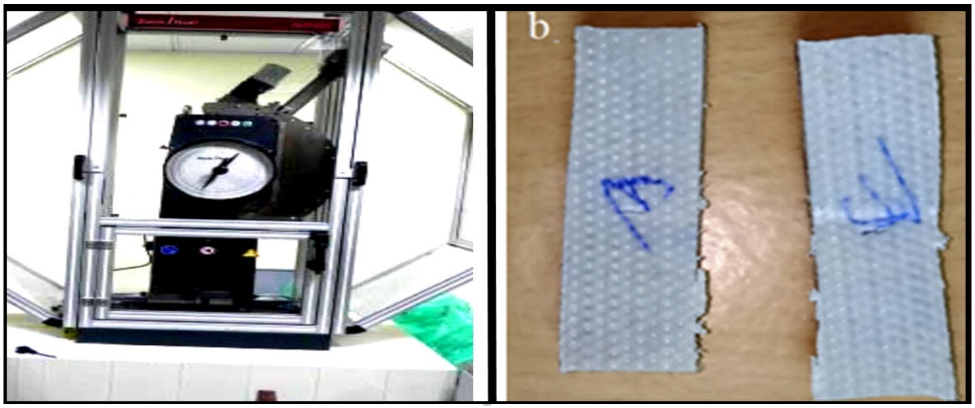

Figure 2. (a) Pendulum Impact Tester and (b) Undeformed Samples for Charpy Test

The dimension 55 mm ×10 mm ×10 mm of the sample was taken according to ASTM D4812 (Navaranjan & Neitzert, 2017). No notch was prepared for these samples, and it is tested in a flat mode in the form of the simply supported beam on the Pendulum impact tester (PSW 750). The hammer strikes the sample at the lateral side facing the BFFB. The swing of the striking hammer shows the amount of energy absorbed by the test piece. The larger the amount of swing by the hammer lesser the energy absorbed by the test piece. The amount of energy released during the sample fracture depends mainly on the difference between the hammer swing's initial and final heights. The collision is triggered by using a pendulum from the maximum height ho against the test sample. When the hammer is released, it swings through an arc, strikes the test sample, and, after fracturing, returns to a height hf. Once the pendulum falls, each impulse were recorded until the trajectory of the pendulum is reversed. The observed change in the initial energy and the retained energy signifies a gauge of the energy needed to fracture the test sample. This quantity is called absorbed energy in the Charpy test, and is represented by E_{total}.

To calculate the total amount of absorbed energy following formula is used:

$$E_{total} = mg(h_o - h_f) \qquad (1)$$

Here,

E_{total} = Total amount of energy absorbed,

m = Mass of the hammer,

g = Acceleration due to gravity,

h_o = Initial height of the hammer,

h_f = Final height achieved after striking the sample.

2.2 Flexural Test for Specimen

Flexural tests were performed on three different test pieces of the same dimension and material, and accordingly, three readings were found. To perform the flexural test, the required dimension for testing of the composite was made to cut by ASTM D790 standard. The dimension was 60x20x10 mm, and its cross-sectional area was 60x20 mm. The machine used in this testing was having a maximum capacity of 10 KN and the strain rate was 2 mm/min. The most common purpose of the flexural bending test is to determine flexural strength and flexural modulus. The flexure test method indicates the nature of the sample or job subjected to simple beam loading. This test is also known as the transverse beam test in the case of some materials. For increments of load, maximum fiber strain and stress are evaluated. The results of this test are plotted on a load versus deformation diagram. Flexural strength is equal to the maximum stress generated in the sample's outermost fiber at the time of the flexural test. It is evaluated at the convex or tension surface of the specimen. The slope of the stress vs. deflection curve gives the flexural modulus of the sample. In the case of the linear curve absence, a secant line can be fitted to the curve to obtain the slope. The 3-point bending test setup and after the test sample is present in Figs. 3 (a-b).

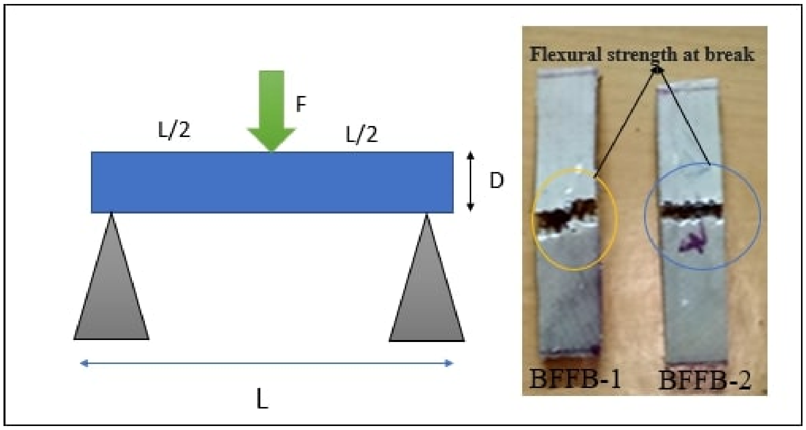

Figure 3. Arrangement for Flexural Test (a) Demonstrating the 3-point Bending Test (b) BFFB Fractured Samples

The 3-point bending test is the most used test for calculating the flexural strength of polymers. The crosshead movement generally measures the deflection of the specimen. This test can easily evaluate flexural strength and flexural modulus. Flexural strength can be obtained from the following formula given in equation 2.

$$\sigma = \mathrm{F \times L} = \frac{3PL}{2bd^2} \quad (2)$$

where:
σ= flexural strength (N/m^2)
F= maximum peak load (N)
L= distance between load points (mm)
b= sample width (mm)
d= sample thickness (mm)

In this analysis, a sharp-edged instrument is used to perform a 3-point bending test and sample was prepared according to the ASTM D790 standard. This method is used to evaluate the flexural properties of reinforced and non-reinforced plastics. According to this standard specimen should be solid and uniformly rectangular. First, the sample was mounted as an overhanging beam and deflected below the constant 2 mm/min crosshead displacement rate. The 10 percent of the span length on both sides was drawn from the overhang and the load was added centrally to the sample. The deflection that occurred during the load application was reported before the matrix and bottom fibers collapsed. The sharp-edged tool depth penetration was also reported.

3. Results and Discussion

3.1 Analysis of Charpy Test (Impact Strength)

In this study, the Charpy test is executed by allowing the hammer to use its nominal initial potential energy up to 85%. The pendulum hammer's size is based on the assumption that loss of speed during sample testing should be kept as minimum as possible (Onal & Karaduman, 2009). During the test, the hammer is pre-loaded to standard height and released. The amount of absorbed energy is registered in the device's database, equivalent to the swingarm's farthest travel. This absorbed energy in joules is equal to the difference between the hammer's initial position and the finishing position. The impact velocity of the hammer was kept at 5.2 m/s with a hammer weight of 10.95 kg. Both the test samples were partially broken after Charpy test. The average values of absorbed energy recorded in Charpy test for BFFB-1, BFFB-2 was 0.7521J and 0.8883 J, respectively tabulated in Table 1.

Table 1. Calculation of Impact Strength and Impact Modulus

Sample No.	Actual energy absorbed (E_{total}) Joules	Impact strength (I_S) I_S=E/a (kJ/m^2)	Impact modulus (I_m) = Impact Energy/ Volume of sample
BFFB-1	0.7521	7.5212	0.0001367
BFFB-2	0.8883	8.8830	0.0001615

Figs. 4 (a-b) illustrates the graph of Work versus Standard travel (mm) for BFFB-1, BFFB-2, respectively. The graphs of samples 1 and 2 demonstrate that while the hammer travels 3.45 mm the work is 0.397 Joules. But at the travel arc length of 10.25 mm, the work done by the hammer is 0.53 Joules for sample 1 and 0.708 Joules for sample 2. The main difference that can be visualized from the above graph is that the maximum standard travel for sample 2 is larger than the standard travel for sample 1. The approximate linear line between 0 and 5 mm indicates the jerk produced at the time of hammer strike. The average values recorded of both the samples were: E_{total} = 0.8202 J and *Impact strength* (I_S) = 8.2021 kJ/m2 in the Charpy test. These observations demonstrates that within short travel of hammer, the work done is large. The linear straight line indicates the hammer's return to its initial position having no obstacles or resistance in its way. The above results demonstrate that energy absorbed and impact strength for composite sample 2 have a larger value than sample 1. In this configuration of composite, it strikes the PVC backing of the sample. Furthermore, the carpet has been designed to sustain the compressive load and shear load, so it quickly falls in impact load testing.

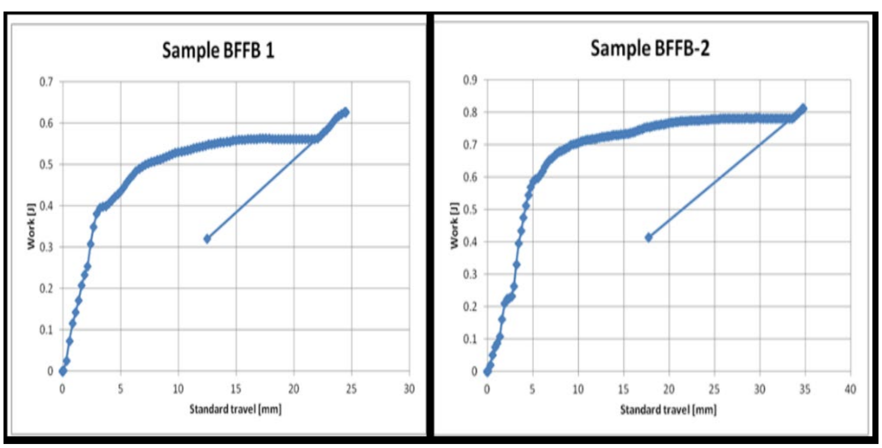

Figure 4. (a-b) Charpy Test: Amount of Energy Absorbed in Joule with their Standard Travel in mm

3.2 Analysis of 3-point Bending Test (Flexural Strength)

The three-point bending test characterizes the behavior of a rectangular-shaped sample subjected to the perpendicular load applied to the longitudinal axis of the sample. In this test, flexural stress is generated in the convex side of the sample and strain-stress in the concave side. (Pan, Zhao, Xu, Hou, & Yang, 2016) This stress, in this way, creates an area of shear stress along the midline. Shear stress must be minimized while ensuring the primary failures evaluate from flexural stress. This can be possible by considering the span to depth ratio in a proper manner. Under 3-point loading conditions, this measure tests the force needed to bend a beam. In this test, two parallel supports are mounted on rectangular or flat-crossed specimens that allow free rotation around an axis parallel to the pin axis and the specimen axis. In this analysis, flexural strength was evaluated, which also differed commonly with width, span length, and temperature, but here the sample thickness remains constant and span length also remains constant. Form Fig. 5, the initial test run shows a sharp rise in the load with a minimum crosshead and soon after, this converts to a large crosshead distance with no increase in the load applied. This happens because of a weak backing surface, which allows the sharp-edged tool to penetrate its surface easily. In this, every sample has a sharp peak demonstrate that fiber fractured quickly after rupturing of epoxy. It showed the approximate sharp peak for the first sample and zigzag peak for the last samples during the rupture. From Fig. 5. We found that maximum load was sustained by sample 2 (Sotayo, Green, & Turvey, 2015). The possible reason for this difference in peak load could be the non-uniform penetration of epoxy inside the sample and bonding of the fibers. In Fig. 5. Sample-1 has an exception of wavy peak show difference of peak load within short deformation. It is because of the yielding of the material when its reinforcing fibers fracture in random order and in a non-uniform way. In the first sample, there is no wave neither yielding phenomenon occurs, but it just broken in a brittle manner, demonstrated the strong bonding and affinity among the fibers with the matrix material. After rupture of the lower or tensile surface of the specimen backing, the remaining load is resisted by the upper surface and its fibers. Both the test samples were partially broken after the bending test. The average values of flexural strength calculated in the test for BFFB-1, BFFB-2 were 28.245 and 22.570 MPa, respectively (Table 2). The average values of flexural modulus calculated in the test for BFFB-1, BFFB-2 were 0.051 and 0.057 GPa.

Table 2. Calculation of 3-point Bending Strength and Flexural Modulus

Sample No.	Flexural strength (MPa)	Flexural modulus (GPa)
BFFB-1	22.570	0.057
BFFB-2	28.245	0.051

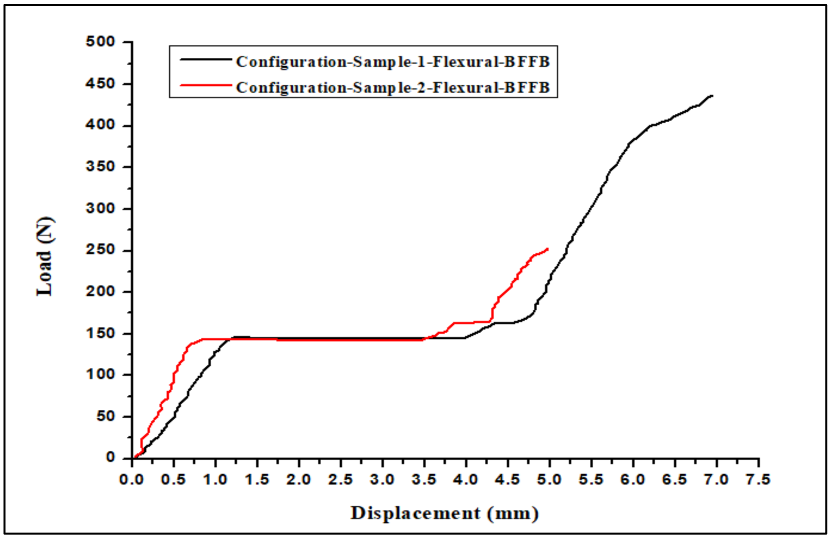

Figure 5. Flexural Test Result

4. Conclusion

This paper focuses on the development of polymer composites from waste nylon carpets. The epoxy and hardener mixture is infused into the waste carpets samples through a modified and effective method (VARTM). Based on obtained results, the following conclusion can be drawn:

- In a vacuum environment, the dispersion of the mixture is uniform without any blowholes and other failures. The impact and flexural performance of the proposed polymer composites samples is examined through the Charpy test and 3-point bending test, respectively. The improper infusion of epoxy at the time of fabrication made the composite weaker and explained low strength composite.
- In the Charpy test case, BFFB configuration samples were tested to find the impact strength from absorbed impact energy values. The values of the absorbed energy in Joule for F1, F2 were 1.6912 J and 1.8319 J, respectively. The samples' impact strength is noticed as 16.9128 KJ/m2 and 18.3198 KJ/m2, respectively.
- The backing got damage at certain places, so it also contributes to the composite lesser strength. The improper infusion of epoxy at the time of fabrication made the composite weaker, maybe explaining low strength composite. The waste carpet and torn fibers at various places cannot give the uniform strength in all the directions of the composite. The outcomes of the impact and flexural test show the feasibility of proposed composites in light structural applications.

The outcomes suggest that the achieved strength and impact behavior can be used for lightweight structural components. There is much work left to be done in the field of management of waste products. The proposed samples can be endorsed for light structural functions, decor items, wall tiles, etc. The addition of other types of hardener and filler materials can improve the proposed carpet waste composite impact and flexural performance

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest.

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References

Laranjeira, E., De Carvalho, L. H., Silva, S. M. D. L., & D'Almeida, J. R. M. (2006). Influence of fiber orientation on the mechanical properties of polyester/jute composites. Journal of Reinforced Plastics and Composites, 25(12), 1269–1278. https://doi.org/10.1177/0731684406060577

Miraftab, M., Horrocks, R., & Woods, C. (1999). Carpet waste, an expensive luxury we must do without! Autex Research Journal, 1(1), 1–7. https://doi.org/10.1533/9780857092991.3.173

Mishra, K., & Vaidyanathan, R. K. (2019). Application of recycled carpet composite as a potential noise barrier in infrastructure applications. Recycling, 4(1). https://doi.org/10.3390/recycling4010009

Mohammadhosseini, H., Abdul Awal, A. S. M., & Mohd Yatim, J. B. (2017). The impact resistance and mechanical properties of concrete reinforced with waste polypropylene carpet fibres. Construction and Building Materials, 143, 147–157. https://doi.org/10.1016/j.conbuildmat.2017.03.109

Mohit, H., Sanjay, M. R., Siengchin, S., Khan, A., Marwani, H. M., Dzudzevic-Cancar, H., & Asiri, A. M. (2021). Effect of TiC Nanoparticles Reinforcement in Coir Fiber Based Bio/Synthetic Epoxy Hybrid Composites: Mechanical and Thermal Characteristics. Journal of Polymers and the Environment. https://doi.org/10.1007/s10924-021-02069-7

Navaranjan, N., & Neitzert, T. (2017). Impact Strength of Natural Fibre Composites Measured by Different Test Methods: A Review. MATEC Web of Conferences, 109. https://doi.org/10.1051/matecconf/201710901003

Onal, L., & Karaduman, Y. (2009). Mechanical characterization of carpet waste natural fiber-reinforced polymer composites. Journal of Composite Materials, 43(16), 1751–1768. https://doi.org/10.1177/0021998309339635

Pan, G., Zhao, Y., Xu, H., Hou, X., & Yang, Y. (2016). Compression molded composites from discarded nylon 6/nylon 6,6 carpets for sustainable industries. Journal of Cleaner Production, 117, 212–220. https://doi.org/10.1016/j.jclepro.2016.01.030

Pan, G., Zhao, Y., Xu, H., Ma, B., & Yang, Y. (2016). Acoustical and mechanical properties of thermoplastic composites from discarded carpets. Composites Part B: Engineering, 99, 98–105. https://doi.org/10.1016/j.compositesb.2016.06.018

Partha, G., T., Rathinamoorthy, R., & Ramachandran, T. (2000). Journal of textile and apparel technology and management : JTATM. Journal of Textile and Apparel, Technology and Management, 9(3), 1–12.

Singh, G., & Dwivedi, S. K. (2020). Decolorization and degradation of Direct Blue-1 (Azo dye) by newly isolated fungus Aspergillus terreus GS28, from sludge of carpet industry. Environmental Technology and Innovation, 18, 100751. https://doi.org/10.1016/j.eti.2020.100751

Sotayo, A., Green, S., & Turvey, G. (2015). Carpet recycling: A review of recycled carpets for structural composites. Environmental Technology and Innovation, 3, 97–107. https://doi.org/10.1016/j.eti.2015.02.004

Sotayo, A., Green, S., & Turvey, G. (2018). Development, characterisation and Finite Element modelling of novel waste carpet composites for structural applications. Journal of Cleaner Production, 183, 686–697. https://doi.org/10.1016/j.jclepro.2018.02.095

Ucar, M., & Wang, Y. (2011). Utilization of recycled post consumer carpet waste fibers as reinforcement in lightweight cementitious composites. International Journal of Clothing Science and Technology, 23(4), 242–248. https://doi.org/10.1108/09556221111136502

Xuan, W., Chen, X., Yang, G., Dai, F., & Chen, Y. (2018). Impact behavior and microstructure of cement mortar incorporating waste carpet fibers after exposure to high temperatures. Journal of Cleaner Production, 187, 222–236. https://doi.org/10.1016/j.jclepro.2018.03.183