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Review Article

Selected Research Briefs on the Fabrication of Value-Added Composites Using Recycled Textile Waste as Reinforcement Material

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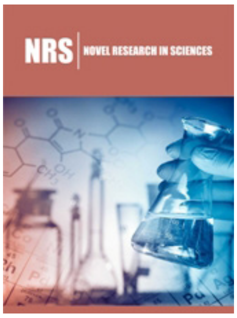

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Abstract

The main findings of a select group of research publications which focused on the use of recycled textile waste as reinforcements in fiber-polymer composites are summarized in this paper. The summary covers the use of recycled fibers, yarns, fabrics and garments as reinforcement materials and common commodity polymers as matrices. It also briefly talks about the fabrication techniques used and provides a highlight of the property enhancements, perceived need for further improvement of select properties and the potential applications of the fabricated composites. The main objective in preparing this summary is to provide useful, easily accessible and readily understandable information in one place so that interested entrepreneurs around the globe can work to expand the composite manufacturing industry, especially that of affordable composites that use recycled textile waste as reinforcement material.

Introduction

The use of natural fibers as reinforcement materials in composites has received much attention due to environmental concerns and the potential offered by the fibers to improve the composite properties. The development of new methods for production of thermoplastic composites with natural fiber reinforcement is of great interest to multiple sectors of the manufacturing and engineering industries. Textile industry produces a huge amount of residue and some of it is poorly managed. Cotton yarn mills produce waste in the shape of fiber flocks with lengths smaller than 10mm. The short length prevents their reintroduction in the textile manufacturing process. Such short fiber waste can be used as reinforcement material in composites made through the injection molding process. Discarded yarns, fabrics and garments can be recycled as reinforcements in a number of polymer composites. In some cases, pre-cleaning of garments and simple layering or alignment of garments may be needed. The use of compatibilizers may also be needed, depending on the end use of the composite and the type of polymer used as matrix material. In most cases, the resulting composites can be expected to show improvement in mechanical and thermal insulation properties.

Inexpensive Fiber-Reinforced Polypropylene Composites

Wei and his associates [1] used discarded denim fabric to enhance the mechanical and thermal properties of cotton-polypropylene composites. Composites with different fiber weight fractions were designed using hand-layup and hot press method. Tensile and impact strengths, and flame-retardant properties of the composites were investigated and their morphology was studied using scanning electron microscopy. It was observed that with a high fabric weight of 84%, the structural integrity and good mechanical behavior of denim fabric gets translated into good tensile strength and impact strength of the fabricated composite. Tensile strength improvement up to 57MPa and impact strength improvement up to 5.1J/mm were observed. In addition, the flame-retardant properties of the composites were modified by three methods. Composites composed of flame-retardant-modified denim fabric exhibited a limiting oxygen index value of 27.3% while composites made by using flame-retardant PP and flame retardant denim fabric showed a limiting oxygen index of 28.7%. It was felt that the improvement in the mechanical behavior and flame retardant behavior would make the composites preferable for automotive interior and general engineering applications. Baccouch & co-workers [2] attempted to enhance the fiber-matrix interface of cotton waste reinforced composite panels by pre-treating fabrics with sodium hydroxide. Cotton waste fibers were treated with sodium hydroxide (NaOH) solution of three different concentrations (0.5M, 1M, and 1.5M). Also, three different soaking times (1h, 3h, and 5h) were used. Mechanical evaluation of treated and untreated reinforcements and composite panels was achieved through standard tensile tests while the chemistries of fiber reinforcements were investigated using Fourier-transform infrared spectroscopy. The fiber-matrix interactions were examined using scanning electron microscopy. Results indicated a remarkable enhancement in mechanical properties of composites made from NaOH treated fibers. The young's modulus of the treated fibers showed an improvement of up to 270% while that of the corresponding composites showed an improvement of 70%.

In one study [3], researchers produced composite panels using waste denim garment as the reinforcement material and recycled polypropylene/polyethylene beverage containers as the matrix material. The composite panels were evaluated for their mechanical properties and also thermal and acoustic insulation behavior. Results showed that the composite panels can be used as support materials with improved thermal and acoustic insulation properties. Sound transmission loss of up to 8 dB and improved thermal resistance were demonstrated. It was felt that the flame retardancy of the composite panel can be improved through appropriate pretreatment of the garments. Kim et al. [4] compared the properties of composites made with cotton fiber and wood fiber as reinforcing materials in polypropylene-natural fiber composites. The effect of the melt index of PP on the mechanical properties of the composites was also investigated. In order to improve the poor interfacial interaction between the hydrophilic natural fibers and the hydrophobic PP matrix, Maleic Anhydride (MAH) grafted PP (PP-g-MAH) was used as a compatibilizer. As expected, the tensile strength of the PP-wood fiber composites showed a decrease with increasing weight % of the wood fibers, whereas that of the PP-cotton fiber composites showed a different behavior. It was observed that to achieve strength improvement of the composite, at least 20% by weight of the reinforcing fiber was needed. For the PP/wood fiber composites, the Melt Flow Index (MI) of PP was also found to be a key factor governing the mechanical properties (tensile and flexural strengths). The use of PP-g-MAH was helpful to increase the tensile and flexural strengths of the PP/cotton fiber and PP/wood fiber composites, due to the increased interaction between the fiber and PP matrix.

In another piece of research work [5], composites of polypropylene and raw cotton fabric were fabricated by hot pressing alternating layers of polypropylene films and cotton fabric to produce a long fiber oriented composite material. Five combinations with different number of reinforcements and matrix layers were prepared, leading to composites with more than 50% of fiber in volume. Characterization of the composites showed a great enhancement of mechanical properties (85% improvement in elastic modulus and 90% in tensile strength) with a density decrease of around 15%. The yarn loops and interlacements of the cotton fabric enhanced adhesion to the matrix through mechanical anchoring, as is observed by SEM. This enabled increased thermal stability and an increase in the storage modulus determined by DMA in the rubbery plateau. The good mechanical properties were explained by the mechanical anchorage of fiber matrix, since PP resin is forced to flow through the fibers of the raw cotton fabric. The resultant composite was stronger, lighter, and stiffer with approximately 50% of weight derived from renewable sources.

Hoque and his team [6] investigated, the mechanical properties of Polypropylene (PP)/natural fiber composites. For the natural fiber component of the composites, cotton fiber was compared with wood fiber. The effect of the melt index of PP on the mechanical properties of the composites was also investigated. In order to improve the poor interfacial interaction between the hydrophilic natural fibers and the hydrophobic matrix PP, Maleic Anhydride (MAH) grafted PP (PP-g-MAH) was used as a compatibilizer. The tensile strength of the PP/wood fiber composites decreased with increasing weight % of the wood fibers. Whereas that of the PP/cotton fiber composites displayed a different behavior. It was observed that to achieve improvement in strength of the composite, at least 20% by weight of the reinforcing fiber was needed. For the PP/wood fiber composites, the Melt Flow Index (MI) of PP was also found to be a key factor governing the mechanical properties (tensile and flexural strengths). The use of PP-g-MAH was helpful to increase the tensile and flexural strengths of the PP/cotton fiber and PP/wood fiber composites, due to the increased interaction between the fiber and PP matrix. Zou and his associates [7] investigated the feasibility of producing PET/cotton fabric composites through compression molding. The influence of plasticizers on mechanical properties of composites was investigated. PET/cotton composites without plasticizers provided 153% higher modulus of elasticity, 36% higher Young's modulus, similar impact resistance but 17% lower flexural strength and 44% lower tensile strength as compared similar weight pure PET sheets.

Fiber-Reinforced Biodegradable Composites

Li & his coworkers [8] focused on developing fully degradable composites using biodegradable polymer matrices [Poly Lactic Acid-PLA, and Cellulose Acetate-CA] as matrices and alkali treated cotton fabrics as reinforcements. The alkali treatment compacted the cotton fabrics and enhanced their tensile strength by 18.4%, roughened the fiber surface and made the fabric more hydrophilic. After the treatment, the composites showed 10% improvement in tensile strength, 36-67% increase in tensile moduli, 28–40% increase in flexural strength and 42–52% improvement in flexural moduli. Compared to the PLA composites, the treated cotton fabric-cellulose acetate composites displayed larger improvement in their properties due to better interfacial bonding between fabrics and the hydrophilic polymer. Peel strength of the later composite increased by 43%, thus demonstrating enhanced interfacial bonding. The stronger interfacial adhesion also prevented the invasion of microorganism and feculence and reduced the degradation rate of the CA composites in the soil. However, the hydrophilic nature made the CA composites more vulnerable to degradation in water. Considering the low cost, biodegradability and acceptable properties for several applications, the authors felt that the work demonstrated an approach to promote environmentally friendly and sustainable reuse for discarded cotton garments.

The work of Battegazzore, et al. [9] measured the thermo-mechanical behavior and impact properties of bio-polymer composites reinforced with multilayered cotton fabric. The suitability of the composites was assessed for building construction, furniture design and automotive interior applications. The measured properties were compared to that of other composites with similar natural fabric content and also to recommended international standards. Flexural properties of PLA composites fully satisfied the requirements for heavy duty load-bearing boards in humid conditions (EN 312 standard), while the PHB copolymer composites satisfied the load-bearing conditions under normal ambient conditions. Heat Distortion Temperature (HDT) analysis using dynamic mechanical analyzer revealed substantial increase (+53 °C) in the temperature for PHB composites which effectively reached 123 °C, potentially extending application to automobiles. Charpy impact strength of PHB composites was also measured. One of the highest values reported in the literature (54.5kJ/m2) was reached with PHB, superior to what is commercially used for the interior parts of cars. Furthermore, an epoxy functional additive used in fabrication was found to reduce the void content and increase the flexural properties and impact strength of the composite.

Miscellaneous Composites Using Natural Fiber Reinforcements

The work of Alomayri & his associates [10] measured the thermal, mechanical and fracture behavior of fly-ash based geopolymer composites reinforced with cotton fabric (0 to 8.3% by weight). Results revealed that fly-ash based geopolymer can prevent the degradation of cotton fabric at elevated temperatures. The effect of cotton fabric orientation to the applied load on flexural strength, compressive strength, hardness and fracture toughness of geopolymer composites was also investigated. The results showed that when the fabrics were aligned in the direction of loading, higher load and greater resistance to deformation were achieved. Karkova et al. [11] studied the elastic properties of reinforcing materials (cotton yarn and a plain knit fabric) and that of the polymer composite materials reinforced by them. Elastic properties were found to depend on yarn and fabric orientations with respect to the direction of loading. The properties also showed dependance on the load span used. Calculated elastic properties of composite materials have shown high agreement with experimentally obtained values.

Hybrid polymer matrix composites of waste cotton fabric and wood saw dust reinforcements were studied by another group of researchers [12] with a view to recycling the wastes from textile and wood processing industries. Polymer composites with cotton fabric and wood-saw-dust reinforcements were fabricated using hot press machine. Their physical, thermal and mechanical behaviors were discussed in terms of moisture absorption, thermal stability, tensile strength, elastic modulus, flexural strength and flexural modulus. Compositional analyses of fibers, matrix and composites was carried out with FTIR spectroscopy. Experimental results revealed that tensile and flexural strength of the composites increased with cotton fabric reinforcement. On the other hand, with increasing wood saw dust strength decreased up to a certain limit and then increased again. Water absorption of the hybrid composites increased substantially with increasing natural filler contents. Maximum water absorption was observed in 20% fabric/wood-saw-dust reinforced polymer composite. Furthermore, TGA graphs suggest better thermal stability of the hybrid composites than that of pure polypropylene. In a study conducted by Bodur & his coworkers [13], the benefits of adding glass fibers to cotton fibers to produce hybrid composites was explored. Glass fibers in different ratios of 2.5, 5 and 10% by weight were added to cotton fiber loadings maintained at of 12.5% and 25% by weight. To achieve better interfacial bonding and improve the effectiveness of glass fiber on the mechanical properties, maleic anhydride coupling agent was added to the mix. Identification of optimal ratios of maleic anhydride, cotton and glass fiber for this kind of composite was explored while giving enough consideration to economic factors and mechanical properties. This study showed that hybridization is one of the promising ways to improve the mechanical properties of novel composite materials.

Geopolymer composites reinforced with different layers of woven cotton fabric were fabricated using lay-up technique in the work of Alomayri, et al. [14]. Mechanical properties, such as flexural strength, flexural modulus, impact strength and fracture toughness of geopolymer composites reinforced with 3.6, 4.5, 6.2 and 8.3% by weight of cotton fibers were studied. The fracture surfaces of the composites were examined using scanning electron microscopy. Results showed that all the mechanical properties of the composites register improvement with increasing fiber content. It was found that the mechanical properties of cotton fabric reinforced geopolymer composites are superior to that of pure geopolymer matrix. In their study, Aruchamy & coworkers [15] used two different woven fabrics (100% cotton woven fabric having cotton yarn in both warp and weft directions and cotton/bamboo woven fabric with cotton yarn in warp direction and bamboo yarn in weft direction) to fabricate epoxy matrix composites. Compression molding method was used to fabricate the reinforced composites. Mechanical properties of cotton/cotton and cotton/bamboo reinforced composites were compared under five different fiber loading conditions (30, 35, 40, 45 and 50% by weight). Fracture morphology was analyzed using scanning electron microscopy. It was observed that cotton/bamboo reinforced composite with 45% fiber weight shows superior mechanical properties namely tensile, flexural, impact, and compression strength and Inter Laminar Shear Stress (ILSS). The work of Niklolic et al. [16] highlighted the potential of cotton fabric as a promising feedstock for the production of bioethanol. The effect of corona pre-treatment of non-mercerized and mercerized cotton fabrics on their glucose and ethanol yield was studied. Fermentation kinetics for ethanol production and the basic process parameters were assessed and compared. Corona pre-treatment of cotton fabrics led to an increase in the glucose yield (compared to control sample) during enzymatic hydrolysis, and consequently the ethanol yield during fermentation by yeast. The system with mercerized cotton fabric was found to be superior giving an ethanol yield of 0.94g/g (based on glucose) after 6 hours of fermentation. Similar results were obtained during the processing of waste cotton materials treated under the same process conditions. The results showed that cotton fabric could become an alternative feedstock for bioethanol production. For potential industrial implementation, the waste obtained from mercerized cotton scraps would be the materials of choice.

Conclusion

This brief review focused on the research work carried out within the last ten years on the subject matter of relevance. It also picked up and summarized only those articles that the author believed may carry the potential to motivate young entrepreneurs who are looking for opportunities to initiate low cost business ventures of their own. It is hoped that the information provided in the article will stimulate the interest of at least some people around the globe to start thinking in the direction of producing and supplying inexpensive composite materials for a range of end uses.

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