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Acoustical and mechanical properties of thermoplastic composites from discarded carpets

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ABSTRACT

Without additional matrix or reinforcement, compression molded composites from waste polypropylene (PP) carpets/nylon (PA) carpets or PP carpets/polyester (PET) carpets have higher mechanical properties and sound absorption than traditional jute/PP composites. Large amount of carpets have been discarded every year, leading to waste of petro-based materials and serious environmental pollution. Fabrication of composites from discarded carpets via compression molding could save petroleum resources and alleviate environmental pressure. In this research, the compression molded composites from waste PP/PA carpets or PP/PET carpets showed good mechanical properties, sound absorption and water stability. Compared to the jute/PP composites, nylon 6,6 (PA66)/PP carpet composites had 37% and 9% higher flexural strength and impact resistance, as well as 45% and 10% higher sound absorption and water stability, indicating their potential for transportation and construction industries.

1. Introduction

Currently, more and more attention has been paid to recycling of petro-based materials due to shortage of oil resources and large demand for petroleum based materials [1]. Lv et al. used waste nylon 6/spandex blended fabrics to make plastics by compression molding [2]; Zou et al. used discarded polyester (PET)/cotton blend fabric for the fabrication of compression molded composites [3]; Petrucci et al. reported that polypropylene matrix were reinforced by cotton flocks from waste jeans fabric via injection molding [4]; Ashori and Nourbakhsh reported that high density polypropylene (PP), PP and old newspaper fiber could reuse and fabricate into composite panels [5]; Jayaraman and Halliwell reported that post-consumer waste plastics and Harakeke fibers could be compounded into composites using the screwless extruder [6].

Carpets are widely used for interior architecture, automobile and aircraft [7]. Currently, almost 4–6 million tons of carpets have been discarded and become one of the largest amounts of solid wastes [8–10]. However, only 2% waste carpets have been recycled [11]. Waste carpets contain non-degradable petro-based materials and thus cause serious environmental pollution. Usage of petro-based materials in discarded carpets is beneficial to environment and could alleviate high pressure from shortage of oil resources. Carpet reusing methods mainly include depolymerization [12], polyamide extraction [13], melt blending [14] and burning for heat energy [15]. Among the above methods, both of depolymerization and polyamide extraction are high cost, although high-quality chemical raw materials could be obtained by the methods. Melt blending is low cost, easy preparation and has no requirement for the separation of carpet compositions. However, high temperature of melt blending probably damage SBR and decrease mechanical properties of subsequent products. Burning method is easy operation. However, high amount of toxic gases are usually released. In addition, some new methods for recycling carpets have been proposed. Wang et al. have used waste carpets to reinforce concrete and increased toughness of concrete composites [16,17]. Schmidt and Cieslak have found there is strong adhesion of carpets to concrete [18]. However, carpets are required to be smashed for preparation of carpet-concrete composites, leading to more energy consumption and high processing cost. Jain et al. have fabricated

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composites using waste carpet and thermoset resins via vacuum-assisted resin transfer molding (VARTM) [11]. However, carpet composites produced by VARTM cannot be reused again. Pan et al. reported that thermoplastic composites from waste nylon carpets or PP carpets were fabricated [19,20].

Fabrication of thermoplastic composites from discarded carpets is a high efficiency approach. The advantages include their reusability and 100% recycle efficiency. The carpet with high-melting-temperature surface fibers could serve as reinforcement materials, while the carpet with low-melting-temperature surface fibers could serve as matrix. According to the types of surface fibers, carpets are mainly classified into nylon 6 (PA6), nylon 6,6 (PA66), PP, PET carpets. Besides surface fiber, carpets mainly contain backing fibers (PP), binders (SBR), fillers ($CaCO_3$). In this research, composites have been developed from PP/PA6, PP/PA66 and PP/PET carpets, which were compression molded at melt temperature of PP. This temperature could protect SBR from heat damage [21]. PP yarns in PP carpets served as matrix, while PA66, PA6, PET carpets and SBR/$CaCO_3$ in PP carpets served as reinforcements. This research studied the potential of fabricating compression molded composites from two types of waste carpets. Effects of ratio of reinforcement, types of fiber reinforcement, SBR and $CaCO_3$ on mechanical properties, water absorption and sound absorption of the carpet composites have also been studied.

2. Experimental

2.1. Materials

PP, PA6, PA66 and PET loop pile carpets were purchased from Carpet Land Inc., Lincoln, NE. Hydrochloric acid (HCl) (37%) was purchased from EMD Chemicals Inc., Gibbstown, NJ. Jute fibers were purchased from Bast Fibers LLC (Cresskill, NJ) and had an average fineness of 32 denier, tensile strength of 312 MPa, breaking elongation of 1.4% and Young's modulus of 24.3 GPa.

2.2. Composition analysis of carpets

Chemical structures of surface yarns and backing yarns of the carpets were measured using Fourier Transform Infrared Spectrometry (FTIR). Measurements were taken on a Nicolet 380 (Thermo-Nicolet, Waltham, MA) spectrophotometer through the diffuse reflectance technique from 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1} and 64 scans. The FTIR spectra obtained were analyzed using OMNIC software (Thermo Electron Corp., Waltham, MA). Surface yarns and backing yarns were disconnected from the carpets. Adhesives of SBR/$CaCO_3$ particles were separated from surface yarns on a Louet laboratory scale carding machine. To remove $CaCO_3$, carpets were soaked in 1% HCl for 24 h and then rinsed in distilled water for 2 h. After dried at 50 °C for 12 h and balanced in a sealed desiccator for 2 h, calcium-free carpets were weighted. The weight ratio of components in the PP, PA6, PA66 and PET carpets is: $CaCO_3$: SBR: PP = 40:10:50; PA6: $CaCO_3$: SBR: PP = 38:40:12:10; PA66: $CaCO_3$: SBR: PP = 40:40:12:8; PET: $CaCO_3$: SBR: PP = 42:38:10:10.

2.3. Thermal analysis

Thermal properties of the PA6, PA66, PET, surface PP yarns and backing PP yarns were measured using a differential scanning calorimetry (DSC). About 10 mg of each type of yarns were placed in aluminum pans and the DSC Mettler Toledo D822^e (Mettler Toledo Inc., Columbus, OH) was operated at a heating rate of 10 °C/min from 25 °C to 200 °C or 280 °C under nitrogen atmosphere. The obtained DSC thermogram was analyzed to determine the melting temperature of PA6, PA66, PET and PP filaments. SBR and calcium carbonate do not have melting temperature due to their non-thermoplasticity. The DSC curve as shown in Fig. 1, melting point of the PA6, PA66, PET and PP were around 225, 260, 260 and 165 °C, respectively.

2.4. Fabrication of compression molded composites

Carpets were placed alternatively between two aluminum sheets and pressed in a laboratory-scale press (Carver, Inc., Wabash, IN) preheated to desired temperatures. Since melting temperature of PP was around 165 °C, the carpets composites (except for 100% PA6 carpets composites) were pressed at 180 °C for 10 min. SBR particles in the carpets could be prevented from damaging or decomposing when compression molded at the temperature of 180 °C. 100% PA6 carpets composites were pressed at 220 °C for 10 min. Different numbers of PA6 carpet and PP carpet layers were prepared to obtain final composites with different ratios of reinforcement and matrix. Different carpets (PA6, PA66 or PET carpets) as reinforcement and PP carpet as matrix were prepared to study the effect of reinforcement on the properties of composites. PA6/PP carpet composites were prepared with PA6 carpets and PP carpets; PA66/PP carpet composites were prepared with PA66 carpets and PP carpets; PET/PP carpet composites were prepared with PET carpets and PP carpets. Thickness of the obtained composites was 4.0 ± 0.08 mm.

To investigate effect of $CaCO_3$ in the compression molded composites from carpets, carpets were treated in 1% HCl for 24 h and rinsed in water to remove calcium carbonate. After dried at 50 °C for 12 h, carpets without $CaCO_3$ were obtained. To study SBR effect, SBR was removed from calcium free carpets, while the separated carpet yarns were prepared for 0 wt% SBR samples as controls.

Jute/PP composites containing 40 wt% of jute fibers had good mechanical properties [22]. Thus, jute/PP (40/60) composites were compression molded at 180 °C for 10 min as a control with the same density and thickness as carpet composites. PP carpets were also compression molded at 180 °C for 10 min as another control with the same density. Types of compression molded composites, temperature and time of compression molding and thickness of the compression molded composites were listed in Table 1.

2.5. Mechanical properties of compression molded composites

Tensile tests were performed on an MTS machine QTest10 (MTS Corporation, Eden Prairie, MN) according to procedure ASTM D638-

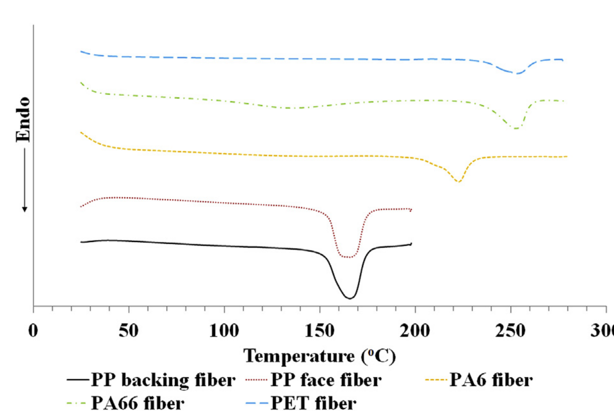

Fig. 1. DSC curves of PP backing fiber, PP face fiber, PA6 fiber, PA66 fiber and PET fiber of carpets.