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Processing, characterization and modeling of recycled polypropylene/glass fibre/wood flour composites

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A B S T R A C T

Polypropylene (PP) is one of the most common thermoplastic materials in the world. There is a need to recycle the large amount of this used material. To overcome the environmental problems, related to the polymer waste, PP was recycled and used as a matrix material in different composites that can be used in high value applications. In this paper, composites made of recycled polypropylene (RPP) reinforced by glass fibres and/or wood flour of the palm tree were prepared, characterized and modeled. The mechanical and thermal properties of these recycled polymer matrix composites (RPMCs) were measured experimentally and modeled theoretically. The mechanical properties included tensile modulus, tensile strength and hardness, whereas thermal properties included thermal stability, melting and crystallinity percentage content were studied. In addition we applied the functionally graded materials concept, the elastic finite element analysis of a layered functionally graded pressurized pipe, which is one of the practical industrial applications, was accomplished in order to have some insight on the performance of such RPMCs. The results reveal that the desired mechanical and thermal properties met the requirements of a wide range of practical applications which can be attained by adding the considered fillers. Also, the proper selection of the layers of the pressurized pipe, which was made of RPMCs, led to decrease of the induced stresses and accordingly increased the operational safety.

1. Introduction

Recycled thermoplastic polymers, which include polypropylene (PP) alone frequently lack sufficient strength and stiffness for use in some engineering applications. This has led to the use of synthetic and natural fillers and the production of recycled polymer matrix composites (RPMCs) due to their desirable properties such as moderate stiffness, strength and large ductility [1]. RPMCs offer inherently durable products well suited for many structural applications such as in construction, in automobile industry and in soil conservation [2–5]. However, their wide spread use in engineered applications has been restricted due to a limited understanding of their mechanical and thermal behavior.

Recycling with the use of cleaner technology contributes to reducing the impact of industrialization upon the environment [6,7]. Wood–plastic composites (WPCs) can be considered as sustainable materials, as the wood can be obtained from landfill agro waste material, and the plastics can be mainly derived from consumer and industrial recycling efforts, as municipal solid wastes. Investigations for structural applications considering WPCs were reported [8]. Wolcott [9] investigated the effects of adding wood cellulose based fibres and found that these fibres not only improve the composite strength and stiffness, but also improve a number of end-use and processing properties such as thermal stability, ultraviolet resistance and workability. Flexural, compressive, tensile and dowel bearing performance of WPCs were documented [10]. Clemons [11] studied RPMCs and measured some of the mechanical properties and their variations with the volume fraction of wood flour (WF). Xu et al. [12] fabricated WPCs by introducing different wood fibres to improve the compatibility between them and the matrix. They measured some of the mechanical properties such as tensile strength and Impact toughness. The effects of different parameters including the WF content on the behavior of PP wood composites were modeled using the Burgers model and a power law equation [13,14]. Rogueda Berriet et al. [15] studied the effects of the recycling process on the mechanical behavior of RPMCs through different loading tests. They also theoretically verified the experimentally measured behaviors of RPMCs by applying different mechanical models. Also, WPCs were modeled analytically taking into account the polymer type and the form of

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Table 1
Description of samples.

Sample	Ratio	Notes
RPP	100%	RPP granules with melt flow index of 12 g/10min
GF	100%	Chopped Short Glass Fiber GF
Chopped wood	100%	Converting chopped wood into wood flour by Cryo mill
RPP/GF composite (GFRPP)	70/30%	Twin Screw Extruder (TSE) with zones Temp. 190 200 210 220 230 (°C)
Wood/GF/RPP composite (WGFRPP)	5/25/70	(TSE) 190 200 210 220 230 (°C)

the reinforcements [16–18]. Testing and analysis were conducted on formulations composed of a variety of commercially available polymer types. In addition, glass fibres (GFs) are known to be suitable reinforcements in polymer composites as they are chemically resistant [19–21]. Hybrid polymer composites containing WF with GFs were manufactured and their properties such as tensile strength, tensile modulus and hardness were characterized [22,23].

In this paper, recycled polypropylene (RPP) was used as a matrix material and GFs and WF were used as reinforcements to produce RPMCs suitable for real world applications. The processed RPMCs were experimentally tested and theoretically modeled to better understand their thermo-mechanical behavior to gain insight into the effects of different microstructural parameters on their thermo mechanical properties and performance. These properties include tensile modulus, tensile strength, hardness, melt flow index and thermal stability. Additionally, finite element analyses incorporating the functionally graded materials concept were performed on a pressurized pipe consisting of different layers. A pressurized pipe was chosen because it represents a practical industrial application and thus provides information regarding the performance of RPMCs such as that considered in the study. The results reveal that the mechanical properties are, in general, enhanced by increasing the volume fraction of the reinforcements.

2. Experimental Details

2.1. Materials and processing

RPP with melt flow index of 12 g/10 min (230 °C/2.16 kg) and density of 0.9 g/cm^3 was provided by Qatar Polymers, Qatar, in pellets form. Additionally, short chopped GFs of type E (silane treated), made in Belgium, were provided by the European OC Fiberglass Company. Fig. 1(a) shows the GFs which were long in nature with average aspect ratio of 360 with approximately 4 mm length. Chopped wood fibers were obtained from the landfill wastes of date palm trees in Qatar. These chopped wood fibers were converted to WF by Cryomil and then dried in the oven at 65 °C for 24 h. SEM images of the pure date palm WF are shown in Fig. 1(b), and it is comprised of fiber bundles, like flakes with average aspect ratio of 333. The used WF is cheaper and easier to process with plastics than wood fibers.

Mixing process of the matrix material, RPP, and the reinforcements, WF and GF, were done in a five-stage Brabender twin screw extruder. The temperatures of the processing zones are in the range of 190–230 °C as listed in Table 1. Table 1 lists the materials compositions with weight ratios of the constituents and also the symbols which were used in this work. The mixtures were fed into the hopper of the extruder and then extruded. The samples were then cooled in water and followed by granulation process. The compounded samples were injected into a PE 5 injection moulding machine, model Fox 8 oxford U1743, and supplied by Tec equipment (TI) to prepare different samples of the standard dog-bone shape of different composites and the length, width and thickness of each specimen were 20, 12.5 and 3 mm, respectively.

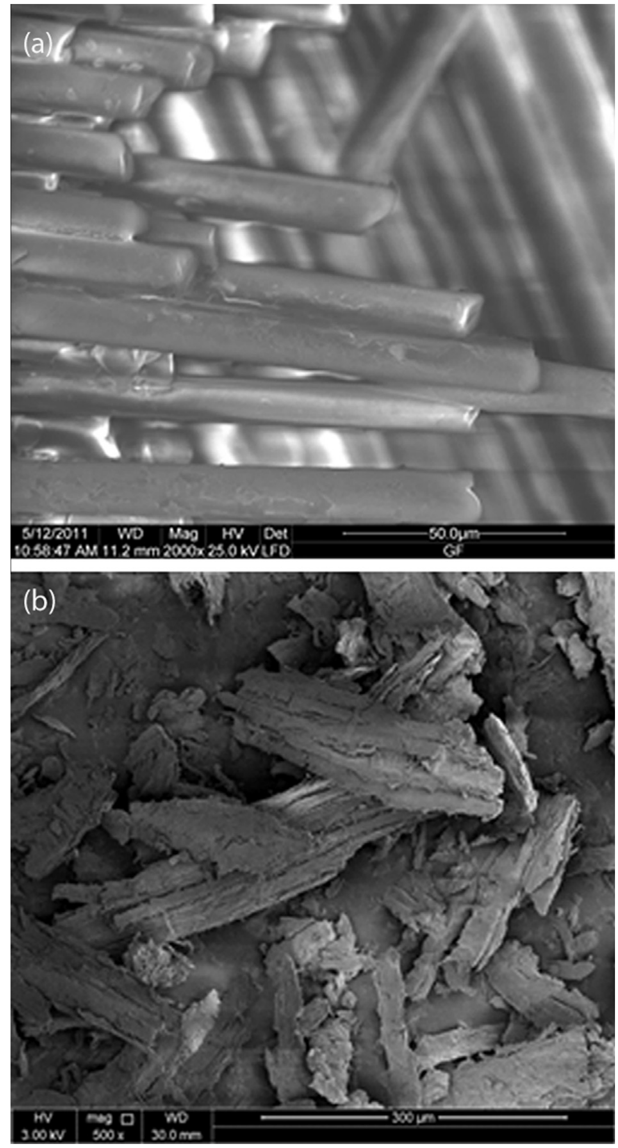

Fig. 1. (a) SEM photos of pure glass fiber and (b) wood flour.

2.2. Experimental tests

2.2.1. Mechanical tests

Tensile tests were carried out according to ASTM: D638-10 using an Instron 4301 universal testing machine and applying a deformation rate (crosshead speed) of 10 mm/min at room temperature. Five samples were tested for each composite and the average value was reported. The tensile stress was determined by dividing the tensile load by the initial sample cross-sectional area. Additionally, the tensile strain was calculated by determining the ratio between the increase in length and the initial gauge length between the clamps.

Morphological analyses were carried out using Philips (SEM)–EDX. The fracture surfaces of the samples after rupture and the bonding between the reinforcements and the matrix were investigated.

Micro-hardness tests were conducted on different samples using the standard Rockwell hardness F scale (HRF) including a