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Thermal and physical characteristics of polyester–scrap tire composites

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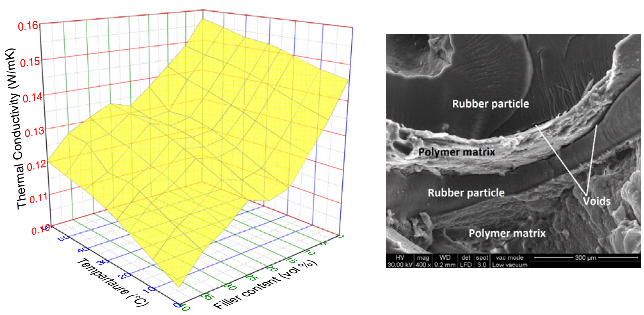
HIGHLIGHTS

- Homogenous rubber–polyester composite is produced with rubber content up to 40 vol.%.
- Produced composite has low density, k of 0.11 W/m K and water retention <2.0%.
- Thermal insulation properties of composites are affected by rubber content and size.
- A non-linear relationship between k and composite density is predicted.
- Incorporating the rubber composite in construction wall reduces the overall k by70%.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the focus was placed on the formulation and development of polyester–filler composite as an insulating material using waste rubber particles as filler. The composites were prepared using different rubber concentrations (0–40 vol.%). The composites were characterized by testing the thermal conductivity, water retention, density, thermal stability and microstructure (SEM). The results revealed that the rubber particles proved to be a good filler that can be used with unsaturated polyester to produce insulating composite. The experimental investigation showed that the addition of rubber particles to the polymer matrix reduces both the thermal conductivity and the density of composites. The low value of thermal conductivity (0.144–0.113 W/m K) and very low water retention (<2.0%) of rubber–polyester composite show promise for constructive applications as a thermal insulator. The SEM micrographs indicated that the rubber particles are well embedded in the polymer matrix with the formation of small voids or gaps within the composite matrix. Increasing the rubber content and size leads to decrease the thermal conductivity and density and at the same time to increase the water retention. On the other hand, the composites showed a slight decrease in thermal stability when compared with neat polymer.

1. Introduction

The United Arab Emirates (UAE) has one of the highest levels of energy consumption per capita in the world [1]. Recent reports concerning energy consumption in the region have said that 25% of the water in Gulf countries has been consumed, with one-fifth of it being used for electricity. According to the International Energy Agency, UAE had an electricity consumption of 10.17 MW h/capita and CO_2 emission of 18.57 t CO_2/capita during the year 2012 [2]. Therefore, there is an ongoing search for finding the proper alternatives to preserve energy and minimize energy losses. Subsequently, heat insulators, part of building materials and some industrial hardware, are steadily getting their importance as a means of saving energy.

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On average, American home space heating and cooling account for 50–70% of its energy use [3]. This percentage could be higher in other parts of the world with more harsh climatic conditions and less energy efficient buildings as for example the Gulf region. On the other hand, using insulating materials extensively in construction will eventually result in a decrease in the energy consumption and will be positively reflected on the environment by reducing the carbon emission.

The generation of scrap tires throughout the world is approximately 1 billion per year and is set to increase in the future as car and truck transportation continues to expand throughout the world [4,5]. Old scrap tires have become an increasing source of waste and pollution especially in the UAE. Waste tires present not only environmental hazards but health and safety issues as well. An estimated 4.8 million waste tires were generated in 2010 in UAE.

The insulating materials are basically made of polymer materials, fillers, and other additives, i.e. composite materials. There are many types of building thermal insulation available, which fall substantially under the following basic materials and composites: inorganic materials (e.g., glass, rock, slag wool, and ceramic products), and organic materials (e.g., cellulose, cotton, wood, pulp, cane, synthetic fibers, cork, foamed rubber, melamine foam, polystyrene, polyethylene, polyurethane, and other polymers). Polymers are generally known to be good insulating materials due to their stable physical and chemical properties. Mechanical properties, however, can be further improved or modified with the addition of inorganic fillers as demonstrated by the increase in the strength of the composite [6].

Reutilization rate of scrap-tires is comparatively much below than annually generated tires. In order to have a successful waste tire-recycling program, there must be a viable market for the end product of the recycled scrap tires. The use of scrap tires in construction is becoming an accepted way of beneficially recycling used scrap tires due to shortages of natural mineral resources and increasing waste disposal costs. Ground rubber has been used in a variety of rubber products such as floor mats, carpet padding, vehicle mudguards, plastic products, burning for production of electricity or as fuel for cement kilns [7]. Crumb rubber (size <6.35 mm) has also been used as modifiers in asphalt concrete. Rubberized asphalt shows better skid resistance, reduced fatigue cracking and better pavement life than conventional asphalt [8].

Many research efforts have been made in recent years to use of rubber from waste automobile tires in construction and infrastructural materials. Van de Lindt et al. [9] have investigated the possibility of increasing the thermal efficiency of a light-frame residential structure through addition of a fly ash-scrap tire fiber composite to traditional fiberglass insulation in light-frame wood residential construction. The relative change in insulation property of the ordinary concrete [10,11] and cementitious composites [12–15] due to adding polymeric based waste material was experimentally investigated. The results revealed that proper addition of selected waste materials into concrete can significantly reduce heat loss or improve thermal insulation performance. Crumb rubber incorporated in geopolymer concrete exhibits better sound absorption property and noise reduction coefficient compared to conventional concrete [16].

Chung and Hong [17] prepared scrap tire composites with potassium hexatitanate as a substitute for asbestos which were used to produce friction material–motor brake pad. Sulcis et al. [18] prepared novel hybrid composites with HDPE matrix and powdered rubber from scrap tires through catalytic polymerization of ethylene. Yung et al. [19] studied the durability of self compacting concrete and replaced part of the sand with 5% waste tire rubber powder to produce self compacting rubber concrete which had high electrical resistance properties, enhanced durability and increased anti-sulfate corrosion.

Issa and Salem [20] investigated the performance of recycled materials crumb rubber as valuable substitute for fine aggregates ranging from 0% to 100% in replacement of crushed sand in concrete mixes. Replacement of fine aggregates with crumb rubber with up to 25% by volume resulted in good compressive strength as well as up to 8% reduction in density was recorded. Due to the enhanced properties such as insulation, damping and ductility of concrete it is advantageous for usage in highway barriers or other similar shock-resisting elements. Recently, Piszczyk et al. [21] studied the effect of ground tire rubber on structural, mechanical and thermal properties of flexible polyurethane foams and showed that addition of tire rubber had positive influence on the thermal stability of the composite.

In this research, focus is made on the formulation and development of polymer-filler composite using waste tires as filler which could be used as a potential heat insulating material. Unsaturated polyester liquid was blended with the filler with a given polymer/filler ratio and then transformed into solid upon thermo-set process. The prepared composites were subjected to different physical and mechanical tests. The physical and thermal properties of the composite were characterized by performing tests for thermal conductivity, thermal gravimetric analysis, water retention and density. The investigated mechanical properties of the prepared composites will be presented in another paper.

2. Materials and methods

2.1. Materials

The polyester used in this study was obtained from Reichhold Inc., Dubai (UAE) as Polylite 721-800E, an isophthalic polyester resin with styrene content of 44–46% and viscosity 280–330 mPa s. It has built in accelerator which gives relatively long gel time, rapid curing combined with relatively low exothermic temperature and short demolding time. Unsaturated polyester is chosen because of its ease of handling, low water absorption values, low cost and its rapid curing with no gases evolved. In addition, the unsaturated polyester known for its low thermal conductivity compared to other thermosets.

The rubber was supplied by the Gulf Rubber Factory (GRF) located in Al Ain (UAE). Two sizes of crumb rubber were used to prepare the composites; rubber #1: fine crumb rubber having particles with size less than 0.8 mm and rubber #2: coarse crumb rubber with particle size ranging from 0.8 mm to 2.0 mm, see Fig. 1a–d.

2.2. Composite fabrication

The composites were prepared using different rubber concentrations (0–40 vol. %) which were added to the unsaturated polyester at room temperature. Table 1 shows the concentration and size of rubber used in the samples formulation. For the curing process, methyl ethyl ketone peroxide was added as an initiator. The composites were prepared using a high viscosity mixer and the mixture was then poured into suitable mold prepared from stainless steel. Different types of molds were fabricated to meet the requirements of the tests that were performed on the prepared composites. The interior surface of the mold was coated with paraffin wax and poly vinyl acetate to prevent sticking of the sample with the mold. It should be mentioned that it was difficult to prepare homogenous composites with more than 40% rubber content. The produced samples were then subjected to different thermal and physical tests according to ASTM standards.

2.3. Thermal conductivity

A thermal conductivity testing machine, Lasercomp FOX-200 was used to measure the thermal conductivity of the produced composites. A specific mold was fabricated according to the dimensions of the sample required by the Lasercomp heat flow instrument. The dimensions of the samples were 150 mm × 150 mm × 20 mm. The measurement conditions follow the standard methods reported by ASTM C1045-07. The steady state method was used in these measurements, where the thermal conductivity was determined from measurements of the temperature gradient in the composite material and the heat input. The average of three measurements was reported here.