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Investigation on the mechanical behavior of polyester-scrap tire composites

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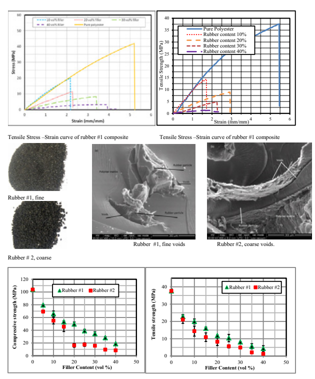
HIGHLIGHTS

- Development of scrap tires - based composites for thermal insulation.
- Two different rubber sizes and nine concentrations are considered.
- Investigation of the rubber-polyester composites mechanical stability.
- Rubber-polyester composites toughness reduces with rubber concentration.
- Good insulator mechanical integrity is achieved.

GRAPHICAL ABSTRACT



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ABSTRACT

An investigation of the mechanical properties of unsaturated polyester composites containing rubber waste particles is presented. The main objective of this work was to formulate and develop polyester-rubber composite as an insulating material with acceptable mechanical performance. To determine the effect of the rubber particles ratio on the compressive and tensile strengths and moduli of a polyester composite 8 different concentrations (i.e., 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% by volume) were considered. The experimental results revealed that mixing rubber particles with the polyester matrix decreased both the compressive and tensile strengths and moduli of the composite. As the rubber content increases, and due to its low hydrophilicity towards polyester resin, the degree of crosslinking between the rubber particles and polyester is reduced causing a noticeable reduction in the composite strengths. On the other side for all investigated rubber contents, the larger the particle size of rubber, the lower the composites strength and modulus of elasticity. This is due to the difficulty of dispersion of the large particles into the matrix resulting non homogenous distribution of the particles and less interfacial contact with the matrix and in turn degradation in the mechanical behavior. However, smaller rubber particles have more specific surface area that could improve the interfacial contact with the polyester matrix. The SEM micrographs indicated that voids within the composite matrix increased with the content and size of rubber particles. Though adding rubber particles reduces the mechanical properties, the prepared composites demonstrate superior mechanical tensile strengths (22.8–1.25 MPa) and compressive strength (79.5–8.42 MPa) if compared with the currently used insulating materials and comparable to some construction materials like the stone masonry.

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1. Introduction

The generation of scrap tires throughout the world is approximately 1 billion per a year and this amount is expected to increase in the future as car and truck transportation is expanding throughout the world [1,2]. It is estimated that, there are 2–3 billion scrap tires stockpiled in the USA. In 2010 an estimated 4.8 million waste tires were generated in United States. Old scrap tires have become a growing source of waste and pollution round the world. Waste tires is not only environmental hazards but also presents a health and safety issues as well.

In tire recycling plants, tire shredders chop tires into smaller particles (i.e., tire shreds and tire chips) which contain steel fibers, rubber, and polymeric fibers [3,4]. These particles are then either ground further or frozen and pulverized. Magnets are usually used to gather the steel fibers before vibrating wire-mesh screens are employed to separate the remaining rubber pieces from the polymeric fibers [5]. It is reported that, almost 15–50% by mass of an average 9 kg tire emerges from this process as a useless rubber fiber blend, that is disposed of in landfills [6].

Nowadays, the rate of reutilization of scrap-tires is much less than the produced tires. In order to have a successful waste tire-recycling program. Therefore, there should be a feasible market for the end product of the recycled scrap tires. The utilization of the of scrap tires in construction becomes an accepted technique of beneficially recycling used scrap tires because of the shortages of natural mineral resources and rising waste disposal prices. Ground rubber is employed in several rubber products as for examples vehicle mudguards, carpet padding, floor mats, plastic products, burning for production of electricity or as fuel for cement kilns [7]. Scrap rubber is also used as modifiers in asphalt concrete [8].

Tire chips and powder have been investigated widely as light-weight filler for embankments and retaining walls [9–14], but have also been used as drainage layers for roads and in septic tank leach fields [5]. According to Humphrey, using of scrap tires in civil engineering applications is due to many advantageous properties such as high bulk permeability, low density, low thermal conductivity, high durability and low cost comparing with other filler materials. The increases in rubber content also reduces Young's modulus [15] and improves ductility [16]. Fattuhi and Clark [17] suggested using concrete–rubber mixtures in some applications for flowable fill such as trench filling and pipe bedding.

Recently, some research work have utilized the rubber of waste automobile tires in constructional and infrastructural applications. A ten-year study on asphalt-rubber surface mixtures carried out by Choubane et al. [18] revealed that the crumb rubber increased ride ratings and decreased surface rutting. Crack resistance of asphalt surface mixtures was enhanced with including crumb rubber [18–21]. Different researchers have shown that increasing the rubber content in the mixture of crumb rubber and mortar or concrete, decreases both compressive strength and unit weight [15–17]. Pierce and Blackwell [12] illustrated that crumb rubber shows to be a technically useful, environmentally benign, and economically viable alternative aggregate source for flowable fill. It can be employed as a complete replacement for concrete sand in flowable fill. It was noticed that scrap rubber contents as high as 38% by weight can be mixed in flowable fill without clear separation of the rubber.

The mechanical characteristics of polypropylene/waste tire dust/kenaf composites were studied by Pang and Ismail [22]. The main findings were that tensile modulus improved with increasing Kenaf loading although the ultimate strength and elongation at break reduced. Addition of coupling agent improved the interfacial adhesion resulting in increased tensile strength and modulus.

The behavior of recycled crumb rubber as useful substitute for fine aggregates ranging from 0% to 100% in replacement of crushed sand in concrete mixes have been studied by Issa and Salem [23]. Replacement of fine aggregates with rubber particles with up to 25% by volume enhanced the compressive strength as well as up to 8% decrease in density was measured. On the other hand, Pinheiro et al. [24] investigated the bending behavior of bridge decks by studying the effect of rubber addition to composite beams. Adequate amount of rubber addition to the concrete deck can result in improved impact absorption and a lower cracking because of the abrasion wear, self-weight or water absorption.

Recently, Jung et al. [25] investigated the applicability of an epoxy based polymer concrete containing silicone rubber as a runways repair material. It was found that even though small amounts of silicone rubber degrade the mechanical properties (e.g. elastic modulus and strength) it endows standard polymer concrete with sufficient compliance to resist material failure in runway repair systems outdoor environments.

Employing insulating materials broadly in construction will ultimately result in a reduction in the energy consumption and will be definitely reflected on the environment by decreasing the carbon emission. The available insulating materials in the market suffer from the low strength and high cost, which hinder their use widely and in small construction projects. Little attention in the literature has been paid on utilizing the scrap tires in manufacturing of insulating materials. The focus was most likely on the relative change in insulation characteristic of the ordinary concrete [26,27] and cementitious composites [12–15] because of mixing polymeric based waste material. The findings showed that, proper mixing of waste materials with concrete can essentially decrease heat loss or enhance thermal insulation characteristic Van de Lindt et al. [6] have investigated the possibility of increasing thermal efficiency of a light-frame residential structure by mixing a fly ash-scrap tire fiber composite with traditional fiberglass insulation construction. Piszczyk et al. [28] investigated the effect of ground tire rubber on structural, thermomechanical characteristics of flexible polyurethane foams and illustrated that adding tire rubber improved the thermomechanical composite properties.

The main objective of this work is to formulate and develop a waste tires filler-based composite material that may be utilized as a possible and alternative insulator with good mechanical behavior. Unsaturated polyester liquid was added to the filler with different polymer/filler ratios and then through a thermo–set process transformed into solid. The produced composites were subjected to variety of mechanical and physical testing techniques. The investigated thermal and physical properties of the prepared composites revealed that blending of waste rubber to the unsaturated polyester decreases the density of composites and its thermal conductivity as well. The low level of the achieved thermal conductivity (0.144–0.113 W/m K) and very low characteristic of the composite water retention (<2.0%) demonstrate that the composite hasn't only a potential as a thermal insulator but also a potential as a construction materials. These characteristics have been reported by Abu-Jdayil and Mourad [29] in their previous work on the same material when investigating its performance as insulator. In this work, the mechanical behavior of the rubber-polyester composites is investigated by conducting compressive and tensile tests.