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Waste Tetra Pak particles from beverage containers as reinforcements in polymer mortar: Effect of gamma irradiation as an interfacial coupling factor

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HIGHLIGHTS

- Polymer mortar with waste Tetra Pak from beverage containers was elaborated.
- The effects of gamma radiation on compressive and flexural properties were studied.
- The highest mechanical performance is obtained with 1 wt% of Tetra Pak particles.
- The lower gamma dose provides the highest compressive strength.

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ABSTRACT

In this work, composites based on polyester resin and silica sand were elaborated. Partial substitution of silica sand by waste Tetra Pak particles from discarded beverage containers was carried out, namely 1, 2, 4 and 6% by weight. As is well known, Tetra Pak packaging have six layers: four of polyethylene, one of cellulose and one of aluminum. Modified composites were irradiated with gamma rays at doses from 100 to 500 kGy in order to improve the mechanical properties of composites through a better interfacial coupling between the matrix and Tetra Pak particles caused by the irradiation process. The results shown an improvement of 15% on the compressive strength and 16% on the flexural strength, when 1% of Tetra Pak particles and irradiation dose of 100 kGy were used. Higher compressive and flexural deformation was also observed (until 34% higher); therefore a ductile material was obtained, which is not common for these kinds of composites. By increasing the irradiation dose to 200 kGy and concentration higher than 2% of waste Tetra Pak particles, mechanical properties of the composites decreased considerably.

1. Introduction

The composite materials are macroscopic combinations of two or more different materials having a discrete and recognizable interface between them. They consist of a continuous matrix surrounded by dispersed phases. The main functions of the matrix are: (a) to determine the physical and chemical properties; (b) transmit loads to the reinforcement; and (c) protect and provide cohesion. Several types of composite materials include reinforcement with particles or fibers. Moreover, reinforcement-matrix interfaces in composite materials influence the manufacturing processes and determine the performances of them. Some reinforcements may not be compatible with polymer matrices in view of their physical and/or chemical properties, which cause premature

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failure of the composite materials. The compressive and flexural strength of composite materials are affected by different parameters including size, assembly type, operating temperature, loading type, and surface roughness. Special attention is focused on the thickness of the interface [1,2].

As is well known, one of the most important composites is cement based concrete, which has several advantages. However, also has some drawbacks such as, its low tensile strength, low ductility and problems of expansion/contraction with temperature variations. For solving these problems addition of different materials is performed, such as particles or fibers from metals, polymers and ceramics, for to improve the mechanical properties of concrete. As it is known in concrete-polymer composite materials show higher tensile strength and ductility than cement based concretes, but certain limitations on the expansion/contractions exists with the temperature variations. Respect to the density and porosity problems in the concrete, different synthetic or natural materials have been adding; including waste and recycled polymers that have shown significantly diminution on the density, porosity and water absorption [3–5].

Polymer Concrete is a composite material in which polymeric materials are used (as thermoset resins), to bond mineral aggregates, in a similar way to that of Portland cement concrete. In its elaboration several parameters must be taken into account, such as resin type, initiator, and accelerator concentrations. Polymer concrete is increasingly being used in many applications, such as finishing work in cast-in-place applications, precast products, highway pavements, bridge decks, waste water pipes, and even decorative construction panels. The mechanical properties of polymer concrete depend on the concentration, size and type of the mineral aggregates. Different polymer concrete specimens have been elaborated; the most common contain 20 wt% of resin and 80 wt% of mineral aggregates [6,7]. One of the most important applications of polymer concrete is for reparation of cement concrete. Moreover, it is possible to obtain thin overlays with specific advantages as lightweight, fast curing and durable.

In general, particles or fibers are used as reinforcements in composites, and its effectiveness depends on their size, concentration, distribution and length/diameter ratio; such reinforcements are used to increase the rigidity, abrasion resistance, mechanical strength and temperature performance [2]. Moreover, some recycled materials have been used as reinforcements of composite materials; as those obtained from discarded Tetra Pak beverage containers, which are made with cellulose (75%), low-density polyethylene (20%) and aluminum (5%). Recycling of these materials is based on mechanical milling and chemical attack, from which is possible to obtain size reduction and component separation.

Applications of the recycled materials from Tetra Pak packaging include papermaking and manufacture of laminate and agglomerate products. There are some investigations related with these recycled materials, for example: (a) Composites elaborated with lignocellulosic wastes and polyethylene-aluminum (PEAL) obtained from post-consumer aseptic packaging, the reported results show improvement on the strength and Young modulus when increasing lignocellulose concentration; (b) PEAL composites elaborated with sawdust flour as filler show increment on the flexural modulus and tensile strength. Improvements up to 44% on the flexural modulus are obtained when adding 60 wt% of sawdust and rice husk flour into the PEAL composites [8–10].

Flame-retardant thermoplastic composites were developed by extrusion, followed by injection molding using recycled Tetra Pak packaging materials and high-density polyethylene (HDPE), with addition of ammonium polyphosphate (APP) and melamine (MEL) as intumescent flame retardants (FRs). The results show that the incorporation of APP, APP/MEL into composites promoted char formation and improvement on the thermal stability. With APP/MEL ratios less than 3, tensile strength, combustion behavior and flame retardancy are improved. Nevertheless, diminishing on mechanical properties is observed when adding more than 30 wt % of FRs, particularly in tensile strength [11].

A novel electromagnetic interference (EMI) shielding board was elaborated by using recycled Tetra Pak materials and iron fibers. EMI shielding effectiveness (SE) and volume resistivity (VR) was investigated in terms of the concentration, length and number of iron fibers into the matrix. The results indicated that SE increases with the increment of the concentration and length of the fibers, however VR shows an opposite behavior. The boards had excellent EMI shielding performance in two ranges (9000 Hz–200 MHz) and (600–1500 MHz), and were proposed for broad applications, including packaging and construction due to their environmental and economic advantages [12].

Properties of composites depend on the interface between the components. If the interface is weak, the load transfer from the matrix to the fiber (or particles) will not be efficient and/or be the matrix ends loads supporting (and fail, since it is not very resistant), or produce voids between the matrix and fibers, which produce rupture. Gamma irradiation has proved to be an adequate tool for modifications of the physicochemical properties of polymers, through to different effects: (a) scission, branching as well as cross-linking of polymer chains, and (b) oxidative degradation [11,13].

Examples of cross-linking phenomenon include the production of cross-linked polymer for wire insulation, the development of heat shrinkable tubing and film, and the curing of resins used in coating applications. Moreover, gamma irradiation is used as polymerization agent for developing fiber reinforced composite materials, having special applications in aerospace and automotive research areas. Advantages by using ionizing irradiation in these formulations are production at room temperature, and handling on specific applied doses, when comparing with a thermal curing process [14–16].

Applying gamma irradiation to polyester resin produce several effects, for example the glass transition temperature, Tg, increases when increasing irradiation dose. Nevertheless the decomposition temperature is unaffected, whose values are higher in presence of nitrogen than those obtained in presence of oxygen. Such thermal behaviors are related with mechanical features, in particular those for compressive strength where the values increment when irradiation dose is increased [17,18].

In general, the exposure of LDPE to high-energy irradiation as gamma rays, result in the following changes: evolution of hydrogen and cross-linking of its linear chains. Which give features of thermoplastic due to its reticulated. This modified structure produces a thermosetting material, with a higher operating temperature that does not flow at the melting temperature. In the case of the cellulose polymer, degradation begins at 31 kGy and the cross-linking of polymer chains occurs at doses greater than 1 MGy [19,20].

Some relevant studies regarding to improvement of compatibility between composite components through using gamma irradiation have been conducted. In general, a post-thermal curing is necessary to fully complete the polymerization reactions, and in consequence improve the compatibility between components. Using gamma irradiation, by which cross-linking of polymer chains and more fiber-matrix interactions are produced, can circumvent such treatment. The observed improvement of the properties is attributed to the development of an interfacial adhesion between matrix and reinforcement components [12,16–17].

Thermal degradation of Tetra Pak panel boards (TPPB) under inert atmosphere was studied. The results show thermal degradation in the range of 200 °C to 400 °C for paper layer, the other degradation step occurs between 400 °C and 461 °C corresponding