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Recycled cellulose from Tetra Pak packaging as reinforcement of polyester based composites

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HIGHLIGHTS

- Polymer concrete with waste cellulose from Tetra Pak packaging was elaborated.
- The effects of gamma radiation on compressive and flexural properties were studied.
- The highest mechanical performance is obtained with 2 wt% of waste cellulose from Tetra Pak.
- The lower gamma dose provides the highest compressive strength.
- Improvements on the compressive and flexural strength were obtained at irradiation dosages of 100 and 200 kGy.

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ABSTRACT

Addressing the environmental problems caused by waste generated by Tetra Pak packaging, in this work, polyester based composites with 80% of polyester resin and 20% of silica sand were elaborated; where the silica sand was partially replaced by recycled cellulose from waste Tetra Pak containers at concentrations of 1, 2, 4 and 6% by weight. Both recycled cellulose and composite specimens were subjected to ionizing radiation process by using gamma rays. The results show improvements on the mechanical properties (compressive and flexural strength as well as modulus of elasticity) of the composites when they are irradiated at 100 and 200 kGy. Such improvements can be related with the structural modifications caused by gamma irradiation on the cellulose fibers, including changes in the morphology and the crystallinity; which were analyzed through to SEM, IR and XRD techniques.

1. Introduction

Polyester based composites are the result from polymerization of the polyester resin mixed with a mineral aggregate. In this case, the polymerized monomer acts as binder for the mineral aggregates. Precast polyester composites have been used to produce a variety of products like acid tanks, manholes, drains, and highway median barriers. Special features of polyester composites can be an excellent bond agent between cement composite and steel structures, as well as repairing material. Moreover, they show fast curing, improved properties including compressive strength, specific stiffness, vibration damping, durability, as well as ability to form complex shapes, and resistance to chemicals and corrosion [1–4].

Few studies have been reported regarding the effect of fibers as reinforcement of polyester composites. Such fibers include steel, glass, carbon or polyester at different concentrations. Fiber reinforced polymers (FRP) have numerous advantages, including excellent corrosion resistance, high fatigue resistance, low thermal expansion coefficient, and to have lightweight. Moreover, they

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have high specific stiffness and an equally high specific strength in the direction of fibers alignment [5–7].

For solving high demand of construction materials, some strategies are been considered, mainly in the development of new materials based in the use of large amounts of raw, waste or recycled materials, either non-modified or structural modified. Moreover, implementation of green-laws in several countries has generated renewed research interest in eco-friendly composites materials.

Different investigations focused on the use of waste or recycled materials in composites have been developed in the last two decades. Reis [8] added recycled textile fibers to polymer composites manufactured with polymer resin and sand, for improving of their mechanical properties. Smoother failure was obtained, unlike brittleness failure for unreinforced polymer composites. Waste polyurethane formaldehyde (PUF) from packaging and recycled high density polyethylene (HDPE), as substitutes of aggregates in composites was used by Rahman et al. [9]. The results show diminution in density, porosity and water absorption when adding both waste materials. Nevertheless, such low density allows that modified composite can be used in non-load bearing structures and floating structures. Bon-Min et al. [10] added recycled PET fibers (obtained from PET packages) to composites for controlling shrinkage cracks and improving of structural ductility, under normal environmental conditions.

Cellulose is the most abundant, inexpensive and readily available carbohydrate polymer in the world; it has attracted the attention of research community all around the globe. Cellulose is traditionally extracted from plants, having normally branches with hemi-cellulose and lignin has to undergo unhealthy chemical process with harsh alkali and acid treatment. Its intrinsic properties include biodegradability, easy availability, environmental friendliness, flexibility, easy processing and impressive physical and mechanical properties.

Cellulose fibers are playing an important role in a number of applications due to their inherent eco-friendly advantages since the last few decades. They are being explored as the potential alternatives to traditional synthetic fibers for diverse applications with particular emphasis as green reinforcement. Frequently, they are used as the reinforcement component in polymers to add the specific properties in the final product. Moreover, cellulose fibers and their respective polymer composites offer a number of advantages over conventional materials such as considerable toughness, flexibility, easy processing, recyclability and eco-friendliness [11].

Increasing demand on derivatives of plant cellulose has increased wood consumption as raw material, causing deforestation and global environmental issue. Fortunately, different ways to recycle cellulose from products made with cellulose (boxes, bags, containers and office supplies, among others), are being attended [12]. Natural fibers "in natura" were also used in different quantities as polymer mortars reinforcement. Coconut, sugar cane and banana waste were added with excellent results in resistance to crack propagation [13].

Three main effects happen when a material is exposed to ionizing radiation (as gamma rays are): a) cross-linking or reticulation, b) degradation or scissioning, and c) grafting. Physical and chemical modifications on the chemical structure of each polymer depend on the amount of absorbed energy per unit mass (dosage), and the irradiation conditions (either in air or inert atmosphere). Such modifications have repercussion on their mechanical properties [14–17].

In this work recycled cellulose fibers from waste Tetra Pak packaging and gamma irradiation were used for improvement of the mechanical properties of polyester based composites. The cellulose fibers where used as a partial substitute of silica sand in the composites.

2. Experimental

2.1. Materials

Polyester composites ($40 \times 40 \times 60$ mm), were made with unsaturated polyester resin, silica sand and cellulose fibers from waste Tetra Pak beverage packaging. The resin (orthophthalic) was provided by Reichhold Company and marketed under the name Polylite 32493-00™. Silica sand (available from GOSA™) with uniform granulometry had an average diameter of 245 μm. As catalysts for curing resin, methyl ethyl ketone peroxide (MEKP) was used.

2.2. Polymer composite elaboration

Three different kinds of specimens were studied: Type I, composites without cellulose fibers (called by us as Control); Type II, composites with cellulose fibers; and Type III, composites with cellulose fibers and post-cured by gamma irradiation.

Curing of each specimen was at 20.0 ± 3.0 °C for 24 h. In the case of the specimens type III, in a first stage, they were cured by using MEKP catalyst, and after were exposed to gamma irradiation for a second cured process, which is a common technique for curing of polymers, which having advantages on the improvement of physical and chemical properties of them.

3 specimens without cellulose (Type I) were elaborated; 12 specimens corresponding to each fiber concentration (Type II), is to say, (3 units) $\times$ (4 different concentrations) = 12 specimens; and 60 specimens (Type III), corresponding to 3 units) $\times$ (4 different fiber concentrations) $\times$ (5 different dosages), i.e. $3 \times 4 \times 5 = 60$ specimens.

The silica sand was partially replaced by recycled cellulose in concentrations of 1, 2, 4 and 6 wt%, as it is shown in the Table 1.

2.3. Gamma irradiation

Composites (shown in the Table 1), were irradiated at different dose (from 100 to 500 kGy), in air atmosphere at room temperature, by using an industrial irradiator JS-6500 which works with pencils of cobalt 60 (^{60}Co), of 5.2 years of life in average. According to literature, dosages up to 500 kGy are enough for to produce chemical modification in polymers.

The effect of cellulose fibers on the mechanical performance of polyester based composites, can be evaluated directly from results of specimens type II, but the effect of gamma irradiation on such specimens, can be related with modifications of both polyester resin and cellulose fibers. Thus, we decided study in a separated experiment, the effect of gamma irradiation on cellulose fibers through to analyzing its morphology, crystallinity and chemical structure.

2.4. Mechanical tests

After irradiating process, composites were subjected to compressive and flexural test in a Controls™ Universal Testing Machine

Table1
Polymer composite formulation.

Lot Code	Resin (%)	Sand (%)	Recycled-cellulose fibers (%)
PC	20	80	0
PC-1	20	79	1
PC-2	20	78	2
PC-4	20	76	4
PC-6	20	74	6