Polypropylene Fibre Reinforced Polymer Concrete: Effect of Gamma Irradiation

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SUMMARY

Design of polymer concrete involves extensive studies on their materials in order to get improved properties; specifically on the physicochemical properties of both polymer resin and mineral aggregates, including size and shape of the last one. Alternative studies are focusing on using different materials or methods to obtain such improvements. In this work, polymer concrete was elaborated with unsaturated polyester resin, marble particles and polypropylene fibres, after it was modified by using gamma radiation to achieve a complete polymerization. The results show improvements in the compressive strength and in the modulus of elasticity with 0.2 vol.% of polypropylene fibres and irradiation at a dose of 250 KGy. However, lower compressive strains were obtained when using gamma radiation.

Keywords: Polymer concrete, Polypropylene fibres, gamma radiation, marble, compressive strength.

1. INTRODUCTION

Portland cement concrete (PCC) has many favourable advantages such as low material cost and simple application. However, it has some disadvantages and some serious limitations. Its low tensile strength, weak flexural strength, poor resistance to freeze-thaw phenomena and destruction by sulfate and acid attack has limited extensive use of concrete[1-4]. Each treatment to improve concrete provides a solution to a particular problem. However, there has been no single solution which would improve or solve all problems.

Polymer concrete (PC) has lower water absorption and greater stability in the phenomena of freezing – thawing than that for Portland cement concrete (PCC). Moreover, it is more resistant against chemicals and corrosive materials; resistance against chemicals such as acidic, alkaline and sulfate solutions mainly found in industrial environments[5-8].

Elaboration of polymer concrete consists of a polymer binder (that replaces the cement paste), and a mineral aggregate[1-4]. Chemical catalysts, ionizing radiation, heat, infrared or microwave energy can be used for the polymerization[9,10]. The aggregates used in dry state can be silicates, quartz, crushed stone, gravel, limestone, calcareous, granite and clay. In the composition such fillers as fly ash, silica fume, phosphogyps and cinder can be used[11-13].

The performance of polymeric concrete depends on the polymer matrix properties, type of filler, aggregates, curing temperature and component concentrations[11]. The particle size of aggregates has a great influence on mechanical behaviour of the polymer concrete and improves its physical and mechanical strength[2,4]. The effects of temperature on the mechanical properties change considerably. Upon continuing to raise the temperature, unsaturated polyester mortars show a ductile performance followed by a decrease in the load bearing capacity[14].

Some studies show that polymer concrete can be reinforced with several types of fibres, including synthetic,

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natural, and cutting textile waste. Synthetic fibres include polypropylene, glass, carbon and boron; natural fibres include coconut, banana, sugar cane bagasse and cellulose, while textile consists of cotton, polyester, silk and rayon[1,15]. The textile cuttings may not be conceived as either an aggregate or reinforcement. It does however contribute to increase volume of the mixture, lower the weight, and intent to contribute to increase in the flexural and compressive resistance due to its fibrous nature.

In early investigation textile fibres were used as reinforcements of polymer concrete incorporating 1 and 2 wt.% of chopped textile fibres. The results show that respect to the plain unreinforced polymer concrete the compressive strength decreases 30% and 43% when adding 1% and 2% of textile fibre content, respectively. Moreover, bending strength behaviour show that failure becomes less brittle as textile fibres content is increased in the polymer concrete mixture[15].

Fracture properties and mechanical strength can be improved by addition of short glass, carbon or coconut fibres. Moreover, sugar cane bagasse or bamboo can be viable alternatives as sustainable materials for application in industrial design. Bamboo fibre is often brittle when compared with other natural fibres because they have a high percentage of lignin. Nevertheless, by using the steam explosion technique is possible to obtain fibres from raw bamboo trees, and to employ it as reinforcements[16]. Kenaf fibres are good candidates for reinforcement in polymer composites due several properties as: low spiral angle of the structural cellulose; higher cellulose content, smaller fibre diameter and longer size[17]. Kenaf reinforced composites show high tensile strength when adding 20% of fibre, but for higher contents (up to 40%), values are lower. Moreover, the highest flexural strength and impact strength values are obtained with 10% of fibres. With higher fibre content significant fibre-fibre contact is obtained. As a result, it leads to poor interfacial bonding between the fibre and the matrix and hence decreases in the mechanical properties.

Improvements in polymer concrete typically come from modifying the physicochemical properties of both the resins and the mineral aggregates. An alternative to modification by thermal processes or chemical attack is to use gamma radiation, which may have more advantages. It is well known that when using gamma radiation on polymers, three main processes occur: crosslinking, scission, and grafting of chains (which involves generation of free radicals). There is insufficient information available on effects of gamma radiation in composites of the type polymer matrix + mineral aggregates + polymeric fibres. Nevertheless, in the last decade studies on the effects in the bonding interaction at the interface, as well as modifications of the polymer phase and mineral aggregates (fillers) are of potential interest. It is expected that the ionizing energy could improve compatibility between the aggregates and the polymer matrix by means of the structural and surface modification of both components. Thus improvement of the mechanical properties of PC can be obtained[18-19].

2. EXPERIMENTAL PART

2.1 Specimen Preparation

Polymer concrete specimens were prepared with marble (GOSA™, Atizapan, Mexico), a commercial unsaturated polyester resin (Polylite 32494-00™, Reichhold, Atlacomulco, Mexico), and polypropylene fibres at concentrations of 0.1, 0.2 or 0.3% by volume. Polypropylene atactic fibres had 40 μm diameter and 10 mm length (CONSA™, Distrito Federal, Mexico). After mixing the polymer concrete, cubic specimens (5 x 5 x 5 cm) were placed in a controlled temperature room for 24 hours.

2.2 Mechanical Tests

The compressive tests of the polymer concrete specimens were carried out in a Universal Testing Machine model 70-S17C2 (Controls™, Cernusco, Italy), according to the ASTM C-109M standard.

2.3 Morphological Characterization

Fibre surfaces were analyzed by scanning electron microscopy (SEM) in a JEOL model JSM-6510LV machine in the secondary electron mode.

2.4 Irradiation Procedure

Atactic PP fibres and polymer concrete cubic specimens (5 x 5 x 5 cm) were exposed to gamma radiation doses using a ^{60}Co source. The fibres were placed in packets of 50 in a capillary tube. The dosages were 200, 250 and 300 kGy at the dose rate of 3.5 kGy/h; the experiments were performed in air at room temperature. The irradiation was provided by a 651 PT Gammabeam Irradiator manufactured by NORDION (Chalk River, Ontario).

3. RESULTS AND DISCUSSION

3.1 Compressive Strength

PC containing three different marble particle sizes and different polypropylene fibre concentrations have been developed. The selection of the particle sizes was a function of the availability of the commercial mesh (sieve), in our case 25, 14 and 8, which correspond to 0.71, 1.4 and 2.36 mm, respectively. Thus, we have approximately 1:2:3 as the ratio.

Figure 1 shows the compressive strength σ_c values for PC manufactured with different polypropylene fibre concentrations, and irradiated at different radiation doses. There were four different kinds of PCs: 1) without fibres and non-irradiated (PC taken as control; namely by us as PC control);

2) without fibres and irradiated; 3) with fibres and non-irradiated; and 4) with fibres and irradiated. Thus, the analysis is described in terms of the fibre concentrations and the radiation doses.

We respect to the fibre concentrations some results can be observed: a) For non-irradiated PCs the compressive strength increases slightly when adding polypropylene fibres (15% as maximum when adding 0.2% of fibres); b) while for irradiated ones the σ_c values increase for PCs with 0.1% and 0.2% of fibres; nevertheless for higher fibre concentrations the values decrease. In general, the addition of polypropylene fibres improves the compressive strength of polymer concrete.

According to the increment of gamma radiation dose, the following behaviour is observed for the σ_c values: a) two well-defined stages are seen for each fibre concentration. In the first stage the σ_c values are increasing according to the gamma radiation dose up to 250 kGy, and in the second one for higher dose the σ_c values decrease; b) the maximum values are achieved at 250 kGy. An explanation for such behaviour seems to be related to the radiation effects on the polyester resin; as already noted, the irradiation causes chain relaxation and cross-linking having a maximum effect at 250 kGy; and for higher doses chain scission begins and in consequence lower σ_c values are present.

The highest compressive strength (namely 65 MPa), is observed for PC irradiated to a dose of 250 kGy with 0.2 vol.% of polypropylene fibres; it is 62% higher than that control PC (without fibres and non-irradiated). Thus, we recommend combining such parameters to obtain the highest σ_c values.

When comparing the σ_c values for non-irradiated PCs with others PCs containing different mineral aggregates, it can be seen that values ranging from 40 to 46 MPa, are similar to that for PC with silica sand (49 MPa)[20]; but lower than that for PC with CaCO3 (86 MPa)[21].

In the case of irradiated PCs there are significant differences. The present σ_c values ranging from 46 to 65 MPa, are lower than that for PC with silica sand (62-86 MPa)[20], or with $CaCO_3$ (126-135 MPa)[21].

3.2 Compressive Strain at Yield Point

In **Figure 2**, compressive strain values at the yield point of the polymer concretes are shown. For PC without fibres and non-irradiated, the values

Figure 1. Compressive strength of polymer concrete with different fibre concentrations, irradiated at higher doses

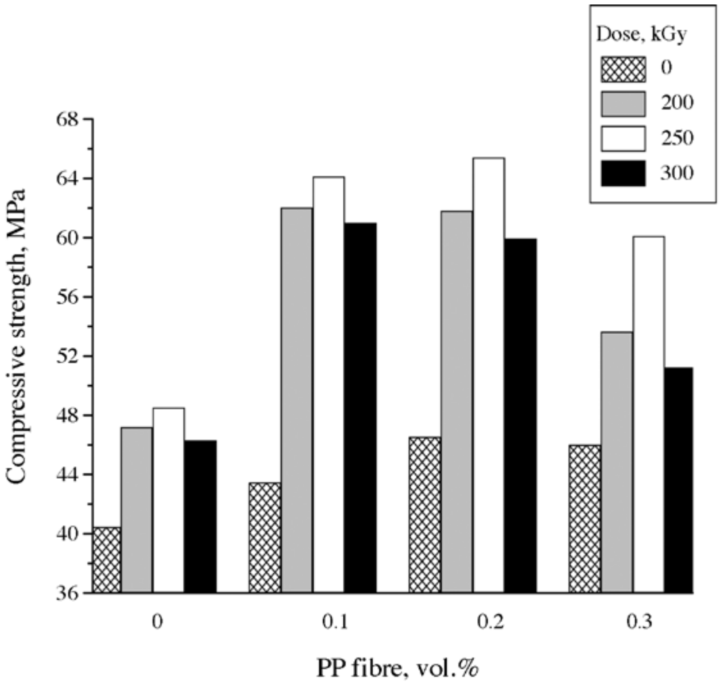
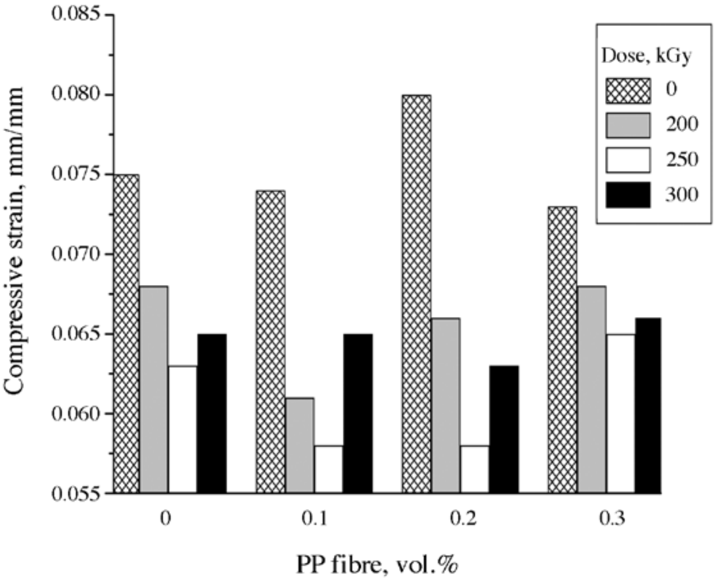


Figure 2. Compressive strain of polymer concrete with different fibre concentrations, irradiated at higher doses



are 0.075 mm/mm; when they are irradiated a decrease of the yield strain is observed; the values diminish up to 250 kGy, and for a higher dose the values increase. The diminution is 23% less than that for the polymer concrete control.

In the case of PC with fibres but non-irradiated the values ranging from 0.074 to 0.080 mm/mm, the higher values are obtained for PC with 0.2% of fibres. When applying radiation a typical behaviour is observed: the values diminish up to 250 kGy and for higher dose they increase. Nevertheless, all values are lower than that for polymer concrete control.

The highest value is reported for non-irradiated PC with 0.2 vol.% of fibres, namely 0.08 mm/mm. Such a value is higher than that reported in the literature for polyester concrete, 0.01 mm/mm, making it a less brittle material.

As observed for compressive strength results, the compressive strain has the same behaviour: the values decrease for irradiated PCs.

3.3 Modulus of Elasticity

In **Figure 3** the modulus of elasticity, Ec values of the polymer concretes are shown. For concrete without fibres and non-irradiated, the modulus of elasticity value is 8.4 GPa, when irradiating them an improvement of 97% is obtained; having 16.6 GPa as value.

In the case of polymer concrete with fibres and non-irradiated, the values range from 8.4 to 11.4 GPa; the maximum value is obtained for PC with 0.2% of fibres. Finally, for polymer concrete with fibres and irradiated the values range from 11.5 to 18 GPa, having the highest value at 250 kGy, which is 142% higher than that for the polymer concrete control.

On comparing the maximum values for both kind of polymer concrete: without fibres+irradiated and with fibres+irradiated, a minimal percentage difference is observed between them, only 8%. Thus, the major contribution to the modulus of elasticity is due to gamma irradiation in comparison to those obtained for fibre concentration. Thus a dosage of 250 kGy is enough to create chain crosslinking in the polyester resin and to promote modulus of elasticity.

When comparing the modulus of elasticity results of non-irradiated PC manufactured with different mineral aggregates found in the literature, it was observed that the values ranging from 8 to 11 GPa were higher than that for PC with silica sand + polypropylene fibres (5.7 GPa)[22] or PC with silica sand (7.3 GPa)[20], or with $CaCO_3$ (7.6 GPa)[21].

In the case of the Ec values for irradiated-PCs, the differences are more notable. The values ranging from 9 to 18 GPa are higher than that for PC with silica sand + polypropylene fibres (9.6 GPa)[22], or PC with silica sand (7.4-16.3 GPa)[20], or with $CaCO_3$ (10.5-16.1 GPa)[21].

When adding polypropylene fibres to polymer concrete some notable behaviour is observed: a) for non-irradiated PC, higher values of compressive strength and strain as well as modulus of elasticity are obtained, and b) for irradiated ones both compressive strength and strain have similar behaviour; nevertheless higher values for modulus of elasticity are obtained.

The mechanical properties of polymer concrete can be attributed to the modifications caused by gamma radiation, in particular on polypropylene fibres as seen in **Figure 4**. Non-irradiated PP fibres show a homogenous surface (**Figure 4a**), while irradiating at 200 kGy stripped regions on the fibre surfaces are seen (**Figure 4b**). Increment of the gamma dose provokes more damage on the surface, and small particles are formed (less than 1 μm) (**Figure 4c**). Finally upon irradiating at 300 kGy more damage is observable; zones and some cracks along the axial direction are observed, as a consequence of gamma radiation.

Figure 3. Modulus of elasticity of PCs with different fibre concentrations, irradiated at higher doses

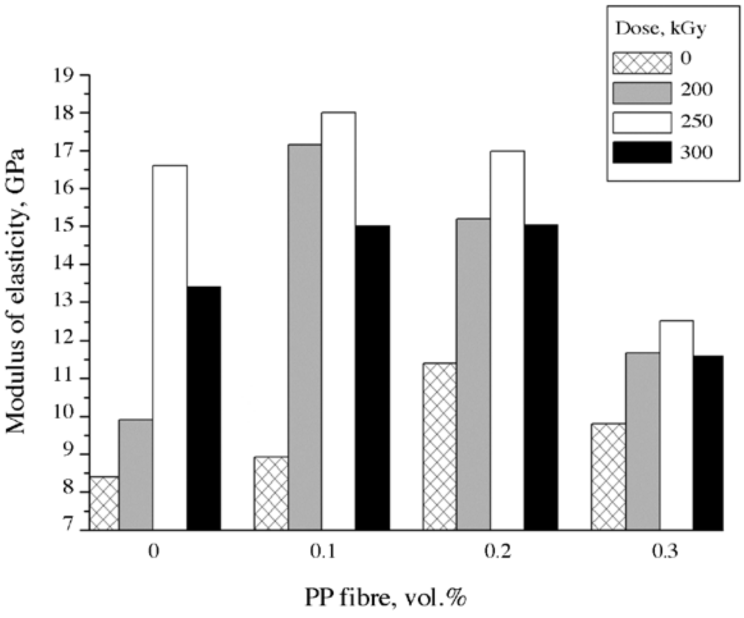
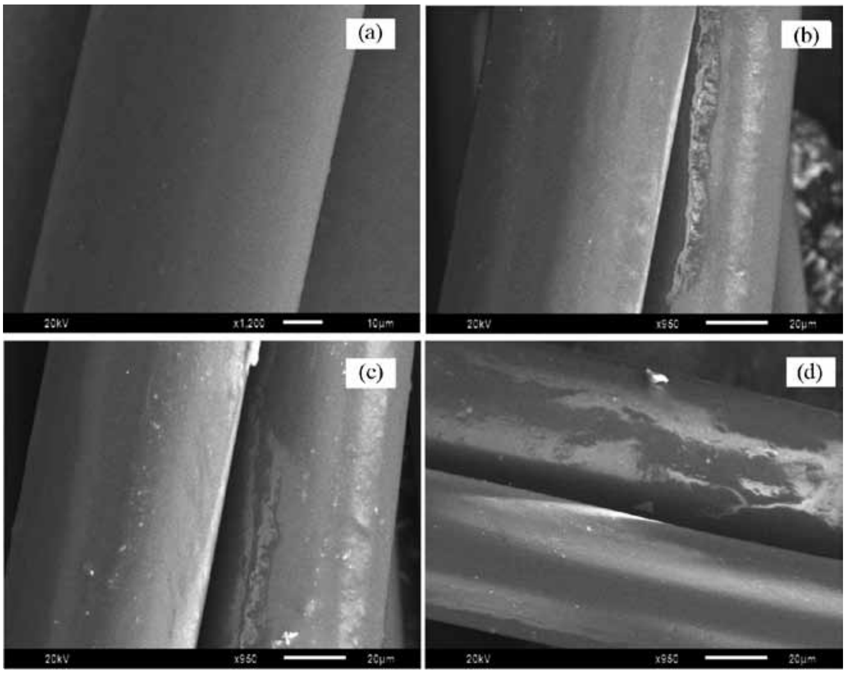


Figure 4. SEM images of polypropylene fibres: a) non-irradiated; and irradiated at b) 200 kGy; c) 250 kGy; and d) 300 kGy



4. CONCLUSIONS

Both polypropylene fibres and gamma radiation are already adequate tools for improvement of the mechanical properties of polymer concrete. Adding 0.2% vol of polypropylene fibres improves the compressive strength (15%), compressive strain (6%) and modulus of elasticity (35%), when compared to polymer concrete control (without fibres and non-irradiated). Moreover, when applying a dose of 250 kGy, is possible to obtain improvements of 62% on the compressive strength, and of 142% on the modulus of elasticity, but conversely a diminution of 23% on the compressive strain.

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