



Luffa fibers and gamma radiation as improvement tools of polymer concrete



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HIGHLIGHTS

- Polymer concrete with silicious sand, unsaturated polyester resin and luffa fibers was elaborated.
- The effects of gamma radiation and the luffa fiber concentration on compressive and flexural properties were studied.
- We show that the compressive strain and the elasticity modulus are higher than plain concrete.
- The higher gamma dose provides the highest elasticity modulus.

ARTICLE INFO

Article history:

Received 29 January 2013

Received in revised form 23 April 2013

Accepted 4 May 2013

Available online 30 May 2013

Keywords:

Polymer concrete

Luffa fibers

Gamma radiation

Mechanical properties

ABSTRACT

This work presents a study on the effects of luffa fibers and gamma radiation as tools for mechanical improvement of polymer concrete based on a polyester resin/foundry sand mixture. Different concentrations of irradiated and non-irradiated fibers (0.3, 0.6 and 0.9 wt%) and higher irradiation doses were used. The results show that the compressive strength and flexural strength values decrease gradually when increasing irradiated-fiber concentration, respect to plain concrete (without fibers and non-irradiated). Conversely an opposite effect occurs when polymer concrete is gamma irradiated, i.e. both the degree of polymerization and cross-linking of the polymeric resin are increasing. Moreover, the values for compressive and flexural strain as well as dynamic elasticity modulus increase when increasing irradiated-fiber concentration. The highest bending deformation is obtained with 0.9 wt% of fibers and 100 kGy of radiation dose.

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1. Introduction

Polymer Concrete (PC) is a composite material comprising a thermosetting resin bonded to mineral aggregates. Mechanical improvements of polymer concrete are based primarily on the properties of polymer resin and mineral aggregates as well as their concentrations. The mineral aggregates involve several linked characteristics: specific area, interfaces with the matrix, strength and deformability, geometry and size. For example aggregates with

irregular geometry and high surface area improve the anchorage with the matrix [1,2]. Moreover, some authors refer to different aggregate sizes ranging from 0.063 to 2.36 mm (mesh 230 to mesh 8) and different concentrations: from 70 to 90 wt% of polymer resin; the most common at 80 wt% of mineral aggregate and 20 wt% of polymer resin [3,4].

The mix design of polymer concrete involves an aggregate size gradation to provide the lowest possible void volume that will require the minimum polymeric binder concentration necessary to coat the aggregates and to fill the voids. Thus a variety of aggregate types have been used: silicates, gravel, limestone, calcareous rock, granite, clay, quartz, calcium carbonate, fine fly ash, phosphor-gypsum, cinder, silica fume, silica sand; the last one the most used due to size distribution, ranging from 0.6 to 4.0 mm (mesh 30 to mesh 5).

New alternatives for physicochemical modifications of polymer resin and mineral aggregates have been proposed. The low hard-

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ness of unsaturated polyester resin has been partly result adding liquid elastomers (reactive and/or non-reactive), or introducing dispersed solids, consisting of a soft immiscible phase as polymeric fibers [5–7]. Other methods, such as chemical attack or heat treatment are costly and time consuming.

When adding fibers the elastic characteristics of polymer resin is reinforced and improvement on fracture resistance is obtained, with better control and size distribution of cracks [8]. A lack of information concerning to fiber reinforced polymer concrete is present, moreover if natural fibers are contemplated. Some studies including the use of glass, carbon or boron fibers, as well as natural fibers as coconut or sugar cane bagasse. For example, when using short glass fibers or carbon fibers, the fracture properties are improved [8,9].

Natural fibers are a resource environmentally clean, renewable and biodegradable; then everyday more industries have interest in their use [10]. A natural fiber that has captured attention in applied research is luffa fiber, due to its physicochemical properties. They are from a subtropical plant of the cucurbitacea family, which produces a fruit with a fibrous vascular system (luffa). The fibers are composed mainly of cellulose (54%), hemi-cellulose (20%) and lignin (15%); with sizes between 1.5 cm and 1.5 m and a average diameter 8–10 μm [10]. It is abundant in China, Japan and other countries in Asia, Central and South America.

The study of the effects of natural fibers on the mechanical properties of resin based composites is in its early stages. One of the main characteristics of raw luffa fibers (without surface treatment) is its capacity to absorb moisture easily and its high potential as reinforced material in hybrid composites [11].

In polymer concrete physical interactions are present between polymer resin (matrix) and mineral aggregates, but no chemical bonds are present [12]. Therefore, improvements on the interfacial interaction between them are required. One proposal is to use gamma radiation to modify the surface of polyester resin and thereby achieve compatibility [13–18]. One can achieve good control of the dimensions and the elimination of internal stress; which cause reduction in mechanical strength [6].

The elastic modulus is the most often used characteristics of composites. In the case of building structures, the non-destructive tests (NDTs) take into account the acoustic impedance of the system components – important factors influencing ultrasonic wave propagation. Evaluations of different parameters such as defect detection, layer thickness or delaminations have been carried out by ultrasonic methods [19]. The dynamic elastic modulus is determined by measuring the pulse velocity along the composite and using electrical transducers located on the opposite sides of the cubic specimens of concrete. The energy supplied the ultrasound depends on how compact is the composite, including the void presence. One thus obtains the dynamic elastic modulus, $E_d = V^2 d / (1 + u) (1 - 2u) / (1 - u)$, here “ V ” is the pulse velocity; “ d ” is the mass density of the concrete specimen; and “ u ” is the Poisson ratio.

The gamma radiation applied to polymers causes three different process: breaking, cross-linking of chains, or graft. The permanence of any of these processes depends on the nature of the radiation, the chemical structure of the polymer and the applied dose [14,20]. Compared to thermal process or chemical attack, gamma radiation has more advantages in addition to spend less time and money. The advantages are: (a) initiating radiation requires no activation energy, (b) does not require catalysts or additives to initiate the reaction, (c) the initiation is homogeneous throughout the system [21], d) the process can be carried out at any temperature and can be interrupted at a specific reaction time, (e) the termination reaction is practically controlled, the polymer can be analyzed to a specific reaction step, and (f) during temperature initialization reaction is maintained, unlike the one presented in a conventional exothermic curing (without irradiation) [20–23].

The use of small concentrations of synthetic fibers in polyester resin ensures a homogeneous distribution of them. An optimal fiber concentration is required depending on the resin type. For example, improvement of 95% is obtained when using glass fibers as reinforcement and silane group agent. Moreover, with synthetic fibers the ductility increases but the modulus decreases; inclusive with long fibers the friction increases. Some works related to fiber reinforced polymer concrete show improvements on mechanical properties: adding 1 wt% of glass fibers the compressive strength is improved by 9%; or adding 2 wt% of carbon fibers an 16% is obtained [24].

In this paper polymer concrete is elaborated according to three different methods as follow: (a) PC = Plain Concrete, (b) AIF-PC = Added-Irradiated-Fiber PC and (c) DI-PC = Directly-Irradiated PC. The plain concrete does not contain fibers and non-irradiation is used. For the case of AIF-PC, luffa fibers are previously gamma irradiated and then adding to polymer concrete; and for DI-PC first non-irradiated luffa fibers are adding and mixed with foundry sand and polymer resin, after all PC is gamma irradiated. The compressive and flexural strength of all different polymer concrete were evaluated. Our research opens a window of opportunity for the use of low cost materials, as organic luffa fibers, and to promote environmental conservation.

2. Experimental part

2.1. Specimen preparation

We have prepared three different kind of polymer concrete: (a) PC, (b) AIF-PC and (c) DI-PC. The plain concrete was elaborated with 70 wt% of foundry sand and mixed with 30 wt% of polyester resin. While for the AIF-PC and DI-PC specimens the polyester resin concentration was maintained equal, but the foundry sand content was varying according to the luffa fiber concentrations (0.3, 0.6 and 0.9 wt%), used as reinforcement.

The polymer concrete specimens were elaborated with an isophthalic polyester resin (Aropol™ FS 3992) and siliceous sand (SP55-Sibelco). The resin was accelerated by 1% of cobalt octoate, and the methyl ethyl ketone peroxide (MEKP) was used as initiator. The sand with uniform granulometry had an average diameter of 245 μm (mesh 60); which was chosen as an intermediate value between particle-size ranging from 150 to 355 μm (mesh 100 to mesh 45), with which satisfactory results were obtained in previous studies [13].

Four different PC lots were prepared at different day; each lot contained six specimens. That is, for AIF-PC and DI-PC method of preparation 24 concrete specimens were made. After mixing, the polymer concrete prism specimens ($4 \times 4 \times 16$ cm) were placed in a controlled temperature room at 23.0 ± 3.0 °C for 24 h.

2.2. Mechanical tests

Mechanical behaviors of reinforced and plain PC formulations were assessed by means of flexural and compressive tests. For each PC formulation four specimens were tested. Prismatic specimens were tested in three-point bending up to failure at a constant loading rate of 1 mm/min over a span of 100 mm, as specific by RILEM CPT PCM-8 test method. The two pieces of each broken specimen in bending were posterior tested in compression by using Instron Universal testing machine, with a load cell of 100 KN, at the loading rate of 1.25 mm/min, following the procedure described in UNE 83821 test standard. The dynamic modulus of elasticity was measured by using an ultrasonic testing equipment for building materials: Ultrasonic Pulse Velocity Tester model 58-E0048 (Controls™, Cernusco, Italy), with an ultrasonic resolution of 0.1 ms.

2.3. Morphological characterization

Both irradiated and non-irradiated luffa fibers were dried in a rotovapor for 24 h. Then the luffa surfaces were analyzed by scanning electron microscopy in the secondary-electron mode by using a JEOL model JSM-6510LV machine.

2.4. Irradiation procedure

Both the luffa fibers and the polymer concrete with luffa fibers were exposed to gamma radiation dose of 50 and 100 kGy in air at room temperature. A dose rate of 3.5 kGy/h was applied by using a Transelektro irradiator LGI-01 provided with a ^{60}Co source manufactured by IZOTOP Institute of Isotopes Co. Ltd., Budapest, Hungary, and located at the National Institute of Nuclear Research (ININ-Mexico).

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