Effect of the Loofah-fibers on the mechanical properties of Polymer Concrete

M Martínez-López 1, G Martínez-Barrera 2* and E Martínez-Cruz 1

1 Posgrado en Ciencia de Materiales, Facultad de Química, Universidad Autónoma del Estado de México, Toluca México.

2 Laboratorio de Investigación y Desarrollo de Materiales Avanzados (LIDMA), Facultad de Química, Universidad Autónoma del Estado de México, Km.12 de la carretera Toluca-Atlacomulco, San Cayetano 50200, México. E-mail: gonzomartinez02@yahoo.com.mx

Abstract: Polymer Concrete was reinforced with Loofah fibers in order to improve the compressive and flexural strength. Polymer concrete specimens were prepared with 70% of silicious sand, 30% of polyester resin and various fiber concentrations (0.3, 0.6 and 0.9 vol%). The results show decrease in the values of mechanical properties including flexural strength, compressive strength and compression modulus of elasticity.

1. Introduction

In early civilizations natural polymers combined with inorganic materials were used to produce high strength construction materials. Natural polymers as albumen, blood and rice were used in ancient mortars; the ‘asphalt’ a natural polymer was used in Babylonia in the mortars and clay brick walls; while in Harappa bituminous mortars were used, or the most famous "glutinous rice paste lime" used to build the Great Wall of China [1- 3].

Concrete is the most widely used structural material in the world, due to its easy preparation and low cost. Some disadvantages on concrete are: a) the pores which becoming entrance points for water, water vapor, gases and chemical substances that could damage to concrete; b) the roughness of concrete surface deteriorates rapidly due to its high abrasion; c) poor resistance to aggressive substances and salty water; d) poor resistance to heat. One alternative for such problems is the incorporation of polymer materials into concrete. They have good binding with mineral aggregates. Combining these with organic compounds, promotes the development of polymer-based materials with wide properties. Moreover, with synthetic polymers is possible to produce cheaper and more flexible materials [4].

Polymer concrete (PC) is a particulate composite where thermoset resins binds inorganic aggregates instead of the water and cement binder typically used in Portland cement concrete (PCC). Polymer concrete consists of a polymeric matrix and dispersed particles of strengthening phases. The polymers constitute the continuous phase hence the composite behavior is largely determined by the properties of the polymer, which are dependent on time, structure and temperature [5]. These composites have some advantages compared to ordinary cement concrete such as: fast hardening, high mechanical strength and high chemical resistance. The features of polymeric concrete depend on the polymer properties, type of filler and aggregates, and the component concentrations. Its applications are continuously diversifying including the building cladding dating from 1958. In recent years the applications include: cultured marble for counter tops, as repair material, overlays for bridge and floors, sport arenas and stadiums, laboratories, hospitals, factories; also precast polymer concrete is used for drains, underground boxes, manholes, acid tanks and cells, tunnel lining, shells, floor tiles, architectural moldings and machine tools and bases.
Polymer binder can be a thermoplastic, but more frequently a thermosetting polymer. The most frequent polymers are: methyl methacrylate, polyester prepolymer-styrene, epoxy prepolymer-hardener and furfuryl alcohol.

The polymer concrete advantages versus conventional hydraulic concrete include: Lightweight (1/10 to 1/3 of the concrete weight); high compressive, flexural and tensile strengths (3 to 5 times higher than conventional concrete); reduced installation costs by its easy handle; stable under freeze/thaw conditions; higher impact resistant; low water absorption (less than 1%); resistant to alkalines, acids, weathering and other forms of deterioration; outperforms conventional materials for longer service and has lower life cycle costs; nonflammable and nonconductive.

In order to improve the mechanical strength and the control on the cracks, fibers are added to the polymer concrete. Historically the natural fibers were used for reinforce building materials, but with the arrival of the plastic era, the synthetic fibers shift to natural fibers. Nowadays many scientific and technological efforts are developing for to use again natural fibers as reinforcements. Many natural reinforcing materials can be obtained at low cost by using manpower and technical know-how. Recent studies show that the addition of natural fibers on hydraulic concrete does not significantly influence on the compressive strength but the tensile strength, flexural strength and toughness are substantially improved. The most important contribution of the fibers can be evaluated by determining the fracture toughness of the composite [6-8]. Substantial experience and broader knowledge of the optimal compositions, properties and stress-strain relationships of the fiber-reinforced polymer concrete are necessary with respect to design, production and quality control. However, the data on polyester and epoxy polymer concrete are rather limited, and there is an increasing interest in the deformation characteristics under working conditions. Some studies include chopped strand glass-fibers for to improve the strength and the crack propagations [9].

Natural fibers (coconut, banana, sugar cane bagasse and cellulose) and glass, carbon or boron fibers have been added to polymer concretes. In particular the coconut fibers are excellent reinforcements, and the crack propagation can be controlled by addition of short glass or carbon fibers. A new natural fiber that has attracted attention is the luffa fiber (60% cellulose, 30% hemicellulose and lignin 10%) due to its surface area, low specific gravity, tensile strength (29.4 MPa) and elasticity module (3.4 GPa) [10,11].

In this work the compressive and flexural strength, as well as the modulus of elasticity were measured on polymer concrete reinforced with loofah fibers. The influence of fiber reinforcement was investigated.

2. Experimental

2.1. Specimen preparation

The polymer concrete specimens were elaborated by mixing silica sand SP55-Sibelco (as mineral aggregate with average diameter \(d_{50}\) of 245 μm and 2.65 g/cm³ of density) and a commercial unsaturated polyester resin (orthophthalic) in a 70/30 volume ratio. The resin is a viscous liquid with a styrene monomer content of 30% (‘Aropol™ FS 3992, Matexplás, Porto, Portugal). The proportions of the methyl ethyl ketone peroxide (MEKP) initiator added to the polymer for initiating the free radical polymerization process was 1 mL/b by 100 g of the resin weight.

Four different lots of polymer concrete were prepared according to the loofah-fiber (average diameter of 245 μm) concentration, namely 0, 0.3, 0.6 and 0.9 vol%. Each lot has six specimens, meaning 24 polymer concrete specimens for each test. After mixing, the polymer concrete specimens (4x4x16 cm according to RILEM CPT/PC-2 standards) were placed in a controlled temperature room at 23.0 ± 3.0°C for 24 hours.

Mechanical Tests
The compressive and flexural tests of the polymer concrete specimens were carried out in an Instron Universal Testing Machine, with a load cell of 100 kN, according to UNE 83821:1992 test standard and RILEM standards flexural analyses (three-point bending tests).

3. Results and Discussion

3.1. Compressive strength

In Figure 1a we show the compressive strength $\sigma_c$ values for polymer concretes elaborated with different loofah fiber concentrations. The values diminish when increasing the fiber concentration. The lowest value, namely 19 MPa is 30% less than that for polymer concrete without fibers. Such lowest value was obtained by polymer concrete with 0.9 vol% of fiber.

Some considerations are involved in the diminution of the compressive strength of the polymer concretes: a) When the polymer concrete is subject to compression, a major number of fibers contribute to increase the number of cracks and consequently the numbers of failures, thus lower compressive strength is obtained; b) High porosity and large liquid absorption capacity (13.6 g/g) of the loofah fibers contribute to diminish the compressive strength; c) Unlike other fibers, such as steel or polypropylene, the loofah fibers do not have uniform characteristics as diameter or length, due to its own nature. This anisotropy in loofah-fibers affects significantly when applied the load.

3.2. Compressive strain at yield point

The compressive strain at yield point values are shown in Figure 1b. The values are increasing when the fiber-loofah concentration increases. The highest value, namely 0.24 mm/mm is 21% higher than those for non-fiber polymer concrete. The compressive strain values have an opposite behavior than those for the compressive strength (as one increases the other decreases).

3.3. Compression Modulus of Elasticity

The values of the compression modulus of elasticity $E_c$ are decreasing when the loofah-fiber concentration increases (Figure 2a). Similar behavior was observed for the compressive strength values. The lowest value (1.89 GPa) is 33% minor than those obtained by non-fiber polymer concrete.
3.4. Flexural Strength

The flexural strength values of the polymer concrete with loofah-fibers are shown in Figure 2b. The values decrease when loofah-fiber concentrations are increasing. The lowest value, namely 9 MPa, is 18% minor than those obtained by non-fiber polymer concrete.

4. Conclusions

By adding loofah fibers to polymeric concrete it was possible to diminish the compressive strength (42%); flexural strength (23%) and Young's modulus (48%). Nevertheless, the compressive strain was increasing (26%). Such results can be attributed to the characteristics of the loofah fiber, high porosity and water absorption capacity. The fiber pores act as "flaws" in the polymer concrete, thus adhesion between the resin and sand decrease.

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