Composite Structures 111 (2014) 468–472

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Mechanical behavior of piassava fiber reinforced castor oil polymer mortars

J.M.L. Reis *, E.P. Motta

Theoretical and Applied Mechanics Laboratory – LMTA, Mechanical Engineering Post Graduate Program – PGMEC, Universidade Federal Fluminense – UFF, Rua Passo da Pátria, 156 Bl. E sala 216, Niterói, RJ, Brazil

ARTICLE INFO

Article history:
Available online 31 January 2014

Keywords:
Natural fiber
Natural polymer
Polymer mortars
Mechanical properties

ABSTRACT

From the past decades, growing global awareness concerning natural resources and recycling has resulted in the interest on biocomposites. Natural fibers embedding on natural polymers constitute an excellent alternative for the development of biocomposites. The aim of this work is to evaluate the use of natural fibers, piassava (*Attalea Funifera Mart*) scraps from broom industry, as reinforcement of natural polymer based mortars. The biopolymer matrix is manufactured from castor oil obtained by expressing the seed of the plant *Ricinus Communis*. Mechanical properties of castor oil polymer mortars reinforced with 1 and 2 wt%. of piassava fibers lees are analyzed with particular regards to compressive, flexural and fracture properties. The results showed that castor oil polymer mortars reinforced with piassava fiber lees produces similar properties to epoxy based polymers mortars therefore, proving that it is an excellent biocomposite alternative.

1. Introduction

Sustainable material is a concept connected to the growing global awareness raised from the scarcity of natural resources and energy, solid waste generation and greenhouse gas emission. The discussion about the preservation of natural resources and recycling has increase the interest concerning biomaterials with the focus on renewable raw materials. Biocomposites consist of biodegradable polymer as matrix material and usually biofiber as reinforcing element [1]. Since both components are biodegradable, the composite as the integral part is also expected to be biodegradable. By embedding natural reinforcing fibers, e.g. flax, hemp, ramie, etc. into biopolymeric matrix made of derivatives from cellulose, starch, lactic acid, etc.; new fiber reinforced materials called biocomposites were created and are still being developed [2].

Natural fibers have the advantages of locally available renewable resources, low cost, lightweight, possibility of environmental protection and good mechanical properties compared with traditional reinforcement material such as glass fiber [3–8]. Natural fibers offer reduced dependence on non-renewable energy/material sources, induce lower pollutant and lower greenhouse gas emissions, enhance energy recovery and produces biodegradable components after use [9–14]. Piassava is a lignocellulosic fiber extracted from the leaves of palm tree native from the south of the state of Bahia, Brazil [15]. The main use of the piassava fibers is in the production of industrial and domestic brooms, brushes and kiosk coverings. However, it is estimated that 20% of those fibers are eliminated during the industrial process, being burnt in most of the time [16,17].

The fiber content (around 48%) is the highest among the lignocellulosic fibers [18,19] compared to other lignocellulosic materials, and the ash level (0.8%) is low [20]. Studies with piassava (*Attalea Funifera Mart*) fiber showed that it can be used to reinforce polymer matrix composites [16–19,21,22]. It was reported that composites of epoxy and unsaturated polyester polymer mortars reinforced with piassava fiber showed an improvement of mechanical performance due to the increase of fiber polymer matrix interface adhesion [21,22]. Polymer mortar (PM) is a cementless composite, made of inorganic aggregates bonded together by a binder resin, in this case castor oil polyurethane resin, which substitutes the cement. The composition of PM is determined by its applications, and its strength is influenced by the ratio of aggregate to resin content [23–25]. In this work, to characterize the biocomposite, a natural resin, manufactured from a plant oil, is used as polymer mortar matrix. Castor oil is obtained from extracting or expressing the seed of a plant, which has the botanical name *Ricinus communis* [26]. Chemistries can synthesize polyols and prepolymers having different characteristics originating from the

* Corresponding author. Tel.: +55 2126295588; fax: +55 2126295585.
E-mail address: jreis@mec.uff.br (J.M.L. Reis).

http://dx.doi.org/10.1016/j.compstruct.2014.01.023
0263-8223/© 2014 Elsevier Ltd. All rights reserved.

castor-oil plant which, when mixed, produces a polyurethane [27]. Castor-oil-based polyurethane is competitive in comparison to other polymers because, in addition to its main mechanical properties, it derives from a low-cost natural and renewable raw material. Furthermore, it is flexible, rigid, and possesses molecular interchains and intercross strength conferred by the balancing of the chemical characteristics of the polyol in combination with the pre-polymer [28].

The proposal of this work is to study the mechanical properties, compressive, flexural and fracture, of piassava fiber reinforced polymer mortars manufactured with a polyurethane resin derived from castor oil and compare to synthetic polymer mortars. The fabrication process development and the mechanical characterization of this new biocomposite are essential for its structural or functional application, presenting a great potential in the construction industry.

2. Materials and methods

2.1. Materials

To manufacture piassava fiber castor oil polymer mortars specimens, piassava fiber lees, foundry sand and castor oil polymer resin were mixed. Piassava fibers were obtained from the broom industry of northeast state of Bahia and have been described as harder than others lignocellulosic fibers. The main application of piassava fibers is to produce brooms but a significant amount of residue is produced and cannot be used. Normally it is disposed in landfills and is called lees [17].

The piassava lees were shredded and used as partial replacement of natural aggregate. The ratio used in these mixtures was 1% and 2% in weight, substituting aggregates in the mixture. This amount of piassava fibers was chosen according to previous study [21]. Large amount of natural replacing fibers, more than 2%, do not reinforce polymer mortars. It only contributes to increase porosity and decrease the mechanical properties.

Lees were washed and vacuum dried for 24 h in order to eliminate the impurities and humidity. The density of piassava lees was determined using a pycnometer, and it was found 1.10 g/ml.

The aggregate was foundry sand with a homogeneous grain size, with uniform grains and a mean diameter of 300 μm, with finesses modulus between 3 and 5. The aggregate content was 88% in weight. The specific gravity of the foundry sand was 2.63 g/cm^3. Before being added to the polymeric resins to reduce moisture content, the foundry sand was dried, insuring a good bond between polymer and inorganic aggregate.

The employed thermosetting castor oil polyurethane resin was developed by the Group of Analytic Chemistry and Technology of Polymers, USP, São Carlos, Brazil and was manufactured and provided by Plural Brazil. Resin content was 12% in weight and no filler was added. Table 1 presents the castor oil polyurethane resin properties [29,30].

The castor oil polyurethane resin consists of two components, polyol and pre-polymer. The polyol was synthesized from the castor oil and a tri-functional polyester with hydroxyl index of 330 mg KOH/g was obtained. The pre-polymer was synthesized from diphenylmethane diisocyanate (MDI) and pre-polymerized with a polyol also derived from castor oil, keeping a percentage of isocyanate free for posterior reaction. The approximate densities of the pre-polymer and polyol were 1.17 and 0.98 g/cm^3, respectively. The castor oil resin was processed mixing the procepolyol and pre-polymer in a weight ratio of 1:1.

Piassava fiber reinforced castor oil polymer mortars compression, flexural ad fracture specimens were compacted in a steel mold. The specimens were cured at 110 °C during 3 h.

Table 1
Castor oil polyurethane resin properties.

Property	Castor oil polyurethane
Color	Dark yellow
Density (g/cm^3)	1.1
Hardness shore *D*	70
Modulus of elasticity (GPa)	2.0
Glass transition temperature – Tg (°C)	60

2.2. Methods

Prismatic polymer mortar beams 40 mm × 40 mm × 160 mm were tested by three-point bending up to failure at a loading rate of 1 mm min^{-1}, with a span length of 100 mm, according to the RILEM specification TC113/PCM-8 [31]. Despite the very short span compared to the thickness, shear effect was disregarded. Polymer mortar is considered an isotropic material and the plane cross-section theory was assumed. To determine the compressive properties, the two leftover parts of each broken specimen in bending were tested at the loading rate of 1.25 mm min^{-1}, following the procedure described in UNE 83821:1992 standard [32]. Applied test operating methods in flexure and compression were similar to those specified in EN 196-1:2005 [33].

To determine the fracture properties, the Two Parameter Method (TPM) [34] was used. This method is a direct method to calculate critical stress intensity factor, K_{Ic}, which is a measurement of a material's resistance to crack extension when the stress state near the crack tip is predominantly plane strain, limiting the plastic deformation, and the opening mode monotonic load is applied. Also the fracture energy was calculated according to RILEM [35]. Fracture tests specimens had 30 mm × 60 mm × 240 mm and were conducted using a universal testing machine with a cross-head speed of 0.5 mm min^{-1}. The crack mouth opening displacement (CMOD) was measured using a COD gauge clipped at the bottom of the beam and held in position by two 1.5 mm steel knife edges glued at the specimen.

3. Results and discussion

Piassava fiber reinforced castor oil polymer mortars test results are presented in Table 2.

According to Table 2 it can be seen that, piassava fibers act as reinforcement to castor oil polymer mortars. In compression a small decrease in strength, 2.1%, is calculated for 1% of piassava fiber content and an increase of 4.4% is reported for 2% of piassava fiber content. According to Ribeiro et al. [22] when piassava fibers were used as reinforcement in polyester polymer mortars and tested in compression an increase in strength was observed, 14.3% for 1% piassava fiber content and 10.5% when 2% of piassava fibers were used as aggregate replacement. Comparing to plain castor oil polymer mortar to epoxy ones from previous work [29] a slight decrease, 2.2%, is observed and an increase of 55.2% when compared to unsaturated polyester PM.

When piassava fiber reinforced castor oil polymer mortars are tested in flexion it is observed that the flexural strength decrease for both piassava fiber content. For 1% of piassava fiber content a decrease of 12.7% in the flexural strength is reported and when 2% of piassava fiber is analyzed, a diminish of 9.6% is observed. Again, similar behavior to synthetic polymer mortars is reported. An insignificant improve, 0.8%, in the flexural strength was calculated by Ribeiro et al. [22] when 1% of piassava fibers were used in polyester polymer mortars, and a decrease of 3.5% in the flexural