Construction and Building Materials 128 (2016) 315–323

Contents lists available at ScienceDirect

Construction and Building Materials

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

Comparative analysis of the sisal and piassava fibers as reinforcements in lightweight cementitious composites with EVA waste

Felipe M.R. dos Santos *, Thiago F. de Souza, Danilo M. Barquete, Franco D.R. Amado

State University of Santa Cruz, Rodovia Jorge Amado, km. 16, Bairro Salobrinho, Ilhéus, Bahia, Brazil

HIGHLIGHTS

- Both vegetable fibers caused a reduction of 10–30% in the compressive strength.
- EVA affects significantly and negatively the compressive strength of the composite.
- There was a gain in tensile strength in bending when sisal fibers were added.
- Fibers changed behavior of the matrix, making the composites more ductile and tough.
- Sisal fiber was more efficient as reinforcement in cementitious composites with EVA.

ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 20 September 2016
Accepted 6 October 2016
Available online 25 October 2016

Keywords:
Cementitious composite
EVA waste
Piassava
Sisal
Vegetable fiber

ABSTRACT

In this work, was performed a comparative analysis of the mechanical properties resulting from the addition of sisal and piassava fibers in lightweight cementitious composites with EVA. The workability, compressive strength, apparent specific mass, tensile strength in bending and deformation capacity were assessed in mixtures and cylindrical and prismatic specimens. EVA reduced apparent specific mass and mechanical properties of the composites. Sisal produced a maximum increase of 49.08% in tensile strength in bending of cementitious matrix with EVA, whereas piassava ensured greater deformation capacity up to rupture, with maximum elongation of 12.693 mm. Ultimately, sisal was more efficient as reinforcement.

1. Introduction

To meet the new demands of society, new products must eliminate or minimize environmental impacts. In the civil construction sector, a large consumer of raw materials and one of the largest generators of solid waste, this trend is associated with the concept of sustainable construction. This concept is directly related to the efficient use of natural and energy resources, rational use of materials, waste management, use of products and technologies with less impact on the environment and social responsibility. A product recently used for this purpose is lightweight concrete, which has reduced specific mass and better acoustic thermal comfort in comparison with the conventional one, in addition to reducing building costs. The technology of lightweight concrete is capable of producing reductions of up to 30% in the cost of a foundation in construction [1].

According to Tutikian et al. [2], lightweight concrete is obtained by the introduction of voids in the concrete mass, by incorporation of air bubbles, through spaces between the particles of aggregates or using aggregates with high rates of "voids" or air bubbles, called lightweight aggregates. The lightweight aggregates can be natural or synthetic. Manufacturing processes include sintering, rotary kiln and crushing, which require high energy consumption. In addition, this production can lead to depletion of natural resources or raw material (thermo-expansive clay). In this context, ethylene vinyl acetate (EVA) waste from the footwear industry becomes a suitable option of lightweight aggregate. Besides the large availability (about 190,400 tons of waste generated worldwide every year), EVA waste does not need any heat treatment to be used as lightweight aggregate [3].

The use of lightweight aggregates can reduce crack propagation, increasing the capacity of energy absorption during fracture. However, it decreases the mechanical properties of concrete. Rios et al. [4], Hwang and Ko [5] and Rossignolo and Agnesini [6] studied cementitious composites with incorporation of styrene butadiene

* Corresponding author.
E-mail address: felipe_mrs@hotmail.com (Felipe M.R. dos Santos).

http://dx.doi.org/10.1016/j.conbuildmat.2016.10.035
0950-0618/

rubber (SBR) waste. Results showed that SBR causes a reduction in the compressive strength of the cementitious matrix, and this reduction increases with the increasing content of SBR. Studies carried out by different authors to obtain concrete with EVA lightweight aggregates showed a reduction in compression strength [3,7–10]. Santiago et al. [7] produced lightweight concrete using, in partial replacement of natural coarse aggregate, EVA waste and construction and demolition waste (CDW), and assessed their influence on the mechanical behavior of concrete under direct compression. Results showed that EVA, unlike CDW, had a strong influence on the compression strength of concrete, reducing it by 77%, when 50% EVA was added, compared with the reference. Similarly, Lima et al. [3] reported the same effect of EVA on the compressive strength of concrete. Other studies, such as the one conducted by Souza [11], showed that EVA lightweight aggregates also reduce the tensile strength in bending of concrete. Lima et al. [3] also evaluated the tensile strength in bending of lightweight concretes produced with EVA and CDW wastes. Through the obtained results, it was observed that the values of tensile strength in bending of concrete decrease with the addition of both CDW and EVA. This reduction is higher for EVA and grows with the increase in its content in the concrete. To minimize this effect on the tensile strength in bending, other types of more resistant aggregates can be incorporated into the concrete mass. An option are fibers, which can be natural or synthetic. Natural fibers have acceptable specific properties (such as tensile strength and elasticity modulus) for use in cementitious composites in many applications, and provide advantages compared with synthetic fibers, such as low density, lower cost and the fact of being obtained from what are considered renewable sources. According to Udoeyo and Adetifa [12], asbestos is the most used natural fiber in construction. However, due to its potential to cause damage to human health, its replacement by other natural fibers has been sought, usually of vegetable origin.

When added to the more brittle matrix, fibers retard and reduce cracking, can improve the tensile strength in bending and impact and increase toughness and ductility, allowing relatively large deformations without loss of integrity [13–16]. For Bentur and Mindess [17], the efficiency of the fibers can be measured by the increase in strength and toughness in the composite. In tensile and tensile in bending tests in sisal fiber-reinforced composites, Lima [14] found a reduction in the tensile strength of composites compared with the reference without fibers. However, a trend towards increase in this property as the fiber content increased was observed. This was also observed by Ismail [18], who, unlike Lima [14], found values of tensile strength of the composites with natural fibers higher than those of the cementitious matrix, reaching 53%. Regarding deformation capacity up to rupture and toughness, both authors confirmed improvements compared with the brittle behavior of the cementitious matrix.

Arruda Filho et al. [19] evaluated the mechanical strength of cementitious slabs with incorporation of industrial wastes (ceramic waste, EVA) and sisal fibers (aligned or randomly distributed). Test results showed values of tensile strength in bending slightly lower (about 3%) than the reference without fibers for the slabs with randomly distributed sisal fibers, and higher values for the slabs with aligned sisal fibers. Moreover, all plates showed a higher deformation capacity up to rupture, being more ductile and tough than the brittle matrix. Souza [11] evaluated the tensile strength in bending of cementitious composites with EVA (percentages: 4, 6, 8 and 10%; sizes: 16 and 50 mesh) and cementitious composites with EVA (6% of 16 mesh) and piassava fibers (percentages: 1 and 2%; sizes: 1, 2 and 4 cm). There was a reduction in the property with the addition of EVA, and a trend towards a greater reduction with the increase in the percentage of incorporation and with the reduction in EVA size. In contrast, piassava fibers increased tensile strength in bending of the composites compared to the reference without fibers and the matrix only with EVA. A trend towards increase in the property with the increase in fiber percentage and size was also observed. The author also concluded that the addition of EVA did not change the brittle behavior of matrix, whereas the addition of piassava fibers modified this behavior, presenting greater displacements (maximum of 17.5 mm for 2% of 4 cm fibers) after the appearance of the crack, improving the deformation capacity of the composite.

Plants such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana and wood are increasingly being applied as means to supply lignocellulosic fibers for reinforcement of composites [20] and for application in construction elements such as roofing tiles, wall panels and water reservoirs. Some disadvantages limit the greater use of these composites in large scale, for example, the reaction of natural fibers with the cement alkalis, which weakens the fibers and reduces the durability of the product. The variability in the characteristics of each type of fiber and the preparation process for use in cementitious matrices are also problems to be overcome, since they hamper the production process.

Agopyan [21] listed 18 types of vegetable fibers potentially useful for civil construction. Savastano Junior and Pimentel [22] selected 8 types of fibers grown by the main Brazilian producing centers. In this paper, sisal and piassava fibers were used as reinforcements because they are abundantly found in the Bahia state. Sisal (*Agave sisalana* Perrine) provides the main hard fiber produced in the world, one of the most widely used and researched natural fibers [23]. Currently, Brazil is the largest producer in the world and Bahia is responsible for 80% of the national production [24]. Extracted from the leaves, the fiber is primarily intended for the cordage and handicraft industry for the manufacturing, for example, of twine, bags, fabrics, nets and mats [24–26]. Palm (*Attalea funifera* Mart.) is the origin of the piassava fiber. In 2014, the collected amount of piassava fibers in Brazil was 45,758 tons, Bahia being the main producing state (43,585 tons), followed by Amazonas (2166 tons), Maranhão (7 tons) and Acre (1 ton). Bahia holds 17 of the top 20 national producers, especially the cities of Ilhéus, Nilo Peçanha, Cairu and Ituberá, which account for 82.9% of total production [27]. Piassava fibers are applied in the manufacturing of brooms, industrial brushes, ropes, baskets, carpet and roofs [28].

Although both fibers have their established markets, their use as reinforcement of composites for construction can add value and ensure a greater demand for them [26,29]. Studies on the use of sisal fiber as reinforcement of cementitious matrices began in the 1980s. Several studies have been conducted on this issue, aiming at the characterization and the development of composites with acceptable properties and durability as well as the production and the financial and technical viability of products for the civil construction. Studies with piassava fiber reinforcing cementitious matrices are more recent.

As sisal fiber is the most widely used commercially and in researches, and piassava fiber is still little explored, this paper aims to carry out a comparative analysis of the properties of cementitious composites produced with each of these fibers singly.

2. Materials and methods

2.1. Materials

The materials used in this paper were Portland cement CP V ARI (Mizu brand), quartz sand with a maximum diameter of 1.2 mm, metakaolin (Metacaulim do Brasil brand), fly ash (Pozo Fly brand), EVA waste, piassava fibers, sisal fibers and water.

The specific masses of cement (3.04 g/cm^3), metakaolin (2.65 g/cm^3) and fly ash (2.28 g/cm^3) correspond to of manufacturer. Table 1 presents some properties of cement, according to