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Basalt fiber ropes and rods: Durability tests for their use in building engineering

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ABSTRACT

Basalt is a common material used in constructions since antiquity. Nowadays its fibers (BFs) are going to be used as an alternative to glass, carbon or aramid fibers for strengthening purposes in building engineering. In particular, the use of basalt ropes on historic masonries seems to be a good solution to give them a monolithic behavior. Besides, basalt fibers reinforced polymer (BFRP) rods have emerged as a possible solution to the corrosion problems of steel reinforcement in reinforced concrete for new or damaged structures or to the strengthening of historic masonries by repointing. Anyway, there is till a lack of knowledge about their durability. Thus this paper presents durability tests performed on BF ropes and BFRP rods. The influence of water, acid and alkali aging solutions on the durability and on the mechanical strength of them was verified. In order to increase the durability in alkali environments (i.e.: concrete), a PMMA coating was also applied on the BFRP rods and its effect was assessed too. Results show that alkali environments could seriously affect the durability of BF ropes and BFRP rods, thus a suitable coating should be provided to protect them before their use on such environments.

1. Introduction

Basalt is an emerging material, whose use is increasing in constructions and civil applications as an alternative to glass, carbon or aramid fibers. Basalt is a natural material that can be found in volcanic rocks. Since antiquity basalt was used in constructions and nowadays continuous basalt fibers are obtained by melting basalt (basalt rocks can be molten approximately between 1500 and 1700 °C [1,2] and forcing it through platinum/rhodium crucible bushings to create fibers [3]. This technology (continuous spinning) can offer the basalt material in the form of chopped fibers or continuous fibers, that can have a great potential application to composite materials [2,4], having an additional advantage in cost: basalt fibers is considered less expensive than the glass ones, the most similar to them [4–18]. As shown by Kogan and Nikitina [19] even if asbestos and basalt fibers present similar composition, basalt seems to be safe, because of different morphology and surface properties avoiding any carcinogenic or toxicity effects, which are presented by asbestos instead.

Furthermore, basalt fibers seem to have better tensile strength than E-glass fibers, greater failure strain than carbon fibers as well as better resistance to chemical attack, impact load and fire with less poisonous fumes [18]. From these advantages, the applicability of basalt fibers as a structural strengthening material is highly expected in constructions and civil engineering. In this way, some recent researches propose basalt in form of short fibers for insulating material (basalt wool), for reinforced concrete (chopped fibers) or like reinforcing material in restoration and rehabilitation of concrete [18] and masonry structures [12,20], or like reinforcing material for FRP bars used in concrete technology [21]. Its application in passive fire protection field [22] is also important.

If basalt fibers have a good resistance to weather, alkaline and acids exposure, basalt products could have not the same good durability and very few research are present in literature on this issue [20,23] and few long-term performance data are available for BFRP composites to date [24,25]. In this way, it is necessary to have as soon as possible experimental results about durability of basalt fiber products in order to show their real performances and evaluate their real applicability.

This work focuses on durability of Basalt Fiber (BF) ropes and Basalt Fiber Reinforced Polymer (BFRP) rods. BF ropes and BFRP rods have in fact good mechanical characteristics [20] and could represent a promising way for architectural heritage retrofitting innovative techniques, which are aimed to strengthen historic masonry [26–28]. Besides, BFRP rods have emerged as a possible solution to the corrosion problems of steel reinforcement in

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reinforced concrete for new or damaged structures. However, they are new commercially available products, so it is very important to define their properties especially their durability in different environmental conditions. To evaluate the chemical durability of fibers or fibers products, different solutions at different pH-values are commonly used in combination with raised temperature, leading to highly aggressive aging conditions.

Thus, accelerated aging tests were performed on both BF ropes and BFRP rods [29,30] in different environmental conditions. The influence of water on their durability was evaluated because this is a critical issue since building constructions and civil structures are usually exposed to moisture during their service life. The influence of alkali was also assessed. This is important because historic masonries, and, especially reinforced concrete, are high alkaline materials. Finally, chloride environmental condition caused i.e. by seawater was tested. The influence of each aging environment on the corrosion process was then evaluated and changes in mechanical properties of ropes and rods were also verified by tensile tests and short beam tests before and after the aging tests [31]. In particular, in order to increase the durability especially in alkali conditions, a polymethyl methacrylate (PMMA) coating was applied on the BFRP rods and the durability tests and the mechanical resistance was verified and compared with that of uncoated materials.

2. Experimental: materials and methods

2.1. Materials: BF ropes and BFRP rods

BF ropes of 4 mm of diameter were used in this experimental program (Fig. 1a). The 4 mm rope was obtained braiding eight rows of basalt fiber yarns over a single row of basalt fiber yarn. The relevant features of continuous basalt fiber yarn used to create the ropes are reported by Quagliarini et al. [20]. In particular, the chemical analysis is consistent with the typical composition of acidic basalt (silica content higher than 46 wt%) with 10 wt% of iron oxide that explains the dark color. BFRP rods of 8 mm (Fig. 1b) of nominal diameter (declared by manufacturer) were used in this work. The most interesting feature of this kind of product is to permit an improved adherence thanks to the wraps of helical braid of fibers that create a continuous embossed rib placed on bar bearing core (Fig. 1c), composed by a basalt fiber filament rowing. As characterized by Quagliarini et al. [20] the fiber content in the rods is around 80% (by weight) and the filled matrix is a vinylester resin. The specimen geometric features have been determined adapting prescriptions provided by Italian Technical Document CNR DT 203/2006 [32] for a little smaller sample. In particular, for an accurate interpretation of characteristic mechanical values derived by following tests, the rods equivalent cross section (A_b), that results equal to 39.01 mm^2, was determined. So the rod equivalent diameter results equal to 7.04 mm.

2.2. Methods

2.2.1. Chemical durability of BF ropes

In order to assess the chemical durability of basalt ropes in different chemical media, the basalt ropes were boiled variously in distilled water, 2 M NaOH and 2 M HCl for 3 h, respectively [29]. Each experiment was performed on three samples. Before the treatment, all the filaments were washed using acetone in order to clean the fiber surface. Taking into account that the treated samples have to be characterized by a tensile test-following test protocol proposed by Quagliarini et al. [20]-specimens with a total length of 700 mm were prepared. After treatment, the filaments were immersed in distilled water for 24 h, removing the residual chemical softly. Both before and after the treatment, the specimens were dried to constant weight in an oven at 105 °C for 12 h. The mass losses of fibers after the treatment were examined using an electronic analytical balance with a precision of 0.001 g. Assuming the mass of initial state fibers $\mathbf{m_0}$ and the mass of treated state fibers $\mathbf{m_1}$, then mass loss ratio were calculated by:

$$\frac{(m_0 - m_1)}{m_0} \times 100 \tag{1}$$

To evaluate the kinetics of the process, the same test was also performed on samples with a total length of 50 mm for treating time ranged from 0.5 to 3 h. The mass losses of fibers as a function of the treatment time were determined as already reported. After samples removal, the leached solutions were analyzed using an atomic emission spectroscopy inductively coupled plasma (AES-ICP) (Model Liberty 200, VARIAN). The pH and the conductivity of the obtained solutions were also determined.

2.2.2. BF ropes characterization

To evaluate the microstructure of the ropes, the surface morphologies of the basalt fibers before and after the treatment in the three different media were characterized using a scanning electron microscope (SEM, FEI, Quanta-200) equipped with an energy dispersive X-ray spectrometer (EDS, Oxford INCA-350). Polished cross sections were also prepared by vacuum impregnation with low viscosity epoxy resin. To evaluate the change in the rope chemical composition after the durability test, on the powdered ropes a chemical analysis were performed by X-ray fluorescence (XRF, Thermo ARL, Advant'XP).

After three hours, rope specimens were prepared for mechanical characterization following the procedure proposed by Quagliarini et al. [20]. An anchorage system consisting of two steel

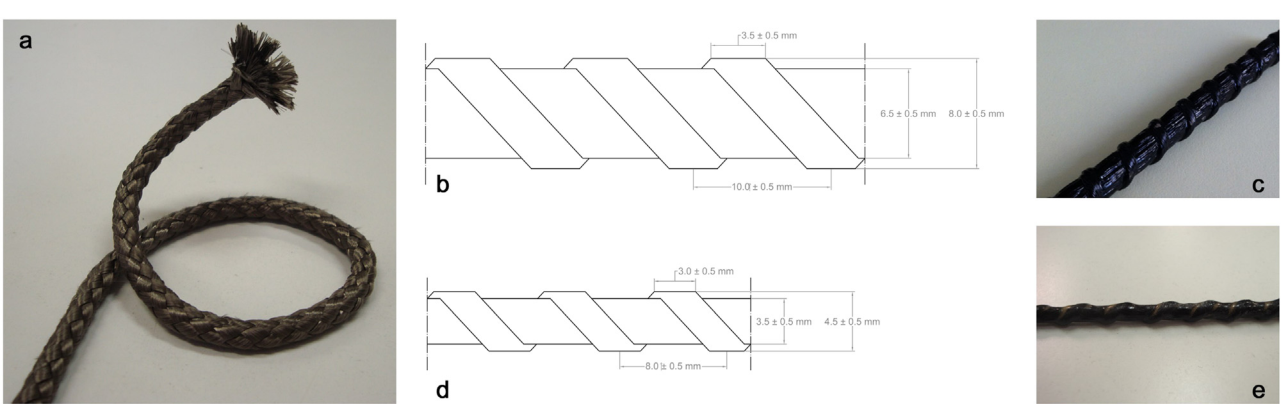

Fig. 1. BF rope: photo (a). 8 mm BFRP rods: geometric dimensions (b and c) and photos (d and e).