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EXPERIMENTAL ANALYSIS ON CONCRETE BLOCKS REINFORCED WITH ARUNDO DONAX FIBERS

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Abstract: *Over the last decade, there has been a growing attention in research and development on non-conventional building materials and technologies, such as vegetable fibers (e.g., flax; hemp; jute; etc.), to be used as eco-friendly materials in a wide range of applications in civil construction. The main reasons of this interest are related to the specific properties, price and sustainability of natural fibers, which can be considered as "green" building materials. In this article, a new kind of fibers, extracted from stem of the Giant Reed Arundo donax L., has been investigated as a potential reinforcement of construction materials. These fibers, which widely grow in Mediterranean areas, but that are diffused all around the world as well, have been extracted from the outer part of plant stem. Then, some experimental concrete bricks, have been prepared with the addition of different weight percentages of vegetal fiber. To assess the mechanical properties of these bricks, tensile tests on single fiber have been performed, as well as compression tests on the whole block. Hence, the differences between concrete bricks without any fiber and those reinforced with different weight percentages of natural fiber have been analyzed, and their potential applications in bio-architecture have been assessed.*

Key words: *bio-architecture, concrete bricks, Arundo donax fiber, mechanical properties, tensile test.*

1. INTRODUCTION

Over the last decades, a growing attention on the use of less polluting materials and technologies [1] and natural fibers instead synthetic ones (*i.e.*, glass, carbon or kevlar fibers) has been focused by both the academic and industrial world [2]. The main reasons of this interest are related to the specific properties, price and low environmental impact of this kind of fibers. A great variety of different natural fibers are actually available as reinforcements of construction materials. The most widely used are flax, hemp, jute, kenaf and sisal, because of their properties and availability while some recent scientific works advance the feasibility to use less common natural fibers [3] such like artichoke [4], okra [5], isora [6], ferula [7], althaea [8], piassava [9], sansevieria [10] and buriti [11]. In this work, a new kind of fibers, extracted from the stem of the giant reed *Arundo donax* L., is investigated as a potential reinforcement in concrete blocks. The giant reed is a perennial rhizomatous grass that grows plenty and naturally in all the temperate areas of Europe (mainly in the countries of the Mediterranean area) and can be easily adapted to different climatic conditions. Thanks to its high growth rate, it represents, in some environmental conditions, an invasive and aggressive species so its disposal is difficult [2]. In Italy, this allochthonous species is invasive in some territorial contexts and in others it is almost completely naturalized. Its field of application is very wide, ranging from the production of reeds in musical woodwind instruments for at least 5000 years to the use as a source of fibers for printing paper [12]. *A. Donax* L. is also used as a diuretic and as a source of biomass for chemical feedstocks and for energy production. Furthermore, this non-wood plant is recently considered in the manufacturing of chipboard panels alternative to those wood-based ones [13].The stem of the giant reed is often used to make fences, trellises, stakes for plants, windbreaks, sun shelters [14]. Owing to their specific mechanical properties (e.g. strength–density ratio), the stems of the giant reed are also employed in agricultural buildings and relevant construction activities.

2. MATERIALS AND METHODS

Some experimental concrete bricks (Fig. 1) – *i.e.*, cubic samples with 15 cm side, and cylindrical samples with 10 cm diameter and 15 cm height - have been prepared in relevant molds, with the addition of different weight percentages of *Arundo donax* vegetal fiber (0.0, 0.2, 0.6 and 1% by weight, respectively).

The concrete samples consist of Pozzolanic cement "CEM IV 325", according to UNI EN 197-1:2011 [15]; sand particles, measuring less than 1,5 mm with a humidity content below 10%, in a percentage of 3.2 of the total volume; quarry gravel, with a characteristic grain size of less than 30 mm, in a percentage of 6.4 of the total volume; and water, in a percentage of 0.96 of the total volume. Regarding fibers, the material used was culms of giant reed. They have been collected along the “Bradano” river basin, in the Basilicata region (Southern Italy), and dried in an oven at 105° until a relative moisture content of less than 10% was reached. The average culm height was 3 m and the average culm diameter was 2 cm. In order to get the most homogenous fibers, samples with different lengths have been cut from culms, avoiding nodes. Only fibers from internodes have been tested. Finally, after vibrating the concrete mix, aimed at improving compactness and adherence of blocks to formworks, the samples have been left for 28 days in a humid environment, so as to promote their curing and hardening.

Fig. 1 Cubic and cylindrical samples for the laboratory tests

To assess the mechanical properties of these bricks, tensile tests on single fiber have been performed, as well as compression and tensile tests on the whole block. All these mechanical tests have been performed at the Laboratories for Testing Materials of the SAFE School of the University of Basilicata (Potenza – Italy) by using a Galdabini PMA10 universal testing machine.

Tensile test on *Arundo donax* fibers

Within the present experimental tests, fibers obtained from the trunk of plant - cut and treated so as to obtain homogeneous shape and size, preferentially between 3-8 cm long - have been examined by tensile test (Fig. 2). The preparation of the fibers to be subjected to tensile tests has been performed according to ISO 22157:2019 [16], respecting the relevant requirements: the cross-section of the samples is almost rectangular, with a width equal to around half the thickness; the span between the anchors is between 50 mm and 100 mm; the anchorage has prevented the samples sliding and crushing.

The tensile tests have been carried out using a maximum 2.5 kN load cell, and is equipped with an internal optical drive that read the displacement. The lower head of the machine is fixed, the upper head is stretching along the axis of the fiber (Figure 2).

Fig. 2 Tensile tests on *Arundo donax* fibers: front view (left) and side view (right)

The sample is fixed to the grips, which exercises a pressure that can be adjusted using a pressure gauge. The tests have been carried out in displacement control, with a loading speed of 2 mm/min (which has been estimated as the right compromise according to the stiffness and size of the sample) and a frame acquisition frequency of approximately 1/700-1/800 ms. All the 10 tested samples – each one having a variable free length of 3-8 cm – have been fixed to the grips of the machine, removing the slack without stretching the sample and making certain that the sample was well aligned and straight within the grips and in the line along the applied load to the fiber, since any misalignment could produce a transverse/torsion movement of the grips, hence introducing errors in the measurement of elongation and contributing to the premature failure of the fiber.

During the tensile tests, failures occurred at the anchorages in some samples. This means that the samples are not subject to a perfectly centred normal deformation but that a certain bending moment component was present. This is essentially due to the low load of these samples and therefore to a lack of sensitivity of the machine to low loads. Most of the samples, on the other hand, have showed a perfectly centred normal deformation with failure in the center or at least away from the anchorages (Fig. 3), so only these samples have been taken in consideration for the experimental analysis.

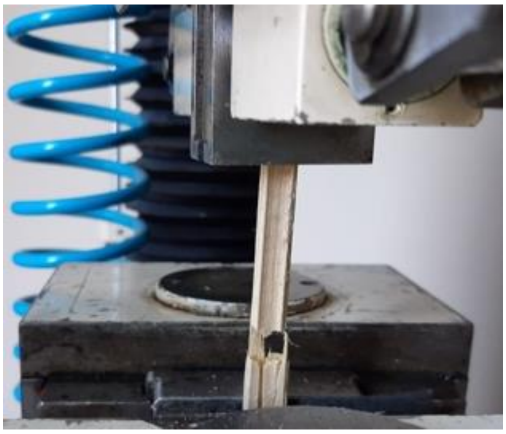

Fig. 3 Tensile test on *Arundo donax* fibers: fibre breaks in the centre

Compression test on cubic samples

After the setting and hardening period (28 days), for each typology of cubic sample, the mechanical behavior of the bricks has been measured by placing them between the rigid steel plates of the testing machine and testing them of unconfined compression strength through displacement controlled uniaxial tests (Fig. 4). This testing machine consists of two columns high stiffness frame, with maximum vertical daylight between platens equal to 185 mm, horizontal daylight between columns of 175 mm, platens diameter equal to 153 mm, ram travel of approximately 45 mm and 2 pressure transducers. The upper frame is fixed, while the lower frame is free to move and compresses the sample.

Fig. 4 Compression test on a concrete brick reinforced with natural fibers

The frames are equipped with a safety device that interrupts the test after breaking the sample, to prevent damage to the accessories used during the tests. A uniform load has been progressively applied without shock, and it has been continuously increased until failure, with the moving head of the testing machine traveling at a rate of 1 mm/min. [17].

Split tensile test on cylindrical samples (Brazilian proof)

A split tensile test - also known as the Brazilian test – has been carried out with the testing machine as well, then involving longitudinal compression along two diametrically opposed generating lines of the cylindrical sample, in accordance with UNI EN123-90-6 [18] (Fig.5).

Fig. 5 Tensile test on a cylindrical concrete brick reinforced with natural fibers

In this case, in the diametrical plane containing the load line, a tension representative of the tensile strength of concrete is generated in the orthogonal direction. The test has been performed on a cylindrical concrete brick by placing the sample with the horizontal axis between plates of a press and compressing them according to two opposite generators, according to UNI EN 123-90-6 [18].

3. RESULTS AND DISCUSSIONS

Tensile test on *Arundo donax* fiber

In Table 1, the tensile properties of *Arundo donax* fibers are reported in terms of average value, with the corresponding 95% confidence interval [16].

Table 1 Tensile strength of the *Arundo donax* fibers experimentally tested

Load (N)	Tension [N mm-²]	Elongation [mm]	Yield Point [N mm-²]	Young Modules [GPa]
2008	133.89±0.33	7.94±0.045	131.76±0.45	2.53±0.0072

In figure 6 the diagram elongation/load for the *Arundo donax* fiber is reported. The mechanical behavior of *Arundo donax* fibers appears to be very interesting, especially because its tensile strength is considerably high before the yield point. Just as a reference, the corresponding value for an ordinary steel used for building, is around 400-700 N mm-²

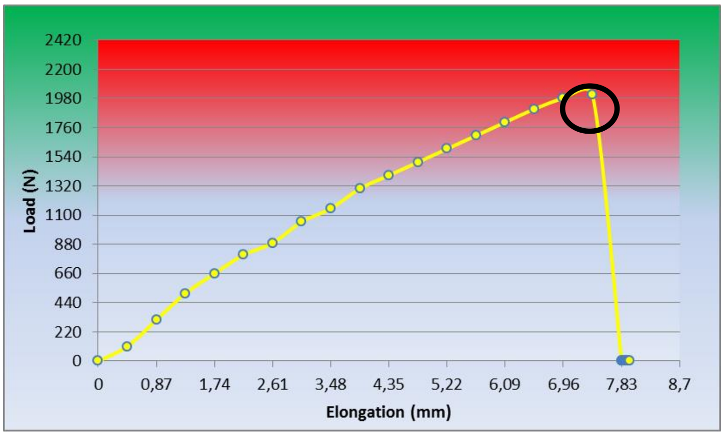

Fig. 6 Elongation/load diagram for the tensile test on *Arundo donax* fiber

This tensile strenght value is more important even if compared with other different natural fibers which have showed, indeed, lower tensile strength and deformation properties as in the case of Spanish broom [19]. In this last case, from the laboratory tests, an experimental mean value of the tensile strength equal to about 41.53 N mm-² (Natural sprig) and 36.62 N mm-² (rope) have been detected, with a high standard deviation depending on the natural variability of the fibers. Indeed, this value difference depends on several factors, such as the fiber origin, the production process, the environment of origin, the part of the fibre considered, *etc*.

Moreover, the value obtained is in line with the value obtained by Spatz et al. [20] who carried out tensile tests on parts of internode of length equal to 150 cm. They calculated the average elastic modulus of the epidermis for internodes extracted in the central part and at the base of the culm of about 10 Gpa. In the case under examination, considering a length of 15 cm, the value obtained has been2.53 GPa.

Compression strength on cubic concrete samples

In table 2 the results of compression tests on the four different types of cubic concrete sample are reported while figure 7 reports a tension/deformation diagram for the samples experimentally tested.

Table 2 Compressive strength of the different concrete bricks experimentally tested

Vegetal fibers	0 [%]	0.2 [%]	0.6 [%]	1 [%]
Maximum applied load (N)	554, 000	389, 000	386, 000	369, 000
Deformation	1.87	1.83	2.2	2.85
Maximum compressive strength (Mpa)	55.4	21.9	17.1	16.3
Tension σ (Mpa)	4.10	2.88	2.86	2.73
Elastic modulus E (Mpa)	2.19	1.57	1.3	0.96

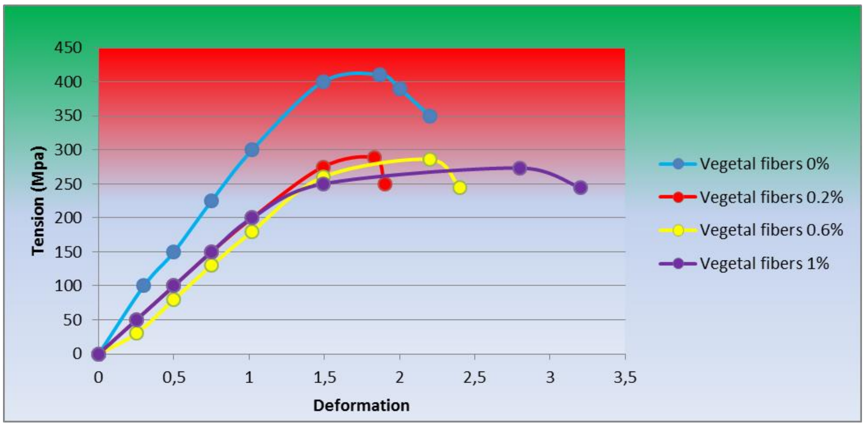

Fig. 7 Tension/deformation diagram for the compression test on cubic samples considered

From the results analysis (Table 2) it can be deduced that the value of the compressive strength of the sample with concrete only, reflects the literature values (typically 30-60 MPa). As we imagined, adding different amounts of fibers (samples 2, 3 and 4) has led the value of compressive strength to decrease so worsening this resistance value.

Directly proportional to the tension is *the "modulus of elasticity"* (or Young's modulus) which represents the stiffness of the material. The lower its value, the lower the stiffness of the sample, then indicating that the material can deform easily.

From figure 7, indeed, it can be noticed that the behavior of this material is almost elastic in the first phase, followed by a very limited plastic phase that quickly precedes the definitive failure of the cubic sample. From the results obtained through the present experimental tests, it can be concluded that further analysis should be performed, aimed to the definition of optimal percentage of natural fibers, also taking into account the length-to-thickness ratio. Indeed, natural fibers, even due to their increased aspect ratio (length/diameter) compared to non-fibrous filler, usually improve the mechanical properties of composite materials [21].

Split tensile test on cylindrical samples (Brazilian proof)

In Table 3 the results of split tensile tests on the four different types of cylindrical concrete sample are reported. The tensile strength values are in line with the values provided by the Technical Standards for Construction, in which the strength of the generic sample is calculated using the (1):

$$\text{Tensile Strength} = (2*F)/(\pi*L*d) \qquad (1)$$

where "F" is the break load, "L" is the sample length, "d" is the diameter of the cylindrical sample.

Table 3 Tensile strength of the different cylindrical samples experimentally tested

Vegetal fibers	**0 [%]**	**0.2 [%]**	**0.6 [%]**	**1 [%]**
Maximum applied load (N)	37,100	20,800	37,500	55,400
Deformation	0.71	0.2	0.69	1.07
Tensile strength (Mpa)	1.6	0.9	1.6	2.04

Figure 8 reports a tensile strength/load applied for the sample 4 (1% of *Arundo donax* fibers), which shows the direct proportionality between the two parameters (elastic phase) before the sample breaks. The analysis of the results reported in table 3 shows the limit from which an increase in tensile strength can be appreciated following the addition of natural fibers: up to a fiber percentage of 0.6% weight (sample 3) there is no improvement in tensile strength, whereas from 1 % onwards (sample 4) the tensile strength also begins to increase in an interesting way, if we consider the narrow range of difference between the various fiber percentages.

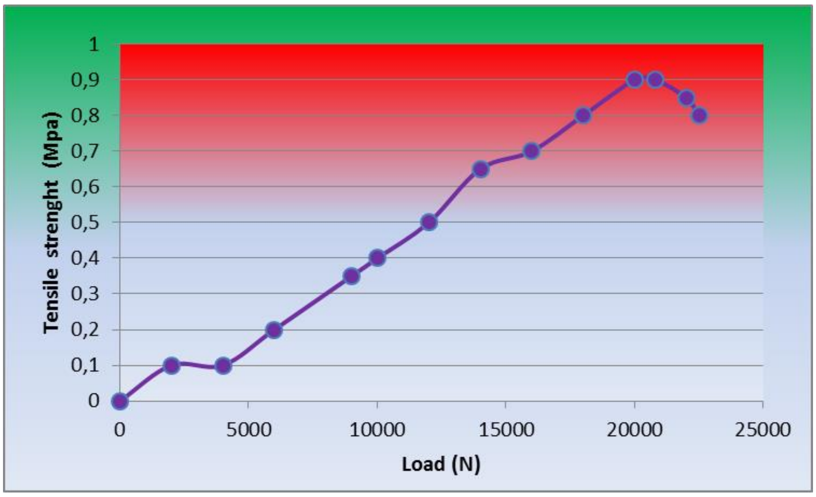

Fig. 8 Tensile strength/load applied diagram for the cylindrical sample number 4.

4. CONCLUSIONS

The experimental tests performed in the present work have confirmed that the compressive strength of the concrete does not benefit from the addition of fiber in any of the three cases. However, some interesting novelties could be deduced concerning the tensile properties. The fiber has a very high tensile strength, especially when compared to other natural fibers such as *Spanish broom*. Moreover the longitudinal elasticity modulus is in line with literature values. As a direct consequence, the indirect tensile tests (Brazilian test) carried out on cylindrical samples of concrete have showed an improvement in the tensile strength of the samples, which starts from a threshold value: from 0.6% in weight of added fiber, there is an increase in strength resistance, as well as the Young's modulus increase. Much more tests are anyway needed in the future, with different percentages of added fiber to reach values comparable, at least as a scale, to the stiffness of steel.

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