Assessing the Alkali-Sensitivity of the Mechanical Behavior of Jute Fibers to Evaluate Their Durability in Cementitious Composites Applications

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Abstract Jute fibers have been studied for their numerous properties and, recently, much attention has been paid to the possibility of using them as reinforcing material in cement based matrices for structural engineering applications. In the context of structural reinforcement methods, the use of composite materials reinforced with synthetic fibers is now quite common, due to their light weight, versatility and adaptability. However, in recent years, the scientific community has been interested on the use of natural composite materials, with the goal of finding innovative solutions with renewable, recyclable, sustainable and biodegradable products for the construction industry. This research investigates the use of jute fibers to assess their suitability as reinforcing materials in cementitious composites for historic/existing masonry structures retrofitting. As a matter of fact, these applications have to consider the possible low durability of jute, like all other cellulose-based fibers, especially into alkaline environments. This work reports the ongoing experimental investigation to set the mechanical performance of jute fibers. The experimental program considers jute yarns in their natural condition and evaluates how the alkaline matrices would affect the fiber mechanical properties. The paper summarizes the first results obtained from durability tests on jute yarns as a first step towards the assessment of the long-term performance of Natural Fiber Reinforced Cementitious Composites.

Keywords Natural fibers · Jute fibers · Durability · Alkali · Mechanical properties

1 Introduction

Jute fibers can be combined with polymers or mortar-based matrices to obtain several composites. In the civil engineering field, they represent an alternative to replace synthetic fibers, to obtain low cost, renewable and biodegradable composites [1, 2].

Jute fiber composites have several potentials and applications for structural purpose, being used as an eco-sustainable alternative to:

– Structural reinforcements used into the NFRC (Natural Fibers Reinforced Cementitious), FRCM (Fiber Reinforced Contentious Mortars), TRM (Textile Reinforced Mortars), FRP (Fiber Reinforced Polymers);
– Bio-concrete, an innovative concrete reinforced with natural fibers, in alternative to reinforcements with asbestos fibers;
– Fiber reinforced self-healing mortar, due to self-healing stimulating capacity of vegetal fibers [3];
– Pultruded structural elements.

Furthermore, jute fiber composites in the civil engineering has several advantages, including, e.g.:

– Carbon footprint reduction, with low emission of CO_2 in atmosphere and low energy consumption during their processing.
– Compatibility with existing masonry structures, when combined with cementitious mortar;
– Improved sustainability, toughness, ductility, flexural capacity and crack resistance of cementitious composites in which jute fibers are used as reinforcement [4–6].
– Lower hazard manufacturing processes, since they are non-abrasive to the equipment and do not cause irritations to human beings.

Despite all the aforementioned advantages, natural fiber composite materials present many limitations and the use of cement-based composites reinforced with jute and others vegetal fibers as a construction material is limited mainly due to the long-term durability of fibers in the alkaline environment. Previous studies indicate that mechanical proprieties of vegetal fibers are strongly reduced in alkaline conditions [7–9]. Considering the material alkali sensitivity, many researchers are investigating strategies to improve durability of plant fibers in cement-based matrices [10–12], also proposing different treatments to this purpose [13].

In this paper the first results are presented of experimental tests on the mechanical properties of jute yarns immersed in three different alkaline environments and evaluated at progressive time steps: 7, 15, 30, 60 days. The evolution of the mechanical behavior of the jute fibers is meant as the basis to define their durability properties as well as those of cement-based matrices in which they are employed as reinforcement.

2 Materials and Methods

2.1 Specimens

Corchorus is a genus of about 100 species that grows in wet and warm climates (Bangladesh, India, China, Nepal, Uzbekistan, South Sudan, Zimbabwe, Egypt, Brazil and Vetnam). Tossa Jute (Corchorus Olitorius) is one of the mains jute types [~~14~~]. 13

Tossa is softer, silkier and stronger than white jute (Corchorus Capsularis). This study considers jute yarns of Tossa fibers from Brazil (Fig. 1), formed with several twisted filaments with linear density about 920 Tex, used as samples 1000 mm long. Physical characterization on each specimen, as mass determination and measurements, was performed.

2.2 Conditioning Solutions

Three different solutions, that simulates the alkaline conditions of most used cement based matrices were considered:

- Carbonated concrete, that contains only calcium hydroxides with pH 10.0, called *Environment 1*;
- Lime mortar, that contains only calcium hydroxides with pH 12.5, called *Environment 2*;

Fig. 1 Jute yarn

Table 1 Environments chemical composition

Environment	$Ca(OH)_2$ (%)	KOH (%)	NaOH (%)	pH
1 Carbonated concrete	0.003	0	0	10
2 Lime mortar	0.16	0	0	12.5
3 Concrete	0.16	1.4	1	13

– Concrete environment, that contains calcium, sodium and potassium hydroxides with pH 13.0, called *Environment 3*;

Table 1 shows the environments chemical composition.

2.3 Mechanical Tests

Mechanical tests were performed on both dry (unconditioned) and conditioned yarns (Fig. 2); tests were carried out at room temperature using a universal testing machine, with a load cell of 1 KN and with displacement control at a rate of 0.5 mm/sec, in accordance with the ISO 2062:2009 standard [~~15~~]. 14

Fig. 2 Test set-up

Tensile strength of jute yarn is measured at their natural condition and at progressive time steps: 7, 15, 30, 60 days exposure in the aforementioned conditioning environments.

3 Results and Discussions

The yarns failure mode results in accordance with yarns morphology and geometry. A progressive rupture of each yarn characterizes the fibers failure mode. The following Figs. 3, 4 and 5 and Tables 2, 3 and 4 show the tensile test results for the three environments considered and refers to the average rupture force obtained in the experimental tests, with the respective standard deviation.

In Environment 1 (carbonated concrete) Jute yarns lose about 15% of their initial rupture force after 7 days of immersion and 20% after 15 days.

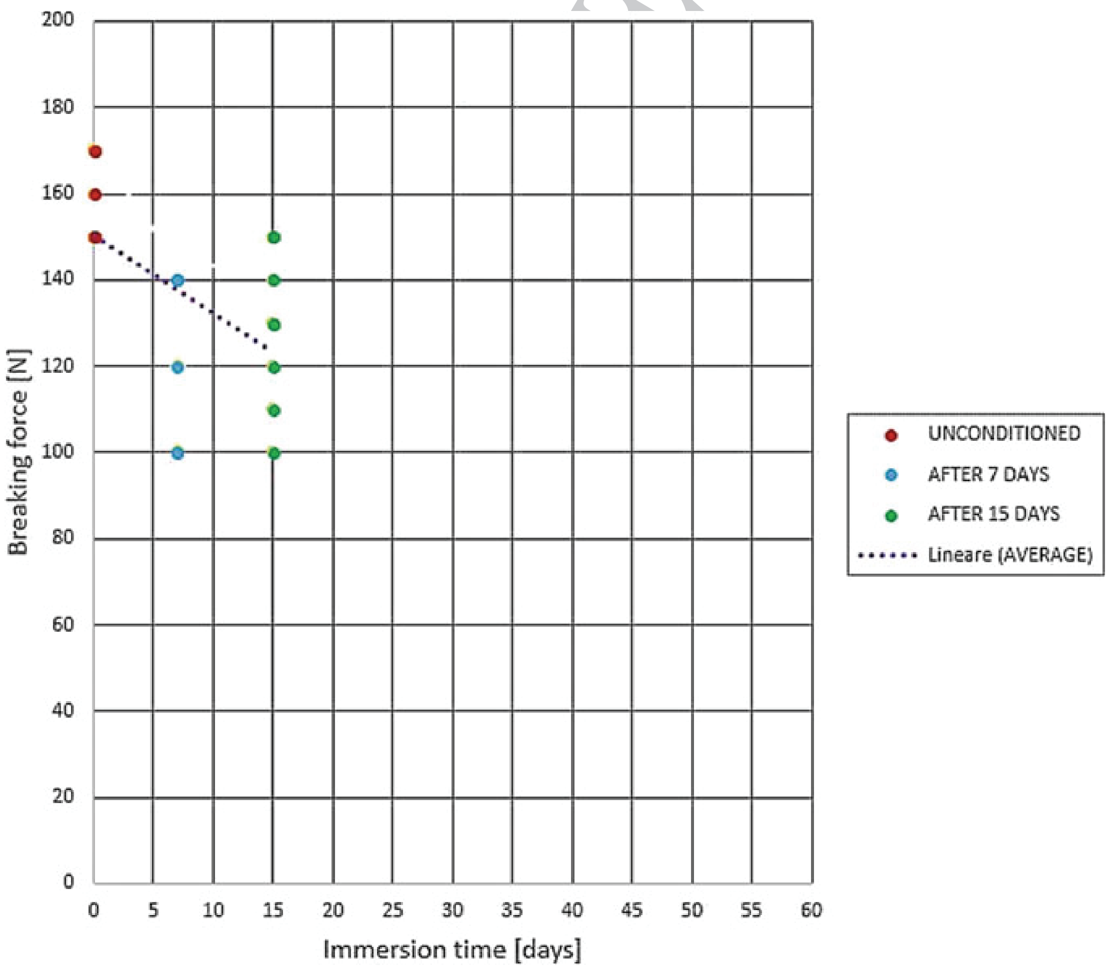

Fig. 3 Environment 1: tensile test results

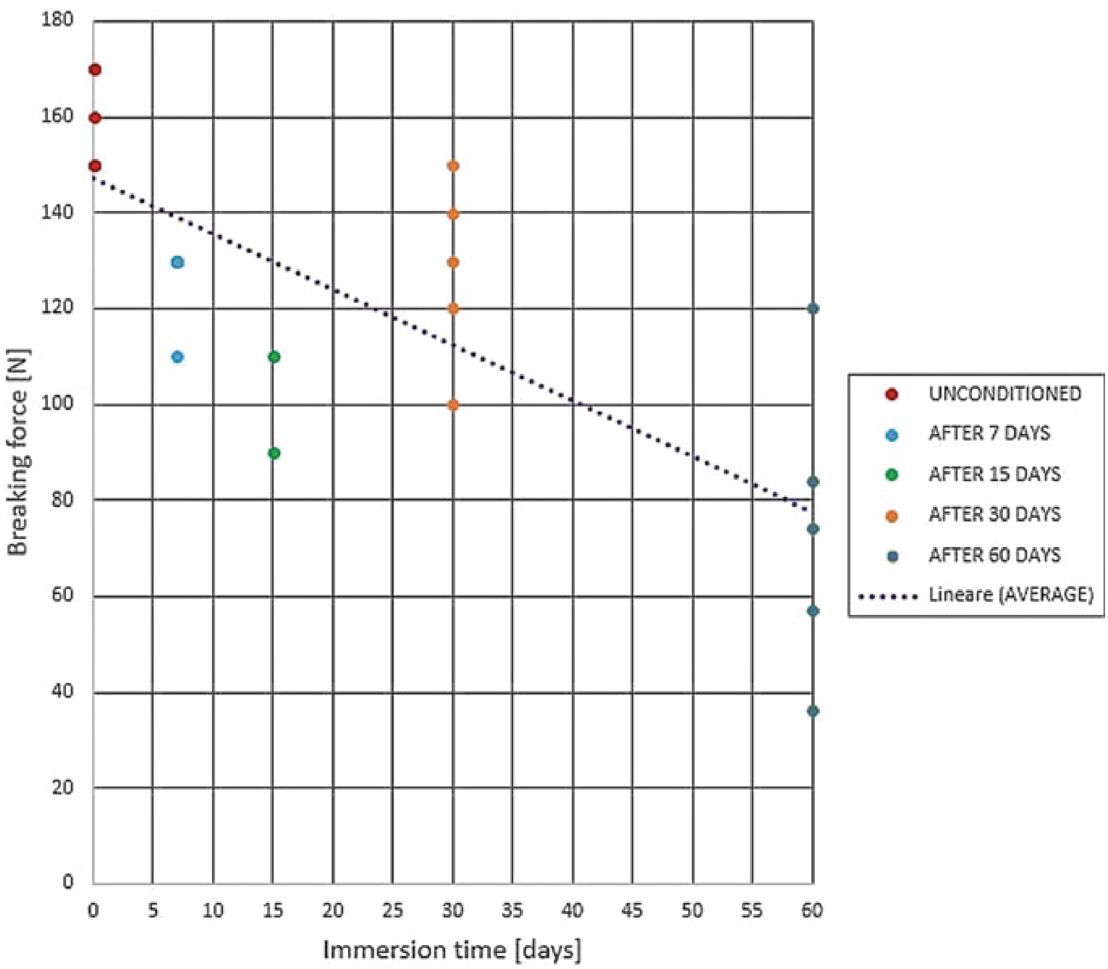

Fig. 4 Environment 2: tensile test results

In Environment 2 (lime solution) Jute yarns lose about 21% of their initial rupture force after 7 days of immersion and 37% after 15 days, 20% after 30 days and almost 54% after 60 days.

In environment 3 (concrete) Jute yarns lose about 30% of their initial breaking force after 7 days of immersion and 37% after 15 days (Fig. ~~6~~). 5 AQ1

The results of environment 1 show that the carbonated solution is the least aggressive condition and environment 3, the "concrete solution", is the most aggressive one for the tested jute fibers.

With reference to environment 2 (lime mortar), tests performed up to 60 days have revealed a peculiar trend: the mechanical properties decreased during the first 15 days, then featured a moderate recovery up to one month, to undergo a further and more important decay in the longer term. This behaviour is related to the sodium hydroxide concentration in the tested solution, which may likely have produced the observed behaviour. As a matter of fact it is known that plant fibres immersed in a low concentrated sodium hydroxide solution (4 to 8%) can in the short period undergo some increase in the fibre mechanical properties. This procedures, also known as mercerization, has been investigated by several authors, in

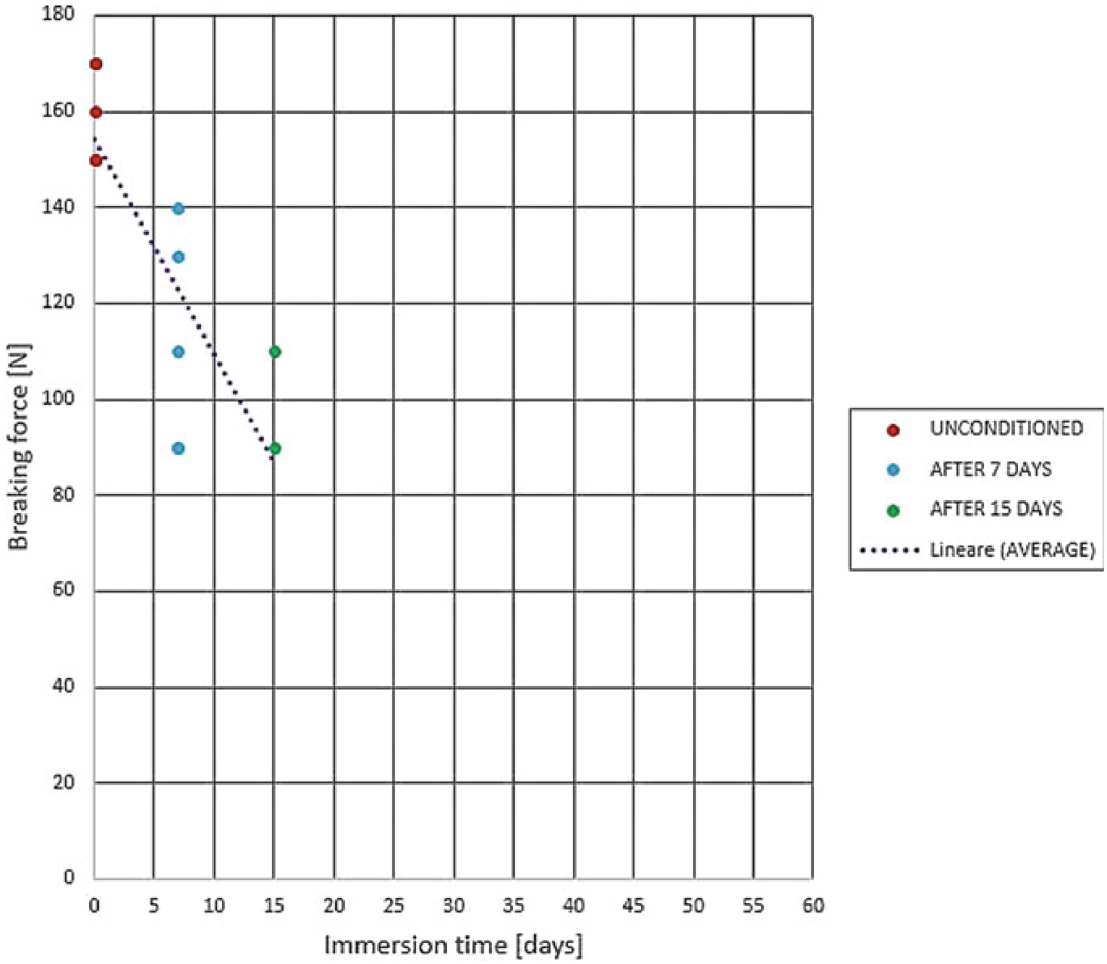

Fig. 5 Environment 3: tensile test results

Table 2 Jute yarns into environment 1

Time	Breaking force (N)	Residual strength (%)
Unconditioned	160 [±7.89]	100
7 days	120 [±21.28]	75
15 days	129 [±16.46]	80

Table 3 Jute yarns into environmental 2

Time	Breaking force [N]	Residual strength (%)
Unconditioned	160 [±7.89]	100
7 days	126 [±7.87]	79
15 days	100 [±16.57]	63
30 days	128 [±19.61]	80
60 days	74 [±31.64]	46

Table 4 Jute yarns into environmental 3

Time	Breaking force (N)	Residual strength (%)
Unconditioned	160 [±7.89]	100
7 days	112 [±21.04]	70
15 days	100 [±16.65]	63

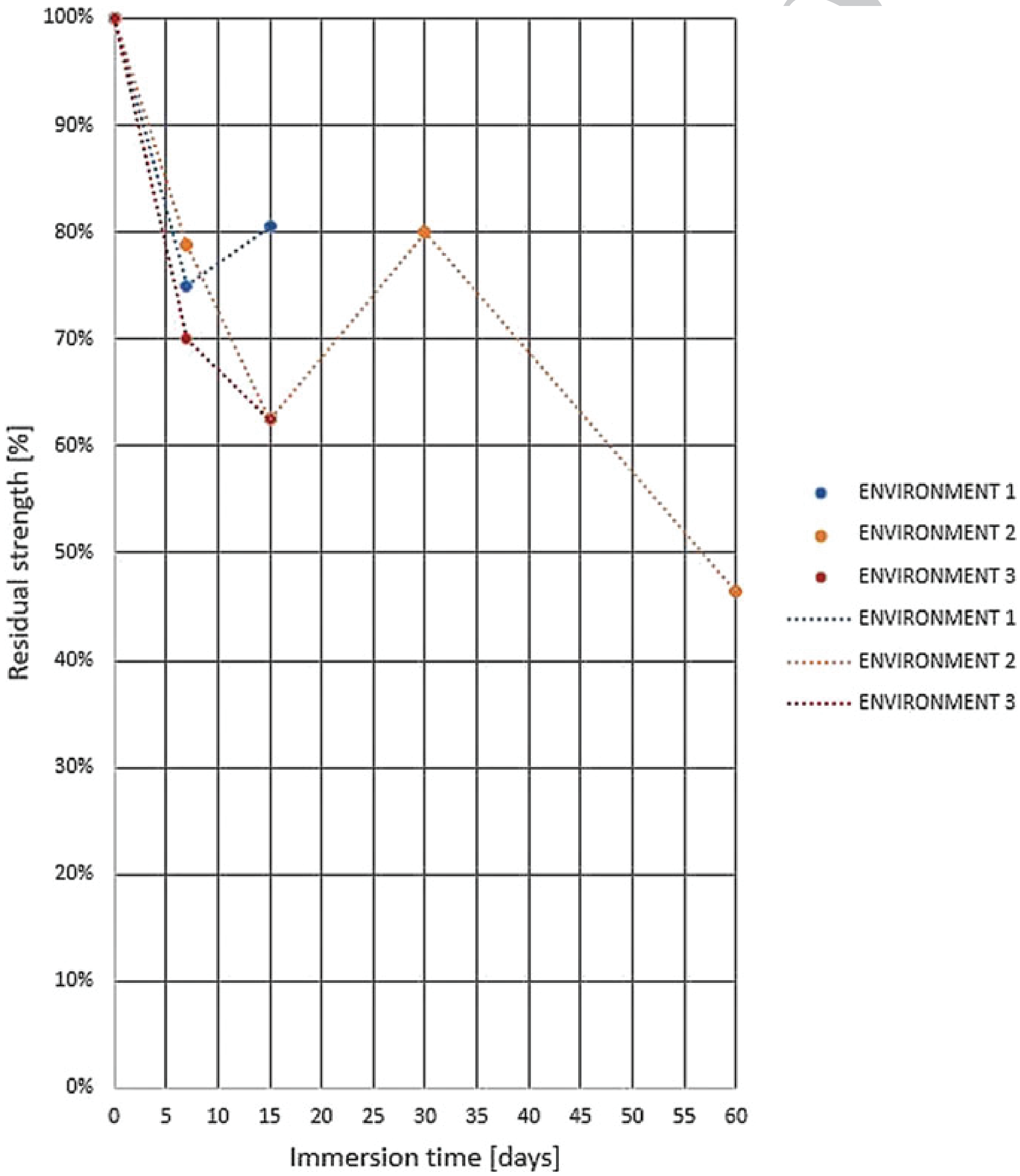

Fig. 6 Average values of jute yarns durability tests

search of the appropriate exposure time and alkali concentration to treat the fibers 15[16]. Jute loses 20% of its strength in the first 7 days but, considering further loss up to 15 days and recovery up to 1 month, it can be said that up to 1 month the performance yields constant.

The results presented constitute the first step of a work in progress and further experimentation is needed. For their application in civil engineering filed special attention should be given when combined with cement-based matrix.

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