Physical and mechanical characteristics of raw jute fibers, threads and diatons

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Abstract

The need for a "systemic" approach to reduce both carbon footprint and seismic vulnerability of the built environment is clearly evident nowadays. Therefore, the use of bio-based materials, is gaining consensus as a sustainable solution due to their low environmental impact and promising properties as a construction material.

This paper investigates the performance of the raw jute fiber and jute threads in view of their possible use as thermal insulation and structural reinforcement in composite systems with inorganic matrices. Specifically, the physical, chemical and mechanical properties of the jute fibers, threads and diatons are investigated. They show that they have potential to be used as a construction material. In fact, water absorption of jute fibers, threads and diatons has been almost similar, ranging in between 1.98-2.50 g(water)/g(fiber), while the specific mechanical performance of fibers worsens as sample size grows from fibers to threads and diatons. Based on the results reported in the present paper, further studies are already under development with the aim to assess the actual thermal and mechanical response of jute-reinforced Textile-Reinforced Mortars (TRM) as a sustainable technology to thermal and seismic upgrading of existing masonry buildings.

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1. Introduction

The construction industry is more and more committed to implementing more sustainable supply and production processes, which would lead to realizing “sustainable cities and communities” as targeted by one of the seventeen “sustainable development goals” recently declared by the UN [1].

In fact, recent surveys have clearly pointed out that the existing built stock is characterized by a huge environmental impact [2] and, hence, significant upgrading interventions are needed to obtain “near zero energy” buildings [3]. One promising strategy to solve this problem is the use of recycled aggregates obtained from construction demolition waste [4] [5].

Moreover, the built environment is affected by remarkable vulnerability levels with respect to both human-induced and natural hazards, earthquakes being among the most deadly and impactful phenomena for buildings and infrastructures [6].

Therefore, the need for a “systemic” approach to reduce both carbon footprint and seismic vulnerability of the built environment is clearly understood by both the scientific community and the sector companies [7].

In this context, the possibility of formulating composite systems characterized by both enhanced insulation properties and good structural behavior is one of the main actions that can have an impact on upgrading existing constructions [8]. Specifically, natural fibers, obtained by various types of plants, have demonstrated to be a key constituent to produce composite systems with the aforementioned performance [9].

Besides some studies available in the literature about the use of natural fibers in Fiber-Reinforced Polymer (FRP) systems [10][11][12][13], also in combination with carbon fibers [14], the use of fibers and fabrics obtained by various plants appears to be particularly well suited as internal reinforcement for mortars in inorganic-matrix composite systems [15][16][17][18]. Specifically, the use of hydraulic lime mortar has proven to be more compatible than cement-based mortars in terms of chemical compatibility and resulting durability performance with natural fibers, such as jute [19], hemp [20] and sisal [21].

Moreover, similar results have been obtained from experimental tests carried out on flax fibers, whose durability has been investigated for various environmental exposures [22]. Textile made out with the same flax fibers have been employed to realize composite systems generally referred to as Textile-Reinforced Mortars (TRMs) whose potential in strengthening masonry

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wall for seismic-like actions has been investigated and demonstrated experimentally [23][24], similarly the mechanical performance of jute TRM can be found in [24].

Building on the results already available in the literature, the preset paper focuses on the mechanical behavior of jute, which have been also used as internal reinforcement in crude earth bricks [25], JFRP [13] and concrete elements [26][27][28]. Moreover recycled jute fibers have been used in the preparation of natural insulation materials [29][30] and the burnt clay bricks reinforced with jute fibers and its thermal properties have been reported in [31].

Therefore, the present paper aims at investigating the mechanical response under tensile actions of various elements, like fibers, threads and diatons made of jute. Moreover, the effect of the exposure conditions, including immersion in tap water, salt water and alkaline solution is analyzed.

Section 2 reports the main properties of the tested materials and describes the experimental tests that are run as part of the present study. The experimental results are, then, summarized in Sections 3 and 4: specifically, the former summarizes the results in terms of relevant physical properties (e.g. water absorption capacity), whereas the latter reports the measured mechanical properties (e.g. tensile strength and stiffness). A discussion about the variation of properties with the sample scale is proposed in Section 5. The main conclusions of the present study are remarked in Section 6.

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2. Material and methods

The raw jute fibers and threads (Fig. 1) were collected directly from farmers based in the state of West Bengal, India. These materials are handcrafted products and are not subjected to any pre-treatment.


(a) (b)

Fig. 1. Jute (a) Jute fiber (b) Jute threads

The present work considers mainly three jute products: raw fibers, threads and diatons (Fig. 2). The jute diatons and jute net-fabrics were prepared using the raw jute fibers and jute fiber threads respectively in the Material Testing Laboratory at the University of Cagliari.

The physical characteristics and mechanical behavior of the raw jute fibers, threads and diatons were determined by water absorption tests and tensile strength tests respectively. Further, the mechanical performance of the jute net-fabrics and diatons used as retrofitting systems for existing masonry, is analyzed in [32].

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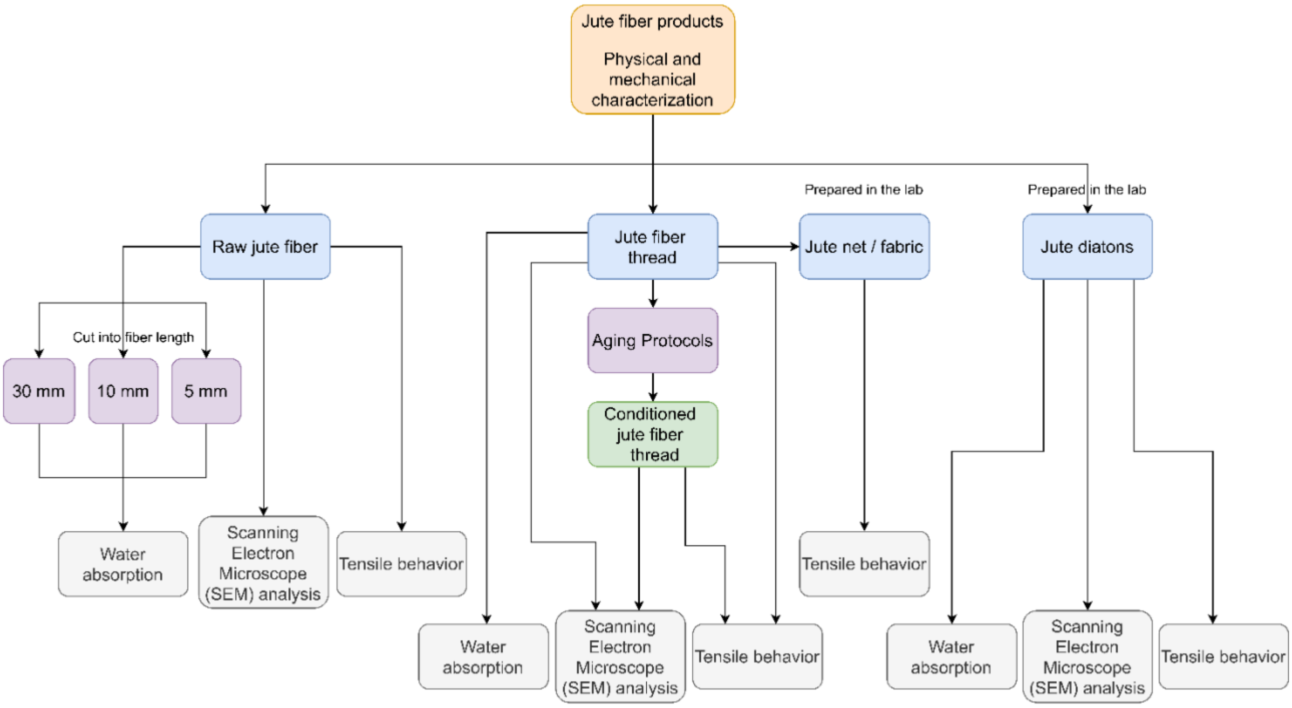

Fig. 2. Jute fiber products tests scheme.

2.1 Materials

2.1.1 Jute fibers

The raw jute fiber type considered in this study is generally referred to as Bangla Tosha - *Corchorus olitorius* (golden shine), with original lengths found to be between 3 and 4 meters (Fig. 1a). These long fibers were manually cut (Fig. 3) with the aim to obtain samples lengths of 30 mm, 10 mm and 5 mm (Fig. 4) respectively. These three fiber samples were soaked with the aim to measure their water absorption capacity, which is relevant in determining the amount of water would be needed to prepare the mortar matrices of the jute-fiber-reinforced composite systems considered in the present study.

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Fig. 3. Manual cutting process for jute fibers.

(a) (b) (c)

Fig. 4. 10 grams of (a) 30 mm, (b) 10 mm and (c) 5 mm chopped jute fibers.

2.1.2 Jute fiber threads

The 3 yarns (Fig. 5) jute threads are fabricated with the same Bangla Tosha jute fiber, as described above. Two classes of threads with different diameters (Fig. 6 (a) and (b)) were used for tensile tests; the thinner thread type has been denoted as 1mm class while the thicker thread has been labeled as 2 mm class.

Fig. 5. Class 1mm 3 yarns jute threads sample.

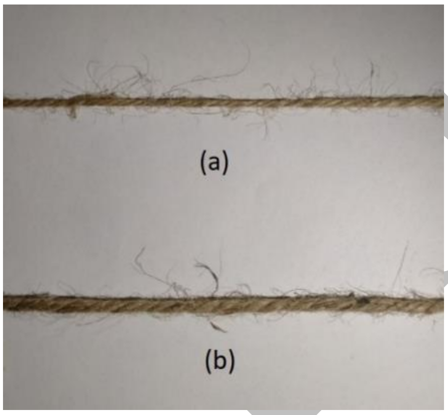

Fig. 6. Jute threads: (a) class 1mm and (b) class 2mm.

A total of 20 samples of 35cm length, from each type of the jute thread classes were cut randomly from the whole lot and have been used to determine the yarn diameter and tex, of these two classes of threads.

The thinner thread (1 mm class) average yarn diameter is 1.17 mm (with Co.V of 6.39%), whereas the yarn weight is 1118.74 tex (with Co.V of 12.04%).

On the other hand, the thicker thread (2mm class) average yarn diameter is 2.15 mm (with Co.V of 5.59%) and the yarn weight is 2140.41 tex (with Co.V of 12.91%).

A total of 5 thread samples from each of the 1mm class and 2mm class were used for water absorption tests. Other 15 thread samples from both classes were subjected to aging treatment and tensile tests, whereas another 5 thread samples from both classes were subjected to only tensile tests (used as reference).

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2.1.3 Jute diaton / horizontal connector mechanical characteristics

Jute diatons, see (Fig. 7), are fabricated to improve the mechanical performance of masonry walls. The diatons are made of the same jute variety as described previously (Section 2.1.1) and each of these diatons was prepared with approximately 25 grams of fiber.

Fig. 7. Jute diaton

While near-about 65cm long fibers were twisted together to form the core of the diatons, other long fibers were wrapped around to tie the core to form the diatons (Fig. 8). The overall diaton diameter was found to be 15.5 mm (9.68% Co.V.). Therefore, these diatons were grouped and categorized as *class 15 mm* and this nomenclature has been used in the following sections.

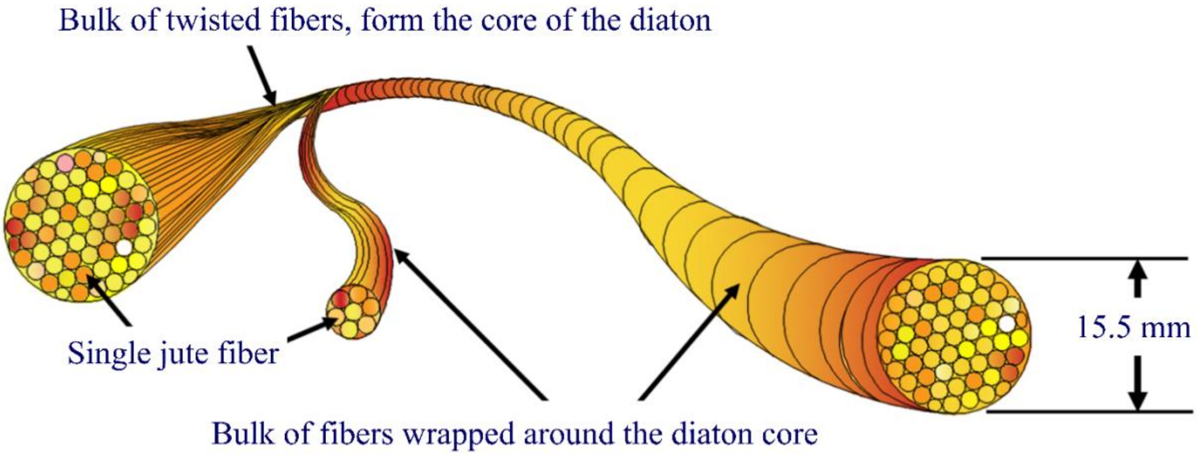

Fig. 8. Diaton fabrication scheme

2.2 Methods

The durability and the tensile strength of the jute threads were determined, exposing them to different aging conditions and then measuring their tensile strength. The characteristics of these aging protocols (see [23]) are reported in Table 1.

Three different solutions were used:

- solution 1 (deionized water) was obtained with 2 liters of pure distilled water (Fig 10a);

- solution 2 was prepared by mixing 35g/l of salt with 2 liters of distilled water (salty water) (Fig 10b)
- solution 3 was made by mixing NaHCO3, Na2CO3 and NaOH in proportion of 1.05 (g/l), 9.724 (g/l) and 6 drops in 0.1 normal solution respectively with 2 liters of distilled water to achieve 9.5 pH level (Alkaline solution) (Fig 9 and Fig 10c).

Five thread samples from both classes (1 mm and 2 mm) were immersed inside three different solutions for a total period of 42 days, i.e., approximately for 1000 hours (Fig 9). Approximately 35 cm (with Co.V. of 5.95%) long threads were cut randomly from the lot.

Threads from class 1 mm were labeled as D1 for samples placed in distilled water; DS1 for samples placed in salty solution and DA1 for samples placed in alkaline solution.

Similarly, for class 2mm threads, the nomenclature D2 was used for samples placed in distilled water; DS2 for the samples placed in the salty solution and DA1 for the samples placed in the alkaline solution. The physical characteristics of the tested samples are reported in Table 1.

Table 1 Aging protocol solutions

	Solution 1 Deionized water (DW)	Solution 2 Salty water	Solution 3 Alkaline solution
Deionized water	2 liters	2 liters	2 liters
NaCl	x	70 g	X
$NaHCO_3$	x	x	2.10 g
Na_2CO_3	x	x	19.45 g
NaOH	x	x	6 drops in 0.1 N solution

Fig 9. Case 3 - Preparation of alkaline solution with 9.5 pH

(a) (b) (c)

Fig 10. (a) Deionised water; (b) Salty water; (c) Alkaline solution

Table 2 Raw jute threads and treated Jute threads diameters and densities

Nomenclatures	Thread diameter	Thread density	Nomenclatures	Thread diameter	Thread density
Class 1 mm threads	**mm**	**g/cm^3**	**Class 2 mm threads**	**mm**	**g/cm^3**
Raw jute fiber thread, without any treatment					
N1.1	1.33	0.87	N2.1	2.01	0.94
N1.2	1.14	1.25	N2.2	2.00	0.73
N1.3	1.22	0.96	N2.3	1.86	0.81
N1.4	1.07	1.05	N2.4	1.91	0.77
N1.5	1.18	1.01	N2.5	1.85	0.82
Jute fiber threads immersed in distilled water for 1000 hours					
D1.1	1.28	0.76	D2.1	1.72	0.76
D1.2	1.21	0.79	D2.2	2.08	0.55
D1.3	1.21	0.94	D2.3	2.30	0.48
D1.4	1.08	1.08	D2.4	1.99	0.56
D1.5	1.21	1.12	D2.5	2.32	0.56
Jute fiber threads immersed in Salty water solution for 1000 hours					
DS1.1	1.28	0.70	DS2.1	1.82	0.83
DS1.2	1.21	1.08	DS2.2	1.94	0.71
DS1.3	1.21	1.11	DS2.3	2.10	0.62
DS1.4	1.08	1.24	DS2.4	2.10	0.56
DS1.5	1.21	0.87	DS2.5	2.13	0.70
Jute fiber threads immersed in alkaline solution for 1000 hours					
DA1.1	1.39	0.90	DA2.1	1.87	0.77
DA1.2	1.21	1.06	DA2.2	2.20	0.58
DA1.3	1.18	0.97	DA2.3	2.05	0.64
DA1.4	1.16	1.21	DA2.4	1.94	0.74
DA1.5	1.10	1.16	DA2.5	2.01	0.59

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3. Experimental results: Physical Properties

3.1 Jute fibers

Water absorption tests were conducted under real conditions and without pre-drying the fibers. The main objective of these tests was to evaluate the quantity of water that would be necessary for composite mixtures with different percentages and sizes of jute fiber. The fibers used were of three different lengths 5, 10 and 30 mm respectively (Fig. 4) and the water absorption test was performed on 10 g of each fiber length. A total of 5 tests were conducted for each type of fiber. The test results are presented in Section 3.

The tests were conducted under environmental condition; no modifications in the physical state of the materials have been done, in order to have real worksite conditions.

(a) (b) (c)

Fig. 11. (a) dry jute fibers; (b) jute fibers socked in water and (c) wet jute fibers

The chopped fibers were immersed in water for 3 hours. The fiber mass was initially measured before putting inside the water in dry conditions. Thereafter, measurements were conducted at every 30 mins. Before every measurement, extra water was drained, keeping the fibers in a fine mesh strainer for about 2 mins.

Each fiber group reached its saturation point around 2 hours after the first immersion. After this point, fibers cannot absorb or trap any more water.

The Jute fibers water absorption WA is defined by equation (1) 29[11], for detailed result see Section 3.1.

$$WA = \frac{W_{wet} - W_{dry}}{W_{dry}} \times 100\ (\%) \tag{1}$$

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where W_{dry} is the fiber weight before immersion while W_{wet} fiber weight after immersion. The water absorption rate, which also includes the extra trapped water, increased rapidly until 2 hours (the point corresponding from W_{dry} to 120 mins in the Fig. 12), whereas from 120 mins to 180 mins the water imbibition remained quasi constant averaging in the range of 58.87 g – 58.89 g for 30 mm, 81.38 g - 81.38g for 10 mm and 91.78 g – 91.84 g for 5 mm, respectively and therefore, it can be said that the fibers reach the saturation point.

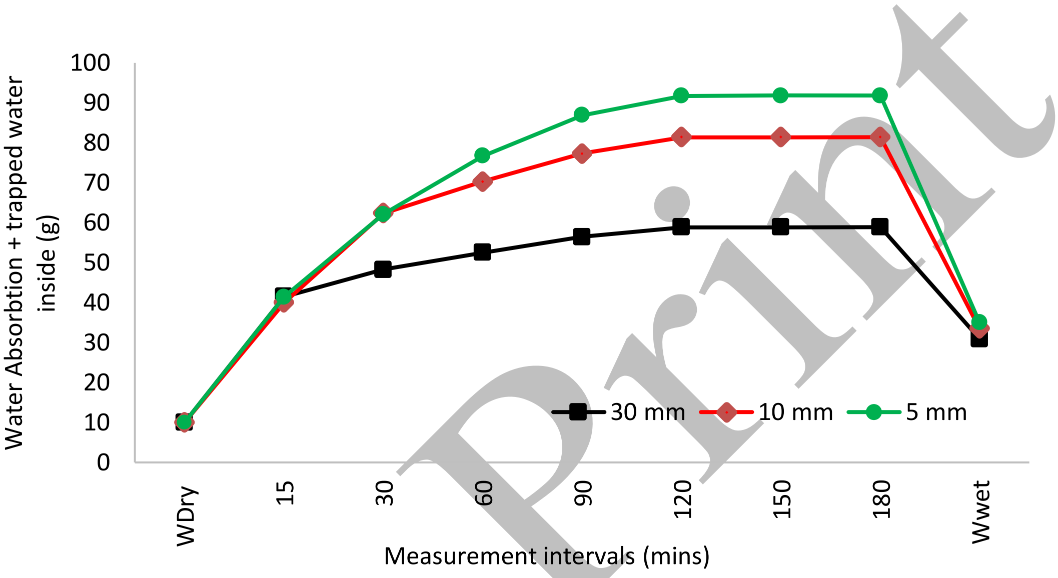

Fig. 12. Jute fibers water absorption

Based on the observations, it is worth to note that the fibers not only absorb water by itself singularly, but they have the tendency to stick to each other due to electrostatic force in dry state as well as in wet state. Therefore, it has been noticed that these fibers together form fiber-balls whenever they come in contact with water (Fig. 13), and these fiber bundles as a whole behave like a sponge to soak and trap extra additional water inside its cavity. This tendency of water trapping increases with the increase in fiber amount. It has been found that 10 grams of jute fiber with 5 mm length can trap 10.43 g more water when compared with 10 mm fiber, and this value is 3 times more when compared with 30 mm fibers (Fig. 12).

Fig. 13. Fiber-balls are formed when fibers come in contact with water.

After 3 hours, fibers were taken out from water (the point corresponding to 180 min in the Fig. 12) and the additional trapped water was squeezed out (the point corresponding to W_{wet} in the Fig. 12). It has been found that the jute fibers can absorb on average 210% (average) for 30mm; 235% (average) for 10mm and 250% (average) for 5mm, of water with respect to its dry mass (W_{dry}).

3.2 Jute fiber threads

Jute threads of both class 1 mm and class 2 mm have shown a similar absorption trend. Five samples of approximately 7cm long were cut from each thread class. Like fibers, threads came to the saturation point around two hours from the immersion time in normal water.

Finally, after 3 hours, threads were taken out from the water (the point corresponding to 180 min, in the Fig. 14) and the additional trapped water was squeezed out (the point corresponding to W_{wet}, in the Fig. 14).

The water absorption percentage obtained using Equation 1, for the class 1mm and class 2mm thread groups found to be 204.44 % and 201.33 % respectively, in average.

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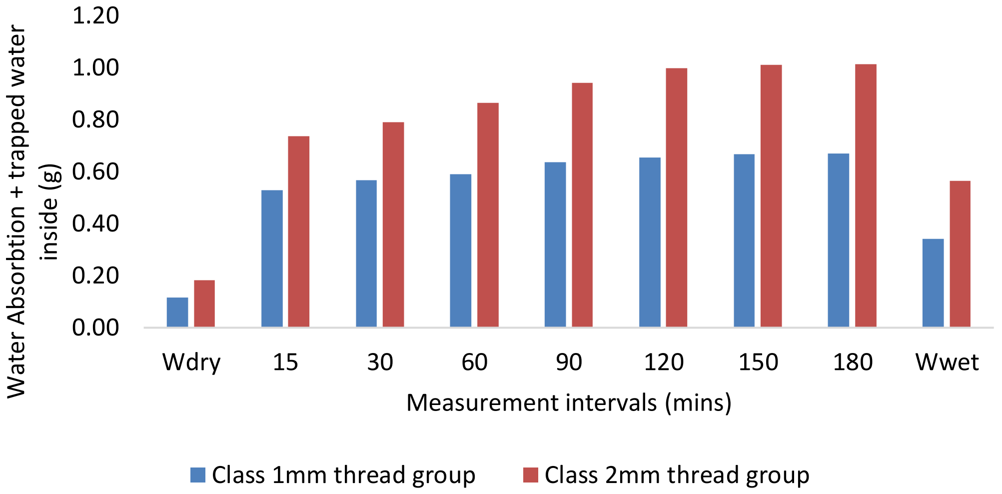

Fig. 14. Jute threads water absorption.

3.3 Jute Diaton

The water absorption tests were also performed on diatons and five samples approximately 17cm long were cut from five random diaton samples.

Also in this case, after 3 hours diatons were taken out from water (the point corresponding to 180 min, in the Fig. 15) and the additional trapped water was squeezed out (the point corresponding to W_{wet}, in the Fig. 15). It has been observed that diatons (with specifications as mentioned in Section 2.1.4) can absorb on average 183.46% of water with respect to its dry mass (W_{dry}) calculated according to Equation 1.

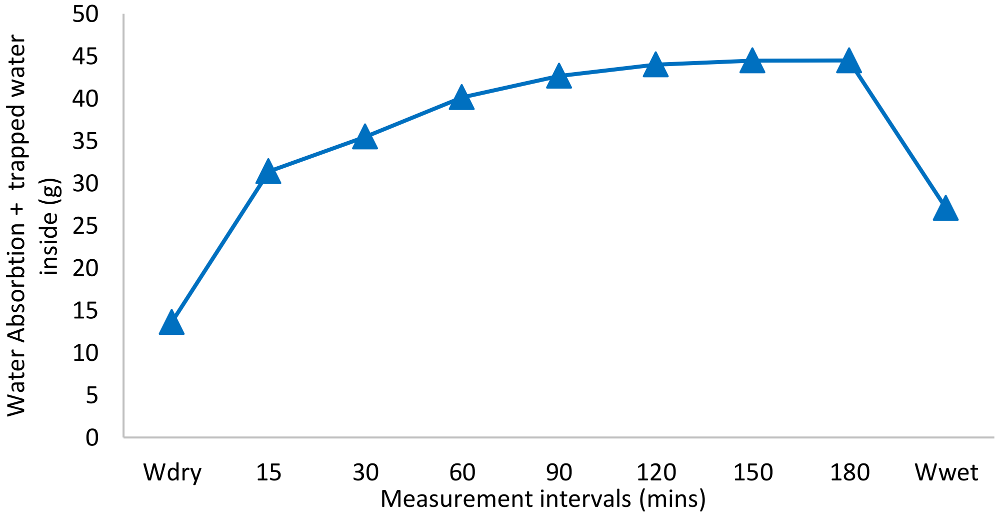

Fig. 15. Diaton average water absorption.

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4. Experimental results: mechanical characteristics

4.1 Jute fibers

A total of 12 individual jute fibers 10 cm long (with Co.V of 2.64%) and with 81.08 µm (with Co.V. of 20.94%) diameter were collected randomly from the raw and intact jute stock (Fig. 1a). The strain energy (U), tensile strength (ft) and axial strain/deformation ratio (ε) of the jute fiber samples were determined by tensile strength tests. A digital force gauge with maximum capacity of 50N and displacement rate of 0.5 mm/min was used for the tests. The fibers were not treated before the tensile tests.

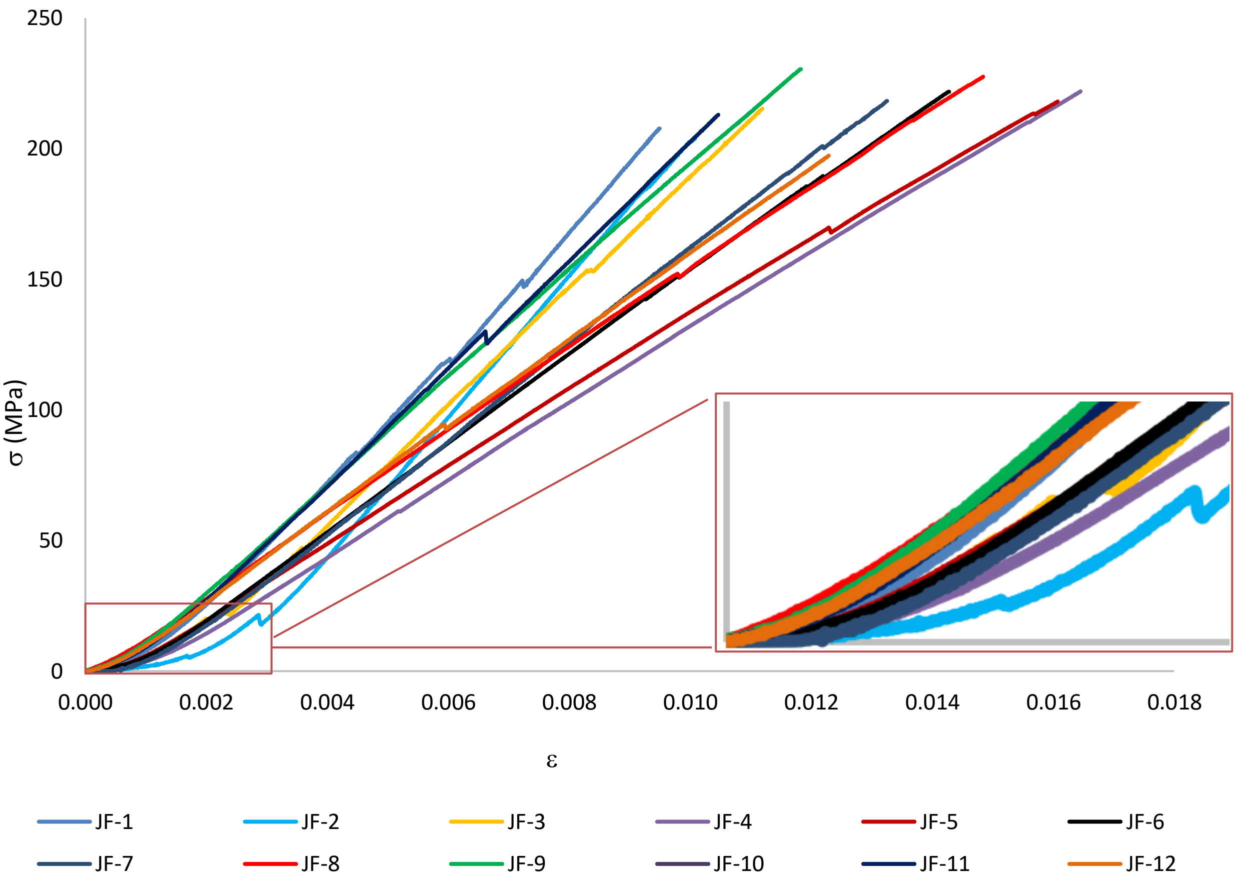

Fig. 16. Tensile stress-strain diagrams of the jute fiber

Looking at Fig. 16 it is possible to see a first horizontal branch of the stress-strain curve due to the fact that the fibers were tested in an initially slack configuration.

The maximum and minimum tensile loads were found to be 1.96 N and 0.59 N, observed in sample JF-4 and sample JF-1 respectively. While maximum strain energy and the maximum

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axial strain measured for the sample JF4 were 0.77 Nmm and 0.017, respectively. Table 3 presents the fiber mechanical characteristics.

Table 3 Mean mechanical properties of jute fiber samples.

Strain energy (U)		Tensile strength (f_t)		Maximum Axial strain (ε)		Young's modulus (E)	
Mean Nmm	CoV %	Mean MPa	CoV %	Mean	Co.V %	Mean GPa	Co.V %
0.77	58.85	215.11	4.42	0.0131	19.08	16.97	17.89

4.2 Jute fiber threads

A total of 20 thread samples from both classes (Fig. 6) were subjected to displacement controlled tensile tests: 5 were not treated (natural state) while 15 samples were subjected to aging protocols as described in Section 2.2. The strain energy (U), tensile strength (f_t) and axial strain/deformation ratio (ε) of the jute thread samples were determined by tensile strength tests, according to the ISO 2062:2009 [33] (see Fig. 17).

Fig. 17. Three yarns class 1mm thread, after complete failure

The tensile force was applied using a Metrocom universal machine characterized by a maximum load capacity of 735 N, a sensitivity/scale division of 2.5 N and a load rate of 2mm/min.

Conversely, a Baoshishan ZP-200N digital force gauge was used to measure the tensile force and its capacity was 500 N with ± 0.2% of accuracy and featured with display resolution of 0.1 N.

The fiber samples elongation was measured with a linear variable displacement transducer having the following characteristics: max. range 50 mm, nominal sensitivity 2 mV/V and linearity -<0.10 %.

Table 4 presents a synthesis of the tensile test results. Interestingly when the samples from both the classes (Fig. 6) were treated in the salty water solution for 1000 hours, the average reduction in their strength and strain energy were found to be 34% and 16% lower respectively for class 1mm thread samples and 28% and 4% lower respectively for class 2 mm thread samples, when compared with the untreated normal raw threads.

Table 4 Mechanical properties of jute threads samples tested in tension.

Treated thread type	Strain energy U		Tensile strength f_t		Maximum Axial strain ε	
	Mean kNmm	CoV %	Mean MPa	CoV %	Mean	CoV %
N1	1.03	34.59	112.45	26.16	0.65	11.71
D1	0.42	17.67	53.27	18.19	0.55	18.28
DS1	0.68	19.05	94.17	12.99	0.58	5.23
DA1	0.86	38.50	101.40	23.73	0.60	25.32
N2	2.05	10.86	56.95	9.73	1.24	29.78
D2	1.27	28.31	36.44	23.81	0.74	4.36
DS2	1.52	34.27	45.63	14.71	0.77	21.17
DA2	1.81	24.41	52.31	12.98	0.90	6.94

N = Normal; D = Deionized water; DS =Deionized water and salt; DA = Deionized water and Alkaline solution

Similarly, when the threads were treated in the alkaline solution for 1000 hours, the reduction in the strength and strain energy found to be 19% and 7% lower respectively for class 1mm thread and 14% and 11% lower, respectively for class 2mm thread, when compared with the corresponding untreated threads.

Moreover, the threads treated in the distilled water have shown the worst performance and the reductions in the strength and strain energy found to be significantly high being more than 50% for all samples and for both classes, when compared with the untreated samples. Therefore, the deionized water aging treatment has inducted more damage to samples of both classes. Whereas the damage was significantly smaller for samples treated in the alkaline solution.

Looking at the results in the Table 4, the scattering can be explained considering that these samples are handmade and consequently the samples quality is not constant. The stress-strain diagrams for untreated and treated samples are shown from Fig. 18 to Fig. 25 . The mechanical behavior is almost linear elastic. While depending on the failure scenarios, it can be highlighted that there could be a small ductility linked to the timing of each yarn collapse.

It has been observed that in some cases, the failure of all three yarns occurred together, for example in the sample N1.2 from the class 1 mm (Fig. 18) and in the sample N2.3 from the class 2 mm (Fig. 22). While in other cases the failure was noticed at first in one of the yarns and thereafter other two or vice versa; as an example the sample D1.3 from the class 1 mm (Fig. 19) and the sample D2.5 from the class 2 mm (see Fig. 23). Whereas in the last case, the failure of each single yarn was noticed one after another; it is the case of the sample DA1.3 in the class 1 mm (Fig. 21).

The Young’s modulus of every sample from each thread class is similar to the average values of that respective class (Table 5). Therefore, every singular thread from each class presents a quite similar elastic behavior.

Table 5 Threads Young's modulus

Thread type	Mean [MPa]	Co.V [%]
Class 1mm	145.63	20.00
Class 2mm	53.10	10.67

The minimum and maximum collapse loads observed in the untreated threads from *class 1mm* category, are 99.83 N and 166.81 N respectively. The values of sample group treated in the distilled water solution are 45.40 N and 73.94 N; the ones of the sample group treated in salt solution are 81.00 N and 119.15 N, while the maximum and minimum collapse loads of the sample group treated in alkaline solution are 56.29 N and 125.13 N respectively.

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If we consider the *class 2 mm* threads, the minimum and maximum collapse loads are, respectively: 139.94 N and 195.25 N for untreated samples; 88.95 N and 147.30 N for threads treated in the distilled water solution; 105.91 N and 187.99 N for the sample group treated in salt solution; 132.49 N and 216.73 N for the sample group treated in alkaline solution.

The outcome of the tensile tests (Table 4) has proved that thinner thread samples (from the class 1mm) have better mechanical performance in comparison to thicker samples (from class 2mm threads). Strain energy and maximum strain (Table 4) have similar trend.

Indeed, untreated samples have the best performance, while the lowest values belong to samples immersed in deionized water. In comparison to standard construction materials, it should be highlighted the very high value of strain reached at collapse. Whereas, in some cases the sample reached more than 100% of original length.

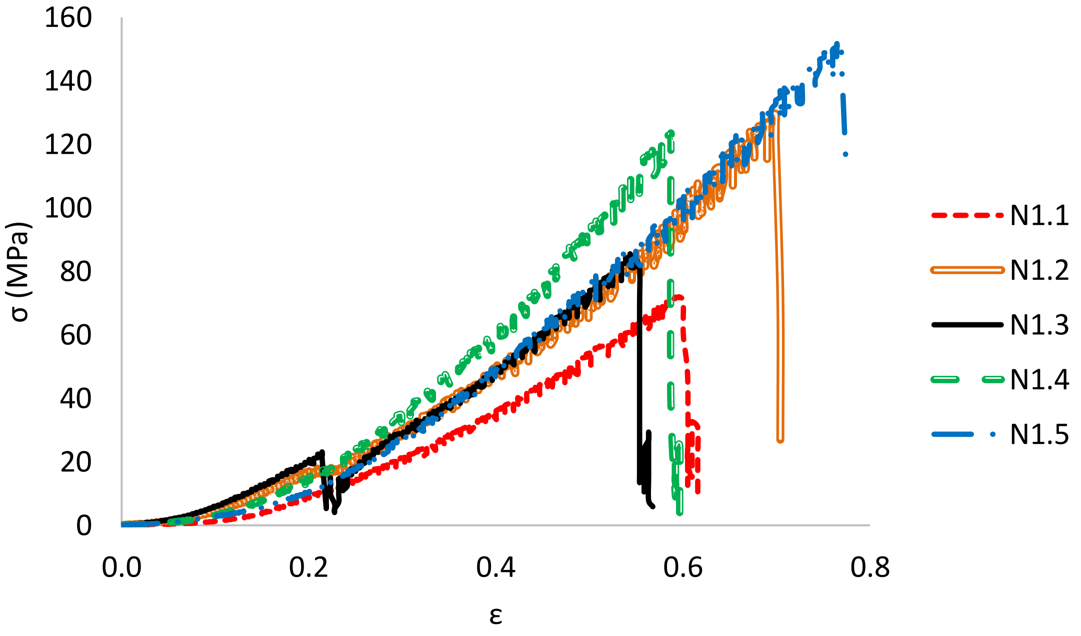

Fig. 18. Tensile stress-strain diagrams of the jute fiber threads of N1 category with diameter class 1mm, without any treatment.

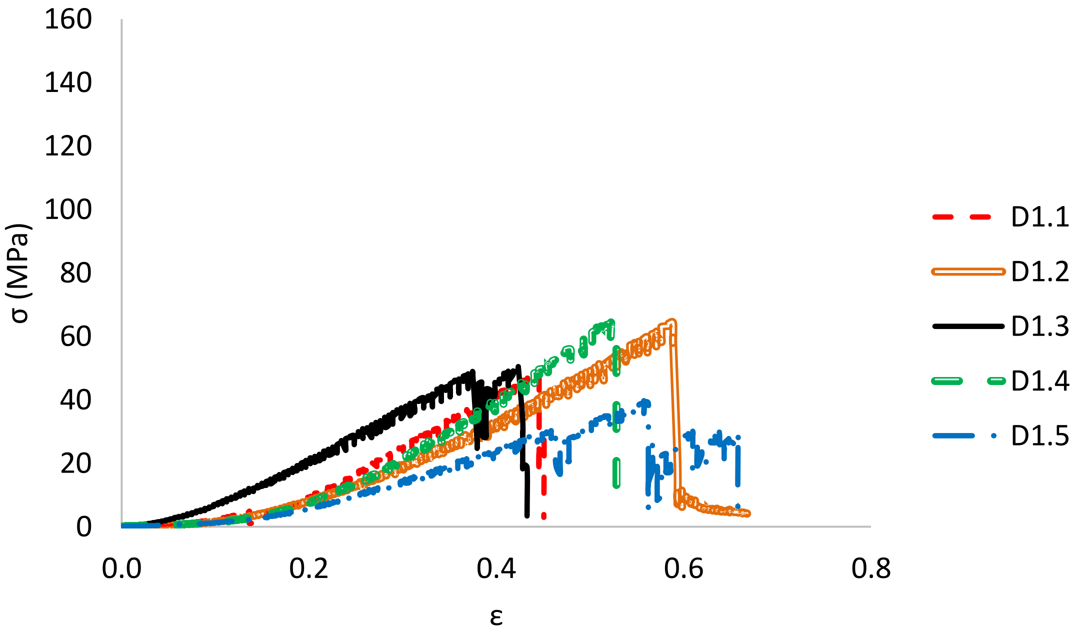

Fig. 19. Tensile stress-strain diagrams of the jute fiber threads of D1 category with diameter class 1mm, treated in distilled water.

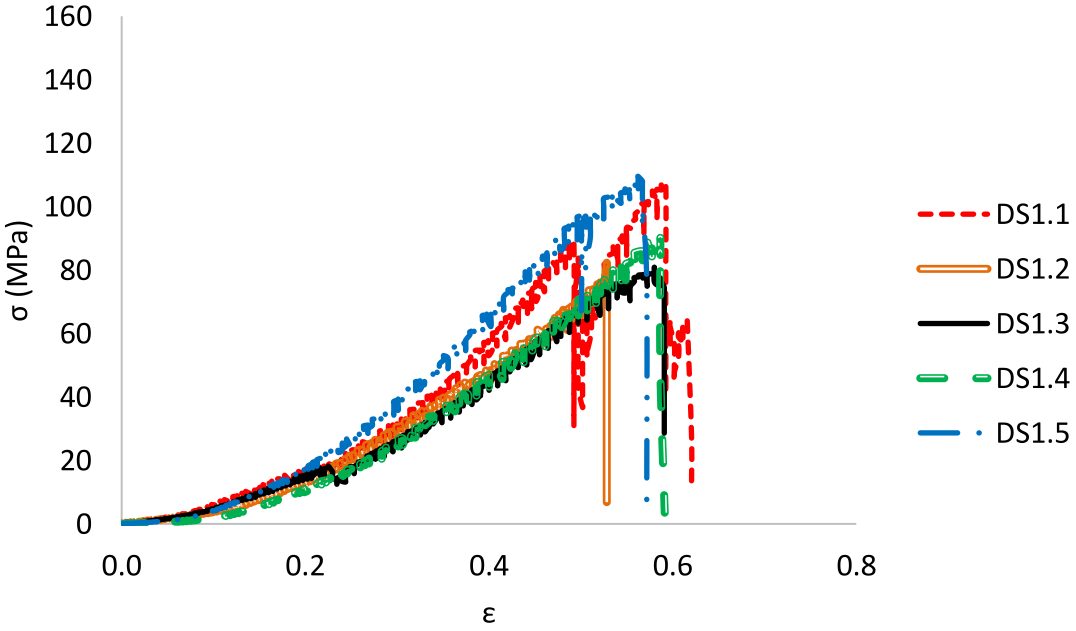

Fig. 20. Tensile stress-strain diagrams of the jute fiber threads of DS1 category with diameter class 1mm, treated in salt solution.

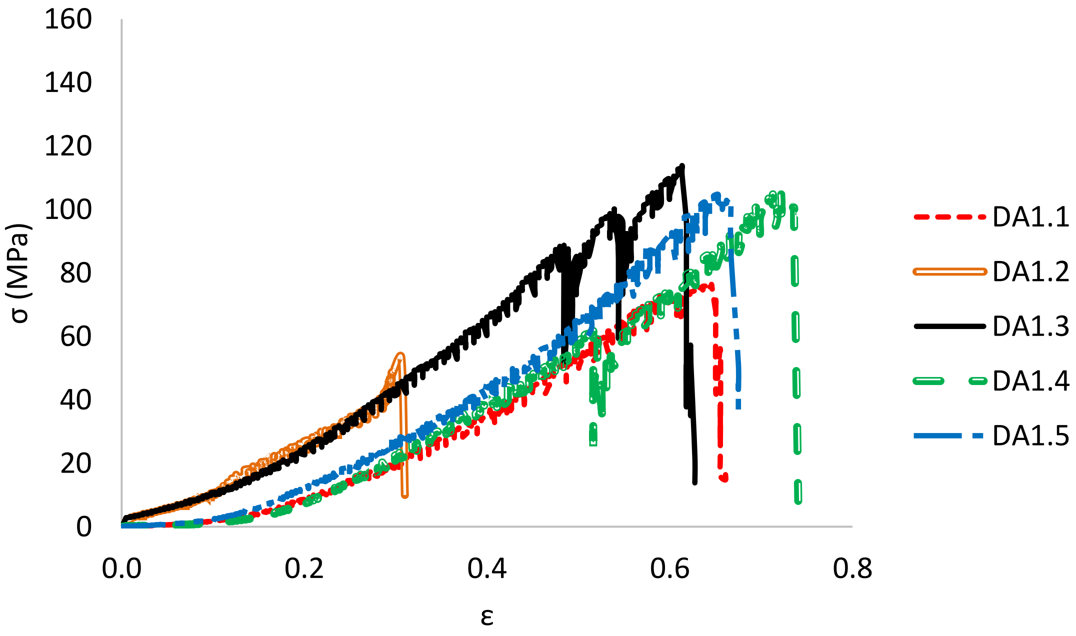

Fig. 21. Tensile stress-strain diagrams of the jute fiber threads of DA1 category with diameter class 1mm, treated in alkaline solution.

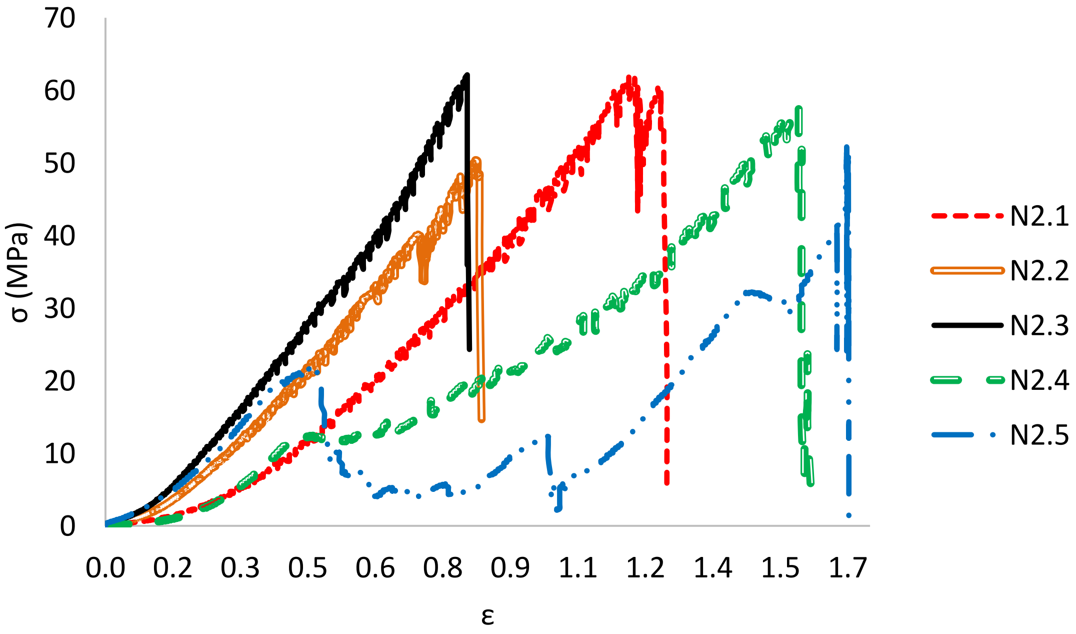

Fig. 22. Tensile stress-strain diagrams of the jute fiber threads of N2 category with diameter class 2mm, without any treatment.

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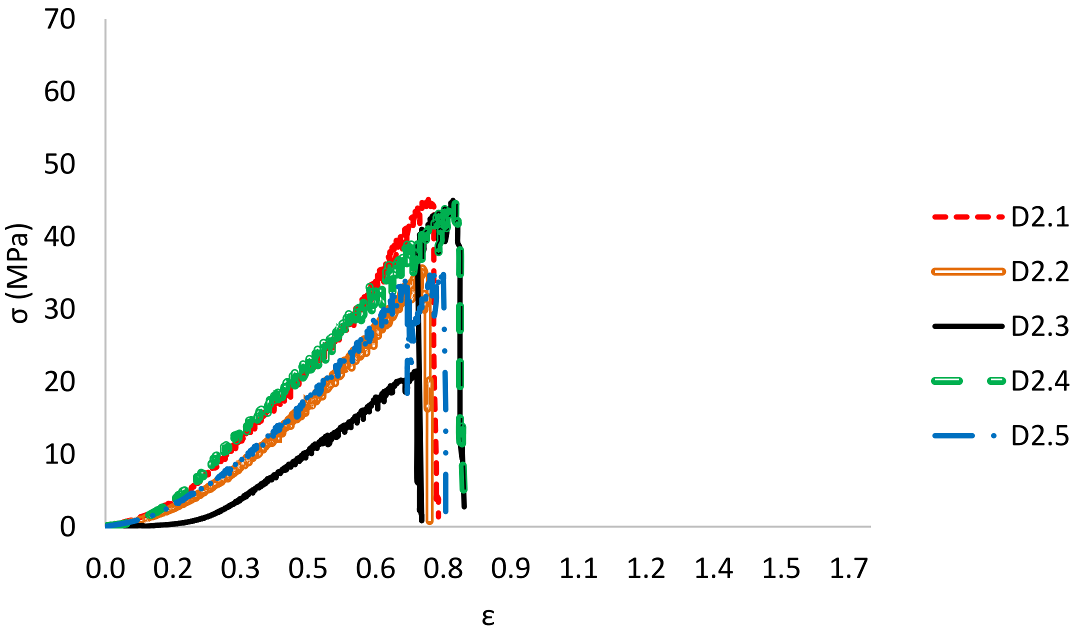

Fig. 23. Tensile stress-strain diagrams of the jute fiber threads of D2 category with diameter class 2mm, treated in distilled water.

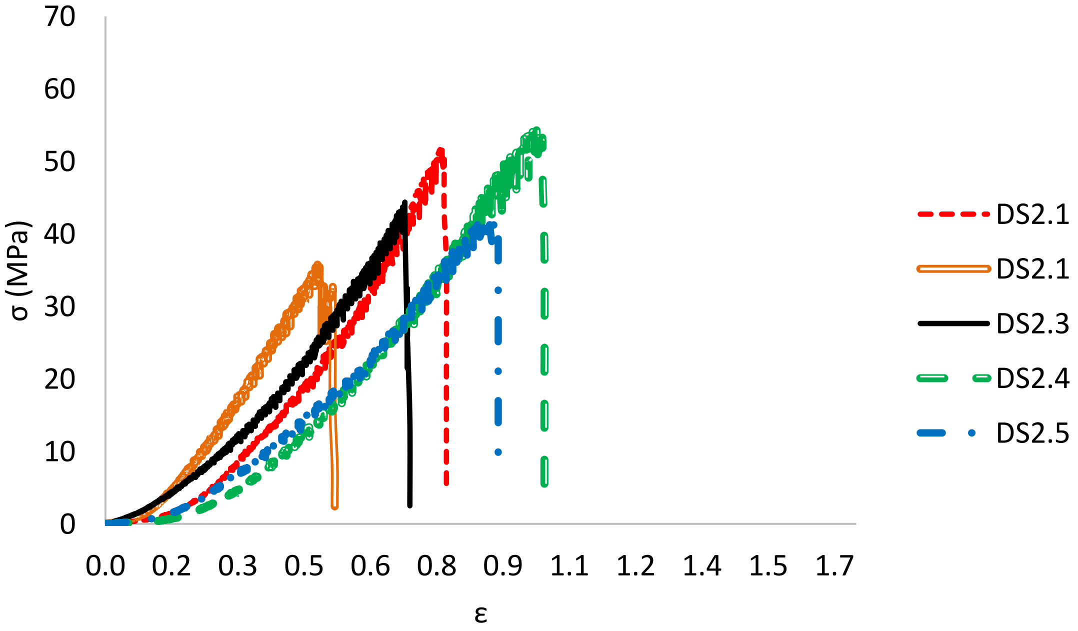

Fig. 24. Tensile stress-strain diagrams of the jute fiber threads of DS2 category with diameter class 2 mm, treated in the salt solution.

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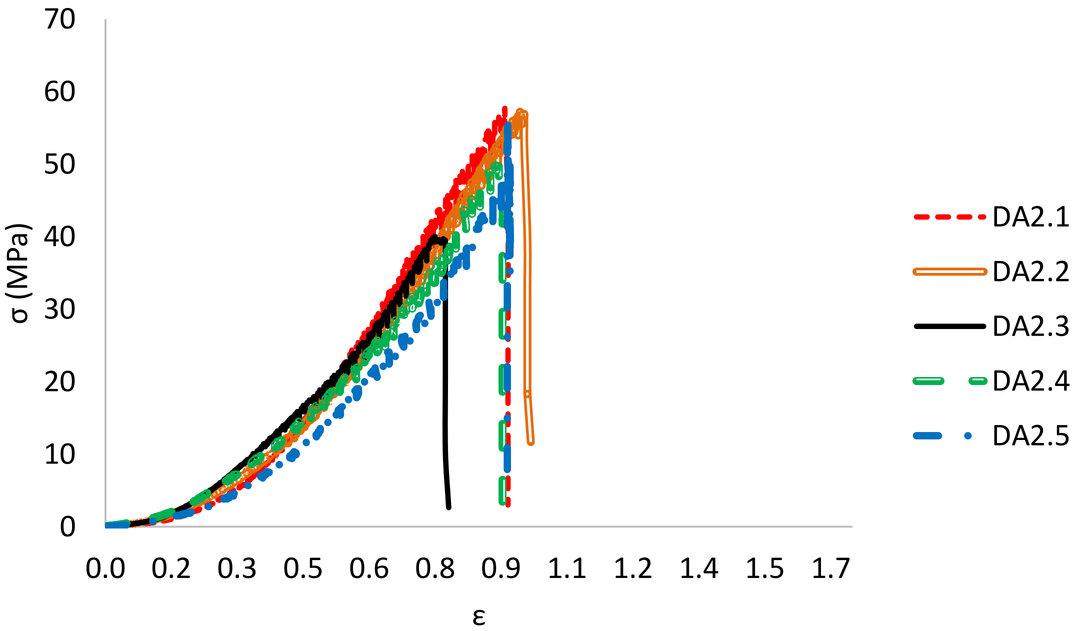
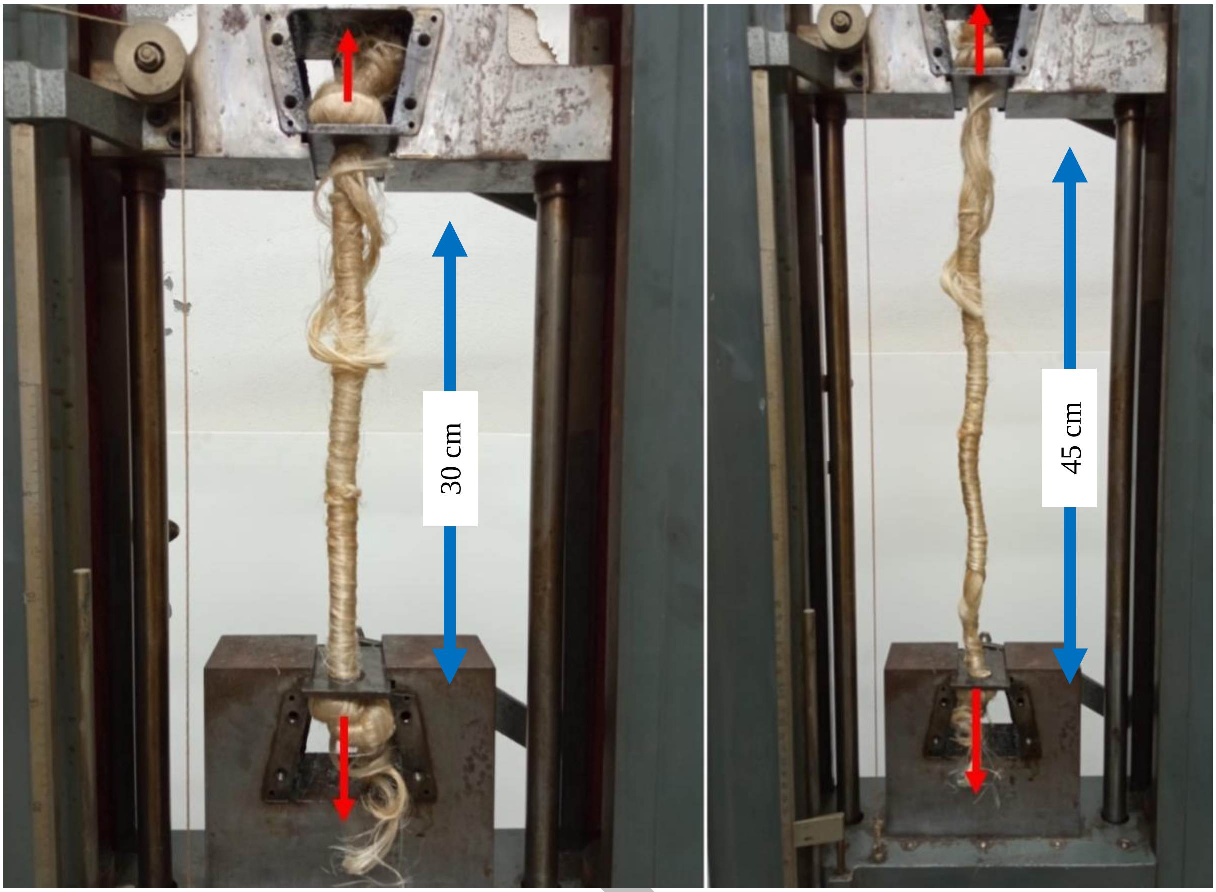


Fig. 25. Tensile stress-strain diagrams of the jute fiber threads of DA2 category with diameter class 2mm, treated in the alkaline solution.

4.3 Jute diatons

A displacement-controlled tensile strength test was conducted using another Metrocom universal machine (see Fig. 26), characterized by a maximum load capacity of 9.8 kN, a sensitivity/scale division of 39 N and a load rate of 0.5 mm/min. The tests have been performed on 5 diaton samples (specifications as described in Section 2.1.4).

The maximum and minimum tensile loads were found to be 3.92 kN and 2.54 for sample 2 and sample 5, respectively. While the maximum strain energy and the maximum axial strain measured for the samples were 127.21 kNmm and 0.40, respectively. The specific mechanical properties of the diatons are lower, when compared with threads (see Table 6 for details).



(a) (b)

Fig. 26. Jute diaton (a) before and (b) after tensile test

Fig. 27 presents the stress-strain diagrams for the diatons and the observed behaviors are not linear with different shapes at the collapse point. Also, it is worth highlighting that in this case we are considering handmade and non-treated (aging protocol) samples; so, significant scatter performances have been observed.

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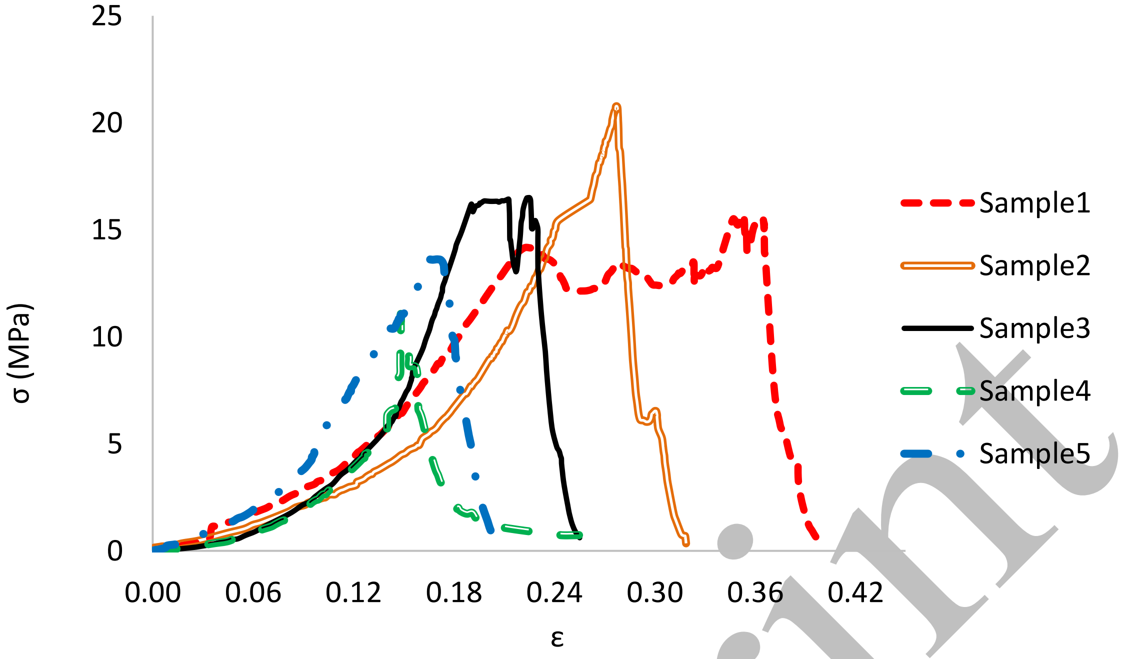

Fig. 27. Tensile stress-strain diagrams of the jute fiber diatons.

Table 6 Mechanical properties of jute diaton samples tested in tension.

Strain energy (U)		Tensile strength (f_t)		Axial strain (ε)	
Mean kN.mm	Co.V %	Mean MPa	Co.V %	Mean	Co.V %
14.18	53.87	15.54	20.77	0.29	23.62

5. Cross scale comparison

Although, all the products are made from the same material, each one has different physical and mechanical characteristics and these can be highlighted through a physical (see Table 7) and mechanical (see Table 8) cross scale comparison.

Table 7 highlights that water absorption of jute fibers (material behavior) in every product found to be almost similar, ranging in between 1.98-2.50 g(water)/g(fiber).

The behavior of the same fiber changes as it works together with other fibers (group behavior). Indeed, its capacity to trap water is affected by relevant parameters, such as length and density of fibers. Similar variations can be seen as threads as considered, but in this case the group behavior is less important while diameter and density play a key role.

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Table 7 Cross-scale comparison: Physical Properties

Type of jute products		Group behavior (Absorbed + trapped)		Material Behavior (Absorbed)	
		Mean g(water)/g(fiber)	Co.V. %	Mean g(water)/g(fiber)	Co.V. %
Jute fiber	Class 0.1mm (5mm)	8.18	6.60	2.50	5.55
Jute fiber	Class 0.1mm (10mm)	7.14	10.07	2.35	8.56
Jute fiber	Class 0.1mm (30mm)	4.89	3.30	2.10	7.67
Jute thread	Class 1mm	3.94	10.40	1.98	12.96
Jute thread	Class 2mm	4.56	4.68	2.10	8.55
Diaton	Class 10mm	3.26	4.98	1.99	2.80

As for the mechanical properties, Table 8 shows that the stiffness tends to be lower for elements of bigger equivalent size and diameter. This can be explained by considering that bigger samples may have a higher number of imperfections that yields to high stress localization points, which can trigger collapse mechanism.

Table 8 Cross-scale comparison: Mechanical Properties

Type of jute products		Ultimate stress		Ultimate strain		Specific Modulus	
		Mean MPa	Co.V. %	Mean	Co.V. %	Mean MPa/(kg/m^3)	Co.V. %
Jute fiber	Class 0.1mm	215.11	4.42	0.0131	19.08	11.32	17.89
Jute thread	Class 1mm	112.45	26.16	0.638	12.75	0.170	14.72
Jute thread	Class 2mm	56.95	9.73	1.197	29.45	0.065	33.65
Jute diatons	Class 15mm	15.54	20.77	0.235	31.68	0.044	20.77

6. Conclusions

The physical and mechanical properties of jute fibers, threads and diatons have been presented with a particular attention to their possible application on structural retrofitting.

Jute fibers can represent a sustainable construction material with interesting mechanical properties. Both raw fibers and threads can be easily used to create diatons, fiber reinforced composite and reinforcement nets.

Jute fibers absorption capabilities are very important for the design mix of fiber reinforced mortar e/o concrete. Different fiber lengths produced different absorption rate, in particular smaller fiber present the highest absorption values. In case of jute threads bigger diameter corresponds to highest absorption.

Particular attention has been devoted to the durability properties of jute threads that has been subjected to different aging protocol. The more important properties deterioration has been recorded in case of distilled water immersion, while salt water and alkaline solution did not produce significant damages.

Jute fibers, threads and diatons present quite good tensile strength that can be useful for construction composite materials design.
Further developments of this research are expected for the design and testing of fiber reinforced composite mortars [34] that can be used as a sustainable technology for existing masonry thermal-upgrade and structural retrofitting [32].

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