NOCMAT 2026, v.1, e004

NOCMAT

https://periodicos.uefs.br/index.php/nocmat

ISSN
XXXX-XXXX

Effect of PLA coating on the physical, morphological and mechanical properties of natural fibre yarns

Efeito do revestimento de PLA nas propriedades físicas, morfológicas e mecânicas de fios de fibras naturais

PAOLILLO, Bruno[1,2]; DI MAIO, Luciano[1]; KOENDERS, Eduardus[2] MARTINELLI, Enzo[1], PEPE, Marco[1]*

1 Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II 132, 84084 Fisciano, SA, Italy

2 Institute of Construction and Building Materials, Technical University of Darmstadt, L5| 06 207, Franziska-Braun-Straße 3, 64287 Darmstadt, Germany

* Autor correspondente: mapepe@unisa.it

Received: May 29, 2026
Accepted: October 29, 2026
Published: November, 3,2026
Citation: B. Paolillo, L. Di Maio, E. Koenders, E. Martinelli, M. Pepe, "Effect of PLA coating on the physical, morphological and mechanical properties of natural fibre yarns", *NOCMAT*, vol. 1, e004, 2026. DOI:

Copyright: © 2026 by the authors. License ABMTENC, Rio de Janeiro, Brazil. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract
This study investigates the effect of a polylactic acid (PLA) based coating on the morphology, cross-sectional area and tensile response of flax and jute yarns intended for sustainable textile-reinforced mortar systems. The objective of this study was to assess the physical and mechanical properties of yarns before and after a coating treatment. The coating was prepared using 5% PLA dissolved in 95% acetone and applied by yarn immersion. Uncoated and coated yarns were characterized through linear density, density measurements, SEM image analysis and tensile tests. The results show that the PLA treatment increased the linear density and cross-sectional area of both fibres, confirming polymer deposition on the yarn surface. SEM observations showed a more compact and regular morphology after coating, with reduced fibre separation and a more continuous external surface. This effect was more evident for jute, which initially showed a more irregular structure. Tensile tests indicated that coated yarns reached higher maximum forces than uncoated yarns, suggesting improved cohesion among elementary fibres. However, when the results were normalized by the increased cross-sectional area, the tensile stress decreased. Therefore, the coating mainly improves yarn compactness and load-bearing capacity rather than the intrinsic tensile strength of the fibre material.
Keywords: SEM; Flax fibres; Jute fibres; natural fibres.

Resumo
Este estudo investiga o efeito de um revestimento à base de PLA na morfologia, área da seção transversal e resposta à tração de fios de linho e juta destinados a sistemas sustentáveis de argamassa reforçada com têxteis. O objetivo deste estudo foi avaliar as propriedades físicas e mecânicas dos fios antes e depois de um tratamento de revestimento. O revestimento foi preparado utilizando 5% de PLA dissolvido em 95% de acetona e aplicado por imersão dos fios. Os fios não revestidos e revestidos foram caracterizados por meio de densidade linear, medições de densidade, análise de imagens por MEV e ensaios de tração. Os resultados mostram que o tratamento com PLA aumentou a densidade linear e a área da seção transversal de ambas as fibras, confirmando a deposição do polímero na superfície dos fios. As observações por MEV mostraram uma morfologia mais compacta e regular após o revestimento, com menor separação das fibras e uma superfície externa mais contínua. Esse efeito foi mais evidente na juta, que inicialmente apresentava uma estrutura mais irregular. Os ensaios de tração indicaram que os fios revestidos atingiram forças máximas mais elevadas do que os fios não revestidos, sugerindo uma melhoria na coesão entre as fibras elementares. No entanto, quando os resultados foram normalizados pelo aumento da área da seção transversal, a tensão de tração diminuiu. Portanto, o revestimento melhora principalmente a compacidade e a capacidade de suporte de carga do fio, e não a resistência intrínseca à tração do material da fibra.
Palavras-chave: MEV; Fibras de linho; Fibras de juta; fibras naturais.

1 INTRODUCTION

Textile Reinforced Mortars (TRM), also known as Fabric Reinforced Cementitious Mortars (FRCM), are widely used for the strengthening of existing structures. In recent years, these systems have gained increasing attention because of their advantages, such as their compatibility with masonry substrates, ease of application, and good mechanical performance [1-3]. In recent years, research efforts have increasingly focused on improving the sustainability of these reinforcement systems through two complementary strategies: replacing conventional cement-based matrices with more sustainable binders and substituting synthetic, energy-intensive fibres with more environmentally friendly alternatives.

In this context, natural fibres are a promising solution for developing more sustainable composite systems. Following the first assessment of natural fibres by Gram [4], they have gained increasing attention in the scientific literature since the early 2000s [5], despite limitations such as high variability and low durability [6-11]. In fact, their use in construction is not new, since natural fibres have been adopted for years due to their availability and low cost.

Synthetic fibres such as carbon, glass, steel, and basalt have become more common because of their lower variability and higher mechanical performance [12-14]. Today, the renewed interest in natural fibres is supported by their good mechanical and thermal properties, which make them suitable for both structural strengthening and energy improvement of masonry buildings. Several studies have shown that the tensile strength of some natural fibres can range between 200 and 400 MPa [8, 9, 15, 16].
Despite these advantages, natural fibres also have some limitations. One of the main issues is their high microstructural variability [11, 17-20]. This variability depends on several factors, including the growth conditions, climate, soil acidity, production process, and retting technique. These aspects influence the morphology and mechanical response of each fibre and, consequently, the behaviour of the yarns and textiles used in the composite system [21, 22].

To reduce these limitations, several studies have investigated the use of coating treatments. The coating surrounds the fibres, improves the cohesion among the filaments, and can make the yarn structure more regular [12, 20, 23-27]. Coating systems are commonly based on polymeric resins or inorganic materials. Among the polymers used as coating systems in the literature, PLA was selected for this study. PLA has emerged as a promising coating material because it is obtained from renewable resources and is biodegradable under suitable conditions. When applied to natural-fibre yarns, PLA can bind the elementary fibres into a more cohesive bundle, regularize the yarn morphology and potentially limit moisture penetration. Recent studies have therefore investigated PLA impregnation as a means of improving the physical and mechanical performance of flax, jute and coir reinforcements for cementitious composites [24, 28-30].

Within this framework, the present study investigates the morphology and cross-sectional area of flax and jute yarns before and after the coating treatment. These fibres were selected because they are easily available and show promising mechanical properties for strengthening applications. The yarn morphology was analysed by Scanning Electron Microscopy (SEM), while the cross-sectional area was evaluated using two different approaches: an indirect method based on linear density and density measurements, and a direct method based on SEM image analysis. The objective of the work is to assess the effect of a bio-based coating system on the mechanical and physical properties of natural yarns.

2 MATERIALS AND METHODS

2.1 NATURAL TEXTILES

Two different natural textiles were used in this study: flax and jute fabrics. Both textiles were selected because they are commercially available and can be used as reinforcement in sustainable Textile-Reinforced Mortar systems. The flax textile was characterised by a grey colour and a mesh density of about 6.2 yarns/cm, while the jute textile showed the typical golden colour and a mesh density of about 5.6 yarns/cm (see Figure 1). Although the flax textile had a higher number of yarns per unit length, the jute yarns appeared thicker and more irregular.

The experimental programme was carried out on uncoated and coated yarns extracted from both textiles. The coating was applied to evaluate the effect of a bio-based treatment on the physical, morphological and mechanical properties of the natural yarns.

2.2 PLA COATING TREATMENT

The coating treatment was developed using polylactic acid (PLA) dissolved in acetone. PLA was selected because it is a bio-based thermoplastic polymer and represents a more sustainable alternative

to conventional synthetic impregnation systems. The density of PLA is around 1.24 g/cm³. The solution was prepared using 5% PLA and 95% acetone by weight.

Figure 1: (a) flax (125 g/m^2) and (b) jute (320 g/m^2) textiles

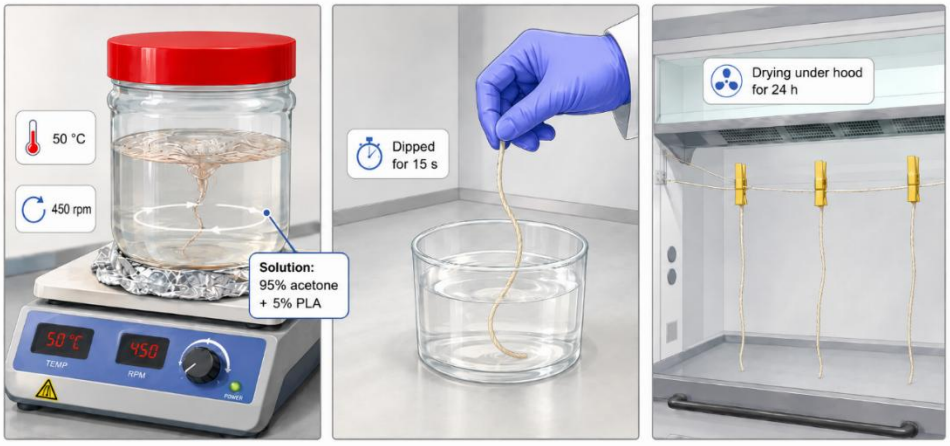


(a) (b)

Although it is well known that PLA can dissolve under alkaline conditions, such as those found in cementitious mortars, its use was selected because of its low environmental impact. The purpose of the PLA coating is mainly to contain the yarn cross-section and keep it more compact during the embedding process, rather than to provide long-term protection in the alkaline environment. For this specific purpose, the use of PLA can therefore be considered justified. Acetone was used to dissolve PLA because it is affordable and can dissolve amorphous or low-crystallinity PLA [30]. Its solvent power increases with temperature. Moreover, it is used as a low-impact solvent and evaporates readily after coating [31], [32]. Furthermore, during a possible industrial process, acetone vapour could be recovered via a fume hood and reused, thereby reducing waste.

The acetone was put into a closed beaker and heated on a hot plate at 50 °C, below the boiling point of acetone. Once the temperature was reached, PLA was added to the acetone and the solution was mixed at 450 rpm until complete dissolution. Then, 20 cm long yarns were immersed in the PLA-acetone solution for a few seconds. After impregnation, the yarns were left to dry at room temperature (21 °C) for 24 h (see Figure 2).

Figure 2: Yarn coating treatment



This procedure was used for both flax and jute yarns. The aim of the treatment was to improve the cohesion among the elementary fibres, reduce the irregularity of the yarn surface and obtain a more defined cross-section.

2.3 PHYSICAL AND VISUAL CHARACTERIZATION

The physical characterization included the evaluation of linear density, density and equivalent cross-section area of the yarns. These parameters were measured for both flax and jute specimens.
The linear density was evaluated to determine the mass per unit length of the yarns. The test was performed on ten samples for each type of fabric. Each specimen had a total length of 750 mm and was

weighed in a dry condition using a precision balance. The linear density was expressed in tex, corresponding to g/km, and was calculated as:

$$T_t = \frac{m}{L} \cdot 1000 \quad (1)$$

where T_t is the linear density, expressed in tex; m is the dry mass of the yarn, expressed in grams; and L is the length of the specimen, expressed in metres.

The density was evaluated using the Archimedes method. Each sample was weighed in air and in a reference fluid. The difference between these two measurements was used to calculate the volume of the specimen and, consequently, its density.
The density was calculated according to the relation reported in the Sartorius YDK 01 density determination kit manual [33]:

$$\rho = \frac{W(a) \cdot [\rho(fl) - \rho(a)]}{0.99983 \cdot G} + \rho(a) \quad (2)$$

where ρ is the density of the solid specimen; $\rho(fl)$ is the density of the fluid; $\rho(a)$ is the air density, assumed equal to 0.0012 g/cm³ at 20 °C and 101.325 kPa, respectively; $W(a)$ is the weight of the specimen in air; $W(fl)$ is the weight of the specimen in the fluid; G is the hydrostatic buoyancy of the specimen in the fluid; and 0.99983 is a geometrical correction factor.

The equivalent cross-section area was calculated from the ratio between linear density and density. This value represents an indirect estimation of the yarn area. However, this method does not explicitly account for the internal voids and irregularities of natural yarns.
For this reason, the calculated area was interpreted as an equivalent value and was later compared with the cross-section area obtained from Scanning Electron Microscope (SEM) image analysis.

2.4 SCANNING ELECTRON MICROSCOPE ANALYSIS

SEM was used to analyse the cross-sectional area and evaluate the presence of voids and the influence of the coating. Moreover, the Fibre Intrinsic Efficiency Ratio (FIER) was calculated from the measured area and perimeter values [17]:

$$FIER = \frac{P_f}{P_{eq}} \quad (3)$$

where P_f is the real perimeter of the fibre cross-section, while P_{eq} is the circumference of an equivalent circular fibre with the same cross-sectional area. In this way, FIER allows us to evaluate how much the real fibre section differs from an ideal circular shape.

The image analysis was carried out using a Python script based on OpenCV. The script was developed to process SEM images and to quantify the cross-sectional area occupied by the fibre bundle and by internal voids. First, the original image was converted into greyscale. A contrast correction was then applied to improve the separation between the fibre material and the background. This pre-processing step made the fibre regions easier to detect during thresholding.

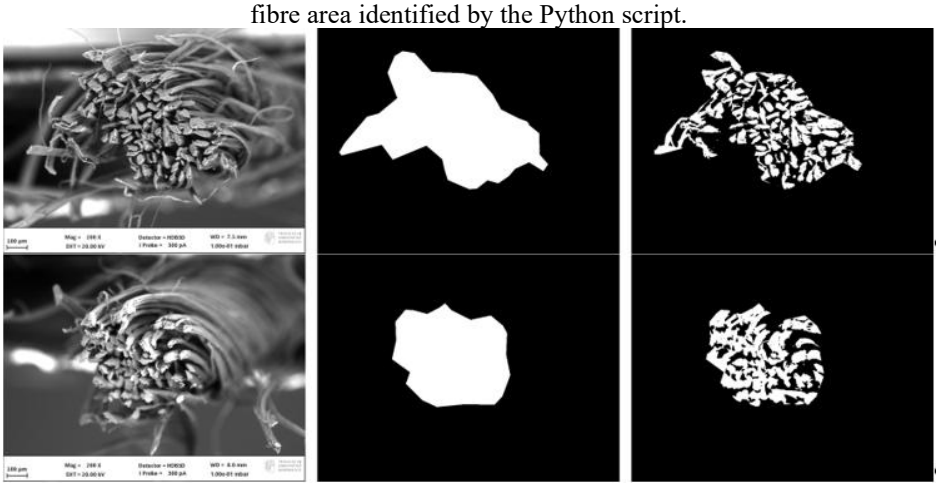
The region of interest was manually selected by drawing the external contour of the yarn cross-section directly on the image. This step excluded the surrounding background and considered only the area enclosed by the fibre bundle. A binary mask was then generated from the selected contour. Inside this mask, a threshold value was applied to distinguish the solid fibre regions from the darker voids. The number of pixels belonging to the total selected area, to the fibre phase, and to the void phase was then calculated.

To convert the measurements from pixels to physical units, the two ends of the SEM scale bar were manually selected. Since the real length of the scale bar was known, the script calculated the pixel-to-micrometre conversion factor. This factor was used to convert the measured areas from px² to µm². The

same conversion was also applied to the length of the manually drawn contour, allowing the perimeter of the selected cross-section to be estimated.

Finally, the script provided the total cross-sectional area, the area occupied by fibres, the area occupied by voids, the fibre percentage, and the contour length. It also saved a summary image showing three outputs: the modified greyscale image, the manually selected mask, and the binary image used for fibre detection. This procedure allowed us to obtain repeatable quantitative information from the SEM images while maintaining manual control over the definition of the yarn boundary.

Figure 3: SEM image processing: (a) original SEM images; (b) mask created around the fibres; (c) effective fibre area identified by the Python script.



(a) (b) (c)

2.5 MECHANICAL PROPERTIES

Mechanical tests were carried out to evaluate the effect of the PLA coating on the tensile response of the natural yarns. The tests were performed on uncoated and coated flax and jute yarns. The aim was to verify whether the morphological changes observed through SEM analysis were associated with measurable changes in the mechanical behaviour.

The yarns were tested under uniaxial tension. For each configuration, several specimens were prepared with the same gauge length. The ends of the yarns were fixed to the testing machine using suitable tabs in order to reduce stress concentration and avoid premature failure close to the grips. Moreover, sandpaper was used to improve the grip. The tests were carried out under displacement control until failure. the displacement rate was 200 mm/min [34]. A 1 kN load cell was used. Furthermore, 20 samples were tested for uncoated textiles and 10 for coated textiles.

During the tests, the applied load and displacement were continuously recorded. From the experimental curves, the main mechanical parameters were calculated: peak load, tensile strength, displacement at peak load and initial stiffness. The tensile strength was calculated by dividing the peak load by the cross-section area of the yarn. Both the indirect area, obtained from linear density and density, and the SEM-based area were considered for comparison.

The failure mode was also observed after testing. Particular attention was given to fibre rupture, yarn splitting and possible effects of the coating on the progressive damage of the yarns.

3 RESULTS AND DISCUSSION

3.1 PHYSICAL CHARACTERIZATION

The dry weight and linear density values obtained for flax and jute yarns are reported in Table 1. The test was performed on ten specimens for uncoated yarns and five coated yarns, with specimen lengths of 750 mm for uncoated yarns and 700 mm for coated yarns.

The results show a clear difference between the two natural fibres. Jute yarns presented higher dry weight and linear density values than flax yarns, both before and after coating. This difference is related to the larger size of the jute yarns, which appeared thicker than the flax ones during the visual inspection of the fabrics.

For flax yarns, the average linear density increased from 100.0 TEX in the uncoated condition to 123.7 TEX after coating. Similarly, jute yarns showed an increase from 284.0 TEX to 368.5 TEX. This increase confirms the deposition of the PLA-based coating on the yarn surface, which produced an increase in the mass per unit length. The increases were 24% for flax and 30% for jute.

Flax yarns showed a more homogeneous distribution of values, both in the uncoated and coated conditions. Conversely, jute yarns presented a higher scatter, confirming the greater irregularity of this type of natural fibre. This variability was also observed after coating and can be attributed to the intrinsic heterogeneity of natural yarns and to the non-uniform deposition of the polymer layer.

From these data, the average linear density values were calculated for both flax and jute yarns. These values were then used for the calculation of the equivalent cross-sectional area.

Table 1: Linear density calculation for uncoated Jute and Flax

Weight and linear density								
Specimen	Flax fibre				Jute fibre			
	Uncoated		Coated		Uncoated		Coated	
	Dry weight	Linear Density	Dry weight	Linear Density	Dry weight	Linear Density	Dry weight	Linear Density
	g	TEX	g	TEX	g	TEX	g	TEX
1	0.073	97.3	0.0914	130.6	0.215	286.7	0.2502	357.4
2	0.063	84.0	0.0848	121.1	0.233	310.7	0.2776	396.6
3	0.076	101.3	0.0823	117.6	0.179	238.7	0.2356	336.6
4	0.077	102.7	0.0857	122.4	0.184	245.3	0.2471	353.0
5	0.076	101.3	0.0888	126.9	0.193	257.3	0.2793	399.0
6	0.079	105.3			0.201	268		
7	0.071	94.7			0.23	306.7		
8	0.072	96.0			0.206	274.7		
9	0.085	113.3			0.26	346.7		
10	0.078	104.0			0.229	305.3		
Average	0.075	100.0	0.0866	123.7	0.213	284.0	0.25796	368.5

Table 1 shows the linear density values obtained for flax and jute fibres, respectively. For each fibre type, ten specimens were tested in order to evaluate the variability of the measured values. Figure 4 shows the density values obtained for flax and jute fibres in both uncoated and coated conditions. For each fibre type, ten specimens were tested in order to evaluate the variability of the measured values.

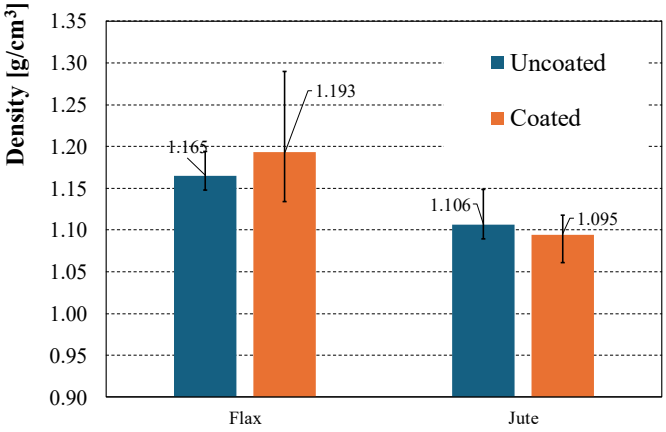
The uncoated flax fibres show density values between 1.15 and 1.19 g/cm³, with an average value of 1.165 g/cm³. After coating, the density slightly increases, with values ranging from 1.134 to 1.290 g/cm³ and an average value of 1.193 g/cm³. This small increase suggests that the PLA-based coating affects the apparent density of the yarn, probably due to the partial filling of surface voids and the formation of a polymer layer around the fibre bundle.

The jute fibres show slightly lower density values than flax. In the uncoated condition, the density ranges from 1.09 to 1.15 g/cm³, with an average value of 1.106 g/cm³. After coating, the average density remains very similar, equal to 1.095 g/cm³, with values ranging from 1.061 to 1.118 g/cm³. This indicates

that, although the coating increases the mass per unit length of the jute yarns, it does not produce a clear increase in the measured density.

The limited scatter of each series suggests similar physical properties among the tested specimens. Overall, flax fibres show higher density values than jute fibres in both uncoated and coated conditions. The coating produces only a limited variation in density, while its effect is more evident in the increase of dry weight, linear density, and cross-sectional area.
Comparisons with literature values should nevertheless be made cautiously, since the apparent density of natural yarns is strongly influenced by specimen architecture, moisture conditioning, measurement method and immersion fluid [35].

Figure 4: Density for coated and uncoated yarns. The error bars show the range between the minimum and maximum measured values.



The cross-sectional area was calculated by dividing the linear density by the density. This calculation gave average values of 0.068 mm^2 and 0.196 mm^2 for uncoated flax and jute, respectively. The cross-sectional areas for coated yarns were 0.091 mm^2 and 0.306 mm^2.

This increase is consistent with the higher linear density measured after treatment and confirms the deposition of the PLA-based coating on the yarn surface. The larger increase observed for jute can be related to its more irregular morphology and larger initial section, which may favor a greater amount of polymer retention within the external voids and between elementary fibres.

3.2 SCANNING ELECTRON MICROSCOPE ANALYSIS

Figure 5 shows the morphology of flax and jute yarns before and after the coating. Both the cross-section and the lateral surface are reported in order to evaluate the effect of the PLA-based coating on the yarn geometry and surface morphology.

For the uncoated flax yarn, the cross-section appears irregular and open, with several elementary fibres partially separated from each other. The lateral surface also shows a clearly fibrillated structure, with visible fibre bundles and small gaps between adjacent filaments. After coating, the flax yarn shows a more compact cross-section. The polymer layer fills the external voids and surrounds the fibre bundle, creating a more regular boundary. On the lateral surface, the coating reduces the surface roughness and covers most of the individual fibres, creating a smoother and more continuous external layer. This should not be interpreted as a positive effect of the coating. A smoother external layer may reduce the bond strength with the mortar matrix in TRM systems.

A similar effect is observed for jute yarns. The uncoated jute section is highly irregular, with a larger number of elementary fibres and visible internal voids. The lateral surface presents a rough and heterogeneous morphology, with fibre splitting and clear longitudinal grooves. After coating, the jute yarn becomes more compact. The PLA-based layer surrounds the yarn and reduces the separation

between fibres. The coated lateral surface appears smoother and more uniform, although some local discontinuities and uncovered zones are still visible.

Overall, the SEM observations confirm that the coating treatment modifies the morphology of both flax and jute yarns. The treatment promotes fibre packing, reduces the irregularity of the external surface, and produces a more continuous polymer layer around the yarn. This effect is more evident in the lateral surface images, where the coated yarns show a clear reduction in fibrillation and surface roughness compared with the uncoated condition.

Figure 5: Morphology of flax and jute yarns before and after the coating

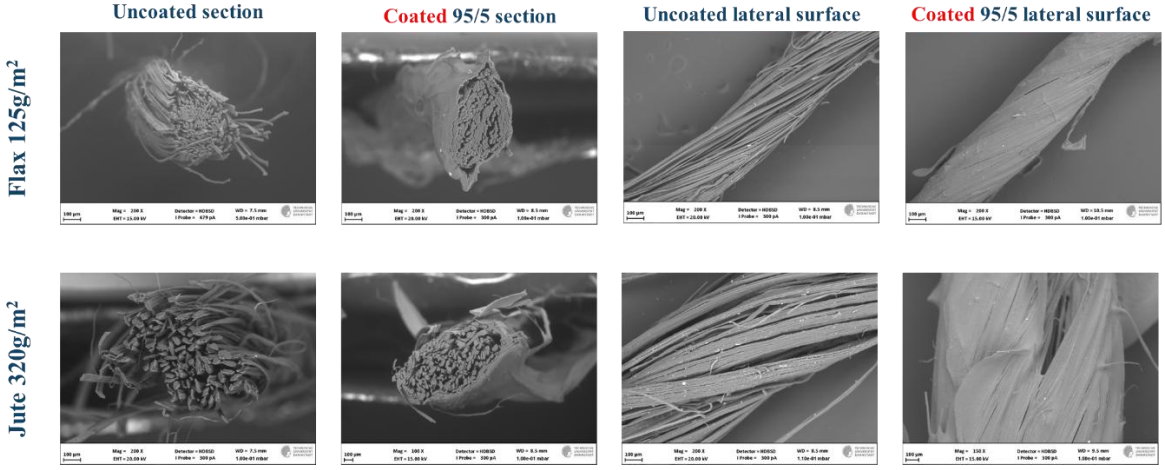
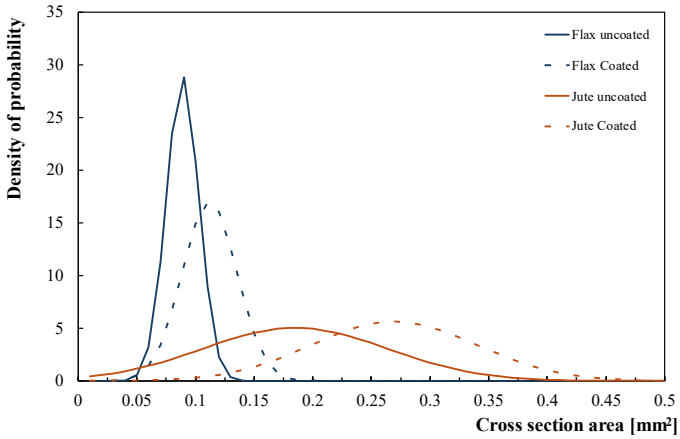


Figure 6 shows the probability density distributions of the cross-sectional area for uncoated and PLA-coated flax and jute yarns. For flax yarns, the uncoated specimens are mainly concentrated in the lower area range, with a narrow distribution and a pronounced peak around 0.09 mm². This indicates a relatively uniform cross-section and limited scatter among the uncoated yarns. After PLA coating, the distribution shifts towards higher values, with the peak located around 0.11–0.12 mm². The coated flax yarns also show a broader distribution, suggesting that the coating increases the apparent cross-sectional area and modifies the morphology of the fibre bundle.

Figure 6: Distribution of probability of yarn cross section area for flax and jute both coated and uncoated



A similar trend is observed for jute yarns, although the distributions are generally wider than those of flax. The uncoated jute yarns show a broad distribution, with the highest density around 0.18–0.20 mm². After PLA coating, the curve shifts further towards higher cross-section area values, with a peak around 0.27–0.28 mm². This confirms that the coating also increases the apparent area of jute yarns, with a more pronounced effect than that observed for flax.

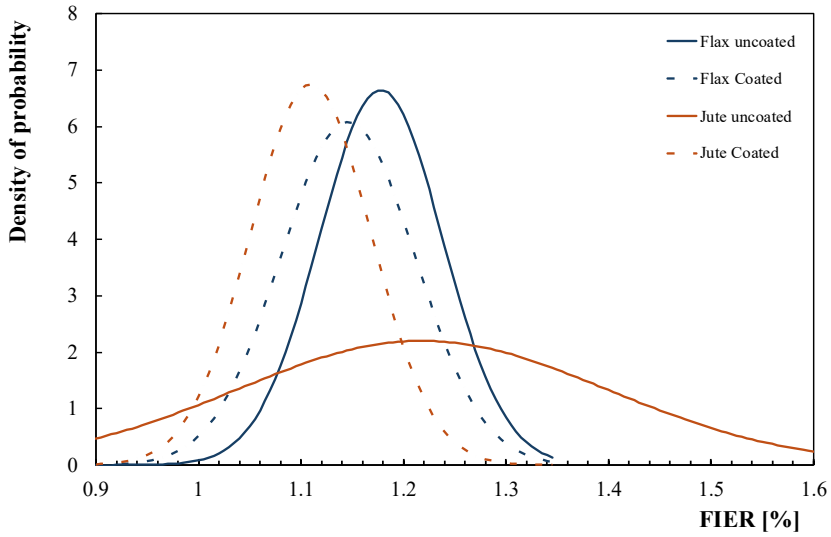
The broader distributions observed after coating can be attributed to the non-uniform retention of PLA along the yarn length and to the intrinsic irregularity of natural fibres. Therefore, the coating improves

the compactness and definition of the yarn section, but it also introduces a certain variability related to the impregnation process. Overall, the results confirm that PLA coating increases the cross-sectional area of both natural yarns, with jute showing larger and more dispersed values than flax.

Figure 7 shows the probability density distribution of the Fibre Intrinsic Efficiency Ratio (FIER) for uncoated and coated flax and jute yarns. FIER quantifies the deviation of the cross-section from an ideal circular shape, with values close to 1 indicating a more regular and circular morphology. The uncoated flax yarns show a narrower distribution with a peak around 1.18. This results in a more uniform geometry.

After coating, the flax distribution becomes wider and slightly shifts toward values closer to 1, suggesting that the PLA treatment tends to regularize the cross-sectional shape and make it closer to an ideal circle. This effect is likely related to the packing action of the PLA, which compacts the elementary fibres, promoting a more rounded configuration. At the same time, the wider distribution indicates that the polymer deposition is not perfectly uniform, thus introducing local variability in the cross-sectional morphology.

Figure 7: Distribution of probability of yarn FIER for flax and jute both coated and uncoated



The uncoated jute yarns show a broader distribution, confirming the higher intrinsic morphological variability of this fibre. This behaviour is consistent with a more irregular cross-section and a less homogeneous arrangement of the elementary fibres within the yarn. After coating, the jute distribution becomes much narrower and shifts toward lower FIER values. This suggests that the PLA coating partially regularizes the yarn morphology by filling surface irregularities and reducing the deviation from an equivalent circular shape. Overall, the results show that the coating affects the two fibres differently: it slightly increases the variability of flax, while it improves the geometrical regularity of jute (see Figure 8).

Figure 9 compares the cross-sectional area obtained from image analysis with the area measured from SEM images for untreated and coated flax and jute yarns.

For the untreated yarns, the calculated area is close to the SEM area for both fibres. Flax shows a calculated area of 0.068 mm², slightly lower than the SEM value of 0.089 mm². Jute shows a calculated area of 0.196 mm², slightly higher than the SEM value of 0.185 mm². The larger error bars, especially for jute, indicate a higher variability in the measured cross-section.

After coating, both fibres show an increase in cross-sectional area. For flax, the calculated area increases to 0.091 mm², while the SEM area reaches 0.112 mm². For jute, the calculated area increases more clearly, reaching 0.306 mm², compared with a SEM area of 0.270 mm². This confirms that the coating

process produces a measurable increase in yarn section, due to the polymer layer deposited around the fibres (Figure 9).

Figure 8: Hypothetical behaviour of PLA treatment

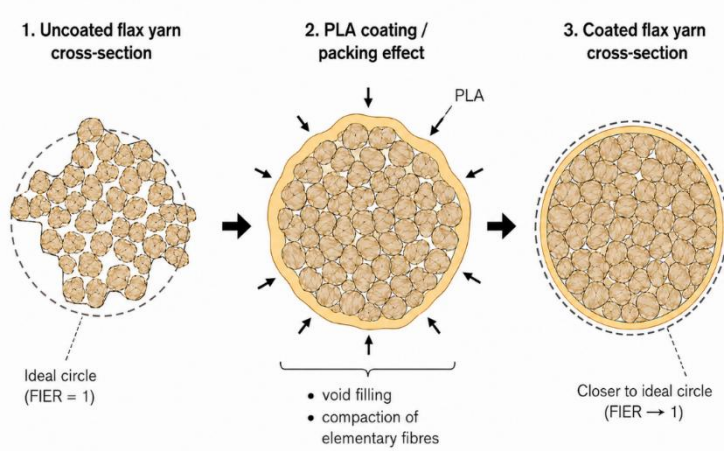
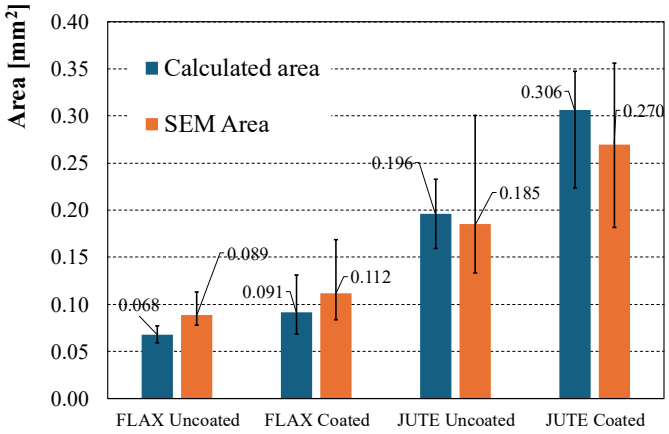


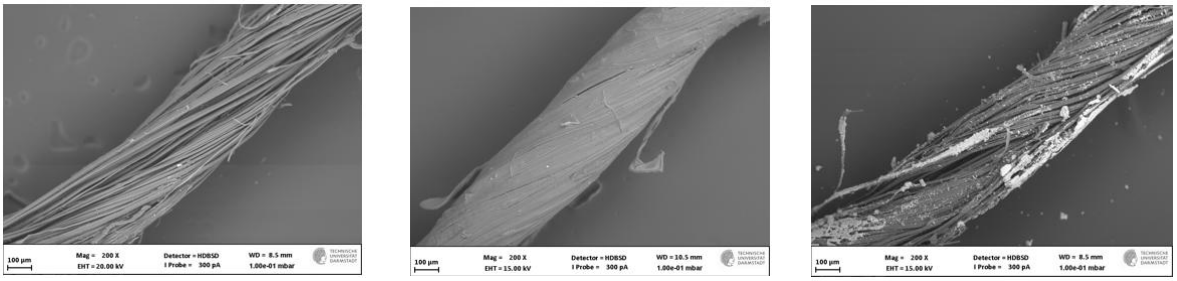
Figure 9: Comparison between SEM Area and Calculated Area. The error bars show the range between the minimum and maximum measured values.



Overall, the calculated values are in good agreement with the SEM measurements. However, the two approaches do not measure exactly the same geometrical quantity. The value derived from linear density and apparent dry density represents a length-averaged equivalent solid cross-section, whereas SEM provides a local two-dimensional measurement at a selected cutting plane and is also affected by the adopted image-segmentation procedure. Ferrara et al. [20] observed that polymer impregnation of flax yarns did not substantially change the mean cross-sectional area, but reduced the yarn perimeter and produced a more regular and less dispersed morphology, even though the polymer did not fully penetrate the innermost filaments. Similarly, Kumar et al. [28, 29] reported that PLA coating binds the elementary fibres into a more cohesive yarn and produces coating-layer-dependent changes in its surface morphology. These findings support the present results, indicating that polymer deposition can regularize the external yarn profile and restrict relative fibre movement without necessarily producing a proportional variation in equivalent cross-sectional area. Therefore, the remaining differences between calculated and SEM values can reasonably be associated with the local nature of SEM measurements, irregular fibre packing, segmentation uncertainty and variations in coating thickness along the yarn.

Figure 10 compares three SEM images. Figures 10(a) and 10(b) show the edges of uncoated and coated yarns at day 0, respectively. Figure 10(c) shows the edge of a coated yarn after 1000 h of alkaline treatment in $Ca(OH)_2$. The coating appears to be completely dissolved, but the microfilaments remain cohesive. After treatment, the coated yarn appears more compact than the uncoated yarn at day 0. This highlights the beneficial effect of the treatment on yarn cohesion [36].

Figure 10: Comparison between (a) uncoated yarn at day 0; (b) coated yarn at day 0 and (c) coated yarn after 1000 h in alkaline ageing treatment

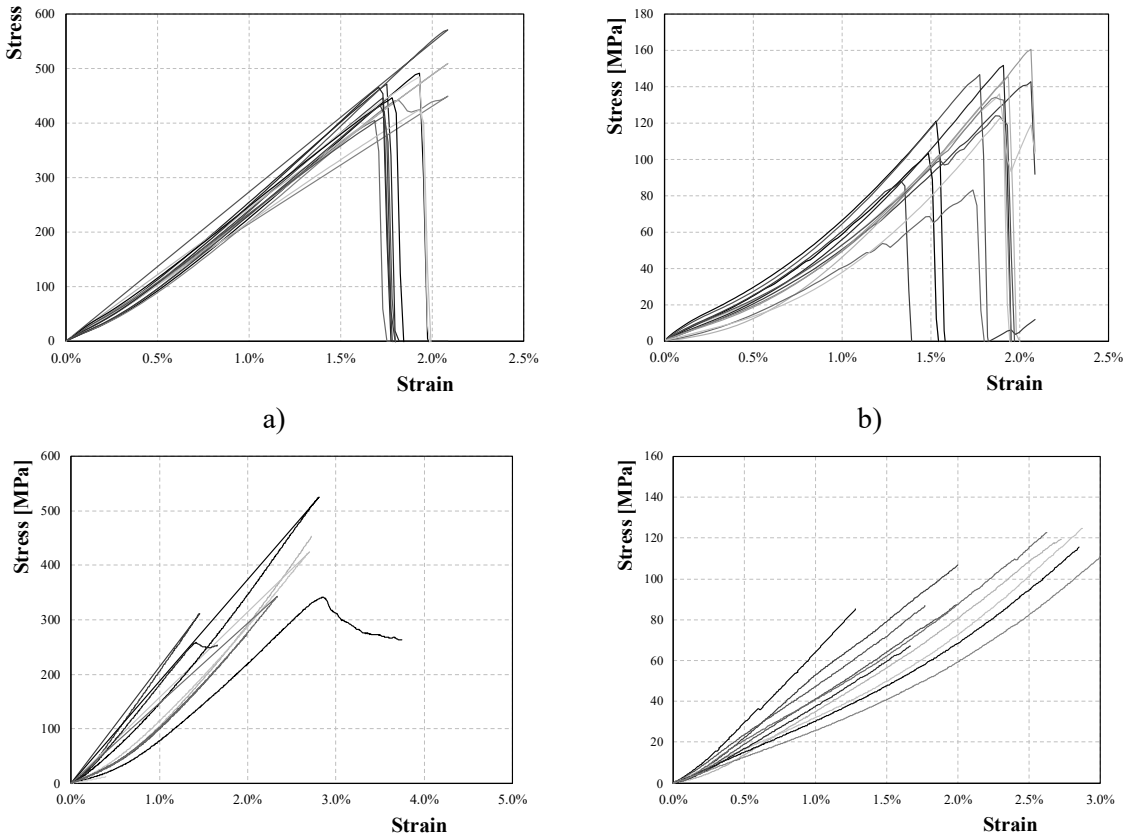


(a) (b) (c)

3.3 MECHANICAL PROPERTIES

Figure 11 shows the results of the yarn tensile tests. Figure 12 compares the tensile force and stress values obtained for uncoated and coated flax and jute yarns. In terms of maximum force, the coating produced an increase for both fibre types. For flax yarns, the force increased from 32.67 N in uncoated condition to 37.59 N after coating. Similarly, jute yarns showed an increase from 25.10 N to 33.07 N. This result suggests that the PLA-based coating improved the load-bearing capacity of the yarns, probably due to better cohesion between elementary fibres and to the partial impregnation of the fibre bundle. The coating may also reduce local fibre separation during tensile loading, allowing a larger number of fibres to contribute to the global response.

Figure 11: Comparison between stress–strain curves for: a) uncoated flax; b) uncoated jute; c) coated flax; d) coated jute



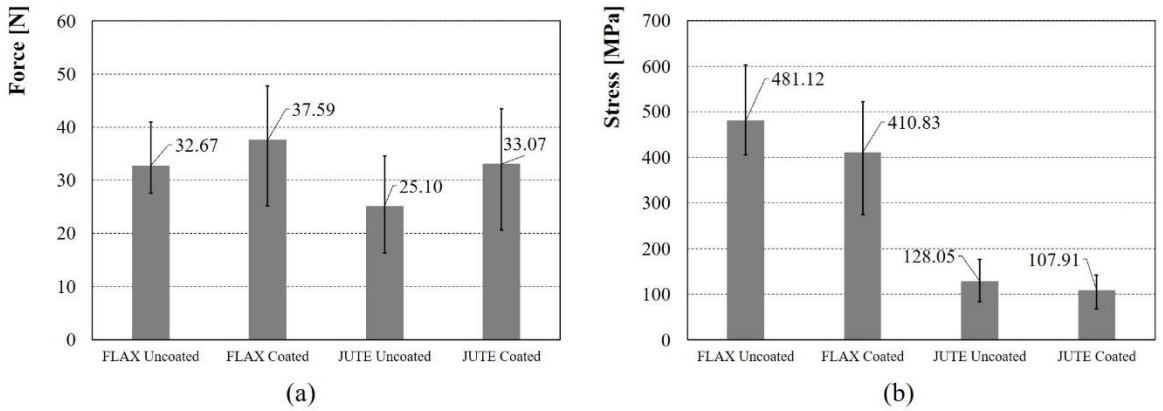
a) b) c) d)

However, a different trend is observed when the results are expressed in terms of tensile stress. The stress was calculated by normalising the maximum force with respect to the equivalent cross-sectional area (from SEM analysis). For flax yarns, the tensile stress decreased from 480.38 MPa in the uncoated condition to 413.03 MPa after coating. A similar reduction was observed for jute yarns, where the stress

decreased from 128.05 MPa to 108.07 MPa. This reduction is directly related to the increase in cross-sectional area produced by the coating. Therefore, although the coated yarns were able to sustain higher forces, the increase in area was proportionally larger than the increase in force, leading to lower stress values. In fact, the cross-sectional area increased by 33% for flax and 56% for jute. This increase led to a decrease in tensile strength.

Overall, the coating improves the tensile response in terms of maximum force, but it does not increase the apparent tensile strength of the yarns when the results are normalised by area. This indicates that the treatment mainly acts by increasing fibre cohesion and effective yarn section, rather than by improving the intrinsic tensile strength of the fibre material.

Figure 12: Comparison between Force (a) and Stress (b) for coated and uncoated yarns. The error bars show the range between the minimum and maximum measured values.



Comparable yarn-scale effects have been reported in the literature. Ferrara et al. [20] observed that XSBR impregnation regularised the morphology of flax yarns and reduced their deformability, although it did not increase the mean cross-sectional area and resulted in a reduction in tensile strength. Conversely, Kumar et al. [29] reported significant increases in tensile strength and stiffness for multilayer PLA-coated coir yarns, which they associated with the binding of elementary fibres into a more cohesive unit and with coating-layer-dependent changes. Moreover, Fidelis et al. [36] showed that polymer coating of jute textiles mainly improved fibre–matrix bonding and reduced fibre degradation. The different responses reported across studies indicate that the effectiveness of polymer treatment depends on fibre morphology, polymer type and amount, penetration depth, coating uniformity and the cross-sectional area adopted for stress calculation. The present results therefore indicate improved yarn cohesion and load sharing, rather than demonstrating an intrinsic strengthening of the fibre material.

The uncoated yarns therefore show higher stress values, while the coated yarns show higher load capacity. Despite this, the lower tensile stress of the coated yarns is mainly due to the increase in equivalent cross-sectional area. However, in a TRM system, the presence of coating would not reduce the number of yarns per centimeter in the textile. Therefore, the higher maximum force recorded for the coated yarns should still be considered a positive result, since each yarn can carry a higher tensile load while the textile density remains unchanged.

4 CONCLUSION

The following points summarize the main conclusions of this study:

- The PLA coating increased the linear density of both flax and jute yarns, confirming the deposition of polymer on the yarn surface.
- The coating also increased the equivalent cross-sectional area. This effect was more evident for jute because of its more irregular morphology and larger number of voids.
- SEM observations showed that coated yarns became more compact and regular. The PLA layer reduced fibre separation and produced a more continuous external surface.
- The treatment reduced the irregularity of the yarn section, especially for jute, and made the cross-section closer to a circular shape.

- From the tensile tests, coated yarns showed higher maximum forces than uncoated yarns. This suggests a better cohesion between micro-fibres and a higher load-bearing capacity of the yarn.
- However, when the results were normalised by the cross-sectional area, the tensile stress decreased for both flax and jute. This reduction is mainly due to the increase in cross-sectional area produced by the coating.
- The coating does not improve the tensile strength of the fibre material. Its main effect is to compact the yarn and increase the force that each yarn can carry. In a TRM system, the number of yarns per centimetre would not decrease after coating. For this reason, the higher maximum force of the coated yarns should still be considered a positive result.

DECLARATION OF GENERATIVE AI

Generative AI tools (Chat GPT) were used exclusively to optimize the graphical quality and visual presentation of Figures and Figure 8. No AI tools were used for data generation, data analysis, or scientific interpretation.

ACKNOWLEDGMENTS

This work was supported in part by the Italian Minister of University and Research as part of the "MaStRoNG: Masonry Structures retrofitting through Robotized sustainable Next-Generation composites" project (FISA-2023-00029 - CUP: D47G2300036000). The present study is also part of the activities carried out by the Authors as part of the "BEST" Project (HORIZON-MSCA-2021-SE-01 Grant agreement ID: 101086440; https://cordis.europa.eu/project/id/101086440.

REFERENCES

[1] L. Ascione, G. De Felice, and S. De Santis, 'A qualification method for externally bonded Fibre Reinforced Cementitious Matrix (FRCM) strengthening systems', Composites Part B: Engineering, vol. 78, pp. 497–506, Sep. 2015, doi: 10.1016/j.compositesb.2015.03.079.

[2] M. Angiolilli, A. Gregori, M. Pathirage, and G. Cusatis, 'Fiber Reinforced Cementitious Matrix (FRCM) for strengthening historical stone masonry structures: Experiments and computations', Engineering Structures, vol. 224, p. 111102, Dec. 2020, doi: 10.1016/j.engstruct.2020.111102.

[3] O. G. Agossou, O. Homoro, and S. Amziane, 'A review of the applications of natural FRCM composites', Journal of Composite Materials, p. 00219983251318829, Feb. 2025, doi: 10.1177/00219983251318829.

[4] S. G. Bergström and H.-E. Gram, 'Durability of alkali-sensitive fibres in concrete', International Journal of Cement Composites and Lightweight Concrete, vol. 6, no. 2, pp. 75–80, May 1984, doi: 10.1016/0262-5075(84)90036-8.

[5] R. D. Toledo Filho, K. Scrivener, G. L. England, and K. Ghavami, 'Durability of alkali-sensitive sisal and coconut Æbres in cement mortar composites', Cement & Concrete Composites, 2000. vol. 22, no. 2, pp. 127–143, 2000, doi: 10.1016/S0958-9465(99)00039-6

[6] S. Alcívar, F. J. Baeza, Y. Mieles-Bravo, and S. Ivorra, 'Improvement of shear behavior of masonry using natural fibers: Experimental evaluation of external reinforcements based on TRM with cabuya fibers', Construction and Building Materials, vol. 506, p. 144948, Jan. 2026, doi: 10.1016/j.conbuildmat.2025.144948.

[7] G. Ferrara and E. Martinelli, 'Tensile behaviour of Textile Reinforced Mortar composite systems with flax fibres', 12th fib International PhD Symposium in Civil Engineering, 2018.

[8] O. Cevallos, R. Olivito, and R. Codispoti, 'Experimental Analysis of Repaired Masonry Elements with Flax-FRCM and PBO-FRCM Composites Subjected to Axial Bending Loads', Fibers, vol. 3, no. 4, pp. 491–503, Nov. 2015, doi: 10.3390/fib3040491.

[9] R. S. Olivito, O. A. Cevallos, and A. Carrozzini, 'Development of durable cementitious composites using sisal and flax fabrics for reinforcement of masonry structures', Materials & Design, vol. 57, pp. 258–268, May 2014, doi: 10.1016/j.matdes.2013.11.023.

[10] F. D. A. Silva, R. D. Toledo Filho, B. Mobasher, and N. Chawla, 'A multi-scale investigation of the mechanical behavior of durable sisal fiber cement composites', Matéria (Rio J.), vol. 15, no. 2, pp. 338–344, 2010, doi: 10.1590/S1517-70762010000200035.

[11] K. Charlet, J.-P. Jernot, J. Breard, and M. Gomina, 'Scattering of morphological and mechanical properties of flax fibres', Industrial Crops and Products, vol. 32, no. 3, pp. 220–224, Nov. 2010, doi: 10.1016/j.indcrop.2010.04.015.

[12] J. Donnini, V. Corinaldesi, and A. Nanni, 'Mechanical properties of FRCM using carbon fabrics with different coating treatments', Composites Part B: Engineering, vol. 88, pp. 220–228, Mar. 2016, doi: 10.1016/j.compositesb.2015.11.012.

[13] F. G. Carozzi and C. Poggi, 'Mechanical properties and debonding strength of Fabric Reinforced Cementitious Matrix (FRCM) systems for masonry strengthening', Composites Part B: Engineering, vol. 70, pp. 215–230, Mar. 2015, doi: 10.1016/j.compositesb.2014.10.056.

[14] E. Bertolesi, F. G. Carozzi, G. Milani, and C. Poggi, 'Numerical modeling of Fabric Reinforce Cementitious Matrix composites (FRCM) in tension', Construction and Building Materials, vol. 70, pp. 531–548, Nov. 2014, doi: 10.1016/j.conbuildmat.2014.08.006.

[15] R. Codispoti, D. V. Oliveira, R. S. Olivito, P. B. Lourenço, and R. Fangueiro, 'Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry', Composites Part B: Engineering, vol. 77, pp. 74–83, Aug. 2015, doi: 10.1016/j.compositesb.2015.03.021.

[16] L. Mercedes, L. Gil, and E. Bernat-Maso, 'Mechanical performance of vegetal fabric reinforced cementitious matrix (FRCM) composites', Construction and Building Materials, vol. 175, pp. 161–173, Jun. 2018, doi: 10.1016/j.conbuildmat.2018.04.171.

[17] S. R. Ferreira, M. Pepe, E. Martinelli, F. De Andrade Silva, and Romildo Dias Toledo Filho, 'Influence of natural fibers characteristics on the interface mechanics with cement based matrices', Composites Part B: Engineering, vol. 140, pp. 183–196, May 2018, doi: 10.1016/j.compositesb.2017.12.016.

[18] M. E. Alves Fidelis, T. V. C. Pereira, O. D. F. M. Gomes, F. De Andrade Silva, and Romildo Dias Toledo Filho, 'The effect of fiber morphology on the tensile strength of natural fibers', Journal of Materials Research and Technology, vol. 2, no. 2, pp. 149–157, Apr. 2013, doi: 10.1016/j.jmrt.2013.02.003.

[19] V. Mazzanti, R. Pariante, A. Bonanno, O. Ruiz De Ballesteros, F. Mollica, and G. Filippone, 'Reinforcing mechanisms of natural fibers in green composites: Role of fibers morphology in a PLA/hemp model system', Composites Science and Technology, vol. 180, pp. 51–59, Aug. 2019, doi: 10.1016/j.compscitech.2019.05.015.

[20] G. Ferrara, M. Pepe, E. Martinelli, and R. Dias Tolêdo Filho, 'Influence of an Impregnation Treatment on the Morphology and Mechanical Behaviour of Flax Yarns Embedded in Hydraulic Lime Mortar', Fibers, vol. 7, no. 4, p. 30, Apr. 2019, doi: 10.3390/fib7040030.

[21] A. R. Bunsell and Textile Institute (Manchester, England), Eds, Handbook of properties of textile and technical fibres, Second edition. in The Textile Institute book series. Duxford, United Kingdom: Woodhead Publishing an imprint of Elsevier, 2018.

[22] V. Placet, F. Trivaudey, O. Cisse, V. Gucheret-Retel, and M. L. Boubakar, 'Diameter dependence of the apparent tensile modulus of hemp fibres: A morphological, structural or ultrastructural effect?', Composites Part A: Applied Science and Manufacturing, vol. 43, no. 2, pp. 275–287, Feb. 2012, doi: 10.1016/j.compositesa.2011.10.019.

[23] G. Ferrara, M. Pepe, E. Martinelli, and R. D. Tolêdo Filho, 'Tensile behavior of flax textile reinforced lime-mortar: Influence of reinforcement amount and textile impregnation', Cement and Concrete Composites, vol. 119, p. 103984, May 2021, doi: 10.1016/j.cemconcomp.2021.103984.

[24] R. Lombardi, L. Di Maio, M. Pepe, B. Paolillo, and E. Martinelli, 'Influence of PLA impregnation on the performances of vegetable fibers for lime-based composites', Procedia Structural Integrity, vol. 64, pp. 1919–1926, 2024, doi: 10.1016/j.prostr.2024.09.258.

[25] O. G. Agossou, O. Homoro, and S. Amziane, 'Evaluation of mechanical behaviour of vegetal FRCM composites through the DIC technique: Effects of textile pre-impregnation and short flax fibres', Construction and Building Materials, vol. 449, p. 138416, Oct. 2024, doi: 10.1016/j.conbuildmat.2024.138416.

[26] R. Bardouh, O. Homoro, and S. Amziane, 'Effect of reinforcement ratio and textile pre-impregnation on the mechanical properties of flax textile reinforced sulfoaluminate matrix', Journal of Composite Materials, vol. 58, no. 2, pp. 265–284, Jan. 2024, doi: 10.1177/00219983231221146.

[27] A. Abbass, M. C. Paiva, D. V. Oliveira, P. B. Lourenço, and R. Fangueiro, 'Graphene/polyurethane nanocomposite coatings – Enhancing the mechanical properties and environmental resistance of natural fibers for masonry retrofitting', Composites Part A: Applied Science and Manufacturing, vol. 166, p. 107379, Mar. 2023, doi: 10.1016/j.compositesa.2022.107379.

[28] B. W. Chieng, N. A. Ibrahim, and Y. Y. Loo, "Bioplasitcizer Epoxidized Vegetable Oils–Based Poly(Lactic Acid) Blends and Nanocomposites," in Handbook of Composites from Renewable Materials, vol. 6, Polymeric Composites, V. K. Thakur, M. K. Thakur, and M. R. Kessler, Eds. Wiley/Scrivener Publishing, 2017, pp. 205–231. doi: 10.1002/9781119441632.ch112.

[29] N. Kumar, P. Rawat, and R. K. Kandasami, 'Enhancing the characteristics of natural coir fiber yarns using biopolymer for textile reinforced cementitious composites', Construction and Building Materials, vol. 489, p. 140427, Apr. 2025, doi: 10.1016/j.conbuildmat.2025.140427.

[30] R. Casasola, N. L. Thomas, A. Trybala, and S. Georgiadou, 'Electrospun poly lactic acid (PLA) fibres: Effect of different solvent systems on fibre morphology and diameter', Polymer, vol. 55, no. 18, pp. 4728–4737, Sep. 2014, doi: 10.1016/j.polymer.2014.06.032.

[31] A. R. Hambleton and E. Mele, 'Dimensional and Structural Instability of Electrospun Polylactic Acid Membranes in Liquid Environments: Role of Water, Ethanol, and Temperature', Fibers Polym, vol. 25, no. 6, pp. 1999–2008, Jun. 2024, doi: 10.1007/s12221-024-00564-x.

[32] D. Prat et al., 'CHEM21 selection guide of classical- and less classical-solvents', Green Chem., vol. 18, no. 1, pp. 288–296, 2016, doi: 10.1039/C5GC01008J.

[33] S. Ydk, 'User's Manual | Betriebsanleitung | Mode d'emploi'.

[34] European Committee for Standardization, 'Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method'. European Committee for Standardization (CEN), Brussels, Belgium, Apr. 2013. Accessed: Aug. 03, 2026. [Online]. Available: https://www.iso.org/standard/60676.html

[35] A. Amiri, Z. Triplett, A. Moreira, N. Brezinka, M. Alcock, and C. A. Ulven, 'Standard density measurement method development for flax fiber', Industrial Crops and Products, vol. 96, pp. 196–202, Feb. 2017, doi: 10.1016/j.indcrop.2016.11.060.

[36] M. E. A. Fidelis, Romildo Dias Toledo Filho, F. D. A. Silva, V. Mechtcherine, M. Butler, and S. Hempel, 'The effect of accelerated aging on the interface of jute textile reinforced concrete', Cement and Concrete Composites, vol. 74, pp. 7–15, Nov. 2016, doi: 10.1016/j.cemconcomp.2016.09.002.

Author Contributions: P. B.: Methodology, Data Curation, Formal Analysis, Writing- original draft preparation. **L. D. M.:** Conceptualization, Methodology. **E. K.:** Conceptualization, Methodology, Supervision. **E. M.:** Conceptualization, Methodology, Supervision. **M. P.:** Conceptualization, Methodology, review and editing, Supervision.