CEMENT MORTARS WITH BOMBYX MORI SILK FIBERS WITH DIFFERENT TYPES OF SURFACE TREATMENTS

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The incorporation of natural fibers in cement mortars is an important area of research and development within the construction industry, as it seeks sustainable and ecological alternatives to traditional fiber reinforcements. This paper investigated the effects of different treatments on “Bombyx mori” silk fibers on the mechanical strength and durability of cement mortars, at the same time their architectural possibilities were analyzed. The studied fibers were cut to 20 mm in length, then treated with liquid calcium hydroxide, linseed oil and natural rubber latex. Finally, they were placed in the cement matrix in layers and arranged lengthwise. The mechanical performance and durability of the material were studied through the physical properties of water absorption by immersion, the mechanical properties of compressive, flexural, and impact strength at 7, 14, and 28 days of curing were also studied. The study was complemented with a simulation of alkaline environment of cement using a solution based on sodium hydroxide, measuring the degree of accelerated degradability of the fibers through mass loss. Overall, the results demonstrated that the composite material with fibers treated with natural latex and linseed oil exhibited higher flexural, compressive and impact strength and lower water absorption.

Keywords: Compressive strength, Flexural strength, Impact strength, Water absorption by immersion.

1 INTRODUCTION

Bombix mori fibers are derived from the cocoon of the silk-producing worm. They consist mainly of fibroin which bind with a sericin binder. Fibroin provides stiffness and strength, while sericin acts as an adhesive binder to maintain the structural integrity of the fiber and cocoon (Ude et al. 2014). Silk fibers can withstand bending without breaking even more than vegetable fibers, which gives them potential for the development of lighter composite materials with better mechanical properties, as well as sustainable properties (Sealy 2014). Bombyx mori silk fibers are mainly used in textile industries and as suture material in biomedicine. However, so far there have been no studies of the potential of these fibers as construction materials, especially in cement mortars. For these reasons, silk fibers need to be evaluated as reinforcement material to analyze their applicability in the construction industry.

Using natural fibers in concrete promotes sustainability and reduces dependence on non-renewable resources. They take up less space in the die, can be handled and processed without causing damage to the environment, help support compression loads without sudden and
catastrophic collapse, while in elements that experience bending stresses, they can control the width of cracks to maintain durability of the structure. But they also have drawbacks that have made people wary of using them: they are biodegradable in alkaline environments like cement matrix, their qualities are not consistent, and their values differ greatly because these characteristics are directly tied to the makeup of their constituents. These could be considered the main challenges for its implementation. Recent research aims to protect fibers by impregnating them with substances, their mineralization or the use of external coating as a physical barrier (de Azevedo et al. 2021). Although the effectiveness of these methods is still under discussion. In this sense, the present research experiments with Bombyx mori fibers impregnated with Natural Rubber Latex (NRL) and Linseed Oil (OL), and mineralized with calcium hydroxide (Ca (OH)2) as reinforcements in cement mortars.

2 MATERIALS AND METHODS

The experimental process was conducted at the laboratories of the Universidad Técnica Particular de Loja (Ecuador). Bombyx mori silk fibers were provided by sericulturists from Yantzatza (Ecuador). The silk fibers were cut to a length of 20 mm (similar length to commercialized industrial fibers). Table 1 shows some physical and mechanical characteristics of silk fibers.

<table>
<thead>
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<th>Table 1. Physical and mechanical characteristics of silk fibers.</th>
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<td><strong>Density</strong> (kg/cm³)</td>
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<td>1.3 – 1.8</td>
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Table 2 and Figure 1A present the various treatments to which they were subjected. Natural rubber latex (NRL) was extracted from rubber trees (Hevea brasiliensis) provided by IMSSA Santo Domingo Industries (Ecuador). On the other hand, the following raw materials were obtained from local markets: refined linseed oil used for wood treatment and artistic oil painting, quicklime, calcium hydroxide powder, sodium hydroxide (98% pure), GU cement, fine aggregates, and distilled water. For the preparation of cement mixes, water from the public water supply was used.

<table>
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<th>Table 2. Treatments applied to fibers.</th>
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<td><strong>Nomenclature</strong></td>
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<tr>
<td>F-Untreated</td>
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<tr>
<td>F-Ca (OH)₂</td>
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<tr>
<td>F-OL</td>
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<tr>
<td>F-NRL</td>
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The mortars were prepared with a 1:2.75 weight ratio and a water/cement ratio of 0.485. The mixtures were performed with a mechanical mixer for 60 seconds at medium speed (for each material addition the mixing was stopped for 15 seconds). In molds 100 mm x 25 mm x 15 mm (length, width, thickness) and 50 mm x 50 mm x 50 mm the fresh paste and the 20 mm long fibers were placed lengthwise and compacted in layers (0.5% fibers were incorporated in relation to the weight of the mixture).

After fresh mortars were placed in molds, they were demolded after 24 hours and cured in water by total immersion for 7, 14 and 28 days. The experiment involved cement mortars with the following characteristics: without fibers (M-Control), untreated fibers (MF-untreated), treated fibers with calcium hydroxide (MF-Ca (OH)$_2$), impregnated fibers with linseed oil (MF-OL), and impregnated fibers with natural rubber latex (MF-NRL).

Figure 1. Accelerated degradation tests in sodium hydroxide: (A) applied treatments, and (B) 4 hours exposure results.

The flexural strength was determined according to UNE EN 12390-5. To determine the flexural strength and modulus of elasticity prisms of 100 mm x 25 mm x 15 mm (length, width, thickness) were developed (da Silva et al. 2017), the values were calculated with Eq. (1) and Eq. (2) respectively. The flexure-tested specimens were observed using electronic microscopy “Andonstar V160”. The compressive strength was determined under the parameters of NTE INEN 488-2. For the compressive strength tests, cubes of 50 mm x 50 mm x 50 mm were developed, the values were calculated with Eq. (3). For both compressive and strength tests, the universal testing machine "SHIMADZU CONCRETE 2000X" and material testing software “TRAPEZIUM X” were used at a speed of 0.8 mm/min and 0.1 mm/min respectively. The absorption of water by immersion was determined under the parameters of NTE INEN 1567. For the immersion water absorption tests, cubes of 50 mm x 50 mm x 50 mm were developed, the values were calculated with Eq. (4).

\[
\sigma_f = \frac{3 (F)}{2 (b)} \left(\frac{L}{h}\right)
\]

(1)

\[
E_f = \frac{(m)}{4 (b) (h^3) (f)}
\]

(2)

Where \(\sigma_f\) is the flexural strength (MPa), \(F\) is the maximum load (N), \(L\) is the amplitude of specimens in the three-point flexural test (mm), \(E_f\) is the modulus of elasticity (MPa), \(b\) and \(h\) are the width and thickness of the sample (mm), \(f\) is the maximum deflection in the center of the specimen (mm).
f_m = \frac{P}{A} \tag{3}

Where \( f_m \) is the compressive strength (MPa), \( P \) is the maximum total failure load (N), and \( A \) is the cross-sectional area of the cube to which the load is applied (mm\(^2\)).

Absorption % = \frac{M_1 - M_2}{M_2} \times 100 \tag{4}

Where \( M_1 \) is the initial mass in grams (dried in an oven for 24 hours at 100°C), \( M_2 \) saturated mass in grams (the specimens were left submerged in water for 24 hours).

In addition, impact strength tests were developed using 50 mm x 50 mm x 50 mm specimens, the impact height (50 cm) and the mass of the object to be impacted (10 Kg) were recorded, the required number of impacts were performed until the specimens show the following characteristics: (a) no appreciable deterioration on the specimen surface, (b) circular lines or strokes around the impact, (c) radial fissures of length < 5 mm, (d) radial fissures of length > 10 mm without material detachment, and (e) material detachment in the form of flakes. The impact resistance test is an adaptation of ISO 10545-5. To prevent the fibers from agglomerating and promote good interfacial bonding, both in the prisms and in the cubes, the fibers were arranged unidirectionally (long fibers). Loading perpendicular to the fibers was applied to replicate real loading conditions and simulate worst-case scenarios to evaluate material strength.

Finally, the study of fiber degradation in alkaline media was developed according to the procedure of (Silva et al. 2015). A 10% concentrated sodium hydroxide solution with a pH similar to that of cement composites (pH~12.4) was used. The treated and untreated fibers were immersed in the alkaline solution, initially for 4 hours and the most effective treatment for up to 28 days, with weighing conducted every hour and every seven days respectively. Measurements were developed with the analytical balance “OHAUS DV214C, 210g/0.1mg”. Fibers impregnated with NRL under alkaline exposure degraded by 2.42 %, 6.10 %, 8.32 % and 89.78 % at 7, 14, 21, and 28 days respectively.

3 RESULTS AND DISCUSSION

Figures 2A, 2B, 2C, y 2D present the test results of mechanical properties of the tested mortars. In relation to MF-NRL, fibers impregnated with NRL improved compressive strength, flexural strength, Young’s modulus, and impact resistance, this can be explained by the synergy between the fiber and NRL, it is known that the modification of fiber surface is an essential requirement to improve the interfacial compatibility between fiber and matrix (improve adhesion) (Machado et al. 2020b). These results are supported by the findings from Figures 1B y 3B, the NRL impregnated fibers presented the lowest percentages of accelerated degradation in an alkaline environment and the least damage to the fibers. NRL water-repels the fibers by forming a polymeric film that partially protects the fiber gaps (Machado et al. 2020a). In addition, the synergy between fibers and NRL is manifested in the change of the hydrophilic character of mortars by the presence of NRL, this was verified from the results of permeability tests (Figure 3A), also, NRL can create a thin matrix layer that surrounds and covers the porosity of the mortar matrix (Awoyera et al. 2023).

In relation to MF-LO its contributions in compressive strength and flexural strength were lower than MF-NRL. It provided no benefits in the Young Module. LO creates a smooth surface with a very low roughness, which causes the fiber to slide inside the matrix, reducing adhesion (Ali-Boucetta et al. 2021). It does not benefit impact resistance. It also does not Benefit the durability of mortars (Page et al. 2019). Ultimately, the interface between the linseed oil-coated fibers and the cementitious matrix is of lower quality.
Finally, in relation to MF-Ca (OH)2 its contributions are less than MF-NRL in flexural strength, Young’s modulus, and impact resistance, which could be explained by an increase in fiber roughness. However, like MF-LO the durability of mortars was adversely affected.

4 CONCLUSIONS

Based on the results, the compatibility of NRL with the fibers and the matrix was verified. The NRL film on the fiber surfaces conferred hydrophobic character and reduced the degradation of the fibers in the matrix. The NRL-impregnated fibers significantly increased the mechanical performance (compressive strength, flexural strength, modulus of elasticity, impact strength), and durability of the mortars (decreased water absorption by immersion). Surface treatments with OL
and Ca (OH)2 confer certain benefits to the mechanical properties of mortars, however, they adversely affect their durability. The mortar mixture containing fibers treated with natural rubber latex shows higher physical and mechanical properties in relation to the control samples and the other treatments. The compressive strength at 28 days was 23 MPa, higher than the M mortar established by the Ecuadorian standard NTE INEN 2 518. However, the water absorption capacity and alkaline degradation of the fibers even with the treatment must be analyzed more closely which creates uncertainty about its structural use, although it could be realized in warm climates. Applications above ground level or indoors are most certainly suggested, in construction segments such as pavements, false ceilings, tiles, blocks, among others.

References


