Mechanical Evaluation of Portland Cement Mortars Reinforced with Short Fibers of Alpaca Wool

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***Abstract*—Portland cement reinforced mortars were manufactured by mixing type I cement, fine sand, alpaca wool (in variable percentages) and water, it was possible to verify the influence of the addition of alpaca wool fibers on the mechanical response in uniaxial compression of the mortars studied. The mechanical results found revealed a systematic reduction of the maximum mechanical resistance when increasing the volume of alpaca wool fibers added in the mortar mixtures studied, on the other hand, a higher degree of deformation was evidenced in mortar mixtures with a greater amount of alpaca wool fibers added, reaching deformation values of up to 18%. The maximum strength values found at 7 days of curing were 1.5 to 5.6 MPa for samples with 20 and 4 Vol.% of alpaca wool added, respectively. The microstructure of the mortars studied consisted of a continuous cement binder phase with sand particles and short alpaca wool fibers dispersed within the binder phase. The actual density and average porosity of the alpaca wool reinforced mortars were 2.49 g/cm^3 and 45%, respectively.**

***Index Terms*—Portland cement, alpaca, wool. mechanical properties, natural fibers**

I. INTRODUCTION

The construction industry is known to have a significant impact on the environment due to the extraction and use of building materials. This problem is being addressed by focusing on the use of sustainable building materials, studying new materials and technologies to reduce the environmental impact of various industrial processes in the construction sector [1].

Several studies have been carried out on cement matrix composite materials reinforced with natural fibers such as cellulose, jute and silica [2]. The environmental impact of their production is lower compared to traditional industrial fibers [3].

The use of wool fiber as a filler material for mortar production has advantages with respect to environmental impact and energy use, as well as an increase in flexural strength and ductility that is proportional to the addition of wool fibers [2].

It is estimated that there are more than four million South American alpacas in Peru [4]. Most of these animals live in the provinces of Puno, Cusco and Huancavelica, being this country the first producer of camelid fiber, responsible for 90% of world production [5]. The alpaca is the most important domestic animal species from the social and economic point of view in Peru, where more than 2.9 million inhabitants are related to this species, involving more than 100,000 producers [6,7]. This natural wool is a very sustainable and ecological material. Among its properties is its ability to be recycled and biodegradable [3]. Recent works have reported the interest of the scientific community in the study of the mechanical response of mortars that contain fibers as means of reinforcement [8-10]. The purpose of this work was to investigate the mechanical properties of mortars reinforced with alpaca wool by varying the amount of short fibers of this material.

II. MATERIALS AND METHODS

A. Starting Materials and Fabrication of the Mortars

The starting materials for the manufacture of control (C) and reinforced (R) mortars were:

- Binder: cement type I
- Aggregates: fine sand sieved by ASTM # 140 mesh (106 microns),
- Reinforcement: alpaca wool fibers sieved by ASTM # 140 mesh (106 microns), only for R mortars.
- Activating liquid phase: potable water

Table I lists the R mortar mixes studied in this work, considering as independent variables (i) binder:fine sand ratio and (ii) the volume fraction of alpaca wool fibers added (for R mortars) and as a dependent variable (for C and R mortars) the maximum uniaxial compressive strength. It should be noted that for comparative purposes, mortars C with 0% alpaca wool fibers and a binder:fine sand ratio of 1:4 have been manufactured in parallel. In all cases (mortars C and R) a water/cement ratio of 0.6 has been considered.

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TABLE I. MIXTURES OF ALPACA WOOL FIBER REINFORCED MORTARS STUDIED IN THIS WORK

Mixture	Relationship binder:fine sand	Volume of fiber added (%)
1	1:4	4
2		8
3		12
4		16
5		20

The manufacture of the mortars followed the following steps:

(i) dry mixing (for 5 minutes) of the binder, aggregate and reinforcement,

(ii) addition of the activating liquid phase and mixing for 5 minutes to obtain a plastic paste,

(iii) pressing of the plastic paste in a 20 mm diameter cylindrical mold at a pressure of 50 MPa (for 2 minutes), and

(iv) demolding and setting in water for 14 days before uniaxial compression tests

B. *Physical, Morphological and Mechanical Characterization*

The physical characterization consisted of determining the real density of the starting materials and of the manufactured mortars, using a Micrometrics helium pycnometer, model AccuPyc II 1345, the morphology of the samples was studied by observations under a CoolingTech optical microscope, model 1600X, on surfaces previously polished with diamond paste (6 microns) and lubricating liquid. The mechanical characterization consisted of uniaxial compression tests at a constant compression speed of 0.5 mm/minute until fracture of the material. The compression tests were performed on cylindrical specimens with a nominal diameter of 20 mm and a height of 40 mm.

III. RESULTS AND DISCUSSIONS

A. *Physical and Morphological Characterization*

The average real densities found for the alpaca wool fibers, fine sand and type I cement were 1.3569, 2.7569 and 3.1236 g/cm^3, respectively. These densities were used to determine the mass fractions of each of the mixtures studied in Table I. On the other hand, the manufactured mortars presented real densities and average porosities of 2.6526 g/cm^3 and 25%, for control mortars, and 2.4902 g/cm^3 and 45 % for reinforced mortars.

Fig. 1 shows optical microscopy micrographs of polished surfaces of the reinforced mortars studied, in all cases it was possible to appreciate the presence of three well differentiated phases, on the one hand, a continuous interconnected Portland cement phase, and on the other hand, two discontinuous phases located within the continuous cement binder phase.

The discontinuous phases were differentiated by their shape, elongated in the case of the alpaca wool fibers and polygonal in the case of the fine sand grains.

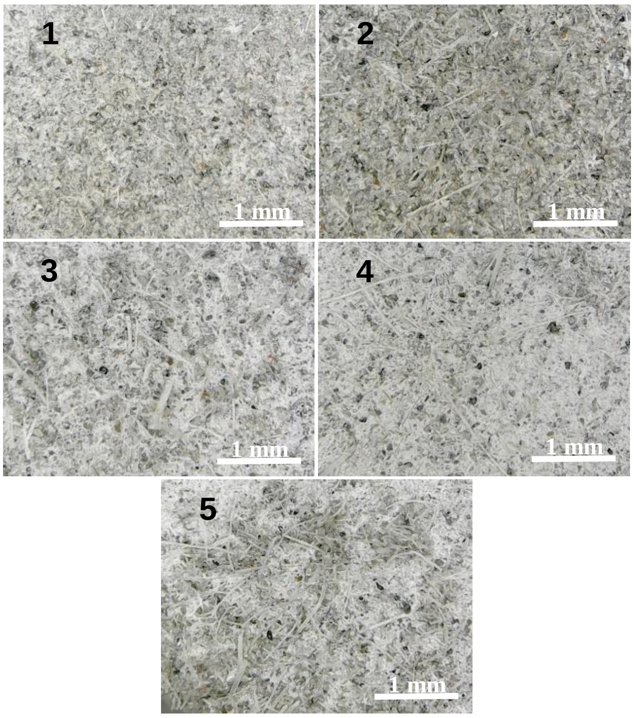

Figure 2. Optical microscopy micrographs of Portland cement mortars reinforced with alpaca wool fibers.

B. *Mechanical Characterization*

Regarding the mechanical characterization, Fig. 2 and 3 show stress vs. strain curves of mortars C and R, with 7 and 14 days of water curing, respectively. From the mechanical data found, it was possible to verify a notable reduction in the maximum compressive strength values as the volume fraction of alpaca wool fibers increased. The average maximum uniaxial compressive strength values, after 7 days of curing (Fig. 2), varied from 5.6 to 1.5 MPa in R mortars, when increasing the volumetric concentration of alpaca wool fibers from 4 to 20 %, respectively.

On the other hand, it was possible to identify a systematic increase in the deformation percentages as the volume of alpaca wool fibers added increased, going from 3% in control mortars to 18% in mortars reinforced with 20 Vol.% of alpaca wool fibers (Fig. 3).

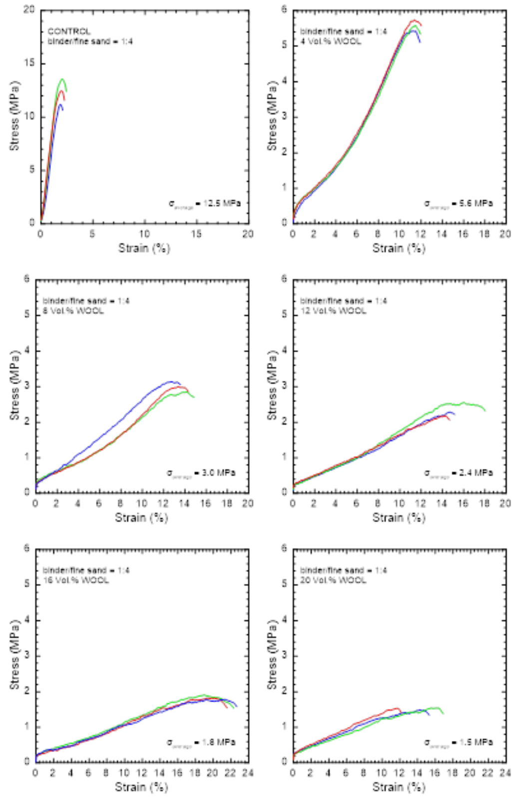

Figure 3. Stress vs. strain curves for control and alpaca wool fiber-reinforced mortars with 7 days curing time. (for each graphic: blue, red and green lines are repetitions for each type of test)

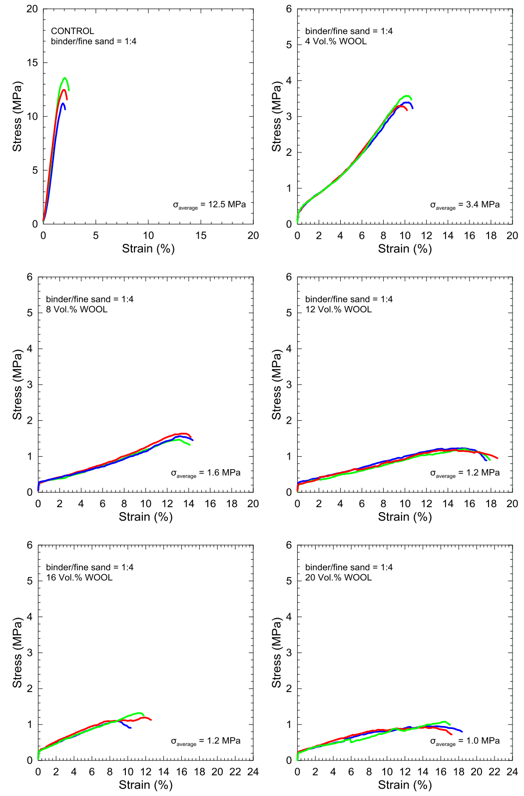

Figure 4. Stress vs. strain curves for control and alpaca wool fiber-reinforced mortars with 14 days curing time (for each graphic: blue, red and green lines are repetitions for each type of test)

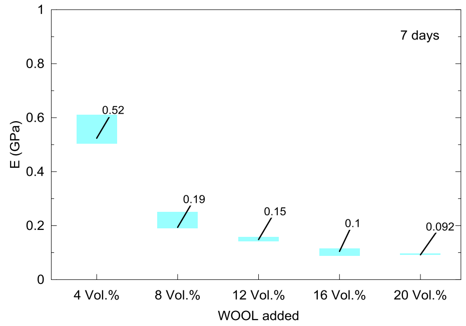

Figure 5. Stiffness of reinforced mortars as a function of the percentage of alpaca wool added after 7 days of curing

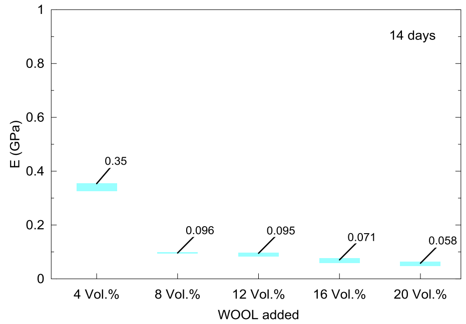

Figure 6. Stiffness of reinforced mortars as a function of the percentage of alpaca wool added after 7 days of curing

Figs. 5 and 6 show the relationship between the added alpaca wool content and the stiffness of mortars fabricated with curing times of 7 and 14 days, respectively. A systematic reduction in stiffness is observed by increasing the alpaca wool content in the mortars studied. The reduction of stiffness values can also be seen after curing from 7 to 14 days, for all the types of reinforced mortars studied. This result is consistent with the increase in the toughness and the degree of deformation of the reinforced mortars when the added alpaca wool content increases (Figs. 3 and 4).

IV. Conclusions

- Alpaca wool fiber-reinforced mortars were successfully manufactured from a mixture of type I cement, fine sand, reinforcing agent (alpaca wool fibers) and water.
- The reinforced mortars studied showed real densities and average porosities of 2.4902 g/cm^3 and 45%, respectively.
- The microstructure of the reinforced mortars studied consisted of three distinct phases, on the one hand, a continuous Portland cement phase, and on the other hand, two discontinuous phases located within the continuous cement phase. The discontinuous phases were differentiated by their shape, elongated in the case of the alpaca wool fibers and polygonal in the case of the fine sand grains.

- It was possible to verify a clear reduction in the maximum compressive strength values by increasing the volume fraction of alpaca wool fibers in the reinforced mortar mixes.
- The average maximum uniaxial compressive strength values, for the reinforced mortars and after 7 days of curing, varied from 5.6 to 1.5 MPa, when increasing the volumetric concentration of alpaca wool fibers from 4 to 20 %, respectively.
- A systematic increase in the deformation percentages of the reinforced mortars was identified as the volume of alpaca wool fibers added in the reinforced mortars increased.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

F. A. Cuzziramos-Gutierrez and G. P. Rodríguez-Guillén carried out the laboratory tests. M. L. Benavides-Salinas and F. A. Huamán-Mamani analyzed the data. F. A. Huamán-Mamani wrote the article, all authors had approved the final version.

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