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Preserving The Great Mosque of Cordoba (Spain): A Preliminary Mechanical Characterization of its original Natural Stone

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INTRODUCTION & AIM

This research centers on three destructive methods: compression tests, three-point bending and split or indirect tensile test. The aim of this study is acquiring knowledge about the mechanical properties of its materials, and the possibility of acquiring that knowledge without creating any damage to the actual building is a challenge.

Laboratory tests were performed on natural stone provided by the primary material supplier for the Mosque's restoration and rehabilitation works. Non-destructive and destructive tests were carried out over 10 ashlars and 100 cubic and prismatic specimens, which were cut from the ashlars, to later correlate the results. Tests were conducted in multiple directions to investigate stone anisotropy.

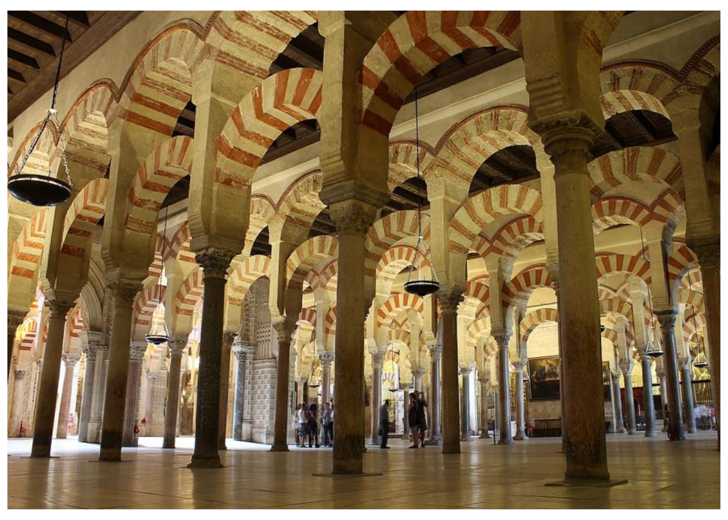


Figure 1. Arcs of the Great Mosque. [1]

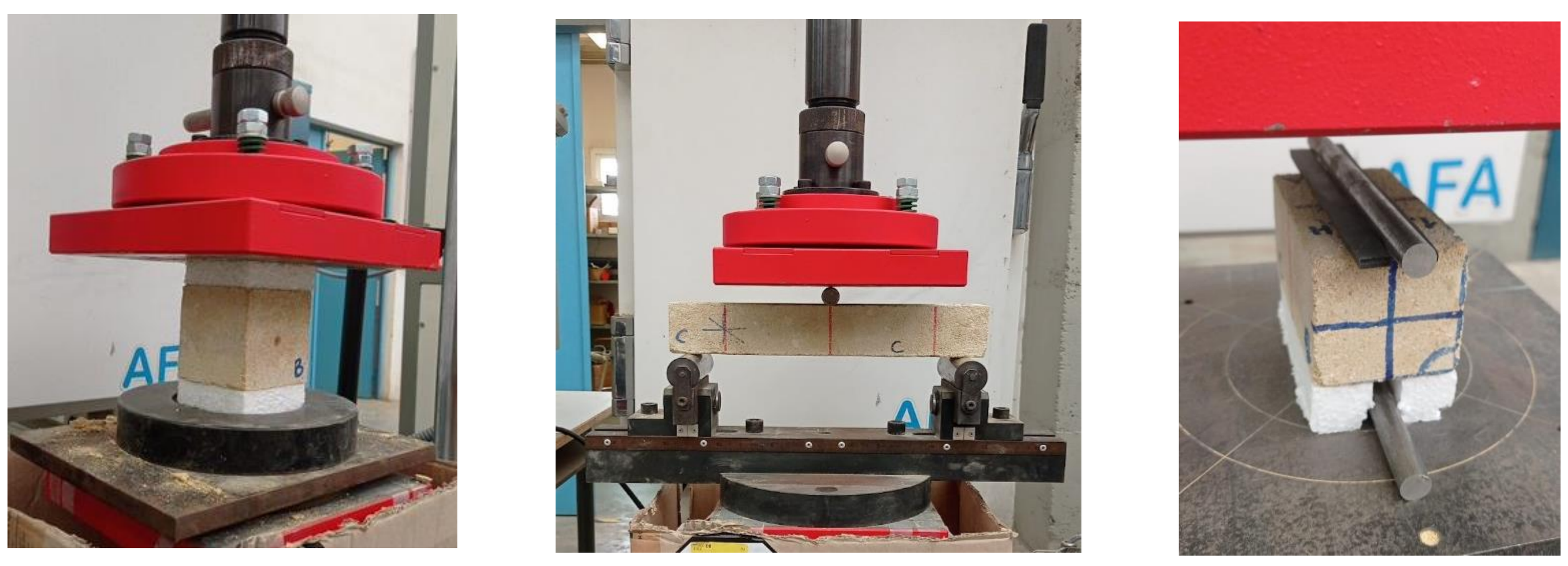
METHOD

The destructive tests carried out for the experimental campaign were performed using a universal servo-hydraulic testing machine. The specimens used for experimentation were both cubic and prismatic shaped with varying dimensions and the test were conducted on different directions.

Figure 2. Ashlar provided by the quarry. Self-made source

Test	Uniaxial Compression				Three points bending		Split test	
Code	UNE-EN 1926/2007				UNE-EN 12372/2007		UNE-EN 12390-1/2022	
Dimensions [mm]	50 x 50 x 50		70 x 70 x 70		50 x 50 x 300		50 x 50 x 100	
Direction	A	⊥ to A	A	⊥ to A	A	⊥ to A	A	⊥ to A
Number	10	10	10	10	10	10	20	20

The compression tests and the three-point bending test were executed under displacement control, whereas the split test was conducted using force control, due to the elevated fragility of the specimens. In addition to this, the density of the stone was investigated through three different methods: nominal, measured volume and inmersion method to compare results against each other to select the optimal one.



Figures 3, 4 and 5. Set up for the destructive tests. Self-made source

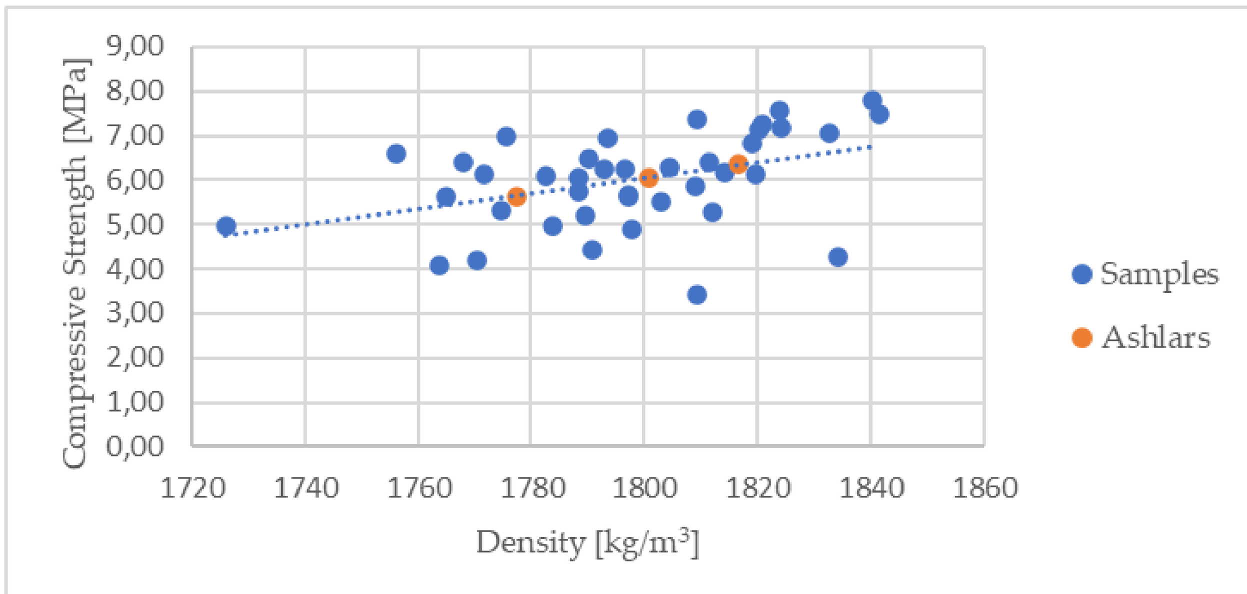
[1]Vollner, N. *Colonnes de la Mezquita* https://commons.wikimedia.org/w/index.php?curid=33238939

[2] Torrero Fuentes. *Caracterización, degradación y conservación de pétreos naturales en la catedral de Santa María de Cuenca*. 2015.

[3] Baeza, J; Compán ,V. *Determining static elastic modulus of weak sandstone in Andalusian historical constructions from non-destructive tests: San Cristobal's stone*. 2022, 1-11.

RESULTS & DISCUSSION

The results of the destructive tests were obtained and presented both in mean value and standar deviation, as well as the results of the density tests and the correlation coefficients. Finally, in figure 6 the density and the compressive strength are compared, obtaining the correlation between those parameters.



$$D = 56.8 \cdot f_c + 1452.8$$

Figure 6. Correlation between density and compressive strength. Self-made source

The first study performed on the compressive strength results was the comparison between the performance of smaller and larger samples. The second study aims to corroborate or refute the hypothesis of the existence of a stronger direction, which would result in a transverse anisotropy of the material. After comparing the results of the destructive tests with the reviewed literature, it is observed that the stone from Santa María de Cuenca [2] is similar in terms of compressive strength. Additionally, after studying the effect of the testing direction, it proves to be isotropic, like the biocalcarenite studied.
The results were not comparable at sample level, given that samples that were tested in compression were not tested for bending or tension. Consequently, a regression analysis was not possible, and a simple proportional correlation was supposed. The correlation coefficient was obtained comparing average ashlars values of each of the properties.
The values of the density obtained using different methods, ranging roughly from 1700 to 1800 kg/m^3, were compared. These values are in line with the ones found in literature for San Cristobal's stone [3].
The material density seems to be linked to its compressive strength. In this case, the comparison between the two properties could be done sample by sample, using the measured volume density. Consequently, a regression analysis was possible, obtaining a good match (Figure 6).

	Compressive strength [MPa]		Bending strength [MPa]		Tensile strength [MPa]		Density [kg/m³]	
Ashlar	Mean	STD	Mean	STD	Mean	STD	Mean	STD
1	6.27	1.06	2.02	0.25	0.70	0.07	1815.08	9.76
2	5.81	0.83	1.94	0.09	0.69	0.09	1811.26	4.81
3	6.17	1.20	1.83	0.40	0.70	0.09	1834.92	8.97
All	**6.08**	1.06	**1.93**	0.27	**0.70**	0.08	**1820.00**	13.00

Table 1. Mean values and standard deviations of compressive, vending and tensile strength and density

CONCLUSION

The proposed campaign proved to be successful for the consecution of the stablished goals. The variation inter- and extra-ashlar were similar, indicating the homogeneity of the material. Based on the obtained results, it can be stated that there is no anisotropy in the stone for the studied properties. It can be concluded that the influence of the sample dimensions on the results of the compressive strength test are negligible. The optimal method for the determination of the stone density is found to be the measured volume method. The bending strength can be approximated by one third of its compressive resistance, while the tensile strength is around one 10% of it.

FUTURE WORK / REFERENCES

For future works regarding this investigation mechanical properties can be associated with material rigidity and, additionally, complimentary tests using the video extensometry technique could be performed.