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The importance of water in traditional gypsum works

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Abstract

Until the second half of the 20th century, the traditional architecture of the Iberian Peninsula was directly linked to the resources available in its immediate surroundings, naturally diversification the built heritage throughout the territory. In its gypsiferous areas, we find a great versatility of construction systems in which the main binder used is traditional gypsum, although this material has been forgotten in the 20th and the 21st century architecture, meanwhile industrial gypsum currently plays a secondary role in the construction sector. Gypsum, like any traditional binder, is a material that is particularly sensitive to the amount of water with which it is mixed, which will be strongly linked to the technique of application, among other technological parameters. Thus, the final performance of the product is, among other things, a consequence of this water/gypsum ratio, as Francisco Arredondo states in some of his works. In them, the behaviour of an industrial gypsum is analysed as a function of the mixing water, relating it in turn to other parameters such as compressive strength, water absorption and bulk density. The aim of this work is to study the influence of the mixing water on the physical and mechanical properties of different traditional plasters, taking into account previous studies, the diversity of traditional uses of gypsum and current application techniques.

Keywords: *Traditional gypsum, hydration of plaster, dosage, mechanical properties.*

1. Introduction

The eastern half of the Iberian Peninsula is rich in gypsum outcrops, to which must be added the regions of Asturias, Valladolid, Palencia, Cádiz, Málaga, Seville and Córdoba. Adding these regions to the eastern, they represent a 58.5% of the total area of the Iberian Peninsula (Gárate Rojas, 1999; La Spina & Grau, 2020a; Bel-Anzué & Elert, 2021). It is therefore not surprising that in "gypsiferous Spain", a large part of the built heritage has been developed through the use of this traditional conglomerate.

It was not until the appearance of Portland cement in the second half of the 20th century that traditional binders such as gypsum, lime or natural cement were relegated to second place, both in terms of the diversity of their uses and their lack of inclusion in the new industrialised construction systems (Sanz Arauz, 2009; Mayo-Corrochano et al., 2022).

In the past, traditional gypsum construction was characterised by its versatility, as the performance of the material, its easy handling and adaptability allowed it to form part of multiple construction systems such as flooring, pavements, interior dividing walls, load-bearing walls, stairs, the manufacture of prefabricated elements with a structural function, decorations, interior and exterior cladding, etc. (Marín Sánchez, 2014; La Spina & Grau, 2020b; Bel-Anzué & Elert, 2021; González-Sánchez et al., 2022a).

Traditional gypsum has different mechanical properties to the industrial gypsum that we know today, which is basically characterised by its high degree of purity, its low resistance and surface hardness, and its high degree of hygroscopicity. On the other hand, in traditional gypsum these same properties are highly variable, which allowed it to be used in many construction systems. The characteristics of this traditional binder are the heterogeneity of the raw material, which is accompanied by associated minerals depending on the place of extraction, what we know as "impurities"; the variability in the percentage of purity of the stone used; the heterogeneous firing at high temperature; the crushing of the fired material; the hardness acquired after laying; the strength; and the durability of the heritage (González-Sánchez et al., 2020; Mayo-Corrochano et al., 2022).

Gypsum, like any binder, is particularly sensitive to the amount of water used during the mixing process. Although the proportion of water that gypsum needs to fully hydrate is relatively low, quantified at around 20% of the weight of anhydrous gypsum (Novo, 1966; Arredondo & Verdú, 1991; Villanueva Domínguez & García Santos, 2001), it is practically impossible to have workability of the gypsum paste with this dosage. For this reason, higher dosages are normally used to guarantee the workability of the material, varying significantly its physical and mechanical properties (Fig. 1).

Consequently, the amount of water used will be strongly linked to the construction technique and to the characteristics of the material used, so it can be stated that the final performance of the product is, to a large extent, a consequence of this water/gypsum ratio (Arredondo, 1963; Arredondo & Verdú, 1991).

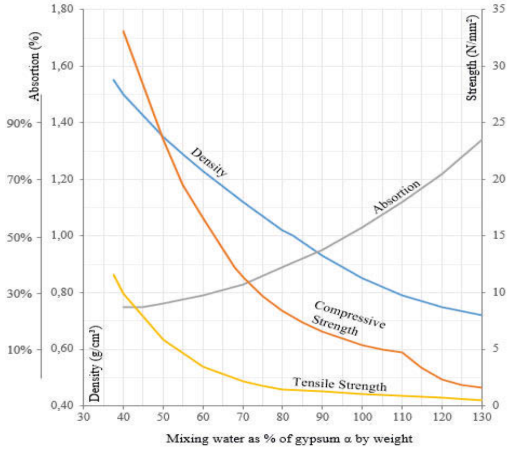


Fig. 1. Properties of gypsum according to test carried out at the *Instituto Eduardo Torroja de la Construcción y del Cemento* (Source: Arredondo, 1963)

2. Objectives

Since the end of the 19th century, there have been authors who have related the influence of the mixing water to the physical and mechanical properties of industrial gypsum, but differs when the study material is a traditional gypsum. One of the most cited authors in relation to this type of studies is Francisco Arredondo, who, in his many publications, clearly relates the influence of the water/gypsum dosage of α-hemihydrate gypsum, which are not the main product used in the construction sector, to the compressive and tensile strength, liquid water absorption and apparent density.

The aim of this work is to study the influence of the mixing water on the physical and mechanical properties of 3 different types of traditional gypsum, which are currently marketed or are in the process of being studied for their future commercialisation, similar to the studies carried out by Francisco Arredondo on industrial α-hemihydrate gypsum. This is a fundamental step towards the further study of this type of material, so unknown and with such different features to current industrial gypsum, which can be assimilated to those produced in the past, and to be able to recover traditional construction systems with current application techniques.

3. Materials and methodology

3.1. Materials

Three different types of traditional commercial gypsum were used for this study: *Argiofloor* (Argio/DécoSystem); *Plâtre* (Plâtres Vieujot); and *Yeso Artesano de Teruel* (Millánplasol) (González-Sánchez et al., 2022b).

3.2. Gypsum chemical characterization

The mineralogical characterisation of the different gypsum was carried out by means of thermogravimetric analysis (TGA), with the STA449 F5 JUPITER equipment of the NETZSCH brand. The interpretation of the results obtained was carried out with the NETZSCH-PROTEUS-80 reference software.

3.3. Paste consistency

Before making the samples, the mixing time and procedure were defined. In this case, the time was 1 minute, and the mixing was carried out mechanically with a mortar mixer model E93 of the MATEST brand, with a working speed in rotation of 140 ± 5 rpm and in planetary movement of 62 ± 5 rpm, according to the UNE-EN 196-1:2018 standard. The working range of the different gypsum pastes was also determined, which means, the range of water/gypsum ratio values in which suitable rheology are achieved for a specific application technique. This was done through the study of its consistency, which measures the diameter of the paste run-off, by the shaking table method, according to the UNE-EN 13279-2:2014 standard.

3.4. Manufacture of samples

A total of 11 pieces of dimensions 290 x 25 x 25 mm were made. The pieces were grouped into 3 units for the study of *Argiofloor* gypsum, 4 units for the study of *Plâtre* gypsum, and the remaining 4 units for the study of *Yeso Artesano de Teruel* Gypsum (Fig. 2). The manufacture of the samples was carried out according to the methodology of the UNE-EN 13279-2:20014 standard. The samples were demoulded 24 h after manufacture and were kept under laboratory temperature and humidity conditions until stable weight. The stability in weight of the samples was determined between 21 and 26 days after manufacture, depending on the amount of mixing water and the type of gypsum, so it was decided to take 28 days as the reference time in all cases. Subsequently, the 11 initial pieces were subdivided into 7 samples, by dry sawing of approximately 40 x 25 x 25 mm, obtaining a total of 77 samples for their subsequent physical and mechanical characterisation.

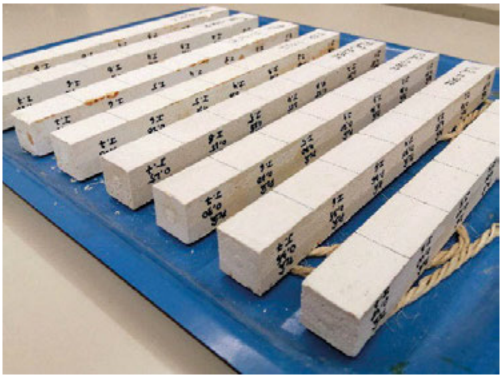


Fig. 2. Pieces of dimensions 290 x 25 x 25 mm

3.5. Characterisation of hardened gypsum

The characterisation of the three types of hardened gypsum pastes was carried out by determining the bulk density and the percentage of porosity of the samples, according to standard UNE-EN 1015-10: 1999 but using ethanol as the liquid; the maximum compressive strength by means of the *Mecánica Científica* brand 42 0440-ESP multi-test press with a load capacity of 50 kN, according to UNE-EN 196-1:2005 and UNE-EN 13279-2:2014; and the total percentage of water absorption by capillarity, according to UNE-EN 15801:2009.

4. Results

4.1. Gypsum characterization

In the comparative graph of the commercial gypsum studied, three significant weight loss intervals can be distinguished (Fig. 3). The first interval is between 100ºC and 300ºC, associated with the loss of water by dehydration of the gypsum. The second interval is between 300ºC and 700ºC, associated with the loss of water by decomposition of the clays. The last interval is between 700ºC and 950ºC, associated with the loss of CO2 by decomposition of the carbonates.

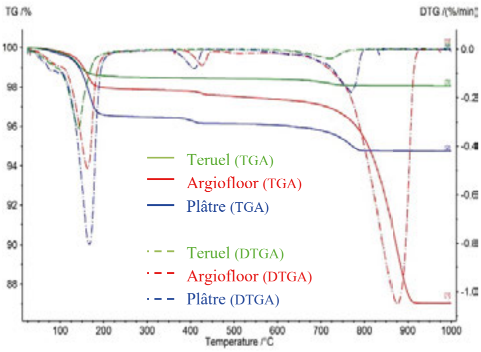


Fig. 3. Thermogravimetric analysis comparative for diverse types of gypsum

		ARG	PLÂ	TER
% Weight loss	100-300ºC	-1,93%	-3,20%	-1,27%
	300-700ºC	-0,77%	-0,68%	-0,23%
	700-950ºC	-10,05%	-1,05%	-0,20%
	Residual mass	87,03%	94,74%	98,06%

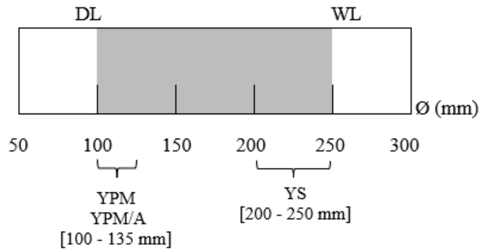
ARG = *Argiofloor* gypsum; PLÂ = *Plâtre* gypsum; TER = *Yeso Artesano de Teruel* gypsum.

Table 1. Percentage of weight loss and residual mass for diverse types of gypsum

The percentage of weight loss for each of the intervals studied and the residual mass for each type of gypsum are detailed below (Table 1). As can be seen, the *Argiofloor* gypsum is the one with the highest weight loss compared to the rest, mainly due to the decomposition of the carbonates it contains. *Plâtre* gypsum is the one with the highest purity of those analysed, and *Yeso Artesano de Teruel* gypsum has a practically negligible content of clays and a low carbonate content.

4.2. Consistency study

The theoretical working range of a gypsum paste depends on its future application, so the working limits were defined based on the consistency study of different commercial gypsum pastes already formulated (Fig. 4).



DL = dry limit; WL = wet limit; YPM = mechanically sprayed gypsum; YPM/A = lightened mechanical sprayed gypsum; YS = gypsum for traditional continuous pavements.

Fig. 4. Diagram of the theorical working rang of gypsum pastes

In order to select the least amount of water to use in this work, defined as "dry limit" DL, it was considered to study the consistency of industrial gypsum for mechanical projection on vertical walls, as is the case of *Proyal* y *Proyal XXI* gypsum (Saint-Gobain Placo Ibérica, 2021a; Saint-Gobain Placo Ibérica, 2021b).

In order to select the highest amount of water to be used in this work, defined as the "wet limit" WL, it was considered to study a traditional commercial gypsum recommended for application as a continuous gypsum pavement, such as NOHUKI decorative gypsum coverings (Millán Plasol, 2021).

Based on the working range, the relationship between the water/gypsum dosage by weight and its consistency was studied for our traditional plasters (Fig. 5).

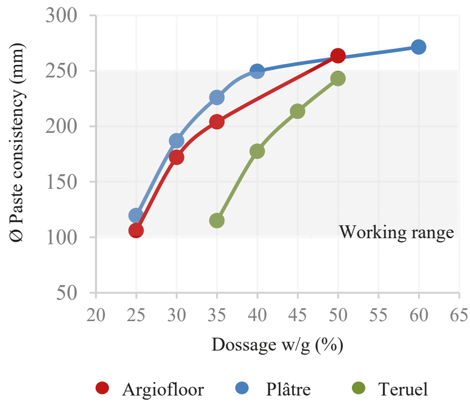


Fig. 5. Different water/gypsum dosage ratios vs the run-off diameter of the gypsum paste obtained by the consistency test

As can be seen, the resulting study area is small and lies between the 25% and 50% dosages. The water/gypsum ratio finally used for the preparation of the test samples is given in Table 2.

	TRADITIONAL GYPSUM		
W/G	**ARG**	**PLÂ**	**TER**
0.50	-	-	x
0.45	-	-	x
0.40	-	x	x
0.35	x	x	x
0.30	x	x	-
0.25	x	x	-

W/G = dosage water/gypsum; ARG = *Argiofloor* gypsum; PLÂ = *Plâtre* gypsum; TER = *Yeso Artesano de Teruel* gypsum.

Table 2. Matrix composition of the samples prepared

4.3. Bulk density and porosity

The graph in Fig. 6, compares the bulk density values obtained for the three traditional gypsum types with the reference density values (Arredondo, 1963). As can be seen, the bulk density values of all traditional gypsum are similar to those of the reference gypsum and they all draw a very similar downward sloping curve. The bulk density for *Argiofloor* and *Plâtre* gypsum is very similar, between 1.60 and 1.70 g/cm^3, and higher than the values obtained for *Yeso Artesano de Teruel* gypsum, between 1.30 and 1.51 g/ g/cm^3.

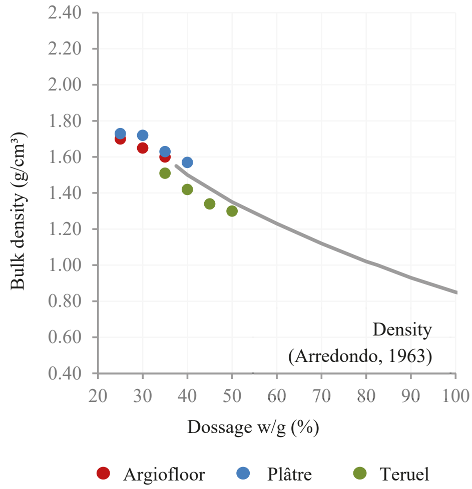


Fig. 6. Different water/gypsum dosage ratios vs bulk density

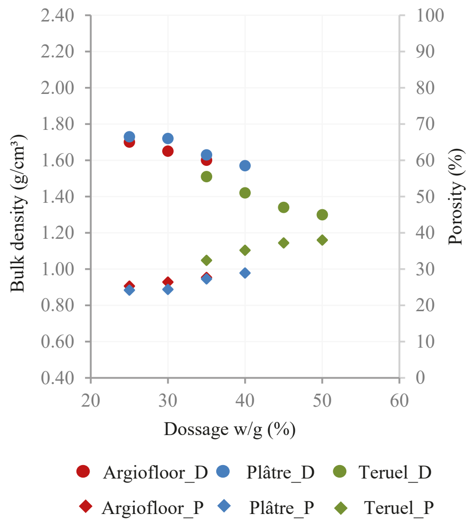


Fig. 7. Different water/gypsum dosage ratios vs bulk density (D) and porosity (P)

As can be seen in the graph in Fig. 7, there is a clear increase in porosity as the percentage of water increases with respect to that of gypsum, and an inversely proportional relationship between the values of density and porosity. As with the apparent density, the *Argiofloor* and *Plâtre* gypsum have a porosity very similar to and lower than that of the Teruel Gypsum, between 25% and 29%.

4.4. Compressive Strength

The graph in Fig. 8, compares the compressive strength values of the three types of traditional plasters with the reference values. (Arredondo, 1963).

As can be seen, the reference compressive strength values are much higher than those obtained for traditional gypsum. However, the inclination of the straight line drawn by the values for traditional gypsum is slightly less steep, especially in the case of *Argiofloor* gypsum.

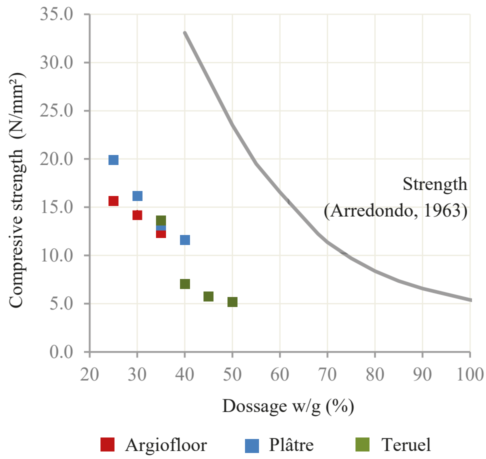


Fig. 8. Different water/gypsum dosage ratios vs compressive strength

In relation to the values obtained, with *Plâtre* gypsum we obtained the highest compressive strength values, between 11.64 ± 0.97 and 19.89 ± 0.71 N/mm^2, followed by *Argiofloor* gypsum, between 12.33 ± 1.49 and 15.67 ± 0.83 N/mm^2. The values obtained for the Yeso Artesano de Teruel gypsum are lower, between 5.17 ± 0.27 and 13.65 ± 1.01 N/mm^2, but it should be borne in mind that the water/gypsum dosage is higher to guarantee its workability.

4.5. Water absorption

The graph in Fig. 9, compares the water absorption values of the three types of traditional plasters with the reference values (Arredondo, 1963).

As can be seen, the absorption values obtained for the three types of traditional gypsum studied are close to the reference values and follow a similar upward trend. In this case, *Argiofloor* and *Plâtre* gypsum have a very similar behaviour in terms of water absorption, with values between 10% and 17%. On the other hand, for the *Yeso Artesano de Teruel* Gypsum, the values obtained are the highest, between 24% and 32%.

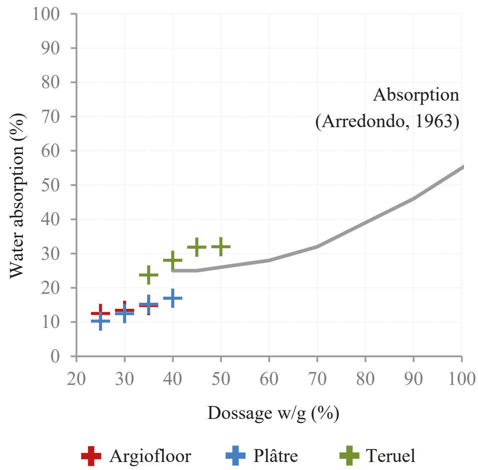


Fig. 9. Different water/gypsum dosage ratios vs water absorption

5. Conclusions

The purpose of this study was to find out the most relevant values of the physical and mechanical behaviour of three different types of traditional plasters, following the example of the studies carried out at the *Instituto Eduardo Torroja de la Construcción y el Cemento* by Francisco Arredondo (Arredondo, 1963; Arredondo, 1991).

Firstly, the relationship between the values obtained for traditional gypsum and the parameters studied was confirmed: as bulk density values increase, values of compressive strength raise too, but porosity and water absorption values are reduced. It is not possible to compare the results obtained in this study with those analysed by Francisco Arredondo, as there are big differences between traditional gypsum and α-gypsum, from their manufacturing process to their final use. However, it can be stated that the behaviour of all of them in relation with their water/plaster ratio describes a similar trend in all the parameters studied, so that traditional plasters also have a special sensitivity to the dosage of water used, and their study is one of the most important parameters to take into account during the installation of the material.

Secondly, *Argiofloor* and *Plâtre* gypsum, although they have a different mineralogical composition, have very similar physical and mechanical behaviour, except for the compressive strength values where *Plâtre* gypsum reaches 20 N/mm2 at a water/gypsum dosage of 25%. It would be necessary to analyse more parameters to determine whether this tendency is repeated in the case of Plâtre gypsum.

Thirdly, comparing all data gathered during the study, in the 35% water/plaster dosage is where the greatest affinity can be found between the three pastes, although there are clear differences between the consistency of the *Yeso Artesano de Teruel* gypsum and the other two: with a bulk density between 1.51 and 1.63 g/cm^3; a compressive strength between 12.33 and 13.65 N/mm^2; a porosity between 27.3% and 32.4%; and an absorption between 14.9% and 23.7%. For this dosage, and according to the values obtained in the consistency study, the *Argiofloor* and *Plâtre* plasters would be suitable for installation as continuous plaster flooring, but the *Yeso Artesano de Teruel* gypsum would have a more appropriate consistency to be projected on a surface.

Acknowledgments

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References

Arredondo, F. (1963). *Estudio de materiales. II. El yeso*. Madrid: Instituto Eduardo Torroja de la Construcción y el Cemento

Arredondo y Verdú, F. (1991). *Yesos y Cales*. E.T.S Ingenieros de Caminos de Madrid

Bel-Anzué, P., Elert, K. (2021). Changes in traditional building materials: the case of gypsum in Northern Spain. *Archaeolgical and Anthropological Sciences*, 13 (10). https://doi.org/10.1007/s12520-021-01438-6

Gárate Rojas, I. (1999). *Arte de los yesos: Yeserías y Estucos*. Munilla-Lería

González-Sánchez, B., Navarro Ezquerra, A., Rosell, J.R. (2020). ¿Qué es el yeso tradicional? El estudio del yeso de Ribera d'Ondara a partir de la monitorización de un horno tradicional. In: *Actas de la 3a Jornada de Doctorado del programa de Tecnología de la Arquitectura, de la Edificación y del Urbanismo 2020*. Barcelona: EPSEB, 30-35

González-Sánchez, B., Navarro Ezquerra, A., Julià Comas, M., Ramírez-Casas, J., Palumbo Fernandez, M. (2022a). Rediscover Traditional Gysum: Territory, Traditional Architecture and Rediscovery of Traditional Gypsum. In: *Protection of Historical Construction*, PROHITECH 202

González Sánchez, B., Navarro, A., Ramírez-Casas, J., Rosell, J.R. (2022b). Traditional Gypsum Pavements with Natural Aditives. In: *Construction Technologies and Architecture*, ICBBM 2021, 575-583

La Spina, V., Grau Giménez, C.J. (2020a). La diversidad tipológica de los hornos tradicionales de calcinación de yeso en España. *Informes de la Construcción*, 72(557): e334

La Spina, V., Grau Giménez, C.J. (2020b). Uses of Gypsum in Spanish architectural heritage: typologies and some unique construction techniques. International Journal of Architecture Heritage, 14:2, 176-195.

Marín Sánchez, R. (2014). Uso structural de prefabricados de yeso en la arquitectura levantina de los siglos XV y XVI. PhD Thesis, Universitat Politècnica de València

Mayo-Corrochano, C., Sánchez-Aparicio, L.J., Aira, J., Sanz-Arauz, D., Moreno, E., Pinilla Melo, J. (2022). Assessment of the elastic properties of high-fired gypsum using the digital image correlation method. *Construction and Building Materials*, 317, 125945

Millán Plasol (2022, January 20) *millanplasol* [Online]. Alcañiz: MillánPlasol, 2021

Saint-Gobain Placo Ibérica, S.A. (2021a). Proyal. Yesos y Plastes. Fichas técnica. Madrid: Placo Saint-Gobain

Saint-Gobain Placo Ibérica, S.A. (2021b). Proyal XXI. Yesos y Plastes. Ficha técnica. Madrid: Placo Saint-Gobain

Sanz Arauz, D. (2009). Análisis del yeso empleado en revestimientos exteriors mediante técnicas geológicas. PhD Thesis, Universidad Politécnica de Madrid

Villanueva Domínguez, L., García Santos, A. (2001). *Manual del yeso*. Asociación Técnica y Empresarial del Yeso de Madrid