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Mortero a base de aglutinantes proteínicos y residuos minerales para elementos interiores. Mortar based on protein binders and mineral waste for interior elements.

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Resumen-- **Para este trabajo se han realizado adaptaciones de las técnicas más destacadas en los antecedentes de tratamientos químicos e hidrotérmicos destinados a la extracción proteica para distintas fuentes derivadas de las faenas alimenticias, a gran escala actualmente; de las cuales se aprovecha las propiedades adherentes basadas principalmente en la queratina, compuesto orgánico con trazas mayores al 90% en plumaje y pelaje animal. Los cuales son procesados químicamente para obtener un aglutinante orgánico dosificado en cuatro mixturas A, B, C y D, en las cuales varía el porcentaje y origen del pegante como también la porción de los áridos minerales residuales pulverizados calcáreos (marmolina) y cerámicos (ladrillo) con los cuales, amasados a mano, se forma una pasta homogénea que se modela en moldes normados para proceder al cálculo de sus propiedades físicas tales como coeficiente de absorción de humedad ambiental, dureza superficial y resistencia mecánica máxima a esfuerzos de compresión y flexión.**

Palabras clave— Aglutinante proteínico; Residuos calcáreos y cerámicos; Insumos materiales.

Abstract— **For this work, adaptations have been made of the most outstanding techniques in the history of chemical and hydrothermal treatments aimed at protein extraction for different sources derived from the food industry, on a large scale at present; of which the adhesive properties based mainly on keratin, an organic compound with traces of more than 90% in animal plumage and fur, are taken advantage of. These are chemically processed to obtain an organic binder dosed in four mixtures A, B, C and D, in which the percentage and origin of the glue varies as well as the portion of the residual pulverised calcareous (marble) and ceramic (brick) mineral aggregates with which, The homogeneous paste is then moulded in standard moulds to calculate its physical properties, such as the coefficient of absorption of ambient humidity, surface hardness and maximum mechanical resistance to compressive and flexural stresses.**

Index Terms— Protein binder; Calcareous and ceramic wastes; Material inputs.

I. Introduction

At present, in the area of construction, where material volumes are in high demand and the waste generated before, during and after, mostly does not have biodegradable properties due to its physico-chemical composition, it is difficult to reuse or recycle. Thus, due to the general characteristics of waste, environmental damage is directly and indirectly increased at local, regional, and global level. For this reason, it is important to highlight the ecological advantages of the use of waste generated by the construction and food industries, the latter being one of the most worrying due to its demand and unstoppable continuous growth, whose current treatments to curb the harmful environmental effects have been limitedly satisfactory due to their complexity, time, and costs (Lynch et al., 2019).

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Among the major food production industries is the red meat industry for human consumption, an important derivative of which is the portion of raw hides and skins, mainly from cows, destined for tanning processes to manufacture leather for both footwear and clothing. Spain is one of the largest producers of these raw materials, in seventh place with a contribution of 3.5% worldwide. Within this industry there is more than one type of waste to consider; in the case of solid waste, such as spoiled leather waste and above all capillary fibres, which generally end up in open dumps, where biological oxidation releases nitrogenous compounds after leaching of substances during and after precipitation, causing eutrophication of water sources (Gaibor et al., 2020). Next to these leftover elements are the liquids, which start at the most elementary stage of leather processing. To simplify these steps, we first mention the release of common salt from the hides, applied immediately after detaching the hides from the muscle tissue to desiccate them for storage in good condition; these are then taken to the tanning plant and immersed in common water, which is saturated with salt, traces of blood, membranes and impurities. This is followed by the water-based alkaline solution where calcium hydroxide and copper salts have been dissolved to remove the hair fibres definitively and to give a first exposure to permanent preservative compounds to the hides. However, from treatment to minimise the impact or recovery of alkaline solutions, particular research looks at the economic and environmental advantages of such practices (Beghetto et al., 2013).

It should also be noted that the 36,000 tonnes per year of waste wool from the textile industry in Spain is unsuitable for the textile industry and is not used for mass industrial purposes. Similarly, regarding industrial poultry waste, the amount of waste generated by the rearing of poultry such as chickens, turkeys, quails, and ducks for food is a cause for concern; an average of five million tonnes of plumage per year worldwide and, like bovine offal, it ends up in landfill sites, adding to the burden on the ecosystem (Poole et al., 2009; Marsal et al., 2009).

As for the construction waste shown in Fig. 1 and specifically the residual generation of brick and ceramics as seen in Fig. 2; it is accelerating globally due to the increase in renovation and reconstruction of old or contemporary buildings, which constitute about 45% of total CDW (Hwang et al, 2019). In 2014, the total waste generated by all activities for the twenty-eight members of the European Union (EU-28), reached an increase of 57.2%, equivalent to 2503 million tonnes, being the highest amount reported in the last 10 years during the period 2004 - 2014. These data confirm the relevance of reinforcing research to support the value of waste, propose new treatment alternatives (Gaibor et al., 2020) and thus avoid using natural resources (sands and gravels) in construction and reduce the costs of waste management for this category (Robbins et al., 2012).

Therefore, this research proposes the search for methods and technologies to obtain a product with added value of intensive production from local elements that compensate part of the inputs demanded in the construction industry and achieve more effective utilities of the raw material described, whose advantages such as: quantity, ease of obtaining, low cost of processing and quality, make it ideal for proposing construction alternatives that make it possible to create blocks with lower demand for resources compared to traditional materials whose waste is totally reusable in the constitution of new pieces that will maintain the characteristic of being completely absorbable by the environment at the end of their useful life, reducing the environmental impact.

The application of organic waste subtracts the amount of biomass left over from economic activities by incorporating this material as part of local construction materials, reducing the environmental impact generated by decomposition on the soil, water, and air, gradually reincorporating the biodegradable material used from these elements into the environment after use (Madurwar et al., 2013).

The use of natural particles and binders minimises the risk of occupational intoxication during manufacture and in the domestic environment, eliminating the presence of mineral particles such as asbestos, mineral wool, among others, including preservatives and gas-emitting adhesives such as formaldehyde, whose restrictions are strictly regulated by international standards such as UNE EN 120 (1999). It should be noted that the absence of plastic elements counteracts the accelerated advance of fire without considerable emission of toxic gases into the air, and even cancels out the pollution of soil and water with particles that do not come from such material (Stec et al., 2011).

The related experimental scientific background is mentioned below as the contribution obtained from the literature review. The article of preliminary studies for wood boards bonded with feather proteins developed by In Yang, who uses alkaline bases for protein isolation, these compounds are sodium hydroxide at 6% and sodium bisulphite at 2%, similarly, the blood-based glue within Charles Cone's patent, considers sodium hydroxide as a primary reagent to dissolve the primary blood bonds, and uses dehydrated blood without any residue (Yang et al., 2018; Charles, 2003). Similarly, the adhesives developed by combining feathers and blood use the base in different percentages, between 5 and 10% for feathers only, but for blood, sulphuric acid is used for the hydrolysate, with the aim of using it as a hardener for the combinations. Within the analysis, there is the possibility of replacing sodium hydroxide with potassium hydroxide, although this is more expensive commercially, if there is no industrial alternative available. When considering the keratin isolation of feathers in the study by Yen Sze, the use of sodium hydroxide is the only alkali that reacts with the feathers thermally in various heat sources and water, however, this study indicates the disadvantages of the increase of the compound on the adherent properties of the proteins (Lee et al., 2016).

The activation of the chemicals used varies depending on both the experimental and performance results to be achieved. Thus, the two modes of hydrolysis highlighted in the research are cited.

Fig. 1. Waste cement mortar derived from construction activity.

Fig. 2. The main waste includes bricks and ceramic pieces.

The first method of hydrolysis, commonly used for the reaction between water, reagents and proteins is thermal, as indicated by the study conducted in South Korea, where the application of conventional heat by means of a source on the surface of the container where the mixture is to reach a temperature of 100°C has had positive results, similarly, applying temperatures of up to 90°C to the combination with feathers for two hours does not vary the effectiveness. However, analysis of the full experimental performance with industrial economic validation is highlighted in the work of Yen Sze, where he applies heat by means of molecular vibrations of the domestic microwave oven at 800 watts of power, thereby achieving an advantage in reaction time by reducing the 150 minutes of conventional heat to 10 minutes with the above procedure, which has yet to be realised on a laboratory scale with a view to amplification (Yang et al.,, 2018). Heat as thermal energy for hydrolysis has clearly been noted in hard organic tissue such as feathers or horn, however, in substances such as blood the use of heat is completely eliminated, for example, in adhesives based on this substance developed as an adhesive, showing that the simple addition of alkalis and water at room temperature causes the reactions necessary for the formation of the binder, as manifested in the US patented product relating to this method (Charles, 2003).

Although, the combination with water is necessary within the process of protein binders, however, a particular research conducted by Chinese researchers in 2008, reveals results on the incorporation of alkaline pH resins such as phenolic polymers during the hydrolysis process in the mixture, with this up to 30% of such synthetic glues can be replaced in large-scale procedures, reducing production costs without altering the strength properties in the boards.

The aim of the work is to develop the application of a binder derived from the adherent protein properties of poultry plumage and capillary filaments (bovine) mixed with calcareous aggregate (marble powder) and ceramic (pulverised brick) to produce modular series for the construction of partition elements (load-bearing and non-load bearing), false ceilings and coverings.

II. Experimental procedure

A. Process

The methodology of the work is mainly based on the elaboration of the protein binder, therefore the two treatments carried out for plumage and fur are described below.

i. Extraction of keratin from plumage

The plumage of poultry for consumption is the most careful waste, as the minimal amount of organic remains found, such as skin, blood, and adipose tissue, can lead to putrefaction if not treated in a timely manner. However, these are not eliminated, which is considered an advantage, as in the past, blood and fat were frequent additives in lime mortars, to which they provided properties such as greater rigidity and cohesion between particles (Fang et al., 2016). For this reason, washing with water and detergents is omitted altogether, and drying is carried out directly at 95°C for 3 hours, preferably within the first 5 hours after slaughtering the birds. The heat cooks the tissues and dehydrates them, completely avoiding bacterial proliferation by moisture between the tissues and storage without biological risk or loss by decomposition of organic compounds. The following series of Fig. 3 show the material with the respective dosages.

Fig. 3. Elements used and dosages. Left: Dehydrated Feather (1800g); center: Sodium Methasilicatum (40g); Right: Water (4000 ml)

Inside the glass or metal (steel) container, water preheated to 80°C is placed, then the sodium metasilicate is stirred until completely dissolved, then the required amount of feathers cut in dimensions of 1 to 1.5 cm are immersed after drying, so the storage requires less space and less volume in the treatment container; they are left to soak in the alkaline liquid (pH 13) for 2 hours at 55°C. Finally, the mixture is put in the oven at 90°C

for 3 hours for the complete cooking of the mixture. With these operations, the alkaline agents easily penetrate even through the most rigid structures of the feathers (calamus and rachis) and end up dissolved in the water, thus forming the amber-coloured binding paste shown in Fig. 5.

ii. Keratin extraction from bovine hair

The vaccine capillary fibres must be completely dry to control the weight in the dosage, they do not require crushing or prior cutting, as due to the thinness of their diameter, they are used in the size that the material is captured, and like the feathers, they do not require washing and direct storage does not have remains that present a biological risk due to decomposition. Fig. 4 show the material with its respective dosages.

Fig. 4. Elements used and dosages. Left: Bovine hair fibre (600g); center: Sodium Methasilicatum (60g); Right: Water (1200 ml)

In a glass or steel container, dissolve the sodium metasilicate in the water preheated to 80°C, then add the hair fibres, soak them entirely in the alkaline solution (pH 14), cover the container and place it in the oven at 90°C for 3 hours, during which time the hair will be completely dissolved in the water as shown in Fig. 5.

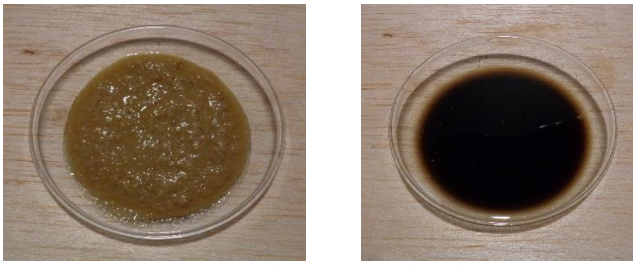

Fig. 5. Paste obtained. Left: Keratin paste from feathers.; Right: Keratin syrup from hair fibres.

B. Dosages

Table 1 shows the dosages with the quantities of aggregate and binders used to be mixed to obtain the 4 combinations. It is important to mention that both aggregates and binders have been measured in grams for the precision that this alternative offers when adjusting the quantities.

After the thermochemical isolation of the keratin proteins of feathers and capillary filaments, the specimens are made in metal moulds of 4x4x16cm Fig. 6, regulated by the UNE EN 196-1 standard with the specifications mentioned in the previous section, however, an approximate of at least 12 samples (3 for each mixture) should be considered for the tests described below, considering the use of remaining parts for certain tests such as: compressive strength and surface hardness.

TABLE I
DOSAGES USED

Dosage	A	B	C	D
Feather Glue	750g	750g	500g	500g
Hair Glue	-	-	200g	200g
Limestone Aggregate	2500g	1500g	2500g	1300g
Ceramic Aggregate	-	400g	-	400g

First, the elementary steps and instruments used for the fabrication of the samples are shown and mentioned in the photographic series.

For the correct measurement in weight (grams) of the aggregates and the feather keratin paste, an electronic balance was used. However, to measure the right amount of black syrup, as the capillary keratin fluid is called, a 500 ml measuring cylinder was used.

After measuring the proportions of both binder and aggregates, each dosage is placed in a plastic container to proceed to manual mixing, with which the mixtures integrate all the components according to each dosage, which is distinguished by a particular shade. Finally, Fig. 6 shows how the pastes in the mould must be dried in the electric oven for 48 consecutive hours to completely dehydrate each piece and use the anhydrous weight for the subsequent calculation of the moisture absorption.

Fig. 6. Dosage A: a) Mixed mixture b) Completed test specimens.

C. Test elaboration

i. Surface hardness

As each dosage is an initially mouldable mixture that undergoes a dehydration process to solidify it, it is important to consider the hardness property that the mixture can finally reach. For this reason, the UNE-EN 13279-2 standard has been used as the Shore C test to determine the surface hardness of each finished element, where ten readings are taken on each smooth side and opposite to where the measurement was taken with the hardness tester; measurements with which an average is calculated for each mixture, whether it is A, B, C or D.

ii. Humidity absorption

To determine the moisture absorption percentage of each mixture, (CH) it is necessary to refer this procedure to the NTE INEN 0896 standard, where it is necessary to verify the weight of each piece on the electronic scale, known as the

initial mass (mi), to then place each sample inside an electric stove at 50°C for 48 consecutive hours to evaporate all the humidity that they have absorbed from the environment.

Then, they must be weighed again on the balance and with this determine the final mass (mf). These figures obtained are calculated by means of the following formula:

$$CH = mi - mf / mf \times 100 \quad (1)$$

As global data, environmental conditions such as temperature (18.5°C) and relative humidity (43%) are exposed. The results in percentages of humidity absorbed by each test tube according to the applications of the formula will be shown in the results graphs.

iii. Compressive strength

Comrpessive strength tests consist of determining the resistance offered by a specimen when subjected to load until it collapses, for which the Ibertest machine has been used as stipulated in the UNE-EN 13279-2 standard.

iv. Flexural strength

In accordance with the specifications stipulated in the UNE-EN 13279-2 standard, each of the samples which are placed in the machine designed for this test called Ibertest, which consists of placing the piece on two lateral supports to be subjected to the flexion for when a cylindrical element is lowered at will that applies force to flex the 16x4x4 cm^3 dry bar in each of the proposed combinations.

III. Results

A. *Surface hardness*

Fig. 7 shows the results obtained in the different combinations throughout the test to determine the surface hardness with the help of the Shore - C Durometer. Here is the maximum hardness reached by combination A, which includes two components: 2500 g of marble and 750 g of glue based on feathers only; However, the contrast to such a hardness of 58.78 shore-c is the mixture C, with a hardness of 54.1 shore-c which consists of 3 components: 2 organic (feather-based glue with 500g and capillary-based glue 2500 ml) and a mineral (marmolina 2500g). Differentiating with it up to 5 points between the minimum and the maximum.

B. *Humidity absorption*

Regarding the percentage of absorption of ambient humidity, Fig. 8 documents the advantage shown by dosage C, with 0.31% of humidity absorbed during the analysis, with a noticeable difference close to twice the absorption capacity of sample D with 0.59%, whose composition consists of 4 ingredients: 2 minerals, brick dust (400g) and marble (1300g) together with 2 organic binders: feather glue (500g) and hair fiber glue (200g).

C. *Compressive strength*

Referring to the compression test, figure 9 shows the maximum resistance achieved by the two-component dose A with 8.02MPa, while the minimum, with 4.69 MPa less, is the 4-component mix D with 3.82MPa followed by sample C with 3.82MPa. Here it can be noted that, between C and D, the lowest values of compressive strength have the incorporation of 200ml of hair fiber-based glue as a common factor.

D. *Flexural strength*

The maximum resistance to flexion shows in figure 10 a clear difference of 4.44 MPa between the highest resistance of combination A with 5.26 MPa, of two components, compared to mixture D with 0.82 MPa (mixture of four ingredients). However, it can be affirmed that the specimens whose composition uses only feather binder are on average 4 MPa more resistant to bending than those that mix the capillary-based binder.

E. *Overall summary of results*

Table 2 summarizes the results obtained in all the tests carried out and, as mentioned, only the maximum average values of each one has been considered and the most notorious fluctuations have been discarded in order to preserve the maximum value without differences that reduce the resistance of each knead.

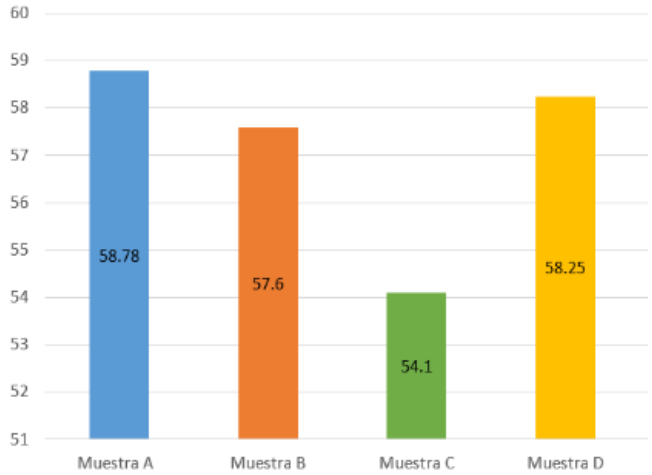

Fig. 7. Average results of Surface Hardness (Shore-C) in batches A B C D.

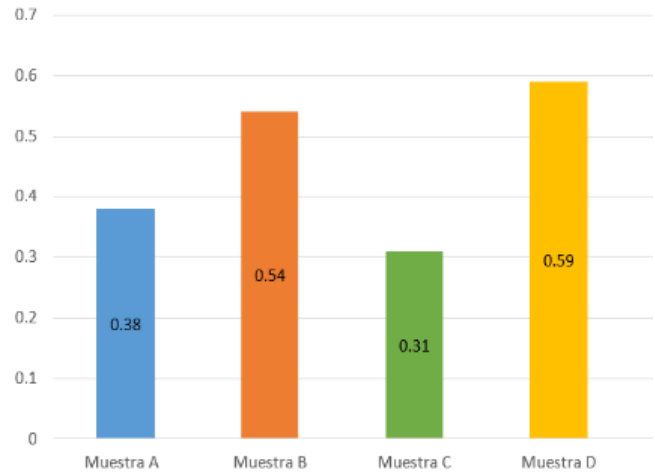

Fig. 8. Average results of Humidity absorption (%) in batches A B C D.

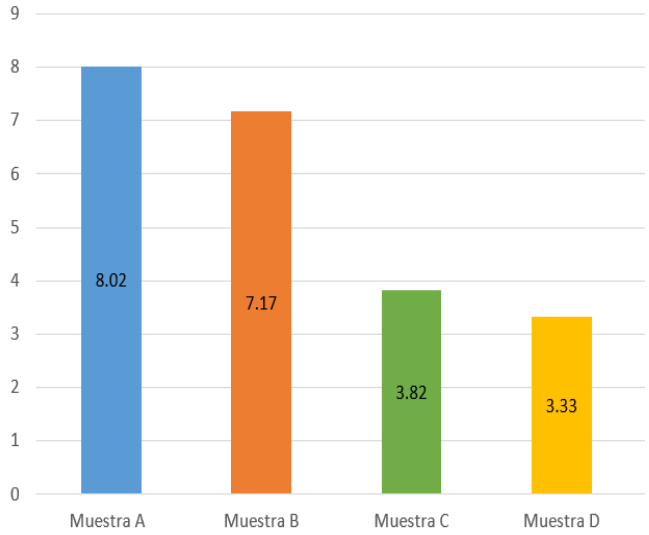

Fig. 9. Average results of compressive strength (Shore-C) in batches A B C D.

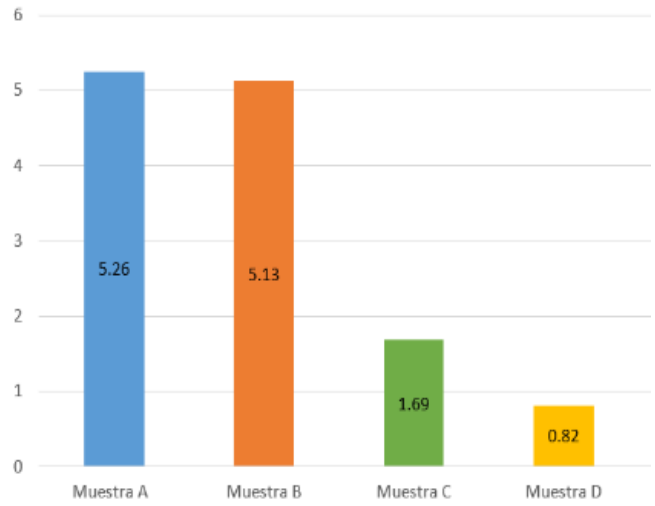

Fig. 10. Average results of compressive strength (%) in batches A B C D.

Regarding the result of all the tests carried out, the following correlation between them is manifested:

• The greater the surface hardness, as demonstrated by mixes A and B, the moisture absorption coefficient is lower, so this high hardness is also positively related to resisting bending and compression efforts with greater advantage.

• On the other hand, it was evidenced that, the lower the surface hardness according to mixes C and D, the moisture absorption coefficient is higher, therefore, the resistance to bending and compression stresses is lower.

TABLE II
DOSAGES USED

Ensayo	A	B	C	D
Surface hardness (Shore-c)	59.76	57.60	56.00	59.00
Humidity absorption (%)	0.38	0.55	0.32	0.60
Compressive (MPa)	8.02	7.17	3.82	3.33
Flexural(MPa)	5.50	5.13	1.99	0.92

IV. CONCLUSIONS

As a result of the research work carried out, the following conclusions can be obtained:

• The bibliographic analysis has been important to support both scientific background, highlighting the biological, chemical, or biochemical processes involved in the formation of the various elements used, thus counteracting the possible adverse reactions or behaviors that may arise before, during and then carry out the combinations. Being the technical support to know the advantages and disadvantages of the product and guarantee the correct dosage, stability, and durability.

• As the tests carried out have shown, the surface hardness reached on average between all the dosages (A, B, C, and D) is 58.07 shore-c, a quality superior to that of plaster with 55 shore-c., which allows all the mixtures to be applied as interior coating mortar, where layers no greater than 1 cm thick dehydrate gradually without significant shrinkage and with mono or polychromatic aesthetic finishes derived from the different binders and mineral aggregates used.

• It is important to consider the humidity absorption value of all the mixtures in the tests carried out is less than 1%, a quality of the incorporation of mineral particles in the mixtures. However, placing them in spaces where humidity exceeds 80% or areas where they may have direct contact with liquid water or steam should be avoided, since in preliminary analyzes it was shown that when saturated with aqueous liquid, stability and resistance disappear as it behaves like an element of raw clay, which returns to its plastic and malleable state after hydration; however, this can be an advantage that facilitates its recycling and reuse without having to go through chemical or mechanical processes that make the recovery of the material more expensive, favoring the circular economy and reducing the pressure of pollution in the environment.

• Regarding the simple compression tests, the final product has a maximum average of 8.02MPa of resistance identified mainly in mix A, followed by mixture B with 7.17 MPa; similar to perforated ceramic bricks which are around 4.5 MPa. The dosages also stand out: C with a maximum resistance of 3.82 MPa and D with 3.33 MPa whose higher values are reached by the compressed earth blocks, which do not exceed 3.5 MPa. Therefore, these data constitute the guarantee of support to elaborate load blocks with dosages A and B as well as C and D.

• Due to all of the above, it is guaranteed that the mixtures can be used to make pieces for load-bearing and non-load-bearing masonry as well as coating.

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