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## Determinación de la absorción de agua de una pieza termoplástica modular impresa Determination of water absorption of a printed modular thermoplastic part.

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**Resumen--** En este trabajo se analizan y comparan los resultados obtenidos en los ensayos de laboratorio, referidos a la determinación de la absorción de agua, de una pieza termoplástica modular impresa y dos piezas de arcilla cocida con los valores estipulados en la normativa vigente y los documentos de declaración de prestaciones correspondientes. Para ello, se fabrica el prototipo impreso en 3D según unos parámetros definidos y se le somete al ensayo descrito en la norma UNE-EN 772-21:2011. Parte 21: Determinación de la absorción de agua de piezas para fábrica de albañilería de arcilla cocida y silicocalcáreas por absorción de agua fría. Igualmente, se realiza la misma operación con un ladrillo cara vista y un ladrillo tosco, ambos con dimensiones similares al anterior. Obtenidos los resultados de los ensayos se observa que la absorción de agua, en las piezas termoplásticas, depende de la adhesión entre las capas de impresión y no tanto del material con el que están fabricadas, como ocurre con las piezas de arcilla cocida.

**Palabras clave—** Pieza termoplástica; Impresión 3D; Construcción sostenible; Absorción de agua; Ensayo de materiales.

**Abstract—** In this work, the results obtained in the laboratory tests, referring to the determination of water absorption, of a printed modular thermoplastic piece and two pieces of fired clay are analyzed and compared with the values stipulated in the current regulations and the documentation of declaration of corresponding benefits. To do this, the 3D printed prototype is manufactured according to defined parameters and is subjected to the test described in the UNE-EN 772-21:2011 standard. Part 21: Determination of water absorption of baked clay and silico-limestone masonry parts by cold water absorption. Likewise, the same operation is carried out with an exposed brick and a rough brick, both with similar dimensions to the previous one. Obtained the results of the tests, it is observed that the absorption of water, in thermoplastic parts, depends on the adhesion between the printing layers and not so much on the material with which they are made, as it occurs with pieces of fired clay.

**Index Terms—** Thermoplastic part; 3D printing; Sustainable construction; Water absorption; Material testing.

### I. INTRODUCTION

**A**DDITIVE manufacturing, or 3D printing, is a process by which elements are created by digitally layering them. It is necessary to create a suitable design and choose a material according to the manufacturing process.

The origin of 3D printing came with the birth of inkjet printing in 1976, developing it in 1984 to use any material and print any object, until it became what it is known today.

Today, this technology has been used to create all kinds of elements according to the needs of the market. In the field of surgical medicine it allows the replication of parts of the human body, such as a limb, or any other limb to be replaced, which is considered a breakthrough in this field. In addition to the progress made in the manufacture of prostheses, mention should also be made of the creation of specialised surgical material, personalised medicines, bioprinting of skin or tissues, among others.

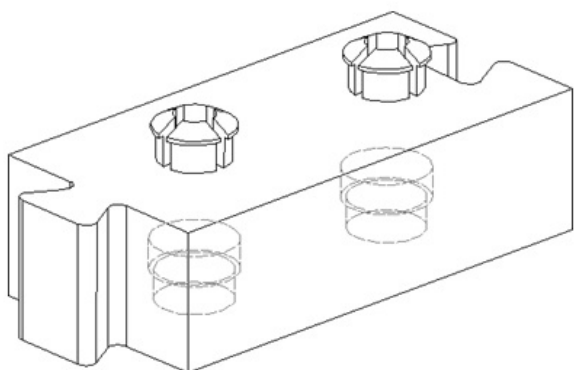


Fig. 1 Printed Thermoplastic Modular Piece

But undoubtedly, one of the greatest advances of 3D printing in the field of medicine is the way to treat cancer, using additive manufacturing to create organs with cancer cells directly from patients and putting them in contact with healthy organs to determine the speed of transmission between them and investigate which treatments are the most effective to prevent the spread of cancer within the human body.

Currently, 3D printing has advanced so much that almost any object can be printed in any material, from jewellery with human ashes to buildings, cars, weapons, etc., so we can say that new technologies are being implemented in most sectors, improving the initial characteristics of their products.

In the construction sector, several printed structure projects have been developed with relative complexity. Additive manufacturing in this field is considered to have multiple advantages over traditional construction in terms of reduced labour, lead times and waste generation.

In a recent study, it has been studied how to further promote 3D printing within the world of building, with a single modular element, made by additive manufacturing and with mainly recycled or recyclable materials from plastics. The real possibilities of this element have been studied and analysed by manufacturing it and then carrying out the relevant laboratory tests for the final evaluation of the product by determining the conclusions of the study.

As a result of this research, the "Printed Thermoplastic Modular Piece" (hereinafter P.T.M.P.) has been created as an element to be considered when building any type of building.

To promote the above-mentioned pieces, it is necessary to know their physical and mechanical characteristics and to



Fig. 3. Immersion of the parts in the water tank

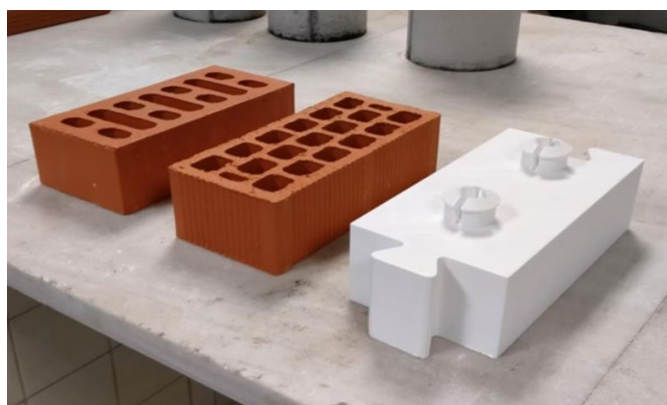


Fig. 2. Bricks to test.

compare them with the pieces currently used in the construction of buildings, i.e. traditional bricks.

This study is considered to quantify the percentage of water absorption of a thermoplastic part and how these results can be improved. This study is about carrying out water absorption tests corresponding to a piece manufactured using the 3D printing technique, an exposed brick, and a rough brick. In these tests, the size of the pieces, the material with which they have been manufactured and, above all, the printing parameters in the P.T.M.P. pieces have been considered.

The aim of this research is to find out the percentage of water that a thermoplastic piece is capable of absorbing in comparison with traditional bricks, although these will not subtract water from the mortar itself, if they can be in contact with aqueous media. Depending on the results obtained, the printing parameters will be modified, optimising the characteristics of the thermoplastic pieces. The aim of this study is to demonstrate the importance of the printing process of a part, the parameters chosen, and the materials used.

## II. EXPERIMENTAL CAMPAIGN

This test aims to determine the water absorption after 24 hours immersion of the samples, determining the increase in weight of the samples. For the study, the standard UNE-EN 772-21:2011 Test methods for masonry masonry units has been considered. Part 21: Determination of water absorption of fired clay and sand-lime masonry units by absorption of cold water.



Fig. 4. Ballast placement in P.T.M.P. parts.

TABLE I  
WATER ABSORPTION TEST RESULTS FOR EACH SAMPLE  
P.T.M.P

MUESTRA						
NOMBRE	REF.	LARGO	ANCHO	ALTO	VOLUMEN	PESO
	P.T.M.P.	239,50	120,10	70,10	2016,35	967,90

## TOMA DE DATOS:

$$M_d = 967,90 \text{ g.}$$

$$M_s = 1215,70 \text{ g.}$$

## RESULTADOS: Absorción de agua.

$$W_s = ((M_s - M_d) / M_d) \times 100\%$$

$$W_s = ((1215,70 - 967,90) / 967,90) \times 100\%$$

$$W_s = 25,60 \%$$

## EXPOSED BRICK

MUESTRA						
NOMBRE	REF.	LARGO	ANCHO	ALTO	VOLUMEN	PESO
	L.V.	237,00	114,10	67,00	1811,79	2114,40

## TOMA DE DATOS:

$$M_d = 2113,90 \text{ g.}$$

$$M_s = 2192,70 \text{ g.}$$

## RESULTADOS: Absorción de agua.

$$W_s = ((M_s - M_d) / M_d) \times 100\%$$

$$W_s = ((2192,70 - 2113,90) / 2113,90) \times 100\%$$

$$W_s = 3,73 \%$$

## ROUGH BRICK

MUESTRA						
NOMBRE	REF.	LARGO	ANCHO	ALTO	VOLUMEN	PESO
	L. Tosco	243,00	110,50	70,10	1882,29	1618,30

## TOMA DE DATOS:

$$M_d = 1615,20 \text{ g.}$$

$$M_s = 1723,10 \text{ g.}$$

## RESULTADOS: Absorción de agua.

$$W_s = ((M_s - M_d) / M_d) \times 100\%$$

$$W_s = ((1723,10 - 1615,20) / 1615,20) \times 100\%$$

$$W_s = 6,68 \%$$

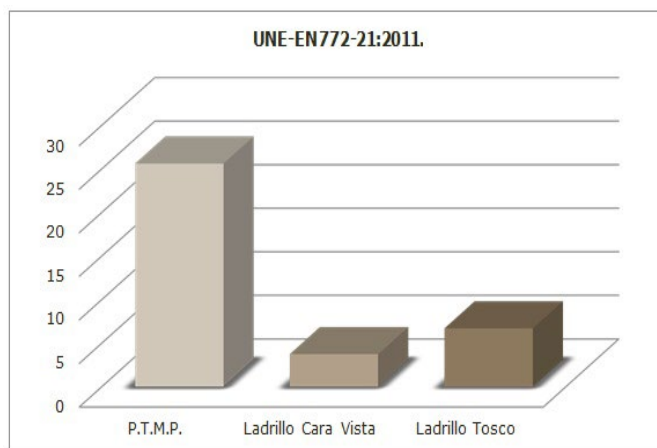


Fig. 5. Water absorption test results comparison

### A. Water absorption test (Piece P.T.M.P.)

To start the test, the specimen is dried to constant mass  $M_d$ . In the case of P.T.M.P. specimens, this process is not carried out because their composition does not contain water.  $M_d$  is taken as the dry weight, as well as all the measurements of the piece.  $M_d = 967,90 \text{ g.}$

The piece is then placed, together with the rest of the samples, in the water tank and left submerged for 24 hours.

When the P.T.M.P. piece is submerged, it is discovered that it floats, due to the amount of air inside it. It is necessary to place a ballast on top of it to keep it submerged. It is observed that air bubbles appear on the surface, a sign that water is being introduced into it.

After 24 hours, the pieces are removed from the tank, the excess surface water is removed and the specimen is weighed again,

$$M_s = 1215,70 \text{ g.}$$

### B. Water absorption test – Exposed brick

For this test, the facing brick sample is dried in a ventilated oven to constant mass  $M_d$ , at a temperature of  $105^\circ\text{C}$ , for 24h, until the loss of mass is less than 0.2% and allowed to cool to laboratory temperature.

The sample should weigh between 2110.17 g - 2114.40 g after drying. In addition, the dimensions of the piece are noted.

After the time has elapsed, the dried specimen is weighed, and the weight loss is checked to ensure that it is less than 0,2 %.

$$M_d = 2113,90 \text{ g.}$$

The pieces are placed in the water tank and left immersed for 24 hours. The samples are then removed from the tank and the excess surface water is removed. The specimen is weighed again,  $M_s = 2192,70 \text{ g.}$

### C. Water absorption test – Rough Brick.

As in the previous test, the specimen is dried in a ventilated oven to constant mass  $M_d$ , at a temperature of  $105^\circ\text{C}$ , for 24 hours, until the loss in mass is less than 0.2% and allowed to cool to laboratory temperature. That is, the sample after drying should weigh between 1615,06 g - 1618,30 g. In addition, the dimensions of the piece are noted.

After 24 hours, the dried specimen is weighed and checked to ensure that the weight loss is less than 0,2 %.

$$M_d = 1615,20 \text{ g.}$$

The pieces are placed in the water tank and left submerged for 24 hours. After this time, the pieces are removed from the tank and the excess surface water is removed. The test tube is weighed again,  $M_s = 1723,10 \text{ g.}$

The results derived from the test UNE-EN 772-21:2011. Test methods for masonry masonry masonry units. Part 21: Determination of water absorption of fired clay and sand-lime masonry masonry units by cold water absorption are as follows:

$$\text{Piece P.T.M.P. } W_s = 25,60\%.$$

$$\text{Exposed brick } W_s = 3,73\%.$$

$$\text{Rough brick } W_s = 6,68\%.$$

### III. RESULTS AND DISCUSSION

#### A. Elaboration of tables and graphs of the water absorption determination test. UNE-EN 772-21:2011.

Table IV shows the difference in masses in the P.T.M.P. parts before and after immersion in water for 24 h., producing a water absorption coefficient of 25.60%. This is since water was introduced into the internal cavities of the immersed piece, causing this increase. According to AENOR, the coefficient of water absorption by immersion must be less than 11%, so the sample does not comply with this requirement, if the test is carried out rigorously.

In the case of the facing brick sample, the coefficient of water absorption by immersion is 3.73 %. According to the provisions of its Declaration of Performance Document No. 0190101/DP, this must be less than 11%, so it complies with this requirement.

In the rough brick, the coefficient of water absorption by immersion is 6.68%, which is lower than the 11% established by AENOR, so it complies with the minimum requirements.

#### B. Analysis and comparison of water absorption test results. UNE-EN 772-21:2011.

Table VII shows the relationship between the mass difference before and after immersion and the water absorption coefficient for each of the test specimens under study.

It is observed that the P.T.M.P. piece is the one that presents the biggest difference between the weights before and after the immersion, produced by the inclusion of water in the internal cells of the same one, as it has been commented previously, and discarding that this difference is due to the absorption of the material by the own characteristics of the thermoplastics.

This difference is represented by 100% of the increase in mass compared to the rest of the specimens, with 7.69% of the increase in the fair-faced brick piece and 43.54% of the difference in mass in the rough brick.

As can be seen, the piece with the highest coefficient of water absorption by immersion is the P.T.M.P. sample, which is erroneous considering the development of the test.

Therefore, it is considered that the rough brick piece is the one that represents the highest value with a water absorption coefficient by immersion of 6.68%.

#### C. Discussion of data obtained from the water absorption determination test. UNE-EN 772-21:2011.

The results obtained from the test, according to UNE-EN 772-21:2011, for each of the samples and the comparison of the data with the minimum requirements established by AENOR and by the Declaration of Performance Document N° 0190101/DP and the Declaration of Performance Document N° KS/LD232.107.10\_8\_7/A/MR/DP, respectively, are shown below.

As can be seen in graph II, the minimum requirement set by the specifications mentioned above is 11% as the maximum value for the coefficient of water absorption by immersion in the three cases, as the Declaration of Performance Document No. KS/LD232.107.10\_8\_7/A/MR/DP, relating to the rough brick sample, does not specify this value.

If it is considered that the test carried out on the thermoplastic part is not valid, for the reasons explained above, the three samples comply with the minimum requirements, the maximum value of which is for the rough brick, representing 60.72% of the maximum value admitted by AENOR.

In short, despite carrying out the tests to determine the water absorption coefficient according to the steps shown in the UNE-EN 772-21:2011 standard, in a rigorous manner, the values obtained for the P.T.M.P. piece are discarded as it is considered that the difference in masses existing in the specimen, before and after immersion, does not correspond to what is established as water absorption, but to an occupation of the liquid inside the specimen. Therefore, it is concluded that the rough brick is the one that shows the highest value with respect to the calculation of this coefficient, being 39.27% below the maximum value required by AENOR.

TABLE II  
WATER ABSORPTION TEST RESULTS FOR EACH SAMPLE ACCORDING TO UNE-EN-772-21:2011  
P.T.M.P.

UNE-EN 772-21:2011.			
	M <sub>d</sub> <sup>237</sup>	M <sub>s</sub> <sup>238</sup>	W <sub>s</sub> <sup>239</sup>
P.T.M.P.	967,90 g	1215,70 g	25,60 %
AENOR	11,00 %		

EXPOSED BRICK UNE-EN 772-21:2011.			
	M <sub>d</sub>	M <sub>s</sub>	W <sub>s</sub>
L. Cara vista	2113,90 g	2192,70 g	3,73 %
D.D.P.	11,00 %		

ROUGH BRICK UNE-EN 772-21:2011.			
	M <sub>d</sub>	M <sub>s</sub>	W <sub>s</sub>
L. Tosco	1615,20 g	1723,10 g	6,68 %
AENOR	11,00 %		

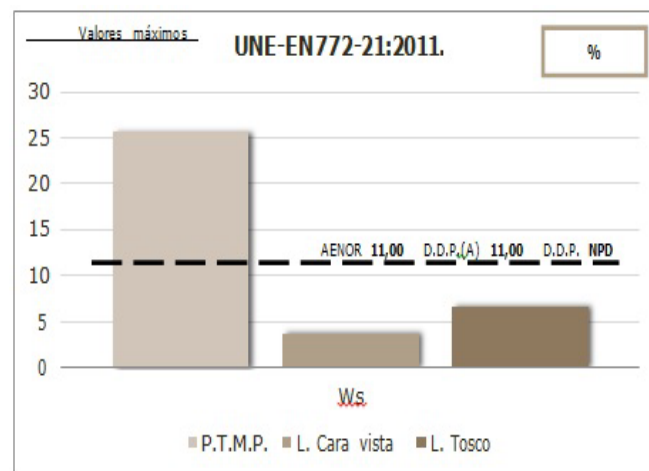


Fig. 5. Water absorption test results comparison

#### IV. CONCLUSIONS

Once the research work has been developed, there is sufficient information on the main characteristics of the printed parts and how they can be improved from the manufacturing process, as well as the behaviour obtained in the laboratory tests.

From the above, it can be concluded that, in the development of this study, the initial objectives have been achieved.

Once the design has been chosen and the specimens have been manufactured, they must be tested to study their behaviour regarding the physical and mechanical characteristics that they must meet to comply with the minimum specifications required for their intended use.

Depending on the results obtained, it is possible to go back, cyclically, to the beginning of a future investigation and modify the initial premises of design and manufacture, intuiting the result.

As for the experimental phase, it is necessary for the three samples to have the same dimensions so that the data obtained can be comparable with each other, as they are not considered to be proportional.

The thermoplastic parts are somewhat lighter than traditional bricks, due to the percentage of internal voids characteristic of 3D printed parts.

In the water absorption test, it is observed that when the piece is submerged, bubbles appear, a symptom of air escaping from the interior of the pieces and, therefore, water entering the internal cells. This causes a significant increase in the mass of the part, so it is necessary to increase the adhesion between layers.

This aspect can be improved by using carbon nanotubes, increasing the printing temperature, reducing the extruder speed or increasing the material flow rate, among others.

Surface post-processing, such as polishing by a solvent vapour atmosphere or direct immersion in the solvent fluid, can also be applied to prevent water from entering the interior of the parts.

This significant increase in absorption is not due to the type of material used, as PETG is considered a non-porous material and therefore does not absorb liquids.

It has been shown that the material used for the manufacture of the printed parts is not water-soluble and therefore cannot be used as a printing support using this methodology.

In short, an innovative prototype can be achieved by implementing new 3D printing technologies in construction, with recycled materials capable of competing with traditionally manufactured parts. A careful analytical phase on the local context has been the premise to guide the design choices to obtain the preservation of the symbolic and historical-architectural value.

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