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Compuestos de yeso con adición de fibras textiles de algodón recicladas.
Gypsum compounds with the addition of post-consumer textile fibres of cotton.

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Resumen-- **La sostenibilidad en el sector de la construcción es clave en la reducción del consumo de recursos como materiales y energía, es fundamental adoptar acciones más eficientes en procesos de construcción como la reutilización de residuos. Por ello el presente trabajo analiza la incorporación de residuos textiles posconsumo de algodón en las propiedades físico-mecánicas de compuestos de yeso. Se realizó un trabajo experimental en donde se ensayaron probetas de yeso de 4x4x16 cm adicionadas con fibras posconsumo de algodón en diferentes formatos, y longitudes (20 y 35mm), adiciones de 0,5% y fibras de 35mm de longitud incrementaron la resistencia a flexión y compresión en un 5,9% y 11% respectivamente, y la absorción de agua por capilaridad descendió un 26% con el 1% de adición. Finalmente se observó que las fibras reducen el desprendimiento de fragmentos de yeso al momento de alcanzar la carga de rotura, mejorando la tenacidad de los compuestos.**

Palabras clave— Residuos textiles; recuperación textil; materiales sostenibles; propiedades físico-mecánicas; yeso.

Abstract— **Sustainability in the construction sector is key in reducing the consumption of resources such as materials and energy, it is essential to adopt more efficient actions in construction processes such as the reuse of waste. For this reason, the present work analyses the incorporation of post-consumer cotton textile waste in the physical-mechanical properties of gypsum composites. An experimental work was carried out where gypsum specimens of 4x4x16 cm were tested with post-consumer cotton fibres in different formats and lengths (20 and 35mm), additions of 0.5% and fibres of 35mm in length increased the flexural and compressive strength by 5.9% and 11% respectively, and the capillary water absorption decreased by 26% with 1% of addition. Finally, it was observed that the fibres reduce the detachment of gypsum fragments at breaking load, improving the toughness of the composites.**

Index Terms— Textile waste; textile recovery; sustainable materials; physical-mechanical properties; gypsum.

I. Introduction

THE production of building materials involves environmental impacts in phases such as transport, construction process, building use, maintenance and even demolition, therefore efforts should be dedicated towards the transformation of the material flow towards a circular economy (GBC, Cándido et al., 2022, 2011). Improving efficiency in the construction sector is key to reducing CO_2 emissions, and the consumption of resources such as wood, minerals, and water; according to statistics, the construction sector accounts for about 40% of total final energy consumption in the European Union and 36% of total CO_2 emissions (González Vallejo et al., 2015).

However, achieving sustainability in resource management implies that we should be able to evaluate the efficiency achieved in terms of natural resource savings and decrease in waste generation or reuse (Jefatura del Estado, 1998).

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Sustainable and environmentally friendly materials made from secondary raw materials and sustainable recycling processes could contribute to the reduction of CO_2 emissions, and the reincorporation of waste from other sectors, such as textiles, in the production of building materials and products (Giesekam et al., 2014).

In the European Union (EU), approximately 5.8 million tonnes of textiles are discarded every year, of which only 1.5 million tonnes (25%) are recycled by charities and industrial companies. This does not include textile waste from the textile industry, which represents a huge amount of unused secondary raw material (Briga-Sá et al., 2018). In 2017, 73% of the garments produced ended up in landfills or incinerators and by 2030 the textile industry is expected to grow by up to 81%, representing an unprecedented environmental impact (Macarthur Foundation, 2022; Díaz Lucía, 2019). The demand for textiles has increased due to economic and population development, about 60% of textile fibres are of petrochemical origin (synthetic fibres such as polyester), the remaining 37% are of natural origin, where cotton predominates, a plant associated with water depletion and pesticide contamination in its cultivation; however, cotton is the most cultivated non-food product worldwide (Sandin et al., Textile Exchange, 2018).

The textile industry's footprint extends beyond the use of raw materials; in 2015, its greenhouse gas emissions amounted to 1.2 billion tonnes of CO_2, higher than the emissions from all international flights and shipping in 2015 (IEA., 2016). In addition, wet processing activities (dyeing, finishing, printing) are the main sources of toxic waste, spinning and weaving processes rely on the use of fossil fuels. Therefore, greenhouse gas emissions, water use, chemicals and waste generated are the main challenges for the industry (Steffen et al., 2015).

A. Textile recycling in building

Among the first research on the use of post-consumer textile waste (clothing) in construction materials is "Sound absorption properties of recycled polyester fibrous assembly absorbers" (2003), where the absorption coefficient of non-woven polyester waste was studied, with the aim of finding a new material of lower cost and environmental impact that can replace insulating materials such as glass wool and rock wool (Lee et al., 2003).

The large amount of textile waste and diversity of fibres such as cotton, wool, silk, polyester, nylon, have been studied as reinforcement in matrices, insulation materials and lightening materials, due to their low cost, low density, availability, energy saving and environmental preservation (Rubino, 2019). The main difficulty when using post-consumer textiles is to determine the fibres of which they are composed, Blanch et al. (2019) by using hyperspectral imaging has improved textile classification processes using infrared, similarly Koopera (2020) has developed machinery for the classification of textiles based on their composition and colour. Determining the fibres that make up the recycled garments allows us to know their characteristics and viability as a reinforcement material, as the fibres have a high surface/volume ratio and are highly resistant (De Araújo, 2019).

Cotton fibres are the most widely used natural fibres in clothing; waste obtained from 100% cotton blue-jeans was used in the production of polyester concrete, achieving an increase of up to 40% in its compressive strength (Peña-Pichardo et al., 2019) In fly ash-based geopolymers, it allows the density of the compound to decrease as the content increases, since it facilitates the entry of residual air bubbles through the mixture, increasing its porosity (Alomayri et al., 2018). However, maximum addition percentages of 2.1% must be considered, since as this percentage is increased, its mechanical strength decreases due to bonding problems between the fibre and the matrix (Alomayri et al., 2013). Finally, fly ash prevents the degradation of the cotton fabric at high temperatures, and a horizontal orientation of the fibres is recommended as it provides greater resistance to deformation than when oriented vertically; however, variables such as length, thickness, fibre type, pre-treatment can modify its performance (Alomayri et al., 2014; Silva et al., 2020).

The application of cotton in layers to produce hydraulic lime panels allowed a better porosity when saturated fibres were used; however, the increase in water decreases the mechanical resistance (Barbero-Barrera et al., 2016). Regarding the additions in composites will vary depending on the matrix, for example, in the case of cement bricks, up to 5% addition is considered optimal (Rajput et al., 2020). In green epoxy, additions of up to 20% fibres have been used Hassan et al., 2020). When fibres were analysed with respect to the physico-mechanical properties of geopolymers, it was found that cotton and sisal fibres showed improvements in compressive (14%) and flexural (6%) strength (Silva et al., 2020).

Post-consumer cotton textile fibres have been used in the manufacture of composites based on cement, fly ash and epoxy resins; however, studies on gypsum are very limited, so it was

Fig. 1. Materials before kneading (a), consistency of the paste obtained (b), unmoulded specimens (c). Source: [27, Fig.3.11, 3.12, 3.14]..

decided to study the influence of post-consumer textile waste on the properties of gypsum for possible applications as reinforcement. Among the researches that have analysed the influence of cotton fibres we can mention Kalkan (2017), who investigated new generation plasters, composed of ordinary white Portland cement 29% (WOPC), hydrated lime powder 5.5% (HPL), pumice 45% (NPA), expanded perlite 8.5% (EPA), calcite powder 6-11% (PCF) and four types of fibres (length 2-5 cm) obtained from textile recycling factories; a water ratio of 0.73 to 1.02 was used depending on the waste and percentage of fibre used. Illustration 11 shows the textile waste, the consistency of the paste obtained and the specimens for bending and compression tests (Barbero-Barrera, 2016).

G. Vasconcelos et al, (2015) analysed samples of gypsum, granulated cork and recycled textile fibres from tyres (polyamide), cork was determinant in the compressive strength as percentages of 5% and 7% decreased the compressive strength, the fibres played a fundamental role in increasing the fracture energy. Tasán et al, (2011) studied gypsum mortars and plasters reinforced with fibres from single-use textile slings (6 mm long), composed of polyester. They analysed samples with 5%, 7.5% and 10% addition, gypsum specimens with 10% additions achieved better mechanical strength, and plaster specimens with 7.5% addition, higher additions decreased the strength of the specimens.

In the studies analysed, textile fibres have been used in the reinforcement of gypsum composites with a water ratio varying from 0.73 to 1.02; additions of less than 2% fibres show better results because as this percentage increases, there are problems in kneading and loss of flexural and compressive strength. Better compression performance was determined with the addition of textile fibres in low percentages, improvement in the fracture and cracking of the samples tested, it should be borne in mind that in all cases the fibres were used in yarn format. The table details the best percentage results obtained from the studies of gypsum matrices (Kalkan, 2017; Tasán, 2011; Vasconcelos et al., 2019) with the incorporation of textile fibres, in each of the properties analysed.

Based on what has been reviewed, we can highlight that in gypsum compounds maximum additions of 10% have been used, however, the best flexural and compressive strengths were obtained with additions of 0.5% to 1.5%; with regard to the length of fibres used in gypsum, these range from 0.6 cm to 5 cm, since as the length of the fibre increases, problems arise in the mixing and homogeneity of the paste, as they tend to become entangled. The A/Y ratio fluctuates between 0.65-1.02; however, an A/Y ratio of 0.80 does not meet the minimum requirements specified in the Spanish standard UNE-EN 13279-1 (AENOR, 2014), which establishes a minimum flexural strength of 1 N/mm2 and compressive strength of 2 N/mm2, so a ratio of 0.65-0.75 will be suitable for the preparation of specimens in this study.

TABLE I
OUTSTANDING PHYSICO-MECHANICAL RESULTS ON GYPSUM COMPOSITES AND TEXTILE FIBRES.

Solicitud	Waste	Water / gypsum ratio	% Addition	Results discussion (%)			
				Density %	Hardness %	Compressive strength %	Flexural Strength %
Gypsum composite (Kalkan, 2017)	Cotton	0.73	0.75	n/a	n/a	+18	-10
		0.82	1.5			+3	-15
		0.93	2			-28	-17
		1.02	3			-30	-32
	Cotton + polyester	0.70	0.75	n/a	n/a	+61	+19
		0.74	1.5			+53	+13
		0.78	2			+27	+9
		0.86	3			+6	-17
	Cotton + polyester + acrylic	0.74	0.75	n/a	n/a	+53	+18
		0.84	1.5			+18	-8
		0.91	2			-13	-16
		0.96	3			-16	-18
Gypsum FGD (Vasconcelos et al., 2015)	Tyre textile fibres (polyamide)	0.80	1	-4.3	n/a	+5.6	n/a
		0.80	2	-3.4		-8.2	
		0.80	3	-6.7		+10.5	
Gypsum mortar (Tasán, 2011)	Polyester (slack)	0.73	5	-1.2	-0.3	-14.4	-3.8
		0.73	7.5	-1.2	-1.1	-18.5	-1.1
		0.73	10	-1.2	-2.0	-19.8	+10
Plaster mortar (Tasán, 2011)	Polyester (slack)	0.76	5	-0.4	+3.4	+4.1	+5.2
		0.76	7.5	-0.3	+2.0	-1.8	+14
		0.76	10	-1.2	+2.5	-10.8	+1.8

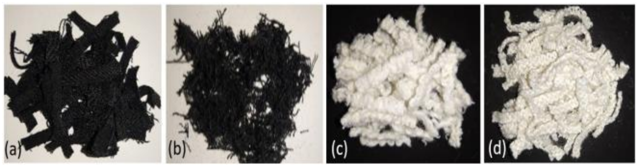

Fig. 2. Post-consumer recycled cotton fibres: N-type fibre (a), NH-type fibre (b), C-type fibre (c), B-type fibre (d).

II. Experimental procedure

A. Materials

LONGIPS gypsum, type B1 gypsum, LONGIPS from the company Saint-Gobain Placo Ibérica, was used for the preparation of the test specimens, which complies with the specifications of the UNE-EN 13279-1 standards. Cotton fibres obtained from 100% post-consumer recycled textiles were used, the N and NH fibre formats were obtained from a pair of trousers (98% cotton + 2% elastane) with a twill type fabric, for which buttons and zips were removed, the garments were cut into 20x20mm and 35x35mm squares, and then the fibres were manually separated to obtain the yarns; fibre format C was obtained from a jersey (100% cotton) with weft knitted fabric, to obtain fibre type B a jersey (100% cotton) with warp knitted fabric was used, the last two fibre formats (C and B) the fabric was cut with a length of 20mm and 35mm and 0.5mm thick, Illustration 2 shows the four types of fibre formats.

B. Samples elaboration

A triple mould of 4x4x16mm was used to make the 45 test pieces, which make up 15 series, one reference series and 14 were added with four formats of cotton textile waste N (twill weave cuttings), NH (twill weave yarns), B (warp knitted fabric cuttings) and C (weft knitted fabric cuttings), with an A/Y ratio of 0.65; and additions of 0.5% and 1.0%. For the elaboration of the specimens, the fibres were saturated in water and then the gypsum was added and the mixture was kneaded, the mixture was poured into the moulds, and demoulded once they reached

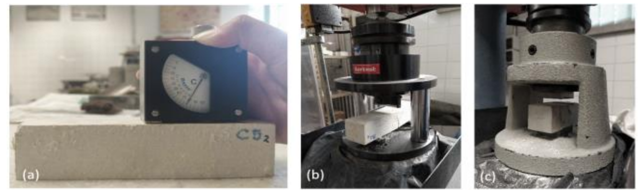

Fig. 2. Post-consumer recycled cotton fibres: N-type fibre (a), NH-type fibre (b), C-type fibre (c), B-type fibre (d).

the adequate resistance, the specimens obtained were dried for 7 days at room temperature, prior to the tests the specimens were placed in an oven for 24 hours at a temperature of 40 ± 2º, they were removed and left to cool until reaching the laboratory temperature, for their test.

Density, flexural strength, compression, and shore C hardness tests were carried out in accordance with standard UNE-EN 13279-2:2014-2 (AENOR, 2014), and for capillary absorption tests, the recommendations of the RILEM (1980).

III. Results

Fig. 4. shows the specimens after the bending test, the NH yarn format in the specimens obtained a better distribution in the mixture, the addition of fibres improved the toughness of the specimens and after the bending test, scissors were needed to separate the two parts of the specimen.

Table I shows the average results obtained for each series. It should be remembered that, in the density, shore C hardness, flexural strength and capillary water absorption tests, the results

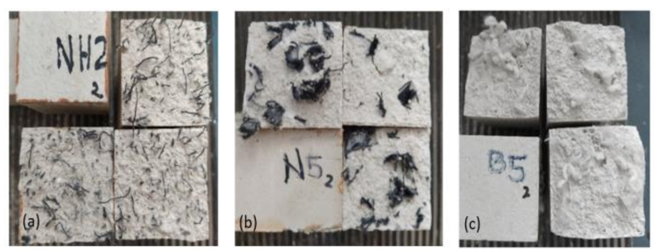

Fig. 4. Specimens with NH2 format yarn (a), specimens with N5 fibre cuttings (b), specimens with B5 fabric cuttings (C).

TABLE II
Results obtained

Name	% Fibre addition	Fibre Length (mm)	Density (g/cm^3)	Shore C Hardness	Flexural strength (MPa)	Compressive strengt (MPa)	Capillarity absorption	
							(gr)	(cm)
REF	-	-	1.13	64.73	2.87	4.91	44.6	8.2
N1	0.5	20	1.15	60.30	2.23	3.55	50.10	9.5
N2	1.0	20	1.14	65.47	2.44	3.60	41.70	8.51
N4	0.5	35	1.14	63.00	2.52	3.90	42.00	8.00
N5	1.0	35	1.14	69.17	2.54	4.26	36.20	7.5
NH1	1.0	20	1.07	69.97	2.91	5.00	40.06	9.5
NH2	1.0	35	1.11	70.03	2.68	5.05	37.60	7.1
C1	0.5	20	1.13	65.50	2.64	4.34	41.50	8.51
C2	1.0	20	1.13	67.87	2.62	4.12	39.10	8.4
C4	0.5	35	1.18	70.00	3.04	5.45	36.00	7.6
C5	1.0	35	1.16	74.73	2.97	5.01	34.10	7.2
B1	0.5	20	1.14	69.00	2.92	4.42	40.32	8.3
B2	1.0	20	1.17	73.93	2.87	5.02	33.01	7.0
B4	0.5	35	1.14	67.27	2.81	4.31	41.60	8.6
B5	1.0	35	1.12	70.53	2.70	4.41	38.20	8.0

were obtained by averaging the results of three specimens in each series, while in the compression tests, the results were obtained from 6 specimens in each series.

A. Discussion.

i. Density

The weight used to calculate the density was the weight obtained after oven drying the samples and the volume was determined by the dimensions of the specimen (4x4x16 cm), the results are shown in Graph 1, the reference specimen achieved a density of 1.13 g/cm3, The series with added fibres have similar densities to the reference specimen except for NH1 and NH2 where the density was reduced by 6% and 2% respectively, in both cases the same percentage of addition was used, however, the fibres with a length of 20mm were the ones that obtained the best results. This is due to the mass/volume ratio of the NH fibre, as it is so light and occupies a larger volume in the gypsum matrix, it was possible to achieve lower densities than the other fibre formats studied.

Finally, to obtain lighter samples, it will be necessary to increase the percentage of addition, however, based on the documentary review, with additions higher than 4%, there were problems with kneading and the composites had lower flexural and compressive strengths.

B. Shore C hardness

The results obtained from this test are shown in Graph 2. According to the information specified in the Longips gypsum technical data sheet, its surface hardness is ≥45 Shore C units with an A/Y ratio of 0.8; and the samples carried out had an A/Y ratio of 0.65 due to this its hardness reached 64.73 Shore C units, in general it can be observed that the values are above the reference value, with respect to the additions used, the samples with 1% present superior results to the samples with additions of 0.5%. The format of the residue has not influenced the results, so we can determine that the hardness is proportionally related to the increase in the percentage of fibre used and the increase in its length. This can be seen in specimen C5, which contains 1% addition in fibres of 35mm in length, resulting in an increase in hardness of 14.78%.

C. Capillarity absorption

It is observed that the greater the quantity of textile fibres, the lower the water absorption of the samples, even though cotton is a fibre that absorbs water very easily, its absorption capacity is lower than that of gypsum, which contributes to a decrease in the absorption of water in the composites.

Sample B2 absorbed 11.5 grams of water less than the reference specimen, i.e., it reduced its absorption capacity by 26%; the centimetres that the water rose in specimen B2 were 12 mm below the reference specimen, i.e., 12% less than the reference specimen.

It is worth mentioning that despite the lower amount of water absorbed, the fibres facilitated the vertical rise of the water, as the water was absorbed more quickly and easily by means of the fibres through the test specimen, due to this, some samples with fibres presented a greater height in mm of ascended water with respect to the reference, despite having absorbed a smaller amount of water in grams, as in the case of test specimen NH1.

D. Mechanical strength

We can see a decrease in the flexural strength in a large number of samples, however, some samples showed an increase in their resistance, standing out the C4 and C5 series with an increase in their resistance of 5.9% and 3.48% respectively, we can determine that in these two cases the fibres used have a length of 35mm, while the samples with a length of 20mm as the N1 specimen showed a decrease of 23% in its resistance, so the length of the fibre plays a fundamental role in the resistance of the composites.

In terms of compressive strength, samples C4, C5, NH2, NH1 and B2 show results superior to the reference, something that most of these series have in common, which have 1% fibre addition and a length of 35mm, reaching an increase in

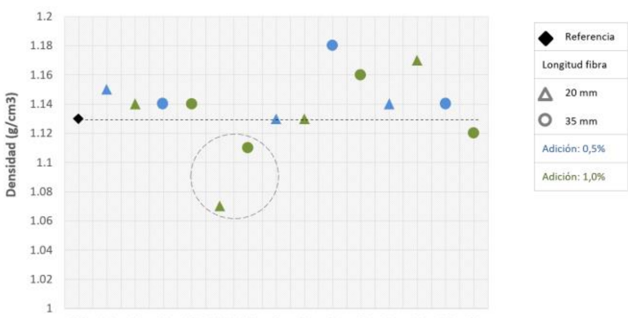

Fig. 5. Density results of the analysed compounds.

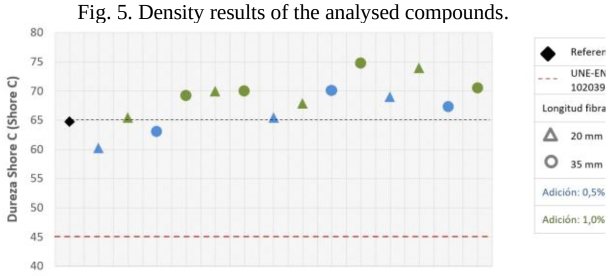

Fig. 6. Surface hardness results of the analysed compounds

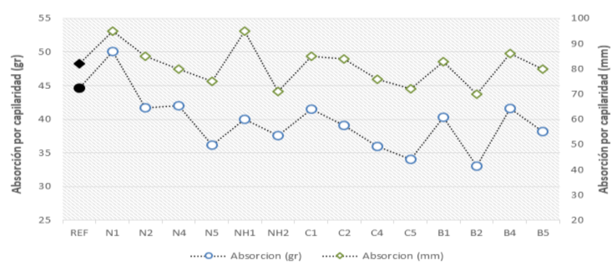

Fig. 7. Capillarity absorption results of the analysed compounds.

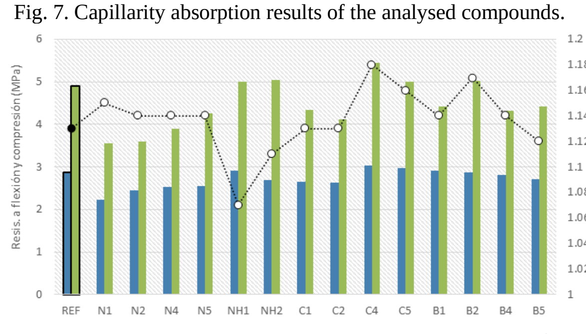

Fig. 8. Mechanical strenght results of the analysed compounds

compressive strength of up to 11% (C4) with respect to the reference. The series with N format, had a decrease in its compressive strength of 28%, unlike the series with NH fibre addition that, despite coming from the same type of garment, due to its format, obtained results with a difference of up to 1.5 MPa, showing the influence of the fibre format in the reinforcement, since the N format corresponds to fabric cuttings and NH are in yarn format.

The results show that the strength of the materials decreases as shorter fibres are incorporated, or in fabric cuttings format, while the fibres in yarn format show better results as they adhere and distribute better in the material.

The density of the samples is related to the compressive and flexural strength in the composites with fibre format type N, C and B, where a loss of strength is established as the density of the composites decreases. However, in the NH format samples, their mechanical strength is not influenced by the decrease in density, with the NH1 series being the least dense and with a mechanical behaviour superior to the reference. In general, this relationship between density and resistance to bending and compression is fulfilled, the higher the percentage of addition (1%) and the length of the fibre (35mm), the higher the hardness (+14.78%), resistance to bending (5.9%) and compression (11%) with respect to the reference specimens.

The increase in the addition of 1% fibres improved the compressive and flexural strengths of the composites and increased their densities, although as we have previously observed, the density is directly related to the format of the residue and its mass/volume ratio. In addition, the yarns with larger diameters increased the densities, while the thinner ones, such as the NH format yarn, decreased the density of the samples.

In the compression tests, it is evident how the addition of fibres prevents the detachment of large gypsum fragments now of reaching the breaking load, keeping the parts of the specimen together, contrary to what happens with the specimen without additions. Therefore, we can affirm that the addition of fibres improves the toughness of the composite obtained.

IV. Conclusions

The present work investigated the reuse of post-consumer cotton textile fibres obtained from garments (trousers and jersey), in different formats (length, type of fabric, yarn/cut of fabric) as a material in the production of gypsum specimens. The gypsum specimens were subjected to physico-mechanical tests of density, shore C hardness, water absorption by capillarity, flexural and compressive strength. The main findings were:

- Based on the documentary review, it was determined that textile waste can be valorised at different levels such as: fabric, cuttings or yarns broadening its possibilities of uses and applications. The length of the fibre was identified as the most influential factor in the physical-mechanical characteristics of the composites. Lengths of less than 6 mm produce a worse mechanical behaviour of the composites, and lengths of more than 50 mm present problems in mixing, as the fibres tend to entangle with each other, hindering a homogeneous distribution of the fibres in the matrix.
- Regarding the percentage of addition, it is not advisable to use additions higher than 7%, as the residue exceeds the volume of the gypsum, making mixing difficult, so additions of between 0.5% and 1.5% are considered adequate. Finally, residues in yarn format and with diameters of less than 0.25 mm allow lighter composites to be obtained, while yarns with diameters of more than 1 mm or with weft and warp separation of more than 1.5 mm improve the surface hardness and resistance to bending and compression of the composites.
- In the experimental phase, it was observed that the incorporation of 1% of post-consumer cotton textile fibres (NH - yarn format) in gypsum matrices reduced the density of the composites by 6% due to the mass/volume ratio of the residue. Therefore, it is recommended to use the waste in yarn format to obtain composites with lower densities.
- Regarding the surface hardness, the length of the fibre was determinant, in the composites with 1% addition of C format fibres (cut point by weft), with a length of 35mm, the hardness increased by 14.78% with respect to the reference specimens; as the length of the fibre was reduced to 20mm, the hardness decreased.
- On the other hand, with additions of 0.5% and longer fibres (35mm), there was an increase in flexural and compressive strength of 5.9% and 11% respectively, with the C fibre format composed of fabric cuttings standing out. The addition of fibres avoids the detachment of large gypsum fragments when reaching the breaking load, improving the toughness of the composites.
- Finally, capillary water absorption decreased as the number of fibres increased, 1% addition decreased up to 26% of the absorption capacity.

Therefore, some of the results obtained from the literature review have been experimentally verified, verifying the influence of textiles on the physico-mechanical behaviour of gypsum composites. The results show a better mechanical behaviour when using fibres in the form of fabric cuttings, and lighter composites with the use of fibres in the form of yarn.

From an environmental point of view, the recycling of fibres and textile offcuts in the production of materials makes it possible to reincorporate these wastes into the production chain, which can improve the physical-mechanical properties of the composites. However, it is necessary to continue with the research and analyse samples with fibre formats of greater length and diameter to determine the exact influence of these variables on the properties of the gypsum-based composites.

References

AENOR,"Yesos de construcción y conglomerantes a base de yeso para la construcción. Parte 1: Definiciones y especificaciones. UNE-EN 13279-1: 2009."Madrid: AENOR: 2009.

AENOR,"Yesos de construcción y conglomerantes a base de yeso para la construcción. Parte 2: Métodos de ensayo. UNE-EN 13279-2:2014." Madrid: AENOR: 2014.

T. Alomayri, F.U.A. Shaikh and I.M. Low, ,"Characterisation of cotton fibre-reinforced geopolymer composites,". Composites Part B: Engineering, vol. 50, pp. 1-6. http://www.sciencedirect.com/science/article/pii/S135983681300019X.

T. Alomayri, F.U.A. Shaikh and I.M. Low, "Thermal and mechanical properties of cotton fabric-reinforced geopolymer composites," J.Mater.Sci., 2013. vol. 48, no. 19, pp. 6746-6752, DOI: 10.1007/s10853-013-7479-2. [Online]. Available: https://doi.org/10.1007/s10853-013-7479-2.

T. Alomayri, F.U.A. Shaikh and I.M. Low, "Effect of fabric orientation on mechanical properties of cotton fabric reinforced geopolymer composites," Mater Des, 2014. vol. 57, pp. 360-365, DOI: https://doi.org/10.1016/j.matdes.2014.01.036. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0261306914000557.

M.d.M. Barbero-Barrera, O. Pombo and Navacerrada, María de los Ángeles, "Textile fibre waste bindered with natural hydraulic lime," Composites Part B: Engineering, 2016. vol. 94, pp. 26-33, DOI: https://doi.org/10.1016/j.compositesb.2016.03.013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1359836816300373.

A. Briga-Sá, D. Nascimento, N. Teixeira, J. Pinto, F. Caldeira, H. Varum and A. Paiva, ,"Textile waste as an alternative thermal insulation building material solution,". Construction and Building Materials, vol. 38, pp. 155-160. http://www.sciencedirect.com/science/article/pii/S0950061812006332.

L. Cândido, W. Kindlein, R. Demori, L. Carli, R. Mauler and R. Oliveira, "The recycling cycle of materials as a design project tool," J.Clean.Prod., 2011. vol. 19, no. 13, pp. 1438-1445, DOI: https://doi.org/10.1016/j.jclepro.2011.04.017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0959652611001521.

B. Carolina, W. Saeys and A. Lambrechts, "Hyperspectral imaging for textile sorting in the visible–near infrared range," Journal of Spectral Imaging, 2019. vol. 8 DOI: 10.1255/jsi.2019.a17.

M. De Araújo,"1 - Natural and man-made fibres: Physical and mechanical properties,". , pp. 3-28. http://www.sciencedirect.com/science/article/pii/B9781845695583500016.

Díaz Lucía, (2019). Copenhagen Fashion Summit. Presented ad Global Fashion Agenda. [Online]. Available: https://www.globalfashionagenda.com/.

J. Giesekam, J. Barrett, P. Taylor and A. Owen, "The greenhouse gas emissions and mitigation options for materials used in UK construction," Energy Build., 2014. vol. 78, pp. 202-214, DOI: https://doi.org/10.1016/j.enbuild.2014.04.035. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378778814003570.

P. González Vallejo, J. Solís Guzmán, R. Llácer Pantión and M. Marrero Méndez, "La construcción de edificios residenciales en España en el período 2007-2010 y su impacto según el indicador Huella Ecológica," Informes de la Construcción, 2015. vol. 67, no. 539, pp. 1-13, DOI: http://dx.doi.org/10.3989/ic.14.017. [Online]. Available: http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion/article/view/4455/5165.

Green Building Council España, Asociación Sostenibilidad y Arquitectura and Centro Complutense de Estudios e Información Ambiental, "Cambio global España 2020-2050. Sector Edificación. La imprescindible reconversión del sector frente al reto de la sostenibilidad,". Cambio Global España 2020/50. Sector Edificación, Abril, https://gbce.es/archivos/ckfinderfiles/Investigacion/CGE_Edificacion_baja.pdf.

T. Hassan and H. Jamshaid, "Acoustic, mechanical and thermal properties of green composites reinforced with Natural Fibers waste," Polymers, 2020. vol. 12, no. 3DOI: https://doi.org/10.3390/polym12030654. [Online]. Available: https://www.mdpi.com/2073-4360/12/3/654.

International Energy Agency, "Energy, Climate Change & Environment: 2016 insights,"., pp. 113. https://www.iea.org/reports/energy-climate-change-and-environment-2016-insights.

Jefatura del Estado, " Ley 10/1998, de 21 de abril, de residuos. BOE 96,"1998[Online]. Available: https://www.boe.es/buscar/doc.php?id=BOE-A-1998-9478.

Koopera, "Reutilización y reciclaje Koopera," (accessed Jul, 2020)., no. Jul,.

Y. Lee, "Sound absorption properties of recycled polyester fibrous assembly absorbers," AUTEX Research Journal, 2003. vol. 3, no. 2[Online]. Available: http://www.autexrj.com/cms/zalaczone_pliki/5-03-2.pdf.

Ellen Macarthur Foundation and Circular fibres initiative, "A new textiles economy: Redesigning fashion's future,". Ellen MacArthur Foundation http://www.ellenmacarthurfoundation.org/publications.

P. Peña-Pichardo, G. Martínez-Barrera, M. Martínez-López, F. Ureña-Núñez and dos Reis, João Marciano Laredo, ,"Recovery of cotton fibers from waste Blue-Jeans and its use in polyester concrete,". Construction and Building Materials, vol. 177, pp. 409-416. http://www.sciencedirect.com/science/article/pii/S0950061818312121.

D. Rajput, S.S. Bhagade, S.P. Raut, R.V. Ralegaonkar and S.A. Mandavgane,"Reuse of cotton and recycle paper mill waste as building material,". Construction and Building Materials, vol. 34, pp. 470-475. http://www.sciencedirect.com/science/article/pii/S0950061812001122.

RILEM, "TC 25-PEM. Protection et erosion des monuments: Recommandés pour mesurer I'artération des pierres et évaluer I'efficacité des méthodes de traitement. Matériaux et Constructions."1980.C. Rubino, ,"Textile wastes in building sector: A review,". Modelling, Measurement and Control B, vol. 87, no. 3, pp. 172-179.

G. Sandin and G.M. Peters, ,"Environmental impact of textile reuse and recycling – A review,". Journal of Cleaner Production, vol. 184, pp. 353-365. http://www.sciencedirect.com/science/article/pii/S0959652618305985.

G. Silva, S. Kim, R. Aguilar and J. Nakamatsu, "Natural fibers as reinforcement additives for geopolymers – A review of potential eco-friendly applications to the construction industry," Sustainable Materials and Technologies, 2020. vol. 23, pp. e00132, DOI: https://doi.org/10.1016/j.susmat.2019.e00132. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2214993719300521.

W. Steffen, K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. De Vries and C.A. De Wit, "Planetary boundaries: Guiding human development on a changing planet," Science, 2015. vol. 347, no. 6223.

D.M. Tasán Cruz, "Caracterización de morteros de yeso reforzados con fibras recuperadas de eslingas textiles de un solo uso," M.S. thesis, Univ. Politécnica de Madrid., Madrid, 2011. [Online]. Available: http://oa.upm.es/10836/.

Textile Exchange, (2018). Textile Sustainability united in action: Accelerating Sustainability in Textiles & Fashion. Presented ad Textile Exchange' 2018; Textile Sustainability Conference.

Ş Kalkan, "Technical investigation for the use of textile waste fiber types in new generation composite plasters." M.S. thesis, Univ. İzmir Katip Çelebi Üniversitesi., Turquía, 2017.

G. Vasconcelos, P.B. Lourenço, A. Camões, A. Martins and S. Cunha, ,"Evaluation of the performance of recycled textile fibres in the mechanical behaviour of a gypsum and cork composite material,". Cement and Concrete Composites, vol. 58, pp. 29-39. http://www.sciencedirect.com/science/article/pii/S0958946515000037.