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Gypsum Composites with CDW as Raw Material

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***Abstract*—**In this study, the feasibility of incorporating ceramic waste from bricks (perforated brick and double hollow brick) and extruded polystyrene (XPS) waste, is analysed.

Results show that it is possible to incorporate up to 25% of ceramic waste and 4% of XPS waste over the weight of gypsum in a gypsum matrix. Furthermore, with the addition of ceramic waste an 8% of surface hardness increase and a 25% of capillary water absorption reduction can be obtained. On the other hand, with the addition of XPS, a 26% reduction of density and a 37% improvement of thermal conductivity can be obtained.

The obtained results are favorable to use these materials in order to produce prefabricated gypsum and also as material for interior cladding walls.

***Keywords*—**CDW, waste materials, ceramic waste, XPS, construction materials, gypsum.

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I. Introduction

FOR years, specialists in solid waste management have dealt only with waste generated by household, commercial and industrial sectors, while the safe and efficient treatment of waste from construction and demolition industry has been ignored. However, each year in Europe 890 million tons of CDW are generated, representing up to 49% of all waste generated in the European Union [1]. From these CDW, on average, 50% are recycled (excluding land without hazardous substances), a percentage that is far from the objectives set by the European Directive [2].

In Spain, this situation is more severe. Spain not only generates more CDW than the average of the European countries, despite in the last years the situation has changed due to the serious crisis concerning the building sector, but it is also among the countries with the lowest recycling rate together with Cyprus, Poland and the Czech Republic with a recycling rate of less than 40%. In fact, the first National Plan for Construction and Demolition Waste [3], established the generation of waste in Spain in 47 million tons, from which only 13,6% were recycled, which at the same time meant that the objectives set in this Plan were not accomplished.

Because of this circumstances, the Spanish government has created several rules focused on minimizing the environmental impact caused by the construction industry and, in particular, a specific standard for the proper management of the CDW (Royal Decree 105/2008) [4] which aims to promote their reduction and avoid landfilling, promoting as well the correct waste management to turn them into resources and save raw materials. However, currently there are no regulations in Spain which considers the reuse of CDW. Only the EHE-2008 (Instruction for Structural Concrete) [5], contemplates in its schedule, 15 recommendations on the use of recycled aggregates in concrete, although the aggregates that are not from concrete are excluded.

This situation is causing that specialized centres start publishing manuals about recycling waste, although the information in these manuals is still insufficient. For example, the catalogue of usable waste in construction, developed by CEDEX [6] which analyses strategies for recycling aggregates from concrete and ceramic waste. Moreover, in an international level, there are some manuals that can be highlighted, e.g., the "Construction and demolition waste guide recycling and re-use across the supply chain" [7] which establishes strategies for the use of crushed concrete and brick in low-grade roads and in pavement sub-bases and the "Construction & Demolition Waste Manual" [8], which classifies the CDW in categories according to the possibility to recycle them. However, no manual establishes strategies for recycling wastes in gypsum composites.

All this has generated interest among researchers in the sector, which has led to the publication of numerous research works studying the feasibility of incorporating CDW in different building materials. For example, there are several works studying the use of CDW, such as paper [9], gypsum boards [10] or rubber [11] in gypsum composites.

The Universidad Politécnica de Madrid is developing a database with different strategies for recycling waste in composite materials. For gypsum composites there are strategies for the incorporation of waste such as rice husk [12], loofah [13], feathers [14], mussel shell [15] or nutshell [16], and for CDW they are studying the use of ceramic waste and waste from synthetic polymers [17].

One of the most generated wastes, in construction sector, are ceramic wastes, which have been studied in lime mortars [18], alkaline cements [19] or cement mortars [20], but none of these studies indicate and verify what kind of applications can be given to such materials. Besides, several authors have investigated the incorporation of ceramic waste in concrete, among which stands Medina et al. [21] and its application in precast concrete [22]. However, there are no studies on the feasibility of incorporating such waste into gypsum composites to increase surface hardness.

On the other hand, the use of waste from synthetic polymers has been widely studied in different construction materials. For example, the use of waste expanded polystyrene foam has been studied to make lightweight gypsum [23] and lightweight

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concrete [24], and the use of waste expanded polystyrene has been analysed to make lightweight gypsum [18] and plaster boards [25]. However, after a deep review of the published scientific literature and documentation, no previous experience has been found about the addition of XPS waste in any type of construction composite.

For all this, the aim of this study is to analyse the feasibility of incorporating: (A) ceramic waste from bricks (perforated brick and double hollow brick) and (B) XPS waste, in a gypsum matrix. Results of this study will be incorporated into the database that is being developed at the Universidad Politécnica de Madrid.

II. Methodology

On the one hand, so as to analyse the feasibility of incorporating ceramic waste and XPS waste as aggregates in a gypsum composite, gypsum plaster E-30 and gypsum A1 has been used, respectively, according to the European Standard EN 13279-1 [26].

Initially the test composites were selected according to particle size and percentage of addition. In the case of ceramic waste there are differences between ceramic waste from perforated brick (A1) and ceramic waste from double hollow brick (A2). The different selected composites were tested to establish the water/binder (W/B) ratio according to European Standard EN 13279-2 [27].

The next step was to analyse the physical and mechanical properties of each composite by testing prismatic specimens (160x40x40) mm3 according to European Standard EN 13279-2 [27]. All samples were characterized by their dry density, mechanical strength and Shore C surface hardness [27], [28]. In the case of composites with ceramic waste, capillary water absorption was also tested according to European Standard EN 459-2:2001 [29] and in the case of composites with XPS waste, thermal conductivity was also analysed. Results were compared between the different composites, always taking into account the reference values obtained with samples prepared without any additives.

III. Results and Discussion

A. Test Composites' Selection

The experimental work was divided into three sections, tests A1, A2 and B, according to the different type of waste incorporated into the gypsum composite. For each of these sections, different composites have been selected according to two variables: particle size and percentage of waste incorporated, resulting in a total of 24 composites and 2 reference samples, as can be seen in Table I.

B. TESTS A1: All of Them Made With Gypsum Plaster E-30 and Additions of Ceramic Waste from Perforated Bricks

The analysis of the results obtained for the composites with additions of ceramic waste in different proportions (25, 50 and 75% by weight of gypsum), both coarse and fine aggregate as compared with the reference values of gypsum E-30, shows an increase in density of up to 23%, an increase in flexural strength of 29%, an increase of compression strength of 31%, an increase of Shore C surface hardness of up to 8% and a reduction of the capillary water absorption of up to 31%. All these values are achieved with the material 25A1G (Fig. 1).

TABLE I
LIST OF COMPOSITES

	Composite	Binder	W/B ratio	% Additive weight on gypsum	Additive Type
TEST A1	REFa	E-30	0.70	-	-
	25A1G		0,60	25%	A1G
	50A1G		0,70	50%	A1G
	75A1G		0,80	75%	A1G
	25A1F		0,70	25%	A1F
	50A1F		0,82	50%	A1F
	75A1F		0,90	75%	A1F
TEST A2	REFa	E-30	0.70	-	-
	25A2G		0,77	25%	A2G
	50A2G		0,80	50%	A2G
	75A2G		0,95	75%	A2G
	25A2F		0,75	25%	A2F
	50A2F		0,85	50%	A2F
	75A2F		0,95	75%	A2F
TEST B	REFb	A1	0.80	-	-
	1XPSg		0.80	1%	XPSg
	2XPSg		0.80	2%	XPSg
	3XPSg		0.80	3%	XPSg
	4XPSg		0.80	4%	XPSg
	1XPSm		0.80	1%	XPSm
	2XPSm		0.80	2%	XPSm
	3XPSm		0.80	3%	XPSm
	4XPSm		0.80	4%	XPSm
	1XPSf		0.80	1%	XPSf
	2XPSf		0.80	2%	XPSf
	3XPSf		0.80	3%	XPSf
	4XPSf		0.80	4%	XPSf

A1G: ceramic waste from perforated bricks (70% Ø2mm and 30% Ø1mm).

A1F: ceramic waste from perforated bricks (25% Ø1mm, 25% Ø0.5mm, 25% Ø0.25mm and 25% Ø<0.25mm.

A2G: ceramic waste from double hollow bricks (70% Ø2mm and 30% Ø 1mm.

A2F: ceramic waste from double hollow bricks with additions (25% Ø1mm, 25% Ø0,5mm, 25% Ø0,25mm and 25% Ø0,25mm.

XPSg: extruded polystyrene waste with course particle size (4-6 mm).

XPSm: extruded polystyrene waste with medium particle size (2-4 mm).

XPSf: extruded polystyrene waste with fine particle size (1-2 mm).

Considering supplementary regulations [30], in Gypsum plaster E-30 is determined that minimum flexural strength in standard test pieces is 3.0 N/mm2 and all the composites satisfy this restriction. Furthermore, current regulation European Standard EN 13279-2 [27] determines that the compression strength should be higher than 2.0 N/mm2 and all composites satisfy the values determined by the current regulations.

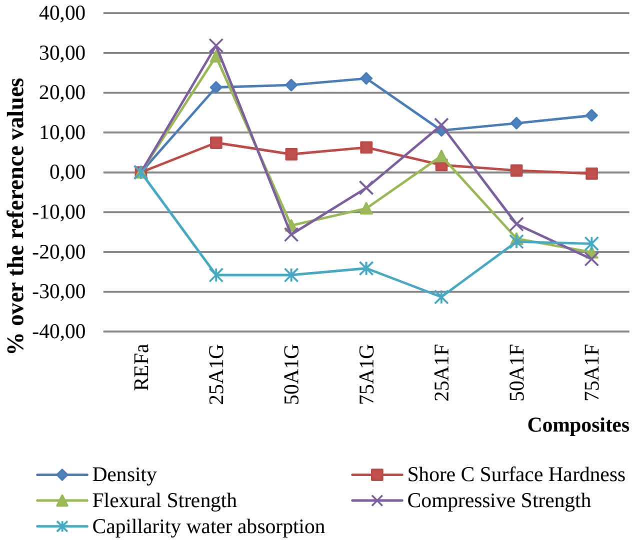

Fig. 1 Percentage of density, Shore C surface hardness, capillary water absorption and mechanical strength of gypsum composites with additions of ceramic waste from perforated bricks (A1), in comparison to a reference composite without additions (REFa)

C. Test A2: All of Them Made with Gypsum Plaster E-30 and Additions of Ceramic Waste from Double Hollow Bricks

The analysis of the results obtained for the composites with additions of ceramic waste from double hollow bricks (25, 50 and 75% by weight of gypsum), both coarse and fine aggregate as compared with the reference values of gypsum E-30, shows an increase in density of up to 7%, a reduction in flexural strength of 2%, a reduction of the compression strength of 14%, an increase of Shore C surface hardness of 1% and a decrease of the capillary water absorption of up to 8%. All these values are reached with the material 25A2F (Fig. 2).

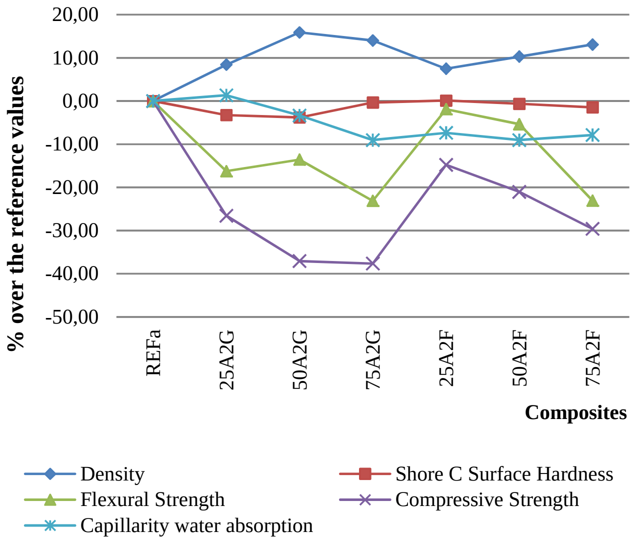

Fig. 2 Percentage of density, Shore C surface hardness, capillary water absorption and mechanical strength of gypsum composites with additions of ceramic waste from double hollow bricks (A2) in comparison to a reference composite without additions (REFa)

Considering supplementary regulations [30], in Gypsum plaster E-30 is determined that minimum flexural strength in standard test pieces is 3.0 N/mm2 and all the composites satisfy this restriction. Furthermore, current regulations European Standard EN 13279-2 [27] determines that the compression strength should be higher than 2.0 N/mm2 and all composites satisfy the values determined by legislation.

D. Test B: All of Them Made with Gypsum A1 and Xps Waste

Fig. 3 shows the results obtained for the composites with XPS waste, in different percentages (1, 2, 3 and 4% by gypsum weight) and three particle sizes (coarse, medium and fine), in comparison to a reference value obtained with a composite with no additives (REFb). Considering European Standard EN 13279-2 [27] composite 4XPSg do not meet the minimum requirement for compressive strength, which is 2 N/mm^2. The results for the rest of the composites show a maximum density decrease of 26% and a maximum thermal conductivity decrease of 37%, which correspond to the composite 4XPSm. However, these improvements involve a flexural strength decrease of 47% and a compressive strength decrease of 63%.

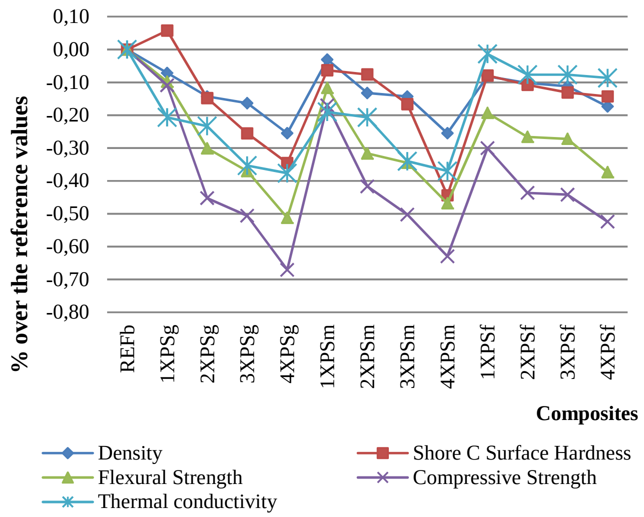

Fig. 3. Percentage of density, Shore C surface hardness, capillary water absorption and mechanical strength of gypsum composites with additions of XPS waste in comparison to a reference composite of gypsum without additions

E. Summary of the Best Results for Its Application in Construction

After analysing the results of all studies performed with different kinds of CDW, a summary table (Table II) with the best composites obtained is performed, showing possible applications in the construction industry.

IV. Conclusions

After analysing all test results and considering the limits set by the rules, it is concluded that the proposed methodology for the preparation of gypsum composites with CDW has obtained positive results because it is possible to incorporate ceramic and XPS waste, separately, on a gypsum matrix.

Considering the limits set by the standard, it is concluded that gypsum plaster E-30, with additions of 25, 50 and 75%, coarse and fine aggregate, both ceramic waste from perforated brick and double hollow brick, is feasible to use them in order to produce prefabricated gypsum and also as material for interior cladding walls. The main reason is that the material not only meets the values established by current legislation relating to mechanical breakage bending and compression; it also increases the surface hardness to 8% and decreases the absorption of capillary water up to 25%.

Furthermore, referring to composites with XPS waste, it is concluded that it is feasible the use of extruded polystyrene waste in gypsum composites. With the incorporation of this aggregate a maximum reduction of density of 26% and a maximum reduction of thermal conductivity of 37% can be earned.

TABLE II
CHARACTERIZATION OF RECYCLED MATERIALS INDICATING THEIR PHYSICAL-MECHANICAL BEHAVIOUR AND POSSIBLE APPLICATIONS

Composite			Composites behaviour over the results for a reference sample without additions (%)							Possible applications
CDW	Particle size (mm)	%*	Density	Shore C Superficial hardness	Flexural Strength	Compressive Strength	Capillary water absorption	Thermal Conductivity		
Ceramic waste from perforated brick	1.00	10	+21	+8	+29	+31	-25	-		1,2
	2.00	15								
Ceramic waste from double hollow brick	1.00	6.25	+7	+1	-2	-14	-8	-		1,2
	0.50	6.25								
	0.25	6.25								
	<0.25	6.25								
XPS waste	4-6 mm	4%	-26	0	-0.5	-63	-	-37		1

Possible applications:
1 Prefabricated gypsum pieces
2 Interior cladding walls

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