LIGHTWEIGHT CONSTRUCTION MATERIAL MADE WITH GYPSUM AND EXTRUDED POLYSTYRENE WASTE

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ABSTRACT

Approximately 3.2 million tonnes of synthetic polymers are produced in Spain, from which 14.4% come from the construction industry. From all the waste generated from this material, 55% is disposed in landfills, 17% goes to energy recovery system and only 28% is actually recycled. Extruded Polystyrene (XPS) is one of the most used synthetic polymers and it is used as insulation material in construction industry, generating approximately 5% of waste by weight of its total production in the building process, meaning a high volume of waste due to the low density of the material. This waste is non-biodegradable and hence its proper management is necessary to reduce its environmental impact. However, despite the existence of recycling techniques for XPS, only 30% of this waste is currently recycled, mainly due to the high cost of this process.

Therefore, the aim of this study is to analyse the feasibility of reusing XPS waste, obtained from discard construction insulation materials, as a lightweight aggregate in gypsum composites. To this end, several prismatic specimens composed by different XPS waste percentages, different particle sizes with and a fixed consistency at a good workability, were analysed by their density, their shore C surface hardness, their flexural and compressive strength and their thermal behaviour. Results show that it is possible to use XPS waste to produce a lightweight gypsum composite. This aggregate helps reducing density up to 25.5% and improves thermal conductivity up to 30%. However, it also decreases the mechanical strength of the composite significantly, but all composites meet the minimum requirements established for these materials.

Keywords: gypsum composite; lightweight gypsum; extruded polystyrene waste; construction and demolition waste; XPS.

1.- Introduction

Synthetic polymers are an essential part of modern society and their consumption continues to increase annually, which involves that the total amount of waste from synthetic polymers that ends up in waste stream is significant.

Extruded Polystyrene (XPS) is one of the most used synthetic polymers and its most common use is as an insulation material in construction industry. The use of XPS in construction applications generates approximately 5% of waste by weight of its total production, meaning a high volume of waste due to the low density of this material. Despite the existence of recycling techniques for XPS waste, less than 30% of this waste is currently recycled, mainly due to the high cost of this process. Therefore, the design of new strategies to achieve high quality recycling rates for this waste is still a need. For example, previous investigations assess the strategy of incorporating different types of waste from synthetic polymers in construction composites. Among others, the following studies can be highlighted:

- Karaman et al. [1] studied the feasibility of incorporating waste PET bottles in a gypsum matrix.
- Abdulkadir and Ramazan [2] analysed the effects of using recycled waste expanded polystyrene foam, as a potential aggregate in lightweight concrete.
- Junco et al. [3] determined the properties of different blends containing cement-polyurethane-sand for the production of lightweight mortars containing recycled foams from polyurethane.
- Ge et al. [4] investigated the influence of aggregate gradation, sand-to-PET ratio and curing conditions on physical and mechanical properties of recycled PET mortar.

However, after a deep review of the published scientific literature and documentation, no previous experience has been found about the addition of XPS in any type of construction composite. Therefore, in view of the foregoing, the main objective of the research study here presented is to analyse the feasibility of incorporating XPS waste in a gypsum matrix to produce a new lightweight gypsum material according to current regulations, as a substitute to the lightweight materials produced with aggregates such as perlite or vermiculite, which apart from being expensive, their production requires too much energy.

2.- Materials and methods

To analyse the feasibility of incorporating XPS waste in a gypsum matrix, the following materials were used:

- Gypsum Iberplast from Placo Saint Gobain, a standard commercial gypsum characterized as B1 according to European Standard EN 13279-1 [5].
- XPS waste (XPSw) from discarded construction insulation materials collected from local building sites.

Due to the initial shape characteristics of XPSw, it had to be previously shredded and sieved, obtaining XPSw with particle sizes: 1-2 mm, 2-4 mm and 4-6 mm, as can be seen in figure 1.

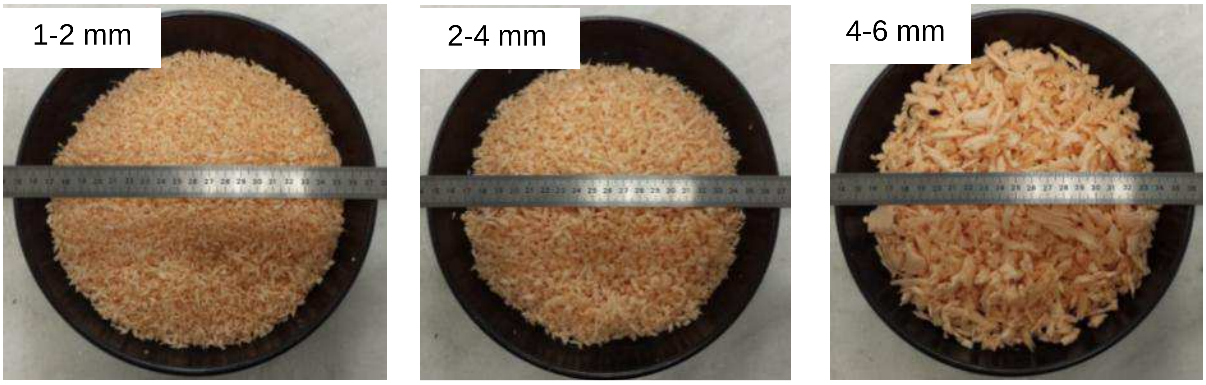

Fig. 1 “XPS waste size samples”

Several series of samples were defined and analysed, as presented in table 1, by elaborating prismatic specimens (160x40x40) mm^3, composed by four different XPSw percentages and seven particle sizes combinations. All samples were characterised by their density in dry state, their flexural and compressive strength after 7 days, their Shore C surface hardness as specified in the European Standards EN 13279-2 [6] and UNE 102039 [7] and their thermal behaviour, in comparison to a reference sample without XPSw.

The procedure to obtain the specimens started with the progressive addition of XPSw to the water to obtain a previous mixture. Gypsum was then incorporated into this mixture to obtain a homogeneous composite. All test specimens were cured at a temperature of 24 ºC and a relative humidity of 50 ± 1% for 7 days, dried in a stove to a constant mass at 40± 2 ºC and cooled to laboratory temperature before being subsequently mechanically and physically tested.

The flexural strength was determined by the load needed to break prismatic specimens supported on rollers positioned at 100 mm intervals. Compressive strength was determined by the load needed to break the broken sections of the specimens previously tested to flexural failure. Shore C hardness was determined by establishing the indent left by an exerted force on each test specimen, measured in Shore C units, from 0 (softest) to 100 (hardest) and thermal conductivity was measured in a laboratory tester by determining the heat flux produced by a constant heat source inside the tester through a prismatic specimen (300x300x30) mm^3, located in one of its sides.

3.- Results and discussion

The average test results obtained have been summarized in **¡Error! No se encuentra el origen de la referencia.** and are further detailed in the following subsections.

Sample	XPSw percentage (%)	XPSw particle size	Density (g/cm3)	Shore C surface hardness	Flexural strength (N/mm^2)	Compressive strength (N/mm^2)
Reference	0	-	0.98	67.28	3.16	5.59
1A	1	4-6 mm	0.91	71.17	2.85	4.98
2A	2		0.84	57.33	2.21	3.06
3A	3		0.82	50.10	1.99	2.76
4A	4		0.73	44.03	1.54	1.84
1B	1	2-4 mm	0.95	63.03	2.79	4.64
2B	2		0.85	62.17	2.16	3.26
3B	3		0.84	56.10	2.07	2.78
4B	4		0.73	37.40	1.68	2.07
1C	1	1-2 mm	0.90	61.97	2.55	3.91
2C	2		0.88	60.03	2.32	3.15
3C	3		0.87	58.47	2.30	3.12
4C	4		0.81	57.67	1.98	2.66
1D	1	0.5%(4-6 mm) 0.5%(1-2 mm)	0.93	70.27	2.82	4.76
2D	2		0.91	57.67	2.80	3.96
3D	3		0.77	47.20	2.01	2.68
4D	4		0.74	32.37	1.58	1.71
1E	1	0.75%(4-6 mm) 0.25%(1-2 mm)	0.92	61.07	2.76	4.93
2E	2		0.84	57.20	2.37	3.68
3E	3		0.79	53.07	2.06	2.77
4E	4		0.69	33.93	1.33	1.47
1F	1	0.5%(2-4 mm) 0.5%(1-2 mm)	0.91	64.00	2.47	4.36
2F	2		0.87	57.53	2.51	3.85
3F	3		0.82	55.00	2.38	3.16
4F	4		0.74	32.37	1.58	1.71
1G	1	0.75%(2-4 mm) 0.25%(1-2mm)	0.97	68.73	2.89	5.64
2G	2		0.86	52.93	2.33	4.01
3G	3		0.80	50.80	2.10	2.99
4G	4		0.69	28.80	1.45	1.65

Table 1 “Test results”

3.1.- Density

It can be seen from table 1 that the progressive incorporation of an increasing percentage of XPSw into the gypsum matrix involves a density reduction between 1.02% and 29.59% in relation to the reference sample, which is probably due to the partial substitution of gypsum by the aggregate [8] or the increase in the porosity, due to the cellular structure of the material [9].

In addition, as can be seen in figure 2, the effect of XPSw percentage factor on waste distribution can be highlighted, as in general, a homogeneous distribution is obtained when adding more than 2% of XPSw, due to the reduction of the setting time and thus also the workability of the composite. With the addition of 1 or 2% of waste, setting time is longer, which involves that EPSw with particle size bigger than 1-2 mm floats and is not distributed homogeneously in the gypsum matrix.

1% XPSw (2-4 mm) 4% XPSw (2-4 mm)

Fig. 2 "Samples section"

Moreover, as can be seen in figure 5, density results have a similar behaviour for all particle sizes combinations, although the use of different percentages of fine XPSw (1-2 mm) has less effect on density than the other particle sizes.

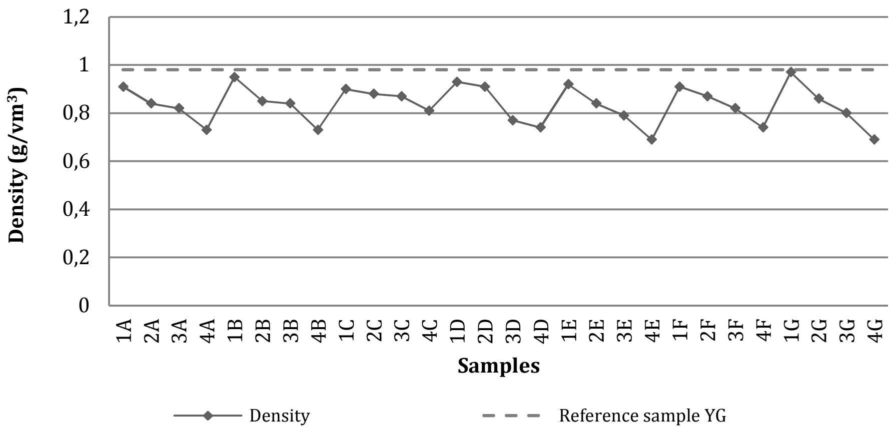

Fig. 3 "Density results"

3.2.- Mechanical strength

Table 1**¡Error! No se encuentra el origen de la referencia.** shows the results for flexural strength after 7 days for all composites and all of them fulfil the UNE-EN 13279 standard, which defines 1 N/mm^2 as the minimum requirement for flexural strength. As can be observed, the percentage of XPSw affects flexural strength. This can be due to the existing relation between density and strength in lightweight composites [10], as XPSw percentage factor affects both of these variables; the progressive incorporation of an increasing percentage of XPSw into the gypsum matrix involves density reduction and a flexural strength decrease between 8.54% and 57.91%. The combination of these two variables can be seen in figure 4. In this graph, three different groups can be observed: on the left, the first group with the lowest density and flexural strength, formed by the composites with 4% of XPSw. On the right, the second group with the highest values for density and flexural strength formed mainly by the composites with 1% of XPSw and the third and biggest group with the rest of the composites. From this third group it is noteworthy the composite 3F, which is the only composite that has lower density and higher flexural strength than the average, although 2E is close.

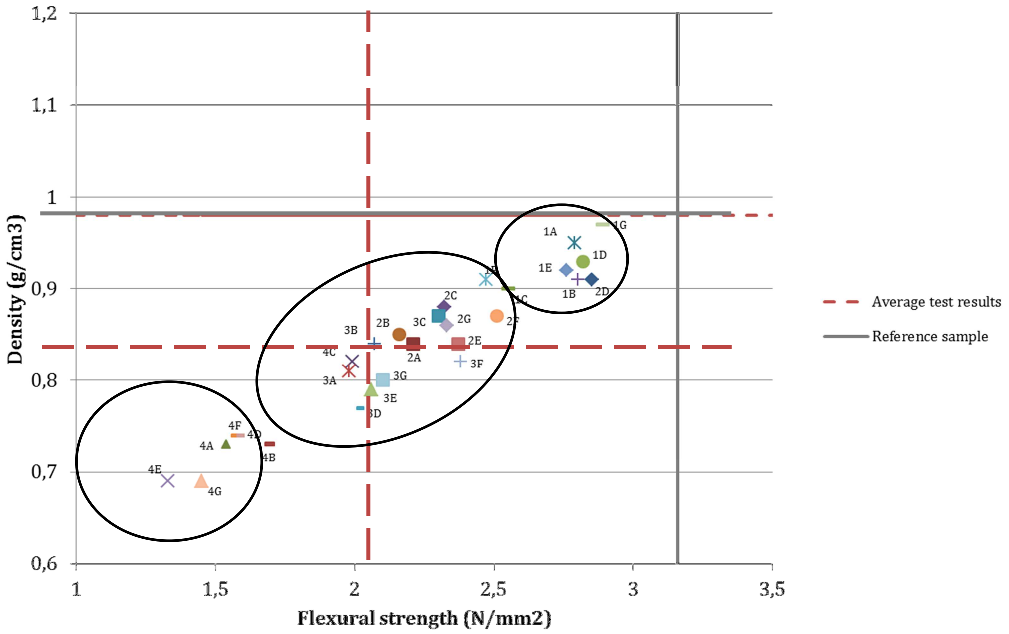

Fig. 4 “Density-flexural strength graph”

On the other hand, it is observed that there are significant differences in the four levels of the XPSw percentage for compressive strength results (table 1). These results show that compressive strength decreases between 11 and 74% and furthermore, most of the samples with 4% of XPSw do not fulfil the UNE-EN 13279 standard, which defines 2 N/mm^2 as the minimum requirement for compressive strength. From the combination of density and compressive strength in the same graph, the same results can be observed. Moreover, although there is no composite with lower density and higher compressive strength than the average, the composites 3F and 2E are the composites with closer values to the average.

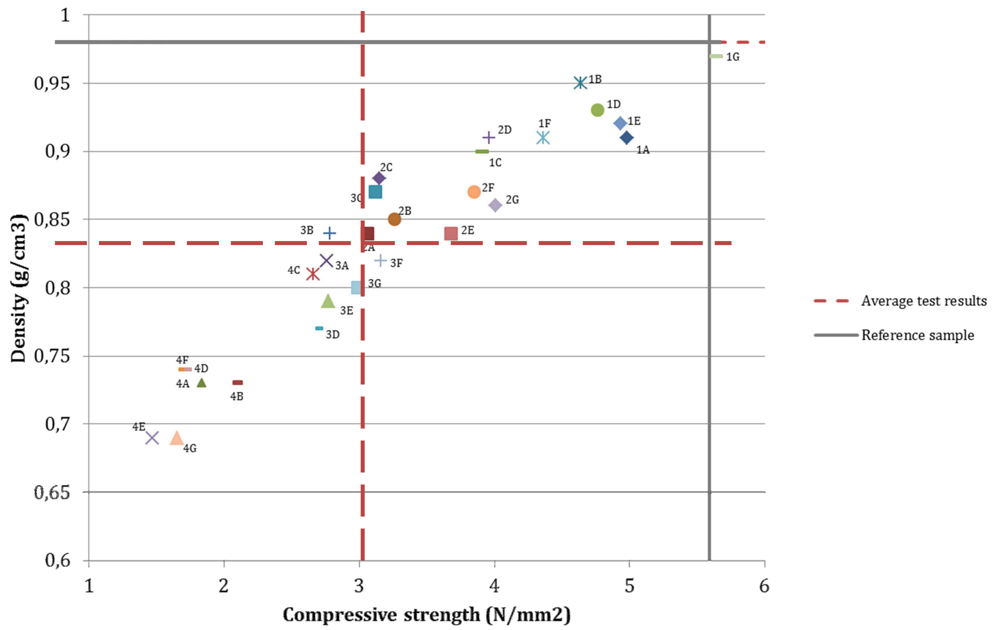

Fig 5 “Density-compressive strength graph”

3.3.- Shore C surface hardness

Due to the presence of XPSw close to the surface of the specimens, all samples present a high surface roughness, especially with course (4-6 mm) and medium (2-4) particle sizes. This effect affects Shore C surface hardness, because the measurement of Shore C surface hardness on or near particles of XPSw is null.

3.4.- Thermal conductivity

Table 5 shows the thermal conductivity results for the composites with the main particle sizes (4-6 mm), (2-4 mm) and (1-2 mm), which are between 1.4% and 37.6% under the reference value. Previous studies indicate that there is a correlation between density and thermal conductivity in lightweight gypsum composites; the more waste, the lower the values of density and thermal conductivity [11] and [12]. Figure 12 shows the thermal conductivity and density results and according to these results this correlation is fulfilled for particle sizes (4-6 mm) and (2-4 mm). However, XPSw with particle size 1-2 mm has similar density to the other composites and higher thermal behaviour.

Sample	XPSw percentage (%)	XPSw particle size	Thermal conductivity
Reference	0	-	0.300
1A	1	4-6 mm	0.238
2A	2		0.230
3A	3		0.194
4A	4		0.187
1B	1	2-4 mm	0.243
2B	2		0.238
3B	3		0.198
4B	4		0.189
1C	1	1-2 mm	0.296
2C	2		0.277
3C	3		0.277
4C	4		0.274

Table 2 “Thermal conductivity results”

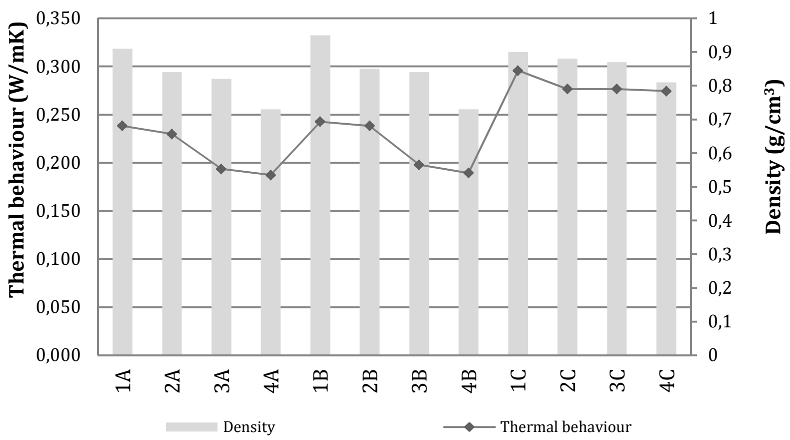

Fig. 6 “Thermal behaviour vs. density for XPSw composites“

4.- Conclusions

This experimental work investigates the effect of extruded polystyrene waste on the main properties of gypsum composites. It is revealed from this work that:

The homogeneous distribution of XPSw depends on setting time. Higher amounts of waste decrease setting time and hence workability, which means that XPSw is distributed homogeneously in the gypsum matrix.

The progressive incorporation of an increasing percentage of XPSw into the gypsum matrix involves a density reduction up to 29.59%, achieved with a composite with 3% 2-4 mm XPSw and 1% 1-2 mm XPSw.

XPSw distribution creates a high surface roughness; more prominent when larger amounts of waste are added. This effect affects Shore C surface hardness, which decreases with the progressive addition of XPSw.

Lower density obtained by adding high amounts of XPSw involves flexural strength decrease up to 57.91% and compressive strength decrease up to 74%. In addition, most of the composites with more than 3% of XPSw do not fulfil the UNE-EN 13279 standard minimum requirements for compressive strength.

- The addition of high percentages of XPSw with particle sizes 4-6 mm and 2-4 mm affects thermal conductivity positively. Up to 37.6% of thermal conductivity improvement can be achieved by adding this waste.

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