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Chemical recycling of EPS in the production of lightened gypsum composites.

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ABSTRACT

New gypsum composites by chemically recycling large volumes of expanded polystyrene (EPS) waste, thereby replacing natural raw materials, is developed in this study. Physicochemical, mechanical and environmental characterization enabled analysis and comparison based on the solvent used. The composites exhibit lower density and thermal conductivity, with good mechanical performance. The environmental impact of the composites is primarily linked to the type of solvent used, and further research is needed to explore more sustainable alternatives. This dissolution process induces microstructural changes, reducing crystal size and, depending on the solvent used, causing crystal agglomeration. The new composites promote the use of secondary materials whilst improving energy efficiency in buildings.

Keywords: plaster composites; waste revalorization; chemical recycling; energy efficiency.

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Contribution of each author
In this paper, the author AZB contributed 50% to the original idea, 33% to the experimentation, 33% to data collection, 100% to the writing of the paper, and 33% to the discussion of the results. Author DFV contributed 50% to the original idea, 33% to the experimentation, 33% to data collection, 50% to manuscript review, and 33% to the discussion of results. Author EAS contributed 33% to the experimentation, 33% to data collection, 50% to manuscript review, and 33% to the discussion of results.

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Reciclaje químico de EPS en la elaboración de compuestos de yeso aligerado.

RESUMEN

En este estudio se desarrollan nuevos compuestos de yeso reutilizando grandes volúmenes de residuos de poliestireno expandido (EPS) mediante reciclaje químico, sustituyendo materias primas naturales. La caracterización fisicoquímica, mecánica y medioambiental, permitió el análisis y comparación en función del disolvente empleado. Los compuestos presentan menor densidad y conductividad térmica, con buen comportamiento mecánico. El impacto ambiental de los compuestos se centra principalmente en el tipo de disolvente, siendo necesario ampliar la investigación hacia alternativas más sostenibles. Esta disolución genera cambios microestructurales, reduciendo el tamaño cristalito y produciendo la aglomeración de los cristales dependiendo del tipo de disolvente empleado. Los nuevos compuestos fomentan el uso de materiales secundarios, a la vez que mejoran la eficiencia energética en los edificios.

Keywords: compuestos de escayola; revalorización de residuos; reciclaje químico; eficiencia energética.

Reciclagem química de EPS na produção de compósitos aligeirados de gesso.

RESUMO

Este estudo desenvolve novos compósitos de gesso através da reutilização de grandes volumes de resíduos de poliestireno expandido (EPS) por meio da reciclagem química, substituindo assim as matérias-primas naturais. A caracterização físico-química, mecânica e ambiental permitiu a análise e comparação com base no solvente utilizado. Os compósitos apresentam menor densidade e condutividade térmica, com bom desempenho mecânico. O impacto ambiental dos compósitos está principalmente ligado ao tipo de solvente utilizado, sendo necessária mais investigação para explorar alternativas mais sustentáveis. Este processo de dissolução induz alterações microestruturais, reduzindo o tamanho dos cristais e causando a sua aglomeração, dependendo do tipo de solvente utilizado. Os novos compósitos promovem o uso de materiais secundários, melhorando simultaneamente a eficiência energética dos edifícios.

Palavras-chave: compósitos de gesso; revalorização de resíduos; reciclagem química; eficiência energética.

NOMENCALTURE

Acronym	Nomenclature
DH	Calcium sulfate dihydrate
EPD	Environmental product declaration
EPS	Expanded polystyrene
ETICS	External Thermal Insulation System
FWHM	Full Width at Half Maximum
GWP	Global warming potential
LCA	Life cycle analysis
MOE_{us}	Young's modulus
SEM	Scanning electron microscopy
TGA	Thermogravimetric analysis
XRD	X-ray diffraction

1. INTRODUCTION

Currently, the European plaster industry has an annual turnover of around €7.7 billion, generating millions of jobs (Future Market Insights Global and Consulting Pvt. Ltd., n.d.). Spain, as the leading producer in Europe, plays a key role in this industry. Gypsum is widely used in construction, both as a cladding and finishing material and in the production of prefabricated boards and panels. From an environmental perspective, it stands out primarily for the lower energy required for its production compared to other binders, as well as its ease of recycling, which allows the original composite (gypsum hemihydrate) to be recovered simply (Elert et al., 2023).

Furthermore, it is a binder that can accommodate a wide variety of additives. Traditionally, the industry has opted to incorporate lightweight fillers such as perlite or expanded clay to produce a lighter product, thereby reducing construction times and facilitating transport, as well as improving the material's thermal insulation properties (Del Río y Fernández Olivares, 2004).

Given the synergy offered by gypsum as a binder when combined with other additives, the research community has made various efforts to use it as a matrix for the recovery of different types of waste (Villoria Sáez et al., 2018). As is well known, the construction sector is responsible for generating 40% of solid waste and for consuming more than 36% of global energy (Yılmaz et al., 2019). This, combined with the increased extraction and consumption of natural raw materials, makes the construction sector one of the industries with the greatest environmental impact.

In this regard, several studies have examined the inclusion of lightweight solid waste from the construction sector, such as expanded polystyrene (EPS). The presence of this waste in landfills has been increasing due to the rise in energy-efficient refurbishment works promoted by the EU, in which the main system used is ETICS (External Thermal Insulation Composite System)

(Schleier et al., 2022). In this system, EPS is predominantly used as the main insulating layer, generating large quantities of non-biodegradable waste that is difficult to recycle, thereby increasing the pressure on already saturated landfills.

Studies incorporating EPS waste into lightweight gypsum composites use pre-shredded waste, generally with a particle size of less than 4 mm in diameter, although granules of up to 11 mm have occasionally been used (Argalis et al., 2023; Villoria Sáez et al., 2020). The amounts added are usually between 3–6% of the binder's weight (Bicer y Kar, 2017; Bumanis et al., 2023). These low addition percentages are due to the low density of the waste, which varies between 28 and 70 kg/m³ (CTE, 2010).

These studies, in particular, highlight a decrease in thermal conductivity due to the significant reduction in the bulk density of the resulting composites. Studies such as that by Bumanis et al. (Bumanis et al., 2023) achieved a thermal conductivity of less than 0.150 W/m·K, incorporating up to 4% of EPS granules with a diameter of up to 1.2 mm. Similar studies, such as that by San-Antonio-González et al. (San-Antonio-González et al., 2015), achieved a thermal conductivity of approximately 0.08 in composites containing 2% granulated EPS with particle sizes less than 4 mm. In both cases, the density was less than 600 kg/m³.

However, the increase in entrapped air resulting from this density reduction negatively impacts the material's mechanical performance. In many cases, the manufactured composites do not even meet the minimum standards of 1 MPa for flexural strength and 2 MPa for compressive strength set out in the current standard (UNE-EN 13279-2: 2014). The preferred points of failure that form between the gypsum matrix and the waste due to poor adhesion between the two also underpin this decrease in mechanical strength, and the use of these materials in construction is not recommended, despite their interesting thermal properties from an energy-saving perspective (de Oliveira et al., 2021).

This study proposes a new method for incorporating EPS waste by dissolving it prior to mixing, resulting in a less heterogeneous material with greater strength whilst retaining its beneficial thermal properties. Furthermore, a comparison was carried out using different solvents to determine whether this affects the final characteristics of the resulting composites.

2. MATERIALS AND METHODS

This section outlines the materials used, the experimental study conducted and the process of preparing the samples used in this research.

2.1 Materials

The materials used in this study were:

- Binder: Building plaster classified as B1 in accordance with standard UNE-EN 13279-1. This binder, consisting primarily of calcium sulphate hemihydrate, has a purity of >80%, a particle size of 0–0.4 mm, a fire reaction class of A1 and a pH of >6.
- Mixing water: drinking water, supplied by Canal de Isabel II (Madrid). This water is free from impurities in accordance with Directive (EU) 2020/2184 (European Parliament, 2020), and has previously been used successfully in the production of gypsum composites in earlier studies (Zaragoza-Benzal, Ferrández, Santos, et al., 2023).
- EPS waste dissolution: Obtained by dissolving EPS waste generated during the energy-efficient refurbishment of façades using an External Thermal Insulation Composite System (ETICS). The EPS used in such projects typically has a thermal conductivity of 0.037 W/m·K, a density of 15-20 kg/m³, and a compressive strength of 0.06 MPa. The dissolution was carried out using two solvents, ethyl acetate and universal solvent, thereby yielding two types of solutions, dsA and dsB, respectively. On the one hand, ethyl acetate ($C_4H_8O_2$) has a purity of 99.5% and a density of 900 kg/m3. The universal solvent is a mixture of

volatile hydrocarbons (toluene, methanol, methyl acetate) with a density of 850 kg/m³. The solutions (dsA and dsB) were prepared at an EPS/solvent mass ratio of 1:2, yielding densities of 700 kg/m³ and 660 kg/m³ for dsA and dsB, respectively.

2.2 Experimental programme

The experimental programme carried out encompasses the physicochemical, physical and mechanical characterisation of the composites produced, as well as an environmental assessment of the composites obtained, through the following tests:

- Physical characterisation: The bulk density, Shore C surface hardness, Young's modulus (MOE_{US}) and thermal conductivity were determined. These properties were measured on RILEM standard test samples of 40 × 40 × 160 mm³.
  The bulk density, in accordance with standard UNE 102042:2023, was determined by measuring the volume of the test samples with a calliper accurate to 0.01 mm and the mass with an electronic balance accurate to 0.01 g.
  The Shore C surface hardness was determined in accordance with the requirements of standard UNE-EN 13279-2:2014, using a durometer. Measurements were taken on two longitudinal faces of the test samples that were in contact with the mould during setting, yielding a total of five measurements per face.
  The dynamic Young's modulus was determined using the ultrasonic method in accordance with standard UNE-EN ISO 14146:2004. An E46 ultrasonic tester (Ibertest) was used for this purpose, enabling the wave velocity to be measured longitudinally along the sample.
  Thermal conductivity was measured using a λ-Meter EP500e, in accordance with the requirements of standard UNE-EN 12664. Test samples of 150 × 150 × 30 mm³. The test was carried out for 90 minutes after reaching a steady state at 10 °C, 25 °C and 40 °C.
- Mechanical characterisation: Tests were carried out to assess flexural and compressive strength, and images were obtained using scanning electron microscopy (SEM).
  The flexural and compressive strength tests were carried out in accordance with standard UNE-EN 13279-2:2014 using an AUTOTEST 200-10SW hydraulic press (Ibertest). For the flexural strength test, three samples were tested for each mix of 40 × 40 × 160 mm³. Meanwhile, for the compression test, six samples were tested at each load level, with a load application area of 40 × 40 mm^2.
  The SEM images were obtained using a Jeol JSM-820 microscope, equipped with an Oxford EDX analyser and operating at 20 kV. The samples were gold-coated using a Cressington 108 auto-metalliser to ensure good electron-beam conductivity.
- Physico-chemical characterization: Thermogravimetric analysis (TGA) and X-ray diffraction (XRD) analyses were carried out on the composites. The TGA analyses were carried out using an SDT Q600 (TA Instruments) from room temperature to 1000 °C at a rate of 10 °C/min in an air atmosphere at a flow rate of 100 ml/min.
- For XRD, a Siemens Krystalloflex D5000 diffractometer with a graphite monochromator and Cu-Kα was used. The measurement was carried out in the range $5° \leq 2\theta \leq 60°$, in 0.04° increments, with an exposure time of 4 seconds per step. In addition, the crystallite size was determined from the full width at half maximum (FWHM) of the intensity peaks obtained in the diffractograms, using the Debye-Scherrer equation (Patterson, 1939).
- Environmental evaluation: The study was carried out using life cycle assessment (LCA) in accordance with ISO 14040 and ISO 14044, with 1 m² of panel for lightweight partitioning used as the functional unit. This analysis covers the entire process from the sourcing of raw materials to the production of the material (A1-A3). Environmental product declarations (EPDs) were used for all raw materials except for EPS waste, which, as a waste product, is not included in the inventory. Similarly, the energy used in production was taken from

previous research (Romero-Gómez et al., 2023) for the Spanish energy mix. For transporting raw materials to the factory, a 16–32-tonne diesel lorry (Euro 6) was used. The assessment was carried out using life cycle inventory analysis, considering only the global warming potential (GWP) impact category.

2.3 Sample preparation

The mixtures were prepared in accordance with the methods and specifications set out in standard UNE-EN 13279-2:2014. The water-to-gypsum ratio for all mixtures was set at 0.7, as determined by the shaking table test. The solutions are incorporated during the final mixing stage, resulting in the complete integration of the residue into a homogeneous mass.

Once the composites had set, the samples were removed from the moulds and stored under laboratory conditions at 23 ± 2 °C and 50 ± 5% relative humidity for 7 days. Prior to testing, the samples were dried in an oven at 40 ± 2 °C for 24 hours. The mix designs presented in Table 1 show how the gypsum binder has been progressively replaced with various solutions of EPS waste, up to 22.7% by mass of the binder, to produce a material with a higher proportion of recovered materials, thereby reducing the use of virgin raw materials. This approach promotes the application of circular economy principles in the development of new construction composites, contributing to a reduction in landfill waste through recovery.

Table 1. Mass proportions used in the preparation of the composites studied.

Sample	Gypsum (g)	Water (g)	dsA (g)	dsB (g)
Y0.7-Ref	1000	700	–	–
Y0.7-dsA100	941	659	100	–
Y0.7-dsA200	882	618	200	–
Y0.7-dsB100	941	659	–	100
Y0.7-dsB200	882	618	–	200

3. RESULTS AND DISCUSSION

This section presents the results obtained from the proposed experimental programme, along with a discussion of them.

3.1 Physical characterisation

Table 2 presents the results of the surface hardness and MOE_{US} tests for all the composites produced.

Table 2. Results for the MOE_{US} and the surface hardness of the manufactured composites.

Sample	MOE_{US} (MPa)	Surface hardness (Shore C units)
Y0.7-Ref	4910.39	78
Y0.7-dsA100	2897.37	73
Y0.7-dsA200	2975.07	66
Y0.7-dsB-100	3218.42	70
Y0.7-dsB-200	2561.21	67

As shown in Table 2, the MOE_{US} is significantly reduced when the various solutions are incorporated into the composites. The Y0.7-dsB-100 composite was the least affected, with a reduction of 34.5%, followed by the Y0.7-dsA100, Y0.7-dsA200 and Y0.7-dsB-200 composites, the latter showing a reduction of 47.8%. This decrease in MOE_{US} would indicate an increase in the material's internal discontinuities caused by the dissolved polymer (López Pedrajas et al., 2022). Other studies have reported similar results when introducing additional lightweight waste materials, such as solid-state EPS (Porras Amores et al., 2019).

Regarding surface hardness, the results show a less pronounced decrease across the samples, with the greatest reduction observed in the Y0.7-dsA200 composite, which exhibited a 15.4% lower hardness. In this case, both solutions had similar effects on the gypsum material. In other studies where recycled material is introduced into the gypsum matrix, this decrease is not as evident, as a homogeneous material is not produced during mixing (De San Antonio, 2017).

Figure 1 below shows the results for the bulk density and thermal conductivity of the manufactured composites, as well as results from similar studies in which solid EPS waste has been incorporated into lightweight gypsum composites. In addition, the values specified by the UNE-EN 13279-1 standard for lightweight gypsum (800 kg/m³) and the thermal conductivity associated with that density (260 mW/m·K) are indicated.

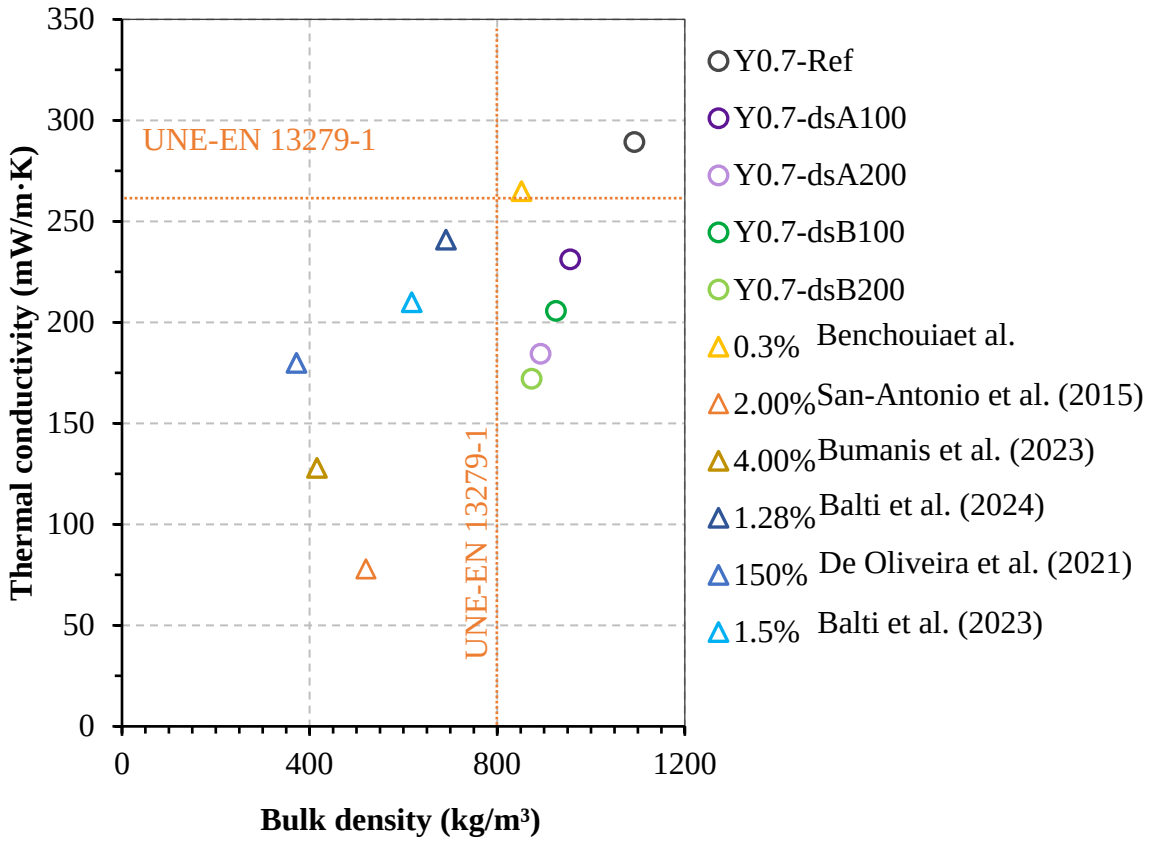


Figure 1. Results for the bulk density and thermal conductivity of the composites produced, compared with those of other similar studies (percentage of EPS added relative to the weight of the binder).

As shown in Figure 1, all the developed composites exhibited lower values for bulk density and thermal conductivity than the reference material. All composites achieved bulk densities of between 850 and 950 kg/m³, whilst thermal conductivities ranged from 170 to 230 mW/m·K. It is

worth noting that the Y0.7-dsB composites exhibited lower values for these properties than their Y0.7-dsA counterparts, with these values decreasing further as the proportion of dissolution in the composites increased.

When comparing these results with similar studies, the composites obtained in this research are consistent, with thermal conductivity and density decreasing as the amount of recycled incorporated material increases. However, it is observed that for similar thermal conductivities, the density of the composites developed in this research is significantly higher. Furthermore, the percentage of recycled material added in this study is higher, which increases the rate of waste recovery and recycling. It should be noted that excessively low thermal conductivities (below 150 mW/m·K) are associated with very low densities (below 600 kg/m³), which often have a negative impact on the mechanical performance of the composites, and may even render them technically unviable (del Río-Merino et al., 2022).

3.2 Mechanical characterization

Figure 2 shows the flexural and compressive strength results for the gypsum composites produced; results from similar studies are also included. Furthermore, the minimum mechanical strengths specified in the UNE-EN 13279-2 standard are 1 MPa for flexural strength and 2 MPa for compressive strength.

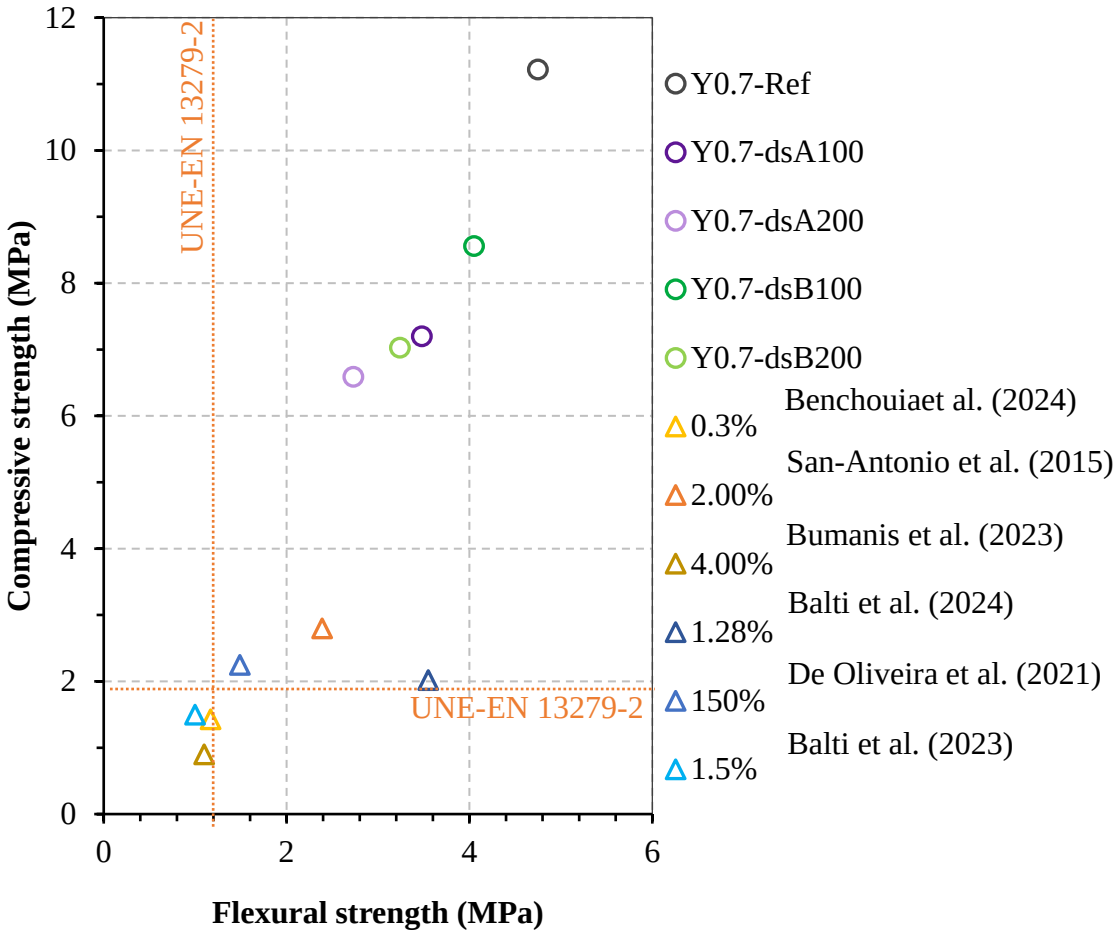


Figure 2. Results for the flexural and compressive strength of the composites produced, compared with other similar studies (percentages of EPS added relative to the weight of the binder).

Figure 2 shows how the incorporation of recycled EPS slurry progressively reduces the mechanical strengths as the proportion of slurry in the composites increases, with the effect being most pronounced in the Y0.7-dsA composites. The lowest flexural and compressive strengths were obtained in the Y0.7-dsA200 composite, with reductions of 42.5% and 41.3% compared to the reference, respectively. In contrast, in the most favorable case (Y0.7-dsB100), the reduction was 14.7% and 23.7% for flexural and compressive strength, respectively. It is thus evident that the property most affected in the composites was compressive strength in all cases.

An analysis of studies in which the waste is incorporated in the solid phase reveals a significant deterioration in mechanical properties. Several of the composites analyzed barely reach the minimum flexural strength threshold of 1 MPa. This deficiency is particularly evident in the compression test, where poor interfacial adhesion between the solid EPS particles and the matrix leads to preferential failure points that compromise the material's structural integrity. Consequently, these composites often exhibit values below the regulatory limit of 2 MPa established by the standard (UNE-EN 13279-2:2014). This behavior contrasts markedly with the results obtained in the present study, in which the mechanical properties not only comply with the standard but also double or even triple the values reported in previous studies

Figure 3 below shows SEM images of the reference composite and the composites with the highest dissolution rates (Y0.7-dsA200 and Y0.7-dsB200).

Figure 3(a) shows the matrix of the reference sample, which has some pores but is generally compact. The acicular crystals characteristic of gypsum sulphate dihydrate (Lanzón et al., 2022) are also visible. On the other hand, in Figures 3(b) and 3 (c), the matrix appears much more porous, with large gaps between crystals, which would explain the reduction in the mechanical properties of the composites. In both cases, a certain shortening and thickening of the gypsum crystals can also be observed, a feature already noted in previous studies (Zaragoza-Benzal et al., 2023), thus confirming the results obtained for the average crystallite size. The main difference observed between the composites with different solutions is that whilst in the Y.7-dsA200 composite the matrix appears more disintegrated, in the Y0.7-dsB200 composite it presents a more cohesive matrix, although the solution produces certain agglomerations of spherical crystals. Both situations would be affecting the mechanical behaviors observed (López Pedrajas et al., 2022).

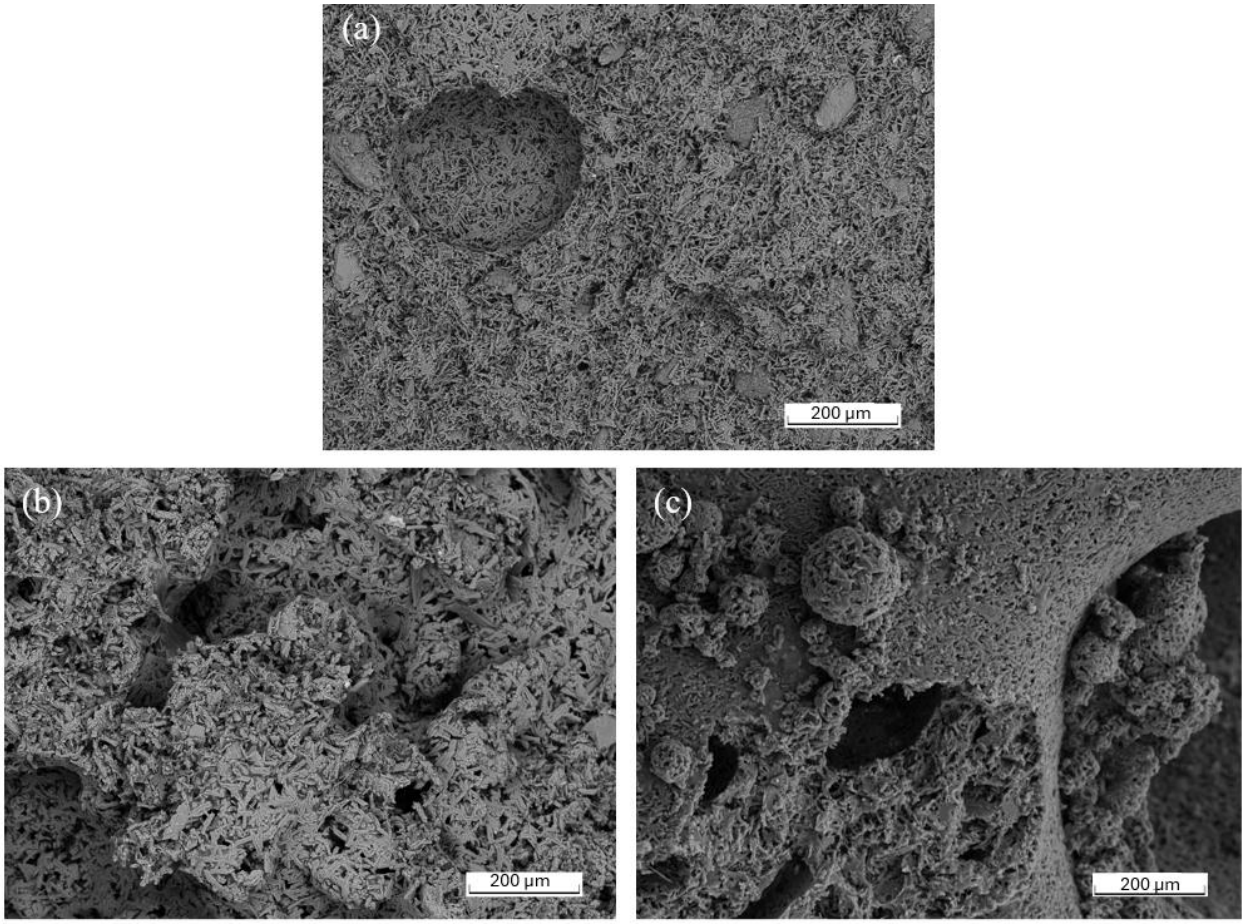


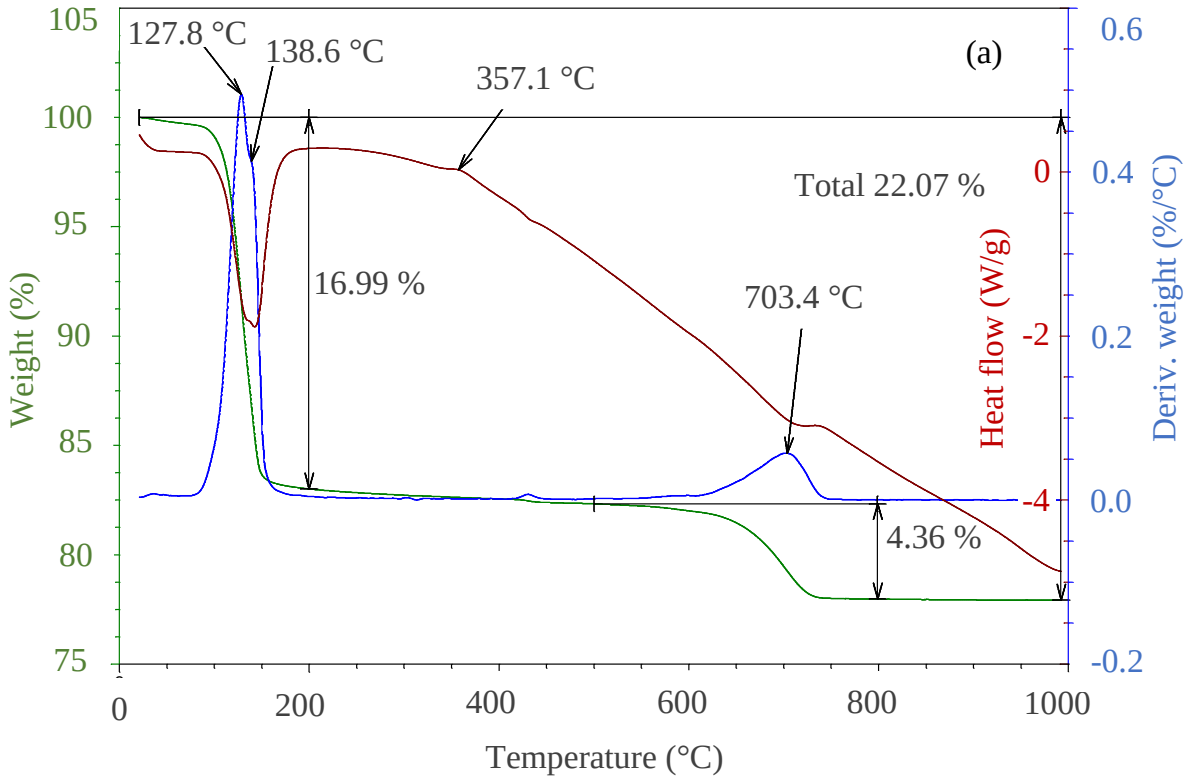
Figure 3. SEM images at 250× magnification of the composites: (a) Y0.7-Ref, (b) Y0.7-dsA200, (c) Y0.7-dsB200.

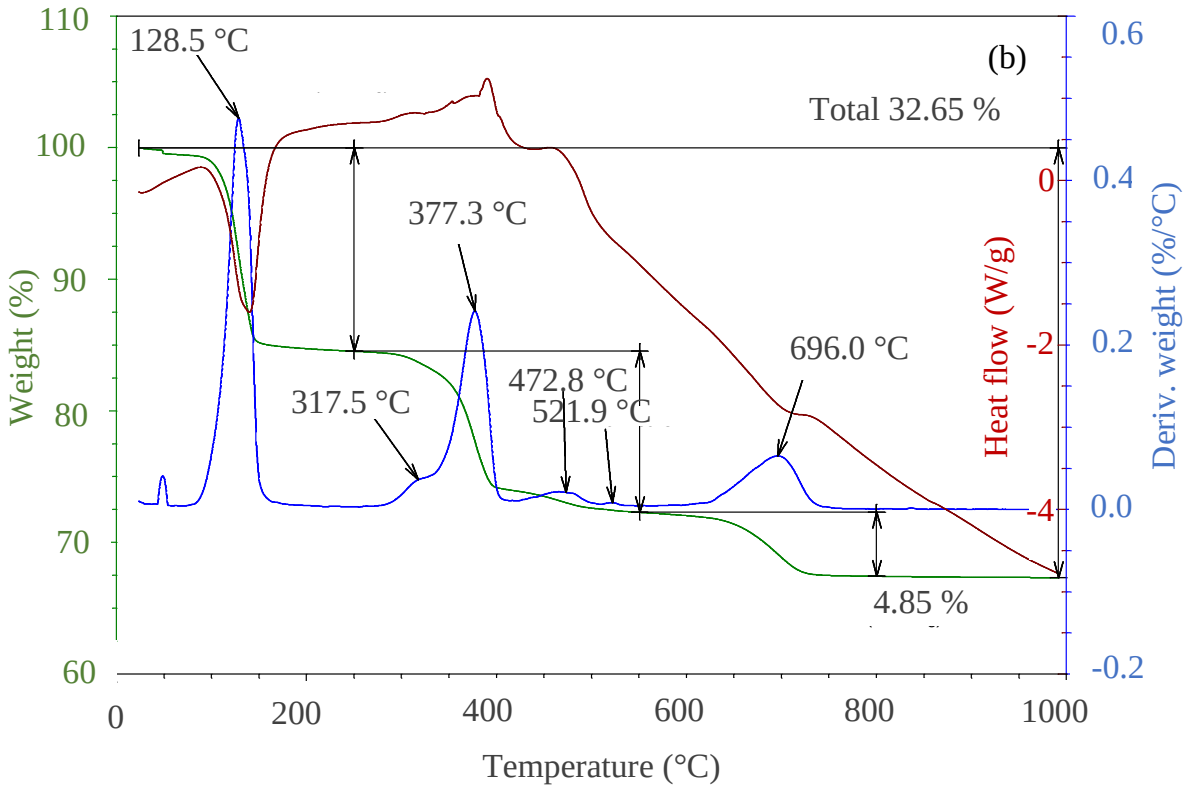
3.3 Physico-chemical characterization

Figure 4 shows the thermogravimetric analyses, where the green line represents the mass loss, the blue line the derivative of the mass loss, and the brown line indicates the heat flux. The test was carried out on the reference sample and the samples with the highest dissolved EPS content (Y0.7-dsA200 and Y0.7-dsB200).

As shown in Figure 4, the reference sample undergoes a total mass loss of 22.07%. Firstly, an initial mass loss (16.99%) occurs during an endothermic process corresponding to the transformation of gypsum sulphate dihydrate into gypsum sulphate hemihydrate, and finally into anhydrite. In the temperature range of 250-550 °C, an exothermic event with no associated mass loss indicates the transformation of α-anhydrite to β-anhydrite. Finally, a small mass loss (4.36%) occurs endothermically in the temperature range 550 °C–700 °C, corresponding to the conversion of calcium carbonate to calcium oxide.

In the samples containing dissolved recycled EPS, the mass loss increases to 32.65% and 29.45% for the Y0.7-dsA200 and Y0.7-dsB200 samples, respectively. In these samples, an exothermic event occurs, corresponding to the combustion of the incorporated polymer. In this process, two distinct mass loss events are observed: the first between 250 °C and 550 °C, and the second between 550 °C and 750 °C. However, for the Y0.7-dsA sample, the mass loss is greater in both events. However, the maximum mass loss rate is similar in both cases.


(a)
127.8 °C
138.6 °C
357.1 °C
703.4 °C
Total 22.07 %
16.99 %
4.36 %
Weight (%)
Heat flow (W/g)
Deriv. weight (%/°C)
Temperature (°C)


(b)
128.5 °C
Total 32.65 %
377.3 °C
317.5 °C
472.8 °C
521.9 °C
696.0 °C
4.85 %
Weight (%)
Heat flow (W/g)
Deriv. weight (%/°C)
Temperature (°C)

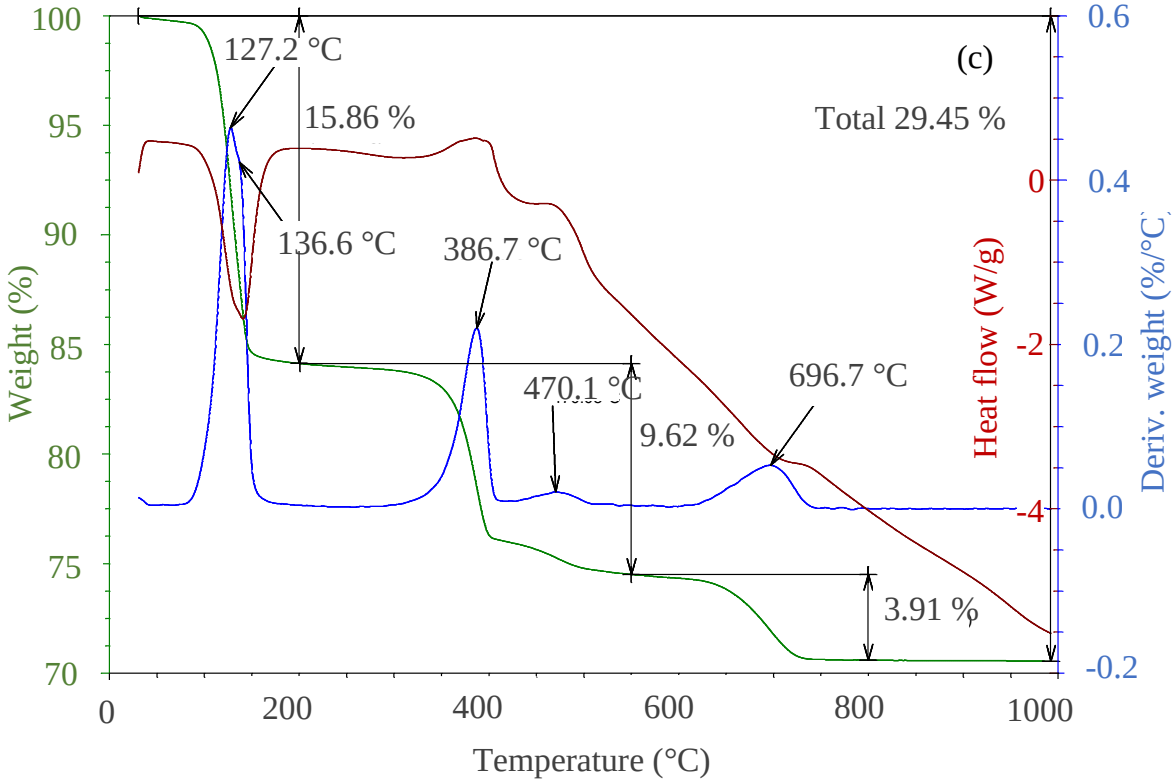


Figure 4. Results of thermogravimetric analyses of: (a) Y0.7-Ref., (b) Y0.7-dsA200, (c) Y0.7-dsB200.

Figure 5 shows the diffractograms for all the samples analyzed in this study; Table 3 lists the average crystallite sizes of the samples.

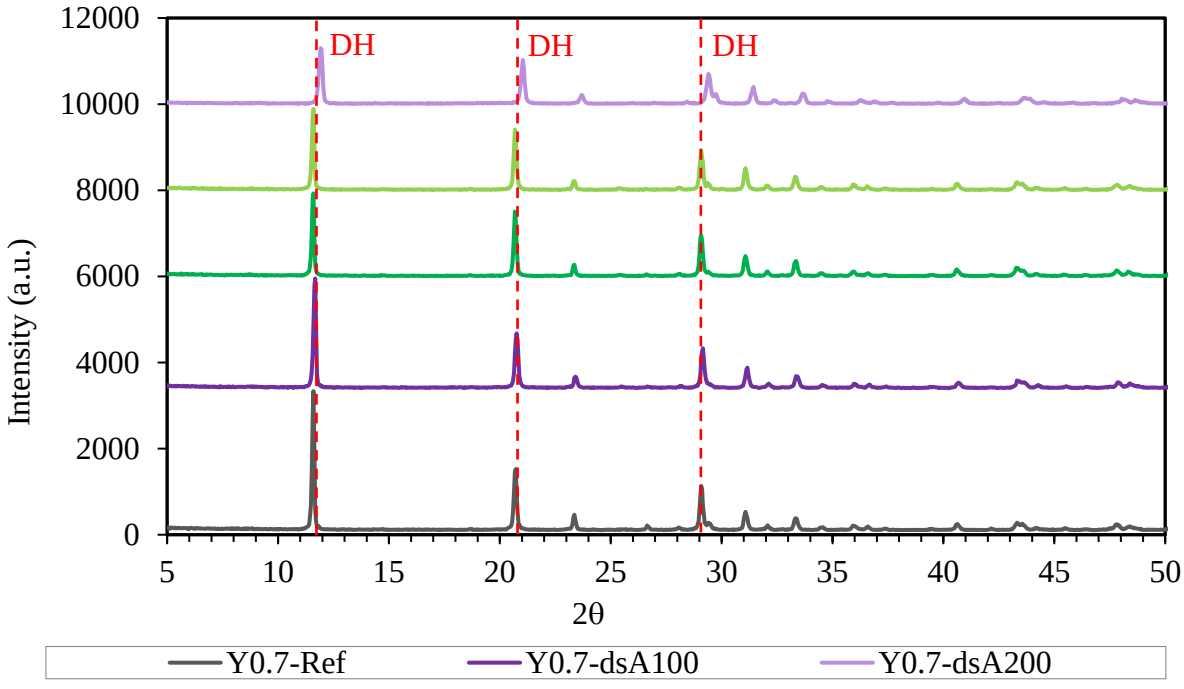


Figure 5. Diffractograms of the samples prepared in this study, showing the main refraction angles of the dihydrate (DH) crystals.

As shown in Figure 5, all composites exhibit peaks corresponding to calcium sulphate dihydrate with the highest intensity at diffraction angles 2θ = 12°, 21° and 29° (Strydom & Potgieter, 1999). In samples where gypsum has been replaced by dsA and dsB, peak intensity decreases, becoming more pronounced as the replacement level increases. In the Y0.7-dsA100 composite, this effect is less evident; however, as the replacement increases in the Y0.7-dsA200 sample, peak intensity is most affected, being the lowest among all samples tested.
Table 3, for its part, complements these results, as the average crystallite size corresponds to the intensities observed in Figure 5.

Table 3. Average size (D) of the ordered crystalline domains in the samples.

Sample	Peak position (2θ, degrees)	β=FWHM (degrees)	D (nm)
Y0.7-Ref	20.69	0.1481	56.97
Y0.7-dsA100	20.75	0.1526	55.27
Y0.7-dsA200	21.04	0.1935	43.61
Y0.7-dsB-100	20.69	0.1532	55.05
Y0.7-dsB-200	20.76	0.1713	49.23

In all samples containing the various solutions, a reduction in crystallite size was observed compared with the reference sample. In the Y0.7-dsA100 and Y0.7-dsB100 samples, the decrease was barely noticeable, whereas it became more evident as the solution volume increased. The Y0.7-dsA200 composite was the most adversely affected in this respect. The modification of crystallite growth upon the inclusion of polymers in solution has been observed by Pedrajas et al. (López Pedrajas et al., 2022), who noted a shortening of the crystals

3.4 Environmental evaluation

Figure 6 shows the results from the LCA, related to CO_2-equivalent emissions (GWP) for the production of 1 m² of board using the designed gypsum composites.

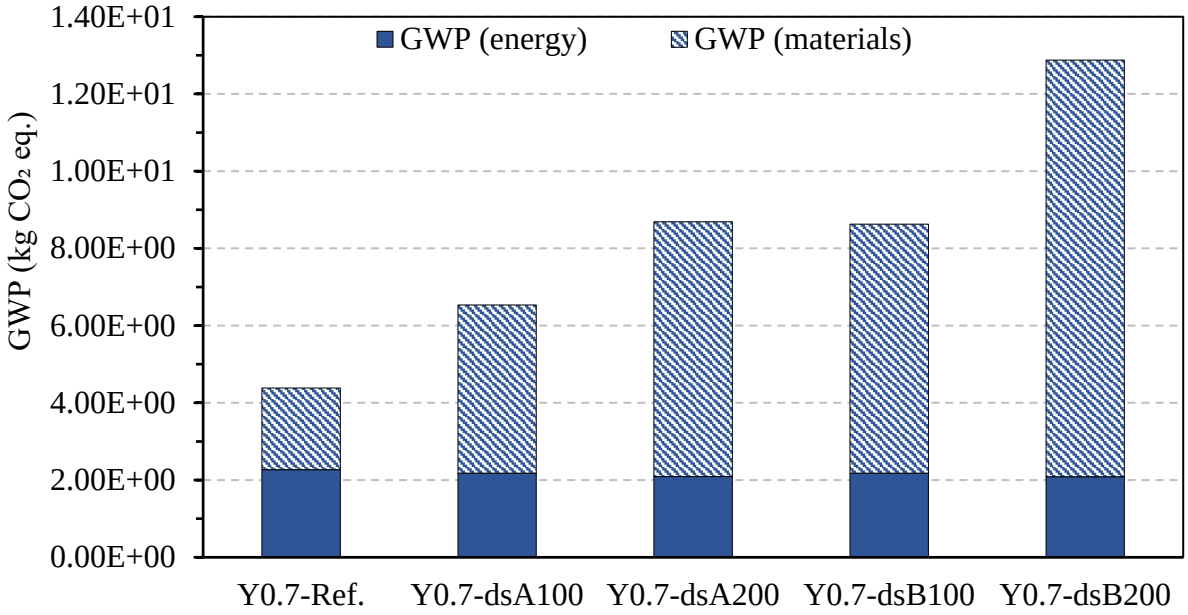


Figure 6. Results obtained for the GWP category, in terms of materials and energy required to produce 1 m² of board using each of the composites produced.

The results shown in Figure 6 demonstrate that, during the production of plates using the composites that include the solution, the energy required decreases slightly compared with the reference, due to the reduction in the material's density. On the other hand, emissions from the materials increase significantly in these same composites, mainly due to the solvents used, with the increase being greater for the dsB solution. These results highlight that although the composites obtained have interesting technical properties, it is necessary to seek other solvents with a lower environmental impact to reduce the emissions generated.

4. CONCLUSIONS

This study has conducted a comprehensive characterization of a new gypsum composite in which the gypsum paste has been partially replaced with various solutions of recycled EPS. The following conclusions can be drawn from the experimental programme carried out:

- Composites containing EPS solution undergo a microstructural change, with their porosity increasing as the amount of solution incorporated increases. Solution dsA caused greater disintegration of the composite, whilst solution dsB tended to form agglomerations of gypsum crystals.
- Increased porosity leads to a decrease in bulk density and thermal conductivity, with this effect being more pronounced in the case of dsB solutions. Similarly, the MOE_{US} and hardness follow the same trend, decreasing progressively as the proportion of gypsum mortar replaced by the solutions increases.
- In all cases, the gypsum crystals were affected, with a reduction in their average size; this was most pronounced in the Y0.7-dsA composites. Furthermore, the TGA results show greater mass loss in these same composites, corresponding to polymer combustion.
- Finally, composites containing solvents increased greenhouse gas emissions, mainly due to the use of solvents as raw materials. It is therefore essential to seek out alternative solvents with a lower environmental impact.

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