Viability of Gypsum Composites with Addition of Glass Waste for Applications in Construction

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Abstract: The design of greener materials is of great interest to develop eco-efficient construction systems, causing less environmental impact and following circular economy criteria. Accordingly, the current study aimed to analyze the viability to incorporate glass waste—from construction and demolition—in gypsum composites, promoting a circular economy in the building construction sector. Gypsum-based composites were formulated using different percentages and particle sizes of glass waste, and samples were prepared. These samples were tested in the laboratory, and the following characteristics were determined: dry density, surface hardness, mechanical strength, water absorption by capillarity, and thermal conductivity. Analysis comparing these composites to reference gypsum without additions showed that it is viable to prepare gypsum composites with the addition of glass waste to reduce water absorption by capillarity, improve mechanical strength, and increase surface hardness. All composites comply with the minimum requirements set by regulations. Therefore, these composites can be applied in the manufacturing of gypsum prefabricated elements or as interior coatings requiring special surface hardness, improved water behavior, and mechanical strength properties.

Author keywords: Construction waste; Recycling; Gypsum; Building; Innovation; Eco-gypsum.

Introduction

Currently, 461 million tons of construction and demolition waste (CDW) are generated per year in the European Union, representing approximately 30% of total waste generated (Eurostat 2017). The proper management of this waste constitutes one of the main pillars of the Europe 2020 Strategy regarding the use of resources, based on the three Rs of a circular economy (reduce, reuse, recycle) (European Commission 2010). Nonetheless, efforts should be focused on turning construction waste into a business opportunity, and the construction industry must adopt the objective of promoting the use of recycled materials (Adams et al. 2017).

According to previous research, the main waste categories generated in building construction are concrete, mortars, and

ceramics (del Río Merino et al. 2018). These wastes have found extensive use as recycled aggregates for concrete and mortars (Matías et al. 2014; Ozbakkaloglu et al. 2018; Saiz Martínez et al. 2016). However, in Spain, the amount of other CDWs has increased in recent years due to an increase of building rehabilitation and retrofitting to improve energy efficiency as a consequence of RD 314/2006, Spain's Technical Building Code (Spanish Government 2006; Villoria Sáez et al. 2018). In particular, glass waste has increased because replacing windows is a common action performed by homeowners due to its simplicity and efficiency in saving energy.

Glass is a transparent material manufactured by melting several inorganic raw compounds at very high temperature, followed by fast controlled cooling, resulting in an isotropic, noncrystallized, hard, stable, and inert material. Glasses are classified based on major composition and the additives used in the manufacturing process. Soda-lime glass, from containers and flat glass, makes up more than 80 wt% of waste glass (Memon et al. 2013; Shi and Zheng 2007). The main raw material is silica; the other most common raw materials are sodium carbonate (Na_2CO_3), limestone (CaCO_3), and dolomite [$\text{CaMg}(\text{CO}_3)_2$]. The resulting glass is composed of oxides originating in the thermal decomposition of the raw materials.

The glass industry uses huge amounts of natural resources as raw materials and is one of the most energy-consuming industries due to the high temperatures needed for melting. However, the recycling of glass as an alternative raw material for manufacturing new construction materials has not had the same success as other aggregates. Although glass waste recovery and recycling are extensive because of the efficiency of remelting glass, there are several difficulties that arise when considering the overall recycling process (Lim 2014). These difficulties have led to a search for alternative recycling options—for example, aggregates for building compounds.

Several studies have analyzed the behavior of different building compounds, where traditional construction raw materials are

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Table 1. Studies on the incorporation of glass waste in gypsum or cement matrix

Reference	Matrix	Waste type	Glass content (%)	Results
Marco et al. (2012)	Cement mortars	Glass powder (0.011–0.016 mm)	70–90	Strength increased with both more fine-grained glass powder used as binder and more cement
Ganjian et al. (2015)	Concrete/paving blocks	Granulated blast furnace, cement dust and crushed glass (4.0–6.0 mm)	53	Best mix achieved with 6-mm replacement: excellent water absorption, freeze/thaw, and density
Bhandari and Tajne (2013)	Cement mortar/blocks	Window glass waste: fine (0.6–1.18 mm); coarse (1.18–4.75 mm)	10–30	Compressive strength decreased as glass waste increased; coarse particles resulted in greater decrease than fine particles; less water absorbed in samples containing waste glass compared with control samples
Lim (2014)	Concrete	Waste glass as fine-powder aggregates in concrete (<4.75 mm)	10–25	Concrete mix with 10% fine aggregate replaced with waste glass maintained compressive strength similar to that of reference
Topcu and Canbaz (2004)	Concrete	Waste glass from bottles (4–6.0 mm)	15–60	Compressive strength decreased with increasing glass waste; with 60% coarse aggregate in concrete mixture replaced with waste glass, tensile strength decreased 37%
Park et al. (2004)	Concrete	Waste glass from bottles: fine aggregate ≤ 5 mm	30–70	Compressive strength decreased with increasing glass waste; with 30% fine aggregate replaced with waste glass, tensile strength decreased 5%
Tounchuen et al. (2014)	Gypsum	Automotive print-screened glass waste powder	0–20	Strength and water insolubility improved

replaced by alternative materials with lower environmental impact. Today, in addition to cement mortar composites, gypsum composites are of crucial importance as finishing materials and are being increasingly used in building construction because they are abundant in nature and have positive technical and ecological properties (Gencel et al. 2016). In particular, the production temperature of gypsum, in comparison with cement, is much lower and thus energy consumption and the CO₂ emissions released during manufacturing are highly reduced compared with the manufacture of cement-based materials. Many studies have explored the behavior of gypsum composites incorporating different construction and demolition wastes, thus helping to close the cycle of the waste generated in building construction and promoting circular economy criteria (Gutiérrez González et al. 2012; Morales Conde et al. 2016; San-Antonio-González et al. 2016; Vidales Barriguete et al. 2018).

Regarding glass waste recycling, much research has focused on incorporating glass in different proportions and sizes for the production of cement mortars (Bhandari and Tajne 2013; Marco et al. 2012; Park et al. 2004), concrete (Du and Tan 2014; Topcu and Canbaz 2004), and ceramic compounds (Kazmi et al. 2017) (Table 1). Several literature reviews on the addition of glass waste in cement composites have been published (e.g., Jani and Hogland 2014; Mohajerani et al. 2017). In particular, Jani and Hogland (2014) reported studies using up to 75% glass waste aggregate of two particle sizes: coarse grain (2.36–0.60 mm) and fine powder (0.30–0.15 mm). This literature review revealed that there is no clear information on how the amount of glass waste added and particle size affect the mechanical properties of concrete (Jani and Hogland 2014; Mohajerani et al. 2017).

Despite much research on using glass waste in cement mortars and other composites, little has been found on incorporating glass in gypsum (Shi and Zheng 2007). Only one study investigated the addition of up to 20% glass waste powder—from the automotive industry—in gypsum (Tounchuen et al. 2014). Its results showed that glass powder improved the resistance and water insolubility of the gypsum composite. For such reasons, the behavior of gypsum incorporating higher percentages of glass waste is of great interest.

This study attempted to further analyze the feasibility of incorporating glass waste in gypsum, increasing the amount added by previous researchers and considering two particle sizes. Gypsum composites containing glass waste can be used as interior coatings or for the production of gypsum-based prefabricated elements needing higher superficial hardness and mechanical behavior. Furthermore, incorporating these fillers in a gypsum matrix reduces the amount of raw material used for its manufacture and represents an improvement over gypsums without additions.

Materials and Experimental Plan

The materials used in this study were

- Coarse gypsum, referred to here as YG, consisting of calcium sulfate hemihydrate and supplied by Saint Gobain Placo (Madrid, Spain).
- Colorless glass waste, obtained from window glass at a building site, crushed with a Micro-Deval crusher (Ibertest, Madrid, Spain) and sieved to obtain coarse-grain (1–2 mm) and fine-powder ($\leq 125 \mu\text{m}$) particles referred to as G and F, respectively (Fig. 1).

Fig. 1. Glass waste: (a) coarse grain; and (b) fine powder.

An experimental plan was developed to analyze the properties of the different gypsum composites. Twelve series of gypsum samples incorporating different percentages of glass waste were prepared with a water/gypsum ratio of 0.8 (Table 2). The experimental plan unfolded in four phases.

In Phase 1, both coarse-grain and fine-powder glass waste was progressively added to gypsum powder. The resulting mixture was combined with water and mixed in a planetary mixer for 2 min, according to European Standard EN 13279-2 (CEN 2006), for homogenization. Three $4 \times 4 \times 16\text{-cm}^3$ samples were formed which were kept for 7 days in a laboratory atmosphere (temperature of $23 \pm 2^\circ\text{C}$ and relative humidity of $37 \pm 1\%$) and stored for 24 h in a Stove IEP Control (IEP Control, Madrid, Spain) model 150 stove at $60 \pm 2^\circ\text{C}$ before testing.

In Phase 2, the samples were tested for density and Shore C superficial hardness as well as compressive and flexural strength. For each test, the mean value achieved with the three samples was calculated and the results were compared not only with the reference sample—to calculate the percentage of deviation—but also with the minimum values established by EN 13279-1 (CEN 2009) for regular gypsums (Type B1) (Table 3). The relationship to estimate the compressive and flexural strength of a gypsum composite once its density is known was also explored by analyzing the results obtained for each sample with different linear regressions, using Microsoft Excel, to obtain the data trend equation. The models' coefficients of determination (R^2) were also determined.

In Phase 3, the composites performing better in the second phase were selected and further tested for water absorption by capillarity and thermal behavior. Once the measurements were

taken, the average values were obtained and compared with the reference sample. Also, a Dino-Lite microscope was used to observe how the waste was distributed and how it bonded with the gypsum composites.

In Phase 4, the reduction in consumed raw material (gypsum) was analyzed in selected composites and compared with the reference sample. This analysis involved the quantities of each material (gypsum, glass, and water) to produce the three samples as well as their weight after demolding.

Experimental Procedures

Glass Waste Characterization

The chemical composition of the glass waste was analyzed by X-ray fluorescence on a Philips Magix (Philips, Spain) machine. Using a Quantachrome SPY-3 stereopycnometer, the real density was determined by measuring the volume of helium [Air Liquide (Madrid, Spain) ALPHAGAZ 99.999%] evacuated by a known mass of sample. The loose bulk density of the glass samples was determined by pouring the solid into a 50-ml test tube and dividing the mass by the volume of bed. It was calculated as the mean value of three measurements for each sample. Loose bulk density was used to measure the macroscopic volume of particles (including internal pores) plus the volume of voids between them. In addition, X-ray diffraction patterns were obtained in a Siemens Krystalloflex D5000 (Siemens, Madrid, Spain) unit using a graphite monochromator with Cu K α (1.2). The samples were scanned over the range $5^\circ \leq 2\theta \leq 100^\circ$ every 0.04° , 1s per step.

Mechanical Characterization

Samples were mechanically and physically tested according to dry density, Shore C surface hardness, and flexural and compressive strength using the Ibertest Autotest 200/10-SW (Ibertest, Madrid, Spain) 200/10-SW test frame according to EN 13279-2 and UNE 102042 (AENOR 2014) standards.

Water Absorption by Capillarity and Thermal Conductivity

Water absorption by capillarity was tested following the methodology developed by Vidales Barriguete et al. (2018) and Del Río Merino et al. (2018), which follows European Standard EN 459-2 (CEN 2011). Samples were weighed and placed vertically in a container with a bottom grid and containing 10 mm of water. Capillarity absorption was measured after 10 min. Samples were weighed before and after the test, and the amount of absorbed water was calculated using the difference between these measurements. Finally, the water capillarity coefficient was obtained using Eq. (1) (Juhász et al. 2014)

$$k = \frac{m}{A\sqrt{t}} = \frac{m}{0.04 \times 0.04 \text{ m}^2 \sqrt{10 \text{ min}}} \quad (1)$$

where m = volume of = absorbed water (kg); A = absorbing surface ($0.04 \times 0.04 \text{ m}^2$); and t = time (10 min).

Thermal conductivity was obtained by means of heat transfer at steady-state using a thermal conductivity analyzer [Model C-Therm TCi (C-THERM Technologies, Madrid, Spain)]. Samples were dried in a stove at $60 \pm 2^\circ\text{C}$ for 24 h and left in a desiccator before testing in the laboratory. A thermal grease was applied on the surface of the sensor and the sample was placed on top. Thermal conductivity was measured in at least six different areas of the sample.

Table 2. Composition of gypsum samples

Series	Composites	Composition
1	REF	Reference sample: no glass waste added
2	YG + 20%F	Different wt% addition of fine-powder glass waste (<0.125 mm)
3	YG + 30%F	
4	YG + 40%F	
5	YG + 50%F	
6	YG + 70%F	
7	YG + 90%F	Different wt% addition of coarse-grain glass waste (1–2 mm)
8	YG + 100%F	
9	YG + 20%G	
10	YG + 50%G	
11	YG + 75%G	
12	YG + 100%G	

Table 3. Specifications for gypsum in construction

Type	Flexural strength (N/mm ²)	Compressive strength (N/mm ²)	Superficial hardness (N/mm ²)
B1—Gypsum for construction ^a	≥1	≥2	—
B2—Gypsum mortar ^b			
B3—Gypsum mortar with lime ^c			
B4—Lightweight gypsum ^a			
B5—Lightweight gypsum mortar ^b			
B6—Lightweight gypsum mortar with lime ^c			
B7—High-hardness gypsum for construction ^a	≥2	≥6	≥2.5

Source: Data from CEN (2009).

^aAmount of gypsum ≥50%.

^bAmount of gypsum <50%.

^cAmount of gypsum depends on whether gypsum alone (>50%) or gypsum mortar (<50%); in all cases, lime content is >5%.

Measurements were taken on all sides except for the upper side, which had a rough surface.

Results and Discussion

Glass Waste Characterization

The chemical composition of the flat glass used is provided in Table 4. The results obtained follow the conclusions reached in the literature for soda-lime glass, which is typically used in the manufacture of flat glass (Jani and Hogland 2014). The main component is silicon oxide for network forming, organized in a three-dimensional (3D) structure of SiO_4 tetrahedra; in minor quantities calcium, sodium, and magnesium oxides constitute the network modifiers.

The real density obtained for the glass waste was 2.7 g/cm^3 ; the loose bulk densities achieved for coarse-grain and fine-powder glass waste were 1.40 and 1.21 g/cm^3 , respectively. Results from the X-ray diffraction test, shown in Fig. 2, reveal the low crystallinity of the sample and the presence of the characteristic band of the amorphous silica (Carsana et al. 2014; Galvão et al. 2015). The amorphous character of glass is due to the disordered 3D network of silicon tetrahedra formed during fast cooling in the manufacturing process (Shi and Zheng 2007).

Mechanical Characterization

According to the results obtained from the density test, all composites increased in density compared with the reference sample. For this reason, according to EN 13279-1, gypsum composites containing glass waste additions cannot be considered lightweight (Type B4) because all densities surpass 1 g/cm^3 . Moreover, results for composites containing the same percentage of glass waste but different particle size (coarse grain or fine powder) showed higher densities with coarse-grain particles compared with fine powder

Table 4. Chemical composition of fine-powder glass waste obtained by XRF

Oxide	wt%
SiO_2	72.8
CaO	19.4
Na_2O	3.43
MgO	2.12
Fe_2O_3	0.852
Al_2O_3	0.485
SO_3	0.338
TiO_2	0.193

Fig. 2. Diffractogram of fine-powder glass waste.

(Fig. 3). In particular, the density of the samples containing 100% fine-powder or coarse-grain glass increased 39.7% and 48.75%, respectively, compared with the reference sample.

When comparing the densities obtained with glass waste in this study with those achieved in other studies with other CDWs in gypsum, it is seen that the densities obtained here are similar to the ones obtained with ceramic waste [del Río Merino et al. (2018)]. Del Río Merino et al. (2018) incorporated ceramic waste with a particle size of 1–2 mm in gypsum and achieved 1.25 g/cm^3 in composites containing 50% ceramic waste over the weight of the gypsum.

Figs. 4 and 5 show the flexural and compressive strength values obtained for each composite. Fig. 4 shows that those containing fine-powder glass waste achieve better flexural strength values as the percentage of glass increases. However, this trend stops when more than 70% fine-powder glass waste is added; at 90% and 100%, flexural strength values slightly decrease although they are still above the reference value. In contrast, flexural strength values decrease when coarse-grain glass aggregates are added, reaching up to a 14% decrease compared with the reference value (gypsum containing 75% coarse-grain glass waste). Experimental results from different studies of cement composites agree that flexural strength decreases with increasing coarse-grain glass waste (Du and Tan 2014; Jani and Hogland 2014).

According to the compressive strength results shown in Fig. 5, it is observed that, generally, a higher percentage of fine-powder glass waste results in greater compressive strength—in this study, increasing resistance up to 60% compared with the reference sample.

Fig. 3. Mean density results obtained for the series analyzed.

Fig. 4. Mean flexural strength obtained for the series analyzed.

Fig. 5. Mean compressive strength obtained for the series analyzed.

Fig. 6. Relationship between compressive strength and density obtained for each sample.

An increase in compressive strength was also found when up to 20% fine-powder glass waste was added to concrete (Batayneh et al. 2007). However, coarse-grain glass waste led to compressive strength values similar to the reference value. Lower compressive strength was also found by Topcu and Canbaz (2004) in cement mortars incorporating coarse-grain glass waste aggregates, due to the aggregates' poor shape, which caused a decrease in adhesive strength between the aggregates and the gypsum (Park et al. 2004).

In general, the results obtained for mechanical strength were better when small particle sizes were incorporated. These results are in agreement with conclusions reached by other studies on cement mortar composites and glass waste (Jani and Hogland 2014; Mohajerani et al. 2017). Therefore, particle size of the glass waste used is an important factor influencing the mechanical behavior of a gypsum composite.

Figs. 6 and 7 show the relationship between density and mechanical strength for each sample. It is observed that coarse-grain glass waste composites perform similarly to the reference sample in all cases, despite having higher densities. In contrast, only compounds with fine-powder glass follow a clear trend, increasing resistance as density increases. In particular, an increase up to 23.5% in flexural strength and around 60% in compressive strength is observed in samples containing 100% fine-powder glass waste.

Equations describing the relationship between density and mechanical strength for composites containing coarse-grain and fine-powder glass waste were explored, but in general adjustment with the data was too low to be accepted ($R^2 < 0.4$), especially

Fig. 7. Relationship between flexural strength and density obtained for each sample.

Fig. 8. Mean superficial hardness obtained for the series analyzed.

for composites with coarse-grain glass waste. However, a good adjustment was found for the polynomial equation describing the relationship between compressive strength and density for composites containing fine-powder glass waste [Eq. (2) and Fig. 6]

$$C = 16.458\rho^2 - 28.606\rho + 18.109 (R^2 = 0.921) \quad (2)$$

where C = composite compressive strength (MPa); and ρ = composite density (g/cm^3).

Results for Shore C hardness are shown in Fig. 8. In this case, all values exceed the reference value, reaching 41.7% when 100% with fine-powder glass and 25% with the same percentage of coarse-grain glass.

The results obtained in the mechanical tests show that all gypsum composites containing glass waste comply with the minimum values set by regulation for standard gypsums (Type B1). However, they also reveal that some composites comply with the values set by Standard RP 35.04 (AENOR 2009) for high-hardness gypsums (Type B7):

- Superficial hardness ≥ 75 Shore C
- Compressive strength ≥ 6 MPa
- Flexural strength ≥ 2 MPa
- Thermal conductivity coefficient = 0.34 W/mK

In general, the analyzed gypsum composites comply with minimum flexural strength (2 MPa) and compressive strength (6 MPa) standards for high-hardness gypsums (especially compounds containing fine-powder glass). Furthermore, composites containing more than 40% fine-powder glass comply with regulations

Table 5. Results for water absorption by capillarity

Composite	Water absorption (mm)	Absorbed water (g)	Capillarity coefficient [kg/(m ² /min ^{0.5})] ^a
Reference	74.00	50.60	10.00
YG + 50%F	36.33	36.83	7.28
YG + 70%F	36.27	33.07	6.54
YG + 100%F	32.83	29.83	5.90

^aCapillarity coefficient calculated using Eq. (1).

Table 6. Results for thermal behavior

Composite	Thermal conductivity λ (W/mK)
Reference	0.35
YG + 50%F	0.27
YG + 70%F	0.28
YG + 100%F	0.31

Fig. 9. Microscopic images (50 $\times$) of the reference sample and a gypsum-based composite.

for high-hardness gypsums, reaching values above 75 Shore C. Also, all densities are similar to those published by del Río Merino et al. (2018) for high-hardness gypsums.

Water Absorption by Capillarity and Thermal Conductivity

Three composites containing fine-powder glass were chosen due to the good results obtained in the mechanical tests: YG + 50%F, YG + 70%F, and YG + 100%F. These composites can be applied in continuous coatings or prefabricated elements for interior partitions needing higher hardness, due to their good properties of superficial hardness and mechanical strength.

Tables 5 and 6 provide results for thermal conductivity and water absorption by capillarity for selected composites containing 50%, 70%, and 100% fine-powder glass. In addition to the three selected composites, the reference gypsum (without additions) was tested for comparison. It was found that adding fine-powder glass reduced water absorption by capillarity in the gypsum reference without additions (Table 5). In particular, the water absorption and capillarity coefficient can be reduced around 44.4% and 59%, respectively, with compounds containing 100% fine-powder glass.

According to the results provided in Table 6, the thermal conductivity coefficients of the gypsum composites are similar to that of the reference sample, achieving about 0.3 W/mK for all composites tested.

Finally, Fig. 9 shows the reference sample and a gypsum-based composite containing glass powder. It is seen that the glass waste is well distributed and adheres to the gypsum matrix.

Consumption of Raw Material

One of the main aims of this study was to provide a way to reduce the amount of natural resources consumed during the manufacture of gypsums composites. For this reason, the amount of gypsum that can be saved or reduced when glass waste is incorporated in composites was explored. Table 7 provides percentage reductions in raw material (i.e., gypsum) with respect to the reference gypsum

Table 7. Reduction in raw material consumption compared with reference sample

Composite	Material	Content (wt%)	Per sample		Quantity per cubic meter	Reduction in raw material per cubic meter (wt%)
			Weight (g)	Volume (cm ³) ^a		
Reference	Gypsum	55.56	218.8	84.17	0.32	—
	Water	44.44	175.1	175.00	0.68	
	Fine-powder glass	0.00	0.0	0.00	0.00	
	Total	100.00	393.9	259.17	1.00	
YG + 50%F	Gypsum	43.48	185.9	71.49	0.28	13.5
	Water	34.78	148.7	148.7	0.58	
	Fine-powder glass	21.74	92.9	34.42	0.14	
	Total	100.00	427.5	254.60	1.00	
YG + 70%F	Gypsum	40.00	175.8	67.62	0.27	18.0
	Water	32.00	140.6	140.6	0.55	
	Fine-powder glass	28.00	123.1	45.58	0.18	
	Total	100.00	439.5	253.83	1.00	
YG + 100%F	Gypsum	35.71	163.5	62.90	0.25	23.8
	Water	28.57	130.8	130.8	0.51	
	Fine-powder glass	35.71	163.5	60.57	0.24	
	Total	100.00	457.9	254.30	1.00	

^aDensities used to obtain volume: 2.7 g/cm³ (glass waste); 2.6 g/cm³ (gypsum); and 1 g/cm³ (water).

without additions. The results show that incorporating fine-powder glass, from 50% to 100% over the weight of gypsum, reduces the amount of gypsum raw material by 13.4% and 23.8%, respectively. The workability of the selected composites varies depending on the amount of waste because the waste absorbs a small part of the mixing water, although it still mixes well. Therefore, the progressive addition of higher percentages of fine-powder glass waste requires greater water quantities to ensure the same consistency.

Conclusions

It is feasible to use glass waste as a substitute for gypsum as a way to encourage the generation of greener construction materials, which generally have lower costs and meet the principals of cleaner production. The addition of glass waste in a gypsum matrix has a noticeable effect on the physical and mechanical properties of the gypsums, improving mechanical and surface hardness compared with gypsums without additions. All gypsum composites analyzed in this study comply with current regulations. In particular, those containing over 40% fine-powder glass waste can be considered high-hardness gypsums, as they comply with the minimum specifications set by regulations for this gypsum type (Type B7).

Although all of the composites studied comply with minimum requirements, fine-powder glass waste is highly recommended because it provided better results in the tests performed. The gypsum composite containing 100% fine-powder glass (over the weight of the gypsum) improved compressive strength by around 60% compared with the reference gypsum. Furthermore, fine-powder glass can increase surface hardness by around 40% compared with an increase of 25% obtained with coarse-grain glass waste. Also, the composite containing 100% fine-powder glass reduced the gypsum content by around 23% compared with the reference sample. Finally, fine-powder glass reduced water absorption by capillarity by up to 45%.

A clear relationship was found between the density and compressive strength of gypsum composites containing fine-powder glass waste. An equation was determined aiming to estimate the compressive strength of the gypsum composite once its density was known. In contrast, composites containing coarse-grain glass waste kept mechanical resistance constant (similar to that of the reference) despite increasing the amount of glass and thus density.

Based on physical and mechanical properties, as well as the low environmental impact of gypsum composites with glass waste, it is worth mentioning that construction products may be produced from mixes containing up to 100% fine-powder glass waste. In particular, these gypsum composites can be used as coatings for interior partitions or for gypsum-based prefabricated elements (such as boards for false ceilings) needing high superficial hardness and better performance against water capillarity. In this way, the consumption of finite resources can be reduced. Also, the use of glass waste will reduce the amount of natural gypsum and thus the corresponding costs of extraction and preparation.

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