Prototype of alveolar gypsum blocks with plastic waste addition for partition walls: Physico-mechanical, water-resistance and life cycle assessment

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Abstract

The development of eco-friendlier building products incorporating waste as an alternative to raw materials has become increasingly relevant within the construction industry. With this in mind, this study presents a prototype of an alveolar gypsum block for partition walls, wherein partial replacement of the binder (i.e. gypsum or cement) was made using two types of plastic waste (i.e. polypropylene- and nylon-based). Two plastic waste-containing composites, with contents considered as optimum in previous studies (AGB/PP/7.5 - 7.5 wt% polypropylene content; AGB/PA6/2.5 - 2.5wt% nylon content), were produced and extensively analysed in comparison to a reference block. Physico-mechanical (bulk density, surface hardness, flexural and compressive strength), water permeability and thermal properties were evaluated and compared to commercially available counterparts. In addition, the prototypes' environmental impact was determined by conducting a simplified life cycle assessment primarily based on the "Global Warming Potential" and "Embodied Energy" categories. The results showed a widespread improvement in the mechanical performance of plastic-containing blocks and more so for those reinforced with nylon fibres when compared to the reference product. Furthermore, notable reductions in thermal conductivity and water permeability were observed on the blocks due to the addition of plastic waste. Both types of blocks presented a slight environmental impact decrease because of the reduction of raw materials (i.e. gypsum). These findings are encouraging from a practical application point of view and may create a notable opportunity for replacing more frequently gypsum with polypropylene- or nylon-based wastes for alveolar blocks for building partition walls.

Keywords: Polypropylene waste; nylon waste; gypsum block; physico-mechanical performance; life cycle assessment

HIGHLIGHTS

- Use of plastic waste to manufacture eco-friendly alveolar gypsum blocks
- Plastic waste-containing blocks showed improved mechanical performance
- Significant reduction in water permeability and thermal conductivity with plastic use
- Lower environmental impact was achieved due to the decreased use of raw materials

ABBREVIATIONS LIST

AGB - Alveolar gypsum block

CC - Coffee capsule

CoV - Coefficient of variation

CO_2 - Carbon dioxide

EE - Embodied energy

EPS - Expanded polystyrene

EU - European Union

FNs - Fishing nets

G - Gypsum

GWP - Global warming potential

HDPE - High-density polyethylene

ITZ - Interfacial transition zone

LCA - Life cycle assessment

LCI - Life cycle inventory

LCIA - Life cycle impact assessment

LDPE - Low-density polyethylene

LFS - Ladle furnace slags

PA - Polyamide

PA6 - Nylon

PC - Polycarbonate

PE - Polyethylene

PET - Polyethylene terephthalate

PP - Polypropylene

PUR - Polyurethane foam

W/G - Water/gypsum

XPS - Extruded polystyrene

1 INTRODUCTION

Climatic change is one of the most concerning environmental challenges currently being faced worldwide. Although many efforts to tackle this widespread issue are exerted at a political level, such as the reduction of greenhouse gas emissions to 55% by 2030 (European Commission, 2020), an increase of alternative decarbonisation approaches in different industrial sectors is needed. The construction industry stands as one of the main sectors that generate the highest negative impacts on the environment since it is responsible for 39% of energy-related global carbon dioxide (CO_2) emissions, wherein 28% comes from operational carbon and 11% arises from energy applied to produce construction materials (World Green Building Council, 2019). Therefore, there is a considerable necessity for cross-sector coordination to revolutionise this industry towards a net zero future, focused mostly on tackling the materials' embodied carbon and other adverse impacts like dust/gas emissions, noise pollution, waste generation, water consumption, and air pollution (Dräger & Letmathe, 2022). Such changes at the corporate level in construction are fundamental for the creation of more environmental-friendly building materials, which have attracted a lot of attention from researchers in the construction field (Brahami et al., 2022; Gangadhara et al., 2022; Zhang et al., 2022), capable of complying with European targets and the UN 2030 Agenda.

The generation of plastic waste, due to uncontrolled production and unsuitable waste management, has become one of the most hazardous types of environmental pollution; over 57 million tonnes of plastic are produced annually in Europe while barely ~10% of post-consumer plastic is recycled (Plastic Europe, 2022). This needs to be addressed by the different sectors involved (i.e. production, using-life, disposal and waste treatment steps) to enhance materials' circularity, mainly the construction sector due to its annual plastic consumption (around 22% of plastic produced at a European level) and wide-ranging relevance in the global economy. An interesting solution would be extending the service life of construction systems by improving their properties or developing new eco-friendly materials by using recycled wastes as a total or partial replacement for raw materials (i.e. gypsum, cement, coarse, sand) (Gao et al., 2021,2023; Umar et al., 2021; Reshma et al., 2022).

There is a growing awareness of the production of new plastic waste-containing construction materials inserted in a circular economy model, which leads to cost reductions, energy savings, and products with better performance (Manjunatha et al., 2022; 2021a). The most sensible solutions offered by researchers within the construction sector to this problem have been: replacing part of the natural aggregate fraction in concrete/asphalt production with plastic waste (Manjunatha et al., 2021b; Thejaswi et al. 2023), using polymeric wastes as reinforcement fibres of concrete or gypsum/mortar composites (Reshma et al., 2021; Manjunatha et al., 2021c) and partially replacing raw binder materials (i.e.. cement or gypsum) to produce new products for building applications like plaster, bricks or precast panels and blocks (Adiyanto et al., 2022; Lamba et al., 2022; Nyika & Dinka, 2022). Considering those structural materials must comply with strict standards to be used in construction, most of those new products containing plastic waste are implemented as non-structural construction systems.

Interesting studies have been conducted on plastic-containing concrete and bitumen elements for pavement construction. For example, Koppula et al. (2023) analysed the effect of a balanced mix containing high-density polyethylene (HDPE), quartz sand, and bitumen to produce new lightweight pavement bricks, which showed reasonable strength and reduced water absorption in comparison to conventional ones. The reinforcement of concrete pavement bricks by using waste plastic fibres (i.e. nylon) was also explored by Yin et al. (2021). In this study, the optimal performance in bending strength and water absorption corresponded to composites with a water/cement (w/c) ratio of 0.40 and waste fibre/cement addition ratio of 1% by volume (v/v%), thus demonstrating the technical viability of using waste plastic fibres.

According to the literature, the development of building bricks by recycling plastic waste as sustainable construction materials has attracted the attention of many researchers (Singh et al. 2023). Among them, the work conducted by Raj and Somasundaram (2022) should be highlighted, wherein aerated concrete masonry blocks incorporating tyre waste powder (up to 15 wt%) as replacement of fine aggregate were manufactured. The authors reported weight reduction, and an improvement in water absorption, water permeability and sorptivity. Attending to the unsustainable waste management menace of E-waste plastics, which are mainly landfilled or burned, Arya et al. (2023) presented a safe recycling proposal towards transforming obsolete keyboard-based plastic into fine aggregate to produce concrete mixed with eggshells and fly ash for masonry blocks production (EN 771-1 +A1, 2016). The highest comprehensive strength (~15 MPa) was obtained with the combination of 3.12%, 3.12%, and 6.25%, relative to E-waste, eggshell, and fly ash, respectively, and thus the product could be classified as second-class brick.

Zulkernain et al. (2022) analysed the influence of using different types of plastics (i.e. PET, HDPE, LDPE, PP) as partial replacement (up to 6 wt%) of sand in the manufacture of cement bricks. As a result, it was confirmed that the proposed mathematical model developed can be used to predict the required hardened properties of plastic cement bricks, leading to greater use of plastic waste in building materials. In addition, the combination of waste gypsum (i.e. wet flue gas desulfurization - WFGD) and fly ash (0-40 wt% replacement level of WFGD) to produce composite blocks was studied by Sithole et al. (2023). The mechanical performance significantly decreased with fly ash addition in comparison to reference WFDG, due to the low pH of the binary mix and reduced pozzolanicity of fly ash incorporated. However, it was suitable to prepare lightweight composite bricks that comply with the minimum compressive strength of 1.5 MPa set by standard to be used in construction, by applying a curing temperature of 40 °C at a 20 wt% fly ash level of replacement.

The need to accelerate and standardise construction techniques to reduce cost, speed up time and minimize environmental impacts has promoted the search for new products that allow precast and modular construction systems. With this in mind, gypsum products have been progressively more implemented in practice due to their versatility, vast number of possible applications, low-cost and relatively low-impact material, and adequate thermal and acoustic properties (Lushnikova and Dvorkin 2016).

Numerous research studies have been conducted on possible alternative recycled solutions for plastic waste as aggregate for gypsum mixes to develop gypsum-based construction products. Pedreño-Rojas et al. (2020b) proposed eco-friendly gypsum plates reinforced with CD and DVD residues. Polycarbonate (PC) waste was used as crushed aggregate in the gypsum matrix, as full pieces into the plates (4 scenarios) or combining them. As a result, lighter plates (around 15% decrease with 60 wt% PP content, in comparison to reference plate) with lower thermal conductivity values (around 0.16 W/(mK)) were obtained. It was found that the best mechanical performance was achieved by the combined use of both reinforcement options, i.e. crushed aggregate and full pieces. Likewise, the use of plastic waste sourced from discarded cables as a partial replacement of gypsum in the production of plasterboards was studied by Vidales-Barriguete et al. (2021a; 2021b). These authors reported that the modulus of elasticity of the new material was enhanced by ~50%, leading to a notable improvement in cracking and impact resistance, when compared to traditional boards. Replacement levels of up to 50 wt% of cable waste were suitable to obtain adequate values of flexural strength within standard requirements. Moreover, plasterboards' resulting roughness pointed to an increase in adherence with an eventual render.

Concurrently, innovative studies related to the proposal of eco-friendly gypsum blocks by incorporating different types of waste as an alternative to traditional brick partition walls have been found in the literature. Among them, the research conducted by Singh et al. (2023, 2022), wherein agricultural waste-based gypsum hollow blocks (600 mm × 300 mm × 150 mm) were produced with a density of between 1070-730 kg/m^3 after adding 0-15 wt% of rice straw-based fibres, should be highlighted. When compared to the solid blocks, the compressive strength of the hollow blocks decreased by 20-50%, but the thermal and acoustic insulation significantly increased. The load-carrying capacity of agro-waste hollow gypsum blocks at an elevated temperature of 800 ºC was also studied, obtaining encouraging results: A1 non-framing material, according to Euroclass classification.

The design of gypsum-based prefabricated blocks was also explored by Santamaría-Vicario et al. (2022), who determined the suitability of using gypsum mortars with waste mineral additions of ladle furnace slags (LFS) as raw material to manufacture precast products. The most suitable content chosen after subjecting gypsum mortar mixes to physico-mechanical, thermal and acoustic performance tests was a 60 v/v% addition of LFS. Similar to mortar specimens, the new solid blocks (340 × 200 × 50 mm^3) presented a trend of decreasing compressive strength (~40% reduction, when compared to reference material).

Villoria-Sáez et al. (2020) developed and tested a new hollow gypsum block (400 × 200 × 10 mm^3) with a sandwich configuration. The core of the block was filled with a gypsum mix (0.8 of water-to-gypsum ratio) incorporating 75 wt% of ceramic waste addition and 2/3 v/v of EPS residue as partial replacement of the binder. Additionally, two laminated plasterboards (6 mm) were placed in the outer layers. Although the new hollow blocks showed lower compressive strength when compared to the reference solid block for traditional wall partitions, an improvement of up to 50% was reported in comparison to the reference non-sandwich hollow blocks without waste additions. Moreover, Katman et al. (2022) found that the incorporation of optimized hollow cores into gypsum blocks leads to better thermal and acoustic performance with minimized use of resources.

Because of the high rate of plastic production in relation to its deficient recyclability, the packaging and fishing sectors are the two greatest contributors to environmental pollution. Most of their plastic wastes are dumped into landfills or incorrectly disposed of directly into the environment, becoming sources of microplastic in marine ecosystems (80% of plastic waste found in oceans comes from terrestrial activities and 20% from fishing works) (United Nations Environment Programme, 2021). After characterizing the nature of discarded products that are leaders in both sectors, polypropylene (PP), polyethylene (PE) and polyamide (PA) should be highlighted and correctly managed. Despite the numerous market opportunities offered by the properties of these types of plastic, like durability, strength, water resistance, and low thermal conductivity properties, the circularity of post-consumer plastic waste is significantly low.

For these reasons, this research study focused on the use of two types of plastic, which are representative of the vast majority of generated plastic waste, i.e. PP (from disposable coffee capsules - CCs) and PA (from fishing nets - FNs), for the production of gypsum-based elements. In previous research (Romero-Gómez et al., 2022; 2023a), the authors evaluated the feasibility of using both types of plastic waste (i.e. PA6 fibres and PP particles) as partial replacements for gypsum to develop eco-friendly composites. In both cases, different replacement levels were analysed to ascertain the optimal mix design. The optimization criterion followed consisted of seeking a maximum quantity of plastic waste that allowed for improved or equal performance of the reference gypsum composite properties. Therefore, the main goal of the current study is to evaluate the applicability of those gypsum composites (Romero-Gómez et al., 2022; 2023a), belonging to a larger research project, to develop an environmental-friendly construction product for interior wall partitions. To this purpose, two types of alveolar gypsum blocks (AGBs) were manufactured by incorporating 7.5 wt% of shredded PP waste and 2.5 wt% of PA6 waste fibres, respectively. The experimental campaign consisted of three phases (Figure 1). Firstly, the design and optimization of a block mould prototype were carried out. Secondly, the evaluation of physico-mechanical (i.e. dry bulk density, superficial hardness, mechanical strength), water permeability and thermal properties of AGBs was conducted in accordance with standard EN 12859 (2012). Also, a simplified life cycle assessment (LCA) of the products was developed, in order to set a complete comparative analysis to determine the most feasible solution for wall partitions, based on environmental, economic and physico-mechanical performance. Finally, a comparative analysis of commercial and the proposed alveolar gypsum block prototypes was carried out in terms of physico-mechanical, thermal, and water-resistant properties to establish the feasibility of developing those new solutions at an industrial level. The foremost novelty of the aforementioned approach is the proposal of a research methodology to manufacture and evaluate the performance of a gypsum-based prototype incorporating two types of highly pollutant plastic fractions. This study aims at minimizing the considerable challenges for the disposal of those residues while producing novel alveolar gypsum blocks with comparable physico-mechanical, water-resistant and environmental properties to those of commercial partition wall systems.

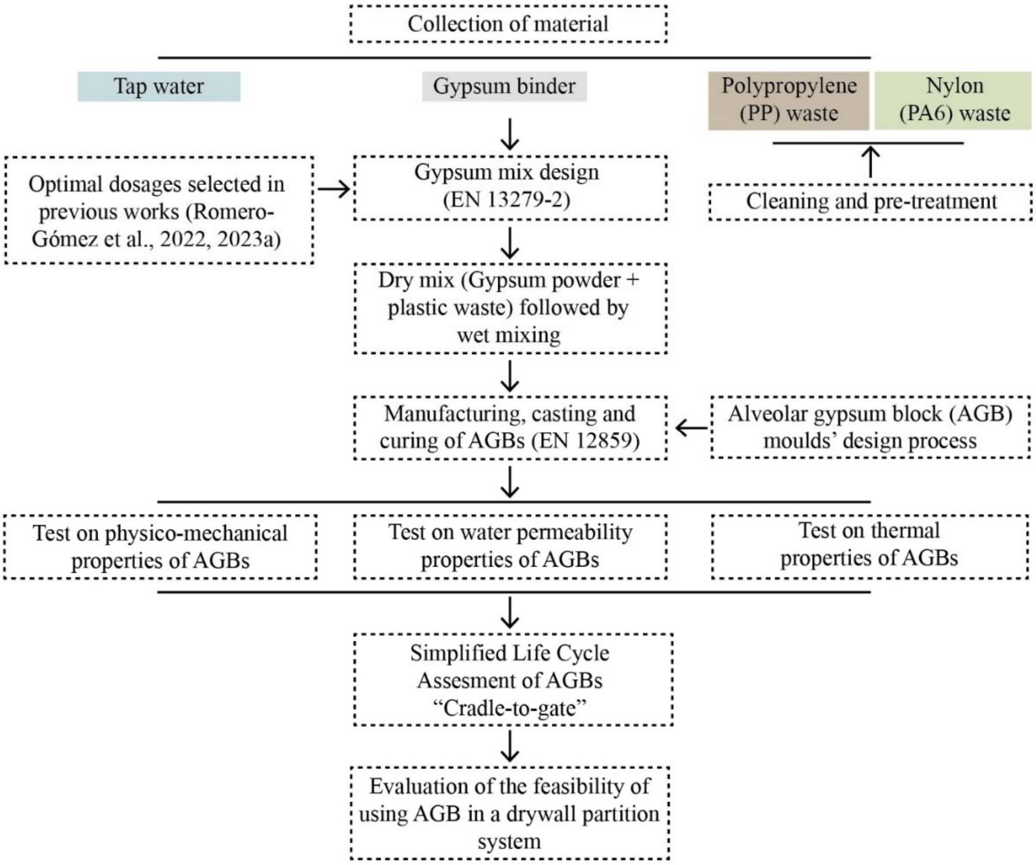


Figure 1. Research methodology scheme of the current study.

2 MATERIALS AND METHODS

2.1 Materials

To develop the current research, the following materials were used:

- Setting-controlled gypsum for construction (B1): purity > 75%, particle size range of 0-1 mm, surface hardness Shore C < 45, flexural strength of 1 N/mm^2, compressive strength of 2 N/mm^2 and a pH > 6, may be highlighted as the main properties, in accordance with standard EN 13279-2 (2009);
- Tap water, according to Council Directive 98/83/EC (1998);
- Polypropylene (PP) waste: shredded particles with an output size < 4 mm (Figure 2a) and a real density between 895-920 kg/m^3. Main mechanical properties of PP particles: tensile strength - 29.5 ± 1.4 MPa; Young's modulus

- 655 ± 9 MPa; yield point - 25.8 ± 1.5 MPa; ductility - 120.3 ± 20.6 %; toughness - 17.1 ± 2.9 J/m^3; resilience toughness - 2.1 ± 0.7 J/m^3 (Domingues et al., 2020). PP waste was sourced from disposable coffee capsules (CCs), subjected to cleaning and crushing processes using a RETSCH SM 2000 cutting mil. A density-based separation in water was used to recover each of the materials (i.e. PP and aluminium particles) to minimize contamination. Finally, PP granules were dried at 100 ± 2 °C until constant mass (Romero-Gómez et al, 2022);

- Nylon (PA6) waste fibres: recycled monofilament fibres with 20-25 mm in length (Figure 2b), constant diameter of Ø240 μm and a real density of 1130 kg/m^3. The main mechanical properties of PA6 fibres are: aspect ratio - L/D of 94; tensile strength - 440 MPa; Young's modulus - 3000 MPa; specific gravity - 1130 kg/m^3 (Srimahachota et al., 2020). PA6 waste fibres were obtained from discarded fishing nets and underwent washing, air-drying and manual cutting procedures (Romero-Gómez et al., 2023a).

(a) (b)

Figure 2. Plastic waste ready to be added to gypsum mix: a) PP particles; b) PA6 fibres

2.2 Alveolar gypsum block (AGB) moulds' design process

The design and manufacturing procedure of the AGB prototype is shown in Figure 3. The dimensions of the blocks (660 mm in length × 500 mm in height × 80 mm in thickness) were established in accordance with standard EN 12859 (2012). Furthermore, the new blocks were carried out with a circular alveolar system of 40 mm in diameter. Pinewood was used as the main material of the mould. Five PVC tubes with 40 mm of external diameter were applied as negatives.

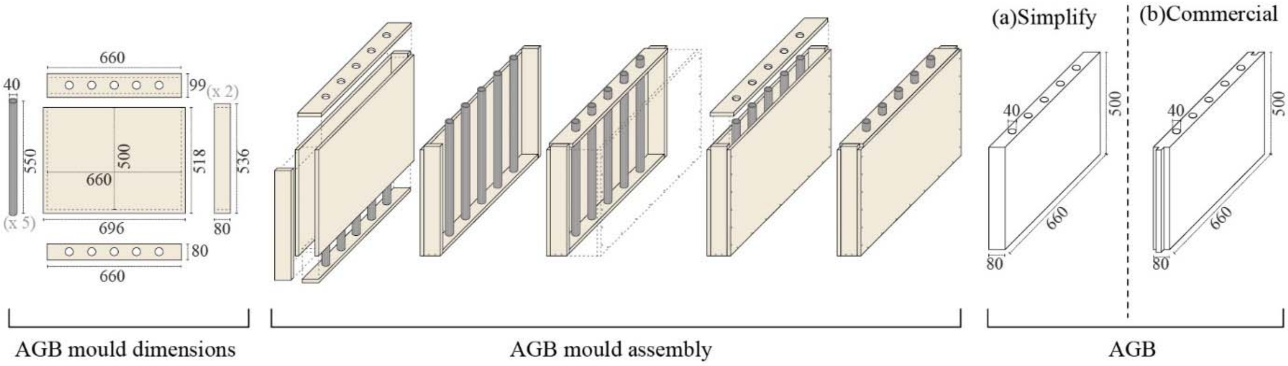


Figure 3. Alveolar gypsum blocks (AGB) mould design, in mm

As seen in Figure 3, commercial AGBs typically have a tongue-and-groove system to facilitate and accelerate the construction process that does not influence the AGBs' physico-mechanical performance. Thus, the mould used to produce AGBs in this study was simplified, removing the tongue-and-groove, to facilitate their manufacturing for the experimental campaign.

2.3 Mix preparation and manufacturing of AGB prototypes

In the authors' previous works (Romero-Gómez et al., 2022; 2023a), specimens with several replacement levels of the same waste material were compared to understand the implications on the physico-mechanical performance of gypsum-based composites. This allowed defining the optimal replacement levels for each type of waste ((7.5 wt% PP waste particles and 2.5 wt% PA6 recycled fibres, in weight of gypsum) that can effectively be used in practice whilst maintaining adequate performance for this specific application (i.e. alveolar gypsum blocks). Regardless of the type of waste incorporated into the gypsum mix, the same guidelines were followed to prepare all the samples (Figure 4). First, the waste (i.e. PP particles or PA6 fibres) was dry-mixed with the gypsum powder to avoid the formation of waste agglomerations. After that, the water (0.55 w/g ratio fixed for all mixes, determined as per standard EN 13279-2) was gradually added and all the components were mixed with a handheld electric mortar mixer for 2 min until a homogeneous state was reached. Three specimens were developed per type of plastic waste, including reference gypsum ones. The mix proportions by type of waste needed to prepare a block sample are summarized in Table 1. The mix code for the different samples is the following: alveolar gypsum block (AGB); type of waste used - polypropylene (PP)/nylon (PA6); percentage of plastic waste addition (e.g. AGB/PP/7.5).

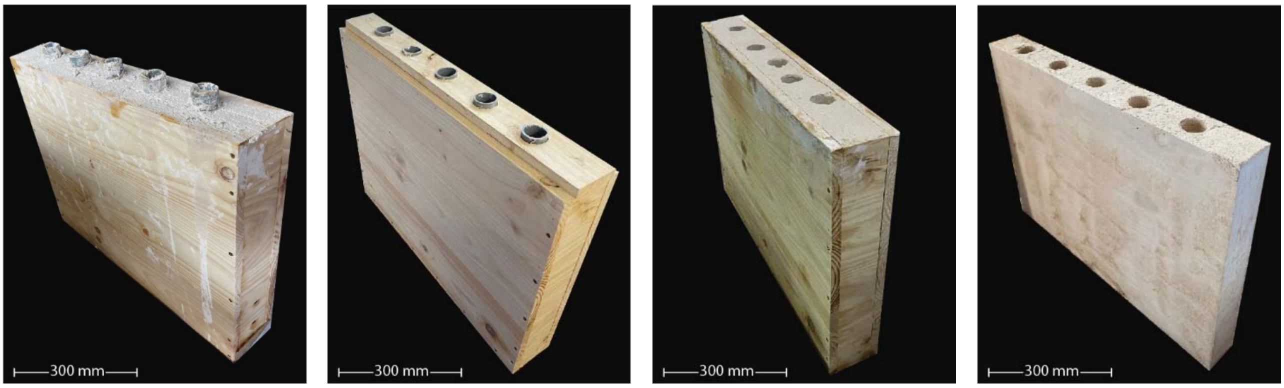
(a) (b) (c)

Figure 4. Samples preparation procedure: a) plastic waste-gypsum dry mixing; b) water incorporation and mixing for 2 min; c) mix ready to be moulded

Table 1. Mix proportions for an AGB specimen of 660 mm × 500 mm × 80 mm

Mix code	**Gypsum [g]**	**Water [g]**	**W/G ratio**	**WasteW aste [g]**	**Waste [% v/v]**
G/CM	30000	16500	0.55	-	-
G/PP/7.5	27750	15263	0.55	2250	17.2
G/PA6/2.5	29250	16089	0.55	750	4.96

After concluding the mixing procedure, the mix was then poured into the aforementioned wooden mould, previously coated with a release agent. Subsequently, a top wood piece was placed in order to level the top surface of the AGB. After 1 h, the PVC tubes were taken off. Finally, the AGB was removed from the mould after 24 h and placed in a dry chamber. The steps described can be observed in Figure 5.



(a) (b) (c) (d)

Figure 5. Moulding procedure to make an AGB: a) pouring of the mix into the mould; b) smoothing of the top surface; c) removal of the cylindrical pieces; and d) AGB after demoulding

2.4 Curing conditions

Attending to the requirements set by standard EN 12859 (2012), after demoulding the AGBs, they were cured in a dry chamber for 18 days, until constant mass. The conditions of the chamber were controlled to maintain a temperature of 23 ± 2 ºC and relative humidity of 55-65%.

2.5 Test methods

2.5.1 Physico-mechanical properties

- *Dry bulk density:* this property was calculated according to the procedure set by standard EN 12859 (2012), based on the relationship between the dry weight and volume of the block samples. The final value of dry bulk density was determined by the arithmetic mean of the three samples measured per AGB type.

- *Superficial hardness (Shore C):* prior to a destructive mechanical test, this method was developed according to standard 12859 (2012). To this purpose, each test piece (660 mm × 500 mm × 80 mm) was placed on a horizontal and flat surface where the superficial hardness was measured by a durometer Shore C (Figure 6a). Twelve measurements were made per surface. The final value was obtained as the arithmetic mean of the highest ten recorded values by the group. Three samples by AGB type were analysed.

- *Flexural strength:* determined by the flexural breaking load of the panels (660 mm × 500 mm × 80 mm) subjected to the three-point method included in standard EN 12859 (2012). The test piece was placed between two parallel cylindrical supports separated by 566 mm (Figure 6b). Then, a continuous load of 20 N/s was applied in the central plain until the block's failure. The flexural testing equipment Form+Test Seidner+Co GmbH D-7940 Riedlingen was applied. For each of the AGB groups, the value of flexural strength was calculated as the arithmetic mean of the three specimens measured.

- *Compressive strength:* considering the absence of specific regulations to evaluate the gypsum blocks' compressive strength, the guidelines established by standard EN 772-1+A1 (2011) for masonry units were followed. Pieces of 300 mm × 300 mm × 80 mm were obtained from samples subjected to flexural test. The compression testing machine Form+Test Seidner+Co GmbH MEGA 6-3000-100 was used to develop this test. Every piece was carefully aligned with the centre of the plate. Then, a centred load was applied with a velocity of 0.05 (N/mm^2)/s, until reaching the maximum load causing failure (Figure 6c). Afterwards, the average value was calculated from three samples per AGB type.

2.5.2 Water permeability

- *Water absorption by pipe method:* this test consisted of measuring the amount of water (ml) transferred from the pipette through a given test area (cm^2) after a set time (20 min.), expressed in ml/cm^2, as per standard EN 16302 (2016). A minimum of three measurement areas were taken by block sample (Figure 6d). The change in the water level in the graduated column was noted at time intervals of 10-60 seconds. Subsequent measurements were registered every 5 min until constant value (max 1 h). Three samples (half of the block resulting from flexural test ~330 mm × 500 mm × 80 mm) by AGB type were analysed. The final value was established as the average value of nine measurements by the AGB group.

2.5.3 Thermal performance

- *Thermal conductivity test:* following the guidelines set by standard ASTM D5930-17 (2009), the thermal conductivity coefficient of three cylindrical samples (Ø60mm /e = 20 mm) per type of mix, was measured by using the ISOMET 2114 equipment connected to a surface probe. The dynamic measurement method was around 30 min per measurement.

(a) (b) (c) (d)

Figure 6. Tests developed: a) superficial hardness (Shore C); b) flexural strength; c) compressive strength; d) water permeability under low pressure.

2.5.4 Simplified Life Cycle Assessment

A simplified comparative life cycle assessment (LCA) was conducted, using a "cradle-to-gate" model to evaluate the environmental impacts of the proposed plastic waste-containing AGBs for use in partition walls. This was done in accordance with previous works, which classified this methodology as the most efficient to evaluate the environmental impact of a construction material (Pedreño-Rojas et al., 2019a; Zabalza-Bribián et al., 2011). The aim of this analysis is to determine whether the environmental suitability of PP- and PA6-containing AGBs outweigh any performance shortcomings and thus discern the validity of their implementation in practice. Therefore, the environmental impacts of each AGB were obtained as follows: identification and quantification of the different materials used to develop the new products, related to the requirements set by standard EN 15804 (2014), modules from A1 to A3 "Product stage", raw material supply, transport and manufacturing processes were considered; application of the LCA methodology in order to obtain the environmental impact of each AGB type - "cradle-to-gate" model.

Goals and scope

Embodied Energy (EE [MJ]) and Global Warming Potential (GWP [kg CO_2eq.]) were identified as the most relevant impact indicators to be applied in LCA for building applications, according to previous research (Pedreño-Rojas et al., 2019b; Omar, 2018; Soust-Verdaguer et al., 2016; Suárez et al., 2016). The impact assessment was conducted following the methodology described by García-Martínez (2010). EcoInvent v3.0 (EcoInvent Association, 2013) and ITEC (ITEC Database, 2023) as LCA databases, as well as manufacturers' information related to equipment efficiency, were used for this analysis.

The functional unit chosen in this work is 1 m^2 of each type of AGB partition wall, having different amounts of gypsum, plastic waste (i.e. PP or PA6) and water. As shown in Figure 7, the system boundary for the process considers three different phases:

- Raw material supply: it includes all the processes to obtain the different materials needed to develop the new composites (commercial gypsum, recycled plastic waste (i.e. PP and PA6) and water);
- Transportation: it makes reference to the transport of each material from the quarry and recycled plant to the product factory;
- Product manufacture: it covers all the mixing, moulding, curing and packaging procedures to get the new AGBs.

Life cycle inventory (LCI) and life cycle impact assessment (LCIA)

The LCI of the production of each material involved in the manufacturing process to obtain each type of AGB was calculated by applying the following steps:

- Identification of the processes and materials that were needed to develop the gypsum-based mixes. All the phases to obtain commercial gypsum (B1) were considered, according to published information (Pedreño-Rojas et al., 2020a). Furthermore, the washing, shredding and drying procedures used by recycling companies to obtain PP and PA6 waste ready to be incorporated into the gypsum mixes were evaluated. However, plastic waste management phases were rejected for the LCA assessment (landfilling, incineration, etc.), as suggested by studies from the literature (Goyal et al., 2023; Pedreño-Rojas et al., 2019b; Nyland et al., 2003), since these are 'final use' or 'end-of-life' phase for materials. So, recycling was the only phase that was considered;

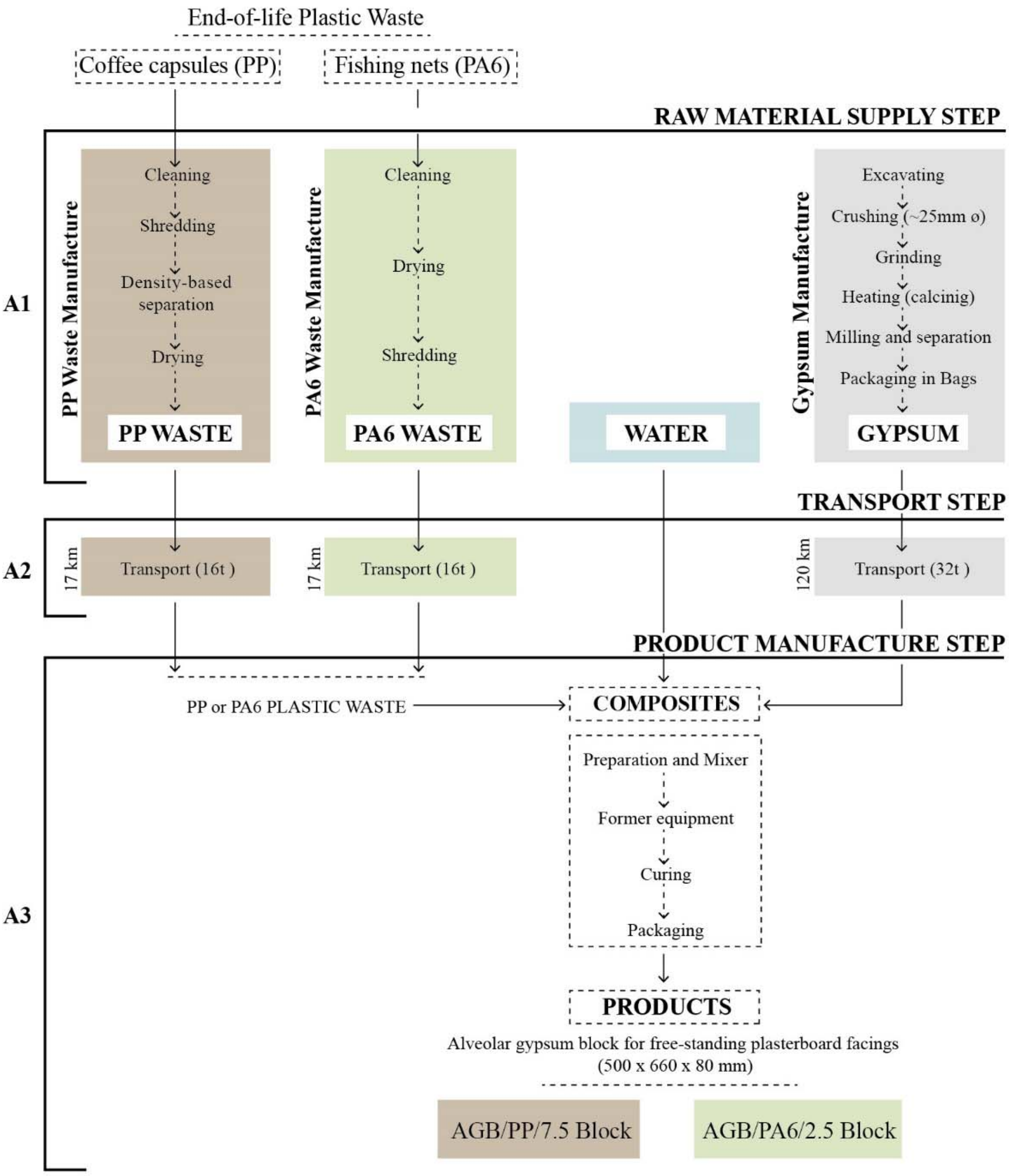


Figure 7. System boundary for the LCA of manufacturing the alveolar gypsum-PP/-PA6 blocks.

- Transport quantification. The means of transport used to bring each material from the gypsum extraction and production or the recycling plant (i.e. PP and PA6 waste) to the gypsum block factory, as well as the distance travelled, were considered;

- Inventory of product manufacture procedure. In this case, all the equipment involved in the production of AGB was considered: mixer machine to obtain gypsum-based composites, formwork equipment to mould AGB, curing chamber and packaging equipment to get the AGB ready to be commercialised. These processes were the same for all the mixes with the exception that a 2 min plastic waste-gypsum powder dry mixing stage was needed for the plastic waste previously to water addition, and therefore considered;
- Determination of the environmental impact of each unit procedure. The impact values of each unit process were sourced from EcoInvent v3.0 (EcoInvent Association, 2013) and ITEC (ITEC Database, 2023) databases;
- Assessment. To obtain the LCIA of the complete procedure, GWP and EE impacts were calculated.

Table 2 summarizes the amount of each material, energy and transport required to produce a square meter (m^2) of each gypsum-based block. In addition, Table 3 shows an inventory of the equipment used with their corresponding power consumption per ton of material to produce the different types of AGB. Finally, a list of the extracted data for each material and procedure included in the LCIA of the products under study is exposed in Table 4.

Table 2. Amount of raw materials required to produce a square meter [m^2] of AGB partition wall

Material used	Unit	Reference material	G/PP/7.5	G/PA6/2.5
Gypsum	kg	90	83.2	87.7
Water	kg	49.5	45.8	48.2
PP waste	kg	-	6.8	-
PA6 waste	kg	-	-	2.3
Electricity	kWh	-	12.5	7.5
Transport 16-32 t	tkm	120	120	120
Transport 7.5-16 t	tkm	-	17	17

3 RESULTS AND DISCUSSION

Concluding the evaluation of physico-mechanical, water-resistance and thermal properties of the proposed alveolar gypsum blocks containing PP and PA6 residues, the results are summarized and discussed in this section. Next, the environmental impact of the new products after reducing the raw material (i.e. gypsum) use by incorporating plastic waste, was evaluated. Finally, the practical feasibility analysis of the new AGBs was carried out, in comparison with similar commercial solutions.

3.1 Physico-mechanical properties

3.1.1 Dry bulk density

Concerning the dry bulk density values obtained from each type of AGB shown in Figure 8, a slight increase in density can be observed in the plastic waste-containing AGB. After incorporating PP waste particles into the gypsum mix, the resulting blocks presented a rise of up to 2.3%, while the addition of PA6 waste fibres led to an increase of ~5%. Although the raw material (i.e. gypsum) with a density of 2300 kg/m^3 was partially replaced by plastic waste (i.e. PP and PA6) with low density (895 kg/m^3 and 1130 kg/m^3, respectively) for the production of AGB, contrary to expectations, lighter materials were not obtained. Similar findings were reported previously (Romero-Gómez et al., 2022; 2023a) in small-scale composites (40 × 40 × 160 mm^3), the data of which can be consulted in Table 5.

Table 3. Inventory of equipment used and energy consumption per ton of material for the production of AGB partition walls

Component		Name in database	Reference source	Power type	Unit	Energy consumption per tonne
Gypsum raw materials	Gypsum extraction	-	Pedreño-Rojas et al. (2020a)	Diesel	l	5.56
	Crushing			Electricity	kWh	32.61
	Calcination			Natural gas	m^3	29.59
	Milling and separation			Electricity	kWh	14.85
	Packaging and storage			Electricity	kWh	11.23
PP and PA6 waste	Washing, shredding and drying facilities	Washing system for thermoplastics	SIKOPLAST (SIKOPLAST Recycling Technology GmbH)	Electricity	kWh	20
PP waste	Density-based waste separation	Centrifuge separator for plastic recycling	TECNOFER (Tecnofer | Recycling plants, machines and equipment for waste treatment)	Electricity	kWh	55
	Drying equipment	-	Pedreño-Rojas et al. (2019b)	Electricity	kWh	0.35
AGB manufacture	Mixer	Horizontal gypsum mixing machine	Yinda Machinery (YINDA Machinery)	Electricity	kWh	0.8
	Former equipment	Gypsum hollow block-making machine	Longkou Deyi Machinery Co., Ltd (DEYI group)	Electricity	kWh	2.78
	Curing	Gypsum blocks tunnel dryer	Münstermann (Thermoprozesstechnik, Handlingsysteme, Luftreinhaltung, Automatisierung - MÜNSTERMANN)	Electricity	kWh	1.11
	Packaging equipment	Gypsum blocks packaging machine	Matthys group (Matthys group, Innovative and customized machinery solutions)	Electricity	kWh	0.02

Table 4. Materials used and their name in EcoInvent v3 (EcoInvent Association, 2013) and ITEC (ITEC Database, 2023) databases. Unit values for Global Warming Potential and Embodied Energy

Component	ID	Name in database	Database	Unit	GWP (kg CO_2 eq.)	EE (MJ)
Gypsum	B0521100	B1/20/2 Gypsum according to EN 13279-1	ITEC	kg	0.16	1.80
Water	2288	Tap water, at user	EcoInvent	kg	0.01	0.01
Electricity (plastic recycling)	698	Electricity mix, Spain (construction)	EcoInvent	kWh	0.50	10.9
Transport 7.5-16t	7301	Transport, lorry 7.5e16t, EURO4	EcoInvent	tkm	0.26	4.33
Transport 16-32t	7304	Transport, lorry 16-32t, EURO4	EcoInvent	tkm	0.15	2.58

The incorporation of 7.5 wt% PP particles and 2.5 wt% PA6 fibres led to a densification of the gypsum matrix, more noticeable in the latter, due to the more extensive particle size distribution of the combined materials and reasonable adhesion at the interfacial transition zone between waste aggregate-matrix. The superficial roughness of the waste aggregate was a key factor in facilitating the gypsum crystal growth throughout the plastic waste's surface, especially noticeable for PP particles.

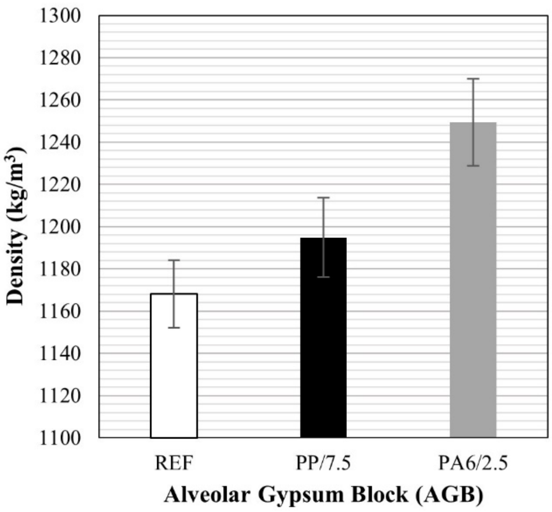


Figure 8. Dry bulk density values of the AGBs

3.1.2 Superficial hardness (Shore C)

The data obtained from the superficial hardness (Shore C) test: 95.6, 95.8 and 95.1, corresponding to G/REF, G/PP/7.5 and G/PA6/2.5, respectively, pointed out that the addition of plastic waste to gypsum matrix did not influence the AGBs' superficial hardness. In addition, all gypsum-based blocks could be classified as high-density blocks, since all the values of superficial harness (Shore C) were over the minimum 80 Shore C units (2012).

3.1.3 Flexural strength

The three-point flexural test setup can be seen in Figure 9 as well as the failure dynamics over time. In Figure 10a, the values of flexural strength obtained from each type of AGB are presented. The addition of PA6 fibres with a replacement ratio of 2.5 wt% led to an improvement of ~8% in flexural strength, while the use of 7.5 wt% PP replacement led to a reduction of this property of 6.5% when compared to the control AGB/REF. Based on previous studies by the authors (Romero-Gómez et al., 2022; 2023a), both wastes were dispersed uniformly within the gypsum matrix and this difference in performance could be explained by the high aspect ratio and high tensile strength of PA6 fibres in comparison to PP particles. Nevertheless, all the values were well over the minimum value of 1.7 kN set by the standard (EN 12859, 2012). Furthermore, the addition of PA6 waste fibres significantly increases the toughness of the material (Romero-Gómez et al., 2023a) and prevents complete breakage of the AGB after being subjected to the flexural strength test, as seen in Figure 7. In AGB/PA6/2.5 blocks, the aspect ratio of PA6 fibres was a key factor in keeping together the resulting pieces of the blocks after breaking point, unlike AGB/PP/7.5 and AGB/REF, which presented a brittle failure, breaking completely.

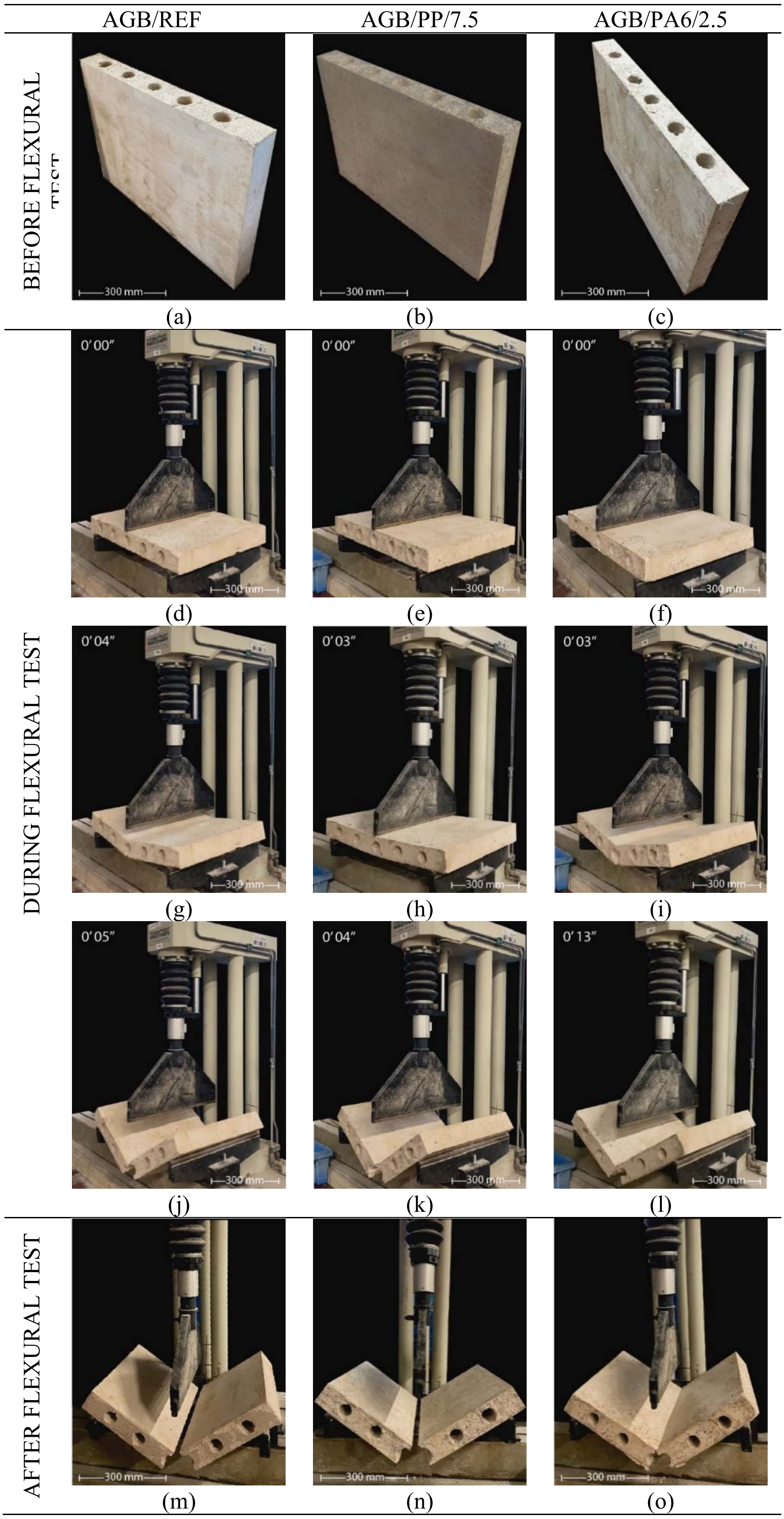
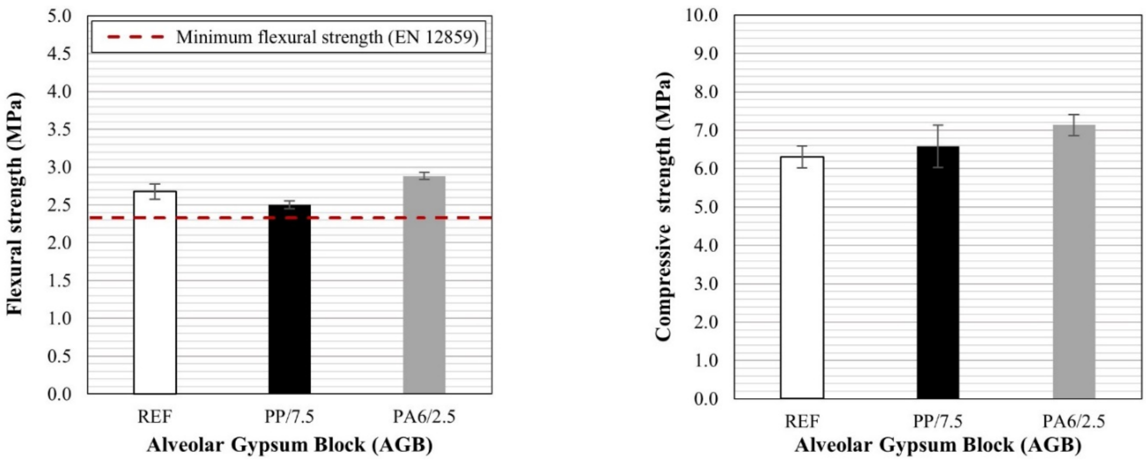


Figure 9. AGBs before, during and after being subjected to the flexural strength test: a), d), g), j), m) AGB/REF; b), e), h), k), n) AGB/PP/7.5; c), f), j), l), o) AGB/PA6/2.5

Similar performance was observed previously by the authors when lower-scale composites containing recycled nylon fibres were subjected to flexural strength tests. After comparing two types of fibre size, it was concluded that longer ones prevented the complete destruction of the piece since they allowed for a more ductile behaviour as a result of their greater anchorage length, which gave rise to higher pull-out resistance (Romero-Gómez et al., 2023a), The research carried out by Yin (2021) and Orasutthikul et al. (2016) also concurred.

3.1.4 Compressive strength

Figure 10b presents the compressive strength results of the different gypsum blocks. As expected, the compressive strength improved with plastic incorporation, due to the densification of the gypsum matrix observed in section 3.1.1 and verified by SEM analysis. The highest value was presented by AGB/PA6/2.5 (7.13 MPa), showing an increase of up to 8.4% with respect to the reference product. Similarly, the addition of PP also led to an increase in compressive strength of ~4.5%, when compared to AGB/REF. However, it must be noted that the enhanced values of compressive strength related mainly to PP waste-containing blocks are not significantly higher than those of the reference blocks, considering the overlapping standard deviation. In addition, a similar diagonal fracture line can be observed in Figure 11 in both AGB/REF and AGB/PP/7.5 specimens. The addition of PA6 fibres seems to have reduced the presence of such external cracks and instead induced linear cracks collinear in the loading direction.



(a) (b)

Figure 10. Mechanical strength data of the AGB: a) flexural strength; b) compressive strength

The possible effects derived from scale change between gypsum plaster composites, previously studied by the authors (Romero-Gómez et al., 2022; 2023a), and the gypsum-based blocks were evaluated in this section. In general, a similar performance was detected in the materials in both studies (Table 5); G/PA6/2.5 and AGB/PA6/2.5 specimens showed the highest density values, superficial hardness and compressive strength. However, significant differences in flexural and compressive mechanical strength values were detected when comparing both scales for each corresponding mix. Reductions of 21% and 11% in flexural strength, and 18% and 15% in compressive strength, corresponding to AGB/REF, and AGB/PA6/2.5, respectively, were registered. However, the change of scale did not seem to have an influence on flexural strength with the incorporation of PP particles, but rather on the compressive strength, since a reduction of up to 21% was detected related to gypsum blocks when compared to smaller composites. Therefore, it can be observed that there was a lower difference in flexural strength values, related to the scale of the samples when plastic waste was added to the gypsum mixes. However, similar reductions of 15-21% were registered in blocks' compressive strength independently of the use of plastic waste as a partial replacement of the gypsum matrix. This fact pointed out that the creation of boreholes with 40 mm of diameter in the gypsum block prototype negatively affected the mechanical strength performance of the new products, especially compressive strength, at block scale (660 mm × 500 mm × 80 mm), due to the reduction of load application section thickness, as was previously observed by Villoria-Sáez et al. (2020).

(a) (b) (c)

Figure 11. AGBs after being subjected to the compressive strength test: a) AGB/REF; b) AGB/PP/7.5; c) AGB/PA6/2.5

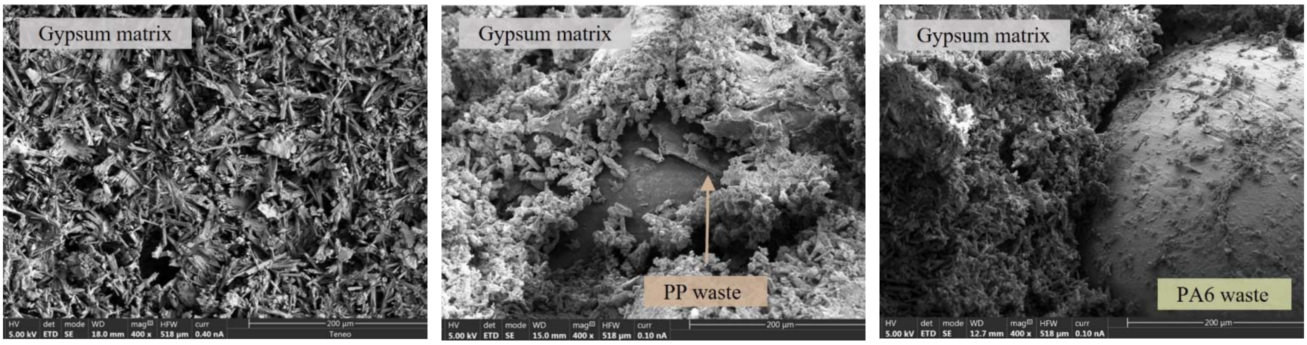


Figure 12. SEM analysis of: a) AGB/REF (400×): b) AGB/PP/7.5 (400×); c) AGB/PA6/2.5 (400×)

Table 5. Summary of the values obtained from physico-mechanical tests. Scale comparison between prismatic samples (40 mm × 40 mm × 160 mm) previously analysed by authors [29], [30] and AGB (660 mm × 500 mm × 80 mm)

Sample code	**Density (kg/m^3)**	**Superficial hardness (Shore C)**	**Flexural strength (MPa)**	**Compressive strength (MPa)**
G/REF	1201.1	94.5	3.39	7.71
G/PP/7.5	1236.4	95.3	2.48	8.36
G/PA6/2.5	1228.4	97.3	3.26	8.35
AGB/REF	1168.0	95.6	2.68	6.30
AGB/PP/7.5	1194.8	95.1	2.50	6.58
AGB/PA6/2.5	1249.3	95.8	2.90	7.13

3.2 Water permeability

The data of the water permeability test are presented in **Error! Reference source not found.**. Encouraging results were shown by gypsum-based blocks containing plastic waste as the water permeability was reduced by 48% when compared to the reference gypsum block. Although the lowest value (0.15 ml/cm^2) corresponded to AGB/PP/7.5 specimens, a significant decrease (of 42%) was also shown by AGB/PA6/2.5 specimens. Thus, the incorporation of impermeable plastic waste (i.e. PP and PA6), as well as the densification derived from the incorporation of both types of plastic wastes as partial replacement of the gypsum matrix did not induce a porous ITZ (Romero-Gómez et al., 2022; 2023a), leading to an improvement of the gypsum block impervious property, which is one of the main handicaps of using gypsum products without additional waterproofing treatments.

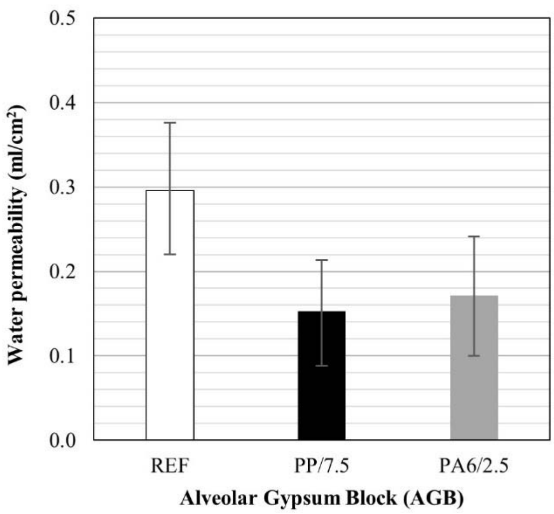


Figure 13. Values of water permeability of the AGBs

3.3 Thermal conductivity

The values of thermal conductivity coefficients obtained for AGB/REF, AGB/PP/7.5 and AGB/PA6/2.5 blocks were 0.39, 0.32 and 0.33 W/mK, respectively. The incorporation of plastic waste led to lower thermal conductivity coefficients when compared to the reference product. Considering that the lowest value corresponded to 7.5 wt% PP-containing gypsum blocks, which means a higher replacement level of plastic waste when compared to those containing 2.5 wt% PA6 fibres, a greater influence of the replacement level can be inferred on thermal properties of gypsum products rather than the type of plastic. The decrement of the thermal conductivity coefficients of the plastic waste-containing gypsum matrix can be attributed to the lower conductivity of the plastic components (PP-0.22 W/(mK); PA6-0.25 W/(mK)), in comparison to the hydrated gypsum (0.39 W/(mK)). These data are in accordance with the previous studies developed by Pedreño-Rojas et al. (2020c) and Vidales-Barriguete et al. (2018).

3.4 Simplified Life Cycle Assessment

As per Figure 14, a comparison of the GWP and EE of the studied AGBs was carried out. Regardless of the type of plastic used as a partial substitute for gypsum, enhanced environmental benefits in terms of energy consumption (MJ ep.) and GWP (CO_2 eq.) were observed for the proposed plastic-containing AGBs with respect to the reference one. AGB/PP/7.5 showed the highest global reduction in GWP and EE (~6% and ~3.5%, respectively) when compared to AGB/REF. PA6 fibre-containing blocks led to a reduction of ~2.5% in GWP and ~2% in EE in comparison to the reference AGB, which is not as noticeable as the PP waste-containing blocks, because of the lower percentage of plastic waste used.

Comparing the graphs of both impact factors, a similar performance can be observed. The highest environmental impacts of the AGBs were registered for the raw material supply phase. This phase corresponds to the whole process needed to obtain the commercial gypsum in comparison to the minimum impact of the plastic waste washing and shredding procedure. Nevertheless, the greater number of pre-treatment procedures required to obtain PP waste aggregate, in comparison to those needed to get PA6 waste fibres, led to a higher electricity energy consumption. Thus, an increase of environmental impact factors (i.e. GWP and EE) corresponding to the raw material supply phase of AGB/PP/7.5 blocks was detected, which partially counteracted the environmental impact reduction achieved by the partial replacement of commercial gypsum by PP waste. In spite of this, the global environmental impact of PP-/PA6-containing gypsum blocks corresponding to this first phase (i.e. raw material supply) was lower than that of the reference AGB. On the other hand, the environmental impacts of the transportation step were similar in all cases, since, as the amount of commercial gypsum transport decreased, the transport of recycled plastic increased. In addition, it must be noted that the values of the GWP and EE impact factors were the same for the product manufacture step since there were no modifications to the procedures conducted in this phase for the different mixes.

Summing up, in Figure 14, the input that contributes the most to the environmental impacts of the proposed gypsum-based products is "Gypsum material". Therefore, further research lines could be focused on the substitution of commercial gypsum for a recycled one and/or increasing the percentage of plastic waste content, by assuming the loss of mechanical strength within the minimum established in the standards (Goyal et al., 2023; Pedreño-Rojas et al., 2020a; 2019b; Sáez et al., 2020).

3.5 Evaluation of the feasibility of using AGB in a drywall partition system

The proposed prefabricated element (i.e. AGB) is a self-supporting construction system for interior partitions that can represent an alternative option for the traditional ceramic system (i.e. double hollow brick). Some of the main features of the AGB system include quick installation, easy assembly, no time-consuming plastering work, lightweight, non-combustibility, toughness, as well as, enhanced thermal due to the hollow core system, thus making it a cost-effective and sustainable solution that should be increasingly commercialized.

The current work proposes two alternative eco-friendly AGBs for drywall partition systems based on a standardized and commercialized building system. In order to evaluate the viability of both products in relation to the current commercial solutions, a comparative analysis between the main physico-mechanical properties of new plastic-waste-containing AGBs and several commercial solutions was carried out (Table 6). Gypsum blocks with hollow cores and other solid blocks were chosen to conduct this comparative assessment.

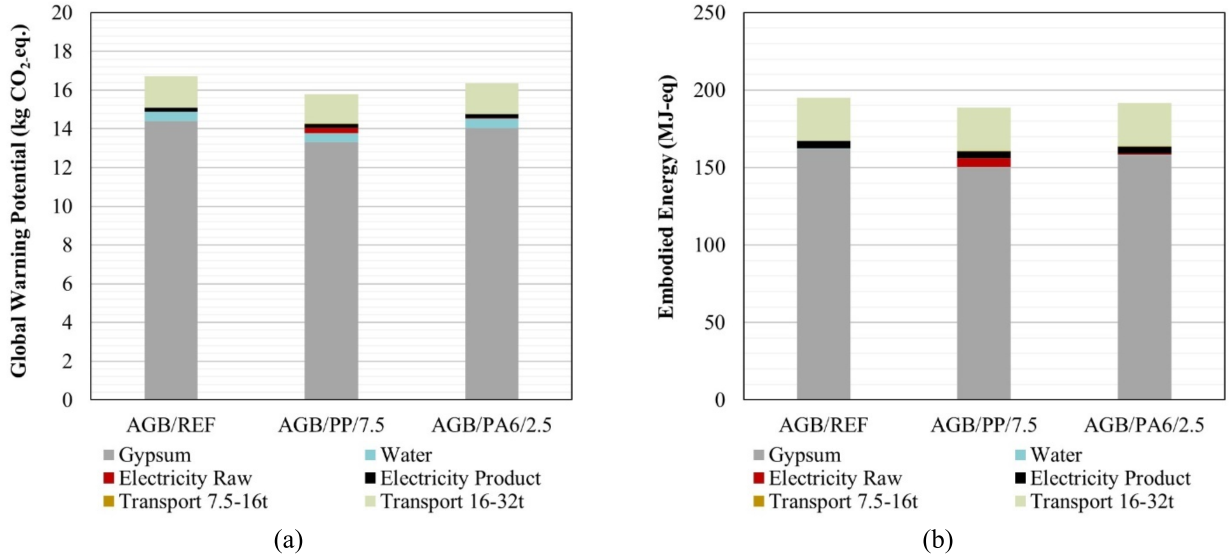


Figure 14. Life cycle impact assessment: a) Global Warming Potential (GWP) (kg CO_2 eq.); b) Embodied Energy (EE) (MJ eq.), refers to a functional unit of each type of AGB

Table 6.Comparison of physico-mechanical properties of the new plastic waste-containing AGBs proposed in this work with respect to different alveolar and solid gypsum blocks available in the market with similar performance

Brand code	**Type of block***	**Dimension (mm)**	**Mass per m^2 (kg/m^2)**	**Density class** (kg/m^3)**	**Superficial hardness (Shore C)**	**Flexural strength (kN)**	**Fire reaction**	**λ (W/(mK))**	**Water absorption (%)**
AGB/PP/7.5	Alveolar (5T)	666/500/80	89 ± 1	D	95	1.8	A2	0.32	H3, no requirement
AGB/PA6/2.5	Alveolar (5T)	666/500/80	93 ± 1	D	96	1.9	A2	0.33	H3, no requirement
VOLMA80	Alveolar (9L)	667/500/80	90 ± 1	D	≥ 80	≤ 1.7	A1	0.35	H3, no requirement
MultiGips M80	Solid	500/500/80	114 ± 1	D	≥ 80	≥ 5.7	A1	-	H3, no requirement
Isolava Isomur	Solid	666/501/80	76 ± 1	M	≥ 55	≥ 2.7	A1	0.32	H3, no requirement
Alba hydro 80	Solid	666/501/80	80 ± 1	M	≥ 55	≥ 2.7	A1	0.58	H3, no requirement

*Type of block: Alveolar (5T - five boreholes in the transversal direction; 9L - nine boreholes in the longitudinal direction)
**Density class: D (Dense); M (medium)

Firstly, attending to the mass per square meter corresponding to each solution, AGB/PP/7.5 and AGB/PA6/2.5 presented similar values to perforated commercial blocks also classified as Dense (D) class (e.g. VOLMA80), according to standard EN 12859 (2012). However, it should be highlighted that a decrease of 22% in weight is possible in the systems containing plastic waste (corresponding to AGB/PP/7.5) presented here when compared to solid dense blocks (i.e. MultiGips M80) due to the hollow core. Nevertheless, this alveolar system leads to a reduction of around 67% in flexural strength in PP- and PA6-containing AGBs, when compared to solid dense gypsum-based blocks and ~30% related to solid medium-dense blocks. Even so, both types of the proposed AGBs presented values over the minimum set by the standard (1.7 kN) and were similar to commercial perforated blocks (e.g. VOLMA80). In addition, the proposed AGBs were better in terms of superficial hardness (highest values of Shore C) when compared to standard solutions; up to 20% and 75% increase related to commercial D and medium (M) class blocks, respectively. This is likely to reduce any visible superficial defects from the use of the surrounding area. Moreover, in accordance with previous studies by the authors (Romero-Gómez et al., 2023b), it is already known that the AGB containing PA6 waste fibres and those with PP residue particles can be considered as non-combustible products, classified as A2 Euroclass fire reaction. Furthermore, a decrease in thermal conductivity (up to 8.5%) was verified because of the partial replacement of gypsum with plastic waste, when compared to commercial alveolar blocks thereby making it a more cost-effective solution to maintain user comfort during the building's service life. Concerning the materials' water absorption, no requirements are needed for the new and commercial blocks since they are classified as H3 (> 5% of water absorption). In sum, the feasibility of manufacturing and applying the new AGBs proposed in this work as an interior wall partition system has been demonstrated since both of the proposed plastic waste-containing solutions can offer similar or even improved physico-mechanical and thermal performance to currently commercialized solutions. A summarized visual comparative assessment of the physico-mechanical, thermal and environmental properties of both types of AGBs proposed in this work (i.e. AGB/PP/7.5 and AGB/PA6/2.5), in relation to reference alveolar blocks without plastic addition, is shown in Figure 15.

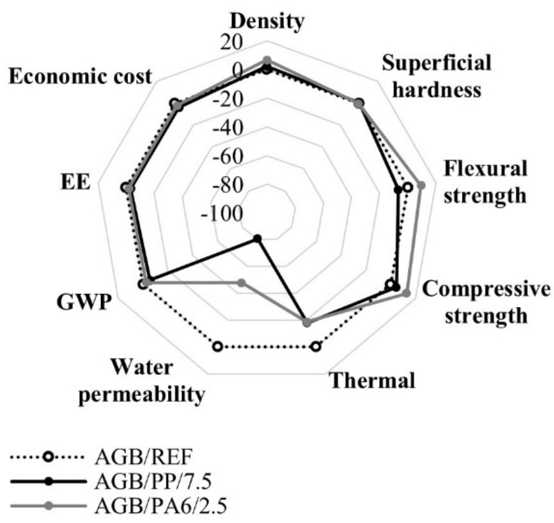


Figure 15. Visual comparative analysis of the physical-mechanical, thermal and environmental properties of the AGBs

It can be inferred that AGBs reinforced with 2.5 wt% of PA6 waste fibres presented the best overall performance. Although a slight increase in density was detected, this led to a notable improvement in flexural and compressive strengths. Furthermore, a notable reduction in thermal conductivity was achieved. Even though the highest reduction of water permeability absorption corresponded to AGB/PP/7.5 blocks, AGB/PA6/2.5 showed reduced water absorption capacity by 48%, with respect to the reference, offering a solution to one of the main handicaps of using gypsum products without a water-repellent treatment. Finally, from an environmental perspective, slight reductions in pollutant impact factors (i.e. EE and GPW), as well as in economic costs, were achieved, associated with the low percentage of plastic waste used. Nevertheless, further reduction is possible, which opens more research lines focusing on the optimization of physico-mechanical enhancements and environmental-economic benefits by increasing plastic waste replacement levels.

4 CONCLUSIONS

Normalized alveolar gypsum block prototypes with dimensions of 660 mm × 500 mm × 80 mm were developed by incorporating PP and PA6 waste as partial replacements of gypsum. The physico-mechanical, water permeability and thermal performance of both types of blocks were analysed and compared to the reference material, thus allowing the following conclusions:

- The incorporation of plastic waste led to an increase in the gypsum-based blocks' density because of the matrix's enhanced compactness. Consequently, the compressive strength of both plastic waste-containing prototypes increased, though more noticeably in the AGB/PA6/2.5 blocks with an 8.4% increase relative to the reference material;
- Regarding flexural strength, significant enhancement was also observed after using 2.5 wt% PA6 waste fibres as a partial replacement of the binder (~8% increase when compared to AGB/REF). Although the incorporation of PP waste led to a slight reduction in the block's flexural strength, all values were over the minimum set by the standard;
- The use of a hollow core system led to a reduction in mechanical performance, regardless of the plastic content, when compared to lower-scale solid composites previously studied by the authors;
- A notable reduction in water permeability was detected in blocks containing plastic waste. The largest decrease in water permeability was achieved by AGB/PP/7.5 blocks (~42%) because of the matrix' densification and the PP's impervious nature. So, independently of the type of plastic used in this case, the water permeability decreases depending on the amount of waterproofing material used, since both led to a reduced porosity at ITZ, contributing to water absorption slowing down;

- Lower thermal conductivity coefficients were obtained with the use of plastic waste as gypsum replacement. The thermal performance of alveolar gypsum blocks was best for those containing the highest amount of plastic (0.32 W/(mK) for 7.5% PP-containing blocks vs. 0.39 W/(mK) of the control blocks);
- Concerning the environmental impact assessment, the block prototypes showed slight enhancements in terms of energy consumption and Global Warming Potential mainly due to the reduction of raw material use, when compared to the reference product. Although a higher amount of waste was added to AGB/PP/7.5 blocks, the need for greater pre-treatment of the waste gave rise to similar values of environmental impact factor in AGB/PA6/2.5 blocks.

Therefore, it was confirmed that both types of the proposed plastic-containing alveolar gypsum blocks could be applied as elements in wall partition systems in building applications since they offered similar performance to that of current commercial solutions. In terms of physico-mechanical performance, better results were obtained in ABG/PA6/2.5 blocks, while AGB/PP/7.5 offered better water resistance and thermal behaviour, as well as lower environmental impacts. Thus, considering that both solutions complied with standard regulations, they could be used as substitutes for conventional partition systems, reducing construction costs, time and environmental pollution.

Finally, considering the limitations of the proposed methodology, the use of relatively low replacement levels of plastic waste must be highlighted. This can be justified by the need to maintain the workability of the material without resorting to the use of water-reducing admixtures and avoid impacting the mechanical performance significantly when compared to the control product. Naturally, this led to little improved environmental performance. Moreover, given the results of the simplified LCA, a relatively high impact related to the pre-treatment of plastic waste (mainly PP) was observed even for the low levels of replacement evaluated here. Therefore, future research must focus on increasing plastic residue content subjected to less impacting treatment processes, despite the potential decline in performance. Such an approach is viable from an optimization perspective since the blocks proposed in the present study were well over the minimum strength requirements set by standards. This would lead to a further decrease in environmental impacts and an improvement in thermal and water-resistant behaviours. Naturally, a more complete LCA could also be developed considering a greater number of impact categories, with the purpose of offering a complete environmental characterization of the new products in comparison with commercial solutions.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Credit authorship contribution statement

M.I. Romero-Gómez: Methodology, Investigation, Writing - original draft, Writing - review & editing

R.V. Silva: Funding acquisition, Project administration, Writing - review & editing, Analysis of results, Supervision.

J. de Brito: Writing - review & editing, Analysis of results.

I. Flores-Colen: Writing - review & editing, Analysis of results, Supervision.

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