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Reuse of wood biomass ash to improve thermal behavior of gypsum plasters

M. Alejandro Pedreño-Rojas[a,*], Paola Villoria-Sáez[a], César Porras-Amores[a], M. Jesús Morales-Conde[b], Inês Flores-Colen[c]

[a]Grupo TEMA, ETS Edificación, Universidad Politécnica de Madrid, Av. Juan de Herrera 6, Madrid, 28040, Spain
[b]Departamento de Construcciones Arquitectónias I, ETS Arquitectura, Universidad de Sevilla, Av. Reina Mercedes 2, Seville, 41013, Spain
[c]CERIS, DECivil, IST, Universidade de Lisboa, Av. Rovisco Pais, Lisbon 1049-001, Portugal

Abstract

Huge amounts of waste are generated each year in the world. In addition, the construction sector is one of the larger producers of residues and a huge energy consumer. Thus, architects, engineers and other actors of the building sector should give solutions in order to reduce that problem. In that sense, the idea of finding solutions for the end of the service life of materials, in order to promote circularity, has been studied by several researchers. In this study, biomass wood ash has been used as aggregate for the generation of new eco-efficient gypsum plasters, for its application in new buildings and rehabilitation works. In order to conduct an exhaustive characterization of the new composites, an experimental campaign of the plasters has been conducted: dry bulk density and thermal conductivity of the plasters have been measured. The results showed that it was possible to add up to 25% of wood ash without modifying the water/gypsum ratios. Moreover, thermal conductivity of the plasters has improved up to18% when the ash was added to the mixture. Finally, the effects of using the new gypsum composites in the thermal envelope of buildings was analyzed by its usage in a rehabilitation case study simulation.

Keywords: Anti-graffiti; Climate change; Efficiency; Durability

* Corresponding author.
E-mail address: alejandro.pedreno@upm.es; mpedreno@us.es

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1. Introduction

The use of gypsum plasters and products is worldwide extended as interior coating in buildings (de Brito and Flores-Colen, 2015). Then, as it is part of the building envelope, its thermal behavior has been subject of study by multiple investigations (Gomes et al., 2017; Bicer and Kar, 2017; Pedroso et al., 2020). Most of them established that the thermal conductivity of a commercial gypsum paste is around 0.30 W/(m·K) (Pedreño-Rojas et al., 2019; Romero-Gómez et al., 2022) and it could be reduced by adding several types of additions. In that sense, many studies have analyzed the use of different aggregates in the mixtures to improve the thermal conductivity of the material. San Antonio-González et al. (2015) and del Río-Merino et al. (2019) evaluated the thermal enhancement of gypsum plasters that incorporate extruded polystyrene waste. Also, Dai and Fan (2015), Morales-Conde et al. (2016) and Pedreño-Rojas et al. (2017) achieved a substantial improvement on the thermal conductivity of gypsum composites when wood waste was added to the mixtures. Cherki et al. (2014) tested the thermal improvement of gypsum products by using cork as aggregate.

Also, some investigations analyzed the incorporation of ashes in the production of new gypsum plasters. Del Río-Merino et al. (2017) evaluated the use of ashes obtained from the production of different types of oils. Previously, Leiva et al. studied the incorporation of several types of ashes from the agro-industrial sector in the production of new gypsum plasters: olive oil production (2009) and rice husk (2014). They concluded that new materials with enhanced thermal and fire behavior can be obtained by adding up to 30 wt.% of aggregate to the mixtures to maintain the workability.

Finally, it must be noted that no previous experiences have been found in which wood biomass ash was used in the production of gypsum plasters. However, some studies analyzed its usage as cement partial replacement in the production of concrete (Fořt et al., 2020). Furthermore, wood biomass ash was also used in the production of clay composites (Fořt et al., 2018).

The primary aim of this study is to evaluate the thermal properties of gypsum plasters when wood biomass ash is incorporated as an aggregate. This research will focus on understanding the advantages of using this mixture as part of the thermal envelope in building rehabilitation projects.

2. Materials and Methods

2.1. Materials

The materials used to generate the new plasters are listed below:

- High purity commercial gypsum, classified as A1 (E-35) by the EN 13279-1 standard (AENOR, 2009).
- Wood biomass ash directly taken from a heat power district plant located in Móstoles (Madrid, Spain).

Those materials were mixed following different aggregate incorporation rates, up to 25 wt.%, maintaining the workability conditions of the pastes (AENOR, 2006). Furthermore, water content of the mixtures was determined by using the flow table and Vicat cone procedures defined in EN 13279-2 (AENOR, 2006). Table 1 collects the composition of each mixture under study related to the use of 1 kg of gypsum powder:

Table 1. Composition of all the mixtures under study.

Composition name	Gypsum [g]	Water [g]	W/G Ratio	Wood Biomass Ash [g]
Reference	1000	800	0.80	-
G+WBA 5%	1000	800	0.80	50
G+WBA 10%	1000	800	0.80	100
G+WBA 15%	1000	800	0.80	150
G+WBA 20%	1000	800	0.80	200
G+WBA 25%	1000	800	0.80	250

2.2. Test Methods

Gypsum mixtures were elaborated following the procedure defined by EN-13279-2 (AENOR, 2006), using the same requirements to obtain the dry state bulk density of the pastes. Prismatic specimens of 40x40x160 mm^3 were produced (Fig. 1).

Fig. 1. Samples preparation according EN 13279-2.

Also, to achieve the thermal conductivity of each plaster, ISOMET 2114 device was used, following the procedure described in ASTM 5334-08 (ASTM, 2009). To obtain it, circular specimens of 60 mm diameter and 15 mm height were made for each mixture.

To evaluate the benefits of their usage in the thermal envelope of rehabilitated buildings, a simulation of its usage in a traditional Spanish house rehabilitation was conducted. The thermal transmittance of the wall façade in three scenarios was analysed: original state and rehabilitated one using conventional coating and the other one with the application of the biomass-gypsum based coating. The thermal transmittance (U [$W/m^2 \cdot K$]) of the wall façade was obtained using the expression presented in eq. 1:

$$U = \frac{1}{\sum R_i} \tag{1}$$

Where Ri [$m^2 \cdot K/W$] was the thermal resistance of each layer of the façade wall according the Spanish CTE Building Elements Catalogue (Spanish Government, 2008).

3. Results and Discussion

3.1. Dry Bulk Density

As it is shown in Fig. 2, the addition of wood biomass ash was linked, for all the mixtures, to an increase on the dry bulk density of the composites, compared to the reference material. The highest increase in the density value was noticed for the G+WBA 20% mixture, achieving +21% higher density than the reference composite. In addition, it can be said that any of the plasters can be considered a lightweight material, as their dry bulk density always surpass 0.8 g/cm^2.

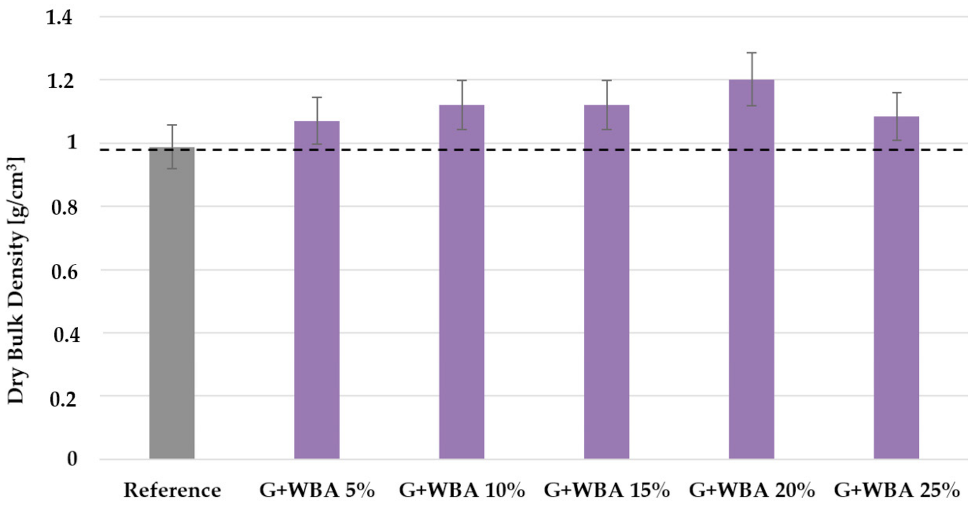

Fig. 2. Dry bulk density results with standard deviation.

3.2. Thermal Conductivity

Fig. 3 shows the registered values for the thermal conductivity of the new plasters. As it can be noticed, for all the composites, the increase on the percentage of waste added to the paste was always linked to a decrease on the thermal behavior of the material. Thus, the best performance in this case was achieved for the G+WBA 25% composite, achieving 0.247 W/(m·K) for its thermal conductivity (17.7% lower when compared to the reference material).

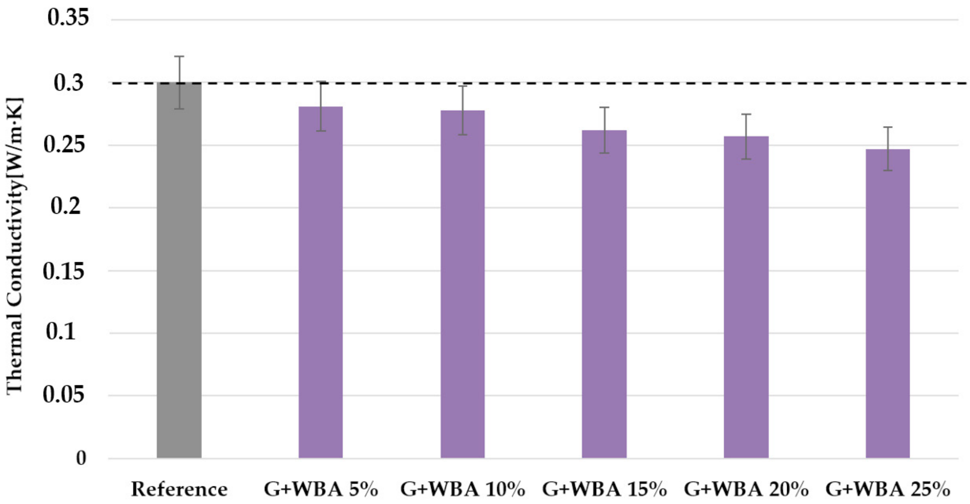

Fig. 3. Thermal conductivity results with standard deviation.

3.3. Discussion

In order to discuss all the obtained results, a comparison between the thermal conductivity values and the dry bulk density is presented in Fig. 4. As it can be appreciated, all the new composites did not follow the regular tendency of the literature in which a decrease on the density values was always linked on an enhancement on the thermal behavior of the material (Morales-Conde et al., 2016; San Antonio-González, 2015). In this case, heavier materials presented better thermal properties. This fact can be completed in a second phase with the mechanical values of the plasters. However, it must be noted that an improvement in the thermal conductivity was also found by previous research works incorporating ashes from the olive and rice production, which claimed lower thermal conductivity coefficients compared to the reference (Leiva Aguilera and Del Rio Merino, 2014; Leiva et al., 2009).

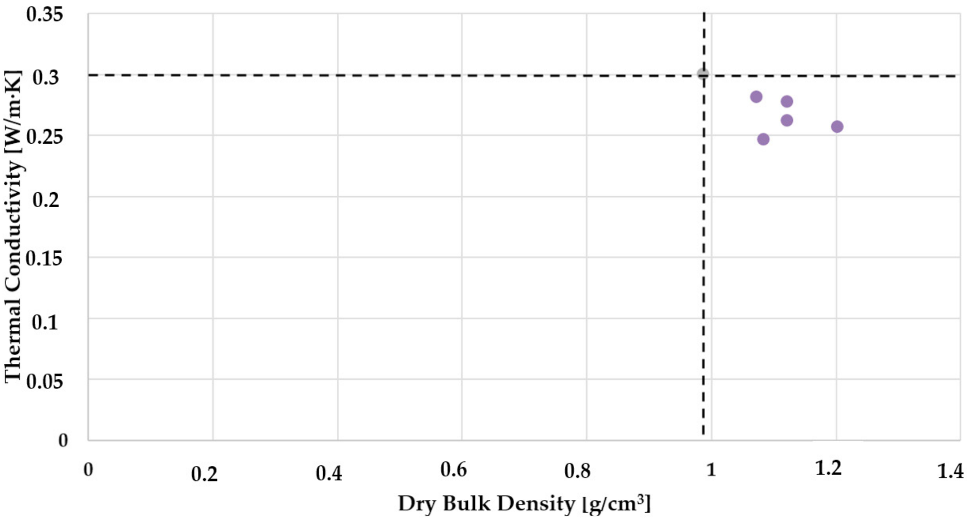

Fig. 4. Comparison between the thermal conductivity and dry bulk density values.

3.4. Case Study Building

Finally, trying to assess the real impact of the new products on a real case study building, a simulation based on a traditional Spanish building (XIX century) rehabilitation was carried out. On it, in order to evaluate the performance of the new gypsum composite in a theoretical rehabilitation work, the thermal transmittance (U-value) of the façade wall, using the thermal resistance of each layer/material, was evaluated under three different scenarios:

- *Scenario A:* Original state of the building, previous of its rehabilitation.
- *Scenario B:* Rehabilitated state using conventional gypsum panels for interior covering (2 cm air chamber + 1.5 cm plasterboard).
- *Scenario C:* Rehabilitated state using G+WBA 25% composite (the one with the best thermal performance) for the interior covering (2 cm air chamber + 1.5 cm G+WBA 25% plasterboard).

Fig. 5 presents the results for the thermal transmittance (U [W/m^2·K]) of the façade wall on the three scenarios under study.

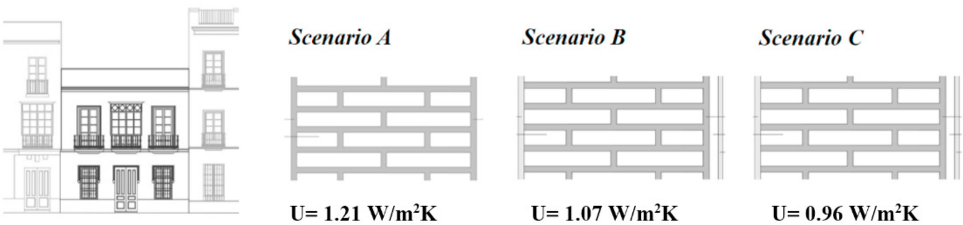

Fig. 5. Thermal transmittance of the façade wall of a traditional Spanish case study building.

As it can be noticed, an improvement of 20.7% (lower value) was obtained comparing the Scenarios A and C and 10.3% comparing B and C ones. This fact shows that biomass-gypsum based coatings are optimal for their use in cases where thermal improvement of a façade is required to achieve the minimum transmittance values required by the regulations (Spanish Government, 2022).

4. Conclusions

In this paper, the thermal behavior of new eco-efficient gypsum plasters with wood biomass aggregate was evaluated. The main conclusions of this research are listed below:

- It was possible to add wood biomass fly ash as aggregate in the development of new gypsum plasters up to 25 wt.% maintaining the workability requirements for the pastes.
- A slight increase on the dry bulk density (up to +21% compared to the reference material) was observed in the new composites.
- An improvement of the thermal behavior of the composites, up to 17.7% for the G+WBA 25% mixture, was noticed.
- The use of the new materials in the theoretical study of the thermal behavior of a rehabilitated façade example shows a significant improvement over the original state solution.
- The new materials are optimal for their use in cases where thermal improvement of a façade is required to achieve the minimum transmittance values required by the regulations.

As it can be appreciated, the developed plasters presented an important enhancement on their thermal properties, evaluating their mechanical properties in a second phase of the research.

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