Influence of Wood and Plastic Waste as Aggregates in Gypsum Plasters

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Abstract. Large amounts of waste are generated each day in the world, being a major concern for the EU28, who establish waste management as a priority line of work within the Horizon 2020. Construction sector is one of the largest residues generators. In that sense, architects and civil engineers should give an answer to solve that environmental problem. One of the options is to reuse waste for the generation of new materials and products for construction. In this research, wood waste (sawdust) from demolition works and polycarbonate waste have been used as aggregates to generate new gypsum plasters. Different percentages of additions (5, 10, 20 and 40%) for each type of waste have been conducted to develop the gypsum composites. Physical (density and thermal conductivity) and mechanical (flexural and compressive strength) properties of the new plasters have been measured using the procedure regulated by standards, comparing them with the reference material values (commercial gypsum without aggregates). The results of the tests show that lighter composites have been obtained when the percentage of waste increased for both type of aggregate. This lightening is higher in composites with wood waste than in those with plastic at the same percentage of addition. Furthermore, an improvement in the thermal conductivity of the plasters have been achieved. On the other hand, a decrease on the mechanical properties of the composites, with higher percentages of additions, have been obtained. For all the cases, the minimum strength value required by standards have been achieved. As a conclusion, lighter gypsum composites with enhanced thermal properties have been obtained, achieving in all the cases an acceptable flexural and compressive strength.

1. Introduction

Large amounts of waste are generated each day in the world, being a major concern for the EU28, who establish waste management as a priority line of work within the Horizon 2020 [1]. Huge amounts of plastic are produced each year in our planet. According to the data given by Plastic the Facts, in 2017, 348 million tonne of plastic were produced in the world (18.5 % in Europe) [2]. In 2016, 27.3 % of the total collected plastic from post-consumer waste in EU28+NO/CH ended in landfills [2]. Furthermore, construction sector is one of the largest residues generators. In that sense, architects and civil engineers should give an answer to solve that environmental problem. One of the options is to reuse waste for the generation of new materials and products for construction [3].
Several researches have evaluated the influence of wood waste in the production of new construction and building materials and products. Corinaldesi et al. studied the use of wood waste as a sand replacement in the generation of cement mortars, achieving composites with enhanced thermal behaviour [4]. Other studies analysed the addition of wood-ash as partial replacement of cement for the development of mortars and concretes [5, 6]. Mohammed et al. used wood chips as partial replacement for fine aggregate in the preparation of concrete [7]. The durability of wood-sand concretes, when subjected to humid and dry environments, was studied by Coatanlem et al. [8]. However, the influence of wood waste in gypsum composites have not been analysed by many researchers. Morales-Conde et al. studied the effects of adding sawdust and wood shavings in different percentages to a gypsum matrix [9]. Those new composites were used later by Pedreño-Rojas et al. to develop false ceiling plates with improved thermal and acoustic properties [10].

On the other hand, other studies have analysed the use of different types of plastic waste as aggregate in gypsum composites. San-Antonio-González et al. developed new gypsum plasters using EPS and XPS waste from construction and demolition waste (CDW). They obtained lighter plasters with an improvement on their thermal properties [11, 12]. The use of pellets as aggregates in a gypsum matrix was analysed by Vidales-Barriguete et al. [13]. Moreover, in previous studies, Pedreño-Rojas et al. used polycarbonate (PC) waste as addition into a gypsum matrix, achieving good strength results [14]. Other types of plastics, like PET or PUR, have also been used by other researches [15, 16].

Although several researchers have developed gypsum plasters using wood and plastic waste, no previous experience has been found comparing the results of the usage of both type of waste at the same percentage (by weight of gypsum) in the mixtures. Thus, wood waste (sawdust) and PC waste from CDs and DVDs were used as aggregates to the plasters. Their density, mechanical properties (flexural and compressive strength) and thermal conductivity have been measured and compared in this paper.

2. Materials and methods

2.1. Materials
The following materials have been used to develop the new gypsum plasters:

- Commercial gypsum for construction: controlled setting gypsum, also known as gypsum for construction, or B1 gypsum according to standard UNE-EN 13279-1 [17] was used.
- Water.
- Wood waste (W): sawdust from old wooden slabs replaced or demolished in rehabilitation works was used as aggregate. The wood waste consists of particles measuring up to 1 mm (figure 1a).
- Plastic waste (P): polycarbonate (PC) waste from recycled CDs and DVDs was used as plastic aggregate to the mixtures. The PC waste consists of pieces measuring up to 4 mm (figure 1b).

![Figure 1](image-url)  
**Figure 1.** Wood (a) and plastic (b) waste used as aggregates in the plasters.
2.2. Test samples
Test specimens were composed of different percentages of wood (W) and plastic (P) waste. The percentages of each type of waste used were 5, 10, 20 and 40 % (percentage by weight of gypsum). In total, 10 different mixtures (divided according to the type of waste used and the percentage of waste in the mixture) as well as the reference sample (R) were produced. Table 1 shows the composition of each mixture per kg of gypsum.

The preparation of the mixtures required the determining of the water / gypsum ratio (W/G) to be used, following the established procedure by the standard [18]. A W/G ratio of 0.55 was obtained for the reference sample (R), all the plastic waste samples and for the mixtures with 5 and 10 % of wood waste. However, and in order to maintain the workability of the plaster, W/G ratio had to be increased for composites with 20 and 40 % of wood waste, as it can be checked in Table 1.

| Sample Series | Gypsum [g] | Water [g] or [ml] | W/G Ratio | Wood Waste [g] | Plastic Waste [g] |
|---------------|------------|------------------|------------|---------------|------------------|
| R             | 1000       | 550              | 0.55       | -             | -                |
| W5            | 1000       | 550              | 0.55       | 50            | -                |
| W10           | 1000       | 550              | 0.55       | 100           | -                |
| W20           | 1000       | 800              | 0.80       | 200           | -                |
| W40           | 1000       | 1200             | 1.20       | 400           | -                |
| P5            | 1000       | 550              | 0.55       | -             | 50               |
| P10           | 1000       | 550              | 0.55       | -             | 100              |
| P20           | 1000       | 550              | 0.55       | -             | 200              |
| P40           | 1000       | 550              | 0.55       | -             | 400              |

In order to test the mechanical properties and the density of the new plasters, six prismatic specimens (40 x 40 x 160 mm³) were elaborated for each mixture. Furthermore, square test samples of 300 mm on each side and 15 mm of thickness were prepared to measure the thermal conductivity of the new materials.

2.3. Test methods
According to European standards [17, 18], all the samples were characterised for their density in dry state and their flexural and compressive strength after 28 days. Furthermore, their thermal conductivity.

Following specimen preparation, these were stored for seven days under laboratory conditions of relative humidity at 50 ± 1 % and a temperature of 24 ± 1 °C, in accordance with regulations [18]. Later, the specimens were placed in an oven at 40 °C until reaching constant weight, enabling their characterization in dry state.

Six samples were tested to evaluate flexural strength which, after three-point bending test rupture (figure 2a), yielded 12 test pieces that were tested to obtain compressive strength values (figure 2b). The tests were performed according to the experimental procedure described in the standards [18] using a Suzpecar multi-test machine with a load capacity of 20 tons and a precision measurement according to the type of control. In control per round, the precision was 0.01 mm/min, whereas in load control it was 0.1 kg/s.
Finally, to measure the thermal conductivity of each plaster the device known as the "thermal house" was used. This non-standardized test enabled to study the thermal behaviour of the new material when subjected to a steady state heat flow by measuring the temperatures on both sides of the material. The temperature registered was compared to the measurements obtained on an EPS plate whose thermal conductivity coefficient was already known (figure 2c).

![Figure 2](image)

Figure 2. Test methods used: flexural strength (a), compressive strength (b) and “thermal house” device (c).

3. Results and discussions

Table 2 shows the results obtained for each plaster and test method.

| Sample Series | Density [g/cm³] | Flexural Strength [MPa] | Compressive Strength [MPa] | Thermal Conductivity [W/mºK] |
|---------------|----------------|-------------------------|---------------------------|-----------------------------|
| R             | 1.34           | 3.72                    | 9.02                      | 0.25                        |
| W5            | 1.26           | 3.68                    | 8.59                      | 0.23                        |
| W10           | 1.19           | 3.19                    | 6.96                      | 0.20                        |
| W20           | 1.04           | 2.73                    | 5.50                      | 0.16                        |
| W40           | 0.80           | 1.39                    | 2.72                      | 0.14                        |
| P5            | 1.28           | 3.83                    | 9.15                      | 0.24                        |
| P10           | 1.24           | 3.54                    | 8.98                      | 0.23                        |
| P20           | 1.23           | 3.05                    | 8.04                      | 0.21                        |
| P40           | 1.19           | 2.62                    | 7.70                      | 0.18                        |

3.1. Density

The dry densities of the gypsum plasters are presented in figure 3. As can be seen, the density values of the mixtures varied between 1.28 and 0.80 g/cm³ by depending on the weight percentage of addition and on the type of waste added. It is observed that, in all cases, the increase in the percentage of waste added to the composite led to a decrease in density in relation to the reference material. The reduction in density is most pronounced in specimens in which wood waste was used as additive, with a fall of 40.29 % in the mixture density with respect to the reference material. In the case of PC waste plasters, the density reduction is 11.19 % compared to the reference specimens. In both cases, the decrease in density corresponds to mixtures with waste aggregate at 40 %.
3.2. Flexural Strength

The results for flexural strength test of the gypsum plasters are shown in figure 4. The flexural strength values of the mixtures varied between 3.83 and 1.39 MPa by depending on the weight percentage of addition and on the type of waste added. As it can be seen, in all cases, the increase in the percentage of waste added to the composite led to a decrease in flexural strength in relation to the reference material. That reduction is most pronounced in specimens in which wood waste was used as aggregate, with a fall of 62.63 % in the mixture flexural strength related to the reference material. In the case of PC waste plasters, the biggest reduction is 29.76 % compared to the reference specimens. In both cases, the decrease in the flexural strength corresponds to mixtures with waste aggregate at 40 %. However, the strength value obtained for the P5 plaster is higher than the one obtained for the reference one. It should be noted that, in all cases, the resistance values obtained are higher than the minimum 1 MPa standard requirement [17] for this type of materials.

**Figure 3.** Density results.

**Figure 4.** Flexural Strength results.
3.3. Compressive Strength

The results for compressive strength test of the plasters are shown in figure 5. The compressive strength values of the mixtures varied between 9.15 and 2.72 MPa by depending on the weight percentage of addition and on the type of waste added. As it happened with the density and the flexural strength, in all cases, the increase in the percentage of waste added to the composite led to a decrease in the compressive strength in relation to the reference material. That reduction is most pronounced in specimens in which wood waste was used as aggregate, with a fall of 69.84 % in the mixture compressive strength related to the reference material. In the case of PC waste plasters, the biggest reduction is 14.73 % compared to the reference specimens. In both cases, the decrease in the flexural strength corresponds to mixtures with waste aggregate at 40 %. However, as it can also be appreciated in the flexural strength, the compressive strength value obtained for the P5 plaster (9.15 MPa) is higher than the one obtained for the reference plaster. Furthermore, it should be noted that, in all cases, the resistance values obtained are higher than the minimum 2 MPa standard requirement [17] for this type of materials.

![Compressive Strength results.](image)

Figure 5. Compressive Strength results.

3.4. Thermal Conductivity

Figure 6 shows the results of the thermal tests in relation to the densities of the new plasters studied. These tests provide results on the thermal conductivity of each proportion, with these values compared to the reference sample. As can be seen, as the percentage of waste in the samples increases, the thermal conductivity of the composite decreases, thus endowing the material with better thermal behaviour. In relation to the two types of additions, the wood-based composites show better thermal behaviour than those that include plastic waste in the same proportion.

It is interesting to note that the decrease in the thermal conductivity of the plate is linked to a decrease in the density of that composite. Therefore, the plate with wood waste at 40% is the one that, in addition to having the lowest density of all (0.80 g/cm³), has best thermal behaviour, with a conductivity value close to 0.14 W/m°K, which implies a reduction of 40.3 % with respect to the reference material.
4. Conclusions
In this research, the influence of the use of plastic and wood waste as aggregate in gypsum plasters was studied. The mechanical performance and thermal conductivity were determined. The following conclusions were drawn:

- The addition of wood and plastic waste in the gypsum plasters leads to a decrease in the density of the composites in relation to the reference gypsum. That drop is bigger in mixtures with wood waste than in those with PC.

- The results of the mechanical behaviour tests (flexural and compressive strength) show a relevant decrease in the resistance of the composite when the percentage of waste added increase. That drop is bigger in mixtures with wood waste than in those with PC. In all of the cases the resistance values obtained are higher than the minimum standard requirement for this type of materials.

- An improvement in the thermal conductivity of the gypsums can be observed when plastic and wood waste are added as aggregates to the mixtures. Wood-gypsum composites present a better thermal behaviour than those with PC at the same percentage.

As a conclusion, it can be said that the new materials are suitable to be used as substitute of commercial gypsum in buildings. They are lighter and with a better thermal behaviour, achieving in all the cases the minimum standard requirement for gypsum plasters.

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References

[1] Pacheco-Torgal, F., 2014. Eco-efficient construction and building materials research under the EU Framework Programme Horizon 2020. Constr. Build. Mater., 51, 151-162.

[2] Plastics Europe, 2018. Plastics the Facts 2018. An Analysis of European Plastics Production, Demand and Waste Data.

[3] Silva, R. V., De Brito, J., Dhir, R. K., 2014. Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Constr. Build. Mater., 65, 201-217.

[4] Corinaldesi, V., Mazzoli, A., Siddique, R., 2016. Characterization of lightweight mortars containing wood processing by-products waste. Constr. Build. Mater. 123, 281-289.

[5] Elinwa, A.U., Mahmood, Y.A., 2002. Ash from timber waste as cement replacement material. Cem. Concr. Compos. 24 (2), 219-222.

[6] Siddique, R., 2012. Utilization of wood ash in concrete manufacturing. Resour. Conservation Recycl. 67, 27-33.

[7] Mohammed, B.S., Abdullahi, M., Hoong, C.K., 2014. Statistical models for concrete containing wood chipping as partial replacement to fine aggregate. Constr. Build. Mater. 55, 13-19.

[8] Coatanlem, P., Jauberthie, R., Rendell, F., 2006. Lightweight wood chipping concrete durability. Constr. Build. Mater. 20 (9), 776-781.

[9] Morales-Conde, M.J., Rodríguez-Liñán, C., Pedreño-Rojas, M.A., 2016. Physical and mechanical properties of wood-gypsum composites from demolition material in rehabilitation works. Constr. Build. Mater. 114, 6-14.

[10] Pedreño-Rojas, M.A., Morales-Conde, M.J., Pérez-Gálvez, F., Rodríguez-Liñán, C., 2017. Eco-efficient acoustic and thermal conditioning using false ceiling plates made from plaster and wood waste. J. Clean. Prod. 166, 690-705.

[11] San Antonio González, A., Del Río Merino, M., Viñas Arrebola, C., Villoria Sáez, P., 2015. Lightweight material made with gypsum and extruded polystyrene waste with enhanced thermal behaviour. Constr. Build. Mater. 93, 57-63.

[12] San Antonio González, A., Del Río Merino, M., Viñas Arrebola, C., Villoria Sáez, P., 2015. Lightweight material made with gypsum and EPS waste with enhanced mechanical strength. J. Mater. Civ. Eng. 28 (2), 04015101.

[13] Vidales Barriguete, A., del Río Merino, M., Atanes Sánchez, E., Piña Ramírez, C., Viñas Arrebola, C., 2018. Analysis of the feasibility of the use of CDW as a low environmental-impact aggregate in conglomerates. Constr. Build. Mater. 178, 83-91.

[14] Pedreño-Rojas, M.A., Morales-Conde, M.J., Pérez-Gálvez, F., Rubio-de-Hita, P., 2019. Influence of polycarbonate waste on gypsum composites: mechanical and environmental study. J. Clean. Prod. 218, 21-37.

[15] Gutiérrez-González, S., Gadea, J., Rodríguez, A., Junco, C., Calderón, V., 2012. Lightweight plaster materials with enhanced thermal properties made with polyurethane foam wastes. Constr. Build. Mater. 28 (1), 653-658.

[16] Karaman, S., Sahin, S., Gunal, H., Orung, I., 2006. Stabilization of waste pet bottles with Gypsum. J. Appl. Sci. 6, 1119-1122.

[17] UNE-EN 13279-1, 2006. Gypsum Binders and Gypsum Plasters - Part 1: Definitions and Requirements.

[18] UNE-EN 13279-2, 2006. Gypsum Binders and Gypsum Plasters - Part 2: Test Methods.