Plaster Added With Plastic Cable Waste as a New Traditional Sustainable Material

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Abstract

The objective of this work is to analyze the possibilities of reusing plastic waste of cables added in a plaster matrix.

Firstly, the experimental process has allowed the physicochemical characterization of the raw material, plaster and plastic waste, consisting in elemental analysis, XRD and thermogravimetric analysis; Secondly, the performance of physicomechanical tests of the mixtures, Shore C hardness, absorption and resistance to flexion and compression.

During the investigation, the water/plaster ratio of 0.8 was maintained, as well as the grain size of the plastic waste as it comes from the recycling factory (maximum 3 mm). On the contrary, the amount of added plastic waste has oscillated up to incorporate 50%, 60% and 70% over the weight of the plaster.

In comparison to a reference sample, the obtained compounds are characterized by having a higher Shore C hardness, a lower absorption by capillarity and a decrease in their values of mechanical resistance.

The addition of plastic waste to a plaster matrix can be considered as a possibility to obtain compounds of greater sustainability to be used in the field of sustainable construction.

Key words: *Plastic waste, gypsum, sustainable construction, recycling*

Introduction

There are numerous studies carried out on the incorporation of waste as an addition or substitution in “traditional” construction materials, which show real opportunities to contribute to sustainable development.

With the entry into force of the current Waste Framework Directive 2008/98/EC, the approach to waste management in Europe is modified, prioritizing prevention and reuse, as opposed to their elimination and recovery (del Río Merino, Garcia Navarro, Villoria Saez, 2011). In the field of construction, managing this means incorporating a new paradigm oriented towards the environment (López de Asiain, 2001), that is, an evolution in the management of resources based on the integral study of the "life cycle" (Merino, González Cortina, Izquierdo Gracia and Salto-Weis Azevedo, 2006) and on the reincorporation of waste into the market following a "circular economy" model (cradle to cradle).

It is estimated that approximately 35% of the waste generated in Europe comes from the construction sector (RCD) (Eurostat, 2014) and, although it is true that the trend in recent years has been decreasing, mainly due to the strong crisis that persists. Therefore, it is necessary to find new ways of reusing and/or recycling these wastes (Alameda, Calderón, Gadea, Gutiérrez-Gonzáleza, 2015). One of the most abundant RCD and, at the same time complicated in its recycling process, is plastic. According to the indicators of the association of European plastics manufacturers Plasticseurope, more than 20% of the plastic manufactured is destined for the construction sector, this means about 10 million tons per year that will eventually become CDW (PlasticsEurope, 2016).

Plastics are chemical substances called polymers that offer many advantages such as variety, durability or slow degradation and, as a disadvantage, their complex recycling phase. For years, plastic waste has been sent to landfill along with the rest of CDW, but this alternative has become

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less and less viable due to the decrease in available areas and the cost it generates (Franco-Urquiza, Maspoch, 2014). It is true that there are currently numerous methods and techniques for recycling plastics, mechanical (when the formulation of the material is known) and chemical (based on the decomposition of the material into monomers with which to start a new polymerization process) but, generally, the lack of homogeneity, that is, the presence of mixed thermoplastic and thermosetting materials, gives rise to complicated phases in any of these transformation processes.

In numerous investigations found, different options are analysed that try to solve this problem. Among them, studies in which plastic waste is incorporated:

- in the manufacture of non-load-bearing construction elements, bricks, blocks and cement-based plates, with which to achieve, in addition to reducing the amount of waste in landfills, cheaper, lighter products with better thermal performance than traditional ones, for the construction of social housing. Disused containers and wrappers are used (Gaggino, Arguello, Berretta, 2007; Los Santos, *et al.*, n.d.).
- in the manufacture of concrete and pavements, to obtain lightness in the first (Kou, Lee, Poon, Lai, 2009) and durability in the second (Reyes, 2007). PVC pipes, vehicle wheels and disused milk bags are used.
- or even for the modification of some of the properties of gypsum compounds, such as the decrease in density (Jiménez Rivero, Guzmán Báez and González Cortina, 2011), the improvement of thermal properties (G. Madariaga, 2008) or the increase in deformation capacity (García Santos, 1988), among others. Furthermore, throughout the search other publications have been found about the use of different plastics such as polystyrenes, polyethylenes, ABS's, polyepoxides, synthetic polymers, polypropylenes, rubbers, etc, as an addition or substitution in cement and plaster matrices.

This has given rise to the present research work, of which no previous experience is known, and whose main objective is to evaluate the reuse of plastics from the recycling of disused electrical cables. As a particular objective, it is intended to analyse the feasibility of reusing these residues added in plaster matrix compounds. For this, the waste is disposed off as it comes from the recycling plant and the maximum percentage of addition is sought without compromising the minimum reference values established for type A plasters in regulations UNE EN 13279-2 and UNE 102042 (UNE-EN 13279-2:2014; UNE 102042, 2014).

Methodology

In the experimental process carried out in this research, a fast-setting plaster was used, with the European designation type A and the Placo Saint-Gobain trademark, manufactured at the San Martín de la Vega plant (Madrid). It has a purity greater than 90%, a granulometry between 0-0.2 mm and a mechanical resistance to bending greater than 3 N/mm2. The plastic waste, that is, the pellets, comes from the recycling company Lyrsa Álava, and is obtained in said company after the recycling process to which the disused cables are subjected to recover the metal of the conductive thread. This pellet is composed of a heterogeneous mixture of thermosetting and thermoplastic materials, with a maximum granulometry of 3 mm (Figure 1). As for the water/plaster ratio used, it was 0.8, constituting a value within that recommended by the manufacturer.

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Fig. 1. *A-Recycling of cables (Company Lyrsa Álava). B-Raw materials used in the compounds*

Firstly, the physicochemical characterization (elemental analysis, XRD and thermogravimetric analysis) of the raw material, both plaster and pellets, was carried out. Second, the compounds were prepared. For this, and following the indications of both UNE EN 13279 and UNE 102042, a series of three 4x4x16 cm prismatic specimens were made with which to carry out the Shore C hardness, absorption, bending and compression tests referenced in said normative.

In order to be able to compare the results obtained, the first series of reference specimens without pellets (REF-0% pellets) was made. Next, the amount of pellets (P) added was increased in the proportions 50% - 60% - 70% on the weight of the plaster (Table 1).

Table 1. *Dosage of the compounds*

Compound	Water (%)	Plaster (%)	Pellets (%)	Apparent density (Kg/m^3)
REF- 0 %P	80	100	0	988.90
50%P	80	100	50	1008.50
60%P	80	100	60	1022.10
70%P	80	100	70	1014.60

Results

Prior to the development of the tests, the sieving of the pellets was carried out in order to define its granulometry. The series of sieves used was the one indicated for sands according to UNE-EN 933-1:2012 (UNE-EN 933-1, 2012). The granulometric curve obtained showed us that 100% of the sample passed through the 4 mm sieve, being the most significant jump between the 2 mm sieve and the 1 mm sieve, sharply reducing the amount of pellets that passed through them from 85% to 16%, respectively.

The first phase of the tests, physicochemical characterization, was carried out in the chemistry laboratory of the Higher Technical School of Engineering and Industrial Design of the Polytechnic University of Madrid. The second phase, making compounds and testing them, was carried out in the materials laboratory of the Higher Technical School of Building of the Polytechnic University of Madrid.

3.1. Physicochemical characterization of the raw material (plaster and granules)

Elemental analysis was performed by X-ray fluorescence assay to verify the constituent elements of the plaster and pellets. An atomic absorption or emission spectrometry model S2-PUMA from Bruker was used.

Once each of the samples had been prepared and introduced, the team began to generate the characteristic radiations for each element that were collected and analysed by the components of the electronic system.

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The results of elemental analysis by X-ray fluorescence are shown in Table 2 (expressed as oxides in the case of pellets).

Table 2. *Elemental analysis of plaster and granules*

Concentration [%] (greater than 0.5%)			
Compound	**Plaster**	**Compound**	**Pellets**
Sulfur oxide	56.4	Organic material	92.6
Calcium oxide	41.9	Aluminum	1.9
Silicon oxide	0.7	Chlorine	1.3
		Bromine	1.2
		Copper	0.8
		Calcium	0.7
		Silicon	0.5

The plaster is mainly composed of S and Ca, with a percentage of 98.3%, as corresponds to its chemical composition of calcium sulphate. In the case of pellets, the organic matter that constitutes the polymers accounts for 92.6% of the composition. The presence of chlorine stands out, which could correspond to PVC, one of the polymers present to a greater extent in electrical cables (Suresh, Mohanty, Nayak, 2017). The presence of copper and aluminium could be due to metallic residues from the electrical cable.

For the *X-ray diffraction*, a Siemens Diffractometer D5000 diffractometer was used, which provided us with the measurement of the emission, absorption, dispersion, fluorescence and diffraction of the electromagnetic radiation of the plaster samples. The X-ray diffractogram of the plaster identified that the sample was formed by calcium sulphate hemihydrate (CaSO4 · 0.5 H2O), and the presence of hydrate was not observed (Strydom, Potgieter, 1999) (Figure 2). The hemihydrate is obtained by partial dehydration of natural gypsum (gypsum stone), also called dihydrate due to its chemical composition (CaSO4 2 H2O), at a temperature slightly above 100 ºC (Villanueva, García Santos, 2001).

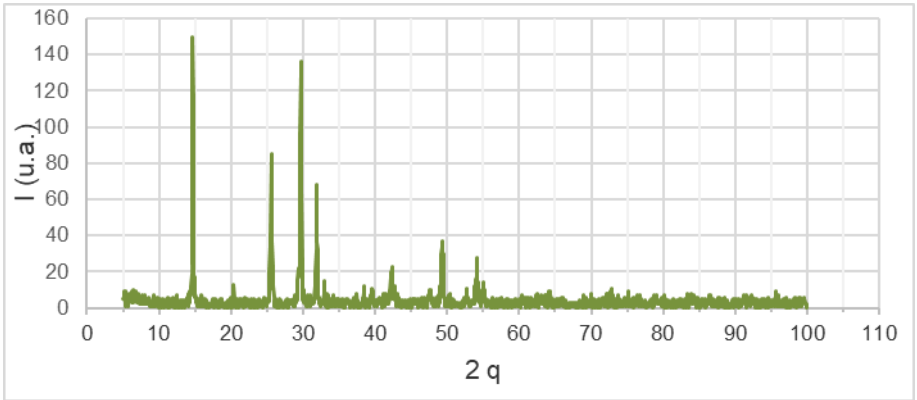

Fig. 2. *X-ray diffractogram on plaster*

The technique of *thermogravimetry*, loss or gain of mass as a function of temperature, was applied for the dynamic gravimetric thermal analysis of plaster and pellets. The equipment used was a TA Instruments SDT Q600 thermobalance, atmosphere of 100 ml/min of air and ramp from room temperature to 1000ºC (10ºC/min). The results reflected in Figure 3 were obtained:

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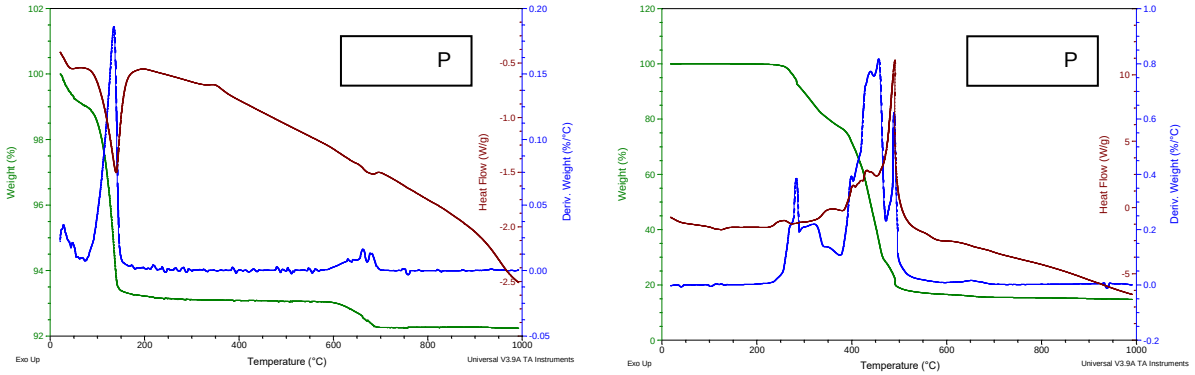

Fig. 3.*Thermogravimetric analysis of plaster and pellets*

The plaster sample shows a total weight loss of 7.7%; after the first weight loss (<1%) due to weakly associated moisture, the second weight loss (endothermic) of around 5.8% between 100 and 200ºC, can be associated with dehydration of the gypsum hemihydrate (CaSO4· 1/2 H2O) to obtain anhydrous calcium sulphate or anhydrite III, which is produced at a temperature below 200ºC (Strydom, Potgieter, 1999). Between 550 and 750ºC there is a loss of mass of around 0.8%. Since it is calcium sulphate, its mass does not change up to a temperature above 1000ºC, this last event may be due to the presence of some retarding or accelerating additive of the setting in the plaster.

Given the heterogeneity of the pellet sample, since it is an industrial waste mixture of very different types of polymers, three analyses were carried out. In figure 3 indicated above, the result of one of them is shown. The pellet sample is thermally stable up to a temperature of approximately 200ºC. From that temperature, and up to approximately 700 ºC, it presents a continuous and very marked loss of mass, with a total value of approximately 84%, which indicates the presence of an incombustible inorganic residue of around 16% in the pellets. The derivative of weight with temperature shows several maxima throughout the range from 200 to 700°C; each of them would correspond to the oxidative thermal decomposition of a component of the sample, which clearly corresponds to its heterogeneity, which is a mixture of polymers (Ehrenstein, Riedel, Trawiel, 2012); Richard, Touhami, Zeghloul, Dascalescu, 2017). Roughly, two zones can be distinguished in the loss of mass with temperature between 200 and 700ºC. The first, of approximately 23%, up to approximately 375ºC, which in turn shows various decomposition processes, and the second, with a mass loss of more than double (60% in this case) which also shows several maxima. Thermal analysis performed on three different portions of samples provides qualitatively similar results.

3.2. Compound tests

The *surface hardness* of all the mixtures was determined, which were subsequently tested for bending and compression. For this, a durometer was used to measure the Shore C Hardness, on the two lateral longitudinal faces of the specimen.

The results did not show figures of significant improvement of the compounds, 80-81, with respect to the reference (0% pellets), 78. Although it is true that the mixture specimens had greater porosity, it was found that it is not a conclusive factor, when quantifying the hardness of the material (Alameda, Calderón, Gadea, Gutiérrez-Gonzáleza, 2015).

In order to know the rate of *absorption by capillarity* of the different mixtures, the water absorption test was carried out, based on the RILEM RC 25-PEM standard (Rilem, 1980) used in other investigations. The results were those shown in Figure 4:

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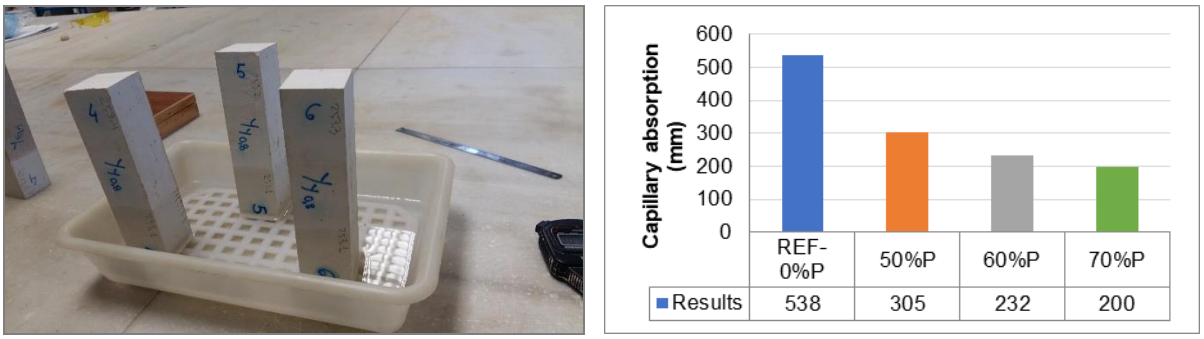

Fig. 4. *Absorption by capillarity at 7 days (mm)*

It was observed that, while in the reference sample (0% pellets) the water managed to rise up to 538 mm, in the 50%G-60%G-70%G mixtures, this amount did not reach more than 305mm-232mm- 200mm, respectively. This meant a reduction of more than 50% of the water absorption capacity by capillarity in the compounds with the highest percentage of residue.

Contrary to plaster, which is known for its avidity for water, the incorporated polymeric residues have the property of being impermeable. This impermeability explains the remarkable decrease in the absorption capacity of the specimens, since the large amount of granules added works as a barrier through which the rise of water is hindered. This fact was more pronounced in the test tubes with the highest percentage of pellets in which, in the last minutes, barely one millimetre of water was absorbed compared to the three or four millimetres absorbed by the reference test tube.

To determine the value of maximum *flexural failure* (flexural strength) and maximum compressive failure (compressive strength) of each series of specimens, the Ibertest Autotest 200 work team was used, which applied the load until it produced breakage and recorded the data obtained in the computer program. The results indicated in Figures 5 and 6 were obtained.

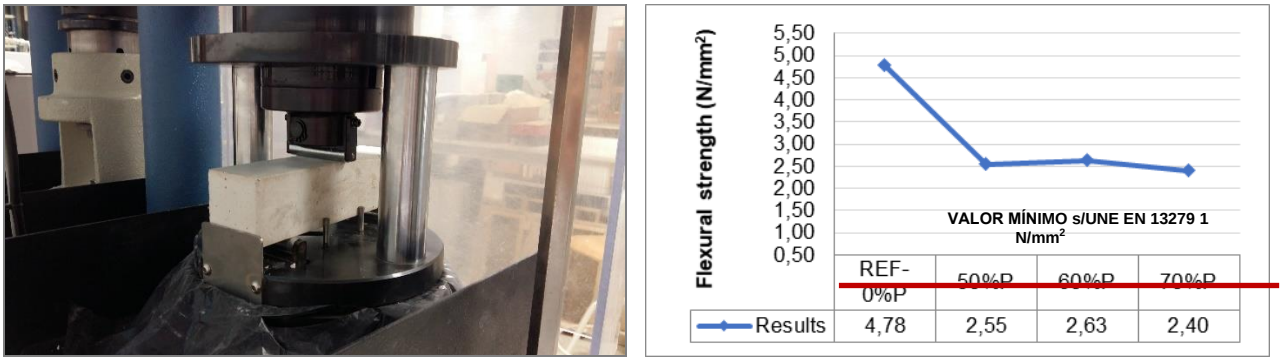

Fig. 5. *Flexural strength at 7 days (N/mm²)*

In the flexural strength test, values of 4.78 N/mm2 were obtained for the reference and values of 2.55 N/mm2 – 2.63 N/mm2 – 2.40 N/mm2 for the 50% mixtures. G – 60%G – 70%G, respectively. These data evidenced two things, on the one hand, compliance with the minimum value according to regulations, 1 N/mm2 and, on the other hand, the decrease of approximately 50% of the value of the reference sample when plastic waste is incorporated into its matrix.

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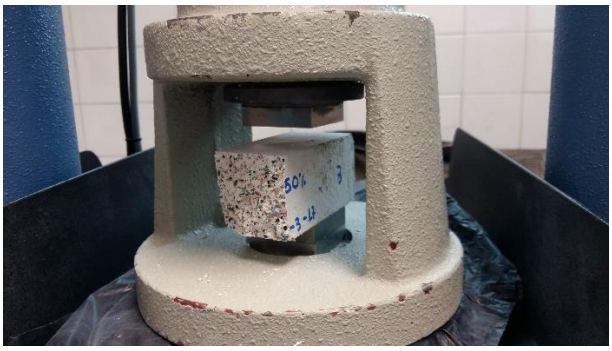

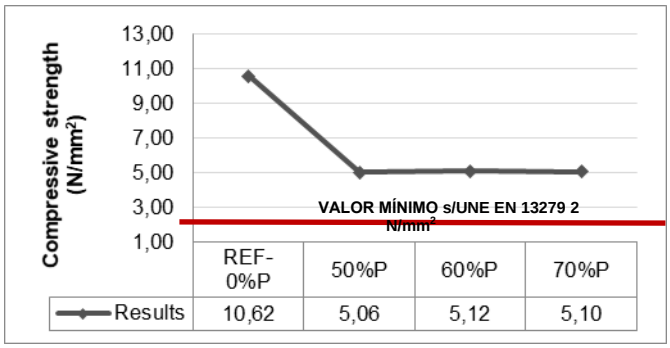

Fig. 6. *Compressive strength at 7 days (N/mm²)*

In the *compressive strength* test, the values reached were 10.62 N/mm2 for the reference and 5.06 N/mm2 – 5.12 N/mm2 – 5.10 N/mm2 for the 50% mixtures. G – 60%G – 70%G respectively. As in the flexural strength test, when the polymeric residues were incorporated, the data complied with the minimum value according to regulations, 2 N/mm2, but, in turn, also showed an approximate 50% decrease over the value for the reference sample.

Conclusions

The study of the results obtained through the tests, allows us to approach both the advantages and disadvantages of the proposed compounds. This study suggests a good possibility of use for compounds made with plastic waste from disused cables, but also indicates drawbacks that should continue to be studied and taken into account:

- The nature of plaster as gypsum hemihydrate (CaSO4·1/2 H2O), the most abundant component of commercial gypsum products for construction due to its plastic properties, is confirmed.
- The analysis of the granules reveals its complex chemical nature, a mixture of very different polymers, which must be characterized in depth, taking into account the subsequent use of the construction elements.
- Good compatibility is achieved in the mixtures, the granules are evenly distributed in the test tubes. With the incorporation of the residue, it is possible to reduce by up to 30% the amount of plaster and water necessary to make the test pieces.
- The surface hardness is not affected by the incorporation of the residue in the plaster matrix.
- The ability to absorb water by capillarity is favourably improved, producing a reducing effect in the face of the threat of humidity in plaster elements.
- The mechanical resistance decreases but values twice higher than those indicated in the UNE-EN 13279-1 standard are always maintained. The addition of plastic cable waste in plaster matrices is an opportunity to obtain more sustainable compounds, thereby reducing the use of natural resources, gypsum stone and water, and minimizing the amount of plastic cable waste.

Therefore, a way of working is opened with which to propose alternatives to the problem of closing the life cycle of this waste with its reincorporation, once again, into the market, following the criteria of a "circular economy" model.

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