

Industrial manufacture and on site application of plaster boards for ceilings with plaster mixes and polyurethane rigid foam waste

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Abstract. The European LIFE Project, Repolyuse – “REcovery of POLYurethane for reUSE in eco-efficient materials” seeks to solve the environmental challenge of resource scarcity and waste management in order to mitigate the effects of climate change. The material is a prefabricated gypsum mortar in the form of a removable roofing plate to which residues of rigid polyurethane foam have been added. That system reduces the weight of the plates about 30%. The investigation has consisted of the final design of the mixtures of plaster mortar with residues of rigid polyurethane foam, mineral fibers, additives and water to achieve the adequate industrial manufacturing system of “Plaster mortar plates lightened with polyurethane foam waste” to put in roofs detachable. In the industry's own production chain, the plasticity, moulding and drying of the plates can be similar to the process of the standard plates. The final result of the plates shows that the Flexural strength, Flatness, Angular deviation, Thermal conductivity, Superficial hardness, Reaction to the fire and Resistance to humidity have been similar to the results obtained in the laboratory. In the end, the plates were placed in two buildings in Spain. Consequently these results have enough been to achieve the CE marking

1 Introduction

The use of polymeric materials as a substitute for aggregates in the manufacture of gypsum, lime and cement mortars has been extensively studied since the last third of the 20th century, with the aim of improving the properties of the materials, such as their mechanical resistance, stability, density and even workability [1] [2]

Awareness of the environmental problems generated by industrial waste, especially plastic waste, has led to a great deal of research aimed at minimising the effect of plastic waste on the environment, either by reusing the waste or recycling it to give it a new lease of life.. The use of polymeric waste in the manufacture of mortar implies an important environmental benefit [3].

The Building Engineering Research Group of the University of Burgos has been working for more than 12 years on the integration of polymer waste into cement, lime and gypsum

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mortars. The result of this research effort has been the concession of a European LIFE Project, "LIFE-REPOLYUSE" Recovery of Polyurethane For Reuse in Eco-Efficient Materials [4], which aims to create the bases for the commercialization of a prefabricated plaster tile that incorporates rigid polyurethane foam waste, for use in false interior ceilings.

Once all the previous investigations had been made in the laboratory to evaluate the performance and suitability of the material [5], the research were carried out at industrial level in order to adapt the production process of the new plates to that of the standard plates, while at the same time studying their economic viability. Finally, suspended ceilings have been constructed from removable panels using the new plates that incorporate waste, and checking that they are easier to install as they are lighter.

It should be noted that the specific results of research carried out in the industry are not presented in this document as the data and processes are protected by confidentiality clauses.

2 Characterization of materials

2.1 Raw materials

The following raw materials have been used to carry out the characterization of the plaster plates in the laboratory.

2.1.1 Gypsum

A "Gypsum based binder E-35" "EN 13.279-1:2009" with high Hemihydrate content and fast setting has been used [6].

2.1.2 Rigid polyurethane foam waste

Rigid polyurethane foam waste has been collected from an industry dedicated to the manufacture of thermal insulation panels for refrigerators. They have been transported to the laboratory in unshaped pieces and crushed to a grain fineness of 4 mm. We refer to the crushed waste as "PU" (Figure 1).



Fig. 1. Polyurethane foam waste. Before and after crushing

2.1.3 Fibers

For the manufacture of the new boards, glass fibres of an average length of 25 mm, identical to those used in the manufacture of conventional plates, it has been incorporated into the mass.

2.1.4 Additives

An alcohol-based fluidizing liquid additive has been used, which is of the same nature as that used in the manufacture of the standard plate [7].

2.2 Prefabricates plasterboard

The panel measures 60x60 cm² and is 1.5 cm thick, the same thickness as the normal panel. The plaster and the polyurethane foam waste has been mixed with water and the additive and the glass fibres have been added. The mould used was the same as that used in industrial manufacturing. No edge trimming was done, nor were any perforations or drawings made on the visible side, which was left untreated once it was demoulded

Different mixtures with 5 types of polyurethane foam waste have been studied. Finally, a dosage has been chosen that uses a volume and a half (1.5) of rigid polyurethane foam waste for one (1) volume of gypsum. The mixture has been designated as "Y1.5B2" [8]. The dosage by weight (g) of the mixture for the manufacture of a 60x60 cm and 1.5 cm thick plate was as follows: (Table 1).

Table 1. Dosage of the roof tile (g/ud)

Gypsum	Polyurethane foam waste (PU)	Water	Glass fibres	Additive
2.000	0.166	2.058	0.020	0.010

3 Experimental procedure

3.1 Laboratory manufacturing

After the rigid polyurethane foam residues have been crushed, the materials are mixed in a mixer machine, using a kneading time of 2 minutes. They have then been poured into the latex mould. To achieve the compaction of the plaster, the table on which the mould is placed has been slightly vibrated for 10 seconds proximately.

When 20 minutes have elapsed from the time of pouring into the mould, the plate has been removed from the mould. It is then placed in an oven at 40°C for approximately 2 days until it reaches a constant weight and finally it is placed on a stand at room temperature until 28 days.

The results of the tests carried out in the laboratory in accordance with Standard UNE EN 13279-2:2004 [9] are shown in the Table 2.

Table 2. Features of the roof tile

Real Density (kg/m ³)	Compression strength at 28 days (MPa)	Flexion strength at 28 days (MPa)	Thermal conductivity (W/m x k)	Reaction to fire
687	3.95	2.23	0.18	Euroclass A1

3.2 Manufacturing in industry

The industrial process of manufacturing a plasterboard for false ceilings has three main stages.

3.2.1 Preparation of components

The materials used in the manufacture of the common plaster plates do not require prior preparation, as the plaster arrives at the factory in silos, the water is obtained directly from the public drinking water network and the fibres prepared in rolls that are cut at the same time as they are incorporated into the kneading process. Finally, the additives are prepared for direct incorporation. The transport of the materials, inside the industry itself, is carried out by very similar mechanical procedures in all the industries of prefabricated gypsum.

The manufacture of the new plaster plates, with PU residues, adds a new material to the process. This material is transported to the industry either in unshaped plates or in pellets (previously compressed polyurethane powder). In both cases, the PU needs to be pre-shredded, so a new process stage needs to be incorporated into the manufacturing process, which is the shredding of the PU residue, before mixing and kneading.

Different studies have been carried out with common crushers in the market (wood crushers or similar), and finally the adaptation of a common crushers in the wood industry was chosen.

The shredding time of the PU waste is not a relevant parameter in the complete production process of the board.

3.2.2 Mixtures and dosages

The materials are arranged in tanks near the kneader and are introduced into the kneader through pipes that dose the amount of material in each process. In the case of manufacturing the standard plates, a gypsum tank is used which doses the necessary amount of plaster by means of a balance. The water is controlled through a flow meter, as well as the additive. Finally, the amount of fibres is controlled through a suitable cutting speed.

For the manufacture of the PU plates it is necessary to add a new PU waste tank (Figure 2-3). The main problem has appeared in dosing the right amount of PU, because due to the low density of the foam particles, their measurement cannot be performed by the usual weighing procedures. In this case, a weighing system with improved accuracy was used.



Fig. 2. Tank of gypsum



Fig. 3. Tank of shredded polyurethane

Once this new tank is incorporated, which is similar in size to the gypsum tank, as the dosage in volume is in a 1/1 ratio, the mixing and kneading process is identical to the standard process, i.e. the components are mixed and kneaded in the traditional way, and then poured into the moulds (Figure 4-5)



Fig. 4. Pouring



Fig. 5. Moulding

3.2.3 *Setting and demoulding*

The setting and hardening of the plaster plates must be such as to facilitate the removal of the plate when it has reached the indicated end of the manufacturing line. Polyurethane plates have a slightly slower setting and hardening process than standard plates, so it has been necessary to add a setting accelerator. In this case, a greater amount of lime has been used in the mixture. An additional problem is the lower mechanical strength of the PU plates when demoulding, which has led to premature breakage in some plates. The solution has been to slightly increase the amount of fibreglass which increases the bending strength of the plate at early ages.

3.2.4 *Packaging and palletizing*

The packing and palletizing of the plaster plates with PU for detachable suspended ceilings is done exactly the same as with the normal plates. The only difference is that, due to the lower density of the PU plasterboard, the pallet is lighter than that of the standard plate, which means savings in handling and transporting the pallet.

3.3 On site application.

The placement of this type of slabs has been carried out in two buildings in Spain, in the cities of Burgos and Vitoria. The installation process is the same as that used for the standard tiles. The same structure has been used with galvanized steel profiles. The time used is slightly less than the time used with the standard plate, since the lighter plates make the work less tiring (Figure 6-7).



Fig. 6. On site application



Fig. 7. Finished roof

4 Results and discussion

The industrial manufacturing process of the plasterboard with polyurethane rigid foam waste, when the dosage of the components has been modified, is feasible and the cost is similar to that of manufacturing the standard board. The physical and mechanical characteristics of the plates with PU, manufactured industrially present results similar to the plates made in laboratory, that is to say the results are suitable for their use in building. Plates with PU have lower bending strength than standard tiles and lower surface hardness. In contrast, the tiles are lighter (28%) than standard tiles. Plaster plates with PU also have lower thermal conductivity than standard plates [10] (Table 3).

Table 3. Comparison of plates. Gypsum PU and Standard Gypsum

Model	“Vasari Square Edge PU” (gypsum-polyurethane)	“Lisa Square Edge” (standard)
Nominal dimensions	593x593x15 mm (± 2 mm)	593x593x15 mm (± 2 mm)
Weight per unit	2.50 Kg ($\pm 5\%$)	3.49 Kg ($\pm 5\%$)
Weight per sqm	6.93 Kg ($\pm 5\%$)	9.69 Kg ($\pm 5\%$)
Flatness	< 1 mm in 1000 mm	< 1 mm in 1000 mm
Angular deviation	<1 mm in all of the sides	< 1 mm in 1000 mm
Flexural resistance	≥ 6 kg	≥ 6 kg
Thermal conductivity	0.22 W/mK	0.26 W/mK
Superficial hardness	>35 Shore C. On a 100 scale	>75 Shore C. On a 100 scale
Reaction to fire	Euroclass A1 (Incombustible)	Euroclass A1 (Incombustible)
Resistance to humidity	90 % HR continuously	90 % HR continuously

In all cases the tiles satisfy the minimum requirements of the European Standards

The effective saving of the use of the panels with rigid polyurethane foam waste presents an important economy of the raw materials (25% gypsum), a saving in the transport and manipulation due to its lower density and the aptitude for its placement in suspended ceilings of detachable panels.

5 Conclusions

The plasterboards with rigid polyurethane foam waste manufactured in an industrial process fulfil all requirements for use in suspended ceilings inside buildings.

The industrial manufacturing process for the plasterboard with rigid polyurethane foam waste is similar to the manufacturing process for the standard boards, and does not involve any additional costs.

The partial replacement of gypsum with PU means significant savings in gypsum, both in the quarrying process and in the furnace firing process, which corresponds to significant savings in the carbon footprint of these boards.

The incorporation of PU in the plate avoids the deposit of plastic waste in a landfill or its incineration, so it is an important environmental benefit.

The greater lightness of the plate and better thermal insulation with respect to a standard plate is savings in transport and handling, which means a benefit to the health of the worker and energy savings in transport.

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