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Improvement of gypsum plaster strain capacity by the addition of rubber particles from recycled tyres

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HIGHLIGHTS

- ▶ Gypsum plaster with different formats and percentages of rubber has been studied.
- ▶ Rubber particles lead to a decrease in mechanical properties of gypsum plaster.
- ▶ Mechanical properties obtained fulfil the UNE-EN 13279-1 standard.
- ▶ Valorization of ELTs residuals is feasible by incorporating them to gypsum plaster.
- ▶ Modified Kraai slabs did not show cracking in gypsum plaster performed.

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ABSTRACT

This paper shows the results of a research project to valorize rubber waste from end-of-life tyres (ELTs). The aim of this study is to improve the elastic behaviour of gypsum plaster by the addition of a highly elastic polymer, such as rubber, so that the elasticity modulus of the resulting compound is smaller than gypsum plaster without additives. In this way, reducing the probability of cracking in the first hours after hardening, due to lack of material elasticity will be possible. This study analyses the mechanical behaviour of gypsum plaster with different granulometries of rubber particles (0–1 mm, 1–2 mm and 2–4 mm), and in different rubber volume fractions (1%, 3% and 5%). The experimental results are compared with results of gypsum plaster specimens without rubber.

1. Introduction

In Europe, the annual cost for ELTs management is estimated at €600 million. Countries of the European Union generate 3,300,000 tons of ELTs per year (IRSG, "The World Rubber Industry Review and Prospects to 2020", December 2010). The main component of ELTs is styrene–butadiene rubber (SBR) and, in spite of the different uses for recycling it, the research for new applications is still a need because of the extremely high amount of ELTs generated.

At the same time, one of the most used building construction materials in Spain is gypsum plaster. It is a material of excellent properties to be used in the construction of buildings. Among the good features of gypsum plaster for the building construction, the following can be highlighted: it has a good acoustic performance; it is a fireproof material, which in response to fire emits water vapour only; it helps to regulate the humidity of the walls and it is a natural, organic and environmentally friendly construction material.

The manufacture of prefabricated gypsum plaster elements involves an industrial process with highly controlled conditions of proportion and curing of the material, where gypsum plaster is subject to ventilation, temperature variations and humidity changes. In any case, if the environmental conditions are not right, the material rigidity leads to a recurring pathology, i.e. cracking.

The best method of minimising cracking in gypsum plaster is proper attention to plaster site preparation. If conditions are the correct ones (thickness, water ratio, temperature and humidity) cracking is not likely to appear. But these conditions vary and are difficult to control at the construction site (see Fig. 1). Environmental conditions can speed up the plaster setting and cracks can then be produced in the surface of the material. Cracking can also be produced because of the thickness is either too large or too small; at the same time, when the wall is too dry it can absorb water from

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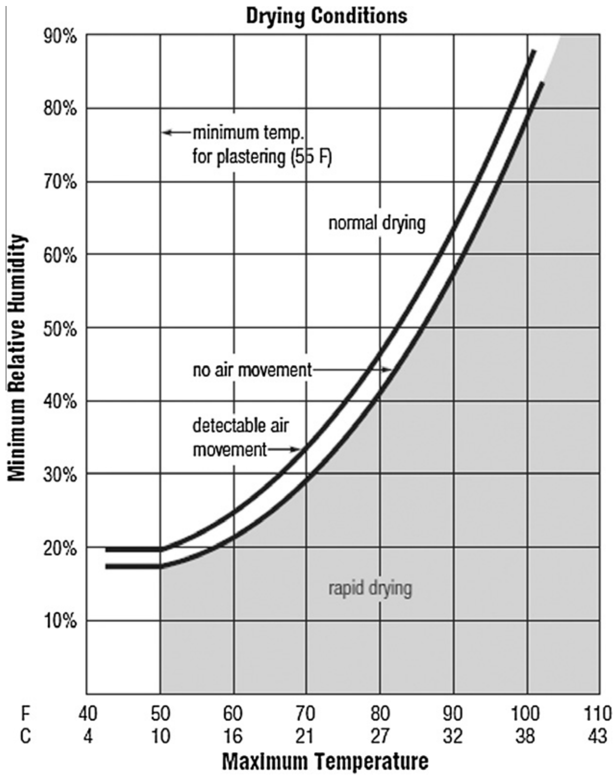

Fig. 1. Drying conditions (USG, 2000) [1].

the gypsum plaster or it can be subject to stresses caused by the excessive strain of structural elements.

In any case, gypsum plaster cracking occurs when internal stresses, which the material supports during setting, outweigh the inherent fracture load of the material. Ways to improve the performance of gypsum plaster regarding these tensions are, on the one hand, to increase the material tensile strength or, on the other hand, to reduce the elasticity modulus, which will help, in turn, reducing the differential stresses.

Regarding the first option – increase of the material tensile strength – numerous research works have dealt with additions, especially with fibrous materials, including those made with glass fibres and polypropylene fibres. Improvements in bending strength are achieved when glass fibres are used as additions [2]. Even with minimal additions of fibres, gypsum plaster shows an improvement in toughness, and this allows the material to continue straining after the maximum load has been applied. With the addition of polypropylene fibres [3], decreases in compressive strength are observed, although values of bending strength in gypsum plaster increase.

As far as the second option is concerned – reducing the elasticity modulus – in 1998 Kovler and Frosting studies [4] concluded that the most effective way to diminish the likelihood of cracking in plasters is to reduce the modulus of elasticity of the material and its deformation by debonding.

The present study proposes the addition of a highly elastic polymer, such as rubber, in gypsum plaster, so that the elasticity modulus of the resulting compound is smaller than the gypsum plaster hardened without additives. In this way, the reduction of gypsum plaster elasticity modulus will improve its elastic behaviour, reducing the likelihood of cracking.

While there are previous works about the use of rubber as an additive in construction materials, these deal mostly with cement mortars and concretes [5–9]. Studies concerning the use of rubber as an additive in gypsum plaster are quite scarce [10,11]. Nevertheless, no evidence has been found of works which have studied the influence of rubber in diminishing the gypsum plaster elasticity modulus and no literature has been found regarding the plaster behaviour improvement in relation to cracking.

Studies with cement mortar combining additions of rubber particles and glass fibres [5] showed smaller values of superficial hardness, compressive strength and bending strength. At the same time, the elasticity modulus of the material diminishes with rubber additions between 50% and 100%. Other studies [6] confirm that with small amounts of rubber, strengths are maintained. Studies on concrete [9], where rubber particles in sizes and percentages similar to the ones incorporated in this research (2% in weight and sizes 0.85–2 mm and 2–4 mm) conclude that no significant losses of mechanical compressive strength or bending strength are produced (between 8% and 20%). In the case of gypsum plaster, some research studies [11] conclude that additions of 20% of rubber produce decreases of 50% in the mechanical strengths.

Therefore, the aim of this research work is to improve gypsum plaster toughness by diminishing the elasticity modulus, using recycled rubber, with the double objective of obtaining a material with a better behaviour regarding cracks and as a way to valorize rubber waste of used tyres.

2. Experimental plan

Tests were carried out in the laboratory of materials of the School of Building Engineering of Madrid (EUATM), in environmental conditions, at an average of 22 °C and 55% relative humidity. Specimens were 40 mm × 40 mm × 160 mm prismatic samples performed with three different water ratios: one in accordance with UNE-EN 13279-2 standard ($w/p = 0.7$), another one with a more fluid consistency ($w/p = 0.8$) and one more with a drier consistency ($w/p = 0.6$). A total of 35 series of test samples were performed with different w/p ratios, different volumetric fractions of rubber and rubber granulometries.

In order to determine the influence of w/p ratio, rubber granulometry and the percentage addition on the performance of gypsum plaster (surface hardness, bending strength and compressive strength) a full 3^3 factorial design was performed, in which the following levels were analysed:

- Water/plaster ratio: 0.6, 0.7 and 0.8.
- Rubber format (rubber particle sizes): 0–1 mm, 1–2 mm and 2–4 mm.
- Rubber percentage (volume fraction of rubber added): 1%, 3% and 5% by gypsum weight.

2.1. Materials

Gypsum plaster used was B1 construction plaster, according to UNE-EN 13279-1 standard. This plaster consists of hemihydrate ($SO_4CaO\ 1/2H_2O$) and artificial anhydrite II (SO_4CaII). It is used as a grip paste for internal linings and as auxiliary binder in construction works. Its flexural strength must be of at least 0.20 MPa.

The rubber used comes from recycled ELTs, with a granulometry size between 0.6 and 2.5 mm. However, due to storage, some material was compacted producing lumps of particles greater than 2.5 mm in size. During sieving, groups of agglutinated particles of 4 mm were retained.

2.2. Sample manufacture

Test samples were performed according to UNE-EN 13279-2 standard. During the manufacture of specimens it was observed a large portion of rubber floated to the surface and this explains that rubber distribution was not completely homogeneous in some of the samples (see Fig. 2).

2.3. Tests performed

Data of wet weight (when they were unmolded), dry weight (constant at 7 days) and of Shore C superficial hardness were obtained. Subsequently, following the UNE-EN 13279-2 standard, tests of bending strength and compressive strength were performed.

In addition, five series of samples were produced with the water/plaster ratio stated in UNE-EN 13279-2 standard ($w/p = 0.7$) and various proportions of rubber to study the stress–strain behaviour in bending tests (see Fig. 3).

Finally, modified tests on Kraai slabs were conducted [12] to study the feasibility of this type of testing in the study of gypsum plaster cracks.