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Effects of the use of polyamide powder wastes on the microstructure and macroscopic properties of masonry mortars

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ABSTRACT

This study concerns the fabrication of lightweight mortars in which varying quantities of sand were substituted by polyamide powder waste. The values of apparent density, mechanical resistances, permeability, and thermogravimetric analyses are characterised according to the amount of polyamide powder waste used into the mixtures. The microstructure is analysed by Mercury Intrusion Porosimetry (MIP) and by Scanning Electronic Microscopy (SEM). The reconstruction of the mortar macrostructure is completed using Computerized Axial Tomography (CAT). The progressive increase of the amount of polyamide influences the mortar properties, reducing their density and their mechanical resistances and increasing their porosity. These results support the management of polyamide powder waste as a mean to manufacture lightweight masonry mortars.

1. Introduction

The masonry mortar is one of the most useful and usual materials in the creation of the building structures [1]. On the other side, the use of lightweight mortars presents many positive aspects, as enable to reduce dead load of structures, fit the sizes and dimensions of columns, slabs and beams, whenever the minimum mechanical requirements are provided. Besides, the low heat transfer values of lightweight aggregates mortars usually induce higher thermal insulation properties [2].

For the development and fabrication of lightweight mortars modified with polymers, a relevant issue is to know whether the polymers and additives influence the hydration process of the inorganic binders [3]. The knowledge of the interaction between polymers and cementitious systems might also be significant to understand the final hydrated products. For this reason, numerous authors have already examined the influence of different polymers in cement pastes and have proposed models for the formation of the microstructure in polymer-modified cementitious materials [4,5].

In an effort to reduce the dependence on finite raw materials and the amount of plastics wasted in landfills, several methods for recycling and reusing of construction materials are being adopted. Numerous studies have been done on the valorisation of polymer wastes in mortar or concrete, as polystyrene, poly(ethylene terephthalate), polyethylene, polypropylene, polyurethane and others [6–8]. The European business market for recycled construction materials (such as polyvinyl chloride, gypsum, aggregates and recycled glass) generates revenues of several million each year [9].

In spite of the references describing the use of polyamide-based fibres [10,11], or nylon-based fibres [12], to improve the resistance of construction materials, or the use of redispersible powders-based polymers in mortars [13], no bibliographic reference has been found (as far as the authors are aware) about the use of polyamide-based powder as lightweight fines in cement-based construction materials.

Indeed, the polyamide powder waste (PAW) may therefore be considered as a lightweight component. This product could be potentially competitive with conventional products used at present for the walls and ceiling renderings, due to their intrinsic properties. The amount of PAW is about 2% of the 57 million tons of polymers generated in Europe in 2013 [14], corresponding to more than one million tons. Although there is no consistent statistics about the amount of PAW generated from Laser Sintering production, we can estimate a residue of 20% of the total, involving approximately 200.000 tons of PAW per year. Consequently, the management of a sustainable development requires taking into account these types of wastes.

From this viewpoint, and based on previous investigations about the use of polyamide powder waste to manufacture

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lightweight plasters [15,16], a study has been carried out to determine the influence of this polymer-based waste on the microstructure of masonry mortars but also on their mechanical and physical properties after hardening.

2. Experimental

2.1. Raw materials

2.1.1. Cement

Ordinary Portland cement type CEM I 42.5 R with a density of 3065 kg/m^3 was used for mortar mixes. The chemical composition is shown in Table 1, as per Standard EN 197-1 [17].

2.1.2. Sand

River sand, sieved between 0 and 2 mm with a density of 2600 kg/m^3 was used. The particle size distribution was obtained as per Standard EN 13139 [18] (Fig. 1).

2.1.3. Polyamide powder waste (PAW)

The PAW was obtained from waste raw material generated by industrial Laser Sintering process. Its granulometric size was determined through laser diffraction analysis using a HELOS 12kv SYMPATEC analyser. Samples were analysed for 15 s in an isopropyl alcohol suspension (Fig. 1). The real density of the PAW is 1070 kg/m^3, which was measured with the Pycnometer method, using isopropyl alcohol [19].

Prior to its use as sand substitute, the PAW were observed using Scanning Electron Microscopy (SEM). Its chemical composition was obtained through CHNS elemental analysis using a LECO CHNS-932 analyser (Fig. 2).

2.2. Mixtures

The operating procedure for the fabrication of lightweight mortar consisted of manufacturing traditional mortar (a mixture of cement, sand and water) and, then replacing different percentages of sand with PAW.

Three series of lightweight mortar were produced, Series I with a 1/3 relation cement/(sand + PAW), Series II with 1/4 relation and Series III with 1/6 relation. Although the initial dosages were considered by weight, different amounts of sand were substituted by an equivalent content of PAW in volume. Dosages are given in Table 2.

The consistency of the mixtures, which is defined as the *w*/*c* (water/cement) ratio, was calculated as the amount of added water necessary to ensure good workability, fluency and plastic state in mixtures, with slump flow test. Consistency is done on a shaking table until the average spreading diameter cover 175 mm ± 10 mm (trial and error method), in accordance with Standard EN 1015-3 [20]. Although the test is very useful due to the easiness of apparatus and the simple procedure used, this method could induce variability in the results. For this reason, consistency values have been validated at least five times for each dosage before given a value (the standard only require three).

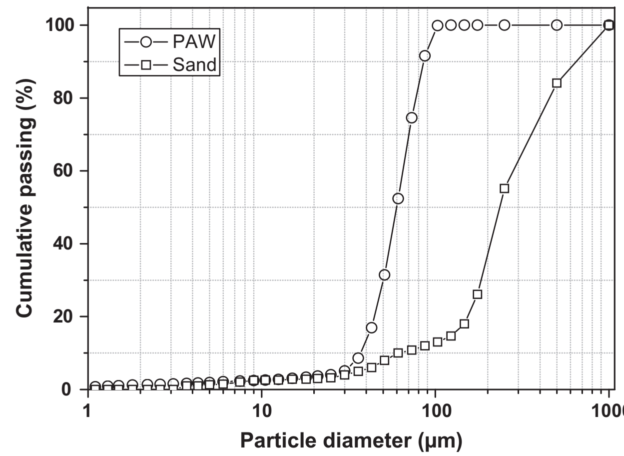

Fig. 1. Laser granulometry of polyamide powder waste (PAW) and sand.

2.3. Characterisation methods

2.3.1. Densities and air void contain

Fresh and hardened density and occluded air were measured at a temperature of 20 ± 1 °C and a relative humidity of 50 ± 1%, according to standards [21,22].

2.3.2. Mechanical properties

Flexural strength and compressive strength were tested according to the EN 1015-11 standard [23], after 7 and 28 days of curing at 20 °C and 98% of relative humidity. Three different test specimens were tested under flexion for each composition and six under compression. The test samples measured 40 mm × 40 mm × 160 mm, and the bottom support rollers were separated at intervals of 100 mm. The resulting fragments in this test broke under compression using a load surface of 40 mm × 40 mm. The measurements for each blend were repeated a minimum of times to obtain a reproducibility of 90% for the mechanical values.

2.3.3. Thermogravimetric analysis (TGA)

After 28 days of curing at 20 °C and 98% of relative humidity, TGA data were recorded in samples under air atmosphere on a Mettler-Toledo TGA/SBTA851 analyser from 15 mg of sample at a scan rate of 10 °C/min from 100 °C to 800 °C.

2.3.4. Liquid water permeability at 25 °C

The permeability to water of the different mortars was evaluated after 28 days of cure by placing a measuring pipette on the surfaces, pouring water into it and measuring the volume of water absorbed by the surface according to the time. This method is then a good indicator of what happens at the surface when the mortar is exposed to water (or condensed humidity). The surface of contact between the water and the substrate was approximately 5 cm^2. The test was conducted at controlled temperature and humidity (20 °C and 65% RH). A similar measurement was made on a glass substrate to evaluate the content of evaporated water during experiment.

Table 1
Chemical composition of cement and PAW.

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	Loss of ignition	Others
Cement (%)	60.4	21.3	6.1	4.0	1.5	1.3	0.4	2.3	2.00	0.7
	C	H	N	S	Others	Total				
PAW (%)	70.4	11.2	7.1	0.1	11.2	100				