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Mechanical and thermal performance of concrete and mortar cellular materials containing plastic waste

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HIGHLIGHTS

- Waste plastics were used to produce concrete and mortar plastic compounds.
- Parameters as density, porosity, and water absorption were studied.
- Mechanical properties of mortar and concrete plastic compounds were measured.
- The studied materials showed an important decrease in thermal conductivity.

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ABSTRACT

In this paper the improvement of thermal insulation behavior of concrete and mortar plastic compounds is presented. The materials studied were obtained by adding to mortar and concrete five different percentages of two types of plastic waste (polyethylene and PVC residues coming out of electric cable protective sheath). Parameters as density, porosity, water absorption and carbonation behavior were studied. The time evolution of mechanical properties (compression and flexural) were characterized to finally study and model the thermal conductivity, that is shown, in all studied cases, to have higher decrease than the expected.

1. Introduction

Plastic materials have become in recent decades an integral development part for different markets. The annual consumption of these materials has had a sustained growth, given their characteristics of low density, strength, ease of design, processability, durability, low weight and last, but not least, their low cost. These features have allowed its use in various sectors such as packaging industry, automotive, industrial applications, piping industry, construction, thermal and acoustic insulation [1].

The increase in production and consumption of polymeric materials likewise involves a growing waste output at the end of its life. This has led to huge quantities of plastic-related residues [2,3]. In this way, recycling has been recognized as a rational necessity, compared to alternative traditional deposit in landfill or incineration.

Recycling companies are the main sources of plastic waste management. In these companies the waste plastics are sorted, separated and treated for later use in production industries. The common treatment processes for plastic waste may involve

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manual or automatic sorting, crushing, sieving and eventually mechanical processing that allows disaggregation and separation of different materials associated with the polymers. Also in some cases it is used the electromagnetic separation (by using this procedure the magnetic metals that may accompany the polymeric residues are separated and recovered for subsequent use) or density separation by which different fractions of other materials, aggregates, nonmagnetic metal, etc. are separated, (buoyancy, air flow separation, etc.) classifying the various plastics according to their density and size.

Once classified, the polymer waste is ready to reentry into the raw materials market if there is added value in this secondary value chain. Unfortunately for many polymers this is not the case (thermoset, crosslinked thermoplastics, etc.).

The present paper is focused on the secondary use of two types of such materials without any added value to return into the secondary raw materials market; mainly crosslinked polyethylene (PE) and polyvinyl chloride (PVC), obtained primarily from crushing electrical copper and aluminum cables, whose envelopes (insulation) exterior and interior are principally formed by such polymers.

It is worth noting that plastic residues coming out of electric cable protective sheath have an added problem, the presence of flame retardant materials (as aluminum tri-hydroxide) that prevents its further secure processing.

The overall purpose of the study presented in this paper was to obtain cement matrix materials, where one of their phases was a polymeric residue, so that the compound may have non-structural applications. During the study, the main possible applications identified were the use of these materials as semi-structural lightweight concretes (or mortars) with improved thermal insulating properties, to use them as the core of sandwich panels for prefabricated enclosures, retaining walls for instance. Obtaining prefabricated lightweight building materials with improved thermal insulation characteristics was identified as target to give waste plastic materials a second opportunity apart of landfill or incineration.

There exists a vast literature on the issue of recycling plastic waste [4–12] being that the addition of polymeric waste materials to cementitious matrix has been studied from late 90s [13–19]. The commercial application of recycled polymer concrete is relatively new in the world of civil engineering [20–23]. The addition of polymer waste to concrete in various forms (fibers or aggregates), has a number of beneficial effects on the material properties resulting compound, as are weight and density reductions, improved mechanical energy absorption, better toughness, enhanced ductility and impact resistance, improvement of insulation capacity (acoustic and thermal) etc. Along with the above improvements and depending on the type of addition, it can be observed undesired effects, such as reduction of the compression strength or the durability of material due to different mechanisms [24–29].

Polyvinyl chloride (PVC), which is one of the waste materials used in this study, is a special case. PVC worldwide production exceeds 30 Mt annually [30], representing one fifth of the total production of plastics. PVC is the second largest volume production thermoplastic only overcome by polyethylene as volume leader in the plastics industry.

Since the 60s, PVC has been used in many products, and taking into account that its life is around 30–60 years (depending on type and treatment), PVC waste is expected to increase in the coming years [31,32]. But the recycling of PVC presents a major issue, because its incineration produces dioxins. There are some studies on the PVC residues treating, by steam gasification or pyrolysis [33–38], but it is clear that it does not exist an effective and appropriate way to recycle PVC. Therefore, there is no doubt that large PVC waste amounts must be disposed of as solid waste, so there is a clear interest in the ways of recycling these residues.

In that sense, in this paper the results of mechanical and thermal properties measured for mortar and concrete plastic materials obtained with plastic waste (PVC + PE), are shown. These materials are not intended to be used as structural materials but rather as "functional" materials. Their thermal behavior characterization was selected initially because it was expected a reduction of thermal conductivity by adding plastic to a concrete or cement based compound. This improved thermal isolation behavior could act as added value for specific applications. What was really surprising was the intensity of the observed reduction as compared to the values predicted by our initial estimations.

2. Materials and method

2.1. Residues used

The waste materials used came from the triturating of "out of use" electrical wires through a procedure that allowed the whole segregation of the conductive metal and the polymeric protective sheath, producing completely disaggregated and heterogeneous mixture subsequently separated.

Metal separation of this mixture was achieved by densimetric methods that discriminate almost completely metal, with great density and polymer particles, whose density is much lower. This separation system has efficacy higher than 97% in metal discrimination, however the obtained polymer fraction is heterogeneous (mainly PE and PVC, but also small quantities of other polymers, trace metals and aggregates). The subsequent classification was performed in another separation system by densitometry in aqueous medium, which allows segregate in the first instance scrap metal contents in the polymer fraction and eliminate the content of another materials as aggregates, whose density and morphology is different from the treated polymers. Subsequently, the polymer fraction was separated and treated with pure water floatation rafts on sedimentation prepared for that purpose, in which the buoyancy of different types of polymers was used to classify them. Thus, typical compounds as polyethylene (PE) whose density is less than water, float, while the more dense as PVC compounds sink. The polymers were extracted and then dried and stored to yield PVCs and PEs with purities of around 80%.

The whole separation process was performed at an industrial scale in the facilities of RMD, a Spanish company, member of the research consortium, aimed at materials recycling.

The morphology of the waste materials obtained after the separation process and the huge amount of these stored without any further application (except landfill or incineration) are shown in Fig. 1. The average chemical composition of waste materials is collected in Tables 1 and 2. As can be seen there are other polymer phases present as polypropylene or polyamide.

2.2. Mortar samples preparation

Mortar samples preparation (Fig. 2) was performed according to Spanish standard UNE 83821 [39]. In brief, the design of dosage for the case of mortar has been carried out taking into account the following assumptions: It has been kept the sand/cement ratio constant at 3/1 and the same type of sand was used for all the samples.

For each sample consistency essay (according to Spanish standard UNE 83811 [40] was performed to calculate the mixing water required to obtain a constant consistency value for the different proportions of PVC or PE added.

A Portland Valderrivas cement type (CEM IV/B (V) 32.5 N) was used for all the samples. Different percentages, 0% (control sample), 2.5%, 5%, 10% and 20% of waste untreated plastics (PVC, PE and PVC + PE mixture) were added to produce the compounds.

Curing of the specimens was performed in a humid chamber at a constant temperature of 20 ± 1 °C and relative humidity of 98 ± 2.

2.3. Concrete samples preparation

Concrete samples preparation (Fig. 3) was performed according to Spanish standard UNE 83301 [41].

Different percentages 0% (control sample), 2.5%, 5%, 10% and 20% of waste untreated plastics (PVC, PE and PVC + PE mixture) were used.

The aggregates sizes used were between: 0/4, 0/8, 8/20 and 8/32 mm. Sieve analysis of the aggregates used was performed according to standard UNE EN 933-1 [42]. The cement used was CEM II/AV 42.5 R LA ROBLA type.

A remarkable effervescence phenomenon (Fig. 4, left) was observed during concrete-PVC compounds preparation. After several tests, it was determined that it could be related to some reaction occurring between alkali contained in the cement and the untreated PVC. The reaction that takes place between these two