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Mechanical and Physical Properties of Cement Mortars Containing Plastic Waste Particles

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ABSTRACT

In the present paper an investigation of mechanical behaviour and thermal conductivity of a lightened building material containing either scraps coming from outsoles of old shoes (SR, acronym of sole rubber) or polyurethane waste particles (PU) is presented. Several mortar mixtures were prepared by replacing quartz sand with 0, 10, and 30% of either SR or PU post-consumer plastics particles. The influence of rubber particle addition on fresh mortar behaviour, compressive and flexural strength of mortar as well as on mortar thermal conductivity was detected. An optimization of mortar mixture proportions was carried out by adding a limestone powder as filler. The experimental investigation showed that the addition of rubber particles reduces both the material unit weight and the thermal conductivity. The thermal insulating effect of rubber particles indicates a high and promising potential for future developments. On the other hand, the addition of limestone powder produced higher thermal conductivity as well as higher compressive and flexural strength.

INTRODUCTION

The reduction of energy consumption in construction, the production of thermally insulating materials and the solution of environmental problems by recycling of industrial and domestic waste are becoming a greater problem. There are many lightweight composites that contain recycled fillers, including waste glass, fly ash, steel slag, lightweight crushed bricks, lightweight expanded clay aggregates, foam polystyrene [Laukaitis et al. 2005]. Therefore, the development of composite construction materials with low thermal conductivity using recycled sole rubber (SR) or polyurethane (PU) waste particles will be an interesting alternative that would solve simultaneously energy and environmental concerns.

Extensive studies have been conducted on used tyre modified concrete and mortars [Eldin and Senouci, 1993; Topçu 1995; Fedroff et al, 1996]. The literature about the use of tyre rubber particles in cement-based materials focuses on the use of tyre rubber as an aggregate in concrete and evaluates only the mechanical properties. Results have indicated that rubberized concrete mixtures show lower density, increased toughness and ductility, higher impact resistance, lower compressive and splitting tensile strength, and more efficient sound insulation.

However, there are a few studies about the use of polymer in lightweight aggregate concrete (LWAC). On the other hand, there is worldwide environmental, economic, and technical push to encourage the structural use of LWAC [Alduaij et al, 1999; Haque and Al-Khaiat 1999]. LWAC has been used successfully for structural purposes for many years. For structural applications of lightweight concrete, the structural efficiency is more important than the absolute strength level. A decreased density for the same strength reduces the dead load, foundation size, and construction costs. With the rapid development of concrete technology in recent years, high-performance concrete has been produced more easily. Since 1980, several investigations on high-performance lightweight concrete have been reported [Slate et al, 1986; Malhotra 1987; Zhang and Gjørv, 1991; Holm and Bremner, 1994].

In the present paper an attempt was made to prepare cementitious (lightweight if possible) mortars by adding to the mixtures either polyurethane (PU) waste particles or recycled rubber coming from outsoles of old shoes (SR), made of a miscellaneous of polyurethane and ETA (ethylene vinyl acetate) particles. Mortars were characterized from mechanical and thermal points of view.

EXPERIMENTAL INVESTIGATION

Materials

A commercial portland-limestone blended cement type CEM II/A-L 42.5 R according to EN-197/1 was used (limestone content of about 12%). The Blaine fineness of cement was 0.42 m^2/g and its specific gravity was 3.05 kg/m^3.

As aggregate fractions, quartz sand (0-5 mm), recycled sole rubber (SR) waste particles (0-12 mm) or polyurethane (PU) waste particles (0-12 mm) were used. Their relative specific gravities were 2.64, 0.58 and 0.50, respectively, and their gradations are shown in Figure 1.

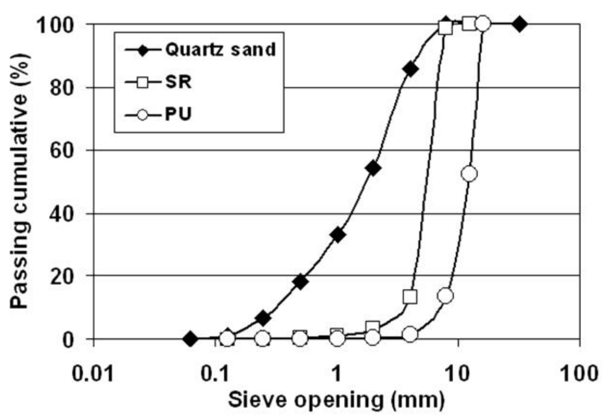

Fig. 1. Grain Size Distribution Curves of the Aggregate Fractions

As a mineral addition, a limestone powder was used, with a Blaine fineness of 0.65 m^2/g and a specific gravity of 2.65 kg/m^3.

As water reducing admixture, a 30% aqueous solution of carboxylic acrylic ester polymer was added to the mixtures if necessary.

Mortar mixture proportions

Mortar mixture proportions are reported in Table 1 as well as the values of consistency of fresh mortars obtained by means of flow table (according to UNI EN 1015-3). The water to cement ratio and the cement to sand ratio were kept equal to 0.60 and 1:3 (by weight) respectively. Sole rubber (SR) or polyurethane (PU) waste particles were alternatively added to the mixtures at a dosage of either 10% or 30% by volume of aggregate.

Then, an improvement of mortar mixture proportions was carried out on mortars prepared with 10% waste particles, by adding a limestone powder as filler, at a dosage of 20% by weight of cement, replacing quartz sand, in order to improve mortar mechanical performance. Limestone powder was added with and without an acrylic-based superplasticizing admixture, at a dosage of 1.0% by weight of cement.

Table 1. Mixture Proportions and Consistency of Mortars

Mixture	REF	SR-10%	SR-30%	PU-10%	PU-30%
Water/cement	0.60	0.60	0.60	0.60	0.60
Water, kg	270	270	270	270	270
Cement, kg	450	450	450	450	450
Quartz sand, kg	1350	1321	1264	1324	1272
SR recycled particles, kg	-	55	165	-	-
PU waste particles, kg	-	-	-	26	78
Consistency of fresh mortar, mm	655	850	585	450	155

Mixture proportions of mortars containing limestone powder are reported in Table 2 as well as the values of consistency of fresh mortars obtained by means of flow table (according to UNI EN 1015-3). The water to cement ratio was kept equal to 0.60 or 0.42 in the absence or presence of superplasticizer respectively.

Preparation and curing of specimens

Nine prismatic specimens were prepared for each mortar mixture, 40x40x160 mm in size, by casting them in steel forms. They were wet cured at 20°C up to 28 days and used for bending and compression tests. Then, flat cylindrical specimens (diameter of 200 mm, 20 mm thick) were cast for thermal conductivity tests and the cylinder bases were suitably polished.

Table 2. Mixture Proportions and Consistency of Mortars with Limestone Powder

Mixture	REF +LP	SR-10% +LP	PU-10% +LP	REF+LP +SP	SR-10% +LP+SP	PU-10% +LP+SP
Water/cement	0.60	0.60	0.60	0.42	0.42	0.42
Water, kg	270	270	270	190	190	190
Cement, kg	450	450	450	450	450	450
Quartz sand, kg	1260	1231	1234	1260	1233	1236
SR recycled particles, kg	-	55	-	-	52	-
PU waste particles, kg	-	-	26	-	-	24
Limestone powder, kg	90	90	90	90	90	90
Superplasticizer, % by weight of cement	-	-	-	1.0	1.0	1.0
Consistency of fresh mortar, mm	630	530	485	760	620	460

RESULTS AND DISCUSSIONS

Unit weight

The values of the unit weight of the various mortar mixtures after 28 days of wet curing are reported in Table 3. Lightened mixtures can be obtained by adding waste particles without limestone powder, particularly when either PU or SR are added at 30% by volume of aggregate, by achieving a unit weight 20% and 14% lower than reference mortar respectively.

Table 3. Mortar Unit Weights

Mortar mixture	Unit weight, kg/m^3	Relative percentage, %
REF	2031	100
PU-10%	1895	93
SR-10%	1973	96
PU-30%	1621	80
SR-30%	1756	84
REF+LP	2191	108
PU-10%+LP	2090	103
SR-10%+LP	2180	100
REF+LP+SP	2215	109
PU-10%+LP+SP	2109	104
SR-10%+LP+SP	2160	106

Compression test

Compressive strength was evaluated up to 28 days of wet curing according to EN 1015-11. Results obtained are reported in Figures 2 and 3.

On the basis of the results shown in Figure 2 it seems that PU waste particles are slightly less detrimental than SR for compressive strength, despite the lower unit weight of the relative mortars (see Table 4). In particular, although 'PU-30%' mixture is 20% lighter than the reference, its 28-day compressive strength is still higher than 15 MPa.

On the basis of the results reported in Figure 3 it seems that the contemporary use of limestone powder and superplasticizer, in order to improve cement paste properties by lowering its porosity, allows to recover the loss of strength due to the use of 10% rubber waste particles of whatever type. This result is further confirmed by data reported in Table 3.

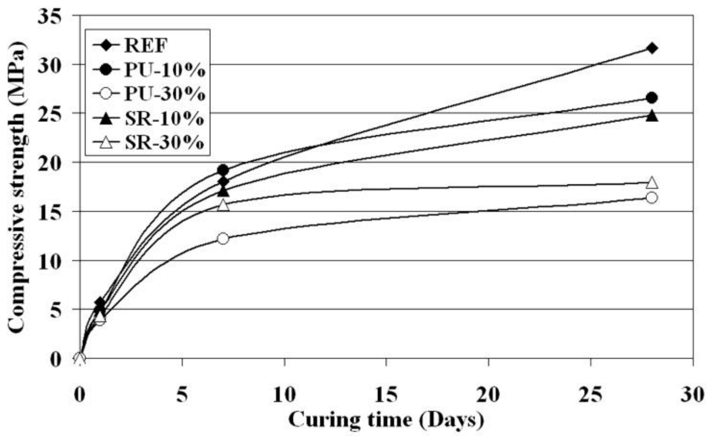

Fig. 2. Compressive Strength vs. Curing Time

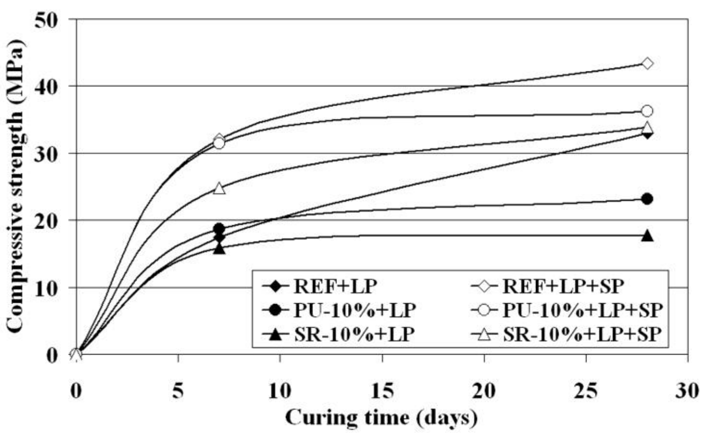

Fig. 3. Compressive Strength vs. Curing Time of Mortars with Limestone Powder

Bending test

Flexural strength was evaluated up to 28 days of wet curing according to EN 1015-11. Results obtained concerning mortars reported in Table 1 and 2 are reported in Figures 4 and 5 respectively.

They confirmed data obtained by compression tests for the mixtures containing PU waste particles, whilst on the other hand mixtures containing SR waste particles performed worse in bending than in compression tests. The reason probably lies in the morphology of SR waste particles (smooth and low porosity surface).

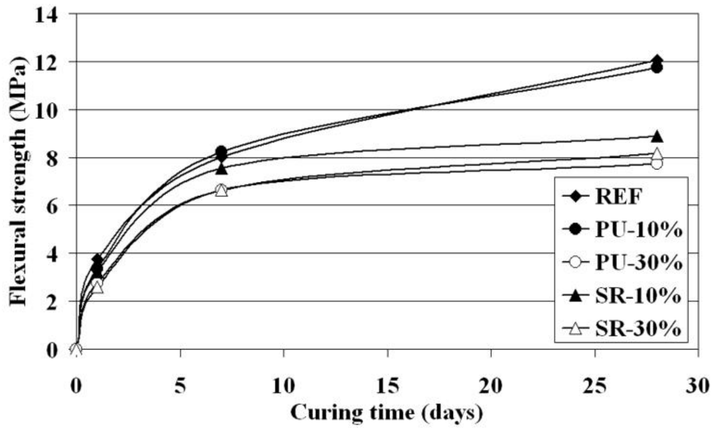

Fig. 4. Flexural Strength vs. Curing Time

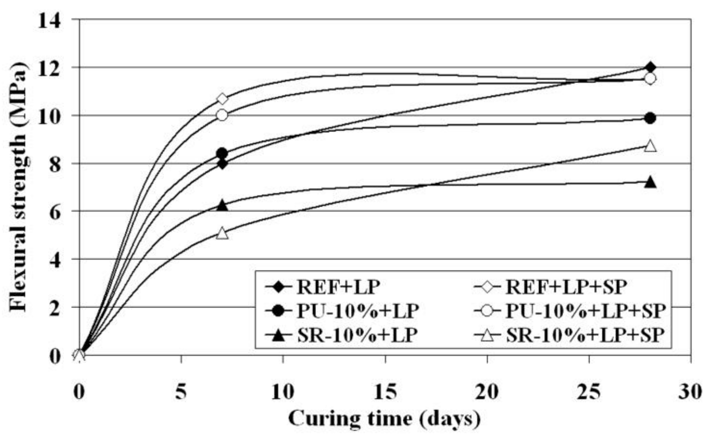

Fig. 5. Flexural Strength vs. Curing Time of Mortars with Limestone Powder

Thermal conductivity test

Thermal conductivity measurements were carried out on mortars containing PU waste particles by using the guarded hot plate method, according to UNI 7745.

Results obtained, reported in Table 4, showed that mortars containing 10% and 30% PU waste particles are characterized by thermal conductivity values 12% and 20% lower that reference mortar respectively. On the other hand, when limestone powder was added to the mixture, due to a mortar lower porosity, thermal conductivity came out to be about the same as that of the reference mixture.

Table 4. Thermal Conductivities of Mortars with PU Waste Particles

Mixtures	REF	PU-10%	PU-30%	PU-10%+LP
Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.739	0.648	0.598	0.717

CONCLUSIONS

The experimental investigation showed that the addition of rubber particles decreases the material unit weight and the thermal conductivity of the composite is reduced. In particular, the addition of 30% by volume polyurethane (PU) waste particles reduces both the material unit weight and thermal conductivity of the composite by 20% with a compressive strength still remaining higher than 15 MPa (threshold value for structural concrete). The thermal insulating effect of especially PU waste particles indicates a promising potential for future developments.

On the other hand, the addition of limestone powder produced higher thermal conductivity as well as higher compressive and flexural strength. In particular, in the presence of superplasticizing admixture and 10% PU particles, the same thermal and mechanical performance of the reference mortar could be achieved.

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