Construction and Building Materials 146 (2017) 603–614

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigations for properties improvement of recycled PE polymer particles-reinforced mortars for repair practice

Amel Aattache, Rabah Soltani *, Abdelkader Mahi

Département de Génie Civil, Faculté d'Architecture et de Génie Civil, Université des Sciences et de la Technologie Mohamed Boudiaf d'Oran, BP.1505, El Menaouar, 31000 Oran, Algeria

HIGHLIGHTS

- Investigations on durability of recycled PE-reinforced mortars using a superplasticiser.
- Mortar with 2% PE volumetric polymer particles induced significant improvements.
- Recycled PE-reinforced mortars appear particularly promising for repair works.

ARTICLE INFO

Article history:
Received 10 December 2016
Received in revised form 12 April 2017
Accepted 13 April 2017

Keywords:
Recycled PE-reinforced mortars
Aggressive media
Properties improvement
Superplasticiser feasibility
Repair practice
Strengthening

ABSTRACT

Investigations for the properties improvement of recycled PE polymer particles-reinforced mortars were carried out using FTIR, XRD, SEM, capillary absorption, mass variation and compression and splitting tensile strengths. The experimental findings highlight great enhancements in the properties of the composite mortar at 2% PE volume content, in comparison with plain mortars and earlier research results. Overall outcomes indicate that such mortar can be qualified as an advantageous and promising composite material for repair practice and strengthening of concrete components in aggressive media, especially when taking into account cost savings and plastic wastes recycling.

1. Introduction

As it is well known, long-term exposition to sulfate and acid environments may cause significant damages to the constituent materials of concretes. Mostly, these environments do not have an immediate safety issue but may progressively induce structural problems [1]. Concretes in such conditions are exposed to potentially harmful deterioration agents during their long life-cycle. Sulfates – common in ground-water, soils and sea-water – as well as high concentrations of gypsum encountered in some soil areas may all be considered as potentially harmful agents to concretes. Besides, waste-water from domestic homes and huge industry developments result in a strongly acidic chemical rejection increase. Sulfate ions affect long-term properties and contribute to the expansion and deterioration of concretes. This damage is related to the leaching of calcium ions of calcium hydroxide (CH) and calcium silicate hydrate (CSH), a process which increases porosity and speeds up the passage of aggressive ions. It is also known that concretes in acid solutions undergo dissolution which induces the precipitation of salts where the chemical reaction (bases + acids = salt + water) may take place. According to these facts, one of the challenges is to put a barrier against the spread of negative ions into concretes, especially coatings which are the most exposed to environmental degradation factors. It is therefore necessary to develop new insight based strategies for concrete compositions or repairs in the presence of structural problems, in order to ensure better performances with nice concrete properties.

Plastic wastes are extremely versatile and exhibit nice properties like light weight, durability, resistance to chemicals, etc. as reported in the review paper by Siddique et al. [2]. Therein, scientific and industrial communities discussed the great strides made in reducing the environmental impact, by growing their interests towards recycling plastic wastes – limited to landfills – therefore exploiting their useful properties to develop innovative and sustainable composite materials. Many authors discussed the effects of recycled plastic reinforcement of concrete in terms of a large

* Corresponding author.
E-mail addresses: aattache.amel@yahoo.fr (A. Aattache), rsoltanidz@yahoo.fr (R. Soltani), mahiabdelkader@yahoo.fr (A. Mahi).

http://dx.doi.org/10.1016/j.conbuildmat.2017.04.110
0950-0618/

number of material properties. In the last past decades, several studies have been worldwide devoted to the development of waste materials in the composition of concretes [3–21] to build up composite materials which could lead to the design of innovative concretes with better performances and environmental sustainability. Particular attention was accorded to the case of concrete reinforcement with PE polymer particles. Thus, different avenues were explored to investigate – from experimental observations – the effect of adding PE polymer particles on the thermal and strength properties in the domain of concrete repair. Today, PE is known for its thermal and strength properties and continues to attract many scientists to exploring durability problems. Indeed, PE encompasses proper features and may show some performance advantages, suitable for concrete components. In addition, this material appears to be a promising alternative for cementitious materials and could particularly be a good alternative of classical materials in repairing and strengthening works.

In the case of mortar repairs, we wish to mention the works in [16–21]. To start with, Benosman et al. [16] carried out experiments on mortars blended with polyethylene terephtalate (PET) polymer particles under sulfate ions attack. They observed significant decreases in the mechanical properties, as compared to plain mortars. They also concluded that this decrease was directly related to the rates of polymer particles used. Differently from Benosman et al. [16], Ghernouti and Rabehi [17] substituted part of the sand by PE polymer particles in different preparations of mortars immersed in acid solutions. The issuing experimental results revealed low increases in loss of mass, as compared to plain mortars. The authors also reported that such mortars permitted to reduce the internal degradation over time. In the study by Senhadji et al. [18], polyvinyl chloride (PVC) plastic wastes were used as partial replacements of sand and gravel at different rates (30, 50 and 70%) by volume of concrete. They measured the resistance of the concrete-based composites to chloride ions penetration and evaluated the beneficial effects in terms of protection of the steel bars against corrosion. Omrane et al. [19] analysed mortars embedded with 2, 4 and 6% of PET polymer particles by cement weight. They observed decreases in sorptivity with increases of polymer particles contents. Similarly to Ghernouti and Rabehi [20], Silva et al. [21] substituted sand with recycled PET polymer particles using two different geometries (plastic pellets (PP) and (PF) plastic flakes) at three ratios (5, 10 and 15%). They reported that capillary water absorption coefficient increased with the volume of plastic wastes ratios.

Such a large variability of plastic wastes and mortars may result in a particularly wide range of possible responses in terms of composite-mortars durability. To the authors, the properties of recycled PE polymer particles-reinforced mortars can be further improved and may therefore become a widely used technique in repairing and strengthening of existing concrete structural members exposed to chemical attacks, for which some requirements must be specified. In more details, composite mortars containing plastic wastes tend to be porous due to the presence of polymer particles, therefore altering the flow characteristics of the mixtures and hence needing excessive mixing water for better workability. In this case, an appropriate addition of volumetric content of PE polymer particles is particularly relevant. Together with these polymer particles, a superplasticiser may both reduce the water content needed without affecting workability and improve the properties of the hardening fresh mortars. Furthermore, a combination of these two constituents may provide significant properties improvement and reduce damages to the reinforced mortars when exposed to environmental degradation factors.

This study is an extension to the works presented in [16–21] by investigating on durability of recycled PE polymer particles-reinforced mortars. Such investigations were carried out for properties improvement of PE polymer particles-reinforced mortars under chemical attacks, using different volumetric contents of PE polymer particles and a superplasticiser. To begin with, we reported the raw materials and aggressive agents used, a step in which the physical and chemical properties were investigated and where different rates of PE were experimented to identify the effect of PE content on water absorption. Next, we examined the specific properties of the superplasticiszer (SP) and the polyethylene (PE) polymer particles using FTIR, XRD and SEM. We then carried out the intended experimental work for compressive strengths, splitting tensile strengths, mass variations, XRD and SEM analyses for the different mortars. We ended with a discussion of the outcomes of the experimental results.

2. Materials and experimental procedure

Within this experimental work, the materials used, for which some of the characteristics of interest are highlighted below, were CEM I/42.5R sulfate resistant cement, silico-calcareous river sand, superplasticiser (SP) powder and polyethylene polymer (PE) particles. The magnesium sulfate ($MgSO_4$), sodium sulfate (Na_2SO_4) and sulfuric acid (H_2SO_4) solutions were used as testing agents.

2.1. Characterisation of the materials

CEM I/42.5R sulfate resistant cement with no mineral additions was selected for the preparation of all the tested samples. The chemical composition of the raw materials used in this cement is clearly described in Table 1. It should be noted that nowadays in Algeria, all types of cement sold on the local market consist of cement clinker blended with SCMs. For the local cement industry, this is to keep up with the trend of the times with the realisation of clean industry process and comprehensive use of wastes.

The fine aggregate used was silico-calcareous river sand having minimum grain size below 1.6 mm. This locally available sand was conforming to the desired particle size distribution and whose sand equivalence and absolute density were 93.6 and 2.5 g/cm^3, respectively. A superplasticiser (SP) powder, with a specific surface ranged between 10 and 20 m^2/g and inducing a pH of about 10, was also considered as partial cement replacement material with a rate of 3%. The size distribution of the non-soluble thermoplastic polyethylene (PE) polymer particles ranged from 80 μm to 0.5 mm. The polymer particles of the examined polyethylene (PE) are illustrated in Fig. 1.

A total of five types of mortars reflecting different compositions were examined, as listed in Table 2. In the sequel, these mortars were labeled NM (normal mortar), SPM (mortar with a superplasticiser) and CM2, CM4 and CM6 (composite mortars) with 2%, 4% and 6% rate of polymer particles, respectively. With regard to mixes, the composition of the mortars was mainly obtained by using a combination of a sulfate resistant cement CEM I/42.5R, only one type of superplasticiser (SP) and polyethylene (PE) polymer particles. In all the mortars, a constant quantity of sand (1350 g) was applied. Amounts (2%, 4% and 6%) of PE polymer particles, as a replacement of cement and water-to-cement (W/C) ratios, ranging from 0.48 to 0.54 with a constant workability (30%), were used in the preparation of the composite mortars (CM/2, 4, 6), respectively.

In details, the normal mortar (NM) is a plain mortar, prepared with cement (450 g), SP (0 g), PE (0%) and W/C (0.60) ratio; the mortar with superplasticiser (SPM) was prepared with cement (436.5 g), SP (13.5 g), PE (0%) and a lower W/C (0.45) ratio. For this latter, the amount of cement was lowered (436.5 g) as part of this cement (13.5 g) was replaced by the superplasticiser (SP). For composite mortars CM2 to CM6, the cement content and the