Construction and Building Materials 73 (2014) 682–687

Contents lists available at ScienceDirect

Construction and Building Materials

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

Properties of plastic mortar made with recycled polyethylene terephthalate

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HIGHLIGHTS

- The effects of fly ash, bitumen, and nano-calcium carbonate on mechanical properties of plastic mortar were investigated.
- The plastic mortar shows high temperature stability.
- Plastic mortar has low water absorption and high sulfate corrosion resistance.
- The SEM test indicates that the PET and aggregate were bonded well.

ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form 30 September 2014
Accepted 8 October 2014

Keywords:
Recycled polyethylene terephthalate
Mechanical property
Durability
Temperature stability
Admixtures
SEM

ABSTRACT

This paper studied the mechanical properties and durability of plastic mortar made with recycled Polyethylene Terephthalate (PET). The effects of gradation and admixtures, including bitumen, fly ash, and nano-calcium carbonate, on strength were investigated. The temperature stability was studied based on the compressive strength at different temperatures. The water absorption and sulfate corrosion resistance were conducted to evaluate the durability. The microstructure of the plastic mortar was observed by Scanning Electron Microscope (SEM). The test results show that increasing the content of fine particles could first increase and then decrease the strength. Partially replacing PET with bitumen and/or fly ash could significantly influence the strength. But the nano-calcium carbonate had no significant effect on strength. The plastic mortar had high stability as temperature changed from 30 to 90 °C. The strength was similar for specimens under different testing temperatures. The plastic mortar had very low water absorption and high sulfate corrosion resistance. The SEM results revealed that the PET and aggregates were bonded well.

1. Introduction

Polyethylene Terephthalate (PET), one of the most common consumer plastics used, is widely used for bottles and containers of food products and other consumer goods, including soft drinks, alcoholic beverages, detergents, and so on [1]. Despite its wide usage, large amount of PET bottles were discarded every year and became a pollutant source. For example, 6 billion PET bottles were discarded in 2009 in Beijing, China, which produced 150 thousand tons of waste PET [2]. According to National Association for PET Container Resources (NAPCOR), there was 5.6 billion pounds of PET bottles available in the United States for recycling in 2012. However, the recycling rate was only 30.8% [3]. Except for the low rate of PET recycling, improper disposal of post-consumer PET could cause environmental issues due to its non-biodegradable property and gases released by incineration [4]. Therefore, finding effective ways to reuse waste PET bottles and improve the recycling rate is becoming very important for environmental sustainability. Studies had been carried out in recent years to convert PET wastes into construction materials. Currently, there are three major ways of recycling PET bottles as construction materials, including depolymerization of PET bottles into unsaturated polyester resin [5–8], usage of PET fiber as concrete reinforcement [9–12], and replacement of partial aggregate with PET wastes [13–15]. Among these methods, using waste PET bottles as aggregate in Ordinary Portland Cement (OPC) concretes or mortars could provide an effective way to recycle waste PET bottles. Physical and mechanical properties of OPC concretes or mortars with waste PET aggregates had been examined in the studies [16–20]. However, there are disadvantages for concrete with PET, such as high temperature sensitivity, high cost, low bond strength

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http://dx.doi.org/10.1016/j.conbuildmat.2014.10.005
0950-0618/

between PET fiber and cementitious materials, and low strength and elastic modulus [21–23].

Recently, a new method of using waste PET as binding materials was proposed [24,25]. The waste PET bottles were shredded, heated to certain temperature, and mixed with aggregate to obtain a uniform fused mixture. Khoury et al. used soil, clay or sand to make plastic soil [24]. Ge et al. made PET mortar with sand or recycled clay brick [25]. Both research show promising results. Compared with traditional cement based material, the new type of mixture had quick strength gain. However, studies on the durability of the plastic mixture and effects of admixtures on the properties are limited. More research is needed.

The aim of this study is to investigate (1) the effects of gradation and admixtures, including bitumen, fly ash and nano-calcium, on mechanical properties of the plastic mortar; (2) the durability of the plastic mortar; and (3) the stability of plastic mortar under different environmental temperatures.

2. Experimental materials and methods

2.1. Materials

Discarded PET bottles were collected and cut into flakes. In order to obtain only PET material, bottle caps and label papers were removed. The density, water absorption and melting point of the waste PET were 1.35 g/cm^3, 0.16%, and 250 °C, respectively.

The natural river sand and mineral filler were combined to produce fine aggregates with different grading for the plastic mortar. The bulk density and water absorption of sand were 2.40 g/cm^3 and 2.76%, respectively. The maximum size of mineral filler was less than 0.075 mm.

The admixtures used in this study include bitumen, fly ash, and nano-calcium carbonate. The bitumen was ordinary grade 70 bitumen with penetration of 70 mm, ductility of 100 cm, softening point of 48.2 °C, and flash point of 264 °C. Type F fly ash with 3.88% CaO was used in this study. The main chemical compositions of cement and fly ash are provided in Table 1. The nano-calcium carbonate was from Shanxi, China. As shown in Fig. 1, the particle diameter ranged from 5 to 40 nm.

2.2. Experimental design

The effects of aggregate gradation, admixtures, and testing temperature on the mechanical properties were studied. The mineral filler was combined with sand to form six different grading (Table 2). The fineness modulus ranged from 1.75 to 3.14. Three different levels were selected for each admixture. The mix proportions were shown in Table 3. The temperature stability of the plastic mortar was evaluated under the testing temperatures of 30 °C, 45 °C, 60 °C, 75 °C and 90 °C.

Based on the previous study [27], a sand to PET ratio of 3 was selected for all mixes. To prepare the specimen, sand was first dried to constant weight in the oven at 110 °C, and then mixed and heated with PET flakes at 280–290 °C until the PET flakes were melted. After that, it was manually mixed to obtain a uniform mixture. The mixture was then poured into the mold, which had been pre-heated to 180 °C, and compacted to produce plastic mortar. After cured under 180 °C for two hours, specimens were demolded and cured in the room condition until test.

The compressive and flexural strengths of the plastic mortar specimens were measured according to ASTM C 109 [26] and ASTM C 348 [27]. The size of specimens for the compressive strength test was 50 × 50 × 50 mm. Prisms of 40 × 40 × 160 mm were casted for the flexural strength test. Since the strength development was very fast for the plastic mortar, only one-day compressive and flexural strengths were tested. All strengths were obtained from three samples, and the average of three samples was presented and discussed in the study.

To test the water absorption, specimens were first dried in the oven. The dry mass of specimens in air was then weighed. After that, the specimens were immersed into the water. At testing time, specimens were taken out of water with its surface water wiped with wet towel and its saturated surface-dry mass was weighed.

Table 1
The main chemical components of fly ash and cement (%).

Components	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	SO_3	LOI
Fly ash	3.88	45.66	31.51	9.70	0.89	3.02	0.37	4.97
Cement	64.63	21.96	4.73	3.68	2.59	0.56	0.3	1.97

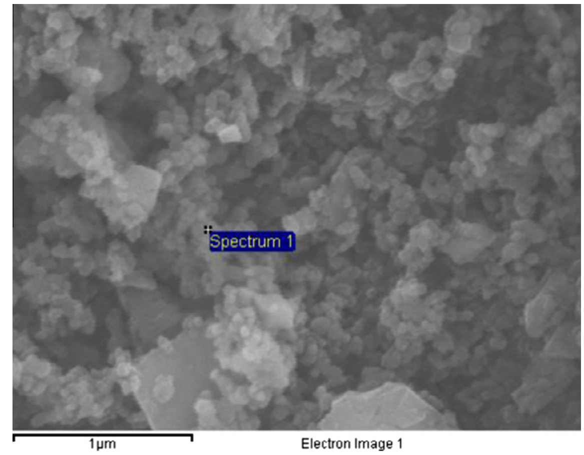

Fig. 1. SEM of nano-calcium carbonate.

Table 2
Grading of aggregate.

Sieve size (mm)	Grading					
	1	2	3	4	5	6
4.75	100	100	100	100	100	100
2.36	85	88	95	95	95	100
1.18	50	53	65	65	65	80
0.60	28	20	44	44	44	60
0.30	15	18	31	32.5	34	50
0.15	8	10	21	21.5	24	35
0.075	5	7	7.5	15	18	20
Fineness modulus	3.14	3.11	2.44	2.42	2.38	1.75

Table 3
The mix proportions of mortar with different admixtures.

Mix	Bitumen (%)	Fly ash (%)	Nano-calcium carbonate (%)
1	0	0	0
2	5	0	0
3	10	0	0
4	15	0	0
5	0	5	0
6	0	10	0
7	0	15	0
8	0	0	2
9	0	0	4
10	0	0	6

The resistance to sulfate corrosion was evaluated based on the wetting and drying method. For each cycle, the 50 × 50 × 50 mm specimens were soaked in the 5% sodium sulfate solution for 16 h, dried for one hour, and then put into the 80 °C oven for 6 h. After that, samples were cooled down to the room temperature. The weight and compressive strength were then tested.

Scanning Electron Microscope (SEM) was employed to examine the microstructure. A gold casting was applied to the surface of samples before the testing. The microstructure was observed under SU-70 SEM, manufactured by Japan.

3. Results and discussions

3.1. Effects of gradation

Figs. 2 and 3 show the effect of aggregate gradation on the strength. Typically, the strength first increased and then decreased as the fineness modulus decreased. Grading 3 and 4 had similar fineness modulus but the strength was much higher for grading 4. The reason was that grading 4 contained more fine particles, which were less than 0.075 mm. As the fine content increased,