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Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates

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Abstract

The purpose of this study was to solve some of the solid waste problems posed by plastics and concrete demolition. To this end, we evaluated the mechanical properties of polymer concrete, in particular, polymer concrete made of unsaturated polyester resins from recycled polyethylene terephthalate (PET) plastic waste and recycled concrete aggregates. The strength and the resistances to acid and alkali compounds of the polymer concrete were measured by varying the coarse and fine aggregate ratio and resin content. Three main observations followed the results. First, we found that the strength of polymer concrete made with a resin based on recycled PET and recycled aggregate increases with increasing resin content; however, beyond a certain resin content, the strength does not change appreciably. Second, the stress–strain curves of polymer concretes with 100% natural aggregate and 100% recycled aggregate exhibited different failure mechanisms of the compressed materials. Third, with respect to acid resistance, the polymer concrete at a resin content of 9% was nearly unaffected by HCl, whereas the polymer concrete with 100% recycled aggregate showed poor acid resistance. Unlike acid, alkali compounds did not seem to attack the polymer concrete with 100% recycled aggregate as observed from the weight change and the compressive strength.

Keywords: Polymer concrete; Recycled PET; Recycled aggregate; Mechanical properties; Stress–strain curve

1. Introduction

Compared to cement-based concrete, polymer concrete (PC) is stronger and more durable. For this reason, polymer concrete is used in many structures such as box culverts, hazardous waste containers, trench lines, floor drains, and in the repair and overlay of damaged cement concrete surfaces such as pavement and bridges. In spite of its advantages, however, polymer concrete is not used widely due to its relatively high material cost compared to cement-based concrete. In fact, a recent survey ranked less expensive resins as the most important factor necessary for the future use of polymer concrete [1]. Binders used for polymer concrete include epoxy, MMA (Methyl Methacrylate), and unsaturated polyester, among others. A large stream of recycled PET is available from recycling applications, and this has made unsaturated polyester resin a widely used and popular binding agent for polymer concrete.

Several attempts have been made to utilize demolition material from concrete and masonry wastes [6–8]. Recycled concrete aggregate has a relatively lower density and higher water absorption characteristics than fresh granite aggregate. Consequently, to compensate low strength of recycle aggregate with high strength of polymer is promising.

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Given the rise in popularity of PET and recycled aggregate concrete, the mechanical properties, including the elastic modulus of recycled-PET polymer concrete with recycled concrete aggregate (RPC, RPC is defined as polymer concrete which is made of recycled-PET polymer and recycled concrete aggregate), were investigated in this study as a function of the ratio of natural and recycled aggregates for both coarse and fine aggregates. The effect of age on the compressive strength of RPC was also studied to determine how strength changed over time. The resistances to acid and alkali compounds of RPC were estimated by varying the natural and recycled aggregate ratios. A scanning electron microscope (SEM) was used to closely examine the difference between the aggregate-binder interfacial zones with RPC using natural aggregate and those using recycled aggregate.

2. Research significance

This paper contributes to the understanding of the characteristics of polymer concrete made with recycled-PET and recycled concrete aggregates. It also provides the necessary data for the disposal of PET waste and demolished concrete in landfills. Results to be achieved are expected to contribute to the following areas of interest:

1. Manufacture of structural grade polymer concrete using recycled concrete aggregate with undesirable physical properties (for example, high water absorption and relatively lower density).
2. Development of new possibilities for the use of recycled-PET and recycled concrete aggregate in polymer concrete.
3. Increase in the use of recycled-PET and recycled concrete aggregate in the production of polymer concrete and, thereby, reduction of environmental pollution and increase in preservation of natural resources.

The recycling of PET and the use of recycled concrete aggregate could lower the material cost of producing useful polymer concrete products.

3. Experiment

3.1. Materials

3.1.2. Resin

Unsaturated polyesters (UP) produced with recycled PET may be used to produce good quality polymer concrete at a relatively low cost and is useful as an energy saving material. The properties of this resin are shown in Table 1. Cobalt octoate (0.1% by weight of resin) was previously added to the commercial UP product as a promoter. Hence, only the addition of the initiator, methyl ethyl ketone peroxide (MEKPO), was needed for the hardening reaction. The styrene monomer constituted 40% of the total UP resin weight.

3.1.3. Microfiller

Calcium carbonate ($CaCO_3$) was used as mineral filler in order to ensure good bonding between the polymer matrix and inorganic aggregates [4,10]. The chemical composition of $CaCO_3$ is given in Table 2.

The microfiller was oven-dried for a minimum of 24 h at 110 ± 5 °C to reduce its moisture content to less than 0.5% by weight, after which it was cooled to room temperature.

3.1.4. Aggregate

Four types of aggregate were used in all concrete mixtures: recycled coarse aggregate (nominal maximum size of 9 mm), recycled fine aggregate, and natural coarse and fine aggregates. The physical properties of the aggregates are given in Table 3.

Residual cement mortar attached to the recycled concrete aggregate particles was observed. The weight fraction of recycled coarse aggregates was 21.5%, which was relatively higher than that for the natural aggregates because of the previously mentioned mortar coating. High water absorption was the most significant difference in the physical characteristic of recycled aggregate.

3.1.5. Mix design

Variables were divided into two groups. The first group of variables, which were related to the study and comparison of the fundamental properties of RPC, is listed in Table 4. These experimental variables indicate how the contents of recycled aggregate affect the strength of RPC and what kinds of relationships exist between the RPC strengths. The curing ages varied from 1, 3, and 7-days to consider the influence of curing age on the RPC's compressive strength.

The second group of variables was selected to investigate the effects of the UP resin content on the strength of RPC and to determine the optimal resin content for maximum strength. The experimental variables II are classified in Table 5.

3.2. Testing procedure

3.2.1. Strengths and elastic modulus

The specimens were mixed and cured at room temperature for 7 days prior to testing. Likewise, in order to consider the influence of curing age on the compressive

Table 1
Properties of UP resin based on recycled PET

Non-volatile materials (%)	Acid value (mg KOH/g)	Viscosity (MPa s)	HDT (°C)	Elongation (%)
60	5	1300	80	4.1