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Characterization of compliant polymer concretes for rapid repair of runways

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HIGHLIGHTS

- Rubber-containing compliant polymer concretes were introduced for repairing runways.
- Tire waste powder enhances mechanical performance with high ductility factor.
- Best mixing ratio of compliant polymer concrete for repairing runways was determined.

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ABSTRACT

A new type of compliant polymer concrete for runway repair is introduced in this paper. To enhance the compliance of epoxy-based polymer concrete, some epoxy resin was replaced with liquid-type silicone rubber or tire waste powder. To estimate the temperature dependency of the mechanical behavior of the compliant polymer concretes, mechanical tests were also carried out. It was found that tire waste powder was more efficient than the silicone rubber in terms of mechanical performance. The experimental work revealed the 72:20:08(T) specimen provided the highest ductility factor while keeping the compressive strength above the minimum required value (30 MPa).

1. Introduction

Cement concretes are well-known materials for runway construction, but when it fails locally, cement concretes are not the best materials for the repair of the runway because they need a long curing time. Polymer concretes can be an alternative because they have excellent mechanical properties with high strength and the curing time can be controlled; as a result, they can offset cement concrete's shortcomings [1]. Therefore, polymer concretes are the best material for the repair of a runway that needs rapid maintenance for immediate opening [2]. For successful repair of a runway with polymer concretes, the dimensional compatibility should be considered for durability [2]. The dimensional compatibility is determined by the drying shrinkage, thermal expansion, and modulus of elasticity of the materials. In general, polymer concretes have 3–4 times higher coefficients of thermal expansion relative to cement concretes, which induces differences in deformation between the two materials when they are used together in runway repair. Even though polymer concretes have excellent bonding characteristics, repetitive expansion and contraction of the repaired part as a result of environmental temperature changes may cause material failure at the bonding surface or the cement concrete part. To avoid excessive stresses at the interface between the two materials under environmental conditions, significant effort has been made to enhance the compliance of concretes by adding ductile materials [3–7].

In this study, highly compliant polymer concretes were considered to alleviate thermal residual stress at the interface between the polymer concrete as a repair material and the cement concrete substrate under service conditions. Two types of ductile materials, liquid silicone rubber and tire waste powder, were mixed in epoxy-based polymer concrete in order to construct compliant polymer concretes. Several combinations of materials were tried in an effort to find the most appropriate mixing ratio as runway repair material, and mechanical tests such as the compressive test were carried out to evaluate the mechanical performance of each combination of materials.

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2. Experiments

2.1. Materials and mixing ratio

To fabricate compliant polymer concretes for runway repair, a standard polymer concrete composed of aggregates and epoxy resin (80:20 by weight), which was suggested by Jung et al. [8], was selected. Liquid silicone rubber (KE-12, Shinetsu, Japan) or tire waste powder was added to the polymer concrete with various mixing ratios. The mixing ratio was denoted as "aggregate:epoxy:rubber," which was used as the name of the specimen to distinguish each type of compliant polymer concrete. When liquid silicone rubber was used, the symbol "S" was added, and when tire waste powder was used, the symbol "T" was added. For instance, "72:20:08(T)" indicates that the weight percentiles of aggregate, epoxy, and tire waste powder are 72%, 20%, and 8%, respectively, and that tire waste powder was used. Aggregate grit numbers 4 (0.85–1.2 mm) and 6 (0.25–0.6 mm) were mixed in a weight ratio of 2:1 and this was mixed again with epoxy resin (ERR 200, Jungdo E&P, Korea).

Liquid silicone rubber can be cured at room temperature, and the particle size of the tire waste ranged from 0.177 mm to 0.297 mm. The degree of dispersion of this powder in the specimens was verified by microscopic observation (Fig. 1a). A hand-mixing method (ASTM C192 [9]) was used to fabricate the specimens.

2.2. Mechanical tests

All the specimens were cured at room temperature for 6 h. During the curing process, the degree of curing was monitored by a dielectrometry sensor, and it was found that 6 h curing guaranteed that the specimens were 99% cured [8]. The cure shrinkage of the polymer concrete was also measured by using a fiber Bragg grating (FBG) sensor for 25 h.

Mechanical experiments such as compressive tests were carried out by a universal testing machine (MTS 810) in an environmental chamber at temperatures of −25 °C, 50 °C, and room temperature. The compressive test followed the ASTM C579-01 test standard with a compression speed of 1.25 mm/min [10]. The dimensions of the specimens were 20 × 20 × 60 mm (see Fig. 1b). Flexural tests followed the ASTM C580-02 test standard with a test speed of 4.31 mm/min and the specimen dimensions were 25 × 25 × 310 mm (see Fig. 1b). The flexural strength was calculated by Eq. (1) and the secant modulus of elasticity was calculated by Eq. (2) [11].

$$S = 3PL/2bd^2 \quad (1)$$

$$E_s = L^3M/4bd^3 \quad (2)$$

where S, P, L, b, d, M, and E_s represent flexural strength, maximum load, span, width, depth, the initial slope connecting the origin and the point at 50% of the maximum deflection, and the secant modulus of elasticity, respectively. The slant shear test, used to check bonding strength, followed the ASTM C882 test standard [12] and the overall dimensions of the specimens were the same as those of the compressive test (see Fig. 1b). Because the slant shear test specimen had a 30° slope at the interface between two materials, a wedge-type insert was prepared in order to fabricate the cement concrete part first. Then, the bonding surface of the cured cement concrete part was treated by abrading paper (grit number 60). The smoothness of the mold surface facilitated effective de-molding after curing. As a result, the bonding surface of the cured cement concrete part was also very smooth. However, in real repair sites, the bonding surfaces are usually quite rough and, as such, the bonding surface of the specimen was ground with abrading paper (grit number 60) in order to provide the appropriate surface roughness. After inserting the cement concrete part in the jig, the polymer concrete was poured into the cavity and cured. The fabrication process is illustrated in Fig. 2a and the mechanical experiment setups are shown in Fig. 2b.

3. Results and discussion

3.1. Degree of cure and cure shrinkage

To check the degree of cure of the polymer concrete, a dielectrometry sensor was used to measure the dissipation factor, which is defined as the dissipated energy divided by the supplied energy. The sensor measures capacitance changes resulting from the mobility changes of dipoles in the epoxy resin during curing, as illustrated in Fig. 3a [13]. The mobility of the dipoles depends on the phase of the epoxy resin; that is, the dipoles are most and least mobile (almost static) when the resin is liquid and solid (in the form of a gel), respectively. In addition, the dielectrometry sensor measures changes in the capacitance resulting from changes in the mobility of the dipoles during curing (see Eq. (3), Ref. [13]). This was done by measuring the dissipation factor of the dry sensor at the beginning of the test in order to determine a baseline (about 0.041 in Fig. 3b) for the measurements. After complete curing (100% degree of curing), the resin has almost the same dissipation factor as that of the baseline. As shown in Fig. 3b, the capacitance

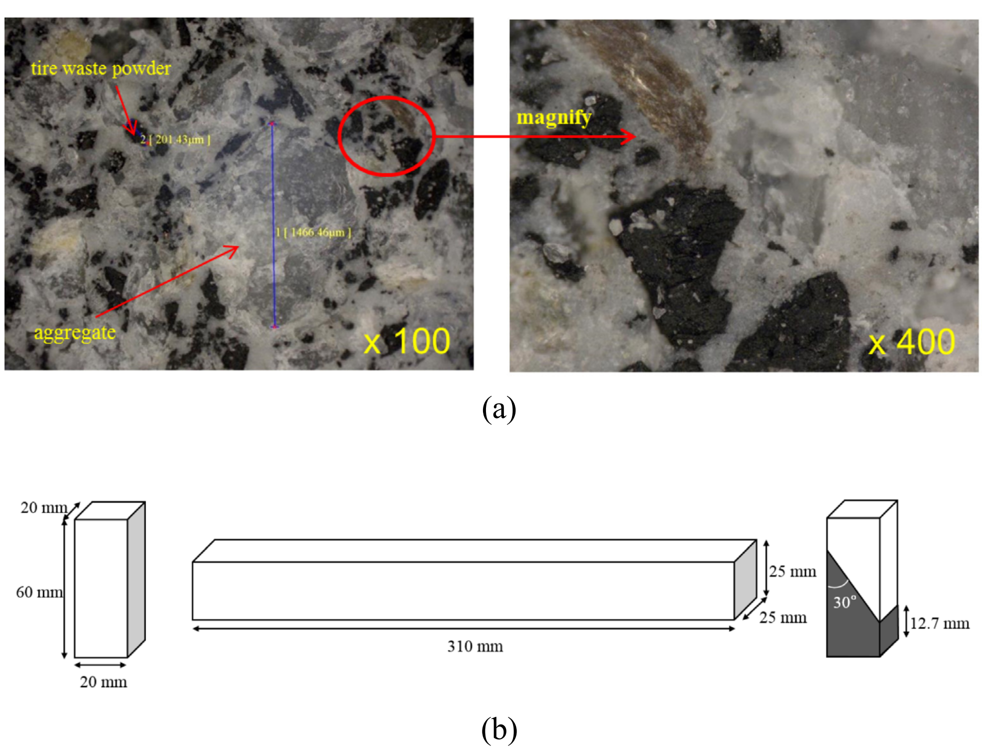

Fig. 1. Polymer concrete specimens: (a) micrographs of the specimens containing tire waste powder for checking powder distribution and (b) configurations of test specimens (compressive, flexural, and bonding tests specimens).