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Evaluation of shrinkage-induced stress in a runway repaired using compliant polymer concrete

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ABSTRACT

The aim of this study is to investigate shrinkage-induced stresses in a part of a runway pavement repaired using compliant polymer concrete. For this purpose, material properties of partially cured polymer concrete at different degrees of cure during the cure process were estimated and used in the stress analysis. To measure the degree of cure and shrinkage strain in the repaired part, a monitoring system comprising dielectrometry and fiber Bragg grating (FBG) optic sensors was installed in an airport (Gimpo airport, Korea). The shrinkage strain values measured at the various degrees of cure of the polymer concrete were used in finite element analysis to estimate shrinkage-induced stresses. To improve accuracy of stress analysis, property change of the polymer concrete during the curing process were also considered. It was concluded that property variations during the curing process should be considered for estimating material failure because the cure shrinkage of the repair material induces tensile stress following the critical loading pattern of concretes.

1. Introduction

There are many causes of damage of airport runway pavements. These causes include dynamic loads of aircrafts, engine heat, chemical erosion, climatic conditions, and shrinkage of repair materials. These factors affect the service life of the runway pavement. Therefore, damaged sections of runway pavements should be repaired as early as possible with appropriate maintenance materials and techniques. Generally, the repair process can be carried out at any time. Thus, an appropriate repair material, which has the required mechanical properties regardless of climatic conditions, should be selected [1,2]. Moreover, the service life of concrete structures such as runways, roads, and tunnels is determined by the mechanical or rheological properties of the used material, external forces, and environmental conditions. The characteristics of repair material are among the most important of design factors. Portland cement concrete, which is representative of materials used in the construction of runways, has excellent structural characteristics and cost benefits. However, this type of repair material takes a substantially long time (approximately 28 days) to attain its maximum compressive strength. This disadvantage limits its application to the initial construction of a runway. To overcome this problem, various construction methods (e.g., precast concrete) and several repair materials were studied to reduce the repair time [3]. One of the representative substitutional repair materials is polymer concrete, which attains high chemical resistance and durability as well as high strength relative to the conventional Portland cement concrete in a relatively short time [4–13]. Consequently, this paving material can increase the service life of a runway and reduce the construction time to allow early opening of a runway. Even if polymer concrete affords a number of advantages to the field of runway rehabilitation, it has relatively high cure shrinkage. This is different from dry shrinkage, which proceeds gradually with loss of water. Moreover, the significant polymerization shrinkage, which happens in a short time in the case of polymer concrete, is generated by the chemical reaction between epoxy binder and hardener. Because the shrinkage of repair material results in excessive stresses in the vicinity of the repaired section, it has to be measured accurately with reliable strain sensors to monitor structural integrity in real time. Fiber Bragg grating (FBG) sensors are suitable for non-destructive measurements and long-term service, and is unaffected by electromagnetic fields. Furthermore, this fiber type sensor seldom affects the behavior of structures because of their significantly small size, and they are highly sensitive to small deformation. Moreover, the single fiber sensor, which has multiple sensing points, can cover a wide ranges of even a huge structure [14–17]. These advantages led to their application as effective monitoring devices in large number of mechanical structures and infrastructures [18–23].

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In this study, several experimental tests were carried out to estimate the degrees of cure and shrinkage-induced strains in the repaired parts, which were prepared at an airport (Gimpo airport, Korea). Moreover, the compressive mechanical properties of compliant polymer concrete were evaluated according to the curing time (from 1 to 6 h) because modulus of repair material directly affects the level of stresses generated by the shrinkage of repair material. The data obtained from the aforementioned experimental work were used to construct the constitutive equation, which captures variations in material properties of compliant polymer concrete with respect to time, and this was used to calculate the generated stress in the repaired part by finite element analysis. Through this experimental and analytic research the major material properties of the newly developed material were fully understood and its reciprocal action with the cement concrete substrate by well-derived time-varying material properties was completely estimated, where the originality of this paper can be found. This result may accelerate the commercialization of the repair material for early opening of runways.

2. Experiments for measuring mechanical properties of compliant polymer concretes

2.1. Specimen preparation

As the repair material, compliant polymer concrete (72:20:08 (T)), which was composed of aggregates (72 wt%), epoxy resin (20 wt%), and powder type tire waste (8 wt%) and had been developed in a previous study, was used because of its excellent stress alleviation capacity [24]. To fabricate specimens for cure monitoring and compressive tests, epoxy binder (ERR 200, Jungdo E&P, Japan), hardener (ERH 200, Jungdo E&P, Japan), aggregates, and tire waste powder (0.18–0.42 mm) were prepared. Those materials were hand-mixed following international standard [25]. Two types of aggregates were used to prepare the specimens: coarse aggregates (0.85–1.2 mm) and fine aggregates (0.25–0.6 mm). These were mixed in the weight ratio of 2:1, which is the ratio used in the actual construction of runways. Thereafter, an amount of tire waste was added according to the defined mixing ratio. To

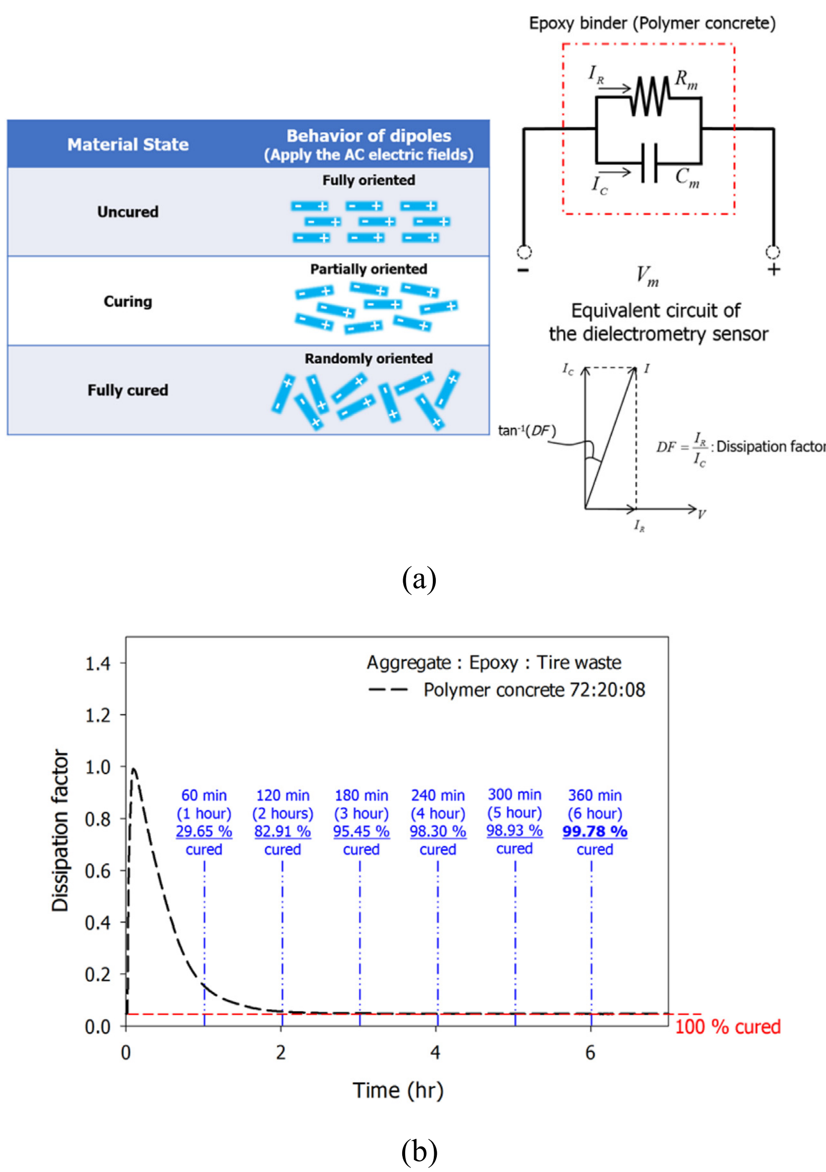

Fig. 1. Measurement of degree of cure of the compliant polymer concrete; (a) equivalent circuit of a cure monitoring system and (b) variation of dissipation factor (DF) with respect to the curing time.