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Stress analysis of runway repaired using compliant polymer concretes with consideration of cure shrinkage

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ABSTRACT

When polymer concretes are used to repair runway pavement, difficulties can result, including stress concentration and premature failure. These difficulties are generated by the differences in the mechanical properties of the polymer concrete used as the repair material and the cement concrete of the substrate. In particular, the mechanical properties of polymer concretes, including the coefficient of thermal expansion, have significant effects on the behavior of a repaired runway. Additionally, the cure shrinkage of the repair material is one of the main factors in the premature failure of the repaired part. To investigate the stresses generated in materials and determine the feasibility of using a polymer concrete as a repair material for runway repair, finite element analyses were carried out by considering the environmental conditions and cure shrinkage of polymer concretes. By replacing some amount of the epoxy resin in the standard polymer concrete with silicone rubber, compliant polymer concretes were developed, and it was found that these compliant polymer concretes were able to considerably reduce the generated stress.

1. Introduction

Portland cement concretes are representative materials for both the construction and maintenance of infrastructures. They have good mechanical characteristics such as a high compressive strength and durability, with a cheap price. However, they also have drawbacks such as high drying shrinkage, bad chemical resistance, and low tensile strength, which shorten the life expectancy of infrastructures such as pavements and runways [1,2]. The long curing time (28 d) required for cement concrete to obtain its full strength has made it difficult to use as a repair material for runways, which require rapid re-opening [3]. Unlike cement concretes, polymer concretes have relatively short cure times and good bonding strengths with substrates. Therefore, they are suitable as runway repair materials to ensure early re-opening. Material characterization studies of polymer concretes have been carried out to use them in engineering applications [4–10]. However, to apply polymer concretes to various infrastructures, several mechanical and physical aspects need to be considered. Like cement concretes, polymer concretes experience material shrinkage during curing (cure shrinkage). In addition, their coefficients of thermal expansion (CTEs) are completely different from those of cement concretes, which generates high stress at the interface between the polymer concrete used as a repair material and the substrate.

In this study, an epoxy-based polymer concrete was considered as a repair material for runways. Epoxy-based polymer concretes have relatively low cure shrinkage [11] values among commercially available polymer concretes, along with good bonding characteristics, chemical resistance, and excellent durability. In general, Portland cement concretes experience long-term drying shrinkage during the dehydration process [12], whereas polymer concretes experience short-term (less than 24 h) shrinkage due to polymerization [13,14]. Cure shrinkage may cause premature cracks or delamination at the interface when a polymer concrete is used as a repair material. Therefore, a low level of shrinkage is preferable for the repair material [15]. Moreover, polymer concretes have 3–4 times higher CTEs than that of an ordinary cement concrete. This may generate excessive stress, which results in material failure at the interface between the cement substrate and the polymer concrete as a repair material under an extreme temperature condition. Therefore, the material behavior in the vicinity of the repair part needs to be closely investigated under different loading and environmental conditions, including variations in the mechanical properties of the polymer concrete such as its Young's modulus and CTE [16–20]. To do this, a thermal analysis was performed to

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Table 1
Material properties according to temperature condition.

Material type	Chord modulus of elasticity [GPa]				Compressive strength [MPa]				Tensile strength [MPa]	
	−20 °C	−11 °C	25 °C	50 °C	−20 °C	−11 °C	25 °C	50 °C	−11 °C	25 °C
Cement concrete	30.18 [27]	27.84 [27]	26.02 [27]	23.42 [28]	55.96 [27]	51.02 [27]	39.55 [27]	39.55 [28]	4.07 [27]	3.04 [27]
Polymer concrete										
80:20:0	23.05^{m}	22.53^{i}	20.44^{m}	17.29^{m}	110.41^{m}	106.71^{i}	91.89^{m}	53.01^{m}	22.41^{c}	19.30^{c}
80:17:3	20.52^{m}	19.91^{i}	17.46^{m}	13.64^{m}	95.93^{m}	90.34^{i}	67.96^{m}	46.43^{m}	18.97^{c}	14.27^{c}
80:15:5	17.91^{m}	17.61^{i}	16.39^{m}	12.60^{m}	71.28^{m}	67.19^{i}	50.83^{m}	39.17^{m}	14.11^{c}	10.67^{c}

Note: Superscripts *m*, *i* and *c* represent measured data, calculated data by linear interpolation of the measured data and calculated tensile strength, respectively.

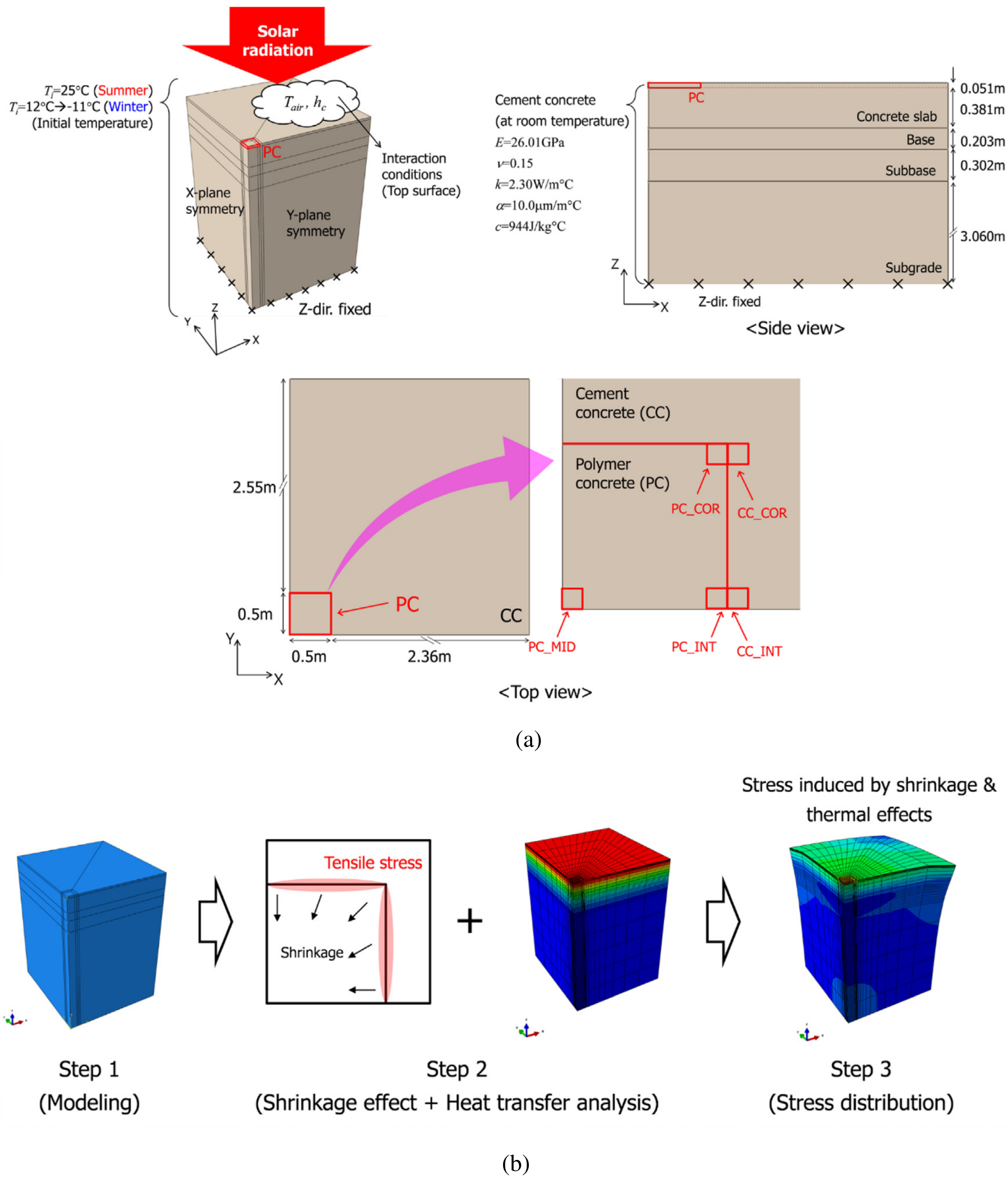

Fig. 1. Maintenance model of runway for finite element analysis: (a) structures and composition of runway and (b) analysis procedure.

determine the temperature distribution [21–25] in a pavement or runway under various climate conditions.

In this study, a stress analysis of a portion of a runway repaired using an epoxy-based polymer concrete was performed under various environmental conditions, considering the cure shrinkage of the polymer concrete and mechanical property variation due to temperature changes. Compliant polymer concretes containing silicone rubbers (3% and 5% on a weight basis) were also considered, and it was found that they considerably relieved the generated stresses.