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Mechanical durability of an optimized polymer concrete under various thermal cyclic loadings – An experimental study

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HIGHLIGHTS

- Tensile strength and mode I fracture toughness of an optimized PC is measured.
- Climate conditions in various seasons are simulated as thermal cyclic loadings.
- Effects of freeze/thaw thermal cycles are investigated on durability of PC.
- Brazilian disc and SENB specimens are used for measuring σ_t and K_{Ic}, respectively.

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ABSTRACT

Investigating the tensile strength (σ_t) and mode I fracture toughness (K_{Ic}) of polymer concrete (PC) materials due to their quasi-brittle behavior is of great interest to engineers. In this paper, the mechanical durability of an optimized epoxy PC, focused on the two above properties, are experimentally investigated under three different freeze/thaw cycles. The diametrally compressed un-cracked Brazilian disc (BD) and the single edge notch bending (SENB) test configurations are used to measure the split tensile strength and fracture toughness, respectively. The thermal cycles; 25 °C to −30 °C (cycle-A), 25 °C to 70 °C (cycle-B) and −30 °C to 70 °C (cycle-C) applied for 7 days to the test specimens; are chosen according to the climate of Iran in different seasons. Experimental results show the noticeable influence of thermal cycles, especially cycle-B, on both fracture toughness and tensile strength. Heat-to-cool thermal cycle-A and thawing thermal cycle-B indicate the most increase and reduction, respectively on both σ_t and K_{Ic} in comparison to ambient conditions. Also, it was shown that the fracture toughness and tensile strength of tested PC materials are reduced by increasing the mean temperature values of thermal cycles.

1. Introduction

Specific properties of polymer concrete (PC) materials such as high strength and low weight rather than ordinary Poland cement concretes [1,2], excellent bonding to other materials [3], ability to withstand corrosive environments and chemical attack [4], fast curing and very low permeability [5] made it a very attractive material in various industries. It has been widely used in construction industry and structural engineering applications such as bridge decking, pavement overlay, concrete crack repair [6], waste water pipe, hazardous waste containers, manholes and decorative construction panels [7]. For example as a practical application, authors have recently designed and manufactured drinking water filtration slabs for Tehran water distillation plant using PC [8]. However, it is necessary to characterize the properties of new materials (such as newly developed polymer concerts) introduced for novel applications according to the special conditions that they are encountered. Common mechanical and fracture properties such as modulus of elasticity, tensile strength, bending strength, compression strength, fracture toughness, and fracture energy have been investigated for different type of PC materials at room temperature [2,9–21]. PC is commonly composed of coarse aggregates, polyester or epoxy resin and chopped strand glass fibers. In order to develop the most economical PC, it is necessary to use minimum amount of polymer (which is the most expensive part

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of PC composition) and best method of curing since the polymer part plays the key role on the physical and mechanical properties of PC materials. Several researchers have investigated the influence of different percentage of resin used in the PC ingredients to obtain an optimum and economic PC. For example, Shokrieh et al. [2] proposed weight of resin 19%, Vipulanandan and Paul [20] used 10–20 wt% and Barbuta et al. [21] used 12.8–18.8 wt% for manufacturing an optimum PC.

The main problem of polymeric materials is related to viscoelastic properties of the polymer, which results in creep and high sensitivity to temperature. Mechanical properties of polymers, undergoing temperature variations, change considerably especially within the glass transition temperature range [22–24]. The glass transition takes place over a wide temperature range, which lies between 20 °C and 80 °C for many resins used in civil engineering. This means that the commercial and industrial polymers can experience the glass transition during their service lifetime [24]. Therefore, in addition to the above-mentioned properties, mechanical durability, defined as the ability of a structure to retain its physique-chemical properties after a mechanical damage [25], is a key function for successful using of a new material which is used in severe environments. From this point of view, most of the available investigations were performed on the mechanical durability of PC at a specific temperature or cycle [22–26]. For example, Agavriloaie et al. [22] investigated the effect of 50 frost–thaw cycles in the temperature range from $-15\,^{\circ}\mathrm{C}$ to $+20\,^{\circ}\mathrm{C}$, on the compressive strength of PC with epoxy polyurethane acryl. It had a loss of compressive strength of 11.58%. Soraru and Tassone [25] evaluated the mechanical durability and the strength degradation process of some classes of PC materials, using Vickers indentation data at various loads. Recently, the effect of temperature variations ranging from room temperature to 90 °C; was studied by Reis [19] on the flexural and compression strengths of epoxy and unsaturated polyester mortars.

In reality, a construction material is exposed to periodic environment loadings during its lifetime that can be simulated by thermal cycles [27]. Therefore, investigation of mechanical durability for these materials under freeze/thaw thermal cycles is of great interest for engineers. For example, Klemm and Marks [28] optimized the composition of PCs subjected to freezing and thawing cycles to design frost resistant PC materials. They employed two admixtures (methyl hydroxy ethyl cellulose – MHEC and polyvinyl acetate – PVA) with different percentages in the composition of PC material and experimentally obtained the values of compressive and flexural strengths after applying 300 freeze/thaw thermal cycles to the specimens. However, PC materials have shown a quasi-brittle behavior under different types of loadings such as compression and bending [2]. Therefore, it can be concluded that brittle fracture due to tensile cracking is the main cause of the overall failure of PC materials and it is important to evaluate the tensile strength (σ_t) and the fracture toughness (K_{Ic}) of this material. The available research studies that investigated the effect of thermal cycles on the fracture properties of PC materials are described here. Reis and Ferreira [29,11] studied the fracture properties of a typical fiber reinforced polymer concrete subjected to two environmental loadings, i.e., freeze/thaw thermal degradation and atmospheric exposure to evaluate only the stress intensity factor and the fracture energy. In another work [13], they evaluated the fracture properties of an epoxy concrete for two different exposures during one year, spring–summer and autumn–winter periods. The mentioned research reveal that only limited scientific works have been done on the strength properties of PC materials under thermal cycles and most of the available research papers are related to measure K_{Ic} at a constant or specific range of temperature or one specific thermal cycle. However, the deterioration of a material depends on how and to what extent it interacts with its surroundings. The environment a PC structure is exposed if considered in terms of sunshine, temperature, rainfall and wind, varies widely in duration, intensity and sequence. As far as the durability of materials is concerned, weight should be given to severe climatic conditions and depends on the confidence level required in the performance of the material, but in general it is the time-averaged climatic factors which should be considered [23].

In this study, the tensile cracking and crack growth resistance behavior of PC material is investigated experimentally under three different freeze/thaw thermal cycles (according to the weathering conditions and climate of Iran at different seasons). Using several diametrally compressed un-cracked Brazilian discs (BD) and single edge notch three-point bending (SENB) specimens made of an optimized polymer concrete, the effect of thermal cycles on both tensile strength and fracture toughness is investigated. It is shown that the amplitude and type of thermal cycles (i.e., cool-to-heat or vice versa cycles) have noticeable influences on the fracture behavior of tested PC material.

2. Experimental programs

2.1. Materials and specimen preparation

Shokrieh and his coworkers [2] have recently studied the optimum percentage of the PC ingredients to obtain the maximum bending and compressive strengths, and also the interfacial shear strength between the PC and inner surface of a steel ring. Using the Taguchi method and performing a set of experimental tests, they found the following weight percentages for an optimized composition of PC: 48.3 wt% of coarse mineral aggregate (with 4–6 mm in size), 32.2 wt% of foundry sand filler (with 0.5–1.5 mm in size), 19 wt% of epoxy resin, and 0.5 wt% of E-glass chopped fibers of length 6 mm. In this study, the same composition was used to investigate the effects of freeze/thaw cycles on the tensile strength and fracture toughness of the optimized PC material. The epoxy resin based on bisphenol *F* with a polyamine hardener was used to fabricate PC materials. The low viscosity (1450 cP at 25 °C) of this type of epoxy resin allows easy mixing and finally making an approximately homogenous mixture. The ingredients, especially sand, are attached to each other (agglomerated) if high viscosity resins are used for manufacturing the PC materials. The chopped glass fibers, sand fillers and epoxy resin with the above-mentioned weight fractions were mixed together inside a container to obtain a uniform mixture.

Several test specimens and experimental methods have been used in the past for evaluating the fracture toughness (K_{Ic}) and tensile strength (σ_t) of different quasi-brittle materials including PC materials [11,16,29–38]. A suitable test specimen should have simple geometry and testing set up. The ease of specimen preparation and convince of its testing using available apparatus are other primary requirements of a suitable test specimen. Moreover, since the PCs are among the brittle materials (i.e., weak against the tensile loads), it is preferred to test them under compressive loads rather than the direct tensile loads. Hence, the edge cracked rectangular beam subjected to symmetric three or four point bending [11,16,29], the center cracked circular disc under diametral compression [30], the edge cracked semi-circular specimen subjected to three-point bend loading [14] are some of the previously used specimens for obtaining the fracture toughness of PC materials. For estimating the tensile strength of PC materials some test specimens such as Brazilian disc (BD) specimen subjected to diametral compression [30,31], rectangular beam subjected to flexural three or four point bend loading [32,33], the split tensile test specimen [35,36], the semi-circular bend (SCB) specimen [14] have also been used by the researchers. Although the loads applied to the mentioned tensile test methods are compressive, the stresses generated at certain locations in the test specimens (i.e., middle edge of bend specimens or the center of diametrally compressed disc specimens) become tensile. Thus, at some critical level of applied load, the specimen is split due to these tensile stresses and the corresponding value of σ_t can be obtained from the available formula using the splitting load of the specimen. These methods are so called indirect tensile strength determination which is often used for estimating of σ_t value for brittle and quasi-brittle materials such as rocks, ceramics, asphalt concretes, ordinary cement concretes and polymer concretes.

In this study, the single edge notch bending (SENB) and the un-cracked circular disc subjected to diametral compression (Brazilian disc) were therefore used to obtain the fracture toughness (K_{Ic}) and tensile strength (σ_t), respectively. Fig. 1 schematically shows the geometry and loading configuration of SENB and BD test samples. Obviously, it can be seen from this figure that both specimens have simple geometry such that their preparation needs only very simple cubic and cylindrical casts. Moreover, they can be easily tested using conventional fixtures and testing machines and the type of applied loading is compressive for both specimens.