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Effect of rubber particles and steel fibers on frost resistance of roller compacted concrete in potassium acetate solution

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HIGHLIGHTS

- The frost resistance of RCC with rubber particles and steel fibers were evaluated.
- RCC will be damaged by the freeze-thaw cycles in 25% (by weight) KAc solution.
- Steel fiber and rubber particles do not improve the frost resistance of RCC.

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ABSTRACT

In this paper, the frost resistance of roller compacted concrete (RCC) mixed with rubber particles and steel fibers was investigated, 25% (by weight) potassium acetate (KAc) solution was the medium in freeze-thaw cycles. The mass loss, relative dynamic elastic modulus, microstructures, and pore structures were measured. The results show the accumulated mass loss is the greatest and up to 155.17 g/m^2 after 300 freeze-thaw cycles in KAc solution when the rubber particles and the steel fibers are added at the same time. If the later hydration of cement is not considered, the improvement effect of the steel fibers and the rubber particles on the reduction of the relative dynamic elastic modulus is also not obvious. The addition of the rubber particles and the steel fibers does not effectively reduce the cracking caused by 300 freeze-thaw cycles in KAc solution because microcracks are observed in all specimens. The incorporation of the steel fibers and the rubber particles also cannot effectively reduce the increase of porosity caused by 300 freeze-thaw cycles in KAc solution.

1. Introduction

It is estimated that 1000 million tires reach to end of life condition annually all over the world [1]. The waste tires which are mostly disposed in high volume will lead to serious environmental and health hazards if they are not properly disposed or recycled [2]. In order to solve this problem of the waste tires, the use of recycled tire rubber in concrete has been introduced as a possible alternative to conventional concrete [3]. Recycled tires can be used in concrete in three forms, rubber powder, crumb rubber (less than 6 mm in size) and rubber chips (larger than 6 mm in size). They can be partially replaced for cement, fine aggregate and coarse aggregate, respectively [4]. Several studies have been carried out to evaluate the effects of rubber in concrete [5–7]. Concrete with rubber particles showed a more ductile behavior, better impact resistance, and stronger energy dissipation than conventional concrete [8–9]. Under the same strength level, the fatigue performance of the rubber concrete was also better than that of the conventional concrete [10]. However, rubber particles have been found to reduce the mechanical properties and durability performance of concrete [11]. Al-Tayeb et al. [12] and Dong et al. [13] reported that the compressive strength decreased with the increase of crumb rubber content. Yung et al. [14], Xue and Shinozuka [15] presented the similar results for different proportions up to 20% replacement of fine aggregates by crumb rubber. Wang et al. [16] also observed that compressive strength decreased with increase in the proportion of crumb rubber when they used crumb rubber (4.75 mm) at a varying percentage up to 40% as a substitute of fine aggregates. Raffoul et al. [17] reported that strength reductions by up to 90% when sand was replaced completely, or by up to 80% when coarse aggregate was replaced by 60% of rubber. The major cause for strength reduction is attributed to the poor adhesion/bonding the hardened cement matrix.

However, Segre and Joekes [18] reported an increase in flexural strength by under-taking NaOH pre-treatment to rubber particles. In addition, large quantities of rubber may reduce significantly the workability of the mixture [17]. Kotresh et al. also reported a

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worsening of workability with an increase in slump test value of 17% for a 10% chipped tire rubber [19]. Guneyisi found the usage of crumb rubber in concrete prolonged the setting time and increased the viscosity of concrete [20]. Thus, to find an acceptable balance between the benefits and the negative effect, use of suitable rubber particles as a replacement for fine aggregate is recommended by many research studies [21–23]. Pacheco-Torres et al. [24] has reported that there was an optimal combination of size and proportion of rubber particles that improved the performance of the material under cyclic load stresses.

Fibers have been widely used for years in various civil engineering applications. The improved post-cracking tensile and flexural strength of fiber concrete lead to an increase in toughness. The main benefit of the use of fibers is the control of cracking [25]. Therefore, some research results have indicated that fibers could compensate for the reduction in mechanical properties caused by the adding of rubber particles [9,26]. Nguyen et al. [27] found the addition of rubber aggregates improved the strain capacity before macro-cracking localization and that steel fibers emphasized this trend. Alsaif et al. [28] observed that the addition of fibers in rubberized concrete mixed with waste tire rubber replacement substantially mitigated the loss in flexural strength due to the rubber content. Noaman et al. [29] found that the compression properties (compression strength, modulus of elasticity and stress-strain diagrams) showed a possible interaction between steel fiber and crumb rubber to enhance such properties of concrete. Turatsinze et al. [30] observed that the addition of steel fibers improved the flexural post-cracking behavior, while the addition of rubber (up to 30% by volume of sand) significantly increased the deflection at peak load. Ganesan et al. [31] reported a 35% increase in flexural strength when 15% of sand (by volume) was replaced with crumb rubber and 0.75% (by volume) fraction of steel fibers was added. Medina et al. [32] reported that concrete with rubber and fibers presented better compressive and flexural behavior as well as impact energy absorption than plain rubberized concrete. Therefore, a positive synergy effect on the crack resistance has been evidenced when steel fibers were used to reinforce rubberized concrete. The ductility, energy dissipation capacity [33] and elastic property [34] were significantly enhanced by the combined action of rubber particles and steel fibers. Furthermore, the combination of rubber particles and fiber reinforcement enhanced the overall behavior of the material at failure compared to conventional concrete [35].

The rubber concrete and steel fiber reinforced concrete has been studied a lot. The synergy effects of rubber particles and steel fibers on the mechanical properties also have been carried out. However, for the effects of rubber particles and steel fibers on the frost resistance of concrete, especially for concrete used for airport runway in cold area, there are still less. Roller-compacted concrete (RCC) has been used in the construction of airport runways, pavements and dams because of the lower cost and the easier placement operations [32,36,37]. RCC requires long-term stable performance when it is applied in airport runways because reconstruction causes a great impact on the air travel industry.

The objective of this paper is to evaluate the frost resistance of RCC mixed with rubber particles and steel fibers, in particular their positive synergetic effect for runway deicing fluid.

2. Experimental

2.1. Raw materials

Ordinary Portland cement (P.O.42.5) was used in this experiment. The physical and mechanical properties of cement are given in Table 1.

River sand (particle size range from 1 to 3 mm) with a specific gravity of 2650 kg/m^3 and fineness modulus of 2.55 was used as the fine aggregate. Crushed diabase (particle sizes of 5–25 mm) with a specific gravity of 2660 kg/m^3 was used as the coarse aggregate. A polycarboxylate based superplasticizer was added to obtain a desirable workability. A potassium acetate based runway deicing fluid complying with Chinese national standard was used as the freezing and thawing medium, the performance index are presented in Table 2. The crimped steel fiber and the rubber particles (particle sizes less than 4 mm) with a specific gravity of 1023 kg/m^3 were used in this study, the properties of fibers are shown in Table 3.

2.2. Fabrication and curing of specimens

The proportion of plain RCC was calculated according to GJB 1578-1992 [38]. The designed flexural strength is 5.0 MPa. The amount of water reducing agent (WR) and air entraining agent (AEA) is 2.76% and 0.0075% by cement weight, respectively. Rubber particles added into concrete often used to replace the same volume of sand, the replacement rate is 10%–20%. The addition of steel fiber is generally 1% −2% of the concrete volume. In this experiment, the volume replacement rate of the rubber particles is 10%, and the usage of the steel fiber is 1.3%. There are four groups of specimens: Plain concrete (RCC), Concrete mixed with rubber particles (RCC-R), Concrete mixed with steel fiber (RCC-F) and Concrete mixed with rubber particles and steel fibers (RCC-RF). 21 specimens with the size of 100 mm × 100 mm × 400 mm are cast in each group. The mixing proportion of RCC is shown in Table 4.

The mixing procedure of steel fiber concrete is as follows: firstly, mix cement, sand, coarse aggregate and rubber particles in a certain proportion for 2 min. Then add water with water reducing agent and mix for 1 min. And then mix for another

Table 2
Performance index of KAc solution.

Specific gravity (at 20 °C)	Freezing point[a]	pH
1.289 ± 0.015 g/cm^3	20.0 ± 4 °C	10.6 ± 0.5

[a] Measured in the aqueous solution of 50% mass fraction.

Table 3
Physical and mechanical properties of steel fiber.

Equivalent diameter/mm	Average length/mm	Aspect ratio	Tensile strength/MPa
0.75	60	80	1170

Table 1
Physical and mechanical properties of cement.

Fineness 0.08/%	Density/ $(g\cdot cm^{-3})$	Specific surface area/ $(m^2\cdot kg^{-1})$	Standard consistency/%	Stability/mm	Setting time/min		Flexural strength/MPa		Compressive strength/MPa	
					Initial setting	Final setting	3d	28d	3d	28d
0.6	3.15	349	25.8	0.5	130	195	5.8	–	29.2	–