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Influence of Barchip fiber on early-age cracking potential of high performance concrete under restrained condition

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HIGHLIGHTS

- The cracking potential of HPC reinforced with Barchip fiber was studied by TSTM.
- Barchip fibers reduced autogenous shrinkage and restrained tensile stress rate.
- Barchip fibers increased cracking age and specific tensile creep.
- The addition of Barchip fibers reduced the early-age cracking potential of HPC.

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ABSTRACT

High performance concrete (HPC), which is a new-tech concrete, has been widely applied for its good workability, lasting durability, low permeability, and high strength. However, the high temperature rise and high autogenous shrinkage induced by the low water-to-cement (w/c) ratio would increase the early-age cracking potential in HPC. In order to reduce the cracking potential of HPC, Barchip fibers are applied to strengthen the early-age properties. Although the influence of Barchip fibers on the mechanical properties of concrete has been studied, investigations on the influence of Barchip fibers on the early-age cracking potential of HPC under adiabatic condition at uniaxial constant restraint degree are still lacking. The early-age cracking potential of HPC reinforced with different amounts of Barchip fibers (0, 4, 8, and 12 kg/m^3) was tested by Temperature Stress Test Machine under adiabatic condition at full restraint degree in present study. Test results and corresponding analysis indicated that (1) the compressive strength and splitting tensile strength were enhanced by the addition of Barchip fibers in HPC; (2) Barchip fibers reduced autogenous shrinkage, restrained tensile stress rate and increased cracking age, specific tensile creep of early-age HPC; (3) the integrated criterion utilized to evaluate the cracking potential decreased first and then increased with increasing amount of Barchip fibers; (4) the optimal Barchip fiber amount of 8 kg/m^3 was recommended for that poor dispersion and fiber clumping may occur in HPC with excessive addition of Barchip fibers.

1. Introduction

Described as low porosity and discontinuous capillary pore structure of cement paste, high performance concrete (HPC) has been fully developed and put into widespread use for its good properties such as high strength, lasting durability, and low permeability by applying a low water-to-cement (w/c) ratio [1–4]. However, high temperature rise [5] and high self-desiccation [6,7] can occur in HPC at early age due to the low w/c ratio, both can increase the cracking potential of HPC [8,9]. As a result of self-desiccation, autogenous shrinkage can induce excessive distortions and even cracking of HPC at early age [10]. Cracking not only reduces the quality of concrete and makes structure out of service [11], but also intensifies the penetration of aggressive external substances into the concrete, which can accelerate other forms of concrete deterioration [12,13]. Many materials have been developed to mitigate the cracking of HPC, such as lightweight aggregates, steel fibers, and super absorbent polymers [14–17]. Fiber reinforcement, which can restrain the propagation of microcracking [18–20], is considered as one of effective ways to

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reduce the early-age cracking potential of concrete [21–27]. The type and composition of fiber influence the performance of early-age concrete. Barchip fiber, the kind of which is synthetic macro-fiber, is a new useful reinforcement material and has been widely applied in concrete [28] for its advantages such as light, high corrosion resistance, impact resistance, and fracture property [28–30]. Therefore, assessing the cracking potential of HPC reinforced with Barchip fiber at early age is necessary.

The early-age cracking potential of HPC is influenced by several factors, such as temperature history, autogenous shrinkage, restrained stress, creep, and restraint degree. The test machines of ring and doubly restrained plate are normally utilized to test the cracking potential of HPC, which are performed mostly at constant temperature [31–34]. However, the shrinkage stress calculation cannot be realized by doubly restrained plate and the restraint degree which closely related to the concrete creep cannot be kept constant in ring test [32,35]. The creep varies at constant and changeable restraint degree, and it influences the development of stress and microcracking of concrete [36]. Therefore, Temperature Stress Test Machine (TSTM), which is a uniaxial restrained shrinkage test machine modified by Kovler [35] to study the early-age cracking potential of concrete [7,37–39], enables measurements of temperature history, autogenous shrinkage, restrained stress, and tensile creep of early-age concrete at uniaxial constant restraint degree in one test [35]. The adiabatic temperature rise profile can be realized by TSTM. Test results show that the interior concrete is well isolated so that no heat escapes into surroundings; therefore the interior temperature of mass concrete is closed to adiabatic temperature rise [5,40]. The adiabatic temperature rise profile should be adopted to study the early-age cracking potential of HPC; this demand can be met by TSTM. So far, a few experimental investigations on the early-age cracking potential of HPC are carried out under adiabatic condition at uniaxial constant restraint degree by TSTM [7,14,37,39,41]. However, investigations on the early-age cracking potential of HPC reinforced with Barchip fiber under adiabatic condition at uniaxial constant restraint degree are still lacking. Therefore, the influence of Barchip fibers on the early-age cracking potential of HPC under adiabatic condition at uniaxial constant restraint degree needs to be investigated utilizing TSTM to better understand its cracking mechanism.

Tensile creep is of great importance in estimating the early-age cracking potential of HPC as it is one of the most crucial factors in evaluating the shrinkage stress accurately [36]. As a result of the restrained stress in the hardening concrete under restrained condition, early-age tensile creep can counteract the shrinkage as a stress relaxation mechanism (relaxing more than 50% shrinkage stress) [27,31]. Mechanisms of compressive creep of fiber reinforced concrete at early age and mature age have been studied [42,43], however, the viscoelastic behavior of concrete under compression differs from that under tension [36]. Limit literatures on the early-age tensile creep of fiber reinforced HPC are available for that the required measurement and interpretation are difficult to be obtained as the chemical and physical properties change simultaneously [31]. In the TSTM test, the restrained and free specimens are simultaneously tested under uniaxial non-constant tensile loading to obtain the early-age tensile creep of concrete [35]; and the real contribution of early-age tensile creep in relaxing stress can be revealed. Although a few studies have been conducted on the early-age tensile creep of fiber reinforced HPC, such as HPC reinforced with steel fiber [44,45], the creep of HPC reinforced with Barchip fiber at early age has not been systematically investigated, especially for tensile creep. Therefore, the influence of Barchip fibers on the early-age tensile creep of HPC under adiabatic condition at uniaxial constant restraint degree utilizing TSTM must be studied.

Researches on the influence of Barchip fibers on concrete properties such as compressive strength, splitting tensile strength, permeability, toughness, and crack width [28,46,47] have been conducted, however, investigations on the cracking potential of HPC reinforced with Barchip fiber at early age are still lacking. The majorities of available studies on the early-age cracking potential of fiber reinforced HPC do not simultaneously consider temperature history, autogenous shrinkage, restrained stress, and tensile creep under adiabatic condition, which greatly influence the cracking mechanism of HPC. Studying and quantifying the influence of all relevant parameters are necessary to have a comprehensive understanding of cracking potential of HPC reinforced with Barchip fiber [48]. Therefore, the influence of Barchip fibers on temperature history, autogenous shrinkage, restrained stress, tensile creep, and cracking potential under adiabatic condition at uniaxial constant restraint degree was investigated in depth by TSTM to have a thorough understanding of the early-age cracking potential of HPC in present study.

2. Experimental program

2.1. Mixture proportions and materials

In present study, four groups of concrete mixtures were applied. As shown in Table 1, the concrete mixture proportions were designed as BF-0, BF-4, BF-8, and BF-12, respectively. Mixture BF-0 was the reference group with no Barchip fibers. The amount of Barchip fibers varied from 0 to 12 kg/m^3, which had an interval of 4 kg/m^3. The Barchip fibers utilized in mixtures BF-4, BF-8, and BF-12 are shown in Fig. 1. The mixture proportions of cement, fine aggregate, coarse aggregate, and superplasticizer were remained

Table 1
Concrete mixture proportions.

Mixture composition	Concrete mixtures			
	BF-0	BF-4	BF-8	BF-12
Water (kg/m^3)	171	171	171	171
Cement (kg/m^3)	512	512	512	512
Fine aggregate (sand) (kg/m^3)	636	636	636	636
Coarse aggregate (kg/m^3)	1131	1131	1131	1131
Barchip fiber (kg/m^3)	0	4	8	12
Superplasticizer (%)	0.6	0.6	0.6	0.6

Fig. 1. The diagram of the Barchip fibers.