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Influence of high temperature on post-peak cyclic response of fly ash concrete under direct tension

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HIGHLIGHTS

- The cyclic tensile behavior of fly ash concrete in direct tension is studied.
- High temperature effect on the cyclic tensile response of fly ash concrete is considered.
- Strain rate effect on the cyclic tensile response of fly ash concrete is considered.
- The accumulation of residual strain is found independent of temperature effect.
- A cyclic constitutive model is proposed to describe the stress-strain relation.

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ABSTRACT

Few data of uniaxial cyclic tension of concrete, especially after high temperature exposure, are available due to the difficulty of testing methods. In the paper, strain rate effect and high temperature effect being considered, uniaxial monotonic and cyclic tensile tests of fly ash concrete are performed under three strain rates and four different temperatures. Experimental results show that, with the increase of temperature, tensile strength and initial modulus decrease while peak strain increases. The envelop curve of cyclic tension coincides with the monotonic curve under the same temperature. As strain rate increases, the accumulation of residual strain increases, which is independent of the high temperature effect. By means of distinguishing between temperature damage and mechanical damage, a model of cyclic behavior of fly ash concrete is proposed. According to the analysis, the nonlinearity of unloading curve is mainly dependent on strain rates while that of reloading curve is related to the temperature. The predicted model by the analytical expressions has good agreement with test data.

1. Introduction

It is well known that concrete is a widely-used construction material with many advantages, such as wide source and low cost, and it has a high compressive strength. The tensile strength of concrete, which mainly controls the cracking behavior and performs a control function in the resistance process of earthquake disaster, is, however, only about a tenth of the compressive strength [1]. Under strong earthquake, unloading and reloading of loads on concrete weaken its tensile strength, causing structures to crack and lose its load capacity, and eventually failure occurs [2].

Concrete structures are sometimes subjected to fire caused by natural factors or human activities in daily life. The weakening effect of fire on the mechanical properties of concrete is very significant. From the mid of 19th century, the study of the mechanical properties of concrete after being subjected to high temperature has gradually become the key point of the researches on the safety of concrete structures [3–5]. Studies have shown that, after the concrete is exposed to high temperature, physical reactions and chemical reactions, such as loss of moisture, dehydration of cement paste and decomposition of aggregate, will inevitably take place inside the concrete material [6]. As a result, for concrete, fire is still a potential dangerous factor to weaken the loading capacity of structure. Especially in earthquake-prone zone, fire often takes place after earthquake [7]. After the concrete is exposed to high temperature, the ability of concrete structures for the secondary earthquake resistance will be greatly weakened even if restoration and reinforcement are made. Thus researches should be taken to study the tensile properties of concrete after exposure to high temperature.

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Table 1
Concrete mix proportions by weight.

Mass of concrete ingredients (kg/m^3)					
Water	Cement	Fly Ash	Sand	Aggregate	Water Reducer
205	328	82	668	1089	2.05

Fig. 1. Instrumented concrete cylinder.

Table 2
Loading procedure under different temperatures.

Temperature	Strain rate	Loading procedure
20/200/400/600 °C	1με/s	Monotonic Loading
20/200/400/600 °C	1με/s	Cycles with constant strain increment of 200με
20/200/400/600 °C	5με/s	Monotonic Loading
20/200/400/600 °C	5με/s	Cycles with constant strain increment of 200με
20/200/400/600 °C	25με/s	Monotonic Loading
20/200/400/600 °C	25με/s	Cycles with constant strain increment of 200με

So far, there are comparatively complete researches on the degradation of compressive properties of concrete after exposure to high temperature. Studies have shown that the degradation of compressive strength is from 15% to 40% when the temperature is close to 300 °C, and the compressive strength of plain concrete at around 550 °C is only 30–45% of that at normal temperature [8,9]. Researches on the tensile properties of concrete under high temperatures are limited. Only a few researchers [10,11] have studied the split tensile behavior and flexural tensile behavior of concrete after exposure to high temperature, and obtained the influence of different temperatures on the split tensile strength and flexural tensile strength. However, due to the difficulty of testing technique, studies on the direct tensile properties of concrete are rare. Only few researchers [12–14] have studied the monotonic softening tensile response and the cyclic tensile properties of plain concrete by experiment at normal temperature. So far, there are no studies on the cyclic tensile behavior of fly ash concrete after concrete is exposed to high temperature. So the gaps in the research

Fig. 2. Specimens tested in the experiment.

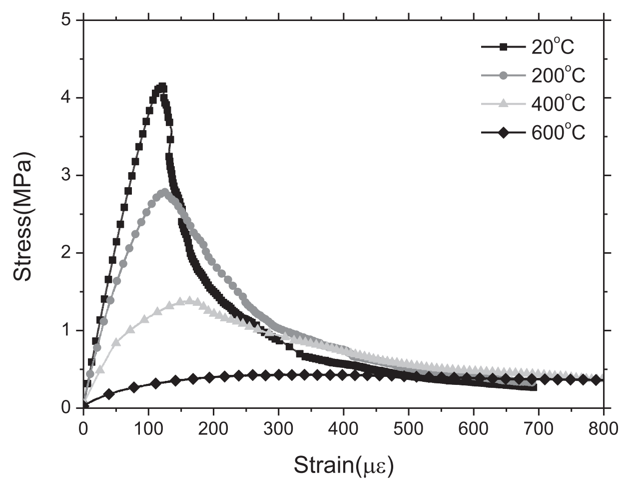

Fig. 3. Stress-strain Curves of Concrete subjected to different temperatures. under $\dot{\varepsilon} = 1\mu\varepsilon/s$.

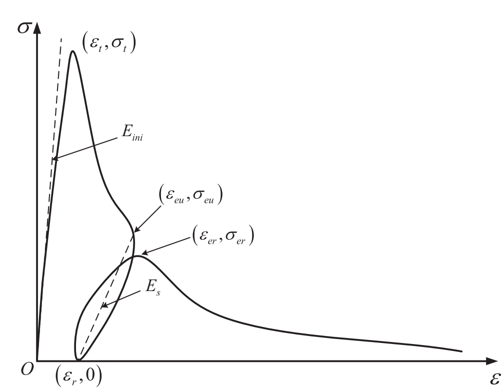

Fig. 4. Illustration of mechanical properties of fly ash concrete in cyclic tension.