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Design and verification of a testing system for strength, modulus, and creep of concrete subject to tension under controlled temperature and humidity conditions

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HIGHLIGHTS

- A device is developed to measure mechanical properties under direct tension.
- The experimental data are verified with these obtained by other well-established testing methods.
- The modified B3 model was found fit the early-age tensile creep well.
- The retardation spectrum was determined for numerical computation.

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ABSTRACT

Investigation on concrete creep under direct tension often encounters experimental difficulties. This paper describes a testing system contrived to perform the tensile strength test, elastic modulus tests and the creep tests subject to direct tension under controllable temperature and relative humidity conditions. The results are analyzed to determine their reliability. The tensile strength and modulus are compared with those obtained from indirect tensile test methods and the estimation from the code equations. Different creep predictive models are used to verify the validity of the early age tensile creep data. The basic creep data are curved fitted with modified B3 model and are characterized using Dirichlet series. Also the retardation spectrum, which presents the parameters' information of the physical model, is plotted. The data generated by this testing system had proved that the system is capable and reliable for repeated performance.

1. Introduction

Cementitious materials are weak under tension. Therefore, tensile stress development and cracking potential assessment have been one of the most critical aspects in concrete community. Characterizing the tensile creep behavior of concrete is of fundamental importance for tensile stress and cracking potential evaluations. However, most researches have been focused on measuring creep or relaxation under compression. Few literatures, in comparison, can be found on concrete tensile properties and tensile creep due to the difficulties in conducting such experiments. These studies, for example, investigated basic tensile creep response to early age loading and stress-to-strength ratio [1–4], restrained conditions [5], Pickett effect [6–8], the measurement of strength and elastic modulus under direct tension [9], and a study of the mechanism of basic creep centered on the development of micro-cracks under constant tensile loads [10].

Reliable data on concrete material properties under tension obtained from direct measurement are very valuable to engineering applications. The design of the apparatus that involves applying direct tension to concrete specimens inevitably faces the following difficulties: application difficulties such as fixation of the specimen and the measurement of very small tensile strain; the rapid and continuing devolvement of concrete material properties during the early ages; environmental factors, namely temperature and humidity, have notable influence on time dependent deformation of concrete. In addition, the phenomena of shrinkage and tensile creep coexist, and they happen in opposite directions when under tension.

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The goal of this work is to develop a test system that is capable of achieving a closed-loop control of the uniaxial tensile loading, temperature, and humidity; detecting the displacement and the stress response of the specimen. This system can be used for testing direct tensile strength, tensile elastic modulus, and early-age creep under tension in a controllable environment. The initial data regarding the direct tensile strength and the tensile elastic modulus are verified with the data obtained by other well-established testing methods. Different creep predictive models are used to verify the validity of the early age tensile creep data. In particular, the modified B3 model was used to curve fit the measured strained history, and the instantaneous tensile elastic modulus are calculated via analytical approach.

2. Testing system design

2.1. Improved equipment

The experimental system being designed in this study, as shown in Fig. 1a and b, combined a servo-electrical loading frame, an environment chamber, and a strain/displacement measuring system. The loading device was a typical closed-loop servo-electrical material test machine, but with an enlarged frame to accommodate the environment chamber. The servomotor can generate axial forces up to 55 kN and can run continuously for a month. A load cell and a linear motion system as shown in Fig. 1c provide the real time feedback of the information regarding the load and displacement of the loading arm to the control board, which would then send out a command to the servo-motor to adjust the loading arm. This algorithm allows the loading system to achieve a load controlled mode. The environment chamber, as shown in Fig. 1c, fits into the work space of the load frame, and the grips of the load frame extend into the environment chamber from the openings on the top and bottom walls of the box. The environment chamber is a primitive closed-loop system. It has a cooling compressor, a heating loop, two fans, a humidifier, and a pair of sensors that provides temperature and humidity feedback to the control board unit. The environment chamber has a temperature service range of 5–60 °C (±2 °C) and RH range of 40–95% (±5%), as well as any combination of temperature and relative humidity from the stated range. The environment chamber was mounted on a rail, as shown in Fig. 1a. If the experiment does not require the chamber, it can easily be moved away from the frame. The strain of a specimen was measured by the linear voltage displacement transducers (LVDT). Its accuracy was ±1 μm.

2.2. Specimen design

Concrete specimens used in past creep experiments under tension usually had a large length-to-thickness ratio, typically equal to or greater than three. The specimens could be prism shaped [2,4,11,12], cylindrical shaped [10,13], or a dog-bone shaped prism with enlarged end sections [3,6,7].

The specimen design of the current study took notice of the successful elements of various specimen shapes from the literature. Fig. 2 illustrates the specimen geometry. It was a spindle-shaped cylinder: 400 mm in over-all length, 250 mm for the reduced section plus the tapered transition. The taper on the neck of the molds were sloped to 45°, and the edges were rounded. The gauge length used for strain measurement was 200 mm in the middle section of the specimen. The rationale was that the reduced section would ensure that fracture occurs within the gage length; and the circular cross-sectional area reduces the stress concentration that would otherwise be found at the edges of the prism. A ϕ 16 threaded shaft was anchored in either ends of the enlarged sections. Tensile load was applied through these shafts. The specimens were cast by using a set of molds, each consists of acrylic tubes nested in the split-tube steel mold. The steel mold aligned the pair of shafts co-axially as shown in Fig. 2a. The specimen was designed to be used in various tests: creep tests, strength tests, and elastic modulus tests.

3. Experimental

3.1. Materials and mixture proportions

Table 1 presents the mixture proportions used in this study. Ordinary Portland cement (OPC) was used. Crushed limestone with maximum grain size of 10 mm was used as coarse aggregate. The fine aggregate was natural sand with fineness

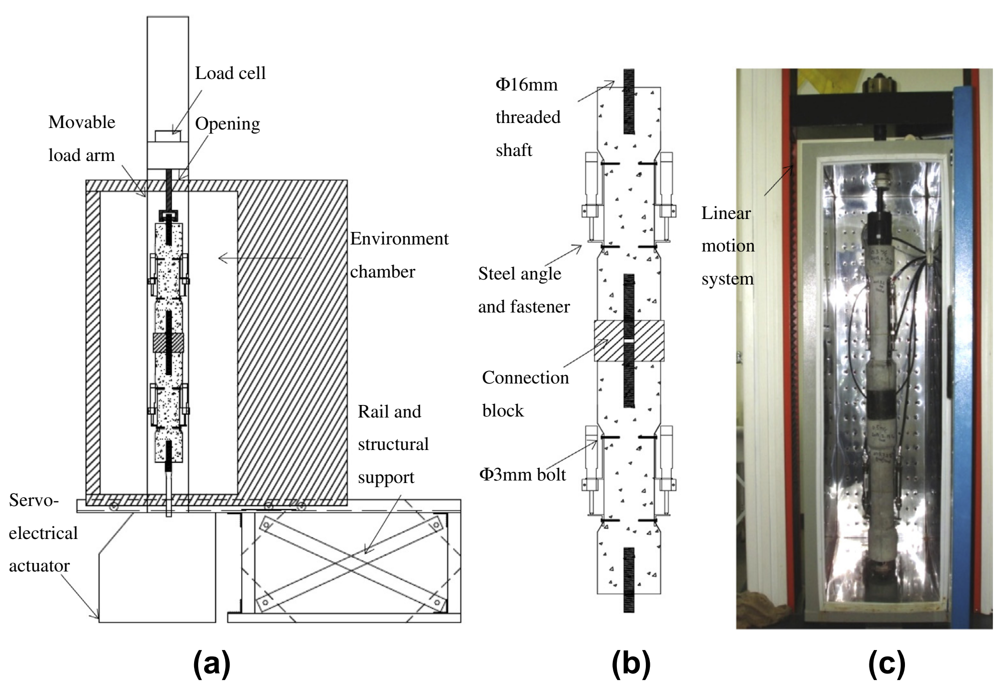

Fig. 1. Testing system: (a) side-view of the testing apparatus assembly; (b) connection of specimens and transducers; and (c) specimens placed in the environment chamber for creep test.