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Using digital image correlation to evaluate plastic shrinkage cracking in cement-based materials

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HIGHLIGHTS

- DIC is applied to evaluate the behavior of plastic shrinkage cracking.
- DIC combined with crack area increases the understanding of the cracking process.
- DIC provides information to evaluate the risk of plastic shrinkage cracking.

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ABSTRACT

Fresh concrete exposed to a drying environment is susceptible to plastic shrinkage cracking, which can result in negative impacts on concrete durability. In the current ASTM standard, plastic shrinkage cracking is evaluated by the average crack width measured at 24 h after concrete placement, considering that the traditional crack measurement tools cannot be used on fresh concrete. In this work, a non-contact strain measurement technique based on digital image correlation (DIC) was applied to study the behavior of plastic shrinkage cracking. The crack areas were also determined by image analysis using MATLAB functions. It was found that DIC can provide a series of strain contour maps that help to understand the process of plastic shrinkage cracking. The effects of air temperature, w/c, and substrate roughness were well explained by both DIC analysis results and crack areas computed in MATLAB.

1. Introduction

Plastic shrinkage mainly results from a rapid surface drying when the water evaporation rate exceeds the bleeding rate of concrete before final set [1]. The cracking occurs when air starts to penetrate the gaps between the solid particles, and the tensile stress developed by restrained shrinkage is beyond the low tensile strength capacity of fresh concrete [2]. Thus, aggressive agents may have the access to the embedded reinforcing steel through surface cracking, leading to the corrosion of the reinforcing steel which causes possible further cracking and spalling in concrete structures [3]. Recent research has been focusing on investigating plastic shrinkage cracking to improve the performance and durability of concrete materials.

Plastic shrinkage cracking has been evaluated under a variety of restrained conditions, including ring tests [4], longitudinal tests [5–7], slab tests [8–11], and substrate restraint tests [3,12–18]. The quantification of cracking in such tests is based on measuring the crack dimensions in hardened concrete specimens, such as the average crack width, total crack length, and crack area, and recording the cracking process, such as the number of cracks at different points in time throughout the cracking process and the time to first crack [19].

In 2006, ASTM Standard C1579 [20] was introduced, which was intended to compare plastic shrinkage cracking behavior in concrete mixtures with different types of fibers [21] or admixtures [21,22]. Considering the traditional crack measurement tools, such as optical hand-held microscope or crack comparator, which may disturb the cracking process in fresh concrete, the crack widths in ASTM standard C1579 are measured at 24 h after starting the experiment when concrete is considered stable. However, to accurately evaluate plastic shrinkage cracking in concrete materials, the formation of plastic shrinkage cracking and the cracking process should be recorded and analyzed [23].

In recent years, image analysis has been widely applied to assess plastic shrinkage cracking due to its non-contact manner, reliable results, high precision, and efficiency [3,24]. Digital image correlation (DIC) is an image analysis technique, which can take full-field strain measurements on an object surface. DIC has been

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successfully applied to analyze the cracking propagation in hardened concrete [25–28], and it can provide accurate and detailed information [29].

2. Significance of research

This paper describes how DIC is applied to evaluate the behavior of plastic shrinkage cracking. The DIC analysis results combined with the crack area obtained by image analysis can produce a more comprehensive understanding of the process of plastic shrinkage cracking. Researchers can benefit from the detailed information that DIC provides when evaluating the risk of plastic shrinkage cracking in cement-based materials.

3. Experimental program

3.1. Specimen geometry and environmental conditions

A plastic form was adopted from Wang et al. [30], which had a surface area of 179 × 137 mm, and a depth of 6 mm. A piece of waterproof sandpaper was attached to the bottom of the form using double-sided tape. Different grits of sandpaper were used to investigate restraint.

An environmental chamber was fabricated to provide a hot, dry, and windy environment, as shown in Fig. 1. A three-speed fan and two small space heaters were used to control wind velocity and temperature, respectively. The relative humidity changes were a result of changes in air temperature. Air temperature, relative humidity, and wind velocity were measured at an elevation about 10 cm above the specimen surface by a Kestrel 4300 construction weather tracker. Cement paste surface temperature was monitored by an infrared thermometer.

3.2. Materials and specimen preparation

The cement paste used in this work was made up of water and commercially available Type GU Portland cement. The cement was stored in laboratory conditions at least 24 h before use. The water temperature was controlled at 30 °C. Cement and water were mixed for 30 s by an electrical mixer conforming to ASTM Standard C305-14 [31]. The cement paste was cast into the form immediately after mixing. A straightedge was used to level the surface of the cement paste specimen for 3 times. After that, a white spray paint was applied onto the cement paste surface to create a unique speckle pattern for DIC analysis. To ensure that the influence of the speckle pattern on the water evaporation rate of the cement paste specimen is consistent, the percentage of the speckle pattern coverage in the beginning of the experiment was determined for each cement paste specimen by image analysis using MATLAB functions. The specimen was then placed in the environmental chamber.

4. Image analysis procedures

Two image analysis techniques were used to evaluate the behavior of plastic shrinkage cracking in cement-based materials in this work. One method utilized processing of photographic images to determine crack area; the other method, DIC, involved tracking of paint speckles to determine strain. Unlike the single crack formed at a specified location and orientation with ASTM C 1579, cracking occurs in a random pattern in this work. For this reason, crack widths are not deemed an appropriate quantitative measure. As well, DIC cannot measure the crack widths [29].

A digital single-lens reflex camera (Canon EOS 5D) with a standard 50 mm prime lens was used in this work, which can provide a resolution of approximately 12.8 megapixels. During experiments, the camera was fixed to a copy stand approximately 46 cm above

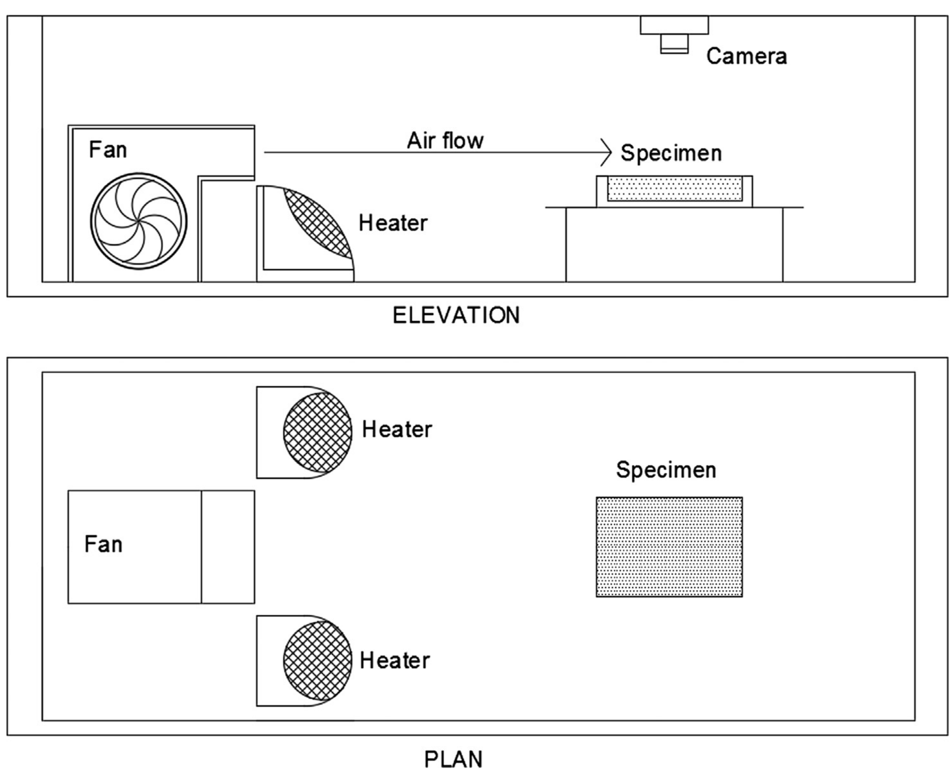

Fig. 1. Diagram of test setup (not drawn to scale).