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Restrained shrinkage behavior of expansive mortar at early ages

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HIGHLIGHTS

- We examined about cracking restraint of expansive mortar by dual ring-test.
- The reduction of shrinkages on the addition of expansive additives was confirmed.
- The cracking potential of expansive mortar develops lower rate than normal mortar.
- The expansive mortar showed substantial stress relaxation.
- The expansive mortar could reduce the degree of restraint under the same restraint condition.

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ABSTRACT

The purpose of this study was to qualitatively assess the shrinkage reduction and cracking restraint of expansive additives under various restraint conditions. The reduction of drying and autogenous shrinkages on the addition of expansive additives was confirmed. The results of a ring test performed to determine restrained shrinkage indicated that at the same age, the cracking potential of expansive mortar based on the stress/strength ratio remained lower than that of normal mortar, which confirmed that the generation of compressive stress at an early age reduced the restrained stress and restrained cracking. From the time that cracking occurred, the expansive mortar showed substantial stress relaxation, reducing the tensile stress caused by the interface restraint load. Moreover, the use of expansive additives could reduce the degree of restraint under the same restraint condition, preventing the occurrence of cracking due to shrinkage.

1. Introduction

In hardened cement paste, volume changes caused by shrinkage is restrained by reinforcing bars, aggregates, and molds. The restrained stress produced by these restraining measures causes early cracking, which decreases the durability and lifetime of the structure. The initial cracking behavior is very complex because of not only the manifestation rate and size of the shrinkage of the hardened cement paste as it ages but also other factors such as strength development, degree of restraint, stress relaxation, age, and shape of the structure.

According to Altoubat and Lange [1], tensile creep relaxes approximately 50% of the shrinkage stress generated on hardened concrete, and See et al. [2] experimentally confirmed that approximately 50% of the entire free shrinkage corresponds to the tensile creep. However, existing tests of the free shrinkage have failed to assess the changes in the stress and degree of restraint produced by strength development and have been unable to assess shrinkage cracking risks and cracking behavior. In particular, when an expansive additive is added to reduce shrinkage, compressive stress is generated because of expansion at an early age under a certain restraint condition; the use of the expansive additive improves shrinkage reduction and resistance against cracking as a compensation for the shrinkage that is expected to occur subsequently. Therefore, when an expansive additive is applied to an actual structure, the effect of the additive is controlled by its expansion rate, which is determined by various restraint conditions of the structure, including the ground, foundation, columns, and beams. Therefore, a restrained shrinkage test and an assessment of the dynamic characteristics of restrained

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shrinkage should be carried out to determine the expansion and shrinkage behavior of an expansive additive.

Since the 1980s, various studies have been performed to assess the restraint and shrinkage behavior of concrete in relation to the cracking caused by shrinkage. The test method used in these studies evaluates the resistivity against cracking by restraining the shrinkage of the concrete. However, it fails to fully restrain the concrete at an early age, when its strength is low. The ring-type restraint test, in which the concrete is deposited in a steel ring, solves this problem because the restraint is imposed immediately after the concrete is deposited. By performing a ring test, Hossain and Weiss [3] found that drying shrinkage occurs evenly in the concrete ring. They also estimated the elastic shrinkage stress by assuming that the concrete ring shows an elastic behavior. Moreover, they assessed the residual stress generated in the concrete by measuring the strain on the inner steel ring. Moon and Weiss [4] used a ring test to assess the restraint and shrinkage behavior under various restraint conditions. They considered various levels of relative humidity, which changes depending on the position of the cross section of the concrete ring, while calculating the free shrinkage strain rate and proposed revisions to the estimation equations developed in previous studies in order to consider the changes in stress in the cross section because of differential drying shrinkage.

In this study, we performed ring tests to qualitatively assess the shrinkage reduction and cracking restraint of expansive additives under various restraint conditions. Simultaneously, we performed free shrinkage and tensile strength tests on specimens having the same cross section under the same exposure condition. Then, we carried out a comprehensive investigation to determine the shrinkage cracking probability, stress relaxation, and degree of restraint.

2. Experiment

2.1. Outline of experiment

In the experiment, two types of specimens with a water/binder ratio of 0.50 were used: (1) an expansive mortar specimen with a fine aggregate to binder ratio of 1:3, in which 5% of an ettringite–gypsum expansive additive was mixed, and (2) a normal mortar specimen. To determine the fresh properties of the specimens, air content and slump flow tests were performed immediately after mortar deposition. To perform strength tests, specimens were de-molded on day 1 and dried in a constant temperature and humidity chamber (temperature: 20 ± 2 °C, humidity: 60 ± 5%), after which their compressive and splitting tensile strengths were measured at predetermined ages.

2.2. Unrestrained shrinkage test

In the unrestrained shrinkage test, a 40 × 40 × 160 mm mold was used to measure the autogenous and drying shrinkages using an embedded strain gage. The autogenous shrinkage specimens were covered with Teflon and plastic sheets to prevent the evaporation of moisture because of the restraint and drying. They were de-molded on day 1 and sealed completely using aluminum tape. The drying shrinkage specimens were de-molded after a day, and a portion of each specimen was completely sealed using aluminum tape to match the volume/surface area ratio (*V/S*) used in the ring-type restraint test. They were then left in the constant temperature and humidity chamber to dry (temperature: 20 ± 2 °C, humidity: 60 ± 5%).

2.3. Restrained shrinkage test

Fig. 1 shows an overview of the ring-type restraint test. Based on the procedures for the ring-type restraint test suggested by AASHTO PP34-98 [5] and existing studies [3,4,6,7], we performed tests using dual ring-type restraint specimens with four levels—A, B, C, and D—to assess the shrinkage, restrained stress, and cracking characteristics under various restraint conditions such as different inner and outer thicknesses of the steel rings and different mortar diameters. To induce even drying shrinkage in the cross sections of the mortar rings, the height of the ring-type restraint specimen was chosen as 75 mm instead of the 152 mm suggested by AASHTO PP34-98 [5], and the bottom wooden panels were covered with Teflon

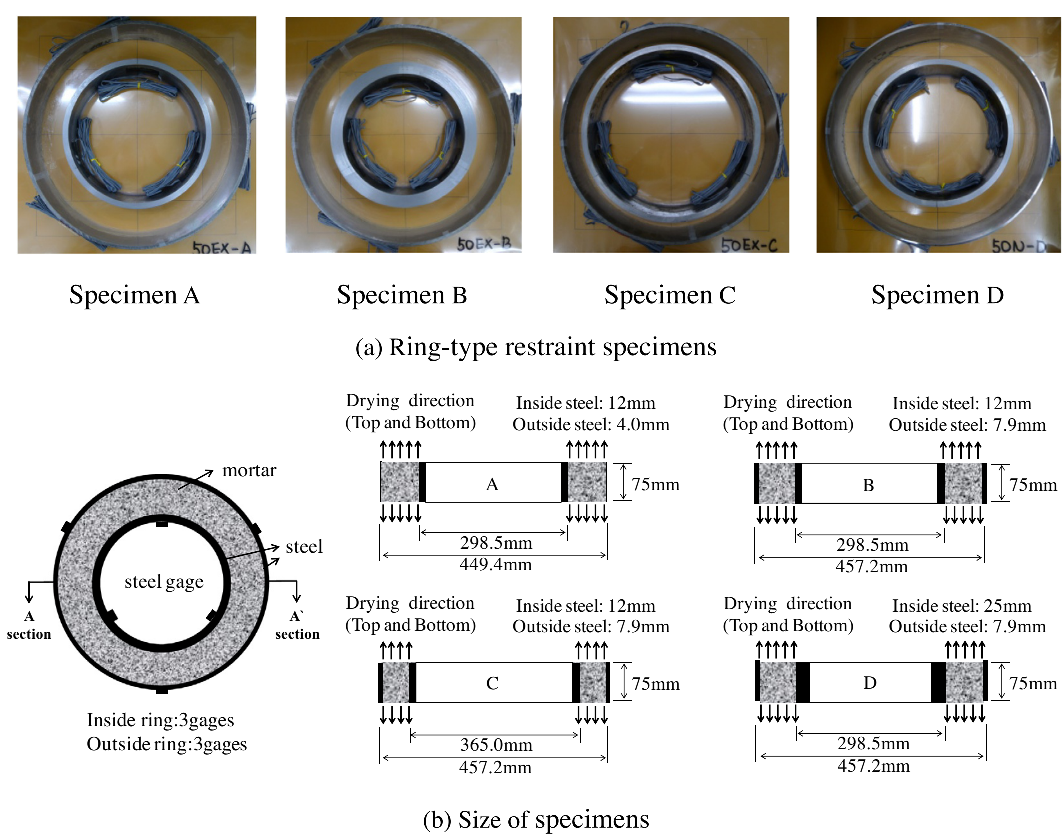

Fig. 1. Overview of the ring-type restraint test.