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A prediction approach of concrete properties at early ages by using a thermal stress device

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HIGHLIGHTS

- We proposed a prediction approach of concrete properties at early ages.
- Many properties, which influence stress prediction, can be predicted by the approach.
- The results of prediction depended on the experimental data.
- All properties were predicted within a 10% error range.

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ABSTRACT

The material properties of concrete are greatly influenced by age, temperature, humidity and loading history, particularly at early ages. However, concrete properties are often predicted using prediction models or a few experiments at a construction site, which can not consider these influential factors, causing a great difference between actual and predicted properties. This paper presents an approach to predict various concrete properties with simple laboratory experiments to minimize the differences in the concrete properties due to the curing conditions. In this approach, the concrete properties were determined by comparing the experimental data with the analytical results. The thermal expansion coefficient, elastic modulus, autogenous shrinkage, and creep coefficient were predicted by optimizing the equations of each material property. In addition, the predicted concrete properties were verified with those obtained from various experiments for elastic modulus, autogenous shrinkage and stress-independent strain. The elastic modulus, autogenous shrinkage, and stress-independent strain were mostly predicted within a 10% error range. Therefore, this study confirms that the proposed approach can be used to predict concrete properties at early ages, that are greatly influenced by various factors.

1. Introduction

Concrete properties such as strength, elastic modulus, shrinkage, and creep are influenced by age, temperature, humidity, and loading history [1–4]. This effect is especially noticeable at early ages during which the hydration reaction rapidly occurs. Therefore, accurate prediction of concrete properties at early ages is necessary for the stress analysis of mass concrete structures [5–7].

Numerous studies have been carried out to predict the concrete properties at early ages and led to development of a large number of theoretical and experimental approaches [8–15]. Among the theoretical approaches, the most widely used method is maturity or equivalent age as proposed by McIntosh [8], Nurse [9], and Saul [10]. The maturity method was first proposed to predict concrete strength considering various curing temperatures, and then it was improved to predict various concrete properties such as elastic modulus and autogenous shrinkage, using Arrhenius equations [11,12]. However, the maturity functions based on Arrhenius equations require activation energy and properties at 28 days, which should be evaluated by several experiments. Experimental approaches were also developed to predict creep, tensile strength, autogenous shrinkage, etc. [13–15]. However, with these experimental approaches, since the experiment is performed at a constant temperature, the predicted concrete properties need to be corrected by considering the curing conditions of the actual structures. Moreover, it is necessary to carry out experiments for each concrete property. Therefore, it is not economical

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to conduct experiments considering all these conditions at a construction site.

Due to the difficulty in predicting concrete properties at early ages, previous studies developed a device (referred to here as a thermal stress device) capable of measuring thermal stresses in concrete specimens experimentally without evaluating the concrete properties and a prediction approach to thermal stresses in mass concrete structures by comparing the degree of restraints [16,17]. However, such an approach has a limitation in that the effect of creep can not be precisely considered because the degree of restraint changes with time due to a change in concrete rigidity.

In this paper, a new approach to predict the concrete properties at early ages is proposed. In this approach, experiments were conducted using a thermal stress device to measure thermal stresses in concrete specimens. The concrete properties, then, were determined by comparing experimental and analytical stresses. Many model equations, which are expressed as a function of time, have been proposed [18–22]. These model equations need to be calibrated by fitting the data obtained from the experiments for an accurate prediction [19]. Therefore, concrete properties were determined by optimizing the parameters of the model equations in the proposed approach. The predicted concrete properties were also verified with those obtained from experiments for elastic modulus, autogenous shrinkage, and stress-independent strain.

2. Prediction approach of concrete properties

2.1. Introduction

The analysis of mass concrete structures can be divided into heat transfer analysis and stress analysis including strain analysis. Each analysis requires different concrete properties. As shown in Fig. 1, concrete properties used in heat transfer analysis are heat generation, heat conductivity, specific heat, unit weight, and convection coefficient. Except for heat generation, it is possible to assume constant values because they vary less with age [23,24]. Many studies on the properties used in the analysis have focused on the prediction of heat generation, because the accuracy of the heat transfer analysis greatly depends on the accuracy of the predicted heat generation [25,26]. In particular, an adiabatic temperature rise test is the most representative test to accurately predict the heat generation of concrete [27]. The adiabatic temperature rise test can be performed without difficulty, so the temperature in mass concrete structures can be accurately predicted through the test and the heat transfer analysis. On the other hand, the thermal expansion coefficient, shrinkage, elastic modulus and creep of concrete, which are used in the stress analysis, change not only with age but also with curing conditions such as temperature and humidity. Therefore, they should be precisely predicted according to age and curing conditions.

This study developed a prediction approach of the concrete properties used in the stress analysis considering changes in concrete properties with age and curing conditions. The proposed approach predicts all the properties required for the stress prediction by comparing the measured stresses obtained from simple laboratory experiments with the predicted stresses obtained from the stress analysis. Therefore, the proposed approach can be easily utilized at a construction site where various experimental facilities are not provided. For this purpose, the thermal stress device developed by the Concrete laboratory at KAIST [17] was slightly modified and used in the experiments of thermal stresses.

2.2. Experiment by a thermal stress device

To accurately predict concrete properties by the proposed approach, the experiments should be conducted under the same conditions as those in the concrete structures. Experiments can be conducted under the same curing conditions as the structures by using a thermal stress device [17]. In addition, it is possible to simulate the restraint conditions of concrete at the surface and inside the concrete structures as well as to simulate the various degrees of restraints by changing the type and thickness of the constraint plates.

The thermal stress device was modified from the original one [17] to minimize the measurement errors, as shown in Fig. 2. No bolt connections were used to remove the slippage of the main frame and constraint plates, but they were welded together. In addition, a dummy specimen for measuring only strain induced by temperature change was added to minimize errors due to the temperature compensation of the strain gauge. The device and dummy specimen were made of invar or aluminum. Electrical strain gauges were attached by M-bond 610 to measure the strains of the device and dummy specimen. J2A-00-S074N-350 and J2A-13-S074N-350 were used as electrical strain gauges for the invar and aluminum respectively.

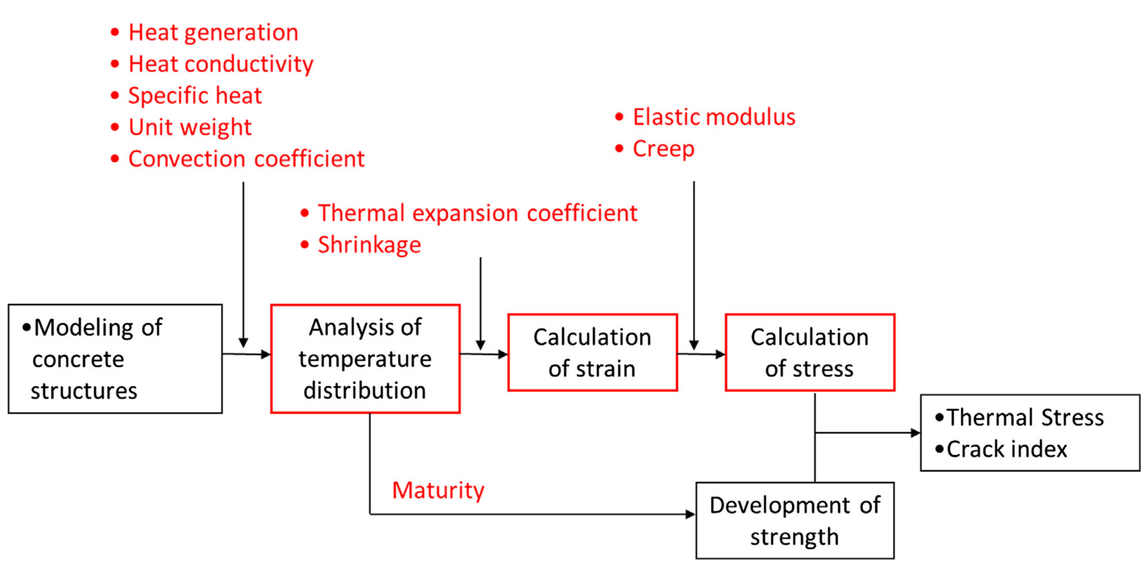

Fig. 1. Analysis procedure of mass concrete structures.