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Prediction of early-age compressive strength of epoxy resin concrete using the maturity method

Nan Ji Jin [a], Inbae Seung [b], Yoon Sang Choi [c], Jaeheum Yeon [d,*]

[a] Dongil Engineering Consultants Co., Ltd., Seoul 05800, Republic of Korea
[b] Beomjun Engineering & Construction, Seoul 06754, Republic of Korea
[c] Korea Conformity Laboratories, Pocheon 11181, Republic of Korea
[d] Department of Engineering & Technology, Texas A&M University-Commerce, Commerce, TX 75429-3011, USA

HIGHLIGHTS

- This study was used bisphenol F-type epoxy resin concrete.
- The compressive strength of polymer concrete was predicted using the maturity method.
- Curing temperature had a greater effect on the maturity index than curing age.
- The constant n associated with hardeners were investigated to use Ohama's equation.
- An appropriate model was presented to predict early-age compressive strength up to 72 h.

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ABSTRACT

This study is investigated with the prediction of the compressive strength of early-age bisphenol F-type epoxy resin concrete when using the maturity method. When testing the compressive strength of epoxy resin concrete, the strength development started from an age of 20 h at a curing temperature of 0 °C, and the difference between the compressive strengths at the ages of 6 h and 168 h was markedly reduced at a higher curing temperature. Thus, it appeared that the bisphenol F-type epoxy resin concrete was heavily affected by curing temperature. In addition, there were significant differences in strength development based on the hardener type. When calculating the maturity index, it was appropriate to use data up to the age of 72 h, and it appeared that the appropriate value of the constant n is 0.4 in the equation proposed by Ohama, et al. The maturity index was more heavily affected by curing temperature than curing age, and there was a significant difference depending on the hardener type. This study reviewed three prediction models, and when using the dose-response curve model, the coefficient of determination (R^2) was the largest, so this is the model that should be used. Although it is possible to apply this model differently based on the hardener type, it was determined that there would be no problem even if a prediction model combining all the test data on the three hardeners was used. In conclusion, when using the prediction model deduced in the study, it was possible to easily predict the early-age compressive strength of bisphenol F-type epoxy resin concrete, and to prove that the maturity method is a non-destructive test useful for cast-in-place applications.

1. Introduction

Polymer concrete is a composite material made of inorganic aggregates and organic polymer resin, and has the characteristics of rapid hardening and high strength. In addition, it is superior to other portland cement concretes in terms of chemical resistance, abrasion resistance, water resistance, and adhesive properties [1,2].

However, liquid resins used as a polymeric binder also have shortcomings: they are expensive, tend to have high hardening shrinkages, and their high viscosity makes workability difficult. For the polymeric binders, thermosetting resins are widely used, including epoxy resins, unsaturated polyester resins, and acrylic resins.

Among these, epoxy resins have been produced commercially across the world since the 1950s, and they are currently widely

* Corresponding author.
E-mail address: jyeon81@tamu.edu (J. Yeon).

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used for construction. They are two-component binders made of a main ingredient and a hardener. Therefore, they have different properties in terms of hardening reactions compared with the three-component types made of a main ingredient, an initiator, and a promotor, such as unsaturated polyester resins. In other words, unsaturated polyester resins can control the hardening time with the promotor and the curing temperature, but epoxy resins can only adjust the hardening speed with the curing temperature.

Most epoxy resins used for concrete in the construction industry are of bisphenol A-type, which have a high viscosity, making workability difficult. It is possible to use a thinner to reduce the viscosity, but this degrades the physicochemical performance.

This study used a bisphenol F-type resin instead of bisphenol A-type resins as the binder. This resin has a lower viscosity than bisphenol A-type resins, making it possible to ensure good workability without adding a thinner such as a solvent, and making it unnecessary to worry about degraded mechanical properties owing to the thinner. In addition, it is superior to bisphenol A-type resins in terms of wet endurance and abrasion resistance [3].

Accordingly, this study attempts to find the properties of compressive strength development of bisphenol F-type epoxy resin concrete for each hardener type, and determine a compressive strength prediction model based on the maturity method.

The maturity method is a technique to account for the combined effects of time and temperature on the strength development of concrete [4]. The origin of the method can be traced back to work on the steam curing of concrete carried out in England in the late 1940s and early 1950s [5].

The maturity method has been used to estimate the strength of concretes, as well as to determine the optimal time to remove forms [6]. Moreover, the method can be used effectively to determine the time to cut joints or to open a road to traffic when laying new pavement or repairing existing concrete pavement. In particular, since polymer concretes tend to show notably fast development of initial strength, it is very important to predict the strength at an early age.

Until now, there has been a relatively large amount of studies on maturity methods for portland cement concrete. Typical studies are concentrated around predicting the early-age strength [7–11], and there have been some studies on estimating the in-place strength of large concrete placements [12,13].

By comparison, it is very difficult to find any study applying the maturity method to the prediction of strength development in polymer concrete. There has been some research on unsaturated polyester polymer concretes [14], but no study could be found on bisphenol F-type epoxy resin concrete, as targeted in this study.

Based on the above points, this study attempts to find the characteristics of strength development in bisphenol F-type epoxy resin concrete for each hardener type as well as a prediction model for early-age compressive strength using the maturity method.

2. Background

2.1. Maturity index

The maturity theory, closely related to the strength development of portland cement concrete, was proposed by Saul [15] in 1951, and elaborated by Bergström [16] in 1953. Saul calculated the maturity index based on datum temperature, the lowest temperature at which strength development can occur. This equation, the Nurse-Saul maturity function, is as follows [5,11]:

$$M = \sum (T - T_o)\,\Delta t \qquad (1)$$

where,

M = maturity index, °C·hrs (or °C·days),
T = average concrete temperature, °C, during the time interval Δt
T_0 = datum temperature (usually taken to be −10 °C)
t = elapsed time, hrs (or days), and
Δt = time interval, hrs (or days)

In the case of portland cement concrete, the theory is based on the fact that strength and maturity have a certain relationship, and that even if there are some differences in curing temperature and curing time, there will be no difference in strength if the maturity is identical.

However, polymer concretes, which use thermosetting resins as binders, show conspicuous differences from portland cement concretes in terms of reaction processes, hardening hours, and strength development speed, thus making it difficult to apply the maturity theory for portland cement concrete as it is. Above all, as polymer concretes tend to show faster strength development, and have a particularly high rate of strength development within 24 h, it is necessary to reduce the influence of Δt used in calculating the maturity index of portland cement concretes. As one of the solutions to the problem, Ohama, et al. [14] proposed to use Eq. (2) in calculating the maturity index by replacing Δt with Δt^n from Eq. (1). Here, since polymer concretes tend to have a shorter hardening duration than portland cement concretes, hours instead of days will be used as the unit of age. In addition, although $n = 1$ can be applied in the case of portland cement concrete, polymer concrete has faster strength development, making it necessary to use a smaller value which must be calculated separately.

$$M = \sum (T - T_o)\,\Delta t^n \qquad (2)$$

where,

M = maturity index (°C hrs)
T = average curing temperature during the time interval Δt (°C)
T_0 = datum temperature (°C)
t = elapsed time (hrs)
Δt = time interval (hrs), and
n = constant

2.2. Strength–maturity relationship

To inquire about the relationship between compressive strength and maturity of epoxy resin concrete, this study applied the following three models evaluated as having high applicability among various prediction models: logarithmic equation, logistic curve, and dose-response curve.

2.2.1. Logarithmic equation

This equation was proposed based on a hypothesis that when expressing the strength with a logarithmic function of the maturity using the Nurse-Saul equation, it would approach a straight line. It was proposed by Plowman [17] in the 1950s, and is widely used as a common equation since this simple equation has only two constants to determine.

$$f_c = a + b\ln(M) \qquad (3)$$

where,

f_c = compressive strength (MPa)
M = maturity index (°C·hrs or °C·days)
a, b = parameters

2.2.2. Logistic curve

The logistic curve [18] is used to express population growth as a mathematical model. It was proposed by Verhulst in 1838 and