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Prediction of the curing time to achieve maturity of the nano cement based concrete using the Weibull distribution model

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HIGHLIGHTS

- Fabrication of the nano cement based concrete.
- Effectiveness of the nano cement based concrete in building construction.
- Prediction of the maturity of the nano cement based concrete.
- Prediction of the rate of change of compressive strength with curing time.
- Assessment of the maturity time using weibull distribution model (99% confidence).

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ABSTRACT

The present investigation deals with the optimization of the curing time using the Weibull distribution model, analyzing the rate of change of compressive strength of the nano cement based concrete. In this investigation, the nano cement was synthesized by sol–gel method using nano silica and hydrated alumina. Additionally, nano cement based concrete was fabricated varying the aggregate and alkali activator content. After measuring the compressive strength of the concrete at four desired curing times viz., 3, 7, 14 and 28 days, the required curing time to achieve a particular rate of change of the compressive strength has been predicted utilizing the equation derived from the variation of the rate of change of compressive strength with the curing time, prior to the optimization of the curing time (at the 99.99% confidence level) using the Weibull distribution model. Results revealed that the required curing time to achieve complete maturity of the nano cement based concrete is ~21 days, while for Portland cement, it is 28 days. Therefore, it can be assessed that the required time for building construction would be less considering the nano cement as a primary binding material instead of Portland cement.

1. Introduction

Curing is the most essential factor for the development of strength and durability of concrete. Usually, curing of the concrete is necessary to perform anticipated functions over the design life of the structure. However, excessive curing time may lead to the escalation of construction cost of the venture and unnecessary delay the construction process. Therefore, a standardized plan is required to be established for the curing of concrete. Curing of concrete can be started immediately after concrete placing and finishing. Most commonly, curing is a process which controls the extent of moisture loss from the concrete during the cement hydration reaction [1]. It occurs due to a series of chemical reactions among the chemical constituents (viz., dicalcium silicate (C_2S), tricalcium silicate (C_3S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrate (C_4AF)) of the cement and water. The rate of reactions controls the properties and performances of the hardened concrete such as strength, permeability, durability, abrasion resistance and resistance to freezing and thawing [2]. As long as the water will present in the cement system, the hydration will be continued [3]. Actually, the curing procedure controls desired moisture and temperature conditions of the bulk and surface of the concrete for an extended period of time. A properly cured concrete must contain an adequate amount of moisture to continue the hydration reaction, which encourages to develop strength, volume stability, freezing and thawing resistivity, etc., of the concrete [1]. In order to obtain a good quality concrete, the curing step must have to follow under a suitable environmental condition in the early stages of hardening [4,5]. Various processes and conditions have been adopted for the curing of concrete to yield adequate strength [6]).

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Usually, the strength of concrete increases with the increase in curing time under a specific condition. Few researchers attempted to estimate the strength of concrete cured in different conditions. Neelakantan et al. [6] reported that the conduction based curing performs better in prediction of 28-day strength using multiple linear or exponential regression models with higher accuracy as compared to that of the microwave based curing. Excluding the traditional modeling, which is based on empirical relations and experimental data [7], certain approaches using regression functions were proposed by Snell et al., Oluokun et al. and Popovics [8–10] to predict the concrete strength at a particular curing time. Some smart modeling systems utilizing artificial neural network [11,12] and support vector mechanics [13] were also developed to predict the concrete compressive strength at a specified curing time. However, the ACI committee recommended that the length of the concrete curing could be depended on the various factors such as mixture proportions, specified strength, size and shape of concrete member, ambient weather conditions, and future exposure conditions. It is reported in the ACI Committee 301 [14] that the minimum curing period of a particular concrete is the time at which 70% of the specified strength will be attained. Additionally, ACI Committee 308 [15] recommended that different types of cement take different times to cure completely. Accordingly, ASTM C 150 Type I cement, ASTM C 150 Type II, ASTM C 150 Type III, ASTM C 150 Type IV or V cement requires minimum three, seven, ten and fourteen days, respectively, for their curing. However, in this investigation, a special type of cement, i.e. nano cement was used to fabricate the concrete. Nowadays, the nano technology has been considered to advance our understanding and control of matter at the nano scale level. Interestingly, the application of nanotechnology has been spread over the structural research toward the development of the smart and sustainable construction material. Recently, the attention of scientists is attracted to develop nano cement and/or ecological building materials incorporating various nano scale material such as spherical nano material (viz., nano SiO_2, TiO_2, Al_2O_3, Fe_2O_3, etc.) nano fiber or nanotube (viz, carbon nanotube (CNT), carbon nano-fibers (CNF)) and nano clay into the cement system [16–19]. In the existing literature, the nano cement concrete was defined as the concrete made of a cement of the particle size less than 500 nm [20]. Accordingly, the nano cement concrete is characterized by high strength, greater durability, rapid construction, reduced environmental impact and, with the whole range of newly introduced smart properties [16,21,22]. In our previous investigation, the hydrothermal synthesis of nano cement using fumed silica and hydrated alumina was reported [23]. Additionally, the physical and mechanical performances of the synthesized nano cement based concrete were also reported [24]. But, the prediction and optimization of the curing time under specific curing condition of nano cement based concrete was not studied.

Reviewing the literature, it is anticipated that various curing processes, conditions and models are adopted to yield adequate strength in concrete at a particular curing time. However, to the best of our knowledge and belief, no report is yet available for the prediction and optimization of the curing age (time) using statistical modeling. In order to cross the limits, a new perception has been introduced utilizing a statistical model to predict the curing time as well as to optimize the curing time of nano cement based concrete. In this investigation, we have studied the rate of change of compressive strength for the nano cement based concrete. Utilizing the equation derived from the variation of the rate of change of compressive strength as the function of curing time, the required curing time to achieve a particular rate of change of compressive strength has been predicted, prior to the optimization of curing time at the 99.99% confidence level using the Weibull distribution model. The analysis process is demonstrated to be very effective not only to predict the rate of change compressive strength and curing time, but also to enlighten the efficacy of nano cement based concrete.

2. Experimental program

2.1. Fabrication of the nano cement based concrete

Concrete samples were fabricated using nano cement synthesized in the laboratory. In this investigation, nano silica, sodium aluminate and calcium nitrate were used as primary raw materials for the hydrothermal synthesis of nano cement. The nano cement was synthesized by preparing the source materials, ripening, mixing, drying, and grinding, followed by the $Ca(NO_3)_2$ treatment and centrifuge. Initially, the sodium aluminate ($NaAlO_2$) was dissolved in alkali solution at 90 °C to form a glassy chain of sodiated aluminum hydroxide, followed by the addition of triethanolamine (TEA). At the same instance, nano silica was dissolved in water to from a high density hydrated gel. Afterwards, mixing of the sodiated aluminum hydroxide glassy gel with the high density gel of hydrated silica leads to form sodium aluminum silicate compounds. Heat evaporation process (105 °C) influences the nucleation and crystallization of the sodium aluminum silicate compounds. Furthermore, to increase the calcium ion content in synthesized material, ion substitution was performed in the presence of calcium nitrate $Ca(NO_3)_2$, followed by centrifuge and drying. The synthesized fine powder of the nano cement material was then stored in a moisture free container. A flow chart for the production of the nano cement is represented in Fig. 1. In a recent study, Jo et al. reported the synthesis of nano cement using silica fume and hydrated alumina [23]. The particle size, specific gravity and fineness of the used nano cement synthesized in this investigation are measured to be 167 nm, 2.11 and 3,582,400 cm^2/g, respectively [23,24]. In the existing literature, it is reported that the nano cement concrete can be defined as a concrete, prepared with a cement of the particle size less than 500 nm. Accordingly, in this investigation, the particle size of the used cement is 167 nm, which can therefore be designated as nano cement concrete. The fine and coarse aggregate of the average particle size ~0.6 mm and ~4 mm, specific gravity ~2.63 and 2.63, and water absorption 0.1% and 0.7%, respectively, were used for the fabrication of the nano cement based concrete. Ten different mix proportions were selected for the fabrication of concrete samples. Table 1 represents the formulation code as well as mix proportions of the components used for the fabrication of nano cement based concrete. In this investigation, 50% NaOH solution (alkali activator) was used for the fabrication of nano cement based concrete. In this study, the hydration reaction among the chemical phases of the synthesized material was

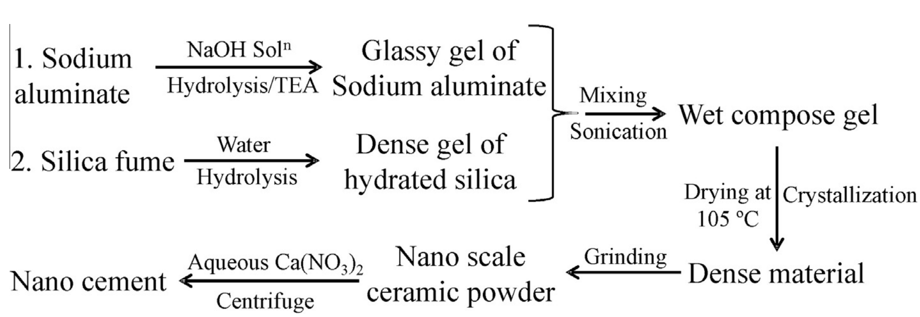

Fig. 1. A schematic representation of the synthesis of nano cement by hydrothermal method using silica fume and hydrated alumina.