DEVELOPMENT OF ELECTROLYZED WATER BASED CONCRETE: A NEW APPROACH FOR EARLY STRENGTH GAIN

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ABSTRACT. In this paper the effects of electrolyzed water in controlling the early age properties of concrete was investigated. The concrete samples were cast using normal and 30 min electrolyzed water. The performances of concrete samples were evaluated by the means of bulk density, apparent porosity, and compressive strength measurement. Analyzing the results, the bulk density and the apparent porosity ofelectrolyzed water based concrete (EC) are found to be greater (1.37 % cured for 3 days and 1.66 % cured for 7 days) and less (6.18% cured for 3 days and 7.56 % cured for 7 days), respectively, as compared to normal water based concrete (NC). Based on the mechanical property analysis it is anticipated that EC achieves greater compressive strength (28.54% cured for 3 days and 20.53% cured for 7 days) than that of NC. The better performance of EC is primarily governed by the accelerated hydration reaction in the presence of hydroxyl ions in electrolyzed water, which, in turn, leads to develop a matured microstructure as justified by SEM analysis.

Keywords: Admixture, Electrolyzed water, Compressive Strength, Bulk Density, Apparent Porosity, Microstructure

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INTRODUCTION

The demand for sustainable and green concrete in construction industry is increasing day by day to reduce greenhouse gas emission, energy consumption, and time of construction period. The green concrete shows several advantages such as less carbon emission, protection of natural resources, utilization of waste materials, advances in concrete properties, etc. [1]. On the other hand, the early strength gain materials can reduce the construction period and cost by achieving the target strength at the early age [2, 3]. In order to achieve the aim, numerous investigations have been carried out to control the performances of concrete using several admixtures [2, 4]. Sodium and calcium based set-accelerating admixture are known to be the most common practice used for early strength gain of concrete [3, 5]. However, there are some lacks in investigating the performance and properties of set-accelerating concrete-admixture. The sodium and calcium based set-accelerating admixtures are not environmentally compatible. These emit some volatile organic compounds and NO_x which are responsible for greenhouse effect [6]. Additionally, use of sodium and calcium based set accelerating admixture may affect the other desired properties of concrete such as durability, corrosion of reinforced steel, and freeze-thaw performances, etc. [2, 7]. Hence, an advanced and new material is sought which can help to gain the strength of concrete at the early age and minimize the greenhouse gas emission simultaneously. In this event, use of electrolyzed water as a cement set accelerator would be a promising approach. In this study, effect of electrolyzed water on the early age performance of concrete has been investigated. The electrolyzed water can produce molecular hydrogen and hydroxyl ions that help cement to get set and hydrate rapidly to gain strength earlier. Use of electrolyzed water would be very effective in developing green and early age strength gaining construction material.

EXPERIMENTAL INVESTIGATIONS

Materials

In order to prepare electrolyzed water based concrete samples, 30 min electrolyzed water (produced by anelectrolysis bottle, VYOM^{TM}), Portland Pozzolanic cement IS: 1489 (part 1) [8] manufactured by Ambuja cement Ltd., locally available fine and coarse aggregates were used. The specific gravity of the used cement was measured to be 2.79. The specific gravity and the grading zone of the used fine aggregate were determined in accordance with IS: 2386 (part 3) [9] and IS: 383 [10] to be 2.66 and zone II, respectively. The coarse aggregate belonged to maximum value of 20 mm graded aggregate of nominal size determined by sieve analysis in accordance with IS: 383 [10] and the specific gravity of the coarse aggregate was measured in accordance with IS: 2386 (part 3) [9] to be 2.74. The hydrogen concentration and pH of 30 min electrolyzed water were measured to be 0.5±0.02 ppm and 9.3±0.1, respectively.

Preparation and characterization of concrete samples

In order to assess the physical, mechanical, and microstructural properties, the M 20 graded concrete was produced. The mix formulation of concrete was designed in accordance with IS: 10262-2009 [11].Table 1 depicts the formulation details of concrete fabricated using normal water and electrolyzed water. For all concrete batches, cement: fine aggregate: coarse aggregate: water was kept 1:2.037:3.282:0.55 by weight. In this study, the normal water

based concrete and 30 min electrolyzed water based concretes are designated as NC and EC, respectively.

Table 1 Formulation details of concrete fabricated using normal water and electrolyzed water

TYPE OF CONCRETE	CEMENT (kg)	FA[a] (kg)	CA[b] (kg)	WATER (kg)	TYPE OF WATER USED	SAMPLE CODE
Normal concrete	2.610	5.318	8.565	1.437	Normal water	NC
Electrolyzed water based concrete	2.610	5.318	8.565	1.437	30 min Electrolyzed water	EC

[a]Fine aggregate, [b]Coarse aggregate

In this study, a conventional mixing method was used to prepare the concrete samples, followed by the casting of concrete was done using 100 mm side cubic molds. Prior to casting of concrete, the slump and compacting factor tests were done in accordance with IS: 1199-1959[12]. The cast samples were left for setting, followed by allowing to water cure for 3 and 7 days.The bulk density and apparent porosity of concrete were done in accordance with ASTM C 948 [13]. The compressive strength of NC and EC samples were determined by using a hydraulic universal testing machine (UTM) of 1000 kN capacity in accordance with IS: 516-1959[14]. At least three concrete specimens from each batch were tested to obtain an average result. The microstructure of 7 days cured samples evaluated using a scanning electron microscope (SEM), Hitachi S3800, Japan.

RESULTS AND DISCUSSIONS

Physical and Mechanical Properties Analysis

In the fresh stage, the physical properties of concrete were evaluated by slump and compacting factor tests. In the hardened stage, the physical and mechanical properties of concrete were assessed by measuring bulk density, apparent porosity, and compressive strength test.

From the Figure 1, the slump and compacting factor values (Figure 1.a) of EC are found to be 10.81% and 4.64% less as compared to that of NC. It indicates that the EC is little stiffer than that of the NC due to rapid setting of cement in presence of electrolyzed water. However, the compressive strengths (Figure 1.b) of 3 and 7 days cured EC samples are found to be 28.54% and 20.53% more, respectively, than that of the NC cured for same time. The early age strength gain of EC is primary governed due to the formation of greater extent of hydrated products [3] by quick hydration reaction of cement in presence of electrolyzed water. It is observed from the Figure 1.c that irrespective of curing time, the bulk density of EC is higher than that of the NC. The bulk densities (Figure 1.c) of 3 and 7 days cured EC are, respectively, found to be 1.37% and 1.66% more as compare to NC. Additionally, it is noted that the apparent porosity (Figure 1.d) of EC is 6.18% (for 3 days cured sample) and 7.56% (for 7 days cured sample) less than that of NC. The less apparent porosity of EC leads to improve more bulk density and more mechanical strength due to filling up of capillary pores by the hydrated products. This clearly indicates that the formation of hydrated product is more for EC at the early age due to the accelerated hydration reaction of cement [3, 5, 15] in the presence of molecular hydrogen and hydroxyl ions in electrolyzed water. In fact, due to the pre-breakage of H-O-H bond of water molecule ($H_2O \rightarrow H_2 + OH^-$) by electrolysis, the

hydroxyl ion concentration of 30 min electrolyzed water is increased (pH = 9.3 ± 0.1) which is more liable to be react with cement clinkers and can influence the dissolution cement particles and flocculation of hydrated products in pore elucidation of hydrated cement system. Accordingly, the rapid hydration of cement in the presence of electrolyzed water helps to achieve a comparatively matured microstructure than that of normal water at same early age of curing which is further justified by SEM analysis in the next section.

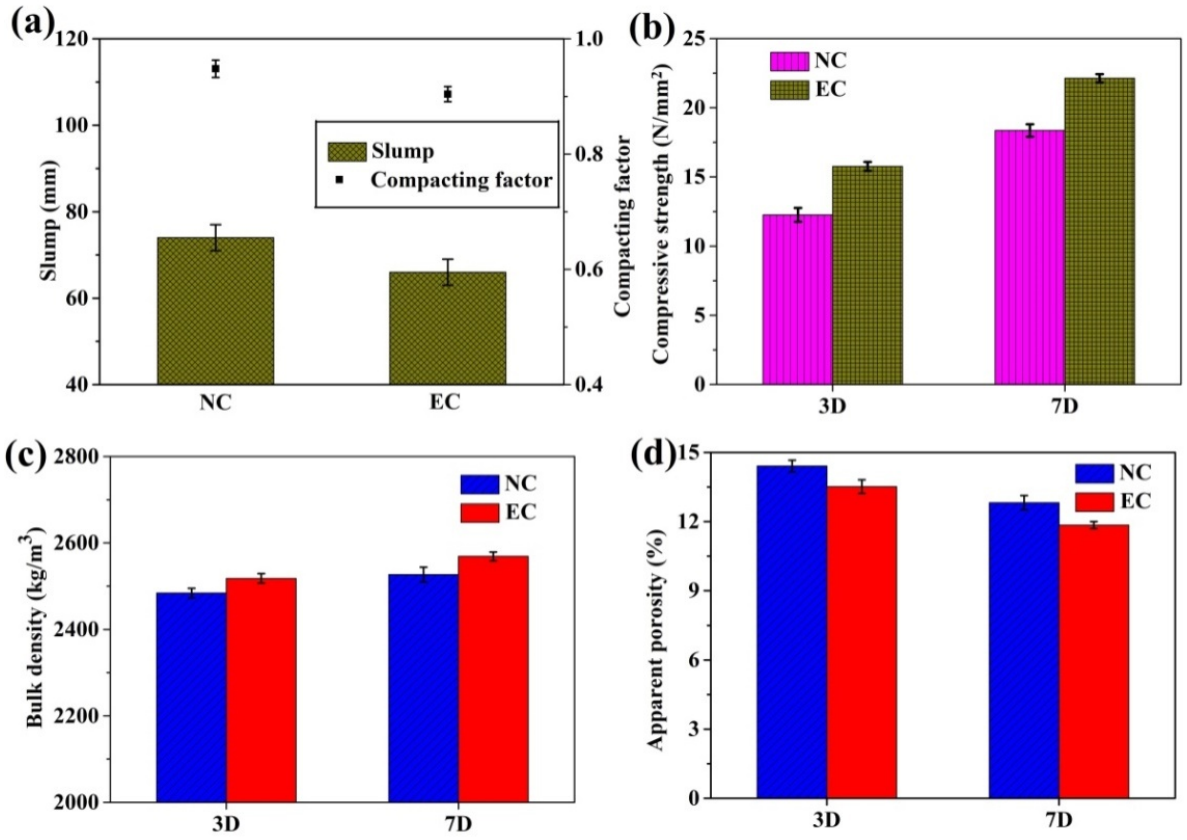

Figure 1. Variation of (a) slump and compacting factor value, (b) Compressive strength cured for 3 and 7 days, (c) Bulk density cured for 3 and 7 days, and (d) Apparent porosity cured for 3 and 7 days of the NC and EC.

Microstructure Analysis

The microstructures of NC and EC were analyzed using a scanning electron microscope (SEM). Figure 2 represents the SEM images of NC and EC hydrated for 7 days. The physical and mechanical performances of concrete depend on the microstructure. A matured microstructure of concrete indicates a less porous and denser product, which directly implies the products having better mechanical performances. From the figure, a discrete and flaky microstructure is observed (Figure 2.a) for NC, while for EC, a matured microstructure is observed (Figure 2.b). Additionally, the microstructure of EC is observed to be less porous than that of NC. The main reason for attaining the matured microstructure of EC is the formation of greater degree of hydrated products [3, 5, 16] by quick hydration of cement in the presence of electrolyzed water. Hence, SEM analysis confirms that a greater degree of hydrated cement product formation takes place for EC at early age than that of NC.

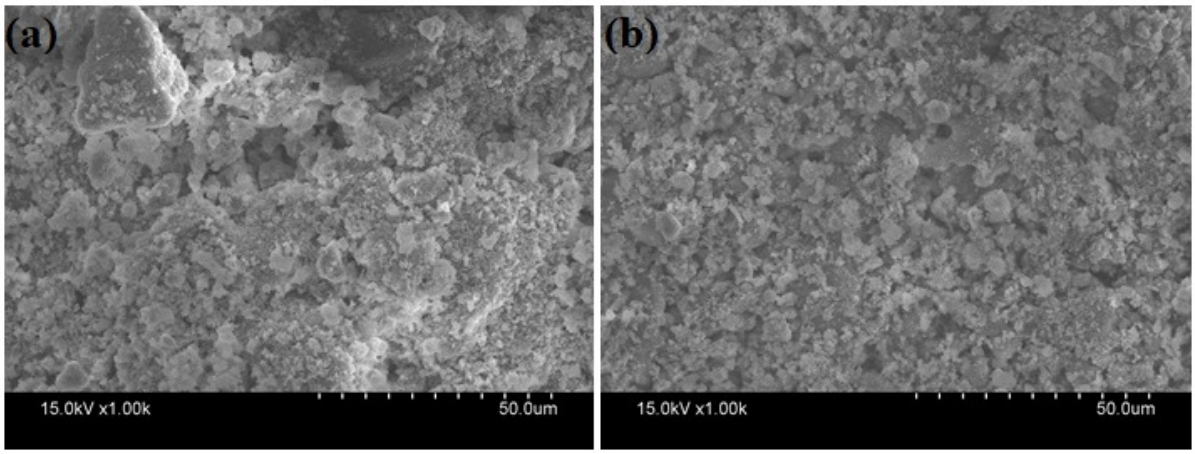

Figure 2 SEM image of the (a) NC, and (b) EC cured for 7 days

CONCLUSIONS

The study reveals that the use of 30 min electrolyzed water increases the compressive strength of the concrete significantly at early age. The early strength gain of EC is attributed due to the formation of a greater degree of hydrated product at the early age which is further clarified by the SEM analysis. Hence, the use of electrolyzed water as a sustainable concrete additive is demonstrated to be very effective not only to early strength gain and repair of concrete structures, but also brings several beneficial opportunities in the construction sector by reducing the construction time and minimizing delays.

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