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Hydrogen-rich water revealed benefits in controlling the physical and mechanical performances of cement mortar

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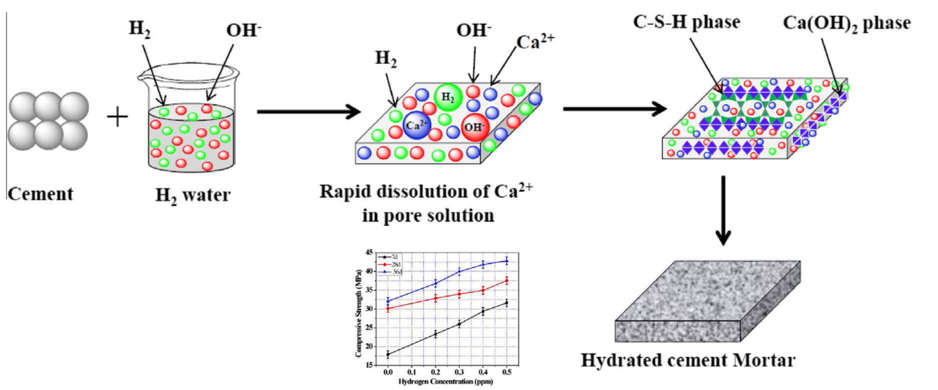
HIGHLIGHTS

- Hydrogen rich water revealed benefits as a cement admixture.
- H_2 rich water controls the physical, mechanical and setting behavior of cement.
- H_2 water leads to set the cement finally within 15 min upon addition of water.
- Efficacy of H_2 rich water in enhancing the early age mechanical strength of mortar.
- Design of a model to explain the overall performances of H_2 rich water.

GRAPHICAL ABSTRACT



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ABSTRACT

The present investigation deals with the effectiveness of hydrogen-rich water in controlling the physical and mechanical performances of cement mortar. In this study, the different concentrations of hydrogen-rich water (0.2, 0.3, 0.4, and 0.5 ppm) were used to fabricate the mortar samples. The impact of the hydrogen-rich water was evaluated analyzing the setting time, flow table value, bulk density, water absorption, apparent porosity, compressive strength and flexural strength of the cement mortar samples. Analyzing the results, the final setting time of the control, as well as 0.5 ppm hydrogen-rich water based cement, is measured to be 257 ± 3 min and 14 ± 3 min, respectively. Additionally, the compressive as well as flexural strength of 7 days cured 0.5 ppm hydrogen-rich water based cement mortar is found to be 59% and 30% higher, respectively, as compared to that of the control mortar. This could be primarily governed by the formation of the greater extent of hydrated cement product in the presence of hydrogen-rich water. Therefore, it is demonstrated that the hydrogen-rich water behaves like a cement set accelerator admixture. Finally, a model has been proposed to explain the overall performances of hydrogen water based cement mortar.

1. Introduction

The development of high performance and sustainable construction material using non-hazardous chemical and consuming minimum energy is sought around the world. Nowadays, adequate research has been executed to develop high performance and sustainable construction materials [1–3]. Recently, several concrete admixtures, such as mineral admixture and chemical admixtures are available to control the performances of concrete magnificently [4,5]. Usually, the admixtures can able to improve the quality and manageability of the concrete. Additionally, it can control the

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acceleration or retardation of setting time amongst other properties that could be rehabilitated to get a targeted results. The mineral admixtures, such as fly ash, ground granulated blast furnace slag, silica fume, metakaolin, and rice husk ash, etc., are added to the cement clinker as a supplementary material [6–8]. Additionally, the alkali activated mineral admixtures are used to improve the quality and the performances of the concrete [9–15]. These are usually industrial waste products and comparatively cheaper [15]. However, the efficacy of these admixtures in controlling the performances of the cement concrete at the application site is not adequate. Whilst, the chemical admixture is found to be more efficient in controlling certain characteristics of the concrete during fabrication, casting and curing [4,5]. The chemical admixtures are water soluble material, which are added in the concrete to control certain properties [16,17]. Understanding of the mechanism of chemical admixtures in controlling the performances of the concrete is now being an aspect of the cement research. The common chemical admixtures used to control the performance and properties of the concrete are classified as (i) set-retarding, (ii) air-entrainment, (iii) water-reducing, (iv) set-accelerating, (v) shrinkage reducing, (vi) superplasticizers, (vii) corrosion-inhibiting admixture [4,5,18–20].

The set retarding concrete admixtures are used to delay the cement hydration reaction. The carbohydrates, hydroxy carboxylic acids and their salts, and phosphates are considered to be the conventional set retarders [4,5]. The air-entrainment admixture, such as natural wood resins, synthetic detergents, and salts of petroleum acids produces a more workable concrete as compared to that of the non air-entrained concrete [4,5,18]. Additionally, the chemical admixtures, such as animal and vegetable fats and oils (i.e., oleic acid, coconut oil derivatives) and synthetic materials (i.e., alkyl/aryl sulfates and sulfonates) are used to improve the severe frost action or freeze/thaw cycles of concrete [5]. The water-reducing admixtures (calcium-lignosulfonate, sulfonated melamine formaldehyde, sulfonated naphthalene formaldehyde, etc.) can produce a desired slump of the concrete with a lower water–cement ratio [4,19]. The water-reducing admixtures are used to obtain a specific strength of the concrete using lower water content [4,5]. Whereas, the set-accelerator is a type of chemical that increases the rate of cement hydration reaction at the early stage so that the cement sets faster [4,5,21]. The most important reason for using accelerators is to speed up the pace of construction by reducing the time required to gain a minimum load-bearing capacity of the concrete. This is particularly helpful in cold weather, when the rate of cement hydration at the early age is two or three times slower as compared to that of the warm weather [4]. Hence, to increase the production rate, reduce the damaging risk of the concrete structures at the early age, earlier completion of the construction, and compensate the effect of low temperature for developing the early age strength of the concrete, the set accelerator admixtures are used. The calcium chloride is used as a common set accelerator [21–23]. Additionally, calcium formate, calcium nitrate, calcium nitrite, calcium thiosulphate, sodium thiocyanate, sodium and potassium carbonate, lithium carbonate, triethanolamine and carboxylic acid can also be used as the cement set accelerator [4]. Numerous investigations carried out to examine the effect of chemical admixtures on the hydration, hardening, morphological features, surface area and pore volume changes of cement concrete, however, no consensus justification has yet found, which would provide a satisfactory explanation in controlling the overall performances of the concrete in the presence of chemical admixtures.

Reviewing the literature, it is, therefore, apparent that the chemical admixtures successfully control the performances of the concrete in a particular application; nevertheless, it shows a negative effect on the other desired properties. Additionally, the use of chemical admixtures has a greater environmental concern in developing green and sustainable construction material. The underlying mechanism for controlling the performances of the concrete utilizing admixtures is yet to be investigated adequately [4,5]. Furthermore, the conventional set accelerator (calcium chloride) shows the enormous negative effect on the volume stability, long term strength, freeze–thaw durability, alkali–aggregate reaction, sulfate attack, chloride permeability and corrosion of the reinforced steel [4,20]. In this context, a new concept has to be introduced in the cement and concrete research to overcome the difficulties associated with the set accelerator. Therefore, the utilization of the hydrogen-rich water as a cement admixture would be a promising approach to control the performances of the cement composites. In this investigation, we have studied the effect of hydrogen-rich water as a cement admixture in controlling the physical and mechanical performances of cement mortar. Utilization of hydrogen-rich water as a cement admixture is demonstrated to be very effective to reduce the setting time of cement and improve the mechanical properties of cement mortar as well.

2. Experimental

In order to evaluate the effect of hydrogen-rich water in controlling the physical and mechanical performances of the mortar, a systematic work program was carried out. In this study, the mortar samples were fabricated using different concentrations of hydrogen-rich water, followed by characterization and property evaluation.

2.1. Materials

Ordinary Portland cement conforming to ASTM C150 [24] purchased from the Ssangyong Cement Industrial Co., Ltd. (South Korea) was used as a primary binding material for the fabrication of mortar samples. The particle size, specific gravity, and fineness of the used cement are reported to be 10–30 μm, 3.15, and ~2800 cm^2/g, respectively [25,26].

In this study, the mortar samples were fabricated using the fine aggregate. In order to find out the particle size and the grading zone of the used fine aggregate, the sieve analysis was performed in accordance with ASTM C 136–04 [27]. Fig. 1 depicts the experimental value of sieve analysis as well as the standard value of the upper and lower limit of a particular graded (Grading zone III) fine aggregate. Based on the sieve analysis, it is ascertained that the used fine aggregate belongs to the grading zone III. Additionally, Fig. 2 represents the variation of the retention (%) of fine aggregate as the function of the spherical diameter of the sieve. The maximum retention (%) of fine aggregate is observed to be 0.3 mm spherical diameter sieve. Therefore, the average particle size of the used fine aggregate is presumed to be 0.3 mm.

The hydrogen-rich water was produced using a chemical mixture purchased from Hydraction H_2 Vision Inc. (www.h2vision.co.kr) Seoul, Korea. The chemical composition of the mixture is reported to be 95% glycerol, 2% MgH_2 and 1% SiH_4.

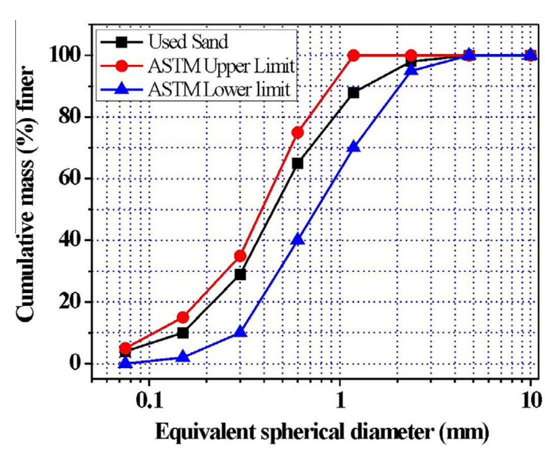

Fig. 1. The experimental value of sieve analysis as well as the standard value of the upper and lower limit of a particular graded (Garding zone III) fine aggregate.