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Investigation of the acid and sulfate resistance performances of hydrogen-rich water based mortars

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HIGHLIGHTS

- Evaluation of the long-term performances of the hydrogen-rich water based mortar.
- Determination of the structural properties of mortar exposed to acid/sulfate media.
- Hydrogen-rich water improves the acid and sulfate resistance of mortar.
- Production of the greater extent of hydrated product restricts acid/sulfate attack.
- Development of a hypothesis to explain overall performances of the mortar.

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ABSTRACT

The present article illustrates the acid and sulfate resistance performance of control (CM) and the hydrogen-rich water-based mortar (HM) samples. The 28 days cured CM and HM samples were exposed to 5% HCl, 5% HNO_3, and 5% sodium sulfate solutions for 30, 60, 90, 120, 150, and 180 days to evaluate their acid and sulfate resistance performances. The impact of acid and sulfate attack was evaluated measuring the weight and compressive strength loss of mortar samples in the different exposure regimes. Additionally, water absorption, porosity, and sorptivity tests were performed to evaluate the transport properties of the mortars. Analyzing the result, a lesser extent of compressive strength loss (47.63% in HCl, 39.47% in HNO_3, and 3% in Na_2SO_4) was observed for the hydrogen-rich water-based mortar as compared to that of the control mortar (57.33% in HCl, 55.4% in HNO_3, and 14% in Na_2SO_4) after 180 days exposure. Based on the X-ray diffraction, Fourier transform infrared spectroscopy, and scanning electron microscopy analysis, a plausible mechanism has been proposed to explain the beneficial effect of the hydrogen-rich water-based mortars against acid and sulfate attacks.

1. Introduction

Currently, there is a growing interest to develop sustainable construction materials. The major component of sustainable development is the material's durability. Concrete durability is the most important parameter in developing modern civil infrastructures. The durability of concrete materials is defined as the ability to resist abrasion, weathering, and chemical attacks while maintaining its performance and serviceability in any environment [1]. The ACI committee (2001) reported the several types of chemical attacks such as acid attacks, alkali attacks, chloride ingress, carbonation, and sulfate attacks, etc [2]. All of these chemical attacks lead to deteriorate the overall durability of cementitious materials. The broad spectrum of acid media makes concrete susceptible to acid attacks. Usually, the wastes of chemical industries produce several acids and carcinogenic components during dispose of, which in turn come in contact with concrete structures, consequently, leads to the deteriorating concrete's life. However, natural environments may also cause acid attacks on concrete structures [3]. Sulfate attacks in cement mortar systems are characterized by the formation of expansive salts that lead to deteriorate the overall performance of cement mortars [4–6]. Acid and sulfate attacks possess serious damage to the concrete structures; many structures lose its serviceability every year due to the acidic and sulfate-bearing environments. This has led the researchers to find out an economical technique for improving the structural durability. Various mineral and chemical admixtures are used to enhance certain properties of concrete. Mineral admixtures are usually incorporated in concrete materials not only to enhance the physical and

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mechanical properties of concrete but also to enhance their overall durability against alkali silica reaction, acid attacks, chloride ingress, and sulfate attacks [7–11]. Portland cement blended with pozzolans and slags possesses benefits against acid attack. Nevertheless, blended cement has the disadvantage of slow strength gain at early ages. Silica fume, the most commonly used pozzolan in blended cement, offers resistance against corrosion properties improving the microstructural characteristics of concrete materials, thereby increasing their mechanical strength [12]. Additionally, use of rice husk ash, metakaolin, and fly ash as supplementary binder offers a significant resistance against chemical attacks [13–15]. Alkali-activated geopolymer concrete has also been reported to achieve better performance against acid attacks at elevated temperatures. Furthermore, fly ash-based geopolymer concrete is reported to possess an improved durability performance as compared to OPC [16,17].

In addition to mineral admixtures, chemical admixtures are also used to successfully control the acid and sulfate resistances of concrete. Generally, the use of water reducers and superplasticizers promotes the flowability and durability of concrete by reducing the permeability and absorption of corrosive chemicals. Lignosulfonates and hydrocarboxylic acids provide a certain degree of sulfate resistance ability to the concrete [18]. Several amines and fatty acids are used to improve the acid resistance performances of cement mortars. Additionally, utilization of ammonium stearate is reported to be very effective in improving the acid resistance of mortars reducing the mass loss due to chemical attack [19]. On the other hand, use of polymer admixtures, such as styrene-butadiene latex, significantly reduces the permeability of corrosive materials. Certain water repellents, known as hydrophobic pore-blocking or damp proofing admixtures, can also improve the resistance to some specific chemical attack on concrete [20]. It is reported elsewhere that precipitation of the carbonates of calcium and barium reduces the porosity of cement mortar by forming additional hydration products, which in turn increases the sulfate resistance ability [5]. In the most common practices, apart from the incorporation of mineral and chemical admixtures, usage of low alumina cement (sulfate resisting cement), a low water to cement ratio, and a proper curing technique are suggested to be the most crucial parameters to counter the sulfate and chemical attacks in cement systems.

Reviewing the literature, it is apparent that various cement admixtures and techniques are able to control the durability against acid and sulfate attacks. However, the effect of hydrogen-rich water in controlling the durability of the cement mortar has not been investigated at all. It was reported in our previous investigation that the use of a very low concentration, i.e., 0.5 ppm hydrogen-rich water allows the cement to set within 14 ± 5 min, which can improve the early age mechanical strength of mortar producing a greater extent of hydrated cement product [21]. From the chemical standpoint, it is expected that use of hydrogen-rich water accelerates the cement hydration process, which is presumed to increase the production of calcium silicate hydrate (C-S-H) phase. Consequently, improves the strength of the mortar. Usually, the durability of concrete materials depends on the growth of microstructure as well as the C-S-H phase development during the hydration process. However, sometimes, the acceleration of cement hydration may possess negative effects on the long-term strength and durability. Based on the extensive literature survey, it is ascertained that the effect of hydrogen-rich water on the other desired properties, such as corrosion resistance, sulfate attack, acid attack, freeze-and-thaw durability, is yet to be investigated adequately. The prime aim of the present study was to investigate the effect of hydrogen-rich water on the long-term performance of cement mortar in aggressive media. In order to execute the goal, in this study, the acid and sulfate resistance performances of the hydrogen-rich water-based mortars is investigated. The use of hydrogen-rich water (produced using a metal hydride mixture) for the fabrication of mortar was demonstrated to be very effective in controlling the acid and sulfate resistance performances of the mortar producing a greater extent of hydrated cement product and developing a compact microstructure as well. The utilization of hydrogen-rich water in fabricating cement concrete is expected to be a sustainable construction material development.

2. Experimental

2.1. Materials

Locally available OPC (21.95 wt.% SiO_2, 6.59 wt.% Al_2O_3, 2.81 wt.% Fe_2O_3, 60.12 wt.% CaO, 3.32 wt.% MgO, 2.11wt.% SO_3, and 2.58 wt.% LOI) conforming to ASTM C 150 [22] provided by Sayeong Inc., Korea was used as the primary binding material in this study. River sand with an average particle size of 2.34 mm conforming to the grading requirements of ASTM C-33 was used. Hydrogen-rich water was produced by mixing a chemical mixture provided by H_2 Vision Inc. Korea (www.h2vision.co.kr). The chemical mixture is capable of generating hydrogen when placed in normal water by the following reactions. The chemical composition of the chemical mixture consisted of 95% glycerol, 4% MgH_2, and 1% SiH_4.

$$MgH_2 + H_2O \rightarrow Mg(OH)_2 + H_2 \quad (1)$$

$$SiH_4 + H_2O \rightarrow Si(OH)_4 + H_2 \quad (2)$$

The aggressive acidic environment was simulated by using 5% hydrochloric and nitric acids. For the sulfate resistance, a 5% sodium sulfate solution was used.

2.2. Fabrication of mortar samples

In order to analyze the effectiveness of the hydrogen-rich water as a durability enhancing admixture, the performance of specimens made from hydrogen-rich water was compared to their control counterparts made from normal water. Hydrogen-rich water was produced with different strengths, viz.: 0.2, 0.3, 0.4, and 0.5 ppm, and the mortars fabricated from them are referred to as 0.2HM, 0.3HM, 0.4HM, and 0.5HM, respectively. The mortar prepared from normal water is named 0CM. The hydrogen concentration in water was controlled and monitored using a hydrogen needle sensor (DHS-001, ABLE, Tokyo, Japan). All mortar mixes used in the experimental program were prepared using a standard mortar mixer in accordance with ASTM C305-12 [23]. Table 1 shows the formulation summary for the normal and hydrogen-rich water-based mortars. Cubic mortar samples ($50 \times 50 \times 50\ mm^3$) were made at a water/cementitious material mass ratio (w/c) of 0.485 with sand to cement ratio of 2.75. All samples were processed in a similar manner according to ASTM standards. The water (normal or hydrogen-rich) was first introduced into the mixer, and then the dry material (cement + sand) was added to the water and mixed for 30 s, where the mixing was done in three steps in sequential order. The mortars fabricated using hydrogen-rich water appeared bit stiff yet fluid enough to be properly compacted in the molds. The mortars were cast into molds and kept in plastic sheeting for 24 h to avoid the evaporation of water. After removing the specimens from the molds, they were cured in water for 28 days at 23 ± 2 °C and 100% RH.

2.3. Testing methods

2.3.1. Water absorption and porosity

Mortar samples from each mix were moist cured for 28 and 180 days. At the end of curing periods of 28 and 180 days, the