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Strength Properties of Rice Husk Ash Concrete Under Sodium Sulphate Attack

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Abstract: The use of pozzolanic materials in concrete provides several advantages, such as improved strength and durability. This study investigated the strength properties of rice husk ash (RHA) concrete under severe durability (sodium sulphate attack). Four RHA replacement levels were considered in the study: 10%, 20%, 30%, and 40% by weight of cement. The durability performance of the RHA blended cement exposed to sodium sulphate solution was evaluated through compressive strength, reduction in strength, and weight loss. Test results showed that RHA can be satisfactorily used as a cement replacement material in order to increase the durability of concrete. Concrete containing 10% and 20% of RHA replacements showed excellent durability to sulphate attack. The results also indicate that the amount of $Ca(OH)_2$ in the RHA blended cement concrete was lower than that of Portland cement due to the pozzolanic reaction of RHA.

Keywords: Strength, Sodium sulphate, Concrete, Durability, Rice husk ash

1. Introduction

Sulfate attack is one of the most important problems concerning the durability of concrete structures [1]. According to Al-Akhras [2-3], the chemical interaction of sulfate attack is a complicated process and depends on many parameters including concentration of sulfate ions, ambient temperature, cement type and composition, water cement ratio, porosity and permeability of concrete, and the presence of supplementary cementitious materials. Several researchers [4-5] have confirmed that limiting C_3A and C_4AF contents is not the ultimate solution to the problem of sulfate attack. However, the incorporation of pozzolanic materials such as RHA, slag, fly ash (FA), metakaolin (MK), palm oil fuel ash (POFA), silica fume (SF), etc. as partial replacements for OPC has been found to be a beneficial technique for enhancing the resistance of concrete to sulfate attack [6-9]. Previously, Torii and Kawamura [10], found that FA and silica fume appear to increase the resistance significantly, but only when the amount is above a certain level, which is dependent on the type of sulfate solution. In another study, Al-Akhras [2] concluded that the use of metakaolin (MK) as a replacement of cement has increase the sulfate resistance of concrete. The sulfate resistance of MK concrete increases by increasing the MK replacement level. In a related study, Chindaprasirt et al. [11] discovered that POFA fineness also contributes to the sulfate resistance of concrete. It was noted that the finer the POFA, the lower is the expansion and loss in compressive strength of concrete immersed in magnesium sulfate solution. Based on the available current literature, several researchers have confirmed that the incorporation of supplementary cementitious materials as partial replacement of OPC is a beneficial technique to enhance the resistance of concrete to sulfate attack. For this reason, it is important to study the effect of RHA blended cement under sodium sulfate attack.

2. Materials

Ordinary type I Portland cement was used as the major binder in the production concrete. The chemical composition of the OPC used in this study was within the standard range of 70% CaO, 17.8% SiO_2, 3.9% Al_2O_3, 3.2% Fe_2O_3, 1.5% MgO, and 3.6% SO_3. The OPC similarly indicated a compound composition of 54.5%

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C_3S, 18.2% C_2S, 9.4% C_3A, and 10.5% C_4AF. The chemical analysis on the OPC was carried out using XRF apparatus in accordance with BS EN 197-1 [12].

Rice husk was initially incinerated in a gas furnace at a heating rate of 10°C/min; the temperature was increased until 700°C, after which it was maintained for 6 h. After the incineration, the RHA was left inside the furnace to cool and then collected the following day. Afterwards, the RHA was ground using a laboratory ball mill with porcelain balls. SiO_2 was identified as the main component of the RHA. In addition, SiO_2, Al_2O_3, and Fe_2O_3 comprised 93.48% of the material, in accordance with C618-15 [13], which requires that these three main oxides should comprise not less than 70% of the pozzolanic material.

3. Methods

Compressive strength is commonly considered as the most important property of concrete. In this study, the compressive strength test of all the concrete mixes was performed on 100 × 100 × 100 mm cubes. The specimens were compressed by a compression machine with maximum capacity of 3000 kN with a loading rate of 150 kN/min. The reported compressive strength was the average of the three samples. The test was conducted according to the British standard test method BS EN 12390-3 [14].

Sodium sulfate is the sodium salt of sulfuric acid. When anhydrous, it is a white crystalline solid of formula Na_2SO_4 [15]. At the laboratory, the sodium sulfate (Na_2SO_4) solution was prepared by mixing the chemical with distilled water at 5% by weight of volume [1]. In this research, 5% of Na_2SO_4 was used to represent extremely severe sulfate exposure according to ACI 318-08. At each cycle (wetting-drying), the solution was replaced by a freshly prepared one or based on the change in the pH of the solution. This method has been used successfully by Vuk et al. [5] and Sahmaran et al. [16].

4. Results and Discussion

Fig. 1 represents a graphical illustration of the compressive strengths of OPC concrete and RHA concrete subjected to 5% Na_2SO_4 solution at the age of 3, 7, 28, 56, 90, and 180 days. There were no differences in strength observed in OPC concrete and RHA concrete up to approximately 90 days. In general, the compressive strength of concrete initially increased during the period between 3 to 90 days, and then started to decrease until the specimens eventually deteriorated after 180 days. The increase in strength may be attributed to two following reactions. First, the continuous hydration of unhydrated cement components to form more hydration products in addition to the reaction of RHA blended cement with the liberated lime to form more calcium silicate hydrate (CSH) leading to increasing compressive strength. Second, the reaction of sulfate ions with hydrated cement components to form gypsum and ettringite. These two reactions lead to a denser structure as a result of precipitation of the products within voids and micropores [17]. However, the decrease in compressive strength observed in this experimental work was due mainly to the severity of the drying-wetting cycles. The reactions of sulfate ions with hydrated cement become more dominant leading to formation of micro-cracks and this decreases strength. It can be said that the strengths of OPC concrete and RHA concrete subjected to 5% sodium sulfate were observed in four stages: (i) the increased between 3–28 days, (ii) the slowly increased between 28–56 days, (iii) the linearly increased between 56–90 days, and (iv) the accelerating failure after 180 days. The OPC concrete produced low compressive strength compared with RHA10 and RHA20 concrete when subjected to sodium sulfate, and the strength deteriorated after 90 days (see Fig. 1). Obviously, concrete containing 30% and 40% of RHA still showed compressive strength as good as that of OPC concrete even at longer exposure. Furthermore, concrete containing 10% and 20% of RHA replacements showed excellent compressive strengths against sulfate attack.

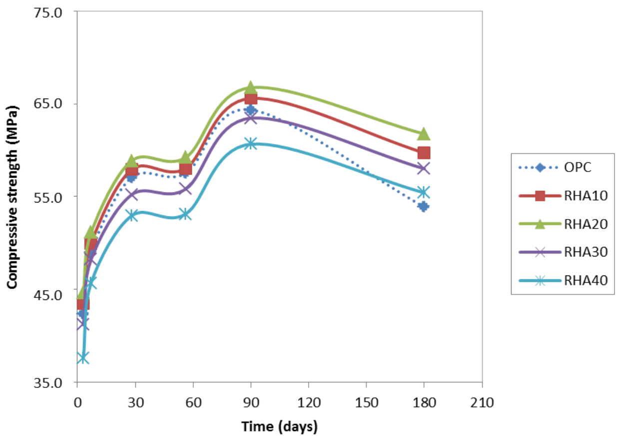

Fig. 1 Compressive strength of OPC concrete and RHA blended cement concrete under sodium sulfate solution

The reduction in compressive strength of concrete subjected to sulfate solution was calculated using Equation 1 as follows:

$$\text{Reduction (\%)} = \left(\frac{f'_{dw} - f'_{sl}}{f'_{dw}}\right) x\ 100\% \qquad \text{Eq. 1.}$$

Where f'_{dw} is the average strength of the specimens cured in tap water and f'_{sl} is the average strength of the specimens under sulfate solution.

The reduction in the compressive strength of OPC and RHA blended cement concrete subjected to sodium sulfate solution with drying-wetting cycles are presented in Fig. 2. The reduction in compressive strength of specimens increased at the earlier age of exposure. For instance, the reduction in compressive strength after 28 days was 0.72% for OPC concrete, followed by 0.49%, 0.35%, 0.42%, and 2.74% for RHA10, RHA20, RHA30 and RHA40 concrete, respectively. However, the reductions of all the specimen concrete after 90 days of immersion were significantly lower than those at 56 and 180 days. This can be explained as follows: as the pozzolanic reaction proceeds, $Ca(OH)_2$ was consumed to react with silicon dioxide (SiO_2); the reaction then produced a number of C–S–H and sulfate ions, which led to the reduction of compressive strength.

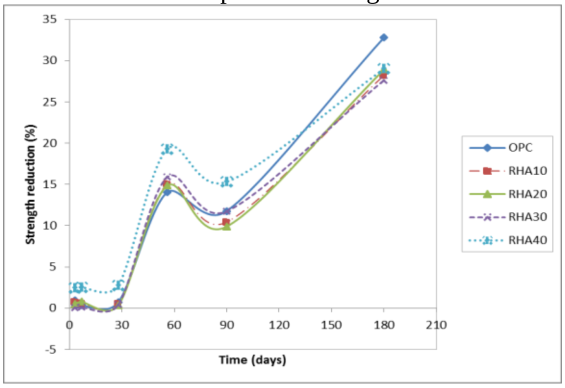

Fig. 2 Reduction in compressive strength of OPC concrete and RHA blended cement concrete under sodium sulfate solution

In this study, the weight loss of the specimens was calculated using Equation 6.2 as follows:

$$\text{Weight loss (WL) (\%)} = \frac{WL_{dw} - WL_{ch}}{WL_{dw}} \times 100\%$$

Where WL_{dw} is the average initial weight of three specimens cured in tap water and WL_{sl} is the average weight of the specimens subjected to sulfate solution.

In general, the weight loss of the OPC concrete and RHA concrete initially increased with increase in the exposure time as illustrated in Fig. 3. For instance, at the age of 28 days, the weight loss of OPC, RHA10, RHA20, RHA30, and RHA40 concrete is about 2.57%, 3.71%, 1.77%, 1.80%, and 1.29%, respectively. However, at longer exposures, for example, 180 days, the value of weight loss due to sulfate attack for OPC, RHA10, RHA20, RHA30, and RHA40 concrete was about 6.66%, 5.92%, 3.07%, 3.13%, and 2.16%, respectively. The increasing weight loss with exposure time may due to the filling up of pores by the reaction products, thereby densifying the hardened concrete mix, resulted in a decrease in the weight of specimens, thus increasing the weight loss with immersion period [18].

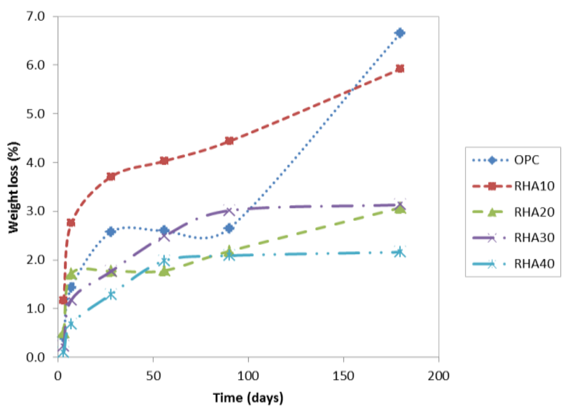

Fig. 3 Weight loss of OPC concrete and RHA blended cement concrete under sodium sulfate solution

5. Summary

Based on the obtained data, it can be concluded that RHA replacement of cement was found to be effective in improving the resistance of concrete under sodium sulphate attack. It can be seen that the strength of concrete initially increased from 3-d to 90-d. The high level replacement of RHA has the advantageous effect in improving resistance in Na_2SO_4 solution. On the other hand, the incorporation of RHA as cement replacement reduced the potential for the formation of gypsum and/or ettringite due to the reduction in the quantity of calcium hydroxide ($Ca(OH)_2$), and thus improved the resistance of concrete to sulfate attack. Therefore, RHA can be used as pozzolans to replace part of Portland cement in making concrete with relatively high strength and good resistance to sodium sulfate attack.

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