THE INVESTIGATION OF ALUMINUM WHITE-POWDERED SLUDGE ON MECHANICAL AND CORROSION PROPERTIES OF CEMENT PASTE

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ABSTRACT

In this study, aluminum white-powdered sludge, which is an industrial waste product from the aluminum-anodizing industry, is used as an admixture in cement paste to observe its effects on the mechanical properties and the corrosion resistance in the reinforced steel bars. The mass ratio of cement and aluminum white-powdered sludge (particularly 1.00:0.05, 1.00:0.1, and 1.00:0.2) is used to prepare cement paste by using 48.5 wt.% water ratio. The effect of the mass ratio of cement and aluminum white-powdered sludge (average particle size of the aluminum white-powdered sludge is less than 45 μm in diameter) on porosity, bulk density, compressive strength, and corrosion resistance have been centered around for this study. Based upon the results of study, as the quantity of the aluminum white-powdered sludge increases, the porosity of cement paste also increases; yet the bulk density and compressive strength of the paste, on the other hands, decrease. However, it was found that the addition of the aluminum white-powdered sludge to the cement paste causes more corrosion on reinforced steel bars and also more damaged on the cement pastes.

Keywords: Aluminum white-powdered sludge, Cement Paste, Corrosion, Mechanical Properties

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1. INTRODUCTION

One of the most commonly used construction materials is not only cement paste but also concrete [1-3]. There are several attempts of utilizing high silica and alumina compounds as admixtures such as bagasse fibers, metakaolin particles, metallic wastes and ceramics (glass) particles [2-9]. Wastes from aluminum industries is of particular interests to be used as an admixture since it has been reportedly improved the mechanical or other properties in cement pastes or even in concrete [3].

The addition of aluminum into cement paste reportedly results in the increase in the porosity and consequently causes the weight's reduction in the cement paste [2-3,10-14]. Apart from that, corrosion of reinforced steel bar continues to be of problematic concerns in the reinforced concrete structure by scientists and engineers [15-16].

In this study, the waste from aluminum anodizing industries, which is called the aluminum white-powdered sludge, is used to investigate by mixing it into cement paste. In particular, the focus of this study is to investigate the effect of aluminum white-powdered sludge admixture on the porosity, bulk density, compressive strength, and corrosion behavior of the cement paste.

2. EXPERIMENTAL

The Portland cement, type 1, is used in this study to mix with the aluminum white-powdered sludge, which is obtained from the aluminum anodizing industries. The aluminum white-powdered sludge has the average particle sizes less than 45 μm in diameter and is used as received. The cement paste is prepared using tap water to mix both aluminum white-powdered sludge and Portland cement with the water ratio of 48.5 wt.%.

As shown in Table 1, the chemical compositions of cement powder and aluminum white-powdered sludge are analyzed using X-ray analytical microscope technique with X-ray Fluorescence (XRF: Horiba x-ray analytical microscope XGT-2000W). According to Table 1 the main chemical compositions found in cement is the same as in aluminum white-powdered sludge, which consists of aluminum oxide (Al_2O_3), silica dioxide (SiO_2), ferric oxide (Fe_2O_3) and calcium oxide (CaO).

Table 1 Chemical compositions of the cement and the aluminum white-powdered sludge by XRF.

Chemical compositions	Contents (%)	
	cement [3]	aluminum white-powdered sludge
aluminum oxide (Al_2O_3)	41.830	99.571
silicon dioxide (SiO_2)	53.088	0.008
ferric oxide (Fe_2O_3)	2.764	0.194
calcium oxide (CaO)	2.153	0.032
zinc oxide (ZnO)	0.050	0.025
copper oxide (CuO)	-	0.014
others	0.115	0.156

For the cement paste's preparation followed by the ASTM C109, the three different mass ratios of cement and aluminum white-powdered sludge, 000:0.05, 1.00:0.1, and 1.00:0.2, have been used for this study, which is later referred to 5%, 10%, and 20% aluminum white-powdered sludge's addition, respectively.

The measurements of bulk density, porosity, compressive strength, and topographical images are made from an electronic densimeter with 0.001 g/cm^3 resolution, image analyzer

software (Image-Pro version 4.5.0.29), universal testing machine (UTM H50KS, Hounsfield), and scanning electron microscope (SEM: Philips XL 30 series), respectively.

In addition, the solution for the mass loss and electrochemical measurements is the 3.5 wt.% NaCl. The configuration for sample's preparation of the corrosion investigation is the same as a previous report [3]. The duration times used for the corrosion experiments are 30, 60, 90, and 120 days for both mass loss test and electrochemical measurements. The Pt electrode and the Ag/AgCl (3M KCl) electrode are used as the counter electrode and reference electrode, respectively. The potentiostat instrument used for the electrochemical experiments is the AutoLab (PGSTAT302N).

3. RESEULTS AND DISCUSSION

3.1. Chemical Analysis of the Materials by XRD

The XRD patterns of the cement paste and cement paste mixed with the aluminum white-powdered sludge (the average particle size of 90 μm) are depicted in Fig.1. As depicted in Fig. 1, the cement paste and the cement paste mixed with aluminum white-powdered sludge do not indicate any significant difference in terms of chemical composition, which mostly contains the phased of calcium sulfoaluminate (CFA), tricalcium silicate (C_3S), calcium hydroxide (CH), calcium silicate hydrate (CSH), and tetracalcium aluminoferrite (C_4AF). Nevertheless, the phases of dicalcium silicate (C_2S) and tricalcium aluminate (C_3A) are presently observed when the addition of aluminum white-powdered sludge is exercised. In addition, the addition of the admixture with high aluminum oxides will not obstruct the hydration reaction of cement [16-17].

Figure 1 XRD patterns of (a) only cement paste and cement paste mixed with the aluminum white-powdered sludge: (b) 5% aluminum white-powdered sludge's addition, (c) 10% aluminum white-powdered sludge's addition, and (d) 20% aluminum white-powdered sludge's addition.

3.2. Bulk Density and Compressive Strength of the Cement Paste

The bulk density of the cement paste mixed with the aluminum white-powdered sludge at different ratios is demonstrated in Fig.2. Based upon Fig.2, the mixed cement paste with aluminum white-powdered sludge exhibits lower bulk density than the unmixed cement paste.

In addition, the increase of the amount of the aluminum white-powdered sludge mixed to the cement paste results in indifference of the bulk density, unlike using aluminum dross [3].

Based on the experiment as seen in Table 2, the average pore's sizes determined from the Image-Pro version 4.5.0.29 from are approximately 142, 144, and 146 μm in diameter for adding 5 wt. %, 10 wt.%, and 20 wt.% of aluminum white-powdered sludge to the cement paste, respectively, which seems to be more or less the same. However, the addition of aluminum white-powdered sludge tends to yield more average pore's size than without adding aluminum white-powdered sludge. It is believed that the porosity's density is expected to be higher when the average pore's sizes is lowered, which results in a higher bulk density in the case where there is no addition of aluminum dross as shown in Fig.2 [2,21].

Figure 2 Effect of different aluminum white-powdered sludge contents (5%, 10%, and 20% aluminum white-powdered sludge's addition) on bulk density of cement paste mixed with aluminum white-powdered sludge at different particle sizes.

Table 2 The average pore's size for different quantities of aluminum white-powdered sludge's addition mixed in the cement.

Addition of aluminum white-powdered sludge in cement (%)	average pore's size (μm)
0	133
5	142
10	144
20	146

The compressive strength of the cement paste mixed with the aluminum white-powdered sludge at different quantities after 28 days of curing time is demonstrated in Fig.3. Based upon Fig.3, the increase of the amount of the aluminum white-powdered sludge mixed to the cement paste results in a decrease in compressive strength. However, the addition of the aluminum white-powdered sludge results in the improvement of the compressive strength rather than without the additions of the aluminum white-powdered sludge. This observation is also in agreement with a previous study [3].

3.3. Corrosion Behavior of Reinforced Steel Bar in Cement Paste

The mass loss of the reinforced steel bar in the cement paste in the 3.5 wt.% NaCl is investigated for different immersion times (30, 60, 60, and 120 days). Based upon Fig.4, mixing of

aluminum white-powdered sludge in the cement paste does not prevent corrosion to occur in the reinforced steel bar. In fact, the addition of aluminum white-powdered sludge speeds up more corrosion than without the addition of aluminum white-powdered sludge. This is in an agreement with the previous report [3]. The addition of aluminum white-powdered sludge results slightly more pores in the cement paste, which can enhance the encapsulation of the corrosive environments such as moist, Na^+ , Cl^- , and other possible species in the matrix. By having such a situation, the corrosion can then be accelerated than usual.

Figure 3 Effect of different aluminum white-powdered sludge contents (5%, 10%, and 20% aluminum white-powdered sludge's addition) on compressive strength of cement paste mixed with aluminum white-powdered sludge (the average particle size $< 45 \mu\text{m}$) after 28 days of curing time.

Figure 4 Comparison of normalized mass loss of reinforced steel bars in the cement paste and in the cement, paste mixed with 5 wt.% aluminum white-powdered sludge ($< 45 \mu\text{m}$ in diameter) after soaking in 3.5 wt.% NaCl for different duration times of 30, 60, 90, and 120 days.

The SEM images of reinforced steel bars are topographically depicted in Fig.5. As the immersion time increases, the cement paste mixed with 5 wt.% aluminum white-powdered sludge becomes more corroded in the matrix's texture. However, there is no obvious cracks observed unlike the previous study when aluminum dross was used as an admixture [3].

From the electrochemical measurements as shown in Fig.6 in terms of potentiodynamic scans for several immersion times (30, 60, 60, and 120 days) of reinforced steel bars cement paste with the addition of aluminum white-powdered sludge, the information regarding the corrosion potential (E_{corr}) and the corrosion current density (i_{corr}) can be obtained using the Tafel slope analysis.

Figure 5 Corrosion of reinforced steel bars in cement paste mixed with aluminum white-powdered sludge (the average particle size $<45\ \mu\text{m}$) a) before and after immersing in 3.5 wt.% NaCl solution for several immersion times, b) 30 days, c) 60 days, d) 90 days, and e) 120 days.

Figure 6 Potentiodynamic scans of reinforced steel bars in cement paste and cement paste mixed with aluminum white-powdered sludge after immersion in 3.5 wt.% NaCl solution for 30, 60, 90, and 120 days (the average particle size $<45\ \mu\text{m}$ and 5% aluminum white-powdered sludge's addition).

As summarized in Table 3, as the immersion time increases, the E_{corr} value decrease but the i_{corr} value increases, which is observed for not only mixing aluminum white-powdered sludge in the cement paste but also without addition aluminum white-powdered sludge.

Table 3 The summary of E_{corr} and i_{corr} of reinforced steel bar mixed with aluminum white-powdered sludge (the average particle size $<45 \mu\text{m}$ and 5% aluminum white-powdered sludge's addition).

Immersion times (day)	Control (cement paste only) [3]		Cement paste (aluminum white-powdered sludge)	
	E_{corr} (V vs Ag/AgCl)	i_{corr} (A/cm ²)	E_{corr} (V vs Ag/AgCl)	i_{corr} (A/cm ²)
30	-0.62	1.02×10^{-7}	-0.83	7.50×10^{-7}
60	-0.64	1.51×10^{-7}	-0.82	7.80×10^{-7}
90	-0.70	2.01×10^{-7}	-0.76	1.10×10^{-6}
120	-0.69	2.22×10^{-7}	-0.77	1.80×10^{-6}

In addition, Table 3 also reveals that the addition aluminum white-powdered sludge to the cement paste enhance the corrosion to occur in a significant rate. This is due to that fact that the silica and alumina from aluminum white-powdered sludge cause more chance of pozzolanic reaction to take place, which consequently requires more calcium hydroxide. Such situation leads to lower pH or more acidic in the system and initiates more corrosive environments for the corrosion of reinforced steel bar inside the cement paste [22-23].

4. CONCLUSION

The addition of aluminum white-powdered sludge into the cement paste results in more porosity in the cement paste than that without the addition, which is not that in a significant degree. The bulk density of the cement paste with adding aluminum white-powdered sludge becomes slightly lowered than that without adding aluminum white-powdered sludge. Nevertheless, the compressive strength of the cement paste with the addition of aluminum white-powdered sludge is higher than that without the addition of aluminum white-powdered sludge. The corrosion on the reinforced steel bar is enhanced by pores in the cement paste. To summarize the study, adding admixtures can improve mechanical properties of the cement paste but it can damage the reinforced steel bar if the pore's formations in the cement paste are much generated.

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