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Effect of fly ash on the potential alkali silica reaction of ferronickel slag aggregate

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Abstract: Ferronickel slag (FNS) is generated as a by-product during the production of ferronickel. The rapid cooling process of the slag may lead to the formation of amorphous silica. Therefore, partial replacement of sand with nickel slag aggregate has potential to show expansion due to alkali silica reaction (ASR). The present study evaluates the effect of fly ash as a supplementary cementing material (SCM) to mitigate this deleterious expansion. Fly ash was used as 10%, 20% and 30% of the binder in order to investigate its effect on the reduction of ASR. The results of accelerated mortar bar test (AMBT) show that 10% replacement of cement by fly ash was unable to reduce expansion below the required level. Furthermore, use of 20% fly ash reduced the expansion by 45% compared to 10% fly ash samples, but still the expansion level of the samples was within the category of slowly reactive aggregate according to AS 1141.60.1-14. However, use of 30% fly ash reduced ASR expansion below the 10-day and 21-day limits of the standard. It was found that expansion did not increase for the extended period of test in the samples containing 30% fly ash. The microstructural observation was carried out to confirm the effectiveness of fly ash to mitigate this expansion.

Keywords: Alkali silica reaction, nickel slag, fly ash, amorphous silica.

1. INTRODUCTION

Concrete is the most highly consumed construction material. The demand for concrete is rising by 6% every year because of the immense infrastructure growth in developing countries (Ghods et al. 2017; Mehta 2009). Fine aggregate is an integral part in concrete, which fills up the voids and provides rigidity. Thus, chemically inert and good quality fine aggregate is essential for the concrete industry. Sand has been fulfilling this demand for decades. Therefore, uncontrolled dredging has been observed in different places (Preciso et al. 2012; Davis et al. 2000). Excessive sand mining can cause disruption of the ecosystem and increase the risk of landslides in hills (Padmalal et al. 2008; Sajinkumar et al. 2014). Therefore, it is essential to find a suitable alternative to replace sand for sustainable infrastructure development.

Alkali silica reaction (ASR) is an important issue of concrete using reactive aggregates. The reaction between reactive siliceous aggregate and the alkali present in binder generates an expansive gel. This gel induces swelling pressure that may cause cracking and strength reduction of concrete. This deleterious expansion was brought into light by Stanton (1940). Since then, substantial research work has been conducted on ASR. The alkali (R+) from the pore solution reacts with the silica (≡Si-O-Si≡) in the initial stage of ASR. As a result, alkali silicate (Si-O-R) gel and silicic acid (Si-OH) are generated. Later, the silicic acid reacts with the alkali and produces more alkali silicate. During the final stage, this gel absorbs moisture from pore solution and undergoes volume expansion. This volume expansion creates swelling pressure in the binder matrix and aggregate (Glasser 1992; Ichikawa & Miura 2007).

In order to minimize ASR expansion, various supplementary cementing material (SCM) has been adopted over last decades. SCMs can reduce the alkalinity of the pore solution by alkali binding (Thomas, M. 2011). Thus, the application of ground granulated blast furnace slag (GGBFS) and fly ash could reduce the expansion due to ASR (Thomas, 1996). The chemical composition of SCMs plays a significant role in this process. High calcium fly ash (class C fly ash) found to be less effective to mitigate this expansion as compared to low calcium fly ash (class F fly ash) (Shehata et al. 1999; Shehata & Thomas 2002).

A significant quantity of FNS is generated as a by-product of nickel production process. High density and low water absorption make this aggregate a potential candidate to replace sand from concrete (Saha, & Sarker, 2017a). Our past studies (Saha & Sarker 2017a; 2017b) pointed out that 50% FNS and 50% sand combination provided optimum workability and strength. Thus, the alkali silica reactivity of this aggregate combination has been presented in this paper. Effect of different dosage of fly ash on the potential ASR of FNS has been studied. Fly ash was used as a replacement cement by 10% to 30%. Microstructural study by scanning electron microscopy (SEM) was adopted to evaluate the accelerated mortar bar test (AMBT) results.

2. EXPERIMENTAL WORK

2.1 Materials

Commercially available Class F fly ash and Portland cement (OPC) were the primary binders used in this study. The FNS aggregate was obtained from New Caledonia. The chemical composition of OPC, fly ash and FNS are shown in Table 1. The physical properties of FNS and sand are given in Table 2.

Table 1. Chemical compositions of OPC, FNS & fly ash (mass %).

Material	OPC	FNS	Fly ash
SiO_2	20.29	53.29	76.34
Al_2O_3	5.48	2.67	14.72
Fe_2O_3	2.85	11.9	3.69
MgO	1.24	31.6	0.54
SO_3	2.49	-	0.11
CaO	63.11	0.42	0.60
Na_2O	0.29	0.11	0.19
K_2O	0.45	-	0.96
Cr_2O_3	0.02	1.08	-
P_2O_5	0.17	-	0.10
SrO	0.05	-	-
TiO_2	0.27	-	0.61
Mn_2O_3	0.08	-	0.07
ZnO	0.04	-	-
NiO	-	0.1	-
Co_3O_4	-	0.01	-

Table 2. Physical properties of FNS and sand.

Property	Sand	FNS
SSD density (kg/m^3)	2160	2780
Apparent particle density (kg/m^3)	2320	2850
Fineness modulus	1.95	4.07
Water absorption	0.35	0.42

2.2 Methods

The mortar mix proportions are given in Table 3. Mortar bar samples were prepared during this study according to the Australian Standard (AS 1141.60.1, 2014). A total of four different mortar mixtures were prepared during this study. The mixtures were prepared with an aggregate to binder ratio of 2.25 and water to binder ratio of 0.47. The specimens were 25×25×275 mm mortar bars with studs inserted at the ends. After 24 hours of casting the samples were stripped off from the mould and kept in a water of 80 °C for 24 hours. Afterwards, the samples were taken from the water bath and the surface was wiped. The length was then measured within 10 seconds by a digital length comparator. Later, the samples were placed in 1M NaOH solution at 80 °C for a period of 21 days and the length change was measured in a similar procedure after 3, 7, 10, 14, 17 and 21 days. After 21 days of testing, visual inspection of the sample was carried out. Later, the samples were saw cut with a concrete saw into small pieces for microstructure studies.

Table 3. Mixture proportions of mortars.

Mix ID	Binder (kg/m^3)		Fine aggregate (kg/m^3)		W/C
	OPC	FA	Sand	FNS	
OPC100	602	-	678	678	0.47
FA10	541.8	60.2	678	678	
FA20	481.6	120.4	678	678	
FA30	421	181	678	678	

3. RESULTS

3.1 Expansions of accelerated mortar bar test

Accelerated mortar bar test is one of the quickest test to determine the alkali silica reactivity of aggregates. According to the AS 1141.60.1-14 standard, mortar bar expansions below 0.1% after 21 days of testing are designated as non-reactive. Expansion between 0.1% and 0.3% is classified as slowly reactive and expansion above 0.3% has been placed in a reactive category. The experimental results of the mortar bars are presented in Fig. 1. It can be seen that after 21 days of the testing period, the expansion OPC100 was 0.66% which is well over the allowable limit of 0.3% and classified as reactive. With the addition of 10% fly ash, the expansion was found to be 0.39%, which is still in the reactive category, even though the expansion was reduced by 34% comparing to control specimen. The samples with 20% fly ash exhibited expansion of 0.167%, which is in the slowly reactive category according to the AS 1141.60.1 (2014). In addition, 30% fly ash samples exhibited expansion of 0.03% after 21 days. This expansion value is significantly lower comparing to OPC100 samples and can be classified as non-reactive.

After the test period, the samples were taken out from the test condition and cooled down to room temperature for through visual inspection. It was found that OPC100 and FA10 samples exhibited cracks on the surface. The cracks are considered to be because expansion during the AMBT. However, FA20, which was designated as slowly reactive, did not exhibit any surficial cracks. Furthermore, FA30 did not exhibited any cracks, which is consistent with the low expansion values showed in Fig. 1.

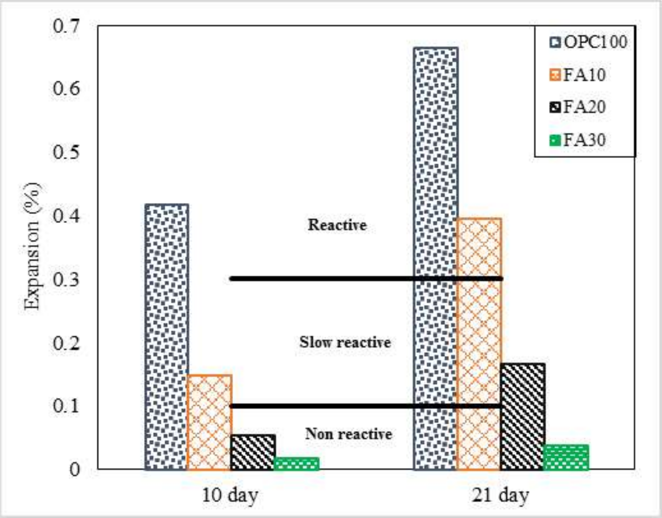

Fig. 1. ASR expansion of samples containing different percentage of fly ash.

3.2 Observation of the microstructure

Microstructure investigation was carried out by scanning electron microscopy (SEM) to evaluate the effect of fly ash on ASR expansion. The samples were carbon coated and images were taken using backscattered electron (BSE). During the imaging of the samples, energy dispersive spectroscopy (EDS) was conducted for both the samples in order to determine the Ca/Si ratio of the gels. Fig. 3 (a) shows the microstructure of the sample of OPC100. This sample had an expansion of 0.66%. It is noticeable that several micro cracks appeared around the aggregate as well as some cracks across the aggregate. The chemical reaction between reactive aggregates of FNS with the pore solution's alkali generated the ASR gel. These cracks developed around the FNS aggregate and extended to the binder matrix, therefore, caused expansion and cracking to the samples. The EDS analysis was carried out to determine the Ca/Si ratio of the ASR gel and it was found to be 1.78. The SEM image of samples containing 30% fly ash (FA30) is shown in Fig. 3. It is noticeable that the aggregate surface did not have any ASR gel to cause significant cracking around the aggregates. The formation of voids is significantly less as compared to OPC100. The EDS analysis on the perimeter of the aggregates exhibited a Ca/Si ratio of 2.63.

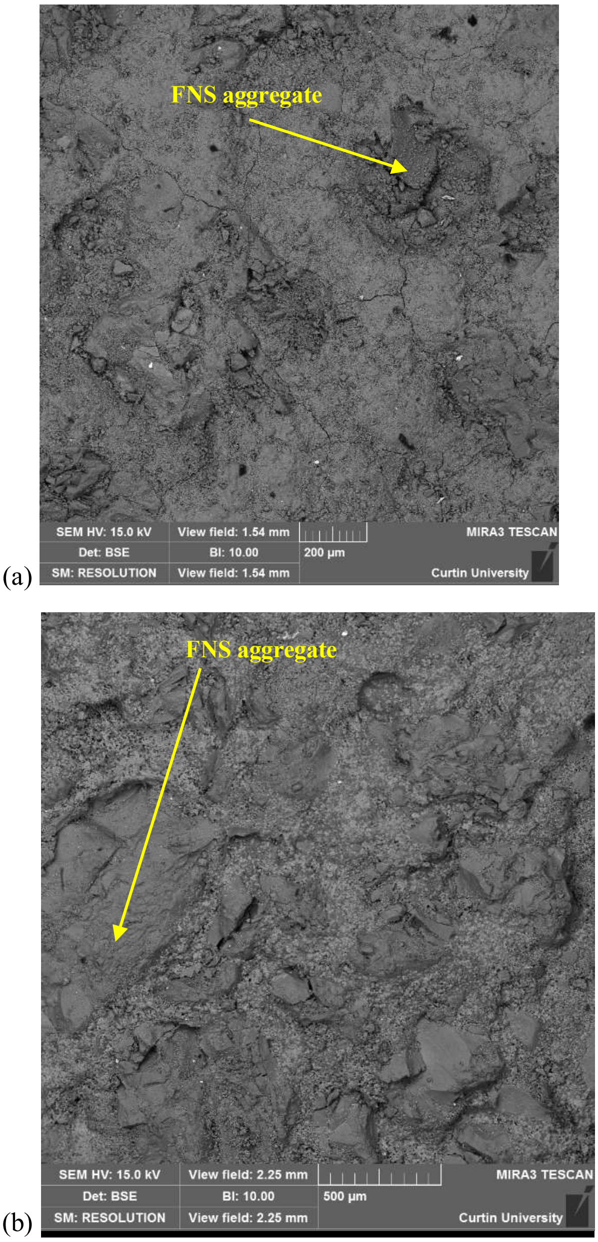

Fig. 3. SEM images of OPC100 and FA30 samples.

4. DISCUSSION

It was found that the use of fly ash reduced ASR expansion of FNS aggregate and 30% replacement was found to be most effective. It is considered that fly ash helped in three different ways. Fly ash reduced the alkalinity of pore solution. Application of fly ash reduced the overall calcium content of the total binder matrix, which acts as a buffer to maintain the pH in pore solution. In addition, the pozzolanic reaction of fly ash removes the free alkali from the pore solution (Shehata et al. 1999; Shehata & Thomas 2002).

Fly ash plays a vital role to reduce the permeability of the binder matrix. The internal voids in the binder matrix are filled by the formation of secondary C-S-H gel produced by fly ash (Ghrici et al. 2007). In AMBT test condition samples are exposed to alkaline solution. Therefore, fly ash reduces the permeability and limits the external alkali absorption.

Fly ash also modifies the ASR gel. Fly ash react with the alkali silicate gel and the change the swelling properties of the gel. The EDS analysis was carried out to determine the Ca/Si ratio of ASR gels for the samples and the values were 1.78, and 2.63 for OPC100, and FA30 samples, respectively. Therefore, ASR gel with high Ca/Si ratio consist of low swelling pressure to cause cracking in the surrounding environment. As a result, 30% fly ash samples did not exhibit expansion and cracking during the AMBT.

5. CONCLUSIONS

ASR expansion of FNS aggregate was studied by the accelerated mortar bar tests. The samples consisted of 50% FNS and 50% natural sand. Cement was replaced by class F fly ash at rates of 10%, 20% and 30%, respectively. The AMBT test was conducted to evaluate the reactivity of the samples and it was found that the samples with 10%, 20% and 30% fly ash were in reactive, slowly reactive and non-reactive category according to Australian Standard. No surficial cracks were noticeable for 20% and 30% fly ash samples, whereas control and 10% fly ash samples exhibited significant cracking. The addition of fly ash reduced the pore solution alkalinity, by alkali binding and modified the ASR gel to minimize the swelling pressure and cracking.

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