USING GEOPOLYMER TECHNOLOGY ON REUTILIZATION OF BOF SLAG

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Abstract - Basic Oxygen Furnace (BOF) Slag is the by-product of the iron making industry. It produced over 150 million tons annually in Taiwan. This kind of slag has great engineering properties, such as, high hardness and density, high compressive strength, low abrasion ratio, and can replace natural aggregate for building materials. However, BOF slag has the expansion problem, due to it contains free lime and MgO. The purpose of this study was to stabilize the BOF slag's expansion behavior by using geopolymer technology, hoping can prevent the expansion problem and reutilization successfully. The experimental results showed that using geopolymer technology can successfully prevent the expansion problem. The main properties are analyzed with regard to their use as building materials. Autoclave is used to study the volume stability of these specimens. Finally, the compressive strength of geopolymer mortar with BOF slag can be reached over 21MPa after curing for 28 days. After autoclave testing, the volume change rate can be controlled lower than 0.2%. In this study have success using these results on ready-mixed concrete plant, and have the same experiment results as laboratory scale, the specimen's compressive strength can be reached over 40MPa after curing for 28 days. These results gave encouragement that using geopolymer technology on reutilized BOF slag has a great potential.

Index Terms - BOF slag, Geopolymer, Free lime, Swell behavior.

I. INTRODUCTION

Basic Oxygen Furnace (BOF) slag is a by-product of the steelmaking industry. In basic oxygen furnace iron making, limestone is added to react with the gangue minerals to form slag[1]. The major chemical composition of BOF slag are calcium, iron and silicon oxides in a total amount of over 70%, aluminum, magnesium, and manganese are also present, and their production in Taiwan is about 1.5 million tons every year[2]. BOF slag has lots of superior engineering characteristics than natural aggregates, such as Los Angeles abrasion, California bearing ratio, compressive strength, and Moh's scale of hardness. But, BOF slag has major problems in recycling and reuse, that is it contains a huge amount of free-lime, it will cause the swell problem [3]. It will cause BOF slag only can using in engineering backfilling or mix with asphalt to form asphalt concrete. However, fine BOF slag (under 4 mesh) not only can't use in asphalt concrete but also can't use in the cementitious system[4], and there were produced over 600 thousand tons of fine BOF slag were storage and can't be used. Therefore, reutilizing the fine BOF slag has become a big issue in Taiwan. The purpose of this study was to stabilize the BOF slag by using geopolymer technology. BOF slag as a replacement for fine aggregates in geopolymer system. According to previous research indicate that geopolymer system can inhibit the expansion properties of swell behavior materials. Because it contains a huge amount of free silicon and it can react with free-lime to form a stable compound. Furthermore, geopolymer material has low permeability coefficient, it can prevent the steam or water get into the core of specimen and react with free-lime.

In this study, BOF slag, granulated blast furnace slag(GBFS) powder and coal fly ash(FA) were used as raw materials to fabricate BOF slag based geopolymer green mortar under the activation by alkaline solutions. The effect of SiO_2/Na_2O moral ratio in alkaline solutions and BOF slag additional amount on BOF slag based geopolymer green mortar's compressive strength and swell behavior are presented in this study. The swell behavior of BOF slag based geopolymer green mortar was using autoclave testing method as accelerated test [5]. After the experimental test, the optimal parameter will testing on the pilot-scale test in the ready-mixed plant.

II. EXPERIMENT PROCESS AND MATERIAL

The fine BOF slag samples were produced by a steelmaking industry in southern Taiwan. The chemical composition of BOF slag as listed in Table 1, and the particle size distribution is shown in Figure 1. XRD analysis result is shown in Figure 2. The major composition in BOF slag was CaO and Fe_2O_3, it also contains 4.7 wt.% of free-lime and it will cause the swell problem. After using CNS15311 to test the swell behavior of BOF slag, the result is shown in Figure 3. As the result shown, the expansion problem of BOF slag is over 4 vol.%, thus, it will have a huge swell problem.

The GBFS powder samples were produced from an iron-making industry in southern Taiwan. The FA(Coal fly ash) were collected from a coal-fired power plant in southern Taiwan. Chemical composition and particle size of GBFS powder and FA are listed in Table 2. The major compositions in GBFS powder were CaO and SiO_2, and the particle size of d_{50}

is around 12.5μ m. About the major compositions in FA were SiO_2 and Al_2O_3, and the particle size of d_{50} is around 26.7μ m. Alkali solution was prepared by mixing NaOH and Sodium silicate.

The experimental procedure and test parameters were shown in Figure 2 and Table 3. All the BOF slag based geopolymer green mortar samples will use autoclave test to measure the volume stability, and this method is according to CNS 1258 standard.

Table 1 Chemical composition of BOF slag

Composition	wt.%
Fe_2O_3	24.1
CaO	37.1
SiO_2	9.4
MnO	2.3
Al_2O_3	4.2
MgO	7.1
Na_2O	4.0
f-CaO	4.7
L.O.I	0.8
Other	6.3

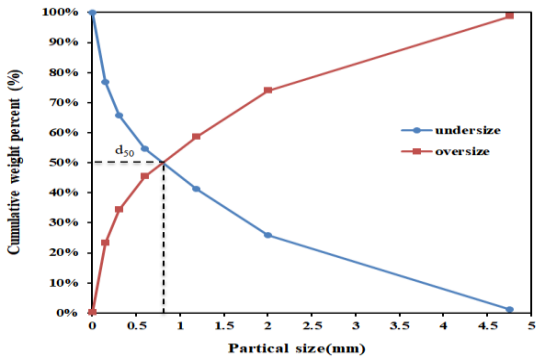


Fig. 1 Particle size distribution of BOF slag

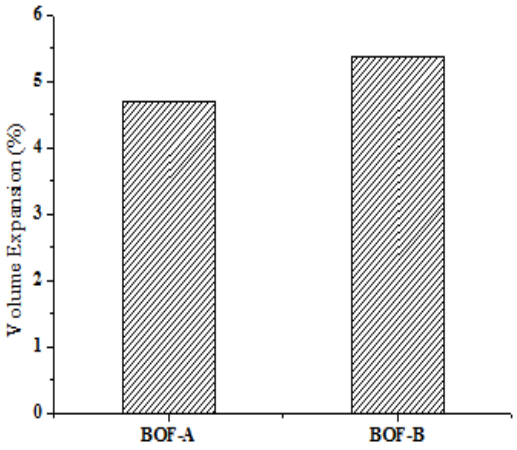


Fig. 2 Swell behavior of BOF slag

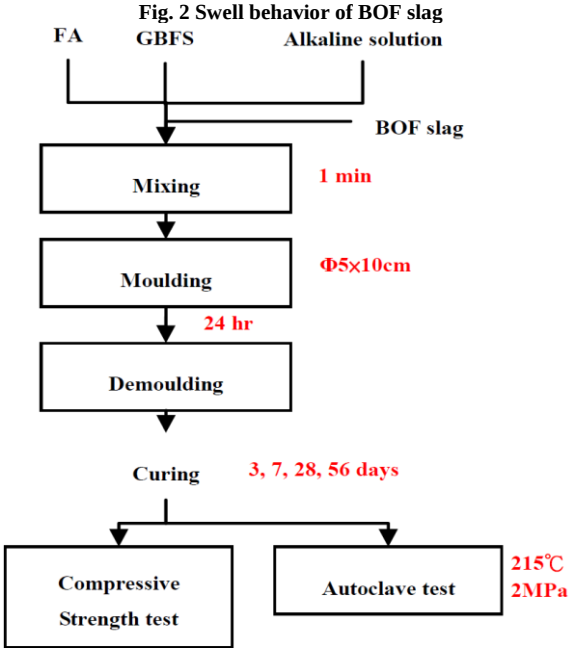


Fig.3 Overall experiment procedures

Table 2 Chemical composition and particle size of GBFS and FA

Composition wt. %	SiO_2	CaO	Al_2O_3	Fe_2O_3	L.O.I.	Other	d50 (μm)
GBFS powder	27.7	57.9	11.2	0.4	-	2.8	12.5
FA	60.2	2.7	19.1	8.7	2.9	6.4	26.7

Table 3 Experiment parameters

Experiment No.	Binder Materials wt. ratio		BOF slag wt. ratio	Alkaline solution SiO_2/Na_2O molar ratio
	GBFS	FA		
GF128	5	5	27.5	1.28
GF140				1.4
GF150				1.5
GF160				1.6

III. RESULTS AND DISCUSSION

The swell behavior of BOF slag in cement and geopolymer system

The result of using BOF slag as fine aggregates in Portland cement system and geopolymer system are shown in Table 4. According to the experiment results, after autoclave test, the steam will accelerate the

reaction of free-lime, and it causes the expansion problem, thus, when BOF slag in Portland cement system, the samples will collapse. But, the geopolymer specimens unaffected after autoclave test. There have two reasons can explain the geopolymer can stabilize the swell behavior of BOF slag. First, the geopolymer system contains a huge amount of free silicon.

These free silicon can react with free-lime BOF slag, and form a stable compound, therefore inhibit the expansion of the BOF slag. Second, the permeability coefficient between cement mortar and geopolymer mortar are listed in Table 5. According to the results shown, the permeability coefficient of geopolymer mortar is less than Portland cement. Thus, it can prevent the steam to get into the interior of the sample.

Table 4 BOF slag swell behavior in cement and geopolymer system (Binder:BOF slag=1:2.75, curing for 7days)

BOF slag in Portland cement system	
Before autoclave test	After autoclave test
	
BOF slag in geopolymer system	
Before autoclave test	After autoclave test
	

Table 4 The Permeability coefficient of cement and geopolymer system (Binder:fine aggregates =1:2.75, curing for 7days)

Experiment No.	Permeability coefficient(cm/s)
Cement mortar	3.24×10^{-10}
Geopolymer martar	2.71×10^{-12}

Effect of alkali solution's SiO_2/Na_2O molar ratio on BOF slag based geopolymer mortar

The effect of alkali solution's SiO_2/Na_2O molar ratio on BOF slag based geopolymer mortar compressive strength are shown in Figure 4.

The compressive strength of BOF slag based geopolymer mortar was affected by the alkali solution's SiO_2/Na_2O molar ratio. As shown in Figure 4, the compressive strength increases as the amount of SiO_2/Na_2O molar ratio increased. Because the structure of geopolymer needs Si, thus, when increasing the SiO_2/Na_2O molar ratio, it will let geopolymer structure more complete and increase the strength at the same time.

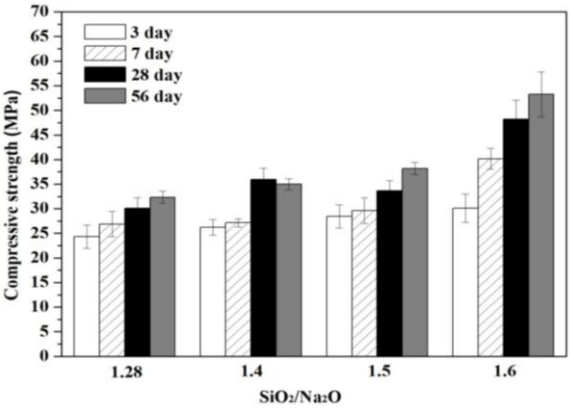


Fig. 4 Before autoclave test, the effect of alkali solution's SiO_2/Na_2O molar ratio on BOF slag based geopolymer mortar's compressive strength (Binder: BOF slag=1:2.75, GBFS:FA=5:5)

The effect of alkali solution's SiO_2/Na_2O molar ratio on length expansion of BOF slag based geopolymer mortar is shown in Figure 5. As the results shown, when the SiO_2/Na_2O molar ratio is 1.4~1.5 has the most slight length expansion. All the samples after autoclave test, it will test the difference of compressive strength, the result is shown in Figure 6. As the result shown, all the compressive strength of BOF slag based geopolymer mortar are increased. Due to the steam from autoclave will accelerate the geopolymer reaction, and cause the strength increased.

Pilot-Scale test of BOF slag based geopolymer mortar

According to the experiment results, it shows that BOF slag based geopolymer mortar is very stable, and the swell behavior of BOF slag can be controlled. Therefore, in order to understand the feasibility of the application in the future, the pilot-scale test was carried out. The pilot-scale test parameters are listed in Table 5. The Situation of BOF slag based geopolymer mortar pilot-scale test is shown in Figure 7, and the compressive strength of BOF slag based geopolymer mortar is shown in Figure 8.

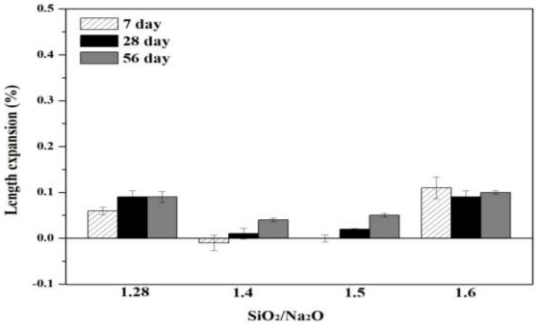


Fig. 5 After autoclave test, the effect of alkali solution's SiO_2/Na_2O molar ratio on BOF slag based geopolymer mortar's length expansion (Binder: BOF slag=1:2.75, GBFS:FA=5:5)

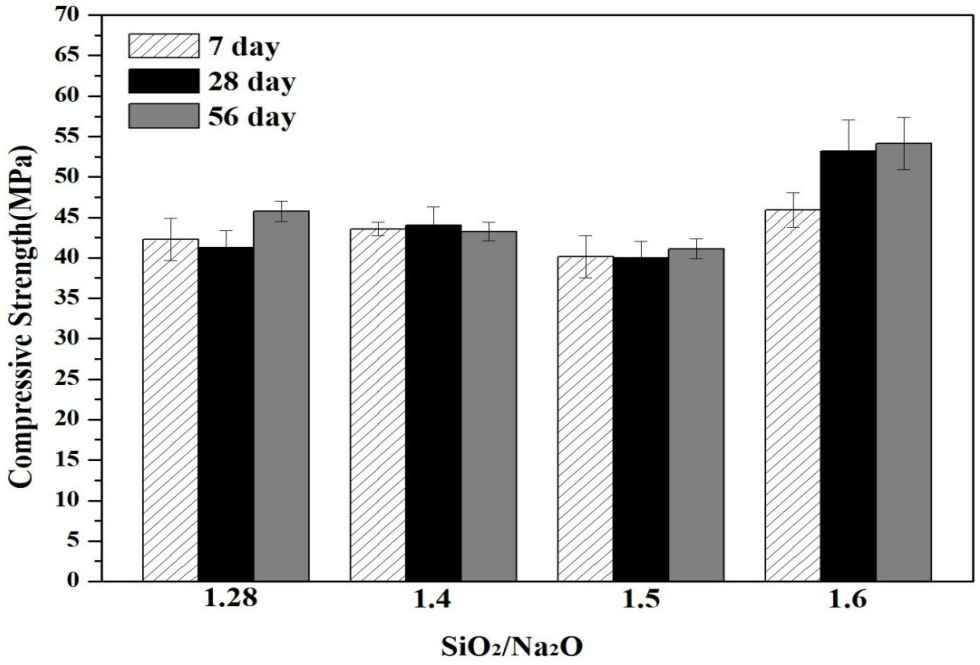


Fig. 6 After autoclave test, the effect of alkali solution's SiO_2/Na_2O molar ratio on BOF slag based geopolymer green mortar's compressive strength (Binder: BOF slag=1:2.75, GBFS:FA=5:5)

Table 5 Pilot-scale test parameters

Experiment No.	Dosage (kg)					Slump Flow (cm)
	Alkali solution	GBFS	FA	BOF slag	Water	
1070723-1	250	250	250	1600	15	26.5
1070723-2	230	180	270	1700	40	26.0

As the result shown, the BOF slag based geopolymer mortar has great workability. The compressive strength of specimen after curing for 28 days, it can be higher than 42MPa, after autoclave test, the compressive strength still can be higher than 30MPa, it is suitable for most of the civil engineering application.



Fig. 7 The Situation of BOF slag based geopolymer mortar pilot-scale test

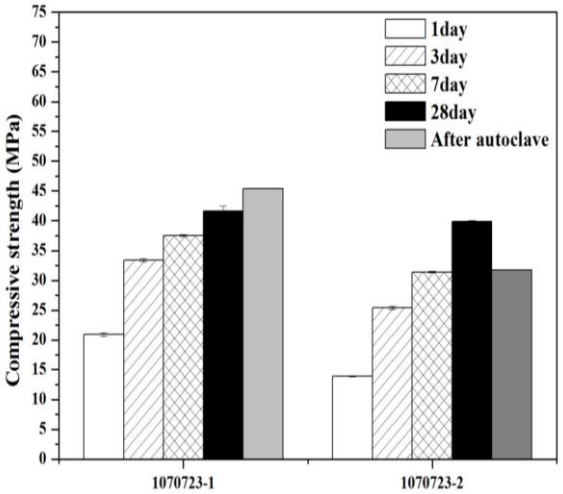


Fig. 8 Pilot-scale test- compressive strength of BOF slag based geopolymer mortar

CONCLUSION

BOF slag based geopolymer mortar was successfully developed in this study. After curing for 56 days, the compressive strength of BOF slag based geopolymer green mortar can be higher than 40 MPa. After autoclave test, the length expansion of BOF slag based geopolymer green mortar can be controlled less than 0.05%, and the compressive strength of BOF slag based geopolymer green mortar can be reached over

45 MPa. After the pilot-scale test, the BOF slag based geopolymer mortar has a similar result to the laboratory-scale test. After curing for 28 days, the compressive strength can be higher than 40MPa.

Therefore, it is believed that the fabrication of BOF slag based geopolymer mortar has great potential for civil engineering application.

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