



## AN EXPERIMENTAL STUDY ON UTILIZATION OF SLAG AND FLY ASH AS AN ALTERNATIVE CEMENTITIOUS BINDER

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### ABSTRACT

*This study investigates the utilization of slag and fly ash (FA) as alternative cementitious binder. Combination of 60% slag and 40% FA was used as new binder. In addition, for activation of slag and FA, sodium hydroxide and calcium hydroxide was used as a chemical activator by 5% weight of the binder, separately. Water to binder and sand to binder ratios was kept 0.55 and 3 in mortar preparation, respectively. Superplasticizer was used by 2.5% of the weight of binder to get reasonable flow for casting. Physical and chemical properties of slag and FA, and fresh and hardened properties of mortar of the new binder were determined and compared with that of OPC. Experimental results reveal that new binder shows slightly lower flow ability than that of OPC. New binder which was activated by sodium hydroxide sets early than OPC. Mortar as produced from new binder with sodium hydroxide shows 12.02, 18.15 and 26.20MPa compressive strength at 7, 14 and 28 days, respectively; while OPC mortar achieved 25.67, 30.08 and 35.78MPa compressive strength at the same ages and conditions. Sodium hydroxide exhibits greater activation performance than that of calcium hydroxide. Thus, depending on the preliminary test results it can be concluded that, with the presence of chemical activator, slag and FA can be used together as an alternative of OPC.*

**Key Words:** Slag, Fly ash, Portland cement, Alternative binder, Chemical activator.

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## INTRODUCTION

Obviously, ordinary Portland cement (OPC) is the mostly consumed cement in the construction industries due to its diversified applications. It could be noted that cement contributes significant impacts on social, urban and economic development of human society but it is one of the elements responsible for carbon dioxide emission (Mehta, 1999). Thus, to reduce demand and consumption of cement, nowadays utilization of ground granulated blast furnace slag, fly ash (FA) and other pozzolans as substitute/supplement of OPC and ingredient of concrete is one of the key research interest in cement and concrete research area. In addition, their application in concrete construction will be the possible suggestions/solutions for the sustainable concrete production which was claimed by the several researchers.

Slag is an industrial by-product generated as waste from steel industries. Approximately, 100 million tons of slag is produced globally in a year (Nehdi, 2001). FA is another waste material produced as by-product from coal operated power plants. It was reported that worldwide FA generation rate is about 900 million tons annually (Malhotra, 2006). It is relevant to mention that slag and FA are pozzolanic wastes which show technical and financial merits. In fact, they are usually discharged into landfills as waste material. Accordingly, huge environmental pollutions including soil and water contamination have been observed for their disposal reasons.

It is well known that slag and FA consist of elevated amount of silicon dioxide or alumino silica in amorphous form. Therefore, they could be used as substitute and supplement of cement in concrete production. Usually, fresh, hardened and durability properties of mortar and concrete are significantly enhanced for their involvement. For instance, utilization of slag in concrete usually shows better performances such as improves durability and reduces porosity of concrete; decreases demand of cement, saves energy (Oner and Akyuz, 2007); increases sulphate resistance (Binici, *et al.* 2007). It was reported that, for 20% FA replacement, compressive strengths of mortar found to be 75% of the standard mortar at the ages of 7 and 28 days but it is more than 100% of the standard mortar after 60 days (Cheerarot and Jaturapitakkul, 2004).

It is noted that most of the previous researches were performed using slag or FA as partial replacement of cement. In the present study, as an alternative of cement, performance (based on setting time, flow and strength) of a new binder (obtained from combination of 60% slag and 40% FA) was investigated through chemical (sodium hydroxide and calcium hydroxide) activation technique; and obtained results were compared with that of OPC.

## EXPERIMENTAL PROCEDURE

Ground granulated blast furnace slag, and FA as collected from local industries, Selangor, Malaysia were used in this study. Locally available OPC was taken to compare the different properties

(physical, chemical, binding, flow, flexure and compressive strength of the new binder). Local river sand passing through 4.75mm sieve was used as fine aggregate. The sodium hydroxide (NaOH) and calcium hydroxide (Ca(OH)<sub>2</sub>) flakes were used as a chemical activator. Superplasticizer (the Darex Super 20 from Grace) was used to increase and maintain a sufficient flow for casting of mortar. Available supply water was used for mortar preparation and curing purposes.

Different tests were performed using following equipments: Automatic Blaine machine to find fineness of materials; Le Chartelier flask used for specific gravity determination; Malvern Mastersizer 2000 (for grain size analysis); X- ray fluorescence (XRF) for chemical composition. Hobart mixing machine was to mix the paste and mortars. A computerized universal testing machine of 30kN capacity (for flexure test) and compression machine (unit test Sdn Bhd brand of 3000kN capacity) was used for compressive strength tests.

ASTM C187-04, ASTM C191-08 testing standard was followed to determine consistency and setting time of paste using Vicat apparatus, respectively. The mortar flow spread test was done using a flow table based on ASTM C1437-07 testing procedure; BSEN196-1 testing standard was used to determine flexural strength of prism (40mm×40mm×160mm in size), and then the broken prisms were used for determination of compressive strength of mortar.

Table 1 represents mixing proportions of the raw materials (slag, FA and OPC). Mixing and preparation of paste and mortar was done according to ASTM C305-06 specification; only few modifications were made such that before pouring the binder to the water, NaOH flakes was pour into the water. For dilatation of NaOH flakes, about 60±10 seconds was required. After casting, prism mould of OPC was opened after one day but more than 3 days was needed to open the moulds of new binder as activated by Ca(OH)<sub>2</sub> (because of delay hardening/strength achievement). Prism samples were kept into curing water tank (at room temperature of 25±2<sup>0</sup>C) until desire testing age of 3 days, 7 days, 14 days and 28 days.

**Table- 1.** Proportions of raw materials used for preparation of mortar (% wt).

Binder	Materials (%)			Super plasticizer (% of binder)	Activator (% of binder)	Water to binder ratio	Sand to binder ratio
	Slag	FA	OPC				
NB1	60	40	0	2.5	5% NaOH	0.55	3
NB2	60	40	0	2.5	5% Ca(OH) <sub>2</sub>	0.55	3
OPC	0	0	100	2.5	-	0.55	3

## RESULTS AND DISCUSSION

### Chemical and physical properties of materials

The chemical and physical properties of materials are presented in Table 2. The Table shows that slag and FA contain total percentage of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> in between 50% to 70% which is higher than the minimum value (50%) as specified in ASTM C-618 for class C pozzolan. The loss

of ignition is higher for FA, which is less than 10% as prescribed of ASTM C-618. It is also found that average particle sizes of the materials are 14.67 $\mu\text{m}$  for slag, 14.95 $\mu\text{m}$  for FA and 16.17 $\mu\text{m}$  for OPC. Specific gravity and fineness of the particles are also mentioned in the Table. Slag shows maximum fineness.

### Consistency, setting time, and flow of binders

The consistency of the new binders was determined and obtained values are presented in Table 3. The Table shows that consistency of OPC is 29.5%, while consistency of new binder shows increased values of 33%. This increased consistency of new binder happens due to fine particles, better fineness and more surface area of slag and FA. Therefore, it can be understood that pastes of new binder show greater consistency as compared to OPC pastes. Cheerarot and Jaturapitakkul (2004) was reported that normal consistency of FA paste is higher than that of OPC.

**Table- 2.** Chemical and physical properties of materials (wt.%).

Material	Chemical Properties, Oxide compositions (%)											
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	MnO	LOI
Slag	33.05	16.36	0.53	45.0	6.41	1.21	0.13	0.42	-	-	-	3.05
FA	48.67	14.31	3.51	1.03	0.39	0.14	0.21	0.79	-	1.13	0.02	6.26
OPC	20.99	4.60	4.44	67.17	2.53	2.98	0.03	0.16	-	-	-	1.3
Physical properties												
	Specific gravity	Average grain size d <sub>50</sub> ( $\mu\text{m}$ )	Fineness (cm <sup>2</sup> /gm)				Color					
			Blaine	Retained on 45 $\mu\text{m}$ sieve								
Slag	2.85	14.67	3919	0.13			Near white					
FA	2.42	14.95	3567	26.21			Blackish white					
OPC	3.14	16.17	2580	13.52			Grey					

Setting time of the new binders is also shown in the Table 3. It is observed from the Table, the setting time of the new binder (activated by NaOH) is lower as compared to OPC. The initial setting time of OPC pastes is found to be 2h and 13min; it is 25min for NB1. Final setting time was also found to be less in the case of NB1. Although initial setting time of new binder is observed to be less than 45 min but final setting time is not more than or equal to 375min (as specified in ASTM C150 for OPC).

**Table- 3.** Consistency, setting time, and flow of binders

Binder	Consistency (%)	Setting time (hour: min)		Flow (%)
		Initial	Final	
OPC	29.5	2:13	5:12	68
NB1	33.0	0:25	1:25	42
NB2	33.0	3:45	12:25	54

Flow of the new binder is also presented in Table 3. This results show that flow of OPC pastes is 68%. But flow is reduced for the new binders. Lower flow ability of the mortar was obtained due to use of local river sand, and more specific surface area of slag and FA. Hence, they require more quantity of water.

### Flexural and compressive strength of binders

Flexural strength of the mortars was determined and test results are presented in Table 4. The Table reveals that flexural strength of new mortars as activated by NaOH is lower at early ages up to 14 days but it is comparable at 28 days. In contrast, mortar as obtained using  $\text{Ca}(\text{OH})_2$  show very low flexural strength up to 28 days.

**Table- 4.** Flexural and compressive strength of binders

Binder	Compressive strength (MPa)				Flexural strength (MPa)			
	3 days	7 days	14 days	28 days	3 days	7days	14 days	28 days
OPC	19.94	25.67	30.08	35.78	3.89	5.62	5.80	6.91
NB1	-	12.02	18.15	26.20	2.34	4.93	5.72	6.14
NB2	-	-	7.35	10.12	-	-	-	1.31

Compressive strength of mortar obtained from NB1 shows less strength up to 14 days, it is reasonable at 28 days. This strength development was found due to the following multiple reasons: (i) pozzolanic effect of slag and FA, (ii) cementitious activity of slag, and (iii) chemical effects of activators. In contrast, the less strength was obtained for the case of  $\text{Ca}(\text{OH})_2$  activator. This happens may be the following cause – when same amount of  $\text{Ca}(\text{OH})_2$  and NaOH flakes dissolve in same volume of water separately, then  $\text{Ca}(\text{OH})_2$  produces lees concentrated solution (in terms of Molarity).

However, the pozzolanic reaction, though it is formed slowly, depends on the availability of  $\text{Ca}(\text{OH})_2$ ; consequently, longer time is required to gain the strength of slag concrete (Oner and Akyuz, 2007). During the hydration of slag, a reaction is occurred among slag with alkali and  $\text{Ca}(\text{OH})_2$ , as a result, there produce additional calcium silicate hydrate gel (ACI Committee-233R 1997).

### CONCLUSIONS

From the chemical test results, it was found that slag and FA contain high amount of silica and sufficient amount of major oxides. Consequently, they perform as a binder with the presence of chemical activators, the  $\text{Ca}(\text{OH})_2$  or NaOH. The new binder exhibits reasonable binding and flow value. It also shows considerable flexural and compressive strength at 28 days. Accordingly, experimental results support that slag and FA can be used as substitute of cement provide that these materials should be prepared properly with maintaining high fineness (Blaine fineness about 3600  $\text{cm}^2/\text{gm}$ ). In addition, chemical activator must be utilized. Thus, depending on the overall test

results, it can be predicted that development of a new binder from locally available slag and FA is likely to be practical. Moreover, a possible and sustainable way would be found for sustainable concrete construction by consumption of slag and FA as a substitute of cement.

## ACKNOWLEDGEMENTS

The authors would be indebted to Almighty Allah for performing this research. Special gratitude and appreciation are due to University Kebangsaan Malaysia; Ministry of Science, Technology and Innovation; Fundamental Research Grant Scheme for economical, technical and experimental supporting to carry out the research.

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