Evaluation Of Using Cement In Alkali-Activated Slag Concrete

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Abstract: This paper presents an evaluation of utilizing cement (OPC) as a partially replacement from slag (GGBFS) in Alkali Activated Slag Concrete (AASC) mixes cured in ambient conditions. The evaluation of mixes was performed based on workability and compressive strength using Taguchi method. The aluminosilicate source was a mix of GGBFS and OPC, while the alkaline activator was made with a mix of Sodium Hydroxide (SH) and Sodium Silicate (SS). The four parameters considered in this study are: GGBFS:OPC ratio, Na_2O ratio, solution modulus (Ms) and water to binder ratio (W/B). Nine mixes were conducted using L9 Taguchi array. Slump test and compression test were carried out on all mixes. The results were evaluated by determining Signal-to-Noise (S/N) ratio using Minitab program and making ANOVA analysis using Qualitek-4 program to investigate the optimum level for each parameter. It was found that using alkali activator with a combination of GGBFS and OPC is not effective method to produce AAC because of the very low workability obtained. On the other hand, using slag only as a binder was effective to produce AAC with high compressive strength and desirable workability.

Index Terms: Alkali Activated Concrete, GGBFS, OPC, Ambient Cured, Solution Modulus, Taguchi Method, Compressive Strength.

1 INTRODUCTION

Portland cement concrete (PCC) is the most widely utilized construction material. However, concrete manufacturing has a great impact on the environment because of CO_2 emissions which have a major effect on global warming. The major contributor of CO_2 in the concrete production is Portland cement (PC) [1]. It was reported that the cement industry alone is responsible for nearly 8% of global CO_2 [2]. Moreover, the PC industry is responsible for about 10% of energy consumption in the developing countries [3]. Hence, the development of eco-friendly construction material as an alternative for PCC has become one of the main objectives of the scientific community. Through a few decades ago, many studies performed on AAC as an alternative for PCC and have gained popularity [4], [5], [6], [7], [8], [9], [10], [11]. AAC can be manufactured without PC, so it can be considered green concrete. A source of aluminosilicate and an alkaline activator are the two main constituents of AAC. A lot of studies performed on AAC using heat curing treatment [12] or using ambient curing condition [13] utilized slag, fly ash, silica fume or metakaolin as a source of aluminosilicate. Currently, an innovative binder called hybrid cement or activated blended cement is available. This type of binders utilizes high ratios of wastes, like fly ash or slag, with less ratio of OPC up to 30%, and the mix is alkali activated. It was concluded that the alkali activated hybrid cements that contain low ratios of OPC and high ratios (60-70%) of aluminosilicate materials provide an alternative to the OPC for traditional mortars based on reviewing the fundamental chemistry and analyzing the nature of the reaction products [14]. Daniela et al. [15] investigated the mechanical characteristics at different ages in hybrid cements with 80% slag and 20% OPC. It was reported that the alkali activated hybrid cement recorded a compression strength 10.8 times higher than that of the control 100% OPC. Most of these studies were conducted on pastes or mortars, not concrete. In addition, using GGBFS with different ratios with OPC in the blended cement is needed. The main objective of this study is to investigate the efficiency of utilizing hybrid cement (cement + slag) to produce AAC at ambient curing conditions considering the most efficient parameters (GGBFS:OPC, Na_2O ratio, Ms and W/B) on the workability and compressive strength using Taguchi method.

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2 EXPERIMENTAL PROGRAM

2.1 Material

In this study, OPC and GGBFS were utilized as the binder materials. OPC was of grade 42.5 N in according to BS-EN 197-1 [16]. A locally available GGBFS was used with chemical composition of 41.66% SiO_2, 13.96% Al_2O_3 and 34.53% CaO. The used coarse aggregate was natural crushed limestone of 10 mm size and the used fine aggregate was natural sand. SS and SH solutions were mixed together to prepare the alkaline activator. SH solution was prepared by dissolving SH pullets in potable water and SS solution was supplied by a local commercial producer. The SH had a chemical composition of 60.25% Na_2O and 39.75% H_2O, and the SS had a chemical composition of 31.00% SiO_2, 11.98% Na_2O, and 57.00% H_2O.

2.2 Test Matrix

Four parameters related to compressive strength and workability were considered in the mix design. The four parameters were: GGBFS:OPC (100:0, 80:20 and 70:30), Na_2O ratio (8, 9 and 10), solution modulus (0.8, 1.0 and 1.2) and water to binder ratio (0.4, 0.45 and 0.5). By using Taguchi approach and in accordance with L9 array, nine mixes were

TABLE 1
PARAMETERS AND VALUES USED IN AAC MIXES ACCORDING TO TAGUCHI DESIGN

Mix	GGBFS:OPC (%)	Na_2O (%)	Ms	W/B
CM1	100:0	8	0.8	0.40
CM2	100:0	9	1.0	0.45
CM3	100:0	10	1.2	0.50
CM4	80:20	8	1.0	0.50
CM5	80:20	9	1.2	0.40
CM6	80:20	10	0.8	0.45
CM7	70:30	8	1.2	0.45
CM8	70:30	9	0.8	0.50
CM9	70:30	10	1.0	0.40

Na_2O = Percentage from Binder Content, Ms = SiO_2/Na_2O, W/B = Water to Binder Ratio.

TABLE 2
MIX PROPORTIONS AAC MIXES (kg/m^3)

Mix	GGBFS	OPC	SS	SH	Water	F.A.	C.A.
CM1	450	0	93	41	111	569	1138
CM2	450	0	131	41	112	547	1093
CM3	450	0	174	40	110	524	1048
CM4	360	90	116	37	144	531	1063
CM5	360	90	157	36	76	568	1136
CM6	360	90	116	52	116	550	1100
CM7	315	135	139	32	110	551	1103
CM8	315	135	105	46	147	533	1066
CM9	315	135	145	46	79	570	1139

F.A. = Fine Aggregate, C.A. = Coarse Aggregate.

conducted. Table 1 shows the parameters and values used in AAC mixes according to Taguchi design. The mix proportions for the nine mixes are illustrated in Table 2. The binder content was 450 kg/m^3 for all mixes.

2.3 Specimens Preparation and Testing

The procedure of mixing AAC implemented in this study started with mixing the dry materials (GGBFS or GGBFS + OPC, and aggregates) in the pan mixer for 1 min. Then, adding the amount of alkaline activator to the dry mix and mixing for about 4 min till the mix became homogeneous. The alkaline activator was prepared by mixing the SH pullets, SS solution and water for about 1 hour before adding to the dry mix. The specimens were casted into steel molds with dimensions of 100 x 100 x 100 mm to measure the compressive strength. The specimens were removed from molds after 24 hours and then left in the lab at ambient condition. The compression tests were conducted according to BS EN 12390-3 [17] on three specimens for each mix on the 7th and 28th day. Workability of fresh AAC mixes was measured by slump test according to ASTM C143 [18]. The slump tests were carried out immediately after mixing.

3 RESULTS AND DISCUSSION

3.1 Compressive Strength

The compressive strength for the nine mixes designed using Taguchi method has been presented in Fig. 1. The highest compressive strength after 7 days (f7) and after 28 days (f28) were achieved by mix CM2 specimens, they were 34.9 and 43.0 MPa, respectively. The lowest f7 and f28 were achieved by mix CM8 specimens, they were 20.1 and 24.8 MPa, respectively. To overcome the difficulty of investigating how the considered experimental parameters affect f7 and f28, Minitab program used to calculate the Signal-to-Noise (S/N) ratio of each factor as shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5. Also, ANOVA was employed utilizing Qualitek-4 program to determine the participation percentage of the considered factors on the f7 and f28 as presented in Fig. 6. Fig. 6 shows that the binder type (GGBFS:OPC) is the most significant factor that affects both f7 and f28 of AAC mixes. The percentage of participation is 43.91% and 56.19% for f7 and f28, respectively. The level of 80:20 is the optimum level for them. It can be observed from Fig. 2 that the S/N ratios of f28 for the two levels (100:0 and 80:20) are 31.55% and 31.62%, respectively. The difference between the two ratios is very low (0.07%) which means that the effect of the two levels on the f28 was almost the same. Nevertheless, increasing the OPC in the binder to 30% decreased the S/N ratio from 31.55% to 29.15% with a difference of 2.40% which was the highest difference obtained and the f28 decreased from 43.0 MPa to 24.8 MPa. Also, the trend of S/N ratios for f7 was almost the same as f28. Based on these results, it can be drawn that using OPC as a partial replacement for GGBFS is not effective for the compressive strength of AAC. The W/B ratio is the second significant factor with a percentage of participation of 34.27% and 30.12% for f7 and f28, respectively as presented in Fig. 6. The optimum level of W/B ratio is 0.45 for f28 but for f7, the two levels 0.40 and 0.45 are almost the same as shown in Fig. 5. This indicates that W/B ratio of 0.45 produces high compressive strength of AAC. For f28, the third factor is the solution modulus (Ms) with a participation percentage of 11.76% and Ms of 1.0 is the optimum level as can be noticed from Fig. 6 and Fig. 4, respectively. This indicates that the Ms of 1.0 produce high compressive strength. The Na_2O ratio has the lowest participation percentage of 1.93% and the optimum level of Na_2O ratio is 10 as shown in Fig. 6 and Fig. 3, respectively. This indicates that a high percentage of Na_2O produce a high compressive strength.

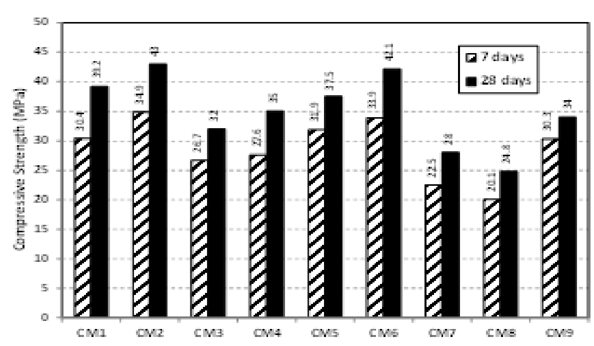

Fig. 1. The 7 and 28-day compressive strength of the AAC specimens.

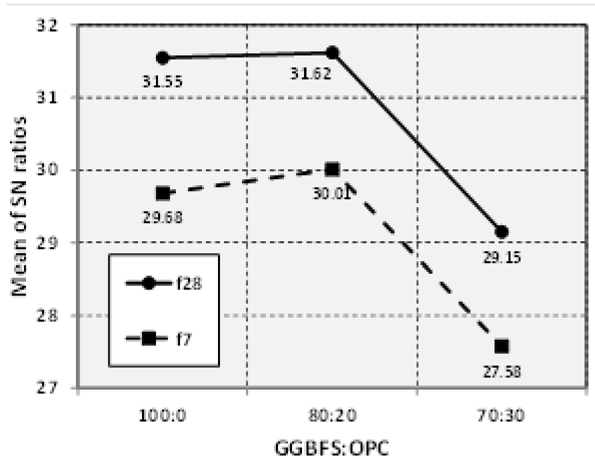

Fig. 2. The significance of GGBFS:OPC on the f7 and f28 of mixes.

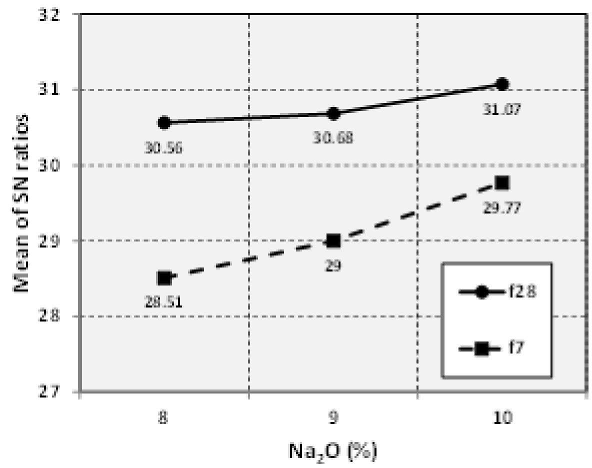

Fig. 3. The significance of Na_2O on the f7 and f28 of mixes.

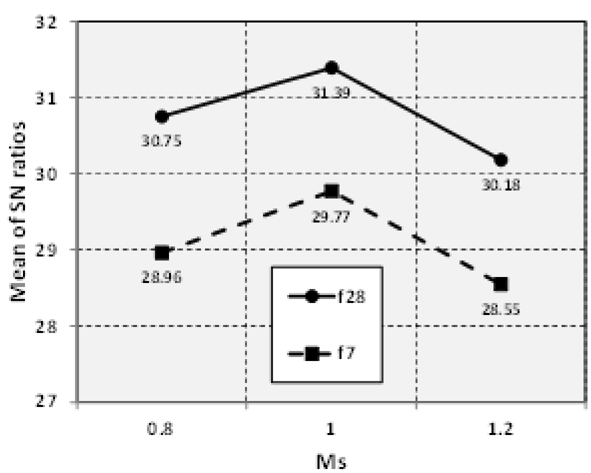

Fig. 4. The significance of Ms on the f7 and f28 of mixes.

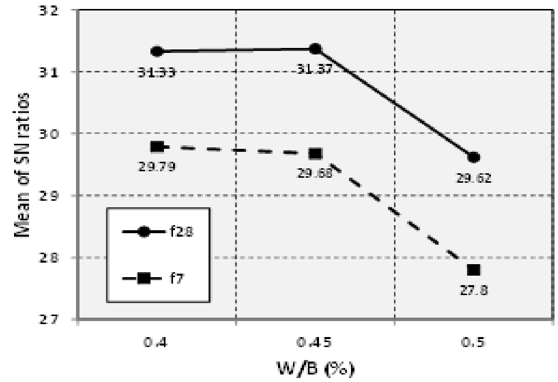

Fig. 5. The significance of W/B on the f7 and f28 of mixes.

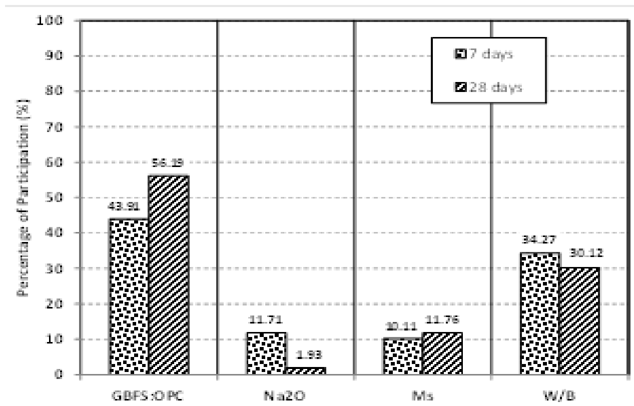

Fig. 6. The Participation percentage for the considered factors on f7 and f28

3.2 Workability

Slump test was used to express the workability of all mixes. The slump values for the nine mixes designed using Taguchi method (CM1 to CM9) are presented in Fig. 7. The highest slump value was achieved by mix CM3 (100% slag), it was 250 mm. The lowest slump value was achieved by mix CM9 (70% slag + 30% cement), it was 20 mm. It is noted that using OPC with alkali activator decreases the workability significantly.

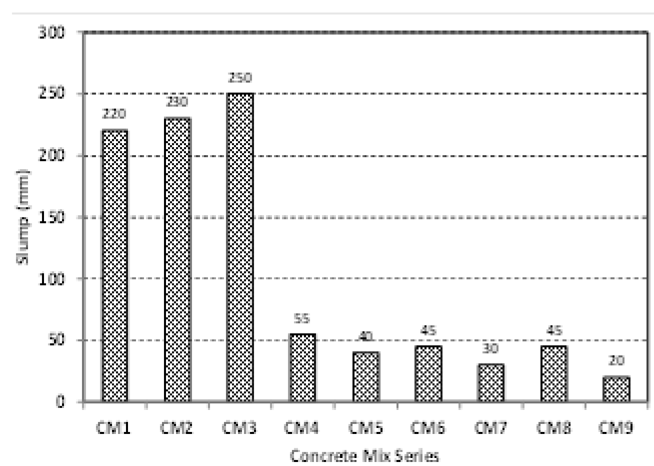

Fig. 7. The slump value of AAC mixes.

4 CONCLUSION

Based on the analysis of the obtained test results from the experimental program conducted in this research, the following points can be easily concluded:

1. Using alkali activator with a combination of GGBFS and OPC is not effective method to produce AAC because of the very low workability. On the other hand, using slag only as a binder was effective enough to produce AAC with high compressive strength and desirable workability at ambient curing conditions, and suitable for in situ construction.
2. The AAC mix with 100% slag, 9% Na_2O, Ms of 1.0 and W/B ratio of 0.45 achieved the highest f28 of 43.0 MPa and a workability with a slump value of 230 mm at ambient curing conditions.
3. Among the studied factors, the most significant factor that affects the f28 of the AAC mixes in this study was the binder ratio (GGBFS:OPC) with participation percentages of 56.19%. The highest f28 and slump value were achieved by developed mixes with a binder of 100% slag.

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