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Performance of Concrete Containing Steel Slag Exposed To Sulphate Environment: A Comparison of Steel Slag and Natural Aggregate Use

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Abstract

Concrete behave very differently when exposed to sulphate. Sulphate may exist in soil, ground water, sea water and effluent discharge by industry. As a result of sulphate attack, cracking, expansion, spalling, loss in volume and strength may take place. To minimize such occurrence, several factors need to be considered such as water/ cement ratio, permeability of the concrete, condition of sulphate exposure, cement composition, curing condition, etc need to be accounted. The idea of this study is to compare the behavior of normal concrete containing steel slag aggregate and normal aggregate under the exposure of two types of sulphate ions namely, natrium sulphate and magnesium sulphate with 0.3molar 5 % concentration for a period of twenty weeks. The durability of concrete containing steel slag i.e. changes in physical, volume and strength after the immersion process has been observed. The result of different water cement ratio of 0.47, 0.52, and 0.55 and steel slag aggregate replacement of 10%, 50% and 100% of total aggregate proportion are presented and analysed. From the result, it shows that the durability of steel slag aggregate and natural aggregate concrete has the same performance.

Keywords

Sulphate attack; Steel slag aggregate; Steel slag concrete; natural aggregate concrete

1. Introduction

Concrete, being one of the most important construction materials is widely used in the industry. It is only second to water as the most heavily consumed substance with about six billion tones being produced every year (Sabir *et al*, 2001).

Waste material has gained attention among researchers as replacement to natural aggregate in concrete making. The sense of using waste materials in concrete is not only because of the economic factor but the more significant aspect is to protect the environment since more and more solid waste are produced day by day. There are also some other benefits can be expected to be gained in terms of quality in concrete by using aggregate from waste products such as sustainability in construction (Maslehuddin *et al*, 2003, Motz *et al*, 2001, Basri *et a*l, 1999, Oikonomou, 2005, Topcu *et al*, 2004 and Sentamarai *et al*, 2005). Durability of concrete has been an interest in research field since the durability problem largely affects concrete long term performance. Repair work due to deterioration of concrete also imposed considerable expense and the economic impact due to the repair works has been a great concern. To be durable, the concrete mass must have high resistance to ingress of external damaging agent which would consequently lead to the disintegration of the hardened mass. To have such resistance, the durability of the concrete should be of primary design concern along with strength design criteria (Neville, 1995).

Sulphate attack is a fairly complex process that can result in a physical or chemical attack on concrete. The sources of sulphate can be internal to the concrete or from external sources, such as groundwater, soils, agricultural run-off, and coastal salt water (Neville, 1997). There are multiple ways sulphate attack can occur. It has been demonstrated that sulphate attack on concrete results from a chemical reaction between the sulphate ion and hydrated calcium aluminate and/or the calcium hydroxide components of hardened cement paste in the presence of water (Taylor, 1997).

The use of non-conventional materials is becoming of increasing. These materials can be incorporated in concrete to facilitate several benefits including the modification and improvement of certain material properties, the conservation of non-renewable natural resources and the utilisation of industrial by-products (Montgomery, 1991).

Using Electric Arc Furnace Slag (EAFS) is a good example. Steel slag, a by–product of steel- making operation, steel scrap is melted in an electric arc furnace along with fluxing agents. Steel Slag chemistry is based upon the fluxing practices and impurities from the selected scrap. The steel slag aggregate, presently produced by a steel plant in northern peninsular of Malaysia is utilised in road construction.

There are two main reasons for using by-product (steel slag) as aggregate in concrete: firstly it can reduce the environmental problem due to the production of primary aggregate in quarry and conserving our natural resources and secondly it will overcome the issue of waste disposal. Slag is currently temporarily stored or used as landfills in steel plant compound or sent to designated landfills (NST, 1997). In Malaysia, very little is known about the use of steel slag in the manufacture of concrete. Therefore, the main thrust of this investigation was to evaluate the viability of steel slag aggregate for use as coarse aggregate in fresh concrete, as such material is likely to provide both environmental and economic advantages.

This study is conducted to ascertain the durability of concrete made of Steel Slag Aggregate (SA) by means of sulphate resistance testing. Sulphate resistance is believed to be a good indicator of concrete durability.

2. Experiment

2.1. Materials

The materials used in this study were ordinary Portland cement in compliance with MS 522 (1989) and BS EN 197-1(2000). River sand and coarse natural aggregate, which were of granite and comply with BS EN 12620 (2002) were use. Crushed electric arc furnace oxidizing slag used in this study obtained from steel plant (located in the north of peninsular Malaysia) of nominal minimum of 10 mm and maximum size of 20 mm. The 20 mm and 10 mm coarse aggregate were then combined in the ration of 2:1 respectively for both the natural aggregate and slag aggregate concrete mixes.

2.2 Physical properties of aggregates

The physical properties of all the aggregates in terms of specific gravity, aggregate crushing values and water absorption are presented in Table 1, determined in accordance with BS 1881: part 3 (1975).

2.3 Preparation of Specimens

The designed water-cement ratios of the mixes range from 0.47 to 0.55. Since there is no existing standard method of designing concrete mixes incorporating slag aggregate the slag aggregate concrete mixes were derived simply by replacing the natural coarse aggregate proportion in the natural aggregate concrete mix design developed using conventional mix design method (Teychenne, 1988). Slag coarse aggregate (air dried) content in the mix is of 4 replacement proportions i.e. 0, 10, 50 and 100% of total coarse aggregate used in the mix. The steel slag aggregate of 0% denotes the control sample. The mix proportions are shown in Table 2.

2.4 Measuring Techniques

Steel cylindrical moulds of size 80 mm diameters and 25mm thickness were used. The small size of specimen used is advantageous for ease of handling, and for quicker sulphate permeation into the interior (Mehta and Gjory, 1974).

Concrete with the same mix proportion and similar method of casting cubes for compressive test were prepared. The moulds were filled with concrete to 25mm thickness and vibrated using compacting table until complete compaction was achieved. The moulds were then covered with wet hessian for 24 hours. The samples were demoulded, marked for identification and transferred to water curing tank.

Specimens were always immersed in the solution. The same methods were used for all mixes. Sulphate attack can manifest in the form of expansion of concrete and can also take the form of a progressive loss of strength due to deterioration in the cohesiveness of the cement hydration products (Mehta, 1993).

2.5 Physical Deterioration and Expansion Tests

After 28 days of water curing, the specimens were then placed in sulphate solution tray containing 0.3 molar natrium sulphate Na_2SO_4 (5%) mixed with 0.3 molar magnesium sulphate $MgSO_4$ were prepared and stored in plastic containers and the specimens were covered with a polythene sheet to minimise evaporation. Previous investigation by Diah and Pitchay (2001) suggested that exposure under these solution is very aggressive.

The volume of the solution and its level were adjusted so that the specimens were always immersed in the solution. To maintain the pH level of the solution within the limit, pH values were monitored every three days and adjusted using titration of sulphuric acid (H_2SO_4). Dimensional changes indicating physical deterioration due sulphate attack on the hardened concrete cylinders were evaluated at 14, 28, 36, 42, 70, 84, 98, 112, 126 and 140 days (20 weeks) interval. At the schedule time, dimension changes due to the sulphate attack on the hardened concrete were observed with digital calliper.

The specimens were retrieved, air dried for 24 hours in the laboratory environment and weighed. The percentage of strength and dimensional changes are calculated using the following relationship.

$$\frac{(D_t - D_i)}{D_i} X\ 100 \qquad (1)$$

Where:
D_i=Average initial dimension of specimens.
D_t= Average at time t dimension after exposure period.

The above method used to determine resistance to the sulphate environment is similar to research carried out by Mehta, Gjory (1974), Al-Amoadi (1995) and Diah and Pitchay (2001).

3. Results

The dimensional changes or expansion tests in specimens were conducted on cylindrical specimens of size 80mm diameter and 25mm height. The specimens were water cured for 28 days before immersed in sulphate solution. Two parameters were measured and recorded i.e. diameter and height of the samples after 20 weeks of exposure to sulphate environment.

The data on the changes in diameter of samples are shown in Table 8 to 11. The results showed that after 20 weeks exposure for control sample, only a small increase between 2.5 to 3.3mm in diameter of the samples. These changes are lower when w/c is decrease. Similar patterns are observed for slag aggregate samples. Sample with 100% slag replacement shows better resistance to sulphate environment.

Changes in original colour of specimens were observed in all samples after 20 weeks exposure. They were observed to be partially white and the crystal formations were discovered. Similar results were obtained by Diah and Pitchay (2001).

Results also indicated that very small percentage changes occurred in diameter of all samples. Control sample after 20 weeks exposure showed about 3.99 percent increase in dimension for w/c 0.55 concrete and only 3.03 percent increase for the w/c of 0.47 concrete, whereas for 100% replacement sample it showed about 2.44 percent increase for the w/c 0.55 concrete and only 1.84 percent increases which is lower than the control sample for the w/c 0.47 concrete. The differences in percentage between control sample and 100% replacement sample is 1.2 percent, which is very small.

All other samples showed same pattern of dimensional changes over the same period of exposure to sulphate environment as compared to control sample. Summarised results in Table 12 clearly indicate and Figure 2 clearly illustrated that in all samples concrete with higher grades are more resistant to sulphate environment. The results also showed that the changes in diameter were, however, observed to be relatively lower in concrete having higher compressive strength.

The data on changes in height of samples are shown in Table 3 to 6. The results showed that after 20 weeks exposure for control sample only a small increase between 3 to 2mm in height of the samples observed. These changes occur for w/c 0.47 to 0.55 of concrete. Summarised results in Table 7 clearly indicate and Figure 1 clearly illustrated that in all samples concrete with higher grade is more resistance to sulphate environment. The results showed that the expansion and changes in volume of concrete were, however, observed to be relatively lower when concrete having higher compressive strength.

Under the conditions of this test, no significant differences were observed in the behavior of control sample and mining sand. It can be concluded that mining sand can be used as alternative to river sand for construction of foundation in the existence of sulphate.

4. Conclusion

In the preliminary investigation no significant differences had been shown in physical properties of slag aggregate as compared to granite aggregate. It must be mentioned here that the crushed Slag aggregates (SA) was kept in a sealed container and used when required. No adjustment of mix water content was made to account for the higher water absorption of Slag Aggregate (SA). From a strength point of view, the Slag Aggregate Concrete (SAC) compared well with the corresponding Natural Aggregate Concrete

(NAC). The compressive strength of steel slag aggregate concrete increased with the proportion of coarse aggregate.

The compressive strength of steel slag aggregate concrete, with 50% steel aggregates was marginally above the control sample therefore a coarse aggregate to total aggregate proportion of 50% may be adopted in future to minimize the weight effect of heavy steel slag aggregate (Kamran *et.al* 2009). Results from this study shows that concrete containing natural aggregate (NA) and replacement of SA enhance the performance of concrete against the Sulphate attack even though the Ordinary Portland Cement were used throughout of this research. Results show that the value of percentage of expansion increased when the value of w/c ration increased. It should be noted that natural aggregate used in this study is good quality granite. Hence, some limitation of the SA as compared to the NA should be expected.

The limitations of SA are the density and the water absorption which is higher compared to NA. Despite the significant limitation, better performance in other properties is assumed to compensate this limitations. From the results, which have been obtained, it can be concluded that practically, the SSA produces comparable performance. The benefits resulting from the study will provide the construction industry with technical information on a valuable resource that has a key role in meeting the challenges of sustainable construction.

Table 1: Physical properties of aggregate.

PHYSICAL PROPERTIES		AGGREGATE	
		Natural Aggregate	**Slag Aggregate**
Specific Gravity	SSD	2.63	3.45
Specific Gravity	Oven Dry	2.61	3.37
Bulk Density	kg/m3	1.36	1.63
Water Absorption	%	0.8	2.44
Aggregate Impact Value	%	17.5	10.18
Aggregate Crushing Value	%	21.09	18.33
Elongation Index	%	29.18	16.65
Flakiness Index	%	13.46	3.01

Table 2: Mix Design.

water-cement ratio	mix	cement (kg/m3)	water (kg/m3)	Aggregate (kg/m3)				Sand
				20 mm		10 mm		
				SA	NA	SA	NA	
0.55	NA M1	375	205	-	570.0	-	285.0	960
	SA M1 - 10	375	205	68.3	513.0	34.2	256.5	960
	SA M1 - 50	375	205	341.6	285.0	170.8	142.5	960
	SA M1 - 100	375	205	683.2	-	341.6	-	960
0.52	NA M2	395	205	-	584.0	-	292.0	915
	SA M2 - 10	395	205	70.0	525.6	35.0	262.8	915
	SA M2 - 50	395	205	350.0	292.0	175.0	146.0	915
	SA M2 - 100	395	205	699.9	-	350.0	-	915
0.47	NA M3	435	205	-	590.0	-	295.0	860
	SA M3 - 10	435	205	70.7	531.0	35.4	265.5	860
	SA M3 - 50	435	205	353.6	295.0	176.8	147.5	860
	SA M3 - 100	435	205	707.1	-	353.6	-	860

Table 3: Changes in thickness of the control sample after immersion in sulphate solution.

INITIAL DIMENSION	**25 mm**										
DESIGN	**Immersion Time (Week)**										
w/c	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
0.47	25.00	25.33	25.33	25.33	25.50	25.67	25.73	25.00	25.67	26.67	26.00
0.52	25.00	25.50	26.00	25.73	26.33	26.33	26.33	25.33	26.33	27.17	27.67
0.55	25.00	25.50	25.33	25.50	25.50	26.33	26.33	25.17	27.00	27.33	27.83

Table 4: Changes in height of the control sample after immersion in sulphate solution

INITIAL DIMENSION		**25 mm**										
DESIGN	**SA**	**Immersion Time (Week)**										
w/c		**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
0.47	10%	25.00	24.83	25.00	25.17	25.50	25.17	25.83	24.67	26.00	27.33	25.33
0.52		25.00	25.33	25.50	25.67	25.83	26.00	26.50	25.00	26.17	26.17	26.67
0.55		25.00	26.00	26.33	26.17	26.17	26.67	26.67	25.50	25.80	25.90	25.90
0.47	50%	25.00	25.67	25.83	25.83	26.00	26.40	25.67	27.00	26.33	26.33	26.33
0.52		25.00	25.33	25.50	26.00	26.33	26.17	26.33	25.83	26.00	26.33	26.17
0.55		25.00	26.67	26.83	26.40	26.83	27.00	27.00	26.50	27.33	27.67	27.00
0.47	100%	25.00	25.67	25.83	25.83	26.00	26.40	25.67	27.00	26.33	26.33	26.33
0.52		25.00	25.33	25.50	26.00	26.33	26.17	26.33	25.83	26.00	26.33	26.17
0.55		25.00	26.67	26.83	26.40	26.83	27.00	27.00	26.50	27.33	27.67	27.00

Table 5: Percentage changes in thickness (mm) of samples exposed to sulphate environment.

AGGREGATE	**design w/c 0.47**			**design w/c 0.52**			**design w/c 0.55**		
	initial thickness	**20 weeks exp.**	**% changes**	**initial thickness**	**20 weeks exp.**	**% changes**	**initial thickness**	**20 weeks exp.**	**% changes**
Control	25.00	26.00	3.84	25.00	27.83	10.17	25.00	27.67	9.65
slag 10%	25.00	25.33	1.30	25.00	26.67	6.26	25.00	25.90	1.96
slag 50%	25.00	26.33	5.05	25.00	26.17	4.47	25.00	27.00	7.41
slag 100%	25.00	25.67	2.61	25.00	25.50	1.96	25.00	25.33	1.30

Table 9: Changes in diameter of the control sample after immersion in sulphate solution

INITIAL DIMENSION		**25 mm**										
DESIGN	**SA**	**Immersion Time (Week)**										
w/c		**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
0.47	10%	80.00	83.00	83.00	83.17	83.17	83.33	83.33	83.33	82.67	82.67	82.5

0.52		80.00	81.50	82.00	82.07	82.07	82.50	82.23	81.50	82.33	82.33	83.00
0.55		80.00	82.67	82.33	82.07	82.40	82.50	82.67	82.00	82.33	82.83	83.17
0.47	50%	80.00	83.00	83.00	83.17	83.17	83.33	83.33	83.33	82.67	82.67	82.5
0.52		80.00	81.50	82.00	82.07	82.07	82.50	82.23	81.50	82.33	82.33	83.00
0.55		80.00	82.67	82.33	82.07	82.40	82.50	82.67	82.00	82.33	82.83	83.17
0.47	100%	80.00	82.00	82.40	81.33	81.50	81.67	81.83	81.67	82.00	81.80	81.50
0.52		80.00	81.67	81.63	81.40	81.50	81.50	82.00	81.67	82.67	81.77	82.17
0.55		80.00	81.67	81.83	82.07	82.10	81.83	82.00	82.00	81.67	82.67	82.80

Table 10: Percentage changes in diameter (mm) of samples exposed to sulphate environment.

AGGREGATE	**design w/c 0.47**			**design w/c 0.52**			**design w/c 0.55**		
	initial diameter	**20 weeks exp.**	**% changes**	**initial diameter**	**20 weeks exp.**	**% changes**	**initial diameter**	**20 weeks exp.**	**% changes**
Control	80.00	82.50	3.03	80.00	87.00	8.05	80.00	83.33	3.99
slag 10%	80.00	82.00	2.44	80.00	83.00	3.61	80.00	83.17	3.81
slag 50%	80.00	83.00	3.61	80.00	82.67	3.23	80.00	84.17	4.95
slag 100%	80.00	81.50	1.84	80.00	82.17	2.64	80.00	82.80	2.44

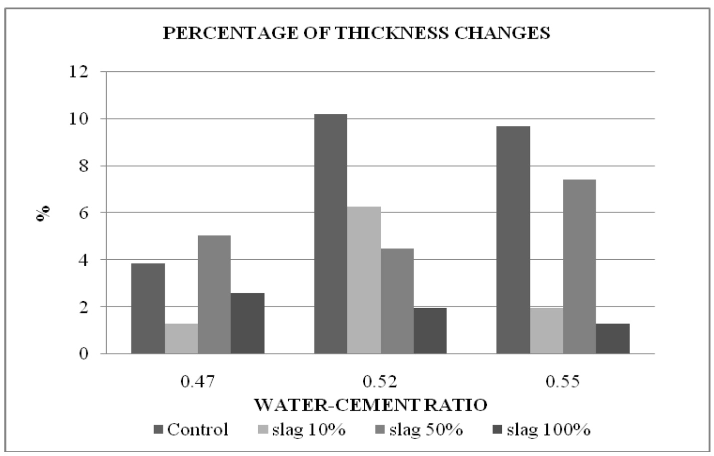

Figure 1: Percentage of expansions in thickness of w/c 0.47, 0.52 and 0.55 concrete samples.

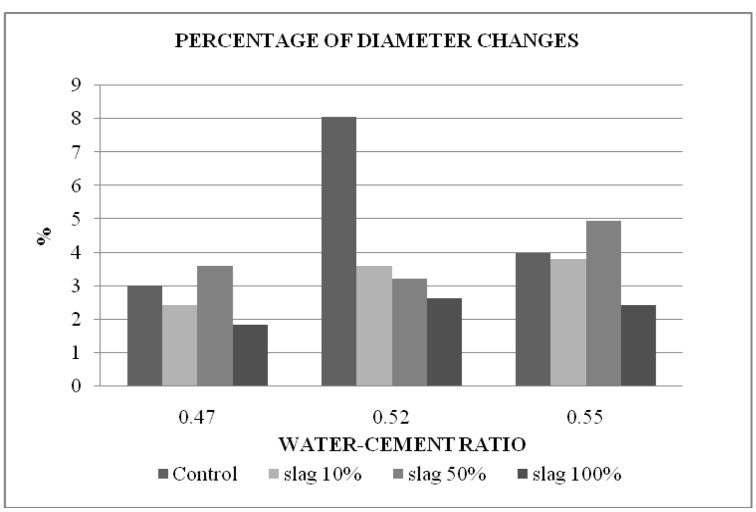

Figure 2: Percentage of expansions in diameter of w/c 0.47, 0.52 and 0.55 concrete samples.

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