MECHANICAL PROPERTIES AND DURABILITY OF PORTLAND CEMENT CONCRETE INCORPORATING GROUND STEEL MAKING SLAG

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ABSTRACT

In Egypt, the iron and steel making companies, suffer from the accumulation of slag. However, only the Helwan iron and steel company uses the blast furnace slag in cement manufacture. In Alexandria, the Alexandria National Steel and Iron Company suffers from the accumulation of steel making slag (500 ton/day) expected to reach 700 ton / day in 1997. This research studied the usage of steel making slag from Alexandria National Steel and Iron Company as a ground material, finer than 75 um, in concrete as a partial replacement of ordinary portland cement. The percentages of cement replacement with ground steel making slag in cement paste and mortar were 0.0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% by weight, while in concrete they were 0.0%, and 30% by volume. Physical, chemical, and mechanical properties of ground steel making slag were studied in order to check their suitability for use with cement. Properties of fresh and hardened concrete containing ground steel making slag as a replacement of ordinary portland cement were determined. The durability of ground steel making slag concrete was investigated by exposing specimens to sodium and magnesium sulphate solutions containing 3.5% SO_3 and seawater up to one year, after 28 days of tap water preconditioning. The performance of these concretes in these environments, was evaluated by measuring expansion and determining reduction in compressive strength and dynamic modulus of elasticity. The results indicated that the performance of concretes containing 0.0% and 30% replacement with ground steel making slag by volume was generally excellent in seawater and sodium sulphate solutions, while their performance in magnesium sulphate environment was not satisfactory. The greater damaging effects of the magnesium sulphate solution on both types concrete are due to the decomposition of the calcium silicate hydrate (C-S-H) gel to magnesium silicate hydrate (M-S-H), which is noncementitious [1]. The durability of concretes containing 30% ground steel making slag as a partial replacement of ordinary portland cement in magnesium and sodium sulphate solutions containing 3.5% SO_3 and in seawater were about similar to the control concretes containing 100% ordinary portland cement.

Keywords: Slag, Ground steel making slag, Sulphate attack, Seawater attack, Durability.

INTRODUCTION

Steel making slag is produced as a by-product of the conversion of pig iron to steel. This involves the lowering and controlled adjustment of the content of various impurities. Refining is achieved by fusion of the pig iron with a flux, such as limestone or dolomite under oxidizing conditions. Impurities which are present in the pig iron in excess such as, carbon, silicon, manganese, phosphorous and sulfur are either oxidized to gases or pass into the slag as complex oxides. According to the different types of steel furnaces there are three types of steel slag: basic oxygen steel slag, open hearth steel slag, and electric-arc steel making slag [2]. For several years, organizations connected with the construction industry have been involved in research on energy conservation in Portland cement concrete. The organization have been encouraging use of less energy-intensive materials. A recent symposium organized by several researchers highlighted the use of waste materials as a building material replacement in the construction industry. Industrial wastes by-products material are now the main reason of environmental pollution due to their accumulation, hence, it is obliging to recycle the industrial wastes, as possible, if we want to minimize the pollution. Many researches were performed to utilize industrial by-products, in order to minimize their effect on the environment. Cement is the most important and expensive material in concrete and its manufacture involves intensive use of raw materials and energy. Thus, replacement of cement by less expensive materials will reduce the cost of construction and simultaneously conserve energy and resources. Replacement is especially effective when the material substituting for cement happens to be a waste material or a by-product of another industry. Typical material of this type are fly-ash, cement kiln dust, silica fume, and blast-furnace slag. Steel Making Slag arising as by-product of steel making companies has no wide use as building material. However, it is used as aggregate in asphalt concrete [3], as aggregate in cement concrete [4], and as land filling [2]. Research on using ground steel making slag combined with cement is limited because it is relatively new as a construction material. The limited data available in the literature is inconclusive and there is no evidence to suggest that behavior of Portland cement incorporating Ground Steel Making Slag follows a similar behavior of other cementitious materials.

RESEARCH SIGNIFICANCE

The purpose of the research reported here is to characterize the Ground Steel Making Slag produced by Alexandria National Company for Steel and Iron from the electric-arc furnace. In addition, the possibility of using ground steel making slag as a partial replacement of ordinary Portland cement in concrete manufacture was investigated by studying the mechanical properties and the durability of these concretes containing 30% ground steel making slag as a partial replacement of ordinary portland cement in magnesium and sodium sulphate solutions containing 3.5% SO_3 and in seawater.

EXPERIMENTAL PROGRAM

Materials and mix proportions

Throughout this study, ordinary portland cement (OPC), natural silicious sand passing through a BS 4.75 mm. sieve was used as fine aggregate and crushed pink lime stone having a nominal maximum size of 19 mm. was used as coarse aggregate for making concrete. The Steel Making Slag used was supplied by Alexandria National Iron And Steel Company in Alexandria (Egypt) from the electric-arc furnace. Representative samples were obtained directly from the supply. The percentages of cement replacement with ground steel making slag in cement paste and mortar were 0.0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% by weight, while in concrete were 0.0%, and 30% by volume. Table (1) summarizes the experimental details of the concrete mixes used.

Grinding of steel making slag

Huge particles of steel making slag were transformed to ground material with three steps: the first step was separating the steel mass and particles by using magnetic block, the second step was grinding the steel making slag particles with big hammer machine to fine materials, and the third step was sieving the fine materials on sieve No.16, No.30, and No.200 respectively to produce ground steel making slag finer than sieve No.200, which was used in this research.

CASTING AND CURING OF CONCRETE SPECIMENS

The concrete specimens were mixed in a horizontal pan mixer of 0.25 cubic meter capacity. Ingredients were weighed and fed into the mixer in the following sequence: coarse aggregate, cement, Ground Steel Making Slag, sand and water. Dry mixing was carried out for 2 minutes followed by wet mixing for 3 minutes. The following number of concrete specimens were cast: 504 Nos. 100X100X100 mm cubes, 64 Nos. 300 mm long X 150 mm diameter cylinders, and 64 Nos. 75X75X285 mm prisms. All the concrete specimens were cast in three layers using vibrating table. The top surface of the mold were finished and leveled, then the specimens were covered with a wet hessiun to prevent evaporation of water from concrete. The specimens were removed from the molds and immersed in fresh water at 20 °C till testing.

TESTING OF FRESH AND HARDENED CONCRETE

The workability tests: slump, compacting factor and vebe test were carried out on freshly mixed concrete in accordance with BS 1881 [5]. The freshly unit weight and the air content of the concrete mixes were also carried out. Compressive strength of concrete was determined according to BS 1881 [5].

Table 1. Concrete mix proportion.

Mix	Mix proportion, kg/m3					W/(C+GS) Ratio	W/(C) Ratio
	cement C	Ground slag GS	Water W	Sand	Pink limestone		
C1	350	0.0	200	730	1020	0.57	0.57
CS1	245	120	189	742	1036	0.52	0.77
C2	400	0.0	200	696	1015	0.50	0.50
CS2	280	136	189	707	1033	0.45	0.67
C3	450	0.0	200	650	1015	0.44	0.44
CS3	315	154	189	661	1032	0.40	0.60
C4	500	0.0	200	609	1015	0.40	0.40
CS4	350	172	189	619	1033	0.36	0.54

The durability of ground steel making slag concrete (30% ground steel making slag + 70% OPC) was investigated by exposing specimens to strong sodium sulphate solution containing 3.5% SO_3, strong magnesium sulfate solution containing 3.5% SO_3, and natural sea water up to one year, after 28 days of tap water preconditioning (zero time test). The performance of ground steel making slag concrete in these environments compared with control concrete (100% OPC) was evaluated by measuring expansion, dynamic modulus of elasticity and determining reduction in compressive strength after 1,3,6,12 months of exposure to sulfate and seawater.

TEST RESULTS AND DISCUSSION

CHARACTERISTICS OF GROUND STEEL MAKING SLAG

a- Chemical composition: Table (2) shows the typical composition of Ground Steel Making slag together with composition of ordinary Portland cement. For the purpose of comparison, typical composition of other by-product materials having cementitious properties such as ground granulated blast furnace slag [Ggbfs] were included [6]. Relative to ordinary Portland cement, Ground Steel Making Slag showed higher metallic aluminum oxide (AL_2O_3) and ferric oxide (Fe_2O_3), and a higher magnesium oxide (MgO) element, but it showed lower silicon oxide (SiO_2), calcium oxide (CaO) and sulphate oxide (SO_3). Relative to [Ggbfs], Ground Steel Making Slag showed higher ferric oxide (Fe_2O_3), but it showed lower alumina oxide (AL_2O_3), silicon oxide (SiO_2) and calcium oxide (CaO). From the visual inspection it appears that Ground Steel Making Slag has a dark gray color.

b- Specific Gravity: The specific gravity of Ground Steel Making Slag was carried out with the use of standard specific gravity bottle and kerosene oil. The specific gravity value was 3.6 compared with the value of 3.15 for ordinary Portland cement. Therefore, any replacement of cement with Ground Steel Making Slag on the basis of weight will decrease the yield of the mix when compared with the control mix (ordinary Portland cement).

c- Fineness: The specific surface for Ground Steel Making Slag and ordinary Portland cement was determined by Blaine's air permeability method in accordance with ASTM C-204 [7]. It was 3850 cm^2/gm for Ground Steel Making Slag relative to 3200 cm^2/gm for ordinary Portland cement. There are no much difference in the values of specific surface between slag and cement.

EFFECT OF CEMENT REPLACEMENT WITH GROUND STEEL MAKING SLAG ON CEMENT PASTE PROPERTIES

The percentages of cement replacement with ground steel making slag in cement paste and mortar were 0.0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% by weight.

a- Standard Consistency: Figure (1) shows the ratio of water to the mixture of cement and ground steel making slag , by weight, required to produce a paste having standard consistence, as defined by ESS 974-91, [8] as a function of cement replacement. The ground steel making slag was slightly finer than the cement and can fit into spaces between cement grains. It would be expected that mixture of cement and ground steel making slag would need extra water demand to produce the same consistency, because part of the water is absorbed by the increased surface area of the mixture and part is used to lubricate the increased volume of solid particles. On the other hand the results showed an opposite effect which may be attributed to the physical presence of some inactive particles in the ground steel making slag.

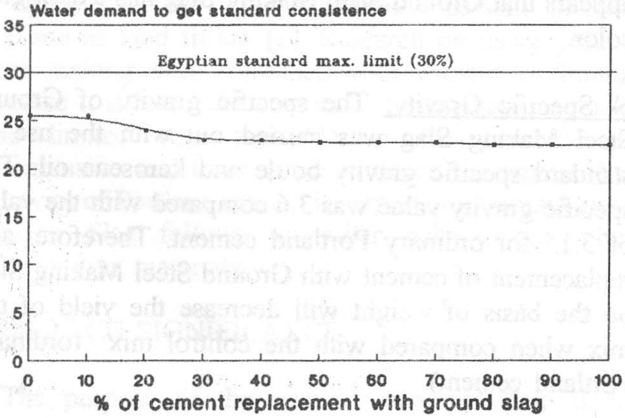

Figure 1. Water demand to produce the standard consistence.

b) *Setting Time*: Figure (2) illustrates the effect of partial replacement by various percentage of ground steel making slag on initial and final setting times of the paste. The figure shows that, as the percentage of cement replacement increased, the setting times were decreased, and were constant after 40 percent replacement until 90 percent. The tests data show that initial and final setting time conform with specified limit for ordinary Portland cement by ESS 974-91 [8] except the sample with 100 percent replacement with ground steel making slag which had a final setting time out of the Egyptian specification. The decrease in the setting time may be attributed to decrease in cement and water demand in blended cement paste due to the physical presence of inactive particles in ground steel making slag.

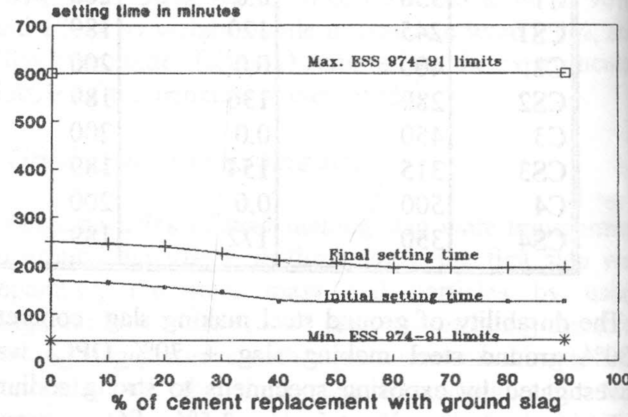

Figure 2: Effect of partial replacement of cement with ground steel making slag on setting time.

c- Soundness: Figure (3) shows the effect of partial replacement by various percentages of ground steel making slag on soundness in cement paste. The figure indicates that the expansion of cement-ground steel making slag paste are to be constant in the range from 0.75 to 1.0 mm and much below the maximum value of 10.0 mm as specified by ESS 974-91 [8].

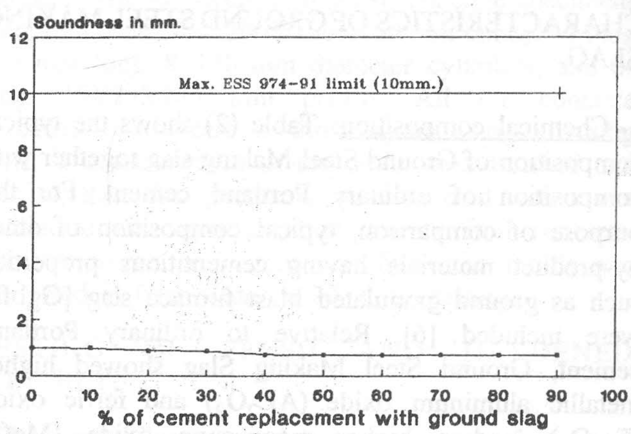

Figure 3: Effect of partial replacement of cement with ground steel making slag on soundness.

Table 2. Comparative chemical analysis of Ground steel making slag (Gsms), Ground granulated blast furnace slag (Ggbfs), and ordinary portland cement (OPC).

Component	Gsms (%)	Ggbfs (%) [6]	OPC (%)
Loss on ignition	1.29	---	1.65
silicon oxide (SiO_2)	17.97	35.20	22.39
calcium oxide (CaO)	27.4	41.30	58.93
magnesium oxide	7.53	1.90	3.99
sulphate oxide (SO_3)	0.51	---	2.51
ferric oxide (Fe_2O_3)	23.19	0.40	3.12
Alumina oxide	14.29	16.70	6.03
Insoluble residue	0.70	---	1.0
Alumina : Ferric	.62	---	1.93
Lime saturation factor	---	---	0.88
Alkalis (Na_2O)	0.06	---	0.22
Alkalis (K_2O)	0.80	---	0.45
manganese oxide	7.00	---	None
Phosphorous	0.46	---	None

EFFECT OF CEMENT REPLACEMENT WITH GROUND STEEL MAKING SLAG ON THE COMPRESSIVE STRENGTH OF MORTAR.

The effect of cement replacement with ground steel making slag on the compressive strength of mortar specimens cured for 3, and 7 days are presented in Figure (4). This figure indicates that replacement of cement with ground steel making slag has resulted in a decreasing in compressive strength at any particular age and the magnitude of strength reduction was increased with the increase in the cement replacement.

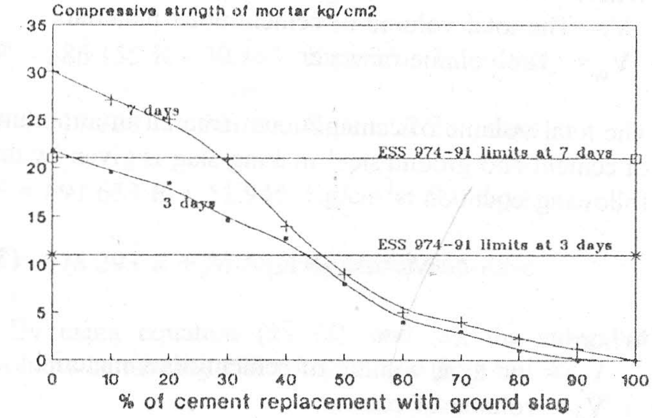

Figure 4: Effect of partial replacement of cement with ground steel making slag on mortar cube compressive strength.

MECHANICAL PROPERTIES OF GROUND STEEL MAKING SLAG CONCRETE

The percentages of cement replacement with ground steel making slag in concrete were 0.0%, and 30% by volume.

Fresh properties

The workability tests: slump, compacting factor and vebe test were carried out on freshly mixed concrete. The freshly unit weight and the air content of the concrete mixes were also carried out. Table (3) summarizes the results obtained with Portland cement and Ground Steel Making Slag concerts. The water content was chosen so as to produce concrete mixes having the same degree of workability (slump = 10 cm).

Table 4. Compressive strength of ground steel making slag and control concretes.

Age in days	Compressive strength kg/cm2							
	C1	CS1	C2	CS2	C3	CS3	C4	CS4
3	195	135	240	175	288	245	325	270
7	268	190	325	235	375	318	422	365
28	350	250	415	306	480	403	535	456
90	415	317	475	360	525	445	585	509
365	438	335	495	380	550	490	605	535

Table 5. Calculation values of V_c / V_w ratio.

Mix	Cement kg/m3	Slag kg/m3	water L/m3	W/C	V_c / V_w
C1	350	0.0	200	0.57	0.56
CS1	245	120	189	0.77	0.59
C2	400	0.0	200	0.50	0.64
CS2	280	136	189	0.67	0.67
C3	450	0.0	200	0.44	0.72
CS3	315	154	189	0.60	0.76
C4	500	0.0	200	0.40	0.80
CS4	350	172	189	0.54	0.82

* V_c / V_w = Volume of cement / Volume of water.

From the a subsidiary experimental program, The relationship between compressive strength (F), and cement to water ratio by volume for portland cement concrete and ground steel making slag concrete, are given by the following equations:-

$F = 470.051\ R - 38.892\ Kg/cm^2$ at 3 days

$F = 586.155\ R - 30.163\ Kg/cm^2$ at 7 days

$F = 717.328\ R - 20.137\ Kg/cm^2$ at 28 days

$F = 691.633\ R + 51.945\ Kg/cm^2$ at 90 days

$F = 678.293\ R + 81.689\ Kg/cm^2$ at 365 days

By using equation (1), (2), and (3), the values of volume cementing efficiency factor (K_v) can be determined at different ages. The values of K_v factors obtained for ground steel making slag concrete at 3, 7, 28, 90 and 365 days are given in Table (6). It is apparent from this table that, values of K_v, increased randomly. This increase could be due to the difference in the rate of hydration between the cement and ground steel making slag, where cementitious components in ground steel making slag were more active at later ages. By using the same procedure as volume cementing efficiency factor, another factor could be determined (weight cementing efficiency factor K_w). Table (7) shows the results of K_w values obtained for ground steel making slag concrete at 3,7,28,90, and 365 days. Table (8) shows the average values for K_v and K_w for ground steel making slag. Figure (5) shows the relationship between mixes and different cementitious content.

Table 9. Expansion of ground steel making slag and control concretes subjected to 3.5% sodium sulfate, 3.5% magnesium sulfate solutions and seawater attack.

Solution	Age in days	Expansion x 10^{-6}							
		C1	CS1	C2	CS2	C3	CS3	C4	CS4
Tap water	0 (28d.)	50	40	70	67	80	70	100	88
	28	70	61	104	94	112	102	160	148
	90	118	110	164	150	190	180	230	225
	180	141	133	189	180	221	214	240	237
	365	174	169	201	195	236	222	250	243
3.5% sodium sulfate	0 (28d.)	50	40	70	67	80	70	100	88
	28	182	188	187	183	177	168	165	163
	90	342	335	315	300	285	273	262	256
	180	541	530	450	435	418	400	343	338
	365	652	637	510	498	460	443	366	360
3.5% magnesium sulfate	0 (28d.)	50	40	70	67	80	70	100	88
	28	212	216	215	203	190	182	177	173
	90	396	382	364	350	330	315	288	280
	180	590	581	482	470	465	451	425	420
	365	800	785	650	638	560	550	510	502
sea water	0 (28d.)	50	40	70	67	80	70	100	88
	28	74	68	106	100	113	103	162	148
	90	170	160	176	169	205	198	139	228
	180	211	206	250	239	243	232	257	243
	365	276	268	277	268	267	253	275	270

Table 10. Compressive strength of ground steel making slag and control concretes subjected to 3.5% sodium sulfate, 3.5% magnesium sulfate solutions and seawater attack.

Solution	Age in days	Compressive strength kg/cm^2							
		C1	CS1	C2	CS2	C3	CS3	C4	CS4
Tap water	0 (28d.)	350	250	416	306	480	403	535	456
	28	378	280	442	339	504	428	559	487
	90	420	319	480	360	527	447	589	511
	180	430	331	490	377	535	465	599	527
	365	441	340	499	389	560	500	610	538
3.5% sodium sulfate	0 (28d.)	350	250	416	306	480	403	535	456
	28	375	285	440	343	510	437	570	497
	90	400	300	460	361	524	447	585	513
	180	375	270	449	340	521	450	590	515
	365	346	249	420	308	496	425	555	481
3.5% magnes-ium sulfate	0 (28d.)	350	250	416	306	480	403	535	456
	28	382	281	445	341	515	435	573	497
	90	393	293	456	354	520	446	584	509
	180	364	264	440	328	514	440	577	502
	365	321	240	390	295	475	401	536	463
sea water	0 (28d.)	350	250	416	306	480	403	535	456
	28	380	292	441	338	505	436	560	495
	90	400	307	482	361	529	452	594	515
	180	386	312	489	368	538	470	599	520
	365	364	275	447	337	521	441	591	506

Table 11. Dynamic modulus of elasticity of ground steel making slag and control concretes subjected to 3.5% sodium sulfate, 3.5% magnesium sulfate solutions and seawater attack.

Solution	Age in days	Dynamic modulus of elasticity t/cm^2							
		C1	CS1	C2	CS2	C3	CS3	C4	CS4
Tap water	0 (28d.)	344	288	353	305	391	353	410	377
	28	358	305	374	326	406	371	423	394
	90	366	313	384	335	414	380	438	407
	180	376	320	391	345	426	393	449	420
	365	389	335	413	366	442	409	465	438
3.5% sodium sulfate	0 (28d.)	344	288	353	305	391	353	410	377
	28	358	308	372	324	407	374	422	389
	90	370	314	379	330	415	381	432	407
	180	365	310	377	329	413	379	438	403
	365	334	284	350	309	399	365	424	395
3.5% magnesium sulfate	0 (28d.)	344	288	353	305	391	353	410	377
	28	360	310	376	327	409	373	422	392
	90	366	315	395	339	418	381	435	400
	180	356	300	371	328	407	373	426	396
	365	318	268	332	292	379	346	404	374
sea water	0 (28d.)	344	288	353	305	391	353	410	377
	28	362	308	374	326	413	375	426	396
	90	365	310	376	328	419	382	436	405
	180	373	318	388	336	424	385	437	411
	365	363	307	377	330	420	381	444	406

Effect of 3.5 % Sodium Sulfate Attack

Effect of 3.5% sodium sulfate solution and tap water on ground steel making slag concrete specimens relative to control concrete specimens were monitored throughout 365 day after 28 days of curing in tap water (zero time).

Length Change

The results of length change measurements after 28,90,180, and 365 days of exposure to 3.5% sodium sulfate solution and tap water, were presented in table (9) for mixes with cement content 350, 400, 450, and 500 kg/m^3. The results indicated that about similar amounts of expansion had occurred in ground steel making slag and control concrete specimens up to one year as shown in figure (6). However slightly lower expansion was observed for the ground steel making slag concrete specimens than the control concrete specimens after 365 days. The results of both concretes indicate up to three and half times, two and half times, two times, and one a half times higher expansion in 3.5% sodium sulfate solution than in tap water after 365 days for cement content 350, 400, 450, 500 kg/m^3 respectively. The expansion of both types of concrete observed here can be related to the sulfate attack on the calcium hydroxide phase of hardened cement paste, resulting in the formation of ettringite which is detrimental to cement paste and causes expansion [1]. Also the presence of C_3A component enhanced the ettringite production due to the formation of chloroaluminate hydrate which reacts with sulfate to form ettringite [1].

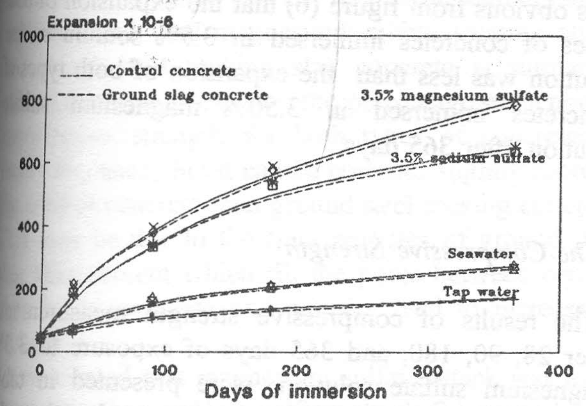

Figure 6: Expansion of ground steel making slag and control concrete exposed to 3.5% sodium sulfate, 3.5% magnesium sulfate, seawater, and tap water up to 365 days for cement content 350 kg/m^3

The Compressive Strength

The results of compressive strength after 28,90,180, and 365 days of exposure to 3.5% sodium sulfate solution and tap water, were presented in table (10) for mixes with cement content 350, 400, 450, and 500 kg/m^3. It is obvious from test results that the compressive strength for concrete specimens immersed in 3.5% sodium sulfate increased with time for both types of concretes up to 90 days for concretes with cement content 350 and 400 kg/m3 and up to 180 days for concretes with cement content 450 and 500 kg/m3. The results indicated that about similar amounts of residual compressive strength had occurred in ground steel making slag and control concrete specimens up to one year as shown in figure 7.

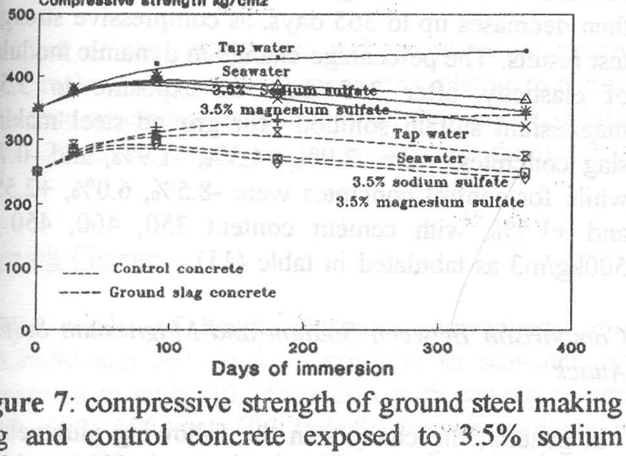

Figure 7: compressive strength of ground steel making slag and control concrete exposed to 3.5% sodium sulfate, 3.5% magnesium sulfate, seawater, and tap water up to 365 days for cement content 350 kg/m^3.

The percentage change in compressive strength after 365 days of exposure to 3.5% sodium sulfate solution for ground steel making slag concretes were +0.40%, +1.0%, +5.4%, and +5.4%, while for control concretes were +1.3%, +1.0%, +3.2%, and +3.8%, for cement content of 350, 400, 450 & 500 kg/m3 receptively as tabulated in table (10).

Dynamic Modulus of Elasticity

Under some conditions, sulfate attack may produce hydration products that would fill the pores in concrete and leads to increase in strength [1]. Under this condition, change in strength and the actual destructive nature of sulfate attack may not be correlated. So the dynamic modulus of elasticity through the variation of pulse velocity, could be more correlated to obvious sulfate attack. The results of dynamic modulus of elasticity measurements after 28,90,180, and 365 days of exposure to 3.5% sodium sulfate solution and tap water, are presented in table (11) for mixes with cement content 350, 400, 450, and 500 kg/m^3. It is obvious from test results that dynamic modulus of elasticity increases with time for both types of concretes immersed in 3.5% sodium sulfate solution up to 90 days for concretes with cement content 350, 400, and 450 kg/m3, and up to 180 days for control concrete with cement 500 kg/m3. The rate of gain of dynamic modulus of elasticity up to one year for ground steel making slag concrete was greater than that for control concretes in both 3.5% sodium sulfate and tap water. The percentage change in dynamic modulus of elasticity after 365 days exposure to 3.5% sodium sulfate solution for ground steel making slag concretes, were - 1.5%, + 0.6%, + 3.5%, and + 4.8% while for control concretes were -3.0%, -0.8%, + 2.0%, and +3.5% for cement content of 350, 400, 450 & 500 kg/m3 respectively, as tabulated in table (11).

The dynamic modulus of elasticity changes over the one year period of exposure to 3.5% sodium sulfate were relatively small (figure 8), indicating no major deterioration of ground steel slag concrete and control concrete specimens, as shown from the compressive strength results. Generally in the sodium sulfate solution, no mass losses were observed in any of the specimens, and deterioration could only be characterized by increase in length. This stage of exposure, up to 365 days, was associated with expansion and weakening of the structure but not with deterioration and spalling of hydrated material from the concrete surface (9).

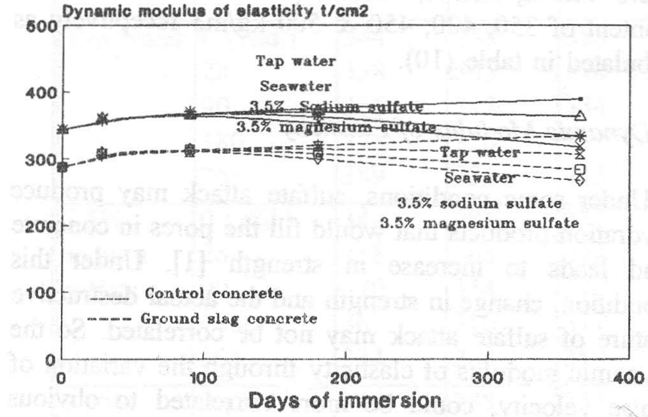

Figure 8: Dynamic modulus of elasticity of ground steel making slag and control concrete exposed to 3.5% sodium sulfate, 3.5% magnesium sulfate, seawater, and tap water up to 365 days for cement content 350 kg/m^3.

Effect of Magnesium Sulfate

Effect of 3.5% magnesium sulfate solution and tap water on ground steel making slag concrete specimens relative to control concrete specimens were monitored throughout 365 day after 28 days of curing in tap water (zero time).

Length Change

The results of length change measurements after 28, 90, 90, and 365 days of exposure to 3.5% magnesium sulfate solution, were presented in table (9), for mixes with cement content 350, 400, 450, and 500 kg/m^3 respectively. Similar amounts of expansion had occurred in steel making slag and control concrete specimens up to one year. Slightly lower expansion was observed in ground steel slag than control concrete immersed in 3.50% magnesium sulfate solution as shown from the results of sodium sulfate attack.

The results of both types of concretes indicated up to four and half times, three times, two and half times, and two times higher expansion in 3.5% magnesium sulfate solution than in tap water after 365 days for cement content 350, 400, 450, 500 kg/m3 respectively.

It is obvious from figure (6) that the expansion of both types of concretes immersed in 3.5% sodium sulfate solution was less than the expansion of both types of concretes immersed in 3.50% magnesium sulfate solution after 365 days.

The Compressive Strength

The results of compressive strength measurements after 28, 90, 180, and 365 days of exposure to 3.5% magnesium sulfate solution, were presented in table (10). It is obvious from the test results that the compressive strength increases with time for both types of concretes up to 90 days for both types of concretes then decreases up to 365 days. The percentage change in compressive strength after 365 days exposure to 3.5% magnesium sulfate solution for ground steel making slag concretes were -4.0%, -3.5%, -0.5%, and 1.5%, while for control concretes were -8.3%, -6.2%, 1.1%, and +0.1%, with cement content 350, 400, 450 & 500 kg/m3 receptively, as tabulated in table (10).

Dynamic Modulus of Elasticity

The results of dynamic modulus of elasticity measurements after 28,90,180 and 365 days of exposure to 3.5% magnesium sulfate solution, were presented in table (11), for ground steel slag and control concrete specimens for mixes with cement content 350, 400, 450, and 500 kg/m3. it is obvious from the previously mentioned table that the dynamic modulus of elasticity increases with time for both types of concretes immersed in 3.5% magnesium sulfate up to 90 days then decreases up to 365 days, as compressive strength test results. The percentage change in dynamic modulus of elasticity after 365 days of exposure to 3.5% magnesium sulfate solution for ground steel making slag concretes, were -7.0%, -4.3%, -1.9%, and -0.7% while for control concretes were -8.5%, 6.0%, +2.5%, and +1.5%, with cement content 350, 400, 450 & 500kg/m3 as tabulated in table (11).

Comparison Between Sodium and Magnesium Sulfate Attack

In general, the changes in the following parameters, expansion, compressive strength and dynamic modulus of elasticity, indicate that the degree of sodium sulfate solution attack and magnesium sulfate solution attack on ground steel making slag concrete is similar to control concrete. However, the percentage reduction of compressive strength for both types of concretes is nearly the same, but it can be consider slightly more in the control concrete than ground steel making concrete. This may be due to the finer particles of ground steel slag than cement which fill the pores between cement particles in concrete and actually lead to increase in strength.

It was noted that magnesium sulfate attack was more aggressive than sodium sulfate attack for ground steel making slag and control concretes. The magnesium sulfate solution attacks most of the constituents of hydrated cement paste. It reacts with calcium aluminate hydrate to give ettringite, magnesium hydroxide, $Mg(OH)_2$, as well as alumina hydroxide, $Al(OH)_3$, and with calcium hydroxide $Ca(OH)_2$ to give gypsum and $Mg(OH)_2$. Besides, magnesium sulfate solution reacts with calcium silicate hydrate (C-S-H) to form gypsum, $Mg(OH)_2$ and silica hydrate which reacts very slowly to form a non cementitious product magnesium silicate hydrate (M-S-H) and additional amount of ettringite [10]. The strength reduces because magnesium silicate hydrate possesses no binding properties and the ettringite causes expansion. The decomposition of the cementitous (C-S-H) gel to non cementitous (M-S-H) is achieved by magnesium sulfate solution, because no ions in sodium sulfate solution can replace the Ca ions in the (C-S-H) gel [1].

Effect of sea water

Effect of seawater attack and tap water on ground steel making slag concrete specimens relative to control concrete specimens were monitored throughout 365 day after 28 days of curing in tap water (zero time).

Length Change

The results of length change measurements after 28,90,90 and 365 days of exposure to seawater, are presented in table (9), for mixes with cement content 350, 400, 450 and 500 kg/m3. Similar amounts of expansion had occurred in steel making slag and control concrete specimens up to one year. Slightly lower expansion was observed for the ground steel slag concrete than control concrete immersed in sea water. The results of both types of concretes indicated up to one and half times higher expansion in sea water than in tap water after 365 days, for cement content 350 and 400 kg/m3, but the same expansion with cement content 450 and 500 kg/m3. It is obvious from figure (6) that the greatest expansion of concrete was that with specimens immersed in magnesium sulfate solution followed by those immersed in sodium sulfate solution then those immersed in sea water. The least expansion was in specimens immersed in tap water after 365 days. Since seawater contain sulfate and could be expected to attack concrete in a similar way as sulphate attack, but because of chlorides, seawater attack does not generally cause expansion of the concrete, the gypsum and ettringite are more soluble in chloride solution than in tap water, and they could be more easily leached away by seawater [11].

The Compressive Strength

The results of compressive strength measurements after 28, 90, 180, and 365 days of exposure to seawater are presented in table (10). It is obvious from the test results that the compressive strength increases with time for both types of concretes up to 365 days. The percentage change in compressive strength after 365 days exposure for ground steel making slag concretes, were + 10.0%, + 10.1%, + 9.5%, and + 11.0%, while for control concretes were +4.0%, +7.5%, +8.5%, and +10.5%, with cement content 350, 400, 450 and 500 kg/m3 as tabulated in table (10).

Dynamic Modulus of Elasticity

The results of dynamic modulus of elasticity measurements after 28,90,180,and 365 days of exposure to seawater, are presented in table (11). The dynamic modulus of elasticity increased with time for both types of concretes immersed in sea water up to 365 days. The percentage change in dynamic modulus of elasticity after 365 days of exposure to seawater for ground steel making slag concretes were + 6.5%, + 8.2%, + 8.0%, and + 7.9%, while for control concretes were +5.5%, + 6.7%, + 7%, and + 8.3%, with cement content 350, 400, 450 and 500 kg/m^3, as tabulated in table (11).

CONCLUSION AND RECOMMENDATIONS

Within limits of the research reported here, it may be stated that Ordinary Portland Cement could be safely replaced by up to 30 percent of ground steel making slag. The water demand to maintain the same workability of concrete, is decreased for ground steel making slag than that for control concrete. For the same workability and different blend cement content, concrete containing 30% ground steel slag and 70% ordinary Portland Cement had lower average 28 days compressive strength, than that containing 100% ordinary Portland cement, because of the slowness of the steel making slag reaction. Two cementing efficiency factors were determined, volume cementing efficiency factor (K_v), and weight cementing efficiency factor (K_w), which depend on the mix design and the volume of cementitious materials. The results of the tests on the durability of concretes immersed in 3.5% sodium sulfate, 3.5% magnesium sulfate, seawater, and tap water were as follows: the greatest expansion of concrete was that with specimens immersed in magnesium sulfate solution followed by those immersed in sodium sulfate solution then those immersed in sea water. The least expansion was in specimens immersed in tap water after 365 days for steel making slag and control concretes. Similarly the greatest reduction in compressive strength was that with specimens immersed in magnesium sulfate solution followed by those immersed in sodium sulfate solution up to 365 days. On the other hand concrete specimens immersed in seawater and tap water had an increase in compressive strength, the increase being higher in specimens immersed in tap water. Results of dynamic modulus of elasticity were in accordance with the results of compressive strength.

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