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Using of Steel Slag in Modification of Concrete Properties

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Abstract

Steel slag which can be considered as solid waste pollutant was used in concrete mixture for road bases and surfaces, bridges, asphaltic concrete, clinker raw material and other fields, instead of cement or filling material.

In this work, steel slag was used as replacement of aggregate or stone, which has the highest content in concrete mixture. Four groups of concrete mixtures with (0, 25, 50 and 60%) by wt. of steel slag from Basrah steel plant were used instead of aggregate.

The first group, without slag, as a standard mixture was used to compare its properties with those of (25, 50 and 60%) by wt. steel slag. The obtained results showed that, density of concrete and compressive strength, also flexural force, after 7 days and 28 days were increased by increasing slag content, while water absorbed content was decreased by increasing slag content.

Those results insure the importance of using steel slag not only in modification of concrete properties, but also to save the environment from huge quantities of slag as solid waste.

أستخدام خبث الفولاذ في تحسين خواص الخلطات الكونكريتية

الخلاصة

ان خبث الفولاذ الذي يمكن اعتباره من الملوثات او النفايات الصلبة يستعمل في خليط الخرسانة المستعملة في أسس الطرق والسطوح والجسور والخرسانة الأسفلتية ومواد السمنت الخام (الكلنكر) وفي مجالات أخرى بدلاً من السمنت أو المواد الحشو.

في هذا البحث تم أستعمال خبث الفولاذ بديلاً عن الحصى الطبيعي الذي يشكل أعلى نسبة في مكونات الخلطات الخرسانية حيث أستخدمت أربع مجموعات من الخلطات ذات (0، 25، 50، 60)% وزنا من خبث الفولاذ من مصانع الحديد والصلب في البصرة بدلاً من الحصى.

المجموعة الأولى كانت بدون أضافة الخبث كخلطة قياسية أستخدمت لمقارنة خواصها مع خواص المجموعات الأخرى التي حل الخبث محل النسب أعلاه من الحصى (25، 50، 60) وزنا %.

لقد أظهرت النتائج التي تم التوصل اليها ان كثافة الخرسانة ومقاومتها للضغط وقوة الثني (Flexural force) بعد 7 أيام وكذلك بعد 28 يوم من تاريخ صنع النماذج قد أزدادت جميعها مع زيادة نسب الخبث بينما قلت نسب أمتصاصها للماء مع زيادة نسب الخبث.

أن تلك النتائج أكدت أهمية أستخدام خبث الفولاذ كبديل عن الحصى ليس فقط في تحسين خواص الخرسانة وأنما ايضاً في تخلص البيئة من الكميات الهائلة من الخبث الناتج من صهر الفولاذ كنفايات صلبة.

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1- Introduction:

Steel slag was existed as by-product during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in arc or induction electrical furnaces, or other melting units.

Knowing that steel slag from Basrah plant may reach sixty thousand MT per year with design capacity.

This was removed from the furnace separately in a rate of about (10-15%) of the produced steel [1-4]. The properties and chemical composition of the slag were stated by Clarkson University, the specific gravity ranges from (2.85-3.0) and bulk density varies from (1.0-1.4 gm/cm^3) [5] .

The active slag made from molten iron has to be water cooled. Chemical composition of typical slag consisted mainly SiO_2, Al_2O_3, CaO and Fe_2O_3 [5].

The slag may be further processed after cooling, mainly crushed and screened to desired size, prior to being used or sold. The main uses of steel slag were in road bases and surfaces concrete, asphaltic concrete and as aggregate in hydraulic cement concrete.

In the past 20th century, slag was found to be excellent aggregate for asphalt road paving [6,7,8,9,10,11,12].

Different forms of slag produced depend on cooling method used. It may be used as a mineral admixture for Portland cement concrete [13, 14].

Work was done in Germany to develop an injection mortar based on furnace slag, gypsum and Portland cement [15, 16]. Various results were obtained by using furnace slag for oil field by different test in the (Fluid Research Association Laboratory) [17] .Another investigation carried out at the King Fahd University, to determine the role of chloride ions in sulphate attack in plain and blended cements [18, 19]. The results indicated that sulphate deterioration in plain cements was mitigated.

Studies conducted at MC Master University in Hamilton, dealt with the fact that when steel slag is used as aggregate, its properties depend on its chemical and mineralogical compositions [20,21,22,23].

The latest development in the disposal and application on iron and steel slag in Japan were described at Shanghai Institute of Metallurgy. Such developments included the air granulated slag process, ultra fine furnace slag, color sand, recovery of the useful constituents in steel slag.

Other uses of steel flag are four water penetrating and antiwear material for pavement, spray abrasives for grinding ship surfaces and water purification agents [24].

2- Aim of the Work:

The main goal for this work is to find useful field of using steel slag, as industrial solid waste. However natural aggregate is available in Iraq,the using of SS for modification of concrete mixtures was one of the methods used to convert the slag from solid environmental pollutant to valuable material from economical-technical point of view.

3- Experimental Part:

3-1 Materials Used in the Work

The materials used in this work to make the samples used in the test consist of;

a- Portlant salt resistant cement of 15 MPa, compressive strength ts_1=45 min, ts_2=10 hrs. (ts_1& ts_2 were curing times).

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b- Natural sand used in concrete (density 1.6 gm/cm^3)
c- Steel slag from Basrah steel plant density (2.94 gm/cm^3) (waste)
d- Drinking water (Tap water)
e- Natural coarse aggregate or stones (5-19) mm size

3.1.1 General Specification of Materials

Iraqi Portland salt resistant cement was brought from local market in 50 kg packed paper bag according to Iraqi Standard No.5/1984.

Natural sand and coarse aggregate were also provided from local market which were according to Iraqi Standards No.45/1984 and No.30 and BS-882/1992.

Steel slag was provided from Basrah steel plant in the form of relatively large masses

Drinking water was available in the laboratory. At the beginning, the masses of steel slag (SS) were crushed in the hammer type crusher (Pascall Engineering) Co. Ltd. ,and then screened to the standard size (5-19 mm), to be in the same sizes as the standard natural aggregate used in concrete. Prepared (SS) was used in the concrete mixture in (25, 50 and 60%) instead of natural aggregate or stone as shown in Table (1).

3.1.2 Chemical Composition of Steel Slag Used

Chemical composition of SS used in this work was analyzed in (S.C. of Geological Survey and Mining, Baghdad). The composition depend on charge materials and melting process. The result was given in table (1) below:

3-2 Description of Samples

Two types of samples were prepared in this work, cubic (100x100x100 mm) blocks and cylindrical shape (100x200 mm) samples. Description of both types of samples were given in Table (2).

3-3 Preparation of Concrete Mixtures Samples

In order to form the samples required in this work, the following steps were undertaken:

1- Metallic molds in which the samples were formed (cubic and cylindrical) shapes were prepared clean and tighten.
2- Concrete of each composition mentioned in Table (2) were made respectively and cast in the prepared molds.
3- To prepare concrete mixtures, water was added to mixed solids materials, in about 50% of cement content. By good mixing with water, uniform mixture was poured in the molds to form the samples, in two stages with (30 sec), vibration after each stage on the vibrating plate in the aim of getting sound samples.
4- Marking the numbers in the cast samples at the same order mentioned in Table (2).
5- Formed samples were left inside the mold for (24 hours), and then opened to have the samples prepared.
6- Samples for water permeability were put in oven to dry at (110 ^{o}C) for (24 hours). After drying, weight of samples were determined, samples were immersed in water bath for (48 hours), then the weight of samples were rechecked . The difference in weight is the water absorbed.
7- The remaining samples i.e. for compressive strength test were immersed in water. For 7 days for some of them and 28 days for the others.

3-4 Testing of Prepared Samples

3-4-1 Testing of Physical Properties

Density Calculation

This has been done by drying the given samples in laboratory oven at (110 ^{o}C) for 24 hours to insure the dryness of the samples. Dry samples were then weighed. Density has been calculated by dividing the dry weight of each sample by volume of the samples, i.e. 1000 cm^3 for cubic one and 1570 cm^3 for cylindrical samples. All these results were shown in Table (3) for each case.

The change in dimensions was not checked in this work .

Water absorption Test

Test has been achieved by using the weight of dried samples as a base, then the given samples were soaked completely in tap water basin for 48 hours, the samples then weighed again.

The difference between the first and second weights was the weight of absorbed water. The percentage of absorbed water was calculated by dividing the absorbed water weight by the dry weight of each sample by (100) to get the value (wt% value). The results were shown in Table (3) for each case.

3-4-2 Testing of Mechanical Properties

Testing of Compressive Strength

This test can be achieved by using the standard compression tester (Type- Avery England 2000 kN load) in concrete lab. The test was carried out after 7 and 28days for cubic samples . The results of tests were given in Table (3) for each case.

3.4.3 Flexural Force Test

Cylindrical samples of 100 x 200 mm were used in this test in the horizontal position, on the same compression testing machine as in the previous tests.

The results of the tests in (kN) after 7 days and 28 days were given in the lower part of Table (4) for tested case.

4- Results and Discussion

Below are some of the main results obtained from all tests carried out in this work .

1- The density of concrete increased from 2.35 gm/cm^3 for samples without slag to 2.60 gm/cm^3 for samples with 60% slag, i.e. by 10% increment for cubic samples, while for cylindrical samples with up to 50% slag, the density increased by about 8%, so that relatively high density concrete could be obtained. The increment indensity was due to more interference of small slag particles, so the final density would be higher and increased by increasing content . (fig 1)

2- Water absorption decreased by increasing slag content from 3.65% without slag to 3.18% with 60% slag content, i.e. decreased by about 13% for cubic samples, and about 25% for cylindrical samples. As a result , smaller empty interspaces would within concrete structure , so that the water ability to be absorbed by concrete would be less and more increasing occurred by increasing slag content (fig 2).

3- The compressive strength of cubic samples after seven days, was increased from 17 MPa without slag to 27 MPa with 60% slag, i.e. increased by about 59% as shown in Fig. (3), and increased from 21 MPa with no slag to 36 MPa with 60% slag i.e increased by 42 % after 28 days.

4- The flexural force for cylindrical samples increased from 45 kN with no slag to 75 kN with 50% slag, i.e. by about 66% after 7 days, while it increased from 60 kN with no slag to 100 kN with 50% slag, i.e. by about 66% as shown in Fig.(4), in which the flexural force also increased by increasing slag content and soaking time.

5-Both compressive strength for standard samples with out slag and flexural force of cylindrical samples after 7 days have about 81% and (75-87)% of that after 28 days respectively (figs 3 & 4) . From this we could state that using steel slag improved concrete properties .

6- Results achieved clarified the improvement in compressive strength and flexural force in concrete mixtures by increasing slag contents after 7 and 28 days. This could be explained by positive effect of slag additions . so they increased by increasing slag content within the same range actually, the rough surfaces of the slag and it's glassy – cement form enable strengthening of concrete by water addition, also slag particles size and shapes interfere in concrete mixtures and decreased water permeability. Also higher density of concrete was due to smaller empty interspaces resulted within the concrete structure. From the above results , we could state that using steel slag , improved concrete properties . By simple estimation , waste steel slag would be enough to produse about 3 MT of concrete from each 1 MT of steel slag , in addition to its environmental benefits .

5- Conclusions and Recommendations

Results achieved could be considered from two important points :-

1. Modification of concrete by using steel slag.
2. protection of environment from the pollution effects of huge quantities of slag rejected from steel smelting in Iraq or in all over the world. Also relatively high density concrete could be used in special purposes.

From the above results we can insure the improvement of the concrete mixture properties due to addition of steel slag .

Accordingly we could state that many advantages were achieved by using steel slag instead of natural aggregates, however the last was available, but it's not industrial pollutant , also this will encourage other investigations to find another filed of using the slag.

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Table(1) Chemical Composition of Slag Used Compared with Blast Furnace Slag

Type of Slag	SiO_2	Al_2O_3	MnO	CaO	Rest
SS used	23.1	14.1	7.87	46	FeO, TiO, MgO, and others
Blast furnace slag*	35	16	0.5	41	

* This was taken from [25]

Table (2) Description of Tests

Sample form	Sample No. for Water Permeability Test		Sample No. for Comp. Str. After 7 Days Test		Sample No. for Comp. Str. After 28 Days Test		Percent(SS) Relative to Natural Aggregate Wt.%
Cubic 100x100x100 mm	1	2	3	4	5	6	0 (Standard Concrete mixture)
	7	8	9	10	11	12	25
	13	14	15	16	17	18	50
	19	20	21	22	23	24	60
Cylidrical 100x200 mm	25		26 flexural		27 flexural		0 (Standard Concrete mixture)
	28		29		30		25
	31		32		33		50

Note1: Standard concrete mixture consists of 1 part cement + 2 parts sand + 4 parts stone by wt.
Note2: The contents of (SS) replaced stone were given in Table (1) in wt %).

Table (3) Results of Water Absorption Tests and Density Calculated

Sample No.	Sample Composition (%wt)	Mass of Dry Samples (g)	Calculated Density (gm/cm^3)	Mass of Moist Samples (g)	Mass of Absorbed Water (g)	Absorbed Water Percent Relative to Dry Mass (%)
1	Standard	2350	2.35	2437	87	3.66
2	Standard	2360	2.36	2445	85	3.65
7	With 25% Slag	2365	2.365	2449	84	3.55
8	With 25% Slag	2372	2.372	2455	83	3.5
13	With 50% Slag	2403	2.4	2482	79	3.3
14	With 50% Slag	2390	2.39	2467	77	3.22
19	With 60% Slag	2625	2.625	2709	84	3.2
20	With 60% Slag	2575	2.575	2656	81	3.16
25	Standard	3557	2.265	3688	131	3.68
28	With 25% Slag	3775	2.404	3890	115	3.05
31	With 50% Slag	3851	2.453	3952	101	2.62

Note: Samples No.25, 28 and 31 are cylindrical of 10x20 cm (i.e. volume ≈ 1570 cm^3) other samples are cubic of 10x10x10 cm (i.e. volume = 1000 cm^3)

Table (4) Results of Compressive and Flexural Strength

Sample No.	**Compressive Strength after 7 days MPa**	**Sample No.**	**Compressive Strength after 28 days MPa**
3	18	5	22
4	16	6	20
9	22	11	26
10	20	12	28
15	26	17	33
16	26	18	34
21	28	23	35
22	26	24	37

Table (5) Flexural force for testes samples after 7 and 28 days

Sample No.	**Flexural Force after 7 days kN**	**Sample No.**	**Flexural Force after 28 days kN**
26	45	27	60
29	70	30	80
32	75	33	100

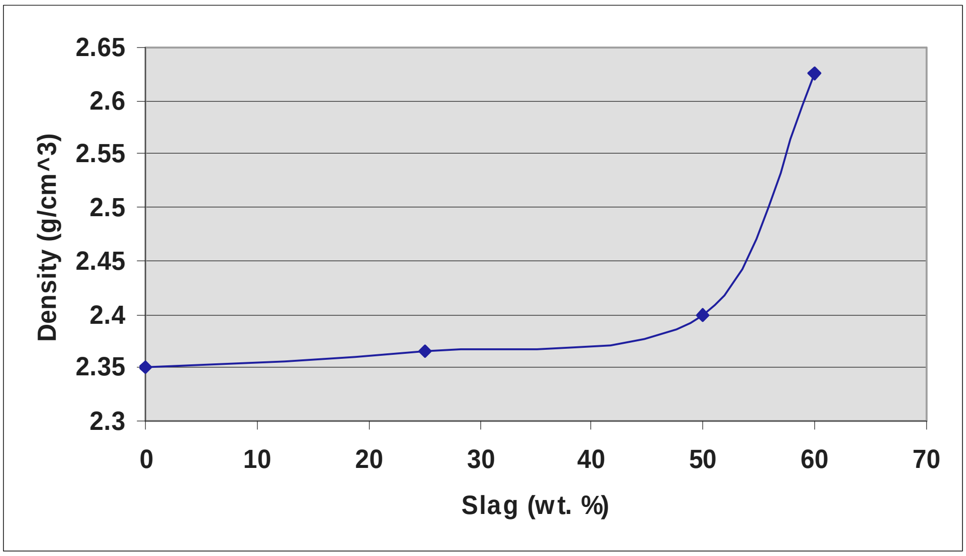

Figure (1) The Relation Between Slag Content and Density of Cubic Samples

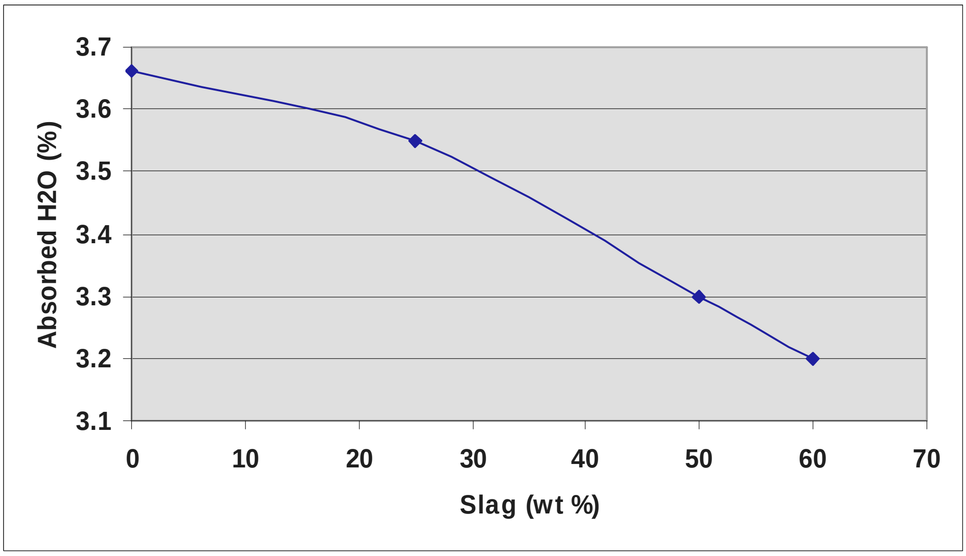

Figure (2) The Relation Between Slag Content and Absorbed Water (%) by Weight .

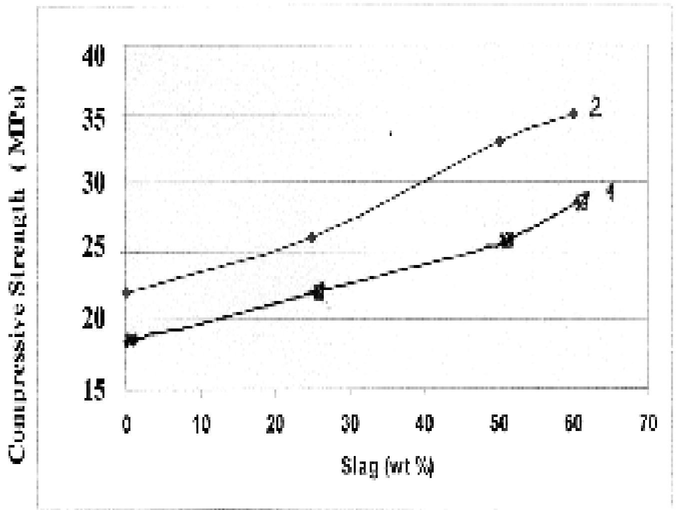

Figure (3) The Relation Between Compressive Strength After 7and 28 Days and Slag Content

1- After 7 days 2-After 28 days

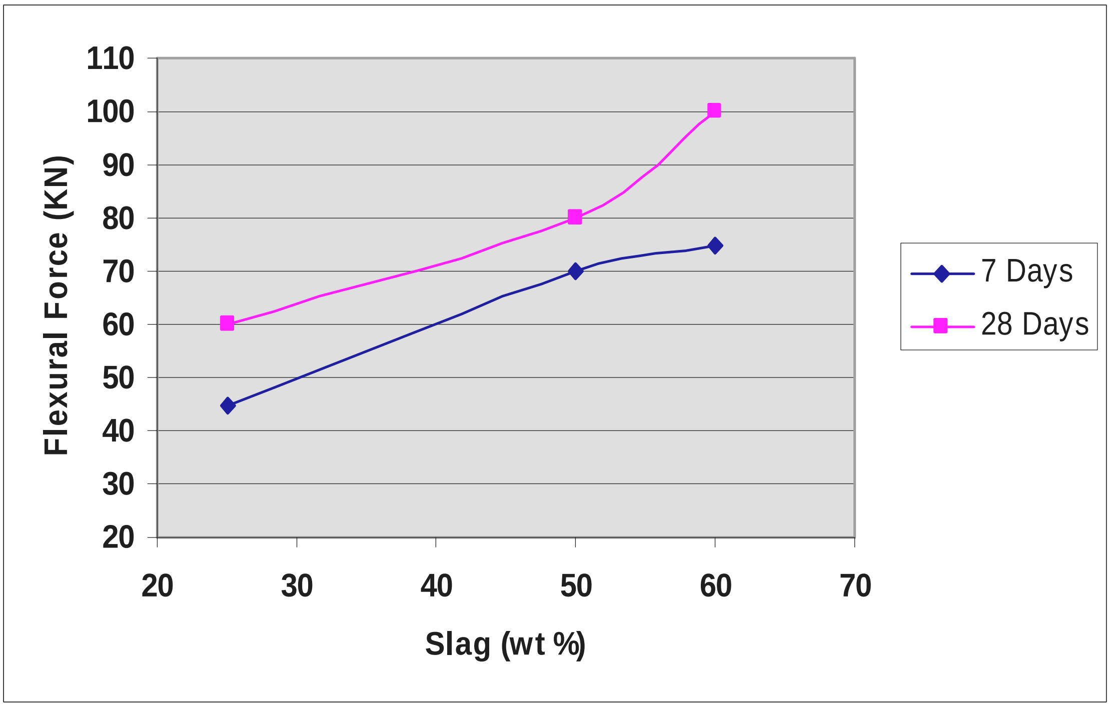

Figure (4) The Effect of Slag Content on the Flexural Strength Property for Cylindrical Samples After 7 and 28 Days