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Use of Steel Slag in Eco-Frienfly Rigid Pavement

استخدام خبث الحديد في الرصف الصلب صديق البيئة

Ahmed Mohamed Tahwia, *Ahmed Hasanen Abd El Raheem* and Ahmed Khaled Elalfy

KEYWORDS:
Recycling, Rigid pavement, Steel slag, Compressive strength, Tensile strength.

الملخص العربي: **- يعد استخدام خبث الحديد كركام في الرصف الخرساني حل اقتصادي وبيئي عظيم للتغلب علي مشكلة نقص الموارد الطبيعية(الركام الطبيعي) . استخدام خبث الحديد كركام كبير بالخرسانة يقلل من التكلفة ويحافظ علي البيئة .الهدف من البحث هو دراسة تأثير استخدام خبث الحديد الأوكسجيني كنسب مختلفة 25% و50% و75% و100% من الركام الكبير في الخرسانة علي خواص الخرسانة في الحالة الطازجة والحالة المتصلدة ومدى تأثيره علي أدائها المعمري عند غمر العينات في محلول كبيرتات تركيز 5% . وقد أوضحت النتائج ان استخدام الخبث كركام يزيد من الخواص الميكانيكية للخرسانة وآمن للأستخدام في حالة تعرض الخرسانة لأملاح الكبريتات.**

***Abstract*—The use of steel slag aggregate in rigid pavement presents a great economical and environmental solution to overcome the decreasing in natural aggregate. The aim of this research is to investigate the potential recycling of Basic Oxygen Furnace Slag (steel slag) in road construction for sustainability an environmental benefit. The steel slag is used as a coarse aggregate replacement in rigid pavement mixes, partly or totally. Recycling ratios of 25%, 50%, 75% and100% are used. The results showed that using steel slag aggregate increases the mechanical properties of concrete, safe to use as aggregate at sulfate attacking when samples were submerged in 5% sulfate solution concentration.**

I. INTRODUCTION

A LARGE amount of roads project is constructed in present time in Egypt, for that this research is seeking to use rigid pavement substitute to flexible pavement because it's durability, stiffness, and ability to bear high traffic loads and began to use it in Cairo-Suez road in 2015.But its resistant is high cost, so that the researcher's started to get solutions to decrease its cost such as using recycled materials as substitution in concrete composition.

Recycling and environmental management are all precepts that are more common in many appearances of life, including concrete paving. The greatest potential for recycling slag aggregate at a high value is to utilize it as aggregate in new concrete slabs whereat the dolomite or gravel and sand, constitute the major component of pavement concrete, representing about 70% of the volume of concrete so utilizing Slag aggregate (SA) as a replacement for natural aggregates is a way to potentially address these economical and environmental concerns [1].

Efforts to preserve non-renewable resources and reduce the related negative environmental influences continue to be a research motivation for researchers and scientists. These efforts represent investigating the potential recycling of industrial by-products materials in road paving one example of these by-products is ferrous slag from steel and iron industries [2].

The term ferrous slag prescribes slag that is produced during steel and iron production and casting. Depending on the steel and iron production process, many slag types can be generated, generally known as blast furnace slag and steel slag. Blast furnace slag is made during the melting and

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reduction of iron ore in a blast furnace, while steel slag is produced during the converting of hot metal to steel or during the melting of scrap in different types of furnaces [3].

Using steel slag aggregate in concrete mixtures has verified to be useful in solving some of the challenges encountered in the concrete industry. Steel slag was used in normal concrete to enhance its mechanical, chemical, and physical properties [4].

Basic Oxygen Furnace Slag (BOFS) is a hot liquid blast furnace metal and fluxes, which consists of (CaO-MgO) and (CaO). They are initially charged into furnace react and remove the faults in the charge. Those faults mainly are generated by carbon as gaseous, and silicon, magnesium, phosphorus and some iron oxide, which react with (lime and dolomite) to form BOFS.

Kothai et al. made different mixes of different replacement ratio of steel slag from 10%, 20% up to 100% and slump test in this mixes decrease from 100 mm to 85 mm with increasing in replacement [5].

Lizadeh et al. prepared four mixtures normal, slag aggregate concrete, and high strength concrete with normal and slag aggregate. The results showed that the normal concrete with slag aggregate higher than the normal concrete with normal aggregate and near to HSC strength because of mechanical and physical properties of Steel aggregate [6].

Ameri et al. showed that The flexural strength of Slag aggregate concrete is higher than normal concrete aggregate because of high roughly surface of slag that increase the bond with concrete and decrease the internal stress between their components.

This research presents experimental results of mechanical properties and durable performance of mixes that have different percentage of steel slag (BOFS) and determine the optimum percentage of steel slag in Mixture.

II. EXPERIMENTAL PROGRAM

A. Materials

1) Cement: Local Portland Cement Type 52.5 N was used. It is provided by Sinai cement factory. It is conformity with the Egyptian Standard (ES4756-1 /2013). The chemical composition is shown in Table 1 and the physical and mechanical properties are shown in Table 2.
2) Coarse aggregate:
   - Crushed Dolomite: Local crushed dolomite of 4.75/12.5 was used. The Physical and mechanical properties are shown in Table 3 and the gradation is shown in Fig. 1.
   - BOFS: Basic Oxygen Furnace Slag. It supplied from Helwan steel. The chemical and physical properties are shown in Table 1 and Table 3 respectively. The gradation of BOFS is shown in Fig. 1.
3) Fine aggregate:
   - Natural sand of 0/4.75 was used. The specific gravity of sand is 2.67and The Physical properties are shown in Table 3 and the gradation of sand is shown in Fig1.
4) Chemical admixture: The superplasticizer (SP) type (F) is used to achieve good workability. It is density of 1.08 kg/lit.
5) Water: The clean water is used in mixing and curing.

TABLE 1
CHEMICAL COMPOSITION OF PORTLAND CEMENT AND BOFS (MASS %)

Constituent	SiO2	Al2O3	Fe2O3	CaO	Na2O	K2O	MgO	SO3	L.O.I	TiO2	P2O5
PC	22.12	5.56	3.69	62.87	0.26	0.11	2.36	0.91	1.22	--	--
BOFS	7	2	45	39.5	0.5	--	4	--	--	0.8	1.2

TABLE 2
PHYSICAL AND MECHANICAL PROPERTIES OF USED CEMENT CEM I 52.5 N

Properties	Cement Fineness (m2/kg)	Setting Time (Minute)		Compressive strength (MPa)	
		Initial	**Final**	**2 days**	**28 days**
Test result	365	75	205	Test result	365
ES 4756-1/2013 limits	Not less than 275	Not less than 45	-	ES 4756-1/2013 limits	Not less than 275

TABLE 3
PHYSICAL AND MECHANICAL PROPERTIES OF DOLOMITE, SAND AND STEEL SLAG AGGREGATE

	Physical Properties				mechanical properties	
	Specific gravity	**Bulk density (t/m3)**	**Clay and fine dust content (%)**	**Absorption (%)**	**Coefficient of Impact (%)**	**Aggregate Crushing value (%)**
Crushed dolomite	2.70	1.62	0.8	2.1	15	23
BOFS	3.69	1.98	-	2.7	14	18
Sand	2.67	1.65	0.6	1.35	-	-
ES 1109/2008	-	-	Less than 3.0	Less than 2.5	Less than 30	Less than 30

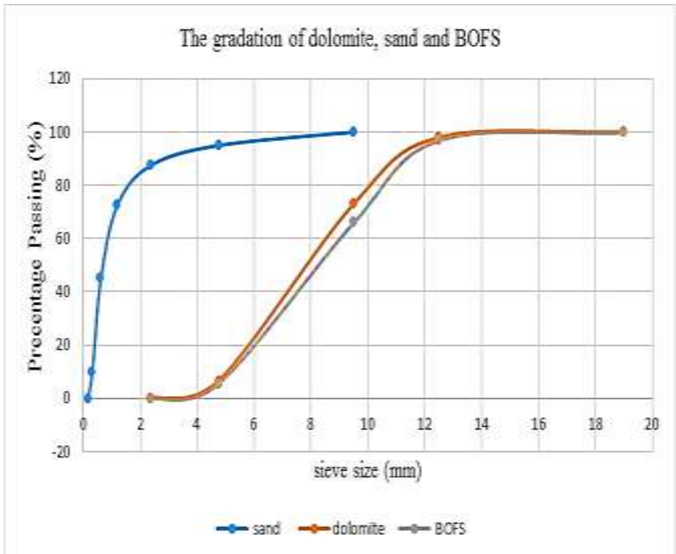

Fig. 1. The gradation of dolomite, sand and BOFS

B. Specimen Preparation and Mixture

Cubes, cylinders, and beams were prepared to conduct all concrete tests. Cubes of 100x100x100 mm, cylinder of 100mm diameters by 200 mm length and beams of 100x100x500 mm.

Divided as:

1- Compressive strength, indirect tensile strength, and Flexible strength at 7, 28, 56 and 90 days.

2- Bond strength at 28 days on 3 cylinders by 1ϕ16 at center.

3- Sulfate attack resistant at 28 days.

The laboratory pan mixer was used in mixing concrete. All samples compacted by using a vibrating table to achieve maximum compaction. The samples were cured in water at (20 ± 2° C) after 24 hours of mixing and casting until testing. The sulfate attack resistance was studied by immersing the 100 mm concrete cube specimens in 5% sodium sulfate solution with concentration 5% by weight until the day of testing. The concrete mix proportions are shown in Table 4.

TABLE 4
MIX PROPORTIONS OF CONCRETE MIXES (KG/M3).

Mix	Mix code	Coarse aggregate		Fine aggregate	Cement	WC	SP
		Dolomite	BOFS	Sand			
M1	M0	1145	---	764	400	140	12
M2	M 25S	907	302	806	400	140	12
M3	M 50S	631	631	841	400	140	12
M4	M 75S	331	995	885	400	140	12
M5	M 100S	---	1395	930	400	140	12

25S, 50S, 75S and 100S: Represent the percentage of coarse aggregate replacement with BOFS

C. Test Procedure

The slump test was carried out to determine the workability of concrete mixes. The test performed according to ASTM C143.

The compression strength test was carried out by using test laboratory machine with capacity 2000 kN according to BS EN 12390-2: 2009. The test occurred on 100 mm concrete cube at the ages of 7, 28, 56, and 90 days. The compression strength value was the average of three test result samples for each mixture. The compression strength test carried out on the 100 mm concrete specimen which immersed in sodium sulfate solution with concentration 5% to study the impact of sulfate attack on concrete specimens. The test was performed at the age of 28days.

The Splitting tensile strength test was performed at7, 28, 56 and 90 days according to BS EN 12390-6:2009 standard. Three cylinders for each mixture 100*200mm prepared to test at different test deadline by using same compression machine.

The Flexural strength test was performed at 7, 28, 56, and 90 days according to ASTM C78. 12 beams were prepared 100*100*500mm to test at each deadline. The beam was simply supported as 450mm clear span, the testing machine with 100 kN capacity and 0.1 kN accuracy was used for testing.

Bond strength between reinforcing bar and the surrounding concrete was determined by pulling out the steel bar from the concrete specimen using universal testing machine with 30-ton capacity and 0.1-ton accuracy. The tests were carried out according BS 1881: part 207: 1992.

III. TESTRESULTSANDANALYSIS

The ensuing subsections present analysis and discussion of the results of each conducted test on the investigated mixtures.

A. Fresh properties

A.1. slump test

Table 5 and Fig. 2 show the effect of BOFS on workability. The results show that the use of steel slag aggregate reduces the workability of concrete. because of the angular shape of the BOFS that increase the bond with cement paste and stability against collapsing. These results are in line with the finding of Kothai et al [5].

TABLE 5
FRESH TESTS RESULTS

	Mix No	Slump test (mm)
Fresh Tests	M1	160
	M2	140
	M3	120
	M4	115
	M5	100

=

B. Hardened properties

B.1. Compressive strength

Table 6 and Fig. 3 show the effect of BOFS on the compression test. The results show that using steel slag as coarse aggregate increase the compressive strength of all mixes because of the rough surface texture and the angular shape of the BOFS that led to the high bond matrix between slag and cement paste. The use of 25% steel slag aggregate led to 12% increase in compressive strength, 50% steel slag aggregate led to 10.5% increase in compressive strength, 75% steel slag aggregate led to 5.6% increase in compressive strength, and 100% replacement led to very similar value to the control mix.

B.2. Splitting tensile strength

Table 6 and Fig. 4 show the effect of BOFS on splitting tensile test. The results show that using steel slag as coarse aggregate increase the splitting tensile strength of all mixes. The mix M3 (50% BOFS replacement) are better tensile strength comparing to control mix. whereat use 50% BOFS replacement get increase 17% on indirect tensile strength from control mix at 90 days, and at an early age at 7 days get increase 39.4% from control mix.

B.3. Flexural strength

Table 6 and Fig. 5 show the effect of BOFS on flexural test. The results show that using steel slag as coarse aggregate increase the flexural strength of all mixes. The mix M2 (25% BOFS replacement) are better flexural strength comparing to control mix. When we use 25% BOFS replacement gets increase 20% on flexural strength from control mix at 90 days, and at an early age at 7 days get increase 30.8% from control mix. Because of physical properties of BOFS such as the rough surface texture and the angular shape of the BOFS.

B.4. Bond strength

Table 6 and Fig. 6 show the effect of BOFS on the bond test. The results show that All mixes have BOFS (M2, M3, M4, and M5) are better bond strength than control mix (M1) because of physical properties of BOFS such as the rough surface texture, angular shape, high porosity, and the high bond matrix between slag and cement paste as a result from interlock the cement paste into open holes on the external surface of aggregate. The mix M2 (25% BOFS replacement) are better bond strength comparing to the control mix. When we use 25% BOFS replacement get increase 28.5% on bond strength from control mix at 28 days.

C. Durability properties

C.1 Sulfate Resistance

Table 7 and Fig. 7 show the effect of BOFS on sulfate resistance test. The results show that all mixtures were decreased in compression strength after sulfate attacking. M5 (100% replacement) is similar decreasing to the control mix.

TABLE 6
HARDENED TESTS RESULTS

	Tests	**Mix No**	**At 7days**	**At 28days**	**At 56days**	**At 90days**
Hardened tests	Unit weight	M1	--	2.38	--	--
		M2	--	2.5	--	--
		M3	--	2.68	--	--
		M4	--	2.74	--	--
		M5	--	2.81	--	--
	Compression strength	M1	35.7	51	57.5	62.5
		M2	53	58	64	70
		M3	52	57	63	69
		M4	50.5	56	62	66
		M5	48	51	60	64
	Slitting tensile strength	M1	2.87	3.72	4.5	4.7
		M2	3.18	4.14	4.78	5.14
		M3	4	4.78	4.9	5.5
		M4	3.97	4.32	4.75	5.31
		M5	3.66	4.27	4.71	5.16
	Flexural strength	M1	3.87	3.89	4	4.5
		M2	4.68	5.09	5.13	5.4
		M3	4.1	4.2	4.73	4.91
		M4	4.09	4.13	4.43	4.93
		M5	3.89	4.15	4.35	4.56
	Bond strength	M1	--	6.5	--	--
		M2	--	8.35	--	--
		M3	--	7.9	--	--
		M4	--	7.75	--	--
		M5	--	7.8	--	--

TABLE 7
DURABILITY TESTS RESULTS

	Mix No	Compression strength at 28 day	Sulfate resistance at 28 days
Durability Tests	M1	51	50
	M2	58	54
	M3	57	55
	M4	56	53
	M5	51	50

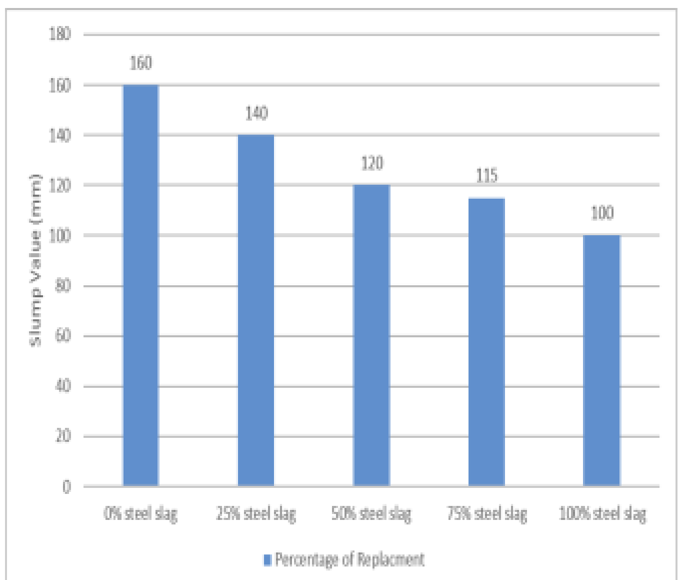

Fig. 2 Slump Value of Different Mixes

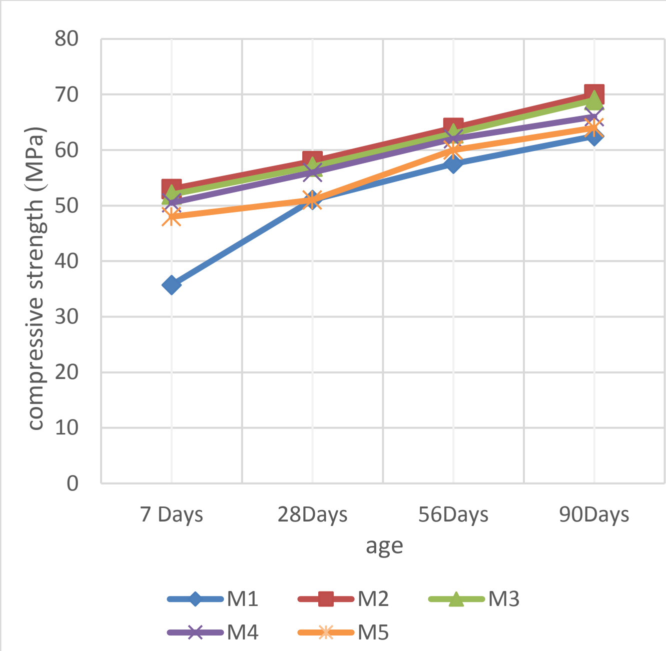

Fig. 3. The Effect of use BOFS on Compressive Strength

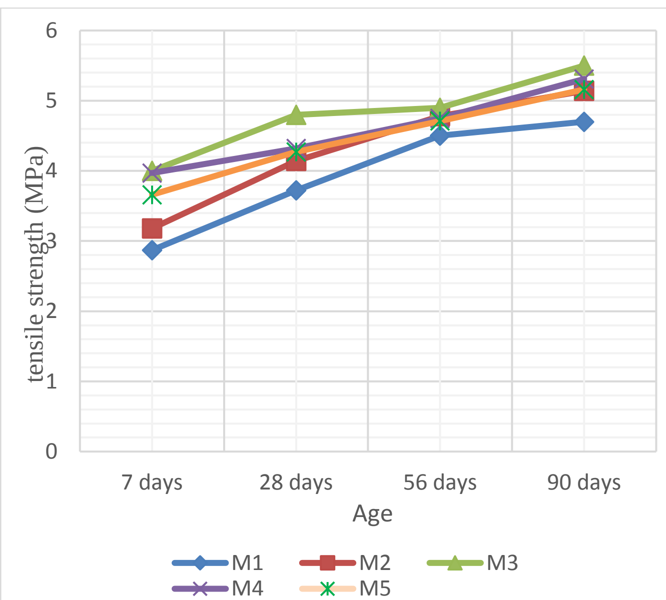

Fig. 4. The Effect of use BOFS on Tension Strength

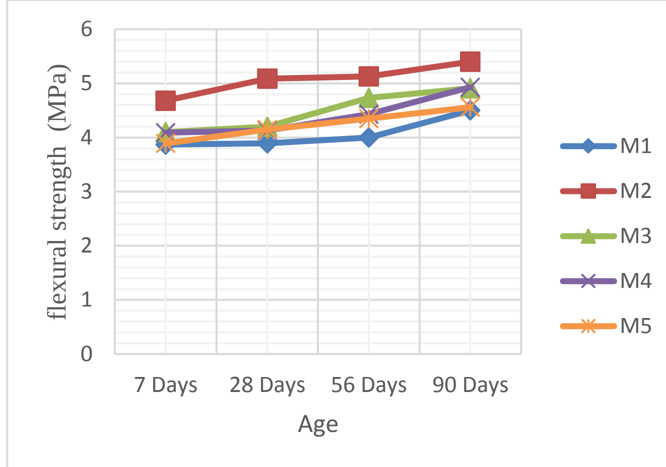

Fig. 5. The Effect of use BOFS on Flexural Strength.

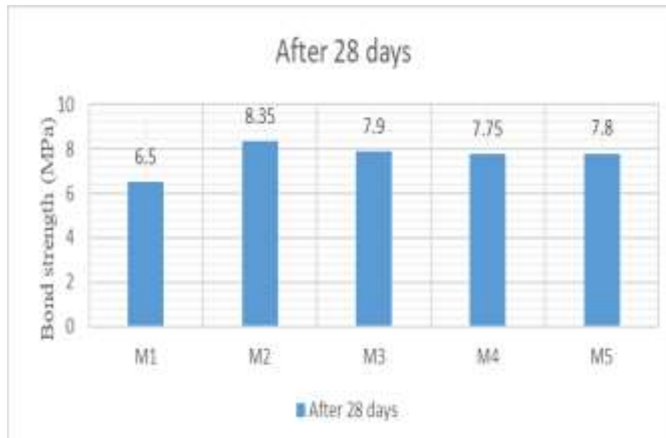

Fig. 6 The Effect of use BOFS on Bond Strength

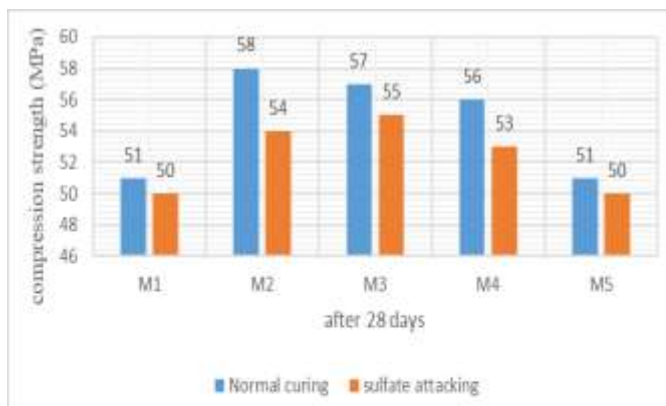

Fig. 7. The Effect of use BOFS on Sulfate Attacking resistance

IV. CONCLUSION

- The use of BOFS reduces the fresh properties where that shown as the slump reduced from 160 mm at zero steel aggregate to 100 mm at 100% steel slag.
- The BOFS increase the compressive strength of concrete, and the results show that 25%, 50%, and 75%BOFS increase the strength by 12%, 10.5%, and 5.6% respectively, and 100% replacement very similar to control mix.

- The BOFS increase the flexural strength of concrete, where 25%, 50%, and 75%BOFS increase the strength by 20%, 8.8%, and 8.8% respectively, and 100% replacement very similar to control mix.
- The BOFS increase the tensile strength of concrete. Replacement with 50% BOFS increase the strength by 17% increase, and 100% BOFS led to 10% increase in strength.
- The BOFS increase the bond strength of concrete, where 25% BOFS increase the strength by 28.5% increase, and 100% replacement led to 20% increase.
- BOFS has positive effect on concrete properties for all mixes due to its physical properties, and safe to use in eco-friendly rigid pavement

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