Effect of Replacement of Fine and Coarse Aggregate by Iron Slag and Steel Slag on Concrete Properties

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ABSTRACT

This study presents the effect of using slag in different proportions as coarse and fine aggregates on the properties of concrete (compressive strength, splitting tensile strength, and modulus of rupture). Two types of slag, iron and steel, were used in different proportions. Each type was used as coarse aggregate (0 to 40%) replacement, fine aggregate (0 to 30%) replacement, or a combination of fine and coarse aggregate (0 to 15%) replacement. These mixtures were compared with the reference mixture (without slag). After conducting the tests of samples at the age of 28 days, it was concluded that the best replacement rate of coarse aggregate with slag is 20%. Also, the best replacement rate of fine aggregate with slag is 20%. Iron slag gives better results than steel slag. The mixture with iron slag as a coarse aggregate 20% replacement gives the best results in compressive strength, tensile strength, and flexural strength, reaching 51.75%, 52.9%, and 36% increases, respectively, in comparison with the reference mixture (without slag).

Keywords: Iron Slag, Steel Slag, Properties of Concrete, Slag in Concrete.

1. Aim of research

The main objective of this study is to know the effect of iron and steel slag on the properties of concrete when they are used as a partial substitute for coarse aggregate and fine aggregate in different proportions, and to find useful ways for the purpose of getting rid of the accumulation of slag in nature, as it is an industrial waste that is harmful to the environment.

2. Introduction

Concrete is widely defined as one of the most significant construction materials. Many materials are also added to concrete to improve its characteristics and strength. These materials include silica fume, fly ash, rice husks, furnace slag, and many others. The use of materials harmful to the environment has become a global issue, as research has increased on how to invest in these materials to prevent their accumulation in nature, where it turns out that it is possible to use these materials as a substitute for building materials, such as cement, coarse aggregate, and fine aggregate, because they have good properties. In other words, substituting materials like fly ash or slag can decrease the setting time while reducing the heat produced during the dehydration process. Furthermore, various additions minimize the amount of water used in mixing, improve workability, and reduce water content simultaneously [1]. During the manufacturing of pig iron, slag is created as a waste product. Iron slag is dangerous and harmful to the environment [2]. It's a non- metallic substance made up primarily of silica, alumina, lime, magnesia, and iron oxide. Slag differs based on the raw materials used, the manufacturing process, and the furnace type. Blast furnace slag (BFS) is the name given to the slag produced by blast furnaces; nevertheless, steel slag is produced by electric furnaces and is made by the melting of scrap [3]. The slag absorbs many undesired impurities, which float on top of the molten iron [4]. (BFS) was tapped from the furnace at a temperature of around 1500 °C [5]. Concrete properties are also influenced by the chemical composition of slag. For example, when the SiO_2 ratio is low, the strength reduces [6]. The chemical composition of slag also affects the slag itself, as the viscosity decreases with an increase of some compounds such as FeO and MgO. In contrast, the viscosity increases with increasing Al_2O_3 content [7]. There are many types of ferrous slag, classified depending on the source as follows [8]:

i. Blast furnace slag (Iron Slag) includes (air-cooled slag, granulated, expanded, and pelletized).
ii. Steel slag includes (open hearth, basic oxygen, and electric arc furnace).

The early-age strength and heat of hydration of concrete are reduced by ground-granulated blast-furnace slag. At older ages, the strength of conventional concrete with similar water-cement ratios will usually outperform them. Slag reduces the permeability of concrete as well as its resistance to chemical attack [9]. Air-cooled is usually used as gravel, but granulated slag is used as an aggregate for roads, sand, and combined with cement clinker [10], [11]. In addition, air-cooled blast furnace slag (ABCFS) is a cost-effective substitute for natural stone as a coarse aggregate in pavement concrete in a benefit-cost study [12]. The electric arc furnace (EAF) is another type of slag-producing furnace; it produces steel slag. However, there are certain disadvantages to EAF-induced smelting, such as the electrical parameters of the electrode being difficult to control, which leads to arc breaking, excessive electrode consumption, long smelting durations, high power consumption, and higher single furnace smelting costs [13]. Natural aggregates are becoming increasingly rare, making their manufacture and transportation more difficult, this was one of the reasons for using steel slag as a substitute for aggregates [14]. Steel slag may also be used to replace granulated blast furnace slag in Portland Slag Cement manufacturing by up to 10% [15]. Also, you can use steel slag as a fine aggregate in construction [16]. It has a highly angular surface texture obtained from steel slag chunk crushing [17], so this type of slag increases linear expansion while decreasing concrete durability [18]. Many research studies [19] – [23] have used slag in concrete and have achieved positive results in terms of improving the properties of concrete.

3. Experimental work

3.1. Materials

A. Portland Cement (Carasta Cement) is manufactured by “Lafarge Company for cement production, Iraq”. They conform to Iraqi Specification, No.5/2019 [24], as listed in Tables (1) and (2).
B. Natural sand from Al-Ukhaidher region with a maximum size of 4.75mm, a rounded particle shape, and a smooth texture with a fineness modulus of 2.74.
C. Crushed gravel with a maximum size of 12.5 mm in (SSD) condition.
D. Iron and steel slag were obtained from “Al-Rawad Technology Company for Iron and Steel, Baghdad” see Figure 1. The slag was crushed manually by using a hummer with a maximum size of 14 mm, after which a sieve analysis was conducted for the purpose of separating the particles. Slag with a size ranging from 14 to 5 mm was used as a coarse aggregate, while the slag passing through a 5 mm sieve size was softened by a small electric mill to a fineness close to that of sand, then sieved and used as a fine aggregate. Tables (3) and (4) show slag properties.
E. A superplasticizer used throughout this work was "Sika ViscoCrete®-5930" (high range water reducer), with a nominal dosage of (1 liter per 100 kg of cement). Sika ViscoCrete®-5930 was manufactured by Sika Company, Iraq. This material was classified as types (G) and (F) in (ASTM C494/C494M) [25].

F. Ordinary tap water was used for mixing and curing.

Figure 1. Iron slag (IS) and steel slag (SS) before the crushing process

Table 1. Chemical composition of cement

Oxides composition	Content%	Limits of Iraqi specification No.5/2019
L.O.I	2.25	< 4
SiO_2	18.14	---
AL_2O_3	6.71	---
Fe_2O_3	2.9	---
SO_3	2.09	< 2.8
CaO	60.74	---
MgO	1.28	< 5

Table 2. Physical properties of cement

Physical properties	Test results	Limits of Iraqi specification No.5/2019
Fineness using Blaine air permeability apparatus cm^2/g	4678	≥ 2800
Setting time		
Initial setting (min.) Final setting (hr.)	125 3:50	≥ 45 ≤ 10
Compressive strength (MPa)		
At age 7 days At age 28 days	25 43	≥ 20 ≥ 42.5

Table 3. Chemical properties of iron slag

Oxides composition	Content %
L.O.I	7.70
SiO_2	36.1
AL_2O_3	26.4
Fe_2O_3	8.35
SO_3	1.11
CaO	15.89

MgO	4.23

Table 4. Chemical properties of steel slag

Oxides composition	Content %
L.O.I	8.31
SiO_2	46.39
Al_2O_3	25.70
Fe_2O_3	5.91
SO_3	3.40
CaO	6.61
MgO	3.48

3.2. Concrete mix

Iron and steel slag are used as aggregate in the concrete mixtures with different percentages divided as follows:

i. reference mixture without slag.

ii. Iron slag mixture

- 10%, 20%, 30%, and 40% instead of coarse aggregate.
- 10%, 20%, and 30% instead of fine aggregate.
- 7.5% instead of fine aggregate and 7.5% instead of coarse aggregate in the same mixture.
- 15% instead of fine aggregate and 15% instead of coarse aggregate in the same mixture.

iii. Steel slag mixture

- 20%, 30%, and 40% instead of coarse aggregate.
- 20% and 30% instead of fine aggregate.
- 7.5% instead of fine aggregate and 7.5% instead of coarse aggregate in the same mixture.
- 15% instead of fine aggregate and 15% instead of coarse aggregate in the same mixture.

Table (5) shows the concrete mixture for 1 m^3. Where Ref: refers to normal concrete mix without slag, IS: iron slag, SS: steel slag, CA: coarse aggregate, and FA: fine aggregate.

Table 5. Details of concrete mix (kg/m^3) relative to the aggregate

Symbol	CA (Kg)	FA (Kg)	IS (Kg)		SS (Kg)	
			CA	FA	CA	FA
Ref	1053	752	0	0	0	0
IS10CA	948	752	105	0	0	0
IS20CA	842	752	211	0	0	0
IS30CA	737	752	316	0	0	0
IS40CA	632	752	421	0	0	0
SS20CA	842	752	0	0	211	0
SS30CA	737	752	0	0	316	0
SS40CA	632	752	0	0	421	0
IS10FA	1053	677	0	75	0	0
IS20FA	1053	602	0	150	0	0
IS30FA	1053	526	0	226	0	0
SS20FA	1053	602	0	0	0	150
SS30FA	1053	526	0	0	0	226
IS7.5CAFA	974	696	947	696	0	0
IS15CAFA	895	639	158	113	0	0
SS7.5CAFA	974	696	0	0	947	696
SS15CAFA	895	639	0	0	158	113

The amount of cement is 456 Kg, water is 136 Kg, and superplasticizer is 4.56 Kg is constant for all samples.

3.3. Mixing procedure

The soft materials (cement and fine aggregate) are mixed together for two minutes, then add the coarse aggregate and mix the components for three minutes until they mix well. Add water with a superplasticizer and mix components for 4-5 minutes until getting a homogeneous mix with the required consistency.

3.4. Casting and curing process

Cube molds of 150 × 150 mm, cylinders of 100 × 200 mm and prisms of 100 × 100 × 500 mm were used. Before casting, the internal surfaces of molds are painted with a light layer of oil to avoid the hardened concrete's adhesion to the mold and to facilitate the process of removing the molds after the solidification process. After mixing the materials well, the molds are cast in two equal layers and each layer is compacted by operating the vibrating table for approximately 25–30 seconds. The outer surface is leveled with a steel trowel. After the casting process is completed, the molds are covered with a piece of plastic to maintain the moisture of the concrete and prevent water evaporation. After 24 hours of the casting process, the molds were removed and the specimens were placed in the water tanks to cure at a steady temperature, see Figure 2. The specimens were taken out of the curing tanks after 28 days to be tested.

Figure 2. Control specimens before and after curing

3.5. Testing of samples

3.5.1. Compressive strength

The compressive strength of concrete in this study was carried out in accordance with BS 1881–116 [26] using (150×150 mm) cubes loaded uniaxially by the universal compressive machine, Figure 3. The results of this test are listed in Table (6).

Figure 3. Compressive machine

Table 6. Compressive strength results

Symbol	Slag %		f_{cu} (MPa)	Increase %
	CA	FA		
Ref	0	0	47.907	---
IS10CA	10	0	64.3	34.22
IS20CA	20	0	72.7	51.75
IS30CA	30	0	55.76	16.39
IS40CA	40	0	47.603	-0.63
SS20CA	20	0	70.12	46.36
SS30CA	30	0	55.963	16.82
SS40CA	40	0	44.99	-6.08
IS10FA	0	10	54.2	13.14
IS20FA	0	20	70.788	47.76
IS30FA	0	30	52.042	8.63
SS20FA	0	20	70.708	47.59
SS30FA	0	30	53.537	11.75
IS7.5CAFA	7.5	7.5	47.810	-0.2
IS15CAFA	15	15	54.589	13.9
SS7.5CAFA	7.5	7.5	50.302	4.99
SS15CAFA	15	15	60.349	25.97

3.5.2. Splitting tensile strength

The indirect tensile strength (splitting tensile strength) tests were made according to (ASTM C 496-86) [27]. Split cylinder strength tests were conducted on (100×200 mm) cylinders as shown in Figure 4. The splitting tensile strength was determined as follows:

$$f_t = \frac{2P}{\pi DL} \quad \text{……….. (1)}$$

Where:
f_t = Splitting tensile strength in (MPa)
P = Ultimate load in (N)
D = Diameter of specimen in (mm)
L = Length of specimen in (mm)
The results of this test are given in Table (7).

Figure 4. Splitting tensile strength test

Table 7. Splitting tensile strength test results

Symbol	Slag %		f_t (MPa)	Increase %
	CA	FA		
Ref	0	0	2.289	---
IS10CA	10	0	2.77	21
IS20CA	20	0	3.5	52.9
IS30CA	30	0	2.564	12
IS40CA	40	0	2.125	-7.16
SS20CA	20	0	2.608	14
SS30CA	30	0	2.5	9.2
SS40CA	40	0	2	-12.62
IS10FA	0	10	2.85	24.5
IS20FA	0	20	3.093	35.12
IS30FA	0	30	2.092	-8.6
SS20FA	0	20	2.75	20.14
SS30FA	0	30	2.263	-1.13
IS7.5CAFA	7.5	7.5	2.6	13.58
IS15CAFA	15	15	2.519	10
SS7.5CAFA	7.5	7.5	2.65	15.77
SS15CAFA	15	15	2.57	12.3

3.5.3. Modulus of rupture

Flexural strength (modulus of rupture) tests were carried out according to (ASTM C 78-84) [28]. This test was made on a (100×100×500 mm) prism loaded at third points as shown in Figure 5. The modulus of rupture was determined as follows:

$$f_r = \frac{PL}{bh^2}$$
………. (2)

Where:
f_r= Modulus of rupture in (MPa)
P = Ultimate load in (N)
L = Length of prism in (mm)
b = Width of prism in (mm)
h = Depth of prism in (mm)
The Results of this test are given in Table (8).

Figure 5. Modulus of rupture test

Table 8. Modulus of rupture test results

Symbol	Slag %		f_r (MPa)	Increase %
	CA	FA		
Ref	0	0	6.25	---
IS10CA	10	0	6.6	5.6
IS20CA	20	0	8.5	36
IS30CA	30	0	7	12
IS40CA	40	0	5.85	-6.4
SS20CA	20	0	7.1	13.6
SS30CA	30	0	6.3	0.8
SS40CA	40	0	5.35	-14.4
IS10FA	0	10	6.4	2.4
IS20FA	0	20	7.45	19.2
IS30FA	0	30	5.5	-12
SS20FA	0	20	7.3	16.8
SS30FA	0	30	6	-4
IS7.5CAFA	7.5	7.5	6.41	2.56
IS15CAFA	15	15	6.3	0.8
SS7.5CAFA	7.5	7.5	6.44	3.04
SS15CAFA	15	15	6.9	10.4

4. Results and discussion

1. Depending on the chemical analysis of slag, iron slag contains Fe_2O_3 more than steel slag and contains SO_3 less than steel slag.
2. In compressive strength, the results explain the following:

- The use of iron slag gave very good results in terms of compressive strength, as the strength increased by 34.22%, 51.75, and 16.39% when it is used as a partial substitute for coarse aggregate by 10%, 20%, and 30%, respectively. But when the replacement ratio was 40%, the compressive strength was almost the same as that of the reference mixture.
- The percentage increase in compressive strength when using iron slag as a fine aggregate by 10%, 20%, and 30% was 13.14%, 47.76%, and 8.63%, respectively.
- When IS was used as coarse aggregate by 7.5% and fine aggregate by 7.5% in the same mixture, it gave results similar to the reference mixture, but when used as coarse aggregate by 15% and fine aggregate by 15% in the same mixture, the compressive strength increased by 13.9%.

- When using steel slag as a coarse aggregate, the percentage increase in compressive strength was 46.36% and 16.82% for 20% and 30%, respectively. When the replacement ratio was 40%, the compressive strength decreased compared to the reference mixture.
- The percentage of increase in compressive strength when using SS as a fine aggregate by 20% and 30% was 47.59% and 11.75%, respectively.
- However, when using SS as a partial substitute for coarse aggregate and fine aggregate by 7.5% for each type of aggregate, the percentage increase in the compressive strength was 4.99%, while the percentage of 15% as coarse aggregate and 15% for fine aggregate, the compressive strength increased by 25.97% when compared with the reference mixture. Figure 6 and Figure 7 show the effects of iron and steel slag on the compressive strength, respectively.

3. In splitting tensile strength, the results explain the following:

- The percentage increase was about 21%, 52.9%, and 12% when (IS) was used as coarse aggregate by 10%, 20%, and 30%, respectively. While the tensile strength is approximately similar to the reference mixture when used (IS) as a coarse aggregate by 40%.
- When (IS) was used as a fine aggregate by 10% and 20%, the percentage increase was about 24.5% and 35.12%, respectively, but the tensile strength was decreased by a few when (IS) was used by 30% as a fine aggregate.
- When combining the two types of slag (fine and coarse slag) as a replacement for fine aggregate and coarse aggregate by 7.5% and 15% for each type of aggregate, tensile strength increases by 13.58% and 10%, respectively.
- As well, the percentage increase was about 14% and 9.2% when steel slag (SS) was used as coarse aggregate by 20% and 30%, respectively. The tensile strength was lower slightly at a percentage of 40%. And the percentage increase was about 20.14% when steel slag was used as fine aggregate by 20%, but at a percentage of 30%, the tensile strength was the same as the reference mixture. While the percentage increase was about 15.77% and 12.3% when used the SS as a coarse aggregate and fine aggregate in the same mixture by 7.5% and 15%, respectively. Figure 8 and Figure 9 show the effects of iron and steel slag on the splitting tensile strength, respectively.

4. The results of the modulus of rupture show the following:

- Using iron slag as a coarse aggregate by 10%, 20%, and 30% led to an increase in the flexural strength, as the percentage increase reached 5.6%, 36%, and 12%, respectively. While the modulus of rupture decreases at a percentage of 40%. The percentage of increase reached 2.4% and 19.2% when (IS) was used as a fine aggregate by 10% and 20%, but at 30% the modulus of rupture decreased a few. While the test result for samples containing (IS) as coarse aggregate and fine aggregate in the same mixture by 7.5%, slightly increased from the reference mixture. When the replacement rate was 15% for each type of aggregate, the results of the examination were almost identical to the reference mixture.
- For samples containing steel slag, the flexural strength increased by 13.6% when the ratio of (SS) was 20% as a coarse aggregate, while the result of using (SS) at 30% as a coarse aggregate was very close to the reference mixture. The flexural strength increased by 16.8% when using SS as a fine aggregate by 20% and the result of the test was approximately similar to the reference mixture at a ratio of 30%, but the percentage of increase reached 3.04% and 10.4% when using SS as coarse aggregate and fine aggregate in the same mixture by 7.5% and 15%, respectively. Figure 10 and Figure 11 show the effects of iron and steel slag on the modulus of rupture.

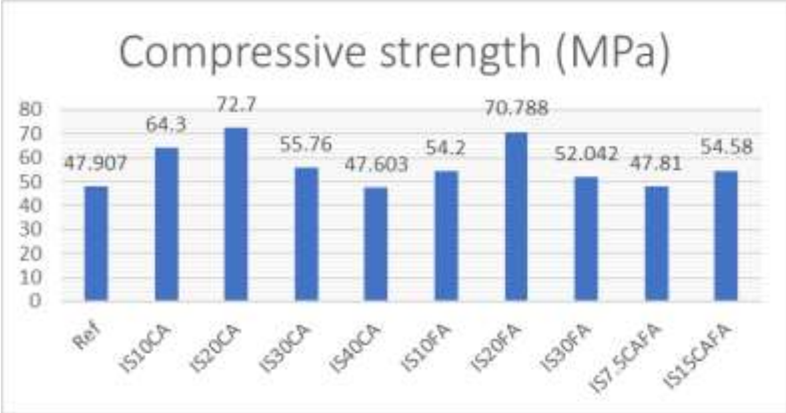

Figure 6. Effect of iron slag on compressive strength

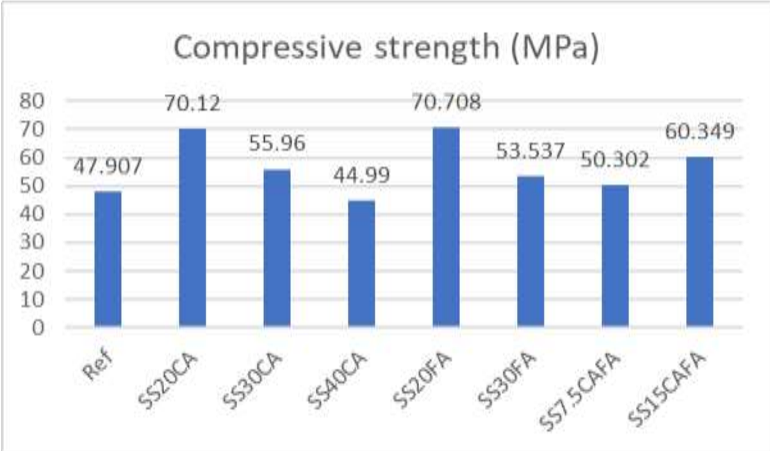

Figure 7. Effect of steel slag on compressive strength

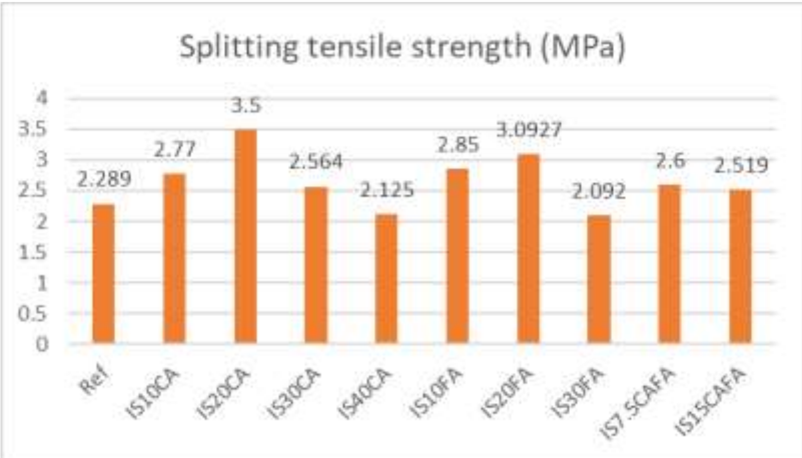

Figure 8. Effect of iron slag on splitting tensile strength

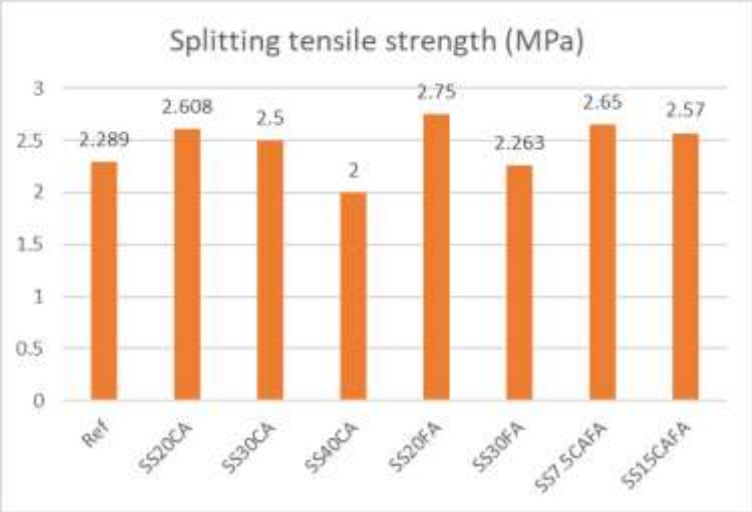

Figure9. Effect of steel slag on splitting tensile strength

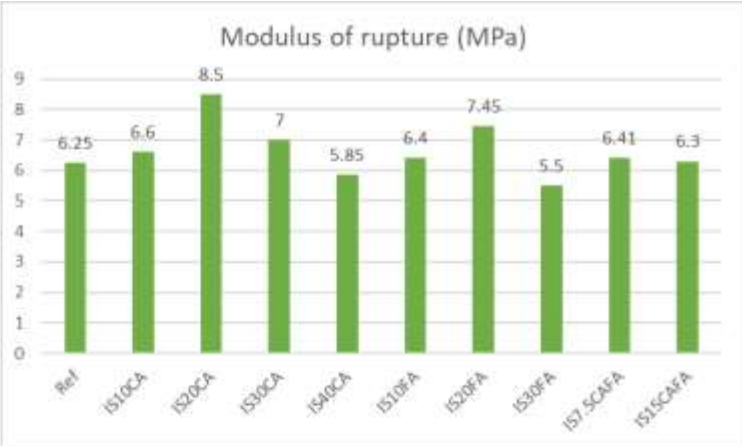

Figure 10. Effect of iron slag on modulus of rupture

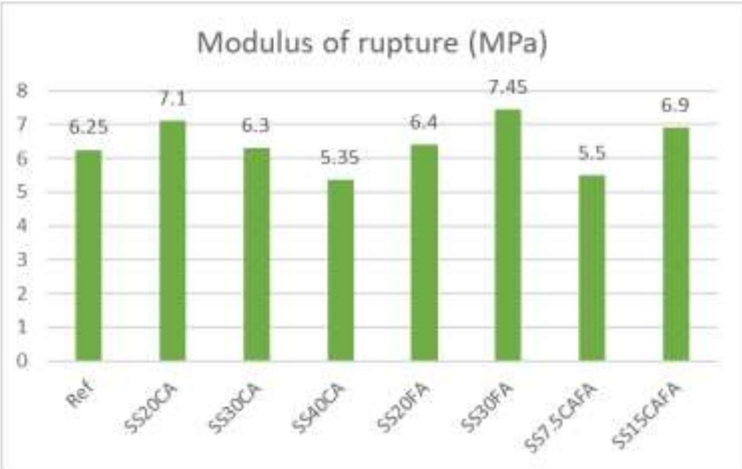

Figure 11. Effect of steel slag on modulus of rupture

5. Conclusions

- The use of slag as a partial substitute for coarse aggregate gives good and effective results in terms of concrete properties.
- Iron slag gives better results than steel slag.
- The best ratio of replacing slag with coarse aggregate is 20%.
- The best ratio of replacing slag with fine aggregate is 20%.

- The use of slag as a partial substitute for aggregate increases the strength of concrete until 40% of the replacement ratio.
- Use of slag as coarse aggregate and fine aggregate in the same mixture significantly increases the compressive strength of concrete.
- When used Iron Slag (IS) as a coarse aggregate by 20%, the compressive strength, splitting tensile strength and flexural strength were increase by 51.75%, 52.9% and 36%, respectively.
- When used Iron Slag (IS) as a fine aggregate by 20%, the compressive strength, splitting tensile strength and flexural strength were increase by 47.76%, 35.12% and 19.2%, respectively.
- The reason for the increase in the compressive strength may be due to the increased bonding between the slag particles and the cement paste because the slag has a rough surface and contains strong iron parts.

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Abbreviations

IS	Iron slag
SS	Steel slag
CA	Coarse aggregate
FA	Fine aggregate
SSD	Surface saturated dry

References

1. M. A. El-Reedy, “Advanced Materials and Techniques for Reinforced Concrete Structures, ” Taylor & Francis Group. Cairo: Egypt, pp. 188–206, 2009, doi: https://doi.org/10.1201/9781420088922.
2. J. Vereš, Š. Jakabský, and V. Šepelák, “Chemical, physical, morphological and structural characterization of blast furnace sludge,” Diffusion-fundamentals, vol. 12, pp. 88–91, 2010.
3. K. Buttiens, J. Leroy, P. Negro, J. Sebastien, K. Edwards , and Y. Lassat, “The carbon cost of slag production in the blast furnace: a scientific approach, ” Sustainable. Metallurgy., vol. 2, pp. 62–72, 2016.
4. M. Kutz, "Mechanical Engineers’ Handbook Fourth Edition," Canada: New Jersey, vol. 1, pp. 4, 2014, doi: https://doi.org/10.1002/9781118985960.
5. ACI 233, “ACI 233R-03. Slag Cement in Concrete and Mortar,” American Concrete Institute, pp. 1–19, 2003.
6. M. S. Mamlouk and J. P. Zaniewski, "Materials for Civil and Construction Engineers," Mexico: New Jersey, pp. 164, 2011.
7. R. G. Reddy, P. Chaubal, P. Chris Pistorius, and U. Pal. " Advances in Molten Slags, Fluxes, and Salts," Springer International Publishers, Switzerland, 2016, doi: https://doi.org/10.1007/978-3-319-48769-4.
8. K. Smith, D. Morian, and T. Van Dam, “Use of Air-Cooled Blast Furnace Slag as Coarse Aggregate in Concrete Pavements — A Guide to Best Practice,” Reporte. No. FHWA-HIF-12-009 February, 2012.
9. J. K. Wight, "Reinforced Concrete Mechanics and Design," United States of America: New Jersey, pp. 52, 2016, http://www.civilittee-hu.com/uploads/1/RC2/book6th.pdf.
10. T. Miyamoto, K. Torii, K. Akahane, and H. Sachiko, “Production and Use of Blast Furnace Slag Aggregate for Concrete,” Nippon Steel Sumitomo Metal Technical Report. No. 109, pp. 102–108, 2015.
11. S. Alberici, J. de Beer, I. van der Hoorn, and M. Staats, “Fly ash and blast furnace slag for cement manufacturing,” Department Business, Energy & Industrial Strategy (BEIS research paper) UK, vol. 35, no. 19, pp. 5–35, 2017.
12. B. Xue, L. Yang, Y. Guo, F. Chen, S. Wang, F. Zheng, and Z. Yang, “Design and Construction of a Laboratory-Scale Direct-Current Electric Arc Furnace for Metallurgical and High-Titanium Slag

Smelting Studies," Metals (Basel)., vol. 11, no. 5, p. 732, 2021, doi: https://doi.org/10.3390/met11050732.
13. J. P. Patel, " Broader Use of Steel Slag Aggregates in Concrete," MSc. thesis, Cleveland State University, Cleveland, 2008.
14. Indian minerals yearbook, "Slag - iron and steel," Government of India, Ministry of Mines, Indian Bureau of Mines, vol. 2016, no. 0712, pp. 1–11, 2017, [Online]. Available: http://ibm.nic.in/writereaddata/files/08242017152436IMYB2016 Slag Iron and STeel_Advance release.pdf
15. J.M. Manso, J.A. Polanco, M. Losanez, and J.J. Gonzalez, " Durability of concrete made with EAF slag as aggregate," Cement and Concrete Composites, vol. 28, no. 6, pp. 528–534, doi: https://doi.org/10.1016/j.cemconcomp.2006.02.008.
16. M. Jihad Miah, M. Kawsar Ali, F. Lo Monte, S. Chandra Paul, A. John Babafemi, and B. Šavija, "The effect of furnace steel slag powder on the performance of cementitious mortar at ambient temperature and after exposure to elevated temperatures," Structures, vol. 33, pp. 2811–2823, 2021, doi: https://doi.org/10.1016/j.istruc.2021.06.047.
17. G. Adegoloye, A.-L. Beaucour, S. Ortola, and A. Noumowé, "Concretes made of EAF slag and AOD slag aggregates from stainless steel process: Mechanical properties and durability," Construction and Building Materials, vol. 76, pp. 313–321, 2015, doi: https://doi.org/10.1016/j.conbuildmat.2014.12.007.
18. Salman, M.M., K.M. Owaid, and D.R. Hussein, "Studing the effect of iraqi steel slag addition on the physical and mechanical properties of cement mortar," J Eng Sustain Develop (JESD), vol. 21, no. 3, pp. 2520-0917, 2017.
19. H. Gupta and A. K. Saxena, "Strength Properties of Steel Slag in Concrete," Int. J. Eng. Res. Technol., vol. 6, no. 11, pp. 93–97, 2017.
20. R. Karolina and A. L. A. Putra, "The effect of steel slag as a coarse aggregate and Sinabung volcanic ash a filler on high strength concrete," IOP Conf. Series: Materials Science and Engineering, vol. 309, no. 1, 2018, doi: 10.1088/1757-899X/309/1/012009.
21. F. Perez-garcia, A. Gonzalez-herrera, M. Jos, and M. D. Rubio-cintas, "Concrete : Mechanical , Physical and Environmental Properties," vol. 12, no. 8, pp. 2–15, 2019, doi: 10.3390/ma12182845.
22. A. V. Bhat and S. K. Tengli, "Behaviour of ground granulated blast furnace slag concrete in marine environment under chloride attack," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 9, no. 1, pp. 1659–1664, 2019, doi: 10.35940/ijitee.A4699.119119.
23. J. Rana and R. Rughooputh, "Partial replacement of cement by ground granulated blast furnace slag in concrete," J. Emerg. Trends Eng. Appl. Sci., vol. 5, no. 5, pp. 340–343, 2014, [Online]. Available: https://www.ingentaconnect.com/content/sabinet/sljeteas/2014/00000005/00000005/art00009.
24. Iraqi Specifications No. (5), "Portland Cement", the Iraqi Central Organization for Standardization and Quality Control, Baghdad-Iraq, (2019).
25. ASTM-C494–99a," Standard Specification for Chemical Admixtures for Concrete," American Society for Testing and Material, Philadelphia, USA.
26. BS 1881-116, Method for determination of compressive strength of concrete cubes British Standards Institute, London, 1983.
27. ASTM C496 – 96, "Standard Test Method for Splitting Tensile Strength of CylindricalConcrete Specimens", American Society for Testing and Material, Philadelphia, USA.
28. ASTM C78-02, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading",

American Society for Testing and Materials, Philadelphia, USA.