INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 4 (2023) 238-250

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Experimental Study About Effect Iron Slag on The Shear Strength of Reinforced Concrete Beams Without Shear Reinforcement

Mariam Ibraheem M. Hussein[1], Mohammed M. Rasheed[1]

[1]Civil Engineering Dept., College of Engineering,
Mustansiriyah University, Baghdad, IRAQ

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.04.018
Received 03 March 2023; Accepted 16 October 2023; Available online 26 November 2023

Abstract: In the last decades, researchers have become more interested in the environmental aspect of investing materials harmful to the environment in various aspects of life, including construction. Slag is considered as one of the industrial wastes that are harmful to the environment. There are many studies on the use of slag as a substitute for building materials because it adds an excellent property to concrete. In this study, the iron slag was used as a partial replacement of coarse aggregate and fine aggregate in different proportions, the study conducts to know its effects on the shear strength of reinforced concrete beams. Ten R.C. beams without shear reinforcement (1100×100×200) mm were studied using iron slag as a coarse aggregate with a ratio of 10%, 20%, 30% and 40%, as a fine aggregate with a ratio of 10%, 20% and 30%, and partial substitute for coarse aggregate by 7.5% and partial substitute for fine aggregate by 7.5% in the same model, finally, partial substitute for coarse aggregate by 15% and partial substitute for fine aggregate by 15% in the same model. According to the test results, it was found that the optimal proportion of replacing slag with coarse aggregate is 20%, which resulted in a 24.58% increase in peak load. While the optimal proportion of replacing slag with fine aggregate by 20%, resulting in a 24.3% increase in peak load.

Keywords: Iron slag, shear strength, RC beam, shear failure, environmentally friendly materials

1. Introduction

To meet the requirements of globalization and keep pace with the progress in life, researchers have taken great care in their studies, that include the using of environmentally friendly materials in order to protect natural resources and reduce environmental pollution resulting from the accumulation of waste, including fly ash, slag, silica fume, metakaolin and other materials. Slag is the mineral admixtures, and it can be considered as basic building material for high strength concrete [1]. In production process of iron slag, the blast furnace is continually fed from the top with iron oxide (ore, pellets, sinter), fluxing stone (limestone or dolomite), and fuel in the manufacturing of iron (coke, typically). The furnace produces two products: molten iron that gathers in the bottom of the furnace (hearth) and liquid iron blast-furnace slag (BFS) that floats at top the pool of molten iron. At a temperature of around 1500 °C, both are regularly tapped from the furnace [2]. There are many types of slag depending on the source of production. By reviewing previous studies, each type of slag helped in developing a specific property of concrete, for example, it is known that the shearing occurs in the beams suddenly and without warning, but the use of slag in the concrete beams shows a ductile failure, which gives a warning before failure [3]. The two forms of BFS or iron slag (IS) are air-cooled slag and granulated slag. The former is

*Corresponding author: eama004@uomustansiriyah.edu.iq

produced by cooling molten slag in open pits or yards, while the latter is produced by rapidly cooling molten slag with a water jet; the former looks like crushed stone, while the latter looks like sand [4]. However, in many researches, slag was used as a partial replacement for cement by grinding it with high fineness, the use of slag as cement adds very good properties to concrete, especially if a percentage of fly ash is used with it, this is what [5] have found, where they used the ground granulated blast furnace slag (GGBS) with fly ash (FA) as a partial replacement of cement; the amounts of (FA) were 20%, 40%, 60%, and the proportions of GGBS were 5%, 6%, 7%, 8%, 9%, and 10%. At 7 and 28 days old, compressive strength, split tensile strength, and flexural strength were tested. The test findings were satisfactory, and the resistors grew as the percentages of (FA) and (GGBS) climbed until they reached 9% of GGBS and 40% of FA, which were deemed an ideal turning point.

Because the grain size of GGBS is smaller than that of normal Portland cement, it has a lower initial strength, although it increases over time. The optimal GGBFS replacement as a cementation material has high compressive strength, low heat of hydration, chemical resistance, outstanding workability, good durability, and cost-effectiveness [5].

As well as, increasing the (FA) concentration in concrete reduces the compressive strength and extends the final setting time. A reduction in the quantity of C-A-S-H gel and the creation of big pores can cause this [6].

The use of BFS for the application has grown over time, and its benefits as a building material have been well known, but in order to encourage its wider usage, new applications must be developed in collaboration with users. The steel industry must continue to cultivate new fields of use and demand for slag, as well as modify its processing technologies, to better respond to future social demands for effective use of natural resources [4], [7]–[13] all of them used slag in concrete and reached positive results in terms of improving the properties of concrete.

2. Aim of Research

This research aims to know the effect of iron slag on the shear strength of reinforced concrete beams without shear reinforcement. This is important as it contributes to the investment of harmful substances to the environment in the right way, which contributes to the production of a new concrete mix and also reduces the environmental pollution that can occur due to the presence of these materials in nature.

3. Shear Strength Expression in Different Codes

(BS 8110, 1985) [14], according to this code, the shear strength of beams without shear reinforcement is calculated using the following equation:

$$V_c = \frac{0.79}{\gamma_m}\left(\frac{100\,A_s}{bd}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} \qquad (1)$$

The reinforcement ratio is 100As/bd, which should be larger than 0.15 but less than 3. The size impact is taken into consideration using 400/d, which should not be less than 0.67 for members without web reinforcement. The concrete partial safety factor is γm=1.25. For beams with a shear span-to-depth ratio of a/d < 2-2.5, the increase in shear strength caused by arching action is considered by increasing the computed shear strength by 2d/a_v.

In the (Eurocode 2, 2004) [15], the design shear resistance of the member without reinforcement in the shear is calculated by:

$$V_{Rd,c} = [C_{Rd,c}K(100\rho f_{ck})^{\frac{1}{3}} + 0.15\sigma_{cp}]b_w d \qquad (2)$$

Where:

$$C_{Rd,c} = \frac{0.18}{\gamma_c}$$

$$K = 1 + \sqrt{\frac{200}{d}} \leq 2$$

$$\rho = \frac{A_s}{b_w d} \leq 0.02$$

$$\sigma_{cp} = \frac{N_{Ed}}{A_c}$$

Where f_{ck} is the concrete cylinder compressive strength in (MPa), N_{Ed} is the axial force in the cross section of beam in (N) and A_c is the cross-section area in (mm^2).

According to (Model Code of Switzerland, 2010) [16], the concrete design shear resistance may be calculated as follows:

$$V_{Rd,c} = K_v \frac{\sqrt{f_{ck}}}{\gamma_c} z b_w \qquad (3)$$

Where $\sqrt{f_{ck}}$ is not to be taken as more than 8 MPa, bw is the section width in mm, z is the effective shear span depth in reinforced concrete members, which is considered to be 0.9d and γc is the concrete aspect factor of safety. The term K_v refers to the influence of strain on the web as well as the aggregate size. To compute K_v in beams without shear reinforcement, Model Code 2010 provides two levels of approximation, levels I and II. For approximation at level II,

$$K_v = \frac{0.4}{1 + 1500\varepsilon_x} \cdot \frac{1300}{(1000 + 0.7K_{dg}z)}$$

Where ε_x is the longitudinal strain in web, while K_{dg} is a factor that accounts for aggregate size.

$K_{dg} = \frac{48}{16+dg} \geq 1.15$, (dg) is the diameter of the aggregate.

For level I, assumption that the strain in the reinforcement stay elastic at the point of shear failure. Also, the maximum size of aggregate was equal to 9.6 mm so, the value of K_{dg} equal to 1.25.

In (ACI 318, 2019) [17], non-prestressed concrete members without shear reinforcement have a shear resistance given by:

$$V_c = 0.17\lambda\sqrt{f_c'}\, b_w d \qquad (4)$$

In this paper, equation (4) will be used to compute the shear strength.

4. Experimental Work

4.1 Materials

Cast iron slag was obtained from Al-Rawad Technology Company for Iron and Steel, Baghdad. Figure (1) shows the cast iron slag before the crushing process. The slag was crushed manually 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 the fineness of sand, then it was sieved and used as a fine aggregate. Table (1) shows the chemical analysis for (IS).

Portland cement (Carasta Cement) manufactured by Lafarge Company for cement production, Iraq was used. They conform to Iraqi Specification, No.5/2019 [18], as listed in Tables (2) and (3).

Natural sand (FA) from Al-Ukhaidher region with (4.75mm) maximum size, rounded particle shape and the texture is smooth with fineness modulus of (2.74).

Crushed gravel (CA) with maximum size of (12.5mm) in (SSD) condition was used.

Superplasticizer (SP) "Sika ViscoCrete®-5930" (high range water reducer), with a nominal dosage of (1 litter per 100 kg of cement). Sika ViscoCrete®- 5930 was manufactured by Sika Company, Iraq. This material was classified as type (G) and (F) in ASTM C494/C494M [19] and ordinary tap water was used for mixing and curing.

Finally, reinforcement bars which satisfied ASTM A615 was used, and Table (4) shows the mechanical properties of reinforcement.

Fig. 1 - Iron slag

Table 1 - Chemical analysis of iron slag

Oxides composition	Content %	Limits of ASTM C 989-05, 2005 [20]
L.O.I	7.70	---
SiO_2	36.1	---
Al_2O_3	26.4	---
Fe_2O_3	8.35	---
SO_3	1.11	≤ 4
CaO	15.89	---
MgO	4.43	---

Table 2 - 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 3 - 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.)	125	≥ 45
Final Setting (hr.)	3:50	≤ 10
Compressive Strength (MPa)		
At age 7 days	25	≥ 20
At age 28 days	43	≥ 42.5

Table 4 - Mechanical Properties of Reinforcement Bars

Ø (mm)	Yield strength fy (MPa)	Limitation	Tensile strength fu (MPa)	Limitation
16	522	≥ 420	661	≥ 620
8	517	≥ 420	654	≥ 620

4.2 Concrete Properties

The details of the used mix are shown in Table (5) and the compressive strength of concrete for each mix are shown in Table (6). The (IS) was used in different percentage divided as follows: 10%, 20%, 30% and 40% as a coarse aggregate, 10%, 20%, and 30% as a fine aggregate, 7.5% as a coarse aggregate and 7.5% as a fine aggregate in the same mix, finally, 15% as a coarse aggregate and 15% as a fine aggregate in the same mix. All models were compared with a reference (without slag).

Table 5 - Details of concrete mix Kg/m^3

Symbol	IS%	Cement	FA	CA	IS		Water	SP
					FA	CA		
Ref	0	456	752	1053	0	0	136	4.56
IS10CA	10	456	752	947.7	0	105.3	136	4.56
IS20CA	20	456	752	842.4	0	210.6	136	4.56
IS30CA	30	456	752	737.1	0	315.9	136	4.56
IS40CA	40	456	752	631.8	0	421.2	136	4.56
IS10FA	10	456	677	1053	75	0	136	4.56
IS20FA	20	456	602	1053	150	0	136	4.56
IS30FA	30	456	526	1053	226	0	136	4.56
IS7.5CAFA	7.5 CA 7.5 FA	456	696	974	56	79	136	4.56
IS15CAFA	15 CA 15 FA	456	639	895	113	158	136	4.56

Table 6 - Cube compressive strength

Symbol	Slag%		f_{cu} (MPa)	Increasing%
	CA	FA		
Ref	0	0	47.907	---
IS10CA	10	0	64.3	34.22
IS20CA	20	0	75.3	51.75
IS30CA	30	0	55.76	16.39
IS40CA	40	0	47.603	-0.63
IS10FA	0	10	54.2	13.14
IS20FA	0	20	70.788	47.76
IS30FA	0	30	52.042	8.63
IS7.5CAFA	7.5	7.5	47.810	-0.2
IS15CAFA	15	15	54.589	13.9

4.3 Beams Details (Dimensions & Reinforcement)

The shear behaviour of ten reinforced concrete beams without shear reinforcement and with rectangular cross section were studied. The dimensions of the beams are shown in Figure (2) and the details of beams are listed in Table (7).

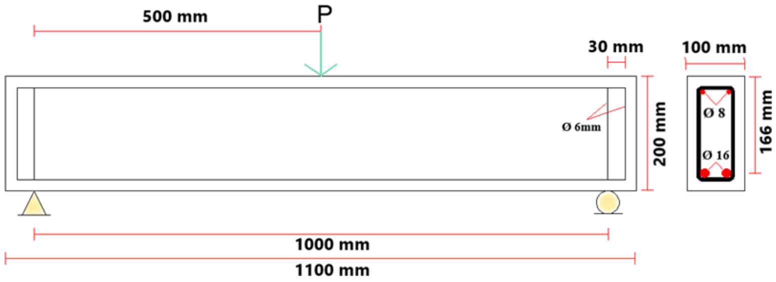

Fig. 2 - Beams details

Table 7 - Beams details

Shear span (a)	Effective depth (d)	a/d	ρ	Cover
500 mm	166 mm	3.01	0.02422	20 mm

To resist flexural, two longitudinal reinforcements with a diameter of 16 mm were used as bottom reinforcement and two longitudinal reinforcements with a diameter of 8 mm were used as top for fixation. Two stirrups with a diameter of 6 mm at each end connect the longitudinal reinforcement. Figure (3) indicates the reinforcement employed in this study. All beams have the same dimensions and reinforcement details.

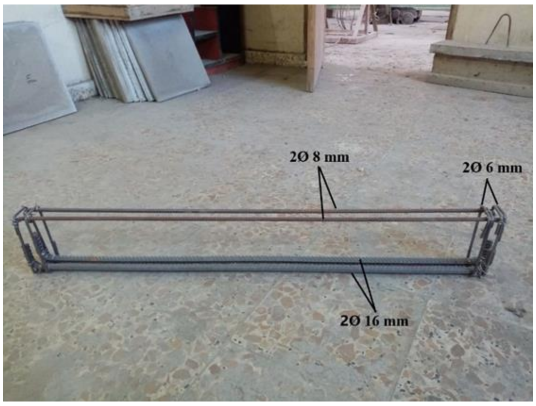

Fig. 3 - Reinforcement cage

4.4 Samples Testing

The beams were tested at the age of 28 days, the beam sits as simply supports in the machine test under one point load at the center of the beam, with a span of 1000 mm center to center between the supports, Figure (4). The dial gauges were installed in the first quarter, at 250 mm from the support center, and in the middle of the beam, at a distance of 500 mm from the support center. To avoid concrete crushing, a 14 cm long, 8 cm wide, and 0.5 cm high iron plate was installed under the load. After checking all of the measurements, the test began by applying increment load 1 kN until failure. During the test, the deflection was recorded (for each 1 kN). Figure (5) shows the beam in testing machine.

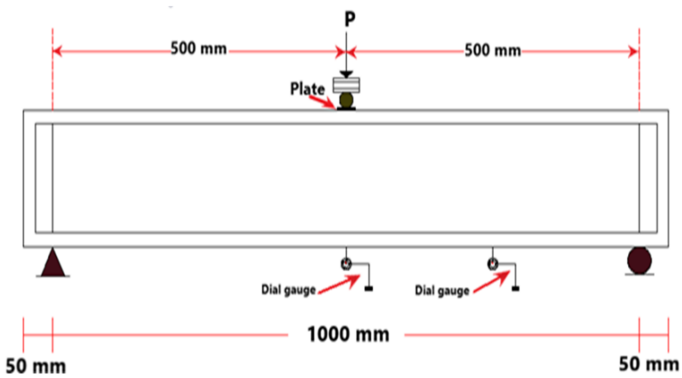

Fig. 4 - Beam set up

Fig. 5 - Beam in testing machine

All samples examined failed in shear. Small cracks appeared in the middle of the beam from the bottom in the early stages of loading, then grew in length and curved towards the loading point until the major crack appeared abruptly at 45 degrees with fine and small cracks branching from it. The development of failure for the beams were depicted in Figure (6).

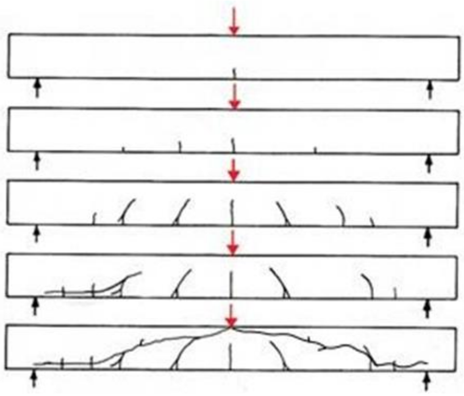

Fig. 6 - Development of shear cracks in the beams without stirrups

5. Test Results

Using (IS) as a coarse aggregate by 10% and 20% replacing increased the peak load by 22.92% and 24.58%, respectively, while when using it by 30% replacing, the shearing behaviour was like the reference beam, however, the use of (IS) by 40% replacing reduced the peak load when compared with the reference beam. As for (IS) as a fine aggregate replacing, the best replacement rate was 20%, which gave an increase in peak load by 24.33%, followed by the model containing 10% (IS10FA), where the load increased by 21.958%, while the peak load was less than the peak load of the reference beam when the percentage of (IS) was 30%. For the model containing (IS) as fine and coarse aggregate by 7.5% replacing of each type of aggregate, it gives a shearing behaviour almost like the reference beam, while the load increased by 4.72% when the proportion of (IS) was 15% for each type of aggregate. Table (8) listed the test results and Table (9) gives a comparison between theoretical and experimental results.

Table 8 - Test results

Symbol	Ultimate load (kN)	Increase%
Ref	60.16	---
IS10CA	73.95	22.92
IS20CA	74.95	24.58
IS30CA	60.38	0.36
IS40CA	53.20	-11.57
IS10FA	73.37	21.95
IS20FA	74.80	24.33
IS30FA	51.96	-13.63
IS7.5CAFA	59.10	-1.76
IS15CAFA	63	4.72

Table 9 - Theoretical ultimate shear load

Symbol	Vc (kN)*	P= 2Vc (kN)	Experimental load (kN)
Ref	17.823	35.646	60.16
IS10CA	19.84	39.68	73.95
IS20CA	21.47	42.94	74.95
IS30CA	18.511	37.022	60.38
IS40CA	17.073	34.146	53.20
IS10FA	18.218	36.436	73.37
IS20FA	20.819	41.638	74.80
IS30FA	17.852	35.704	51.96
IS7.5CAFA	17.11	34.22	59.10
IS15CAFA	18.289	36.578	63

* According to Eq. 4.

6. Failure Modes

All tested beams failed in shear according to research plan and because they were designed without shear reinforcement. Figure (7) shows the failure mode of the beams.

Fig. 7 - Failure mode of tested beams

7. Load-Deflection

The state of deformation of a beam from its initial shape as a result of the workload applied, was called deflection. Knowing the initial cracking load, inelastic range, yielding load, failure load, plastic range, evaluating the ductility index, and computing the toughness (area under the curve) are all advantages of charting the load- deflection curves. The deflection was measured every (1kN) using a (0.01mm) accuracy dial gauges placed at the mid-span and first quarter of each tested beam for the current investigation. Through the relationship of load- deflection, the first cracking load and post cracking ratio were determined as shown in Table (10). Figure (8) shows the deflection behaviour of concrete beams containing different percentages of iron slag and Figure (9) shows the comparison between load-mid span deflection for all beams. The models IS20CA, IS30CA, IS40CA, IS30FA, and IS15CAFA gave deflection higher than the deflection of the reference beam, which was very useful because it gave an indication before the failure, while the other models had a deflection less than the deflection of the reference beam.

Table 10 - First Cracking Load & Post Cracking Ratio

Symbol	Load (kN)		$\frac{P_{cr}}{P_u}\%$	Δ_{cr} (mm)	Δ_u (mm)	Post Cracking Ratio
	P_{cr}	P_u				$\frac{\Delta_{cr}}{\Delta_u}$
Ref	18	60.16	29.92	0.62	3	4.838
IS10CA	45	73.95	60.85	1.22	2.99	2.45
IS20CA	29	74.95	38.69	1.04	5.2	5
IS30CA	19	60.38	31.47	0.69	3.4	4.927
IS40CA	18	53.20	33.83	0.74	2.7	3.648
IS10FA	20	73.37	27.26	0.61	3.27	5.36
IS20FA	16	74.80	21.39	0.43	2.5	5.814
IS30FA	17	51.96	32.72	0.61	2	3.278
IS7.5CAFA	13	59.10	21.68	0.445	2.74	6.157
IS15CAFA	15	63	31.75	0.9	3.3	3.67

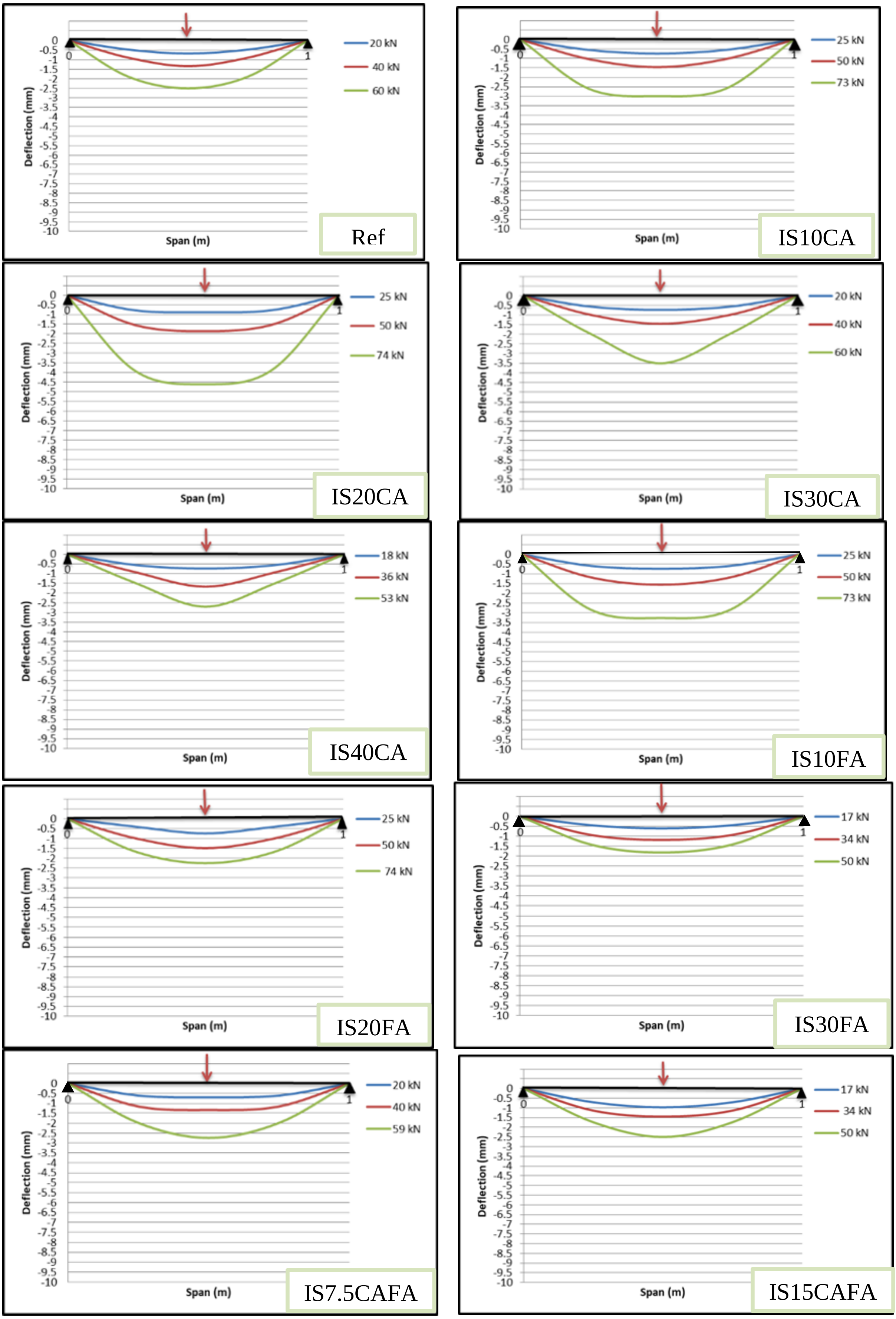

Fig. 8 - Span-Deflection Behaviour of Models

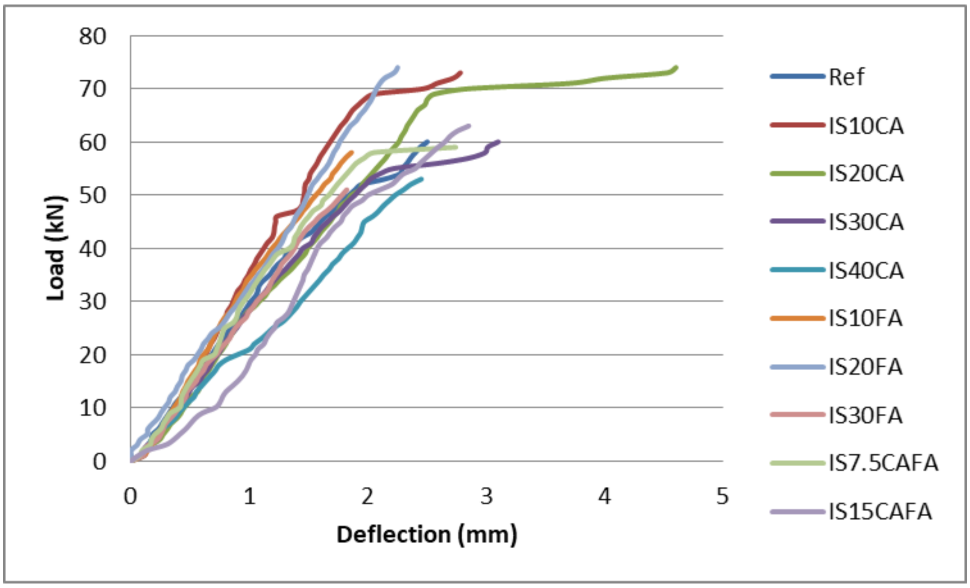

Fig. 9 - Load-Mid span deflection (comparison between all beams)

8. Conclusion

- The use of iron slag gives good properties of concrete in terms of compressive strength and shear behaviour.
- Use iron slag reduces environmental pollution. The best proportion of replacing (IS) with coarse aggregate is 20%, which gave an increase in the peak load by 24.58%. While the best proportion of replacing (IS) with fine aggregate is also 20%, which gave an increase in the peak load by 24.3%.
- Models (IS10CA, IS20CA, IS30CA, IS10FA, IS20FA and IS15CAFA) gave higher shear strength than the reference beam, which represent a good indication of the properties that iron slag adds.
- The use of (IS) helped by given an indicator before the model failed, unlike the reference beam that failed suddenly and without warning.

Acknowledgement

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad – Iraq for its support in the present work.

Notations

IS –Iron Slag
CA –Coarse Aggregate
FA –Fine Aggregate
SP –Superplasticizer
a/d –Shear span to depth ratio
ρ –Longitudinal reinforcement ratio
P_u – Experimental Peak load
V_c –Shear strength
P_{cr} –First cracking load
Δcr –Deflection at first cracking load
Δu –Deflection at ultimate load

References

[1] M. A. El-Reedy, " Advanced Materials and Techniques for Reinforced Concrete Structures," Cairo: Egypt, pp. 188–206, 2009, doi: https://doi.org/10.1201/9781420088922.
[2] ACI 233, “ACI 233R-03. Slag Cement in Concrete and Mortar,” American Concrete Institute, pp. 1–19, 2003.
[3] S. Arivalagan, “Moment Capacity, Cracking Behaviour And Ductile Properties Of Reinforced Concrete Beams Using Steel Slag As A Coarse Aggregate,” Global Journal of Researches in Engineering Civil and Structural Engineering, vol. 12, no. 2, pp.16, 2012.
[4] T. Miyamoto, K. TORII, K. AKAHANE, and H. Sachiko, “Production and Use of Blast Furnace Slag Aggregate for Concrete,” Nippon STEEL SUMITOMO Met. Tech. Rep. No. 109 JULY 2015, no. 109, pp. 102–108, 2015.

[5] S. Asif Ali and P. Shaik Abdullah, "Experimental Study on Partial Replacement of Cement by Flyash and GGBS," IJSRD-International J. Sci. Res. Dev., vol. 2, no. 07, pp. 2321–0613, 2014, [Online]. Available: www.ijsrd.com
[6] A. Kothari, "Effects of Fly Ash on the properties of Alkali Activated Slag Concrete," MSc Thesis, Lulea University of Technology, June, 2017.
[7] M. M. Salman, K. M. Owaid, and D. R. Hussein, "Studying the effect of Iraqi steel slag addition on the physical and mechanical properties of cement mortar," Journal of Engineering and Sustainable Development, vol. 21, no. 03, pp. 24–35, 2017, [Online]. Available: www.jeasd.org.
[8] H. Gupta and A. K. Saxena, "Strength Properties of Steel Slag in Concrete," International Journal of Engineering Research & Technology (IJERT), vol. 6, no. 11, pp. 93–97, 2017.
[9] 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.
[10] F. Perez-garcia, A. Gonzalez-herrera, M. Jos, and M. D. Rubio-cintas, "Concrete: Mechanical, Physical and Environmental Properties," 2019.
[11] 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.
[12] 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, 2006, doi: https://doi.org/10.1016/j.cemconcomp.2006.02.008.
[13] M. J. Miah, M. K. Ali, F. L. Monte, S. C. Paul, A. J. Babafemi, and B. Savija, "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, June 2021, pp. 2811–2823, 2021, doi: 10.1016/j.istruc.2021.06.047.
[14] Bs 8110-1:1997, British Standards Institution, London, no. 1, pp. 28, 1997.
[15] Eurocode 2 :2004. "Design of concrete structures - Part 1-1 : General rules and rules for buildings, " pp. 84–84, 2004.
[16] Model Code 2010, first complete draft.Technical Report, 2. Switzerland, pp. 33-36, 2010.
[17] American Concrete Institute, Building Code (ACI 318-19) and Commentary on Building Code Requirements for Structural Concrete (ACI 318R-19), 2019.
[18] Iraqi Specifications No. (5), "Portland Cement", the Iraqi Central Organization for Standardization and Quality Control, Baghdad-Iraq, (2019).
[19] ASTM-C494–99a," Standard Specification for Chemical Admixtures for Concrete," American Society for Testing and Material, Philadelphia, USA.
[20] ASTM C989, "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars," Am. Soc. Test. Mater., vol. i, no. February, pp. 2–6, 2005, [Online]. Available: www.astm.org.