AIP Conference Proceedings

RESEARCH ARTICLE | JANUARY 29 2024

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AIP Conf. Proc. 2864, 050003 (2024)
https://doi.org/10.1063/5.0186085

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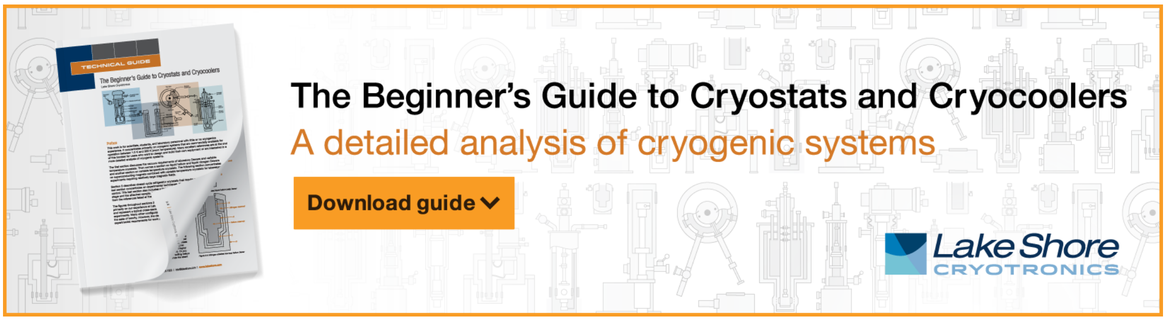

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Flexural Strength of Reinforced Concrete Beams of Concrete Containing Iron Filings as Partial Sand Replacement

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Abstract. In this study, the effect of using iron filler as a partial substitute for natural sand. Four concrete beams 150×200×1600 mm with similar steel reinforcement (one beam for each iron filing percentage) in addition to the reference concrete beam were examined. The beams were tested by ultimate load failure, final deflection, energy absorption, stiffness, ductility index, compressive stress and studying cracks, then comparing them with reference beams to evaluate the effect of iron filing on their structural behavior. The results showed that increasing the iron filing content in the concrete beams led to an increase in the final failure load, final deflection, ductility index, strain, and energy absorption were 6.7, 10.29, 11.37, 25.3, and 35% respectively, compared to the reference beam. While there was a decrease in the initial stiffness and secant stiffness of 12.6% and 3.18%, respectively, compared to the reference beam.

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Keywords. Iron fillings, sand replacement, flexural strength, deflection, energy absorption.

INTRODUCTION

The amount of waste or discarded materials produced in industries, factories, and mechanical plants is growing every day, resulting in increased pollution in the environment. Iron filing is a waste product made up of minute bits of iron that is produced as a by-product of the grinding, filing, or milling of finished iron products. They're either recycled or used in low-quality iron goods, or they're discarded in landfills. The municipal waste components consist of organic matter (57%), paper and cardboard (15%), plastics (15%), iron metal (4%), glass (3%), and other materials (6%) [1]. Sand (fine aggregate) is one of the basic materials used in the production of concrete, accounting for roughly 20-30% of the total volume. Based on worldwide cement output in 2017 of 4100 million metric tons [1] and assuming 90 percent is utilized for concrete production, global concrete production in 2017 required 2.4 billion m^3 (4 trillion kgs) of sand, which would be increasing with the increase in cement consumption. Natural sand demand is steadily increasing as a result of growing infrastructure development. Sand deposits from riverbeds are increasingly depleted, posing a threat to the environment. Because sand from the riverbed is scarce, stones are crushed into a fine powder and utilized as fine aggregate. Quarrying of stones from the mountains has resulted in the depletion of another natural resource, as well as the loss of mountain green cover, not to mention the air pollution that occurs when the stones are mined and crushed to make sand. All of these concerns have prompted the hunt for a low-cost, readily available substitute to natural sand. Thus, the re-use of waste materials into concrete mixture represents vital sustainable construction especially for undegradable materials like plastic wastes.

Many studies have been conducted in which sand was replaced with different materials such as plastic wastes [2, 3] fly ash [4], Quarry dust [5, 6], marble sludge [7,8,9], copper slag [10,11], and so on. Iron filing is one example of a waste product that can be used to substitute sand in concrete. Mironovs et al [12], investigated the feasibility of using iron-containing waste materials in the production of heavy concrete, it was obtained from concrete with a density of 4500 kg m^3. Which is distinguished by its low cost, availability, and, accordingly, the possibility of mass production,

Development and Sustainability in Civil Engineering
AIP Conf. Proc. 2864, 050003-1–050003-12; https://doi.org/10.1063/5.0186085
Published by AIP Publishing. 978-0-7354-4788-2/$30.00

as well as the requirements for recycling. Krikar [13], found that 30% iron filling replacement increased the compressive strength by 17% and if the proportion of iron filings added is more than 10%, there is 13% improvement in strength on the tensile strength of concrete. Olutoge et al [14], concluded that the 10 % and 20 % replacement levels of sand with iron filings increased the compressive strength of concrete by 3.5% and 13.5%, respectively, whereas the 30% replacement level decreased by 8%, compared to the control mix. Krikar et al [15], investigated the replacement of sand with iron waste up to 30%. They found that the maximum compressive and flexural strength of concrete may be attained with replacement percentage of 12%, after which the strength starts to decline (this is in contrast to previous researches [13,14] that found that replacing sand with iron filings increased both compressive and flexural strength by 30%). The present study focused on investigating the flexural behavior of reinforced concrete containing iron fillings waste a sand replacement with four replacement percentages of 5%, 10%, 20%, and 30%.

MATERIALS

Cement

Ordinary Portland cement type I was employed in this study, in which its properties satisfied the requirements of the Iraqi Specification No. 5/1984 [16]. All the characteristics of the cement are offered in Table 1 and Table 2.

TABLE 1. Chemical composition of cement.

Oxide composition	Abbreviation	Content (percent) by weight	Limit of Iraqi Specification No.5/1984
Lime	CaO	63.96	--
Silica	SiO_2	21.32	--
Alumina	AL_2O_3	4.58	--
Iron oxide	Fe_2O_3	3.25	--
Sulphate	SO_3	2.52	< 2.8%
Magnesia	MgO	2.76	≤5%
Loss on ignition	L.O.I	3.47	≤ 4%
Insoluble residue	I.R	1.09	≤1.5%
Lime saturation factor	L.S.F	0.98	0.66-1.02
Main compounds (Bogue's equations)			
Tri calcium silicate	C_3S	50.69	--
Di calcium silicate	C_2S	18.28	--
Tri calcium aluminates	C_3A	8.14	--
Tetra calcium alumina	C_4AF	9.89	--

TABLE 2. Physical properties of cement.

Physical properties	Test result	Limits of Iraqi Specification NO.5/1984
Fineness (blain air permeability) (m^2/kg)	384	≥230
Setting time using Victa's method		
Initial (hrs: min.)	2:00	≥ 0:45 min
Final (hrs: min.)	3:45	≤ 10 hrs
Soundness using autoclave method	0.22	< 0.8
The compressive strength of mortar		
3Days, MPa	20.8	15≥
7Days, MPa	27.4	23≥

Aggregates

The fine aggregates are natural sand (maximum size = 4.75 mm) from Basra, Iraq, while the coarse aggregates are crushed natural stones (maximum size of 20 mm). Table 3 and Fig. 1 show the grading and standards for fine aggregates, which correspond to Iraqi Standard Specification No.45/1984 [17].

Iron Filing

Iron filings were collected from the local workshops in Misan province. Figure 2 shows color and shape of iron filings sample. These granules are a side product of iron manufacturing as shown in Fig. 3. Table 3 shows the specific gravity and absorption rate

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of iron waste particles. The grading was meet the Iraqi specification as shown in Table 4. The grains were graded according to Iraqi Specifications No. 45/1980 Zone II, which were almost identical to natural sand. Figure 1 shows the difference in fine sieves.

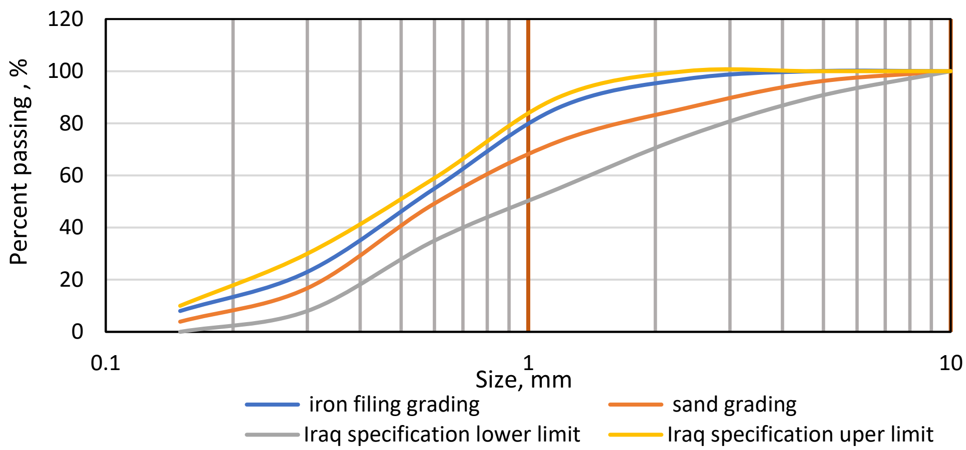

FIGURE 1. Grading curve for original fine aggregate and iron filing.

FIGURE 2. Iron filings particles.

Figure 3. Iron filings as side product of iron cutter.

TABLE 3. Physical properties of fine aggregate, iron filing particles and coarse aggregate.

Physical properties	Natural sand	Iron filing	Iraqi specification. 45/1984	Coarse aggregates	Iraqi specification. 45/1984
Specific gravity	2.56	3.66	-	2.67	-
Sulfate content, %	0.13	0.006	≤0.5%	0.006	≤0.1%
Absorption, %	0.75	0.6	-	0.6	-

TABLE 4. Sieve analysis of Iron filing

Sieve analysis of iron filing		
Sieve size (mm)	**Cumulative passing %**	**Limits of the Iraqi specification % passing for fine aggregate**
4.75	100	90-100
2.36	99.7	75-100
1.18	86	55-90
0.6	55	35-59
0.3	23	8-30
0.15	8	0-10

Mixture Proportions

One of the most common weight ratios for mixing (1:1.9:2.55) from previous work with a target strength of 25 MPa at 28 days is adopted to achieve the closest approximation to reality. The weights of the cement, sand, and gravel, per cubic meter in the mixture are 391.5, 743.85, and 998.3 kg, respectively. The water–cement ratio is 0.52 to find out the effect of iron filling on the workability without using any chemical additive (superplasticizer), and this is what was done in previous studies. Iron filings are

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added to the reference mixture in four different percentages (5, 10, 20, and 30%) a partial substitute for sand. Table 5 lists the concrete mixture proportions.

TABLE 5. Concrete mixture proportion for all Iron filing replacement ratio (w/c= 0.52).

Material (kg/m^3)	0%	5%	10%	20%	30%
Cement	391.5	391.5	391.5	391.5	391.5
Sand	743.85	706.65	669.46	595.08	520.69
Gravel	998.3	998.3	998.3	998.3	998.3
Water	203.5	203.5	203.5	203.5	203.5
Iron filing	0	37.38	75.62	155.6	237.39

Used ten beams, five beams with dimensions 150 ×200 ×1600 mm were used to investigate the effect of iron filing as a partial replacement for sand on the flexural behavior of reinforced concrete beams shown in Figs. 4 and 5. Concrete beam includes two bottom bars ϕ 12 mm diameter for tension reinforcing, stirrups reinforcement bars ϕ 8 mm diameter at 60 mm c/c, and 2 ϕ 10mm top anchorage bars to fix the stirrups.

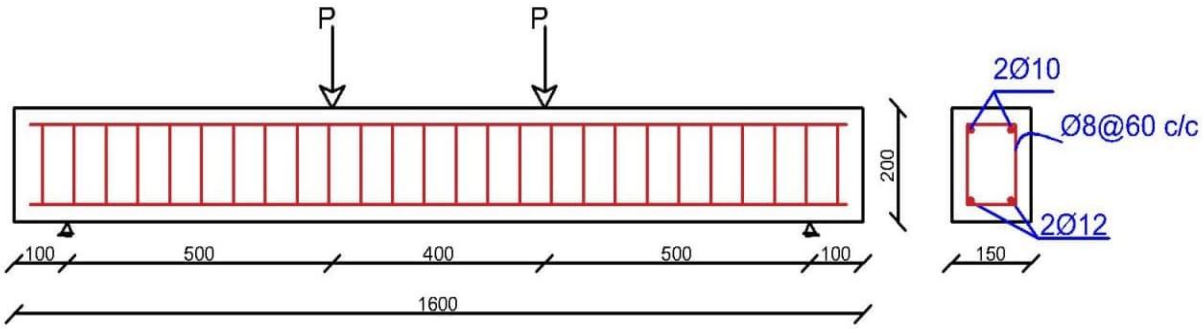

FIGURE 4. Reinforcement details for concrete beams.

FIGURE 5. Wooden molds for beams.

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Test Variable of Reinforced Concrete Beams

Used five beams were tested with different iron percentage. The iron percentages are 0, 5, 10, 20, and 30%. These percentages are variables used as sand replacement weight percentages. The details of concrete beams reinforcement are shown in Table 6.

TABLE 6. Details of concrete beams reinforcement.

Beam ID	F0%	F5%	F10%	F20%	F30%
Iron filing/sand, %	0 (Reference concrete beam)	5	10	20	30

RESULTS AND DISCUSSION

The flexural behavior of the concrete beams via the ultimate load, ductility, the deflection at mid and quarter span, and the crack pattern is investigated. One reference beam with normal reinforced concrete for flexural behavior, and four specimens with different iron filing particle replacement percentages were tested as shown in Figure 6. The mid-span deflection is measured and the beams crack pattern is investigated based on crack path growth for each load increment.

FIGURE 6. Reinforced concrete beam specimens for all iron filing/sand percentages

Ultimate Load

The ultimate loads for all concrete beams are record and listed in Table 7. The ultimate failure load of the reference beam F 0% (without Iron filing) was 83.5 kN. The beams F5% which have a 5% iron filing as sand replacement, showed an ultimate failure load of 84.2 kN and the concrete beams F10% Iron filing replacement recorded 85.6 kN. While concrete beam F20% with Iron filing content of 20% as a sand replacement it observed that the maximum ultimate load was 89.1 kN with increasing by 6.7% compared to the reference beam because the strength and toughness of iron filings as well as its pozzolanic properties justified by Alzaed [13]. The beam F30% which containing 30% of Iron filing as a sand replacement recorded ultimate load of 85.1 kN because the lower fineness modulus of iron filings which leads to higher demand for cement in the concrete matrix. Figure 7 shows the relation between maximum failure load and the Iron filing replacement ratio.

TABLE 7. Ultimate load for beams specimens containing iron filing as a sand replacement

Beam ID	Density, kg/m^3	f_{cu}, MPa	f_c', MPa ($f_c'=0.78f_{cu}$) [18]	Pu, kN	Pu/Pu (Reference beam), %	Change in ultimate load, %
F 0%	2390	25	19.5	83.5	100	0
F 5%	2400	26.7	20.826	84.2	100.83	0.833
F 10%	2430	28.8	22.464	85.6	102.51	2.51
F 20%	2500	32	24.96	89.1	106.70	6.70
F 30%	2540	31.8	24.804	85.1	101.91	1.915

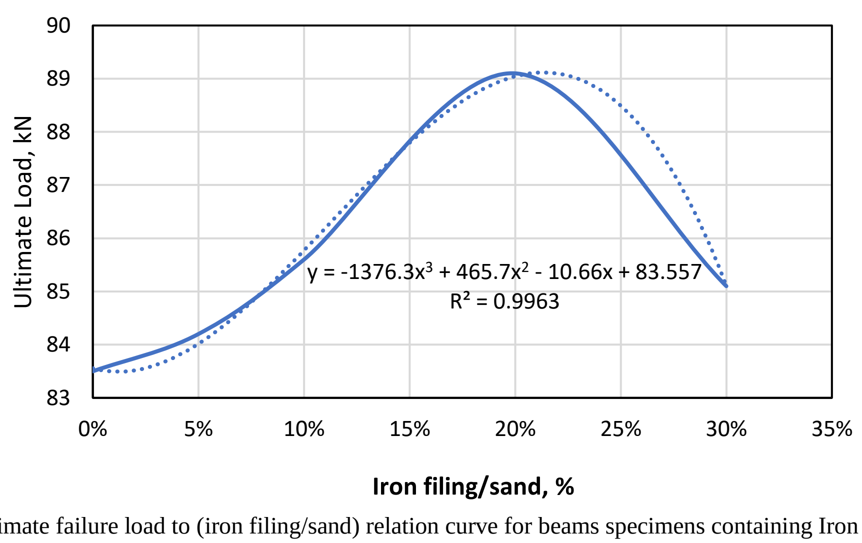

FIGURE 7. Ultimate failure load to (iron filing/sand) relation curve for beams specimens containing Iron filing as a sand replacement.

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Load-Deflections Behavior

Table 8 presents the deflection of concrete beams. Load- deflections at (mid-span) curves were graphed for all beams as shown in Figures 8 and 9. The results are showed that the reference beam F0% had the deflection of 13.30 mm, smaller than all other beams that contained Iron filing as a partial replacement of sand. The results also showed a gradual increase in the maximum deflection as the Iron filing replacement rate increase in the reinforced concrete beams, where the concrete beam F5% is recorded a deflection of 13.55 mm with an increase of 1.9% compared to the reference beam. The results showed that the increase of the maximum deflection with increasing Iron filing, the beams F10%, F20% and F30% showed a maximum deflection of 13.87, 14.67, and 13.41 mm with an increase of 4.3, 10.30, and 0.82 compared to the reference beam respectively.

TABLE 8. Maximum deflection for beams containing Iron filing/sand as a sand replacement.

Beam ID	Ultimate load Pu (kN)	Maximum deflection Δu (mm) at mid span	Maximum deflection Δu (mm) at L/4 span	Δu/Δu (Reference beam at mid span) %	Change in deflection %
F0%	83.5	13.301	11.6	100	0
F5%	84.2	13.554	11.8	101.902	1.902
F10%	85.6	13.873	12.1	104.300	4.300
F20%	85.8	14.67	12.7	110.292	10.292
F30%	84.5	13.411	11.7	100.827	0.827

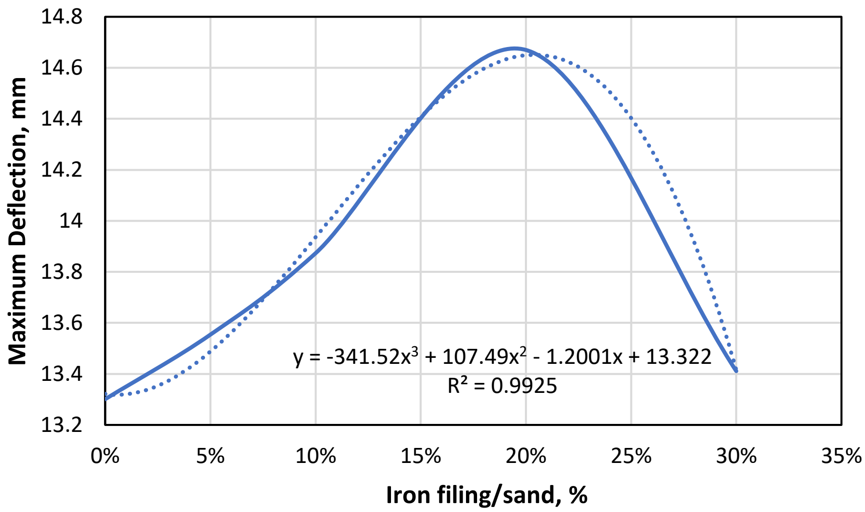

FIGURE 8. Relation curve of maximum deflection to (iron filing/sand) percentages for beams specimens.

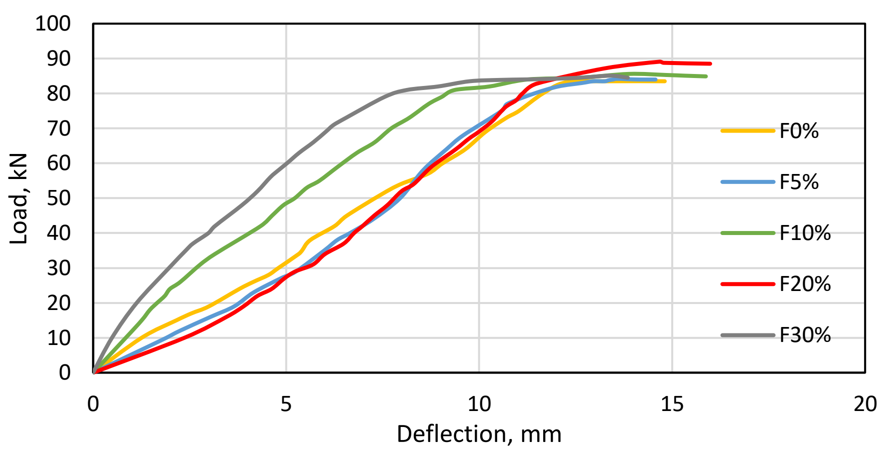

FIGURE 9. Load to deflection curves for beams containing iron filing as a sand replacement.

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Ductility Index

Ductility refers to the ability of reinforced concrete members to withstand significant deflection before failing. The load deflection curve yields the ductility index (DI), which is equal to the ratio of the maximum deflection (Δ_u) to the yield deflection (Δ_y). The ductility of all concrete beams is shown in Table 9. The ductility index follows a path that is similar to the maximum deflection curve as shown in Fig. 10. Ductility is beginning to change with increasing the percentage of iron filing in the concrete, where the beams F5%, F10%, recorded a ductility index of 1.55 and 1.57 with an increment of 10.03 and 11.37%, respectively. While the beams F20%, F30% recorded a ductility index of 1.48 and 1.52 change of 9.11% and 7.63% compared to the reference beam respectively. Therefore, beam F10%, which contains 10% of iron filing, is the highest ductility Because it is the best ratio that is distinguished by its ability to undergo distortions. It is noted that the ductility is sensitive to the percentage of iron filing, as the presence of iron filings led to an increase in ductility.

TABLE 9. Ductility indices for beams.

Beam ID	(Δ_u) Max deflection (mm)	(Δ_y) Yield Deflection (mm)	Ductility Index (DI)	Changing in ductility%
F0%	13.301	9.4	1.415	0
F5%	13.554	8.7	1.557	27.119
F10%	13.873	8.8	1.576	28.633
F20%	14.67	9.5	1.544	26.0004
F 30%	13.411	8.8	1.523	24.349

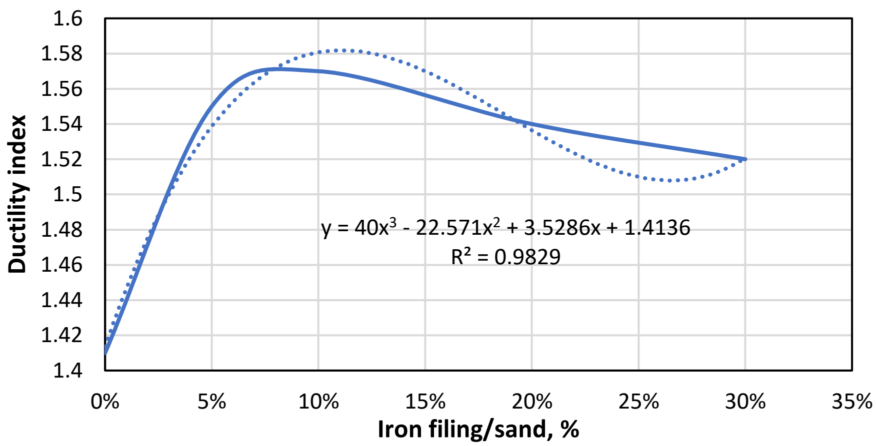

FIGURE 10. Relation curve of ductility index to (iron filing/sand) percentages for beams specimen.

Flexural Compression Strain at Failure Load

The results of flexural strains at failure loads were shown in Table 10 the results showed that when the percentage of iron filing in reinforced concrete increases, the compression strain at failure loads increases. Also, it was noticed through the compression strain curve in Fig. 11, that the compressions strain in the reference specimens F0% is 0.000574. Then a significant increase was observed in a compression strain for concrete beams that containing iron filing particles, where the F 5% beam recorded compression strain of 0.000620 with increasing of 8.38% compared to the control beam, while the beams F10%, F20%, and F30% achieved a compression strain at failure load of 0.000586, 0.000719, and 0.000660 with increasing ratio of 2.17, 25.30, and 15.01% compared to control beam, respectively. The load-strain curves for all beams in Fig. 12 show the difference in brittle behavior between reference concrete beams and those with iron filing particles.

TABLE 10. Compression strain at failure load for beams containing iron filing as a sand replacement.

Beam ID	Compressive strain	Changing, %
F0%	0.0005741	0
F5%	0.0006201	8.387
F10%	0.0005866	2.177
F20%	0.0007194	25.309
F30%	0.000660325	15.019

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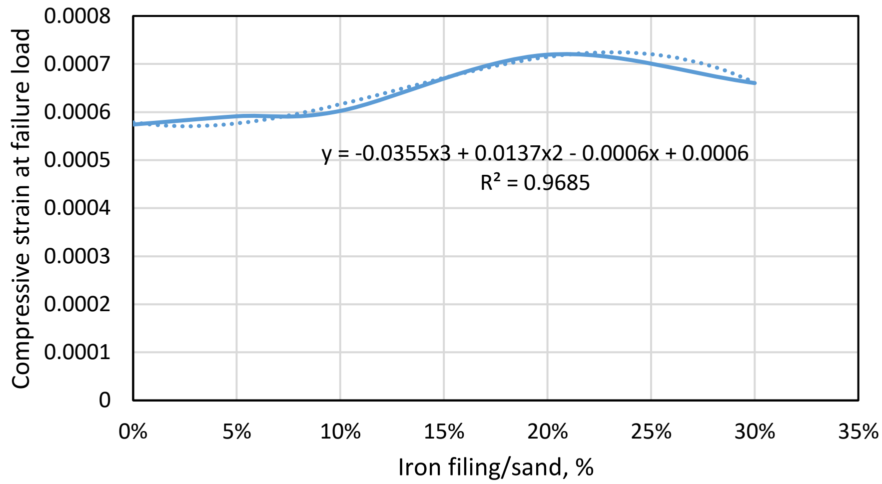

FIGURE 11. Relation of compressive strain to (iron filing/sand) percentages for beams.

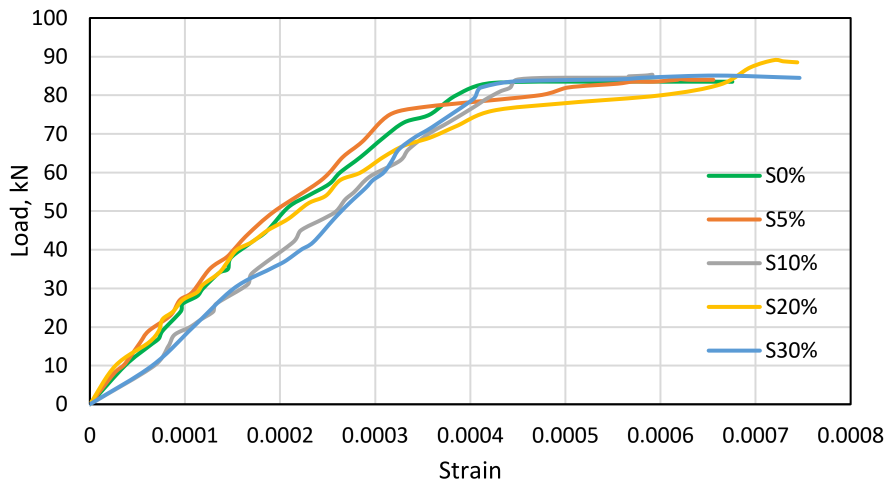

FIGURE 12. Load to compressive strain relation for beams containing iron filing as a sand replacement.

Stiffness

Based on the load-deflection curve as shown in Figure 9, initial stiffness and secant stiffness (effective stiffness) was computed by dividing the maximum applied load (P_u) by the yield deflection (Δ_y) in the case of initial stiffness or the maximum deflection (Δ_u) in the case of secant stiffness. The equations used to show below:

$$\text{Initial stiffness} = P_y / \Delta_y \tag{1}$$

$$\text{Secant stiffness} = P_u / \Delta_u \tag{2}$$

Stiffness is calculated using the. The results presented in Table 11 and Fig. 13 show that the initial stiffness of the reference concrete beam F 0% namely 7.96 kN/mm. The beams F5%, F10% and F 20% are recorded initial stiffness of 7.52, 7.34 and 6.95 kN/mm respectively, with a reduction ratio of 5.52, 7.78, and 12.68% respectively, compared to the reference beam. While for the beam F30% it recorded the highest initial stiffness of 8.22 kN/mm with an increase of 3.2% compared to the reference beam. Secant stiffness decreases with increasing the iron filing content in the concrete beams as shown in Table 11 and Fig. 14. The reference beam F0% is recorded a secant stiffness of 6.27 kN/mm, then, with increasing of iron filing content in concrete beams, the secant stiffness started to decrease gradually, where the beams F5%, F10%, and F20% were achieved a secant stiffness of 6.21, 6.17, and 6.07 kN/mm with a reduction ratio of 0.95, 1.95, and 3.18% compared to the reference specimen respectively. While for the beam F30% it recorded the highest secant stiffness of 6.34 kN/mm with an increase of 1.11% compared to the reference beam. This result is consistent with the results of the deflection in the beams, where an inverse relationship between the deflection and the stiffness. It is clear from the above that adding iron filings increases the deflection, or reduces the stiffness of the beam.

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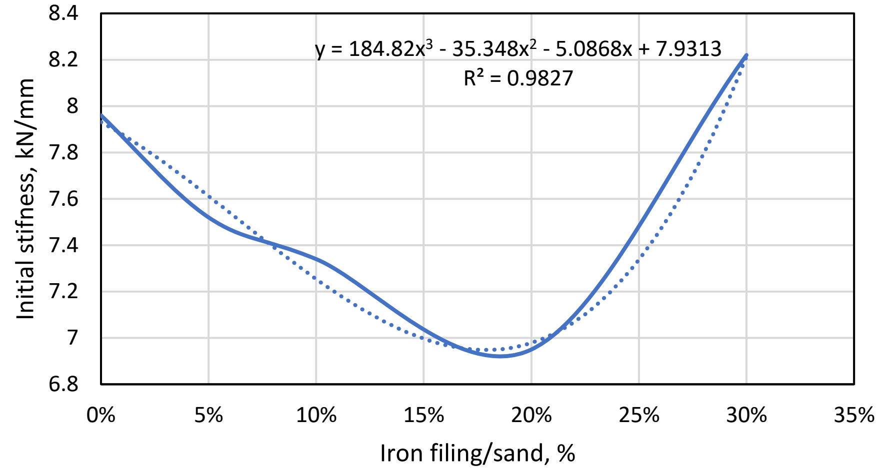

FIGURE 13. Relation curve of initial stiffness to (iron filing/sand) percentage for beams.

TABLE 11. Initial and Secant stiffness results for beams containing iron filing as a sand replacement.

Beam ID	Initial stiffness, kN/m	Variation in initial stiffness, %	Secant stiffness, kN/mm	Variation in secant stiffness, %
F0%	7.96	0	6.27	0
F5%	7.52	-5.52	6.21	-0.95
F10%	7.34	-7.78	6.17	-1.59
F20%	6.95	-12.68	6.07	-3.18
F30%	8.22	3.2	6.34	1.11

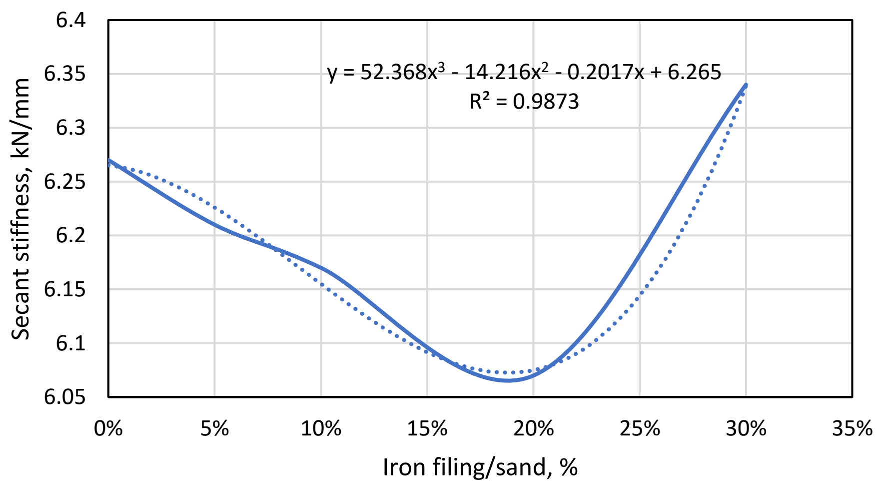

FIGURE 14. Relation curve of secant stiffness to (Iron filing/sand) percentages for beams specimens.

Energy Absorption

The area under the load-deflection curve is used to calculate energy absorption. The energy absorption data for all concrete beams were listed in Table 12, which showed a significant increase in energy absorption due to the inclusion of iron filing particles. The reference beam recorded energy absorption of 585.258 kN.mm. The energy absorption increased with increasing the percentage of iron filing, where beams F5%, F10%, F20%, and F30% achieved an energy absorption of 585.183, 790.507, 671.925, and 834.199 kN.mm. Beam F5% close of reference beam by -0.012% and the remainder is greater than the reference beam by 35.069, 14.808, and 42.53%, respectively. The relationship between energy absorption and percentages of iron filing is illustrated in Fig. 15.

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TABLE 12. Energy absorption results for beams containing iron filing as a sand replacement.

Beam ID	Energy Absorption (T), kN.mm	Changing in toughness, %
F0%	585.258	0
F5%	585.183	-0.012
F10%	790.507	35.069
F20%	671.925	14.808
F30%	834.199	42.53

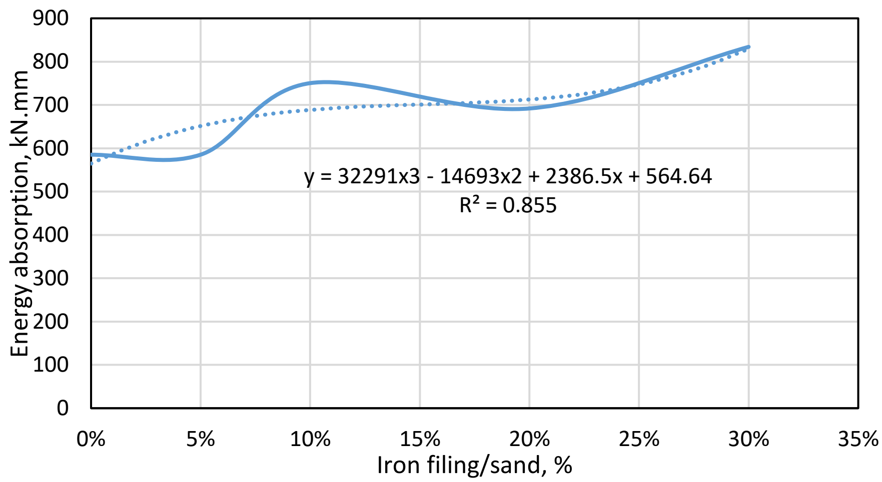

FIGURE 15. Relation curve of energy absorption to (iron filing/sand) percentages for beams.

Failure Modes and Crack Pattern

During loading, crack initiation was observed, and crack growth was indicated on the concrete surface. All beams' crack patterns are shown in Fig. 16. All of the samples had an initial flexural crack in the center. As the applied load increased, more off-center flexural cracks appeared, and one of the flexural cracks at the struts developed into a diagonal crack at Beams F20% and F30%. The failure mode for beams F0%, F5% and F10% are flexure mode, while the failure mode for beams F20% and F30% are flexure – shear mode. The reference beam recorded number of cracks 17 cracks. The number of cracks decreased with increasing the percentage of iron filing, where beams F5%, F10%, F20%, and F30% achieved a number of cracks are 16, 15, 13, and 9 cracks, this indicates that the increase in iron filings reduces the appearance of cracks.

FIGURE 16. Cracks pattern for beams specimens containing iron filing as a sand replacement.

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CONCLUSION

Five reinforced concrete specimens were used to study the structural behavior of steel reinforced concrete beams using iron filing particles as a partial replacement for sand, and the following conclusions were reached:

- The ultimate failure load was increased as the percentage of iron filing in the reinforced concrete beams increased, where the beams F20% recorded a maximum load of 6.7% compared to the control beam.
- The deflection was increased as the percentage of iron filing in the reinforced concrete beams increased, where the beam F20% recorded a maximum deflection of 10.29% compared to the control beam.
- The Ductility index was increased as the percentage of iron filing in the reinforced concrete beams increased, where the beam F20% recorded a maximum deflection of 26% compared to the control beam.
- The compression strain at failure load for flexural behavior was clearly increased with increasing iron filing replacement percentages in the reinforced concrete beams. The beam F20% was greater than the control beam by 25.30%.
- The energy absorption was increased with increasing iron filing replacement percentages in the reinforced concrete beams.
- The initial stiffness and secant stiffness are decreased with the increase of iron filing content in concrete beams, but the beam F30% was increased initial and secant stiffness with an increase of 3.2% and 1.11% respectively compared to the reference specimen respectively.

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