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Shear behaviour of reinforced-concrete beams incorporating iron filings as sand replacement

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Abstract:
This study examined the influence of partial sand replacement with iron filings on the mechanical and physical characteristics of concrete, as well as conducted experimental tests of the shear behaviour of reinforced-concrete beams. Four replacement rates were used in this study, i.e., 5 %, 10 %, 20 %, and 30 % with a reference mixture containing no iron filings. At ages 7, 14, and 28 days, mechanical property tests (slump, density, ultrasonic pulse velocity, compressive strength, and splitting strength tests) were conducted. In addition, the shear behaviour of five reinforced-concrete beams with the same replacement rates (0 %, 5 %, 10 %, 20 %, and 30 %) were experimentally tested. Tests were conducted to determine the ultimate load failure, final deflection, energy absorption, stiffness, ductility index, compressive stress, and crack formations. According to the results, the correlation between the slump test and iron filings is positive; however, that for absorption is negative. With a higher percentage of iron-filing replacement, the density and ultrasonic pulse velocity increased. For specimens with 30,00 % iron filings, the densities, pulse velocities, and slumps were raised by 6,27 %, 2,44 %, and 58,33 %, respectively, compared to the reference specimens, whereas the absorption rate decreased by 20,00 %. Having 20,00 % iron filings produced the maximum compressive and splitting strengths of 28,00 %, which was 4,60 % higher than the reference mixture, whereas 30,00 % iron filings produced the highest flexural strength, which was 9,50 % higher than the reference mix. The findings of beam testing revealed that increasing the iron-filing content in concrete beams increased the final failure load, final deflection, ductility index, and energy absorption by 6,70 %, 10,29 %, 11,30 %, and 35,00 %, respectively. The initial and secant stiffnesses decreased at rates of 12,60 % and 3,10 %, respectively.

Keywords:
iron filings; sand replacement; shear behaviour; ductility; stiffness

1 Introduction

The amount of waste or discarded materials produced in industries, factories, and mechanical plants is increasing daily, resulting in increased environmental pollution. Iron filings are waste products composed of minute bits of iron obtained from the grinding, filing, or milling of finished iron products. Iron filings are either recycled and used as low-quality iron goods or discarded in landfills. Sand (fine aggregate) is one of the basic materials used in the production of concrete, accounting for approximately 20-30 % of the total concrete volume. Based on the worldwide cement output in 2017 of 4,1 million metric tonnes [1] and assuming 90,0 % was utilised for concrete production, the global concrete production in 2017 required 2,4 billion m^3 (4 trillion kg) of sand. Natural sand demand is steadily increasing with cement consumption because of growing infrastructure development. Sand deposits in riverbeds are nearing depletion, thereby posing a threat to the environment. Given the scarcity of sand in riverbeds, stones are crushed into fine powders and utilised as fine aggregates. The quarrying of stones from mountains has resulted in the depletion of other natural resources and loss of mountain green cover. In addition, air pollution occurs when stones are mined and crushed into sand. These concerns have prompted the exploration of low-cost and readily available substitutes for natural sand. Thus, the reuse of waste materials in concrete mixtures, particularly non-degradable materials such as plastic waste, is vital for sustainable construction [2, 3]. Many studies have been conducted on replacing sand with different materials, such as plastic waste [4, 5], fly ash [6], quarry dust [7], marble sludge [8], and copper slag [9].

Iron filings are an example of waste products that can be used as substitutes for sand in concrete. Mironovs et al. [10] investigated the feasibility of using iron-containing waste materials to produce heavy concrete. Krikar et al. [11] found that replacement with 30,0 % iron filings increased the compressive strength of concrete by 17,0 %, and when the proportion of iron filings added exceeded 10,0 %, a slight improvement of 13,0 % in the tensile strength of concrete was achieved. Olutoge et al. [12] reported that 10,0 % and 20,0 % replacement levels of sand with iron filings increased the compressive strength of concrete by 3,5 % and 13,5 %, respectively, and a 30,0 % replacement level decreased the strength by 8,0 % compared with that of the control mix. Krikar et al. [13] investigated the replacement of sand with iron waste of up to 30,0 %. They found that the maximum compressive and flexural strengths of concrete could be attained with a replacement percentage of 12,0 %, beyond which the strength started to decline. This result contradicts that of a previous study [11,12], which found that replacing sand with iron filings increased both compressive and flexural strengths by 30,0 %. Arjun et al. [14] used PVC waste and silica powder to investigate shear strength. The shear strength value of fibre-reinforced concrete was reduced to 25,6 %, and silica fibre-reinforced concrete was reduced to 21,5 % with respect to the normal concrete shear capacity at a maximum of 1,0 % addition of fibre. Mhawi and Dawood [15] investigated the behaviour of concrete-filled steel tube (CFST) columns with 2,5 %, 5,0 %, and 10,0 % iron filings as sand replacements in concrete mixtures to improve the ultimate compressive strength, ductility index, and energy absorption of CFSTs. They found that the ductility index and energy absorption of the column specimens increased in the presence of iron filings. Choi et al. [16] used recycled concrete and studied the extent of its effect on the shear resistance of reinforced-concrete beams owing to the importance of shearing, as it occurs suddenly. The test findings showed that, at a 100,0 % replacement ratio, the concrete shear strength decreased by up to 30,0 % compared to that of natural aggregate concrete.

The present study focused on investigating the physical and mechanical properties of concrete mixes and the shear behaviour of reinforced-concrete beams containing iron-filing waste as sand replacement at replacement percentages of 5,0 %, 10,0 %, 20,0 %, and 30,0 %. An upper limit percentage of replacement of 30,0 % was utilised because the compressive strength began to decline at this percentage. Although the present study focused on the effect of iron filings as sand replacements on the behaviour of reinforced-concrete beams, the present work may be extended to study its effect on reinforced-concrete columns and slabs. In addition, the study of the high-temperature effects on concrete mixtures, including iron filings as sand replacements, is an important topic.

2 Experimental testing of materials

2.1 Materials and methods

Influence of partial sand replacement with iron filings on the mechanical and physical characteristics of concrete, as well as experimental testing of the shear behaviour of reinforced-concrete beams. Four replacement rates were used in this study: 5 %, 10 %, 20 %, and 30 %, with a reference mixture containing no iron filings. At 7, 14, and 28 days, mechanical property tests (slump test, density, ultrasonic pulse velocity, compressive strength, and splitting strength) were conducted. Detailed descriptions of the materials and testing procedures are presented in the following subsections.

2.1.1 Single figures and graphs

Type-I ordinary Portland cement was used in this study. The cement properties satisfied the requirements of Iraqi Specification No. 5/1984 [17]. The cement characteristics are listed in Table 1 and Table 2.

Table 1. Chemical composition of cement

Oxide composition	Abbreviation	Content (%) by weight	Limit of Iraqi Specification No.5/1984
Lime	CaO	63,96	--
Silica	SiO2	21,32	--
Alumina	AL2O3	4,58	--
Iron Oxide	Fe2O3	3,25	--
Sulphate	SO3	2,52	< 2,8 %
Magnesia	MgO	2,76	≤ 5,0 %
Loss on Ignition	L.O.I	3,47	≤ 4,0 %
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	C3S	50,69	--
Di Calcium Silicate	C2S	18,28	--
Tri Calcium Aluminates	C3A	8,14	--
Tetra Calcium Alumina	C4AF	9,89	--

Table 2. Physical properties of cement

Physical properties	Test result	Limits of Iraqi Specification NO.5/1984
Fineness Using Blain Air Permeability Apparatus (m^2/kg)	384	≥ 230
Setting time Using Victa's Method		
3 days, MPa	20,8	15 ≥
7 days, MPa	27,4	23 ≥
28 days, MPa	34,7	--

2.1.2 Aggregates

The fine aggregate used was natural sand (maximum size = 4,75 mm) from Basra, Iraq, whereas the coarse aggregate was crushed natural stone (maximum size = 20 mm). Table 3 and Figure 1 present the grading and standards for fine aggregates corresponding to Iraqi Standard Specification No. 45/1984 [18].

2.1.3 Iron filings

Iron filings were collected from local workshops in Misan Province. Figure 2 shows the colours and shapes of the iron-filed samples. Granules are the side products of iron manufacturing, as shown in Figure 2 and Table 3. shows the specific gravity and absorption rate of the iron waste particles. The grading satisfied the Iraqi specifications listed in Table 4. The grains were graded according to Iraqi Specification No. 45/1980 Zone II, and were nearly identical to natural sand.

Table 3. Physical properties of fine aggregate and iron filings particles

Physical properties	Natural sand	Iron filings	Iraqi specification. 45/1984
Specific gravity	2,56	3,660	--
Sulphate content %	0,13	0,006	≤ 0,1 %
Absorption %	0,75	0,600	--

Table 4. Sieve analysis of iron filings

Sieve analysis of iron filings		
Sieve size (mm)	Cumulative passing (%)	Limits of the Iraqi specification (% passing)
4,75	100,0	90-100
2,36	99,7	75-100
1,18	86,0	55-90
0,60	55,0	35-59
0,30	23,0	8-30
0,15	8,0	0-10

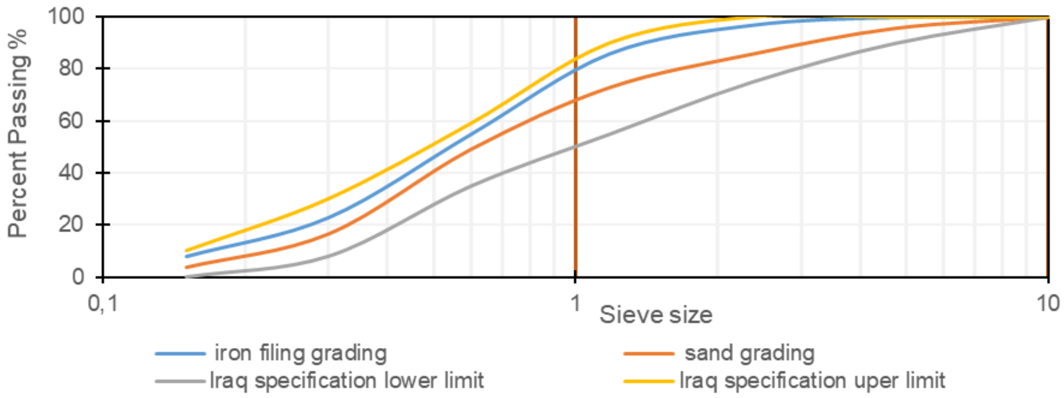


Figure 1. Grading curve for original fine aggregate and iron filings

2.2 Mixture proportions

This section focuses on the proportions of the mixture and replacement percentages used in the mix. The mix proportion is 1:1,9:2,55; as a concrete mix by weight, according to proactive experimental work. The weights of the cement, sand, and gravel per cubic metre in the mixture were 391,50; 743,85, and 998,30 kg, respectively.

The water-cement ratio was 0,52. No super plasticiser was used because the presence of iron filings improved workability.

According to the pre-experiments, iron filings were added to the reference mixture at four different percentages (5 %, 10 %, 20 %, and 30%) as partial substitutes for sand. Table 5 shows the proportions of the different concrete mixtures.

(a)

(b)

Figure 2. Iron filings: (a) particles; (b) side product of iron cutter

Table 5. Concrete mixture proportion for all iron-filing replacement ratios (w/c = 0,52)

Material (kg/m^3)	**0 %**	**5 %**	**10 %**	**20 %**	**30 %**
Cement	391,50	391,50	391,50	391,50	391,50
Sand	743,85	706,65	669,46	595,08	520,69
Gravel	998,30	998,30	998,30	998,30	998,30
Water	203,50	203,50	203,50	203,50	203,50
Iron filings	0,00	37,19	74.38	148,77	223,15

2.3 Types of testing and samples

The mechanical and physical properties of the concrete mixture were determined using 12 cubes with dimensions of 100×100×100 mm, two cylinders with dimensions of 150×300 mm, nine cylinders with dimensions of 100×200 mm, and nine prisms with dimensions of 100×100×500 mm to experimentally obtain the density, compressive strength, modulus of elasticity, splitting tensile strength, absorption, flexural strength, and ultrasonic pulse velocity (UPV).

2.4 Results and discussion of mechanical and physical properties

2.4.1 Slump test

A slump test was performed according to the ASTM C143 standard [19]. The results indicate that the workability of the concrete specimens increased with the percentage of iron filings in the concrete mixture. Similar conclusions were drawn in previous studies [20-22]. The percentage of 10,0 % iron filings significantly increased by 33,3 % compared to the reference mixture, whereas 20,0 % and 30,0 % yielded slump increases of 45,0 % and 58,3 %, respectively, compared to the reference mixture Figure 3. This increase in the slump is due to the smaller surface area of the iron-filing particles than that of the sand particles, which prevents a large amount of water from being saturated on their surface.

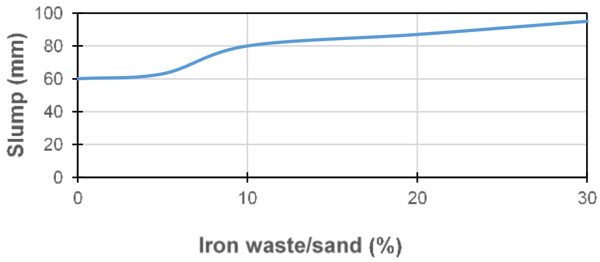


Figure 3. Slump test: measuring and relation between slump (mm) and iron-filing replacement

2.4.2 Density

Dry density measurement results indicated that the addition of iron filler particles to the concrete mixture increased the dry density of the concrete. These results are consistent with those of previous studies [22-26]. The densities for the 5 %, 10 %, 20 %, and 30 % iron-filing replacement ratios were 2400 kg/m^3, 2430 kg/m^3, 2500 kg/m^3, and 2540 kg/m^3, respectively. There were increases of 0,40 %, 1,67 %, 4,60 %, and 6,27 % compared to the reference specimens, respectively.
The test results are plotted as the relationship between the concrete density and iron-filing replacement percentage in Figure 4(a).

2.4.3 Compressive strength

The compressive strength test was performed in accordance with BS1881, Part 116 [27], using a 2000 kN pressure machine. The compressive strength increased when the iron-filing replacement ratio increased from 5 % to 30 % Figure 4(b), and different increases were observed for all three ages. The optimal iron-filing replacement ratio for 28 d compressive strength was 20 %, which yielded an increase of 28 % compared with the reference mixture. In addition, compressive strength increased by 6,8 % when the replacement ratio of iron filings was 5 %. When the compressive strength increased by 15,2 % and 27,2 % when the substitution ratio was 10,0 % and 30,0 %, respectively.
According to Alsaad et al. [23], the toughness and strength of iron filings can be linked to an increase in compressive strength with the amount of iron filings in the mixes [23]. Furthermore, Alzaed [11] reported that iron filings exhibited pozzolanic reactions and characteristics.

2.4.4 Splitting tensile strength

The tests were performed according to the ASTM C496 standard [28]. The results indicated that the splitting tensile strength increased with an increase in the sand replacement ratio with iron-filing particles. The splitting tensile strengths of the 5 %, 10 %, 20 %, and 30 % iron-filing replacement ratios were 2,15; 2,20; 2,25 and 2,30 MPa, respectively, which showed increments of 2,38 %, 4,76 %, 7,14 % and 9,52 % compared with the reference specimens, respectively, as shown in Figure 4(c).
According to Alsaad et al. [23], the increase in direct tensile strength with the percentage of iron filings in the mixes is related to the toughness and strength of the iron filings.

2.4.5 Flexural strength

The bending strength tests were performed according to ASTM C293 [20]. Prismatic samples with dimensions of 100×100×500 mm were used for the test. The bending strengths of the samples increased as the iron residue substitution ratio increased from 5 % to 30 %. The largest increase (4.6%) was observed at the replacement ratio of 20%. The test results are plotted as the relationship between flexural strength and iron-filing replacement percentage, as shown in Figure 4(d).
The flexural strengths of the 5 %, 10 %, 20 %, and 30 % iron-filing replacement ratios were 5,44; 5,45; 5,65 and 5,60 MPa, respectively. There were increases of 0,7 %, 0,9 %, 4,6 % and 3,7 %, respectively, compared to reference specimens. The increase in flexural strength can be attributed to the strength and toughness of the iron filings and their pozzolanic properties. Iron filings may also act as micro-reinforcements in the concrete matrix, thereby increasing flexural strength.

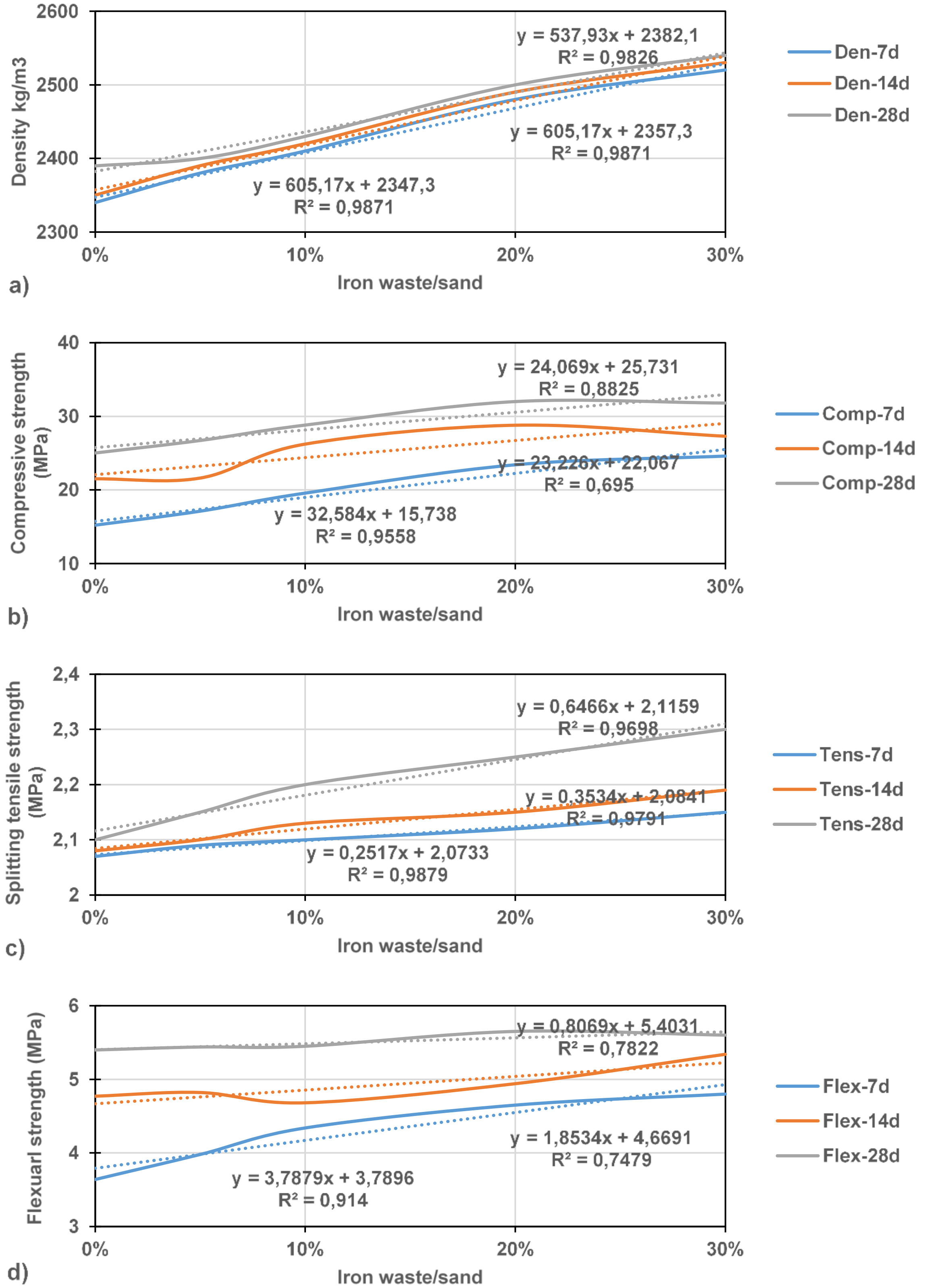


Figure 4. (a) density to iron filings/sand relation; (b) compression to iron filings/sand relation; (c) tensile to iron filings/sand relation; (d) flexural to iron filings/sand relation

2.4.6 Ultrasonic pulse velocities

Ultrasonic tests were performed according to ASTM C597 [29]. Cubic specimens (100×100×100 mm) with a 28 days age and UPV were used for this test. The goal of this test was to employ pulse velocities to determine the impact of iron-filing particles as sand replacements on the concrete quality and to estimate the concrete compressive strength and modulus of elasticity. A high density of iron-filing particles increases the density of concrete containing these particles. The velocities across the specimens with replacement ratios of 5 %, 10 %, 20 %, and 30 % were estimated to be 4800, 4830, 4890, and 4902 m/s, respectively. There were increases of 0,31 %, 0,94 %, 2,19 % and 2,44 %, respectively, compared with the reference specimens, as shown in Figure 5.

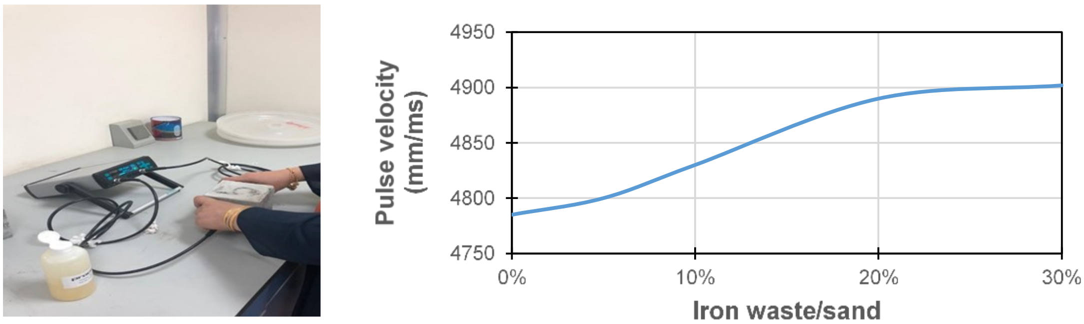


Figure 5. Ultrasonic pulse velocities: testing and results

2.4.7 Absorption test

The tests were conducted according to ASTM C642 [30]. Cubic specimens with dimensions of 100×100 mm were used Figure 6. The specimens were tested at the age of 28 days. The results showed that the absorption rate decreased as the iron-filing percentage increased. The reference mixture exhibited an absorption rate of 5,99 %, and the specimens with 5,00 %, 10,00 %, 20,00 % and 30,00 % iron filings as sand replacements achieved absorption rates of 5,64 %, 5,59 %, 4,83 % and 4,79 %, respectively, as shown in Figure 6. This phenomenon may be due to the shape of the iron-filing particles, which decreased the number of voids and pores in the concrete structure. The absorption rate decreased with the number of voids and pores, thereby reducing permeability when the absorption rate decreased and increasing durability. According to Zhang et al. [31], the resistance of concrete to sulphate attack increases with decreasing water absorption, and surface water absorption can be used to forecast some concrete properties, such as compressive strength, permeability, and sulphate resistance.

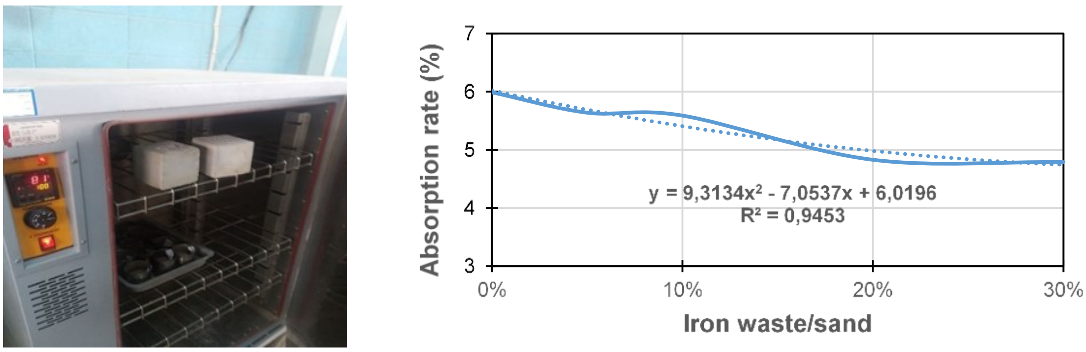


Figure 6. Absorption test and absorption to iron waste/sand relation

2.4.8 Failure mode

The failure modes of various specimens (cubes, cylinders, and prisms) were distinct during the demolition tests. The brittleness of the concrete caused the reference specimens to break. The failure mode of the specimens containing iron filings exhibited cracks with decreasing diameter and length as the replacement percentage increased. This pattern demonstrates that ductility, a critical property that increases the flexibility of concrete, increases with replacement percentage. Figure 7 shows the failure modes of the different specimens.

3 Experimental testing on elements

3.1 Description of specimens

Experimental testing of the reinforced-concrete beams included testing of five beams with dimensions of 150×300×1,600 mm concrete mixtures for specimen casting, as described in the previous section (0 %, 5 %, 10 %, 20 %, and 30 %). All the concrete beams were cast using wooden formwork, as shown in Figure 8. The wooden moulds used in this part were made of a fixed wooden base with movable sides connected to each other, and with the base using screws and nails. All concrete beams were simply supported. The beams were designed with a rectangular cross-sectional area with dimensions of b = 150 mm, h = 300 mm, and a length of 1600 mm.

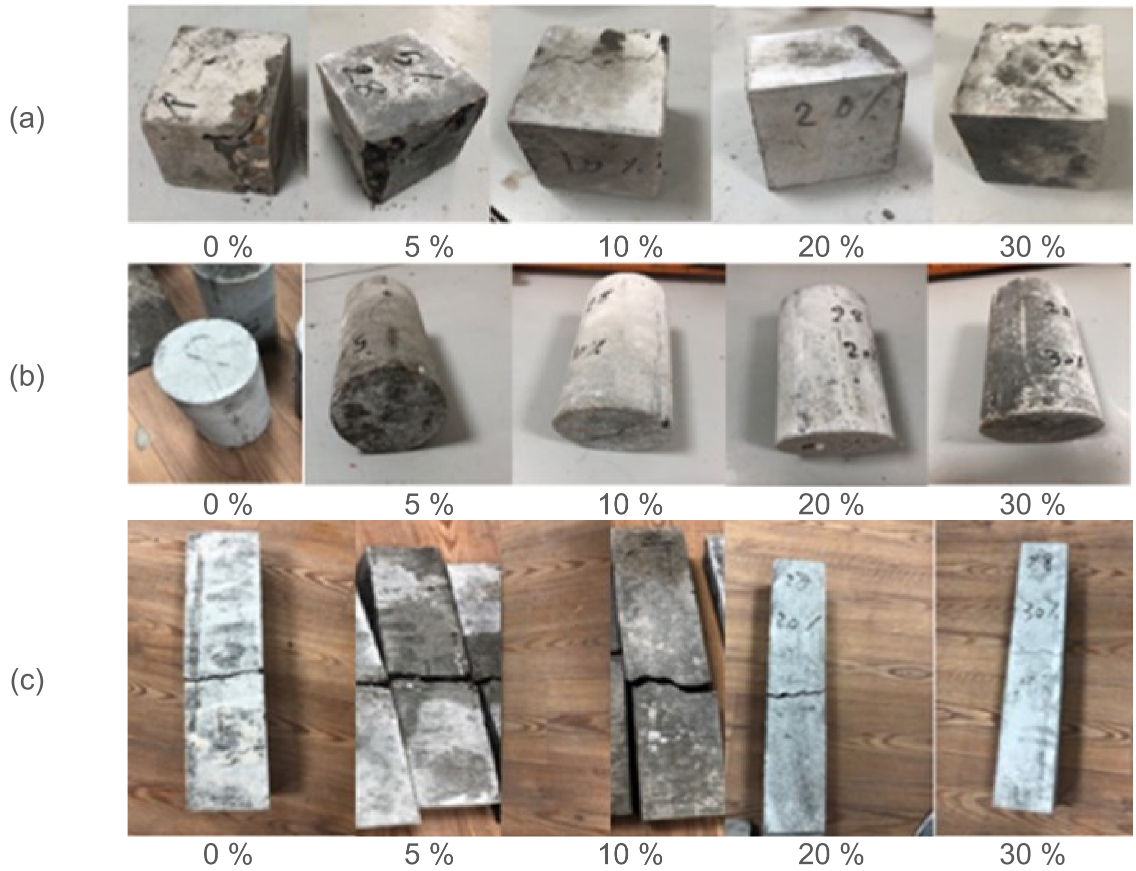


Figure 7. (a) Compression specimen failure modes; (b) splitting tensile specimen failure modes; (c) flexural strength specimen failure modes

Two-point loads at 508 mm apart and two supports with a clear span of 1300 mm were used to test the specimens, as shown in Figure 9. The concrete beams were designed in such a way as to prevent flexural failure of the beams by using a large amount of tension reinforcement (2 × ϕ 16 mm) and should fail by shear, where the distance between each point load and support (a) was 396 mm, while the effective depth (d) of the beam section was 264 mm. Thus, the ratio of (a) to (d) was equal to 1,5. This indicates that a section of the beam should fail in shear. The shear beam reinforcement was designed according to ACI 318-14 Code [34]. All beams were reinforced by 2 × ϕ 16 mm bars in the tension zone and 2 × ϕ 10 mm bars in the compression zone. Stirrups with a diameter of ϕ = 8 mm spaced at 150 mm c/c were used at the shear span.

Figure 8. Wooden moulds for beams

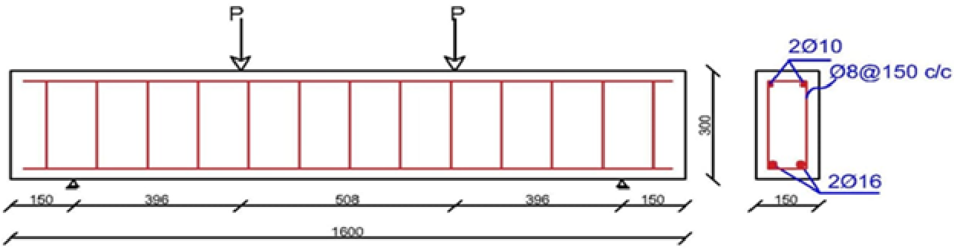


Figure 9. Reinforcement details and loading method for concrete beams

3.2 Testing protocol

In the structural laboratories of the Technical Institute in Misan, an automatic compression machine with a capacity of 600 kN and dimensions (3000×1000 mm height) was used to test the beam, as shown in Figure 10. In addition, it can be manually controlled. The applied loads were increased in successive increments of approximately 10 kN until a failure load was reached. Observations were recorded at each load increment, including the strain value, deflection, first crack, and drawn crack pattern. In hydraulic and pneumatic mechatronic systems, variable linear differential transformer (LVDT) sensors are commonly employed to monitor physical quantities, such as displacement, force, and pressure, as shown in Figure 10.

Figure 10. Testing of beams

3.3 Results and discussion of shear behaviour testing of reinforced-concrete beams

3.3.1 Ultimate load

The reference beam, S0% (without iron filings), had an ultimate failure load of 230 kN. The S5% beam, which contained 5 % iron filings as a sand replacement, had an ultimate failure load of 240 kN. The ultimate failure load of a concrete beam S10% with an iron-filing content of 10 % as a sand substitute was 260 kN. When the concrete beams were replaced with 20 % iron filings, the maximum failure load was 290 kN, an increase of 26,08 % when compared to the reference beam. The S30% beam, which had 30 % iron filings as a sand replacement, failed at a load of 250 KN. The failure load characteristics of S20% were superior. For all beams, Figure 11 shows the relationship between the maximum failure load and iron-filing replacement ratio.

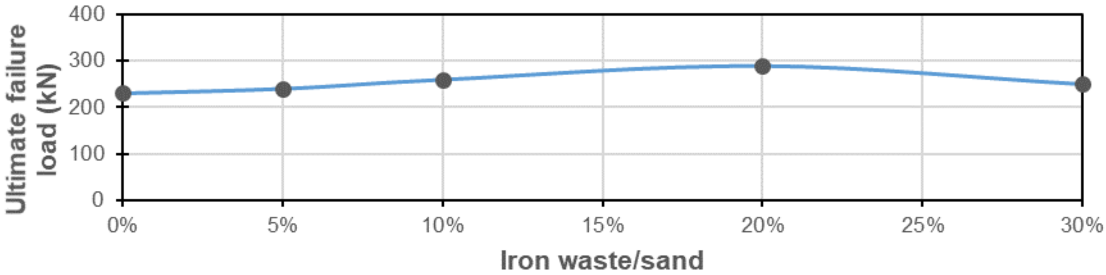


Figure 11. Ultimate failure load versus iron filing/sand for beams

3.3.2 Load–deflection ratio

The deflections of the concrete beams are shown in Figure 12. The load deflections at (mid-span) curves were graphed for all beams, as shown in this figure. The reference beam S0% had a deflection of 8,15 mm, which was lower than all other beams that used iron filings as a partial replacement of sand. The data also revealed a progressive increase in maximum deflection as the iron filings replacement rate in concrete beams increased, with the concrete beam S5% recording a deflection of 9,74 mm with a 19,55 % increase over the reference beam. The results showed that increasing the iron filings increased the maximum deflection, beams S10%, S20%, and S30%, a maximum deflection of 12,54; 13,60 and 10,54 mm with an increment of 53,93 %, 66,89 % and 29,39 % compared to the reference beam, respectively.

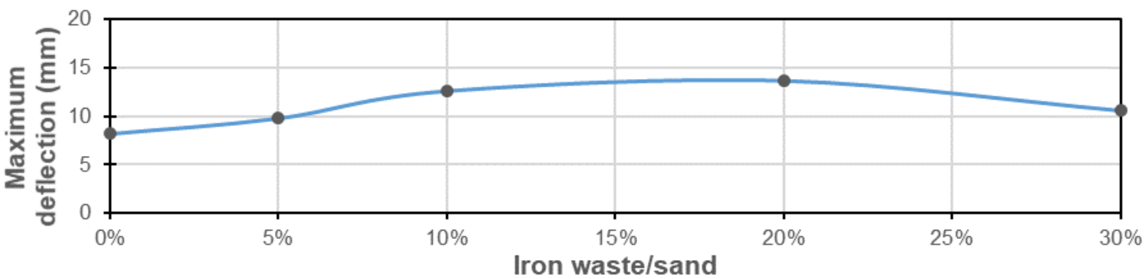


Figure 12. Relationship curve of maximum deflection to iron filings/sand for beam specimens

The relationship between the ultimate failure load and the maximum deflection Figure 13 indicated that beam S20% was the best. This also indicates that the fraction time increases and the failure approaches. The ability of concrete to reduce the impacts of dynamic loads, earthquakes, and impulsive loads is critical.

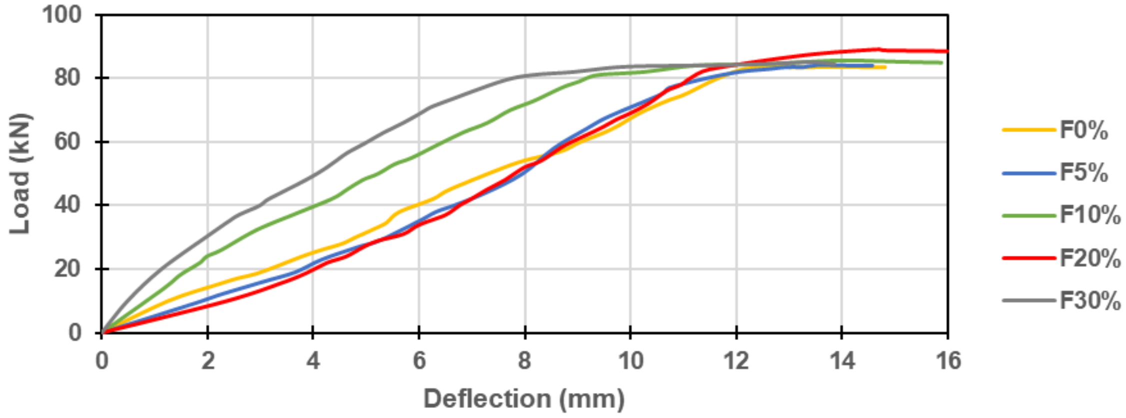
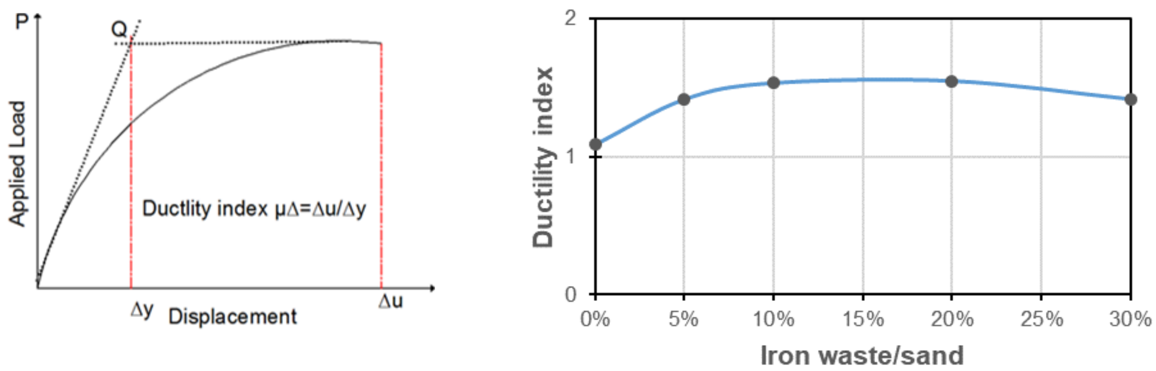


Figure 13. Load–deflection curves for beam specimens containing iron filings as sand replacement

3.3.3 Ductility index

Ductility refers to the ability of reinforced-concrete members to withstand significant deflection before failure Figure 14. The load–deflection curve yielded the ductility index (DI), which is equal to the ratio of the maximum deflection (Δu) to the yield deflection (Δy). The DI begins to change with an increase in the percentage of iron filings in the concrete, where beams S5%, S10%, and S20% recorded ductility indices of 1,41; 1,53 and 1,54; respectively, with increments of 15,23 %, 24,85 % and 26,13 %, respectively. The beams S30% recorded a ductility of 1,41; which represents a variation of 15.51% compared to the reference beam, as shown in Figure 14.



Ductility index (DI) calculation [32]   Relation curve of DI to iron filings/sand percentages

Figure 14. Ductility index

Therefore, beam S20%, which contained 20% iron filings, exhibited the highest ductility. It should be noted that ductility is sensitive to the percentage of iron filings.

3.3.4 Stiffness

Based on the load–deflection curve, the initial stiffness and secant stiffness (effective stiffness) were computed by dividing the maximum applied load (Pu) by the yield deflection (Δy) for the initial stiffness or the maximum deflection (Δu) for the secant stiffness. The initial stiffness of the reference concrete beam, S0%, was 38,64 kN/mm. The beams S5%, S10%, S20%, and S30% had initial stiffnesses of 35,17; 32,73; 27,24 and 34,14 kN/mm Figure 15, respectively, with reduction ratios of 8,98 %, 15,29 %, 29,50 % and 11,64 %, respectively, compared to the reference beam. The secant stiffness decreased with an increase in the iron-filing content of the concrete beams. The reference beam S0% recorded a secant stiffness of 28,21 kN/mm,

then, with increasing of iron filings content in concrete beams, the secant stiffness started to decrease gradually, where the beams S5%, S10%, S20%, and S30% achieved a secant stiffness of 24,62; 20,72; 21,31 and 23,70 kN/mm with a reduction ratio of 12,72 %, 26,55 %, 24,45 % and 15,98 %, respectively, compared to the reference specimen.
This result is consistent with the results of the deflection in the beams, where an inverse relationship exists between the deflection and stiffness. It was found that the addition of iron filings increased the deflection and equivalently reduced the stiffness of the beam.

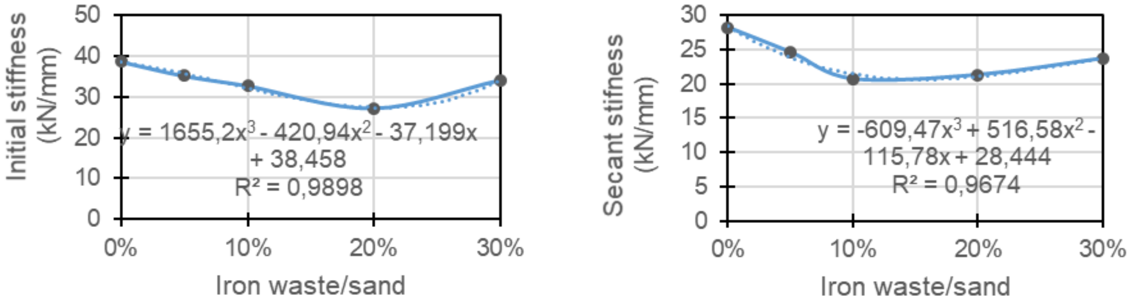


Figure 15. Relation curve of initial and secant stiffness to iron filings/sand percentage for beam specimens

3.3.5 Energy absorption

The energy absorption data for all the concrete beams are presented in Figure 16. showed a significant increase in energy absorption owing to the inclusion of iron-filing particles. The reference beam exhibited an energy absorption of 973,695 kNmm.
The energy absorption increased with an increase in the percentage of iron filings, where beams S5%, S10%, S20%, and S30% achieved energy absorptions of 1294,490; 1942,595; 2090,960 and 1575,030 kNmm, that is, larger than the reference beam by 32,94 %, 99,50 %, 114,74 % and 61,75 %, respectively, owing to the increase in the area under the curve of the load and deflection.

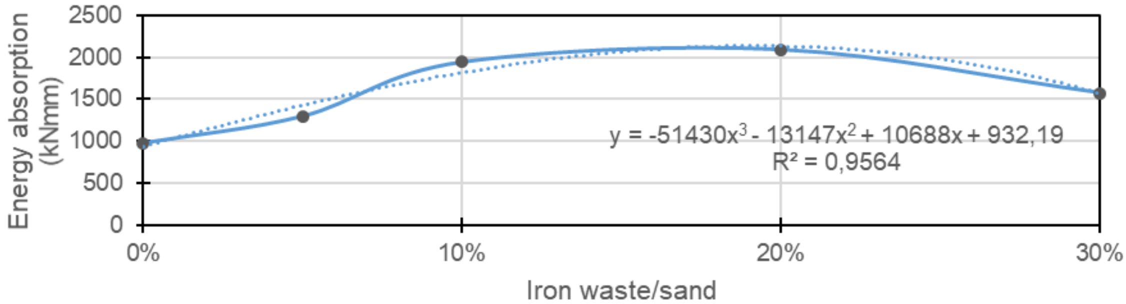


Figure 16. Relation curve of energy absorption to iron filings/sand percentages for beam specimens

3.3.6 Failure modes and crack patterns

During loading, crack initiation and growth were observed on the concrete surface. The crack patterns of all beams are shown in Figure 17. All the samples had an initial shear crack in the struts with diagonal cracks. The failure modes for beams S0%, S20%, and S30% were shear modes, whereas those for beams S5% and S10% were flexure–shear modes.

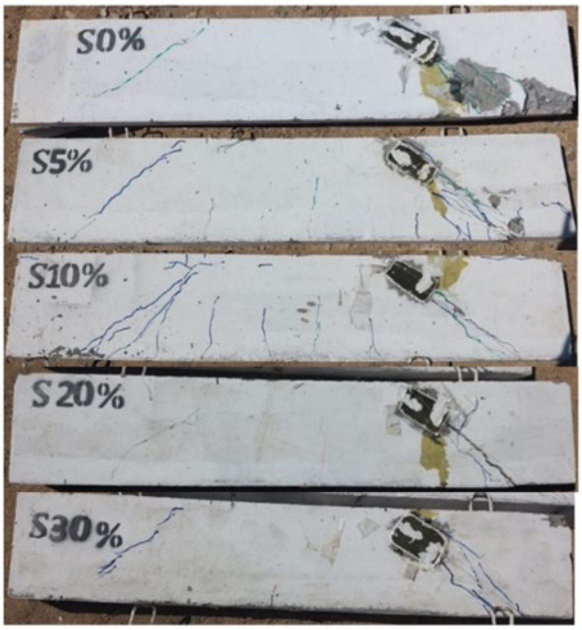


Figure 17. Crack patterns for beam specimens containing iron filings as sand replacement

4 Conclusion

The following conclusions were drawn from the experimental programme on the physical and mechanical properties of concrete using iron filings as a partial substitute for sand:

- At a constant w/c ratio, the workability increased as the percentage of iron filings in the concrete mixture increased. The reference mixture exhibited the lowest workability, whereas the iron-filing percentages of 5,0 %, 10,0 %, 20,0 % and 30,0 % increased by 5,0 %, 33,3 %, 45,0 % and 58,3 %, respectively, compared to the reference mixture.
- The compressive strength increased with iron-filing percentage as the sand replacement in the concrete increased. Iron-filing percentages of 5,0 %, 10,0 %, 20,0 % and 30,0 % increased by 6,8 %, 15,2 %, 28,0 % and 27,2 %, respectively, compared to the reference mixture.
- The splitting tensile strength increased with iron-filing percentage as the sand replacement in the concrete increased. Iron-filing percentages of 5,00 %, 10,00 %, 20,00 %, and 30,00 % increased by 2,38 %, 4,76 %, 7,14 % and 9,52 %, respectively, compared with the reference mixture.
- The flexural strength increased as iron-filing percentage increased and as the sand replacement in the concrete increased. Iron-filing percentages of 5,0 %, 10,0 %, 20,0 % and 30,0 % increased by 0,7 %, 0,9 %, 4,6 % and 3,7 %, respectively, compared to the reference mixture.
- The density increased as the percentage of iron filings increased and as the sand replacement in the concrete increased. Iron-filing percentages of 5,00 %, 10,00 %, 20,00 % and 30,00 % increased by 0,40 %, 1,67 %, 4,60 % and 6,27 %, respectively, compared to the reference mixture.
- The absorption decreased as the iron-filing percentage and sand replacement in the concrete increased. Iron-filing percentages of 5,0 %, 10,0 %, 20,0 % and 30,0 % decreased by 5,8 %, 6,6 %, 19,3 % and 20,0 %, respectively, compared to the reference mixture.
- The UPV increased with the iron-filing percentage as the sand replacement in the concrete increased. Iron-filing percentages of 5,00 %, 10,00 %, 20,00 % and 30,00 %

increased by 0,31 %, 0,94 %, 2,19 % and 2,44 %, respectively, compared with the reference mixture.

- Thus, the above conclusions highlight the significance of using iron filings as sand replacement for concrete applications in civil engineering, primarily because the presence of iron filings considerably improves concrete mix workability without any reduction in mechanical properties. When the presence of water is negative, particularly in hot climates, iron filings exhibit increased density and reduced porosity, which is useful for treating sand problems, such as salt problems.

Five reinforced-concrete specimens were used to study the structural behaviour of steel-reinforced-concrete beams using iron-filing particles as a partial replacement for sand. The following conclusions were drawn:

- The ultimate failure load increased as the percentage of iron filings in the reinforced-concrete beams increased, where beam S20% recorded a maximum load increment of 26,08 compared with the control beam.
- The deflection increased as the percentage of iron filings in the reinforced-concrete beams increased, with beam S20% recording a maximum deflection of 66,89 % compared with the control beam.
- The DI increased as the percentage of iron filings in the reinforced-concrete beams increased, where S20% recorded a maximum deflection of 26,13 % compared with the control beam.
- The energy absorption increased with increasing iron-filing replacement percentage in the reinforced-concrete beams.
- The initial and secant stiffness values decreased with increasing iron-filing content of the concrete beams.

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