Reinforcing mortar with short fibre iron waste

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Abstract. The objective of this work was to reinforce mortar with low-cost fibres. Two groups of mortars were prepared, with and without Styrene-butadiene rubbers (SBR), then each group was reinforced with short fibres of iron waste of approximately 1 to 1.5cm in length and 1mm in thickness (aspect ratios of 10 to 15). These fibres were added at different percentages (10, 20, and 30%) by weight of sand. All groups were allowed to cure for 28 days. The results then showed an enhancement in strength for each group based on measurements of compressive and flexural strength. Moreover, several other properties (dry density, porosity, water absorption) were also improved. The lowest dry density, porosity and water absorption results were 2104.4 Kg/m³, 21.25%, and 10.09%, respectively at 10% iron waste fibres with SBR, while the best results for compressive strength and flexural strength were 33.75 MPa and 7.6969 MPa at 20% and 30% iron waste fibres with SBR, respectively. It can thus be concluded that short fibres of iron waste can partially replace fine aggregate in terms of reinforcing and improving the properties of mortar.

1. Introduction

Waste refers to any material that is rejected after a primary use, or which is deemed defective and of no use in its first context. Truly discarded materials are a threat to the environment, so it is important to reuse as much waste as possible [1]. This makes it important to manage waste and several legal frameworks are in place that enable waste management. Generally, iron waste is not considered beneficial or even non-hazardous; ways to enhance the consumption of iron waste are thus very useful to society. Incorporation of certain wastes can offer advantages to mechanical properties in some materials and structures, such as road materials, rail road bases, and pavement [2]. Many studies have thus investigated the addition of iron waste to construction materials based on adding different percentages of iron waste as a natural sand replacement, with the various outcomes assessed and compared.

Sharma and Singh (2015) studied the replacement of sand in construction materials at many percentages with iron-based waste materials such as iron slag, steel cutting waste, and steel swarf, finding that the compressive strength was improved after the addition of iron slag and comparable strength was also improved with iron cutting waste and steel swarf up certain replacement levels. In particular, iron cutting waste increased mortar freshness and dry density [3]. Another study by Tayeh and Al Saffar (2018) studied two kinds of iron waste replacing sand in many percentages. The first kind was iron powder, which has a similar particle size distribution to the sand used in making the specimens, and the second kind was passed through a 1.18 mm sieve and retained on the sieve (#200). Both kinds of iron were added in different percentages as a natural sand replacement. Destructive tests...
were then utilized on cubes of the hardened mortar to obtain their compressive strength and flexural strength [4].

2. Research Aim
The purpose of this work is to add iron waste fibre to mortar in different percentages and to thus determine its effect on certain physical and mechanical properties of such mortar with and without the addition of SBR.

3. Experimental Procedure

3.1. Materials

3.1.1. Cement. Ordinary Portland cement with a Tassluja trademark from an Iraqi cement factory was used. In order to avoid the effects of moisture on the properties of the cement, it was stored in a dry place. The cement was made to Iraqi standard specification No.5/1984[5]. Tables (1) and (2) show the chemical composition and physical properties of this type of cement.

| Test                  | Results | Limits[5] |
|-----------------------|---------|-----------|
| SiO₂ (%)              | 17.95   | --------- |
| Al₂O₃ (%)             | 3.33    | --------- |
| Fe₂O₃ (%)             | 4.89    | --------- |
| CaO (%)               | 63.79   | --------- |
| C₃A (%)               | 0.55    | ≤ 3.5%    |
| MgO (%)               | 1.23    | ≤ 5%      |
| SO₃ (%)               | 2.38    | ≤ 2.5%    |
| Lime saturation Factor(L.S.F) | 0.95 | ≤ (1.022-0.66)% |
| Loss on ignition(L.O.I) | 3.77 | ≤ 4%      |
| Insoluble residue (I.R) | 1.21 | ≤ 1.5%    |

Table 2. Physical properties of cement

| Test                  | Results | Limits[5] |
|-----------------------|---------|-----------|
| Fineness (m/kg) (blain’s method) | 416     | ≥ 250     |
| Setting time (hr : min) (Vicat’s method) |         |           |
| -Initial setting      | 2:00    | ≥ 45 min. |
| -Final setting        | 4:00    | --------- |
| Soundness (Autoclave) | -0.02   | ≤ 0.8     |
| Compressive strength  |         |           |
| -3 days               | 26.00   | 15        |
| -7 days               | 30.00   | 23        |

3.1.2. Sand. Sand from Al-Ukhaydir land was used as a fine aggregate. The grading of the sand was tested according to the Iraqi standard specification No.45/1984[6]. The results of the sieve analysis process are shown in Table (3).
Table 3. Sieve analysis of sand

| Sieve size (mm) | Passed % | Limits of third area % [6] |
|----------------|----------|-----------------------------|
| 10             | 100      | 100                         |
| 4.75           | 90       | 90-100                      |
| 2.36           | 86       | 85-100                      |
| 1.18           | 77       | 75-100                      |
| 0.6            | 65       | 60-79                       |
| 0.3            | 21       | 12-40                       |
| 0.15           | 6        | 0-10                        |

3.1.3. Styrene-butadiene rubber (SBR). Styrene-butadiene rubber (SBR) is a white copolymer of styrene (25%) and butadiene (75%), and it is the most commonly used rubber in construction work. The SBR used in this work was of ASAS trademark, from the UAE. The major reason for using SBR with the tested mixtures of mortar and iron fibre waste is to reduce the effect of water on the iron, minimising the reaction between them, as well as obtaining good workability, good resistance against thermal degradation and generation of cracks, bonding between layers, and additional weather resistance [7]. SBR properties are given in Table (4), according to the supplier information.

Table 4. Properties of SBR

| Physical& Chemical properties | Value            |
|-------------------------------|------------------|
| Density                       | 1041Kg/m³       |
| pH                            | 8-9              |
| Solid content                 | 35-38%           |
| Temperature resistance state  | -20 to +90°C     |
| colour                        | Liquid           |
| Water resistance              | White            |
| Shrinkage                     | Excellent        |

3.1.4. Iron fibre waste. Iron fibre waste from various workshops in Baghdad and Bab al-Sheikh was used. The length of iron fibres was approximately 1 to 1.5 cm and their thickness was 1 mm, as shown in figure (1). The fibres were cut off manually and stored in a dry place to prevent oxidation; those selected were all without apparent rust. Table (5) shows the physical properties of the iron fibre waste.

Figure 1. Iron fibre waste.
Table 5. Physical properties of iron fibre waste

| Physical properties | Value         |
|---------------------|--------------|
| Specific gravity    | 6.354        |
| Absorption %        | Null         |
| Colour              | Black        |
| Appearance          | Approximately smooth |

3.1.5. Water. Tap water was used in the mixing process, and distilled water was used for the curing process.

3.2. Experimental Work

Mixtures of 1:3 cement: sand with 0.5 water/cement ratios were prepared to make mortar the various tests (physical, compression, and flexural). The iron fibre waste was added at weight percentages of 10%, 20%, and 30%, replacing the sand. The samples were separated into two groups: iron fibre waste reinforced mortar without added SBR, and iron fibre waste reinforced mortar with 10% SBR replacing water by weight. All groups were allowed to cure for 28 days.

The iron fibre waste was added randomly by weight with the sand. The procedure for mortar mixing was carried out according to ASTM C305 [9], with the dry paddle and bowl placed in the mixer, water placed in the bowl, and cement added to it. The mixer ran at a slow speed (140 ± 5 r/min) for 30 seconds before sand and iron fibre waste were added while mixer continued to run at the slower speed. The mixer speed was then converted to medium (285 ± 10 r/min) for further mixing for 30 seconds. The mixer was switched off for 90 seconds, and the process was then finished by mixing for 60 second at medium speed. After the mixing process was complete, the reinforcing mortar was poured into cast iron moulds of dimensions 5×5×5cm. Per ASTM C109 [8], oil was applied by using an impregnated cloth to the faces of the mould for the compression test samples; to remove any excess appearance agent and to achieve a thin and smooth surface on the cubes, as well as making it easier to open the moulds without any damage to the mortar cubes. Good compacting for the reinforced mortar specimens was achieved by applying a vibrating compactor to achieve better bonding between the mortar and iron fibre. After the solidification of all samples, they were cured at a temperature of 23± 2 °C for 28 days.

Per BS EN 196-1:05 [10], the mould was 4x4x16 cm and specimens cured at a temperature of 20±1 °C for 28 days for the flexural test. The cement and water were placed in the bowl and the mixer used at low speed (140 ± 5 r/min). After 30 seconds of mixing, the sand with iron fibre waste was added during the next 30 seconds. The mixer was switched to high speed (285±10 r/min) and mixing continued for 30 seconds. The mixer was switched off for 90 seconds and within the first 30 seconds, reinforced mortar was removed using a plastic scraper and placed in a bowl. The mixing was continued at 285±10 r/min for 60 seconds. The two samples of reinforced mortar were distributed in two approximately equal layers before being compacted by a vibrating compactor using 60 jolts.

All the specimens were cured for 28 days in distilled water and tested in the National Centre for Construction Laboratories and Research (NCCLR), Baghdad.

3.3. Dry Density

The dry density of each specimen was determined according to ASTM C642-97 [11]. The Archimedes method was used to obtain the dry density based on determined wet weight after 28 days, with the specimen immersed in water to calculate the submerged weight. After drying, the specimen in an oven with a temperature of 100 to 110 °C for one day, the measured dry weight was obtained and the dry density calculated per equation (1) [11]:

\[
\text{Dry Density} = \frac{A}{(C-D)} \cdot \rho_w
\]  

where
A: mass of oven dried sample in air (Kg)
C: mass of dry sample in the air after immersion (Kg)
D: mass of sample in water after immersion (Kg)
\( \rho_w \): water density (1,000 Kg/m\(^3\))

3.4. Porosity
The porosity of specimens was determined according to ASTM C642-97 [11]. The procedure for the measurement of porosity was similar to the water absorption tests except that the immersed weight (third weight) was also needed. Porosity was thus calculated according to equation (2) [11]:

\[
\text{Porosity (\%) = } \frac{W_2-W_1}{W_2-W_3} \times 100
\]

where 
W\(_1\): the average dry weight specimen, g
W\(_2\): the average wet weight specimen, g
W\(_3\): the average immersed weight of specimen, g

3.5. Water absorption
Water absorption was determined according to ASTM C642-97 [11]. The specimens were immersed in water at 20±5°C for 28 days. The procedure then included drying the specimens in an oven at a temperature of 100 to 110°C for one day, before the specimens were cooled at room temperature and weighed (Dry weight) after their surfaces were buffed with a dry cloth. The water absorption was then calculated according to equation (3) [11]:

\[
\text{Absorption after immersion \% = } \frac{(B - A)}{A} \times 100
\]

where 
A = mass of oven-dried specimen in air, g
B = mass of dry specimen in the air after immersion, g

3.6. Compression Test
The compression tests were carried out according to ASTM C109 07 [8]. The compressive strength was calculated according to equation (4) [8]:

\[
f_m = \frac{P}{A}
\]

where 
f\(_m\): the compressive strength (MPa)
P: maximum total load (N)
A: area of loaded surface (mm\(^2\))

3.7. Flexural Test
This test measured the flexural strength of specimens according to BS EN 196-1:05 [10]. The flexural testing was performed on three-point loading prism specimens tested using a CONTROLS machine from Milan, Italy. The flexural strength was calculated according to equation (5) [10]:

\[
R_f = \frac{1.5 \times F_f \times l}{b^3}
\]

where 
R\(_f\): the flexural strength (MPa)
b: side of the square section of the prism (mm)
F\(_f\): load applied to the middle of the prism at fracture (N)
l: the distance between the supports (mm)
4. Results and Discussion

4.1. Density
Iron is of high density which influenced the density of the specimens. As the percentage of iron fibre waste increased in the specimens, their density increased. The presence of SBR in the mixture made specimens much lighter, however, because of the light weight of SBR, as shown in figure (2).

![Figure 2. Effect of iron fibre waste on mortar density with and without SBR.](image)

4.2. Porosity
The porosity increases in specimens with SBR were higher than those without it. This increase, shown in figure (3), resulted from SBR’s adhesive properties, which led to agglomeration between the mixing materials that entrapped air, leading to an increase in the total porosity [12].

![Figure 3. Effect of iron fibre waste on the porosity of mortar with and without SBR.](image)
4.3. Water absorption

The water absorption increased in specimens with SBR more than those without SBR as shown in figure (4). This increase corresponds with the porosity results; increased porosity will naturally increase water absorption spontaneously.

![Figure 4. Effect of iron fibre waste on the water absorption of mortar with and without SBR.](image)

4.4. Compression Test

Changes in mechanical properties are controlled by good bonding and compatibility of the fibre and the materials which support them together to carry the load. The highest results for compressive strength were achieved at 20% iron waste fibre replacement both with and without SBR, as shown in figure (5).

![Figure 5. The compressive strength of reinforced mortar by iron fibre waste with and without SBR.](image)
4.5. Flexural Test

The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is a unique test because it reflects three stresses that appear during testing (tensile, compression and shear stress). The results show an increase in flexural strength in all specimens, both with and without SBR. The flexural results improved as the percentage replacement increased, as seen in figure (6), due to the iron fibre’s capability of carrying loads. Using fibre and SBR together also offers good elasticity, which produced the highest results.

![Figure 6. Effect of iron fibre waste on the flexural strength of mortar with and without SBR.](image_url)

Tables (6) and (7) illustrate the change in properties before and after the addition of iron fibre with and without SBR.

### Table 6. Comparison between reinforced and control mortar without SBR

| iron fiber waste % | Density Kg/m³ | Porosity % | Water absorption % | Compressive strength MPa | Flexural strength MPa |
|-------------------|---------------|------------|--------------------|--------------------------|-----------------------|
| control           | 2037.7        | 22.68      | 11.13              | 28.99                    | 5.2221                |
| 10%               | 2136.5        | 21.71      | 10.16              | 25.72                    | 4.0482                |
| 20%               | 2232.4        | 23.61      | 10.57              | 32.03                    | 5.3740                |
| 30%               | 2366.04       | 23.99      | 10.14              | 31.26                    | 6.1385                |

### Table 7. Comparison between reinforced and control mortar with SBR

| iron fiber waste % | Density Kg/m³ | Porosity % | Water absorption % | Compressive strength MPa | Flexural strength MPa |
|-------------------|---------------|------------|--------------------|--------------------------|-----------------------|
| control           | 2058.45       | 17.22      | 8.36               | 25.33                    | 4.6720                |
| 10%               | 2104.4        | 21.25      | 10.09              | 25.12                    | 5.0581                |
| 20%               | 2213.1        | 23.83      | 10.76              | 33.75                    | 6.4972                |
| 30%               | 2301.09       | 24.52      | 10.65              | 27.08                    | 7.6969                |
5. Conclusions
An enhancement in the physical and mechanical properties was achieved by the addition of iron fibre waste to mortar. The best results for such properties were 2104.4 Kg/m$^3$ and 10.09\% for dry density and water absorption, respectively, at 10\% fibre replacement with SBR. For compressive strength and flexural strength, the best results were 33.75 MPa and 7.6969 MPa, respectively, at 20\% and 30\% replacement with SBR respectively.

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