Behaviour of cement mortar containing Iron waste powder as substitute for sand

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Abstract. The effect of replacing the fine aggregate (sand) with iron waste powder was studied. Four mixes of cement mortar with iron waste powder were prepared; two of these groups were prepared without adding SBR (Styrene-butadiene rubbers); while the others were prepared with SBR. These groups were allowed to cure for (7 and 28) days. Each of them consists of iron waste powder with 850µm as partial replacing of sand (10, 20, 30%) by weight. The results show an enhancement of strength for each group after measuring the compressive strength and flexural strength. Otherwise the properties (dry density, porosity and water absorption) were improved too. The best results of compressive strength and flexural strength were (32.66 Mpa, 5.0232 Mpa) at 20% without SBR and 30% with SBR, respectively. The lowest result of dry density were (2109.20 Kg/m3) at 10% with SBR, and the water absorption and porosity were (5.05%, 11.06%) at 20% with SBR. It was concluded that the iron waste powder can be utilized as partial replacer of sand with modifying the properties of cement mortar.

1. Introduction
Waste is unwanted or unusable materials. Waste is any substance, which is discarded after primary use, or is worthless, defective and of no use [1, 2]. Examples include municipal solid waste (household, trash / refuse), hazardous waste, wastewater, radioactive waste, and others. Waste materials are a major environmental problem, which is a threat to the environment. It is important to reuse these materials and dispose of them. So it's very important to manage the waste and believe that waste is not waste by controlled and recycled it along with the legal frameworks that enable the occurrence of waste management [3]. Dumping or disposal of this iron waste causes wastage of metal values and leads to environmental problems and filling the landfills. Rather than disposing these wastes, take full advantage of its mechanical properties. Many studies were carried out by the addition of iron waste in construction materials, the effects of adding different percentages of iron powder as a natural sand replacement were assessed and compared. Aimi N. Hashim and et al. / 2015 investigated the compressive strength and water absorption tests of cement mortar made from Ordinary Portland cement (OPC) with various percentages of ground granulated blast furnace slag (GGBS). GGBS was replaced at percentages (20, 40, 60, 80, 100%) by weight of OPC. These cement mortar used (w/c= 0.7). The samples were tested for water absorption and compressive strength after 7, 14 and 28 days. The most suitable proportion was (60% OPC + 40% GGBS) which gained the highest compressive strength and lowest water absorption at 28days (12.13 Mpa, 10.03%) respectively as compared to 100% OPC (10.88Mpa, 12.59%) and other percentages [4]. In the present study, Besma M. Fahad and et. al /2018 used three particle sizes (75,100,150 µm) of iron powder. Waste in cement mortar replaced sand by weight in different percentages. The results showed improvement in thermal conductivity and thermal diffusivity with (100 and 150 µm) and (100 µm), respectively. The compressive strength, and the other properties dry density, water absorption was improved too [5]. Bassam A. Tayeh and Doha M. Al Saffar /2018 studied two...
kinds of iron waste replaced of sand at percentages (10, 20, 30%). The first kind was iron powder have a similar particle size distribution to that of the used sand, and the second kind was fine; which passed through a 1.18 mm sieve and retained on sieve (#200). The compressive strength at 28 days was increased (10.17%) than cement mortar at 10% of fine iron powder; while flexural strength at 28 days was increased (14.83%) than reference cement mortar [6].

2. The aim of the Research
The scope of this work is to add the iron waste powder to cement mortar in different percentages, and reveal its affect on some physical and mechanical properties with and without the involvement of SBR.

3. Experimental Procedure
3.1. Materials
3.1.1 Cement. Ordinary Portland cement of (Tassluja) trade mark from Iraqi cement factory was used. In order to avoid the effect of moisture on the properties of the cement, it was stored in a dry place. Many of chemical and physical tests were carried out in NCCLR (National Center for Construction Labs. and Researches) to achieve its specification. The cement was identical to the Iraqi standard specification No.5/1984[7]. The table 1 and table 2 show the chemical composition and physical properties of this type of cement.

| Table 1. Chemical composition and properties of cement |
|-----------------------------------------------|
| Oxide      | Results | Limits/IQS 5 (1984) |
| 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 |
|---------------------------------------|
| Properties               | Results | Limits/IQS 5 (1984) |
| Finess (m/kg) (blain’s method)     | 416     | ≥ 250               |
| Setting time (hr : min) (Vicat’s method) | -Initial setting | 2:00 | ≥ 45 min. |
|                                  | -Final setting | 4:00 | ≤ 10 hrs |
| Soundness (Autoclave)            | -0.02   | ≤ 0.8              |
| Compressive strength (MPa)       | -3 days  | 26.00 | 15        |
|                                  | -7 days  | 30.00 | 23        |
3.1.2 Sand. The Sand from Al-Ukhaydir region was used as fine aggregate. A sieve analysis was used to know the grading of the fine aggregate according to the Iraqi standard specification No.45/1984[8]. The table 3 shows the results of sieve analysis process.

| Sieve size (mm) | Passed % | Limits of third area % |
|-----------------|----------|------------------------|
| 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 rubbers are copolymers of styrene (25%) and butadiene (75%) according to the supplier. It’s the most commonly used rubbers. The SBR used in this work was of ASAS trade mark from UAE. The appearance of SBR is white color. The major reason of using SBR with the mixture of cement mortar and iron powder waste as additives is to reduce the effect of water towards iron (minimum reaction between them), good workability, good resistance against thermal degradation and generation of cracks, bonding between layers, weather resistant [9]. Their properties are given in table 4 according to the supplier.

| Physical & Chemical properties | Value          |
|--------------------------------|----------------|
| Density                        | 1040Kg/ m³     |
| pH                             | 8-9            |
| Solid content                  | 34-38%         |
| Temperature resistance         | -20 to +90°C   |
| State                          | Liquid         |
| Color                          | White          |
| Water resistance               | Excellent      |
| Shrinkage                      | Low            |

3.1.4 Iron powder waste. Iron powder waste was used from the residual of workshops in Baghdad/Bab al-Sheikh. The particle size of iron powder was (850µm) after sieving as shown in figure 1. The percentages of replacing sand by iron powder used were 10%, 20%, and 30% by weight; with and without the addition of SBR (Styrene Butadiene Rubber) to cement mortar.
3.1.5 Water. Tap water was used in the mixing process and distilled water for the curing process.

3.2. Experimental Work

The mixtures of (1:3) cement: sand ratio and (0.5) for water/cement ratio were prepared to make cement mortar for different tests (compression-flexural-physical properties). The iron powder waste was added with weight percentages of (10%, 20%, and 30%) replacing of sand. The samples were divided into four mixes: iron powder cement mortar without adding SBR and iron powder cement mortar with 10% of SBR replacing of water by weight. These groups were allowed to cure for (7 and 28) days. The iron powder was weighed to fit the percentage of (10%-20%-30%) before mixing.

The compression test was applied according to ASTM C109 [10]. The iron powder was mixed randomly by replacing weight from sand. The procedure of cement mortar mixing was according to ASTM C305 [11]. The dry paddle and bowl were placed in the mixing position in the mixer, then the materials were introduced for a batch into the bowl and mix. The mixing water was placed in the bowl and added the cement to the water; then switch ON the mixer and mix at slow speed (140 ± 5 r/min) for 30 second. After that the sand and iron waste powder were added slowly over a 30 second period, while mixing at slow speed. The mixer had been changed to medium speed (285 ± 10 r/min), and mixing for 30 second. The mixtures were finished by mixing for 60 second at medium speed. After the mixing process was finished, the reinforcing cement mortar was poured in cast iron molds of (5×5×5cm) dimensions. A well compacting for reinforcing cement mortar specimens were applied by vibrating compactor to achieve better bonding between the cement mortar and iron powder waste. All samples cured at a temperature of (23 ± 2) °C for 7, 28 days.

According to BS EN 196-1:05 [12], the dimensions mold for flexural test was (4x4x16 cm) and the specimens cured at a temperature of (20 ± 1) °C. The cement and water were placed in the bowl; the mixer was switch on at low speed for (140 ± 5 min⁻¹). After 30 second of mixing, the sand with iron powder waste was added during the next (30) second. The mixer was switched to high speed (285±10 min⁻¹), and continues the mixing for (30) second. Switch off mixer for (90) second. Through the first (30) second, cement mortar was removing by plastics scraper and place in a bowl. The mixing was continued at (285±10 min⁻¹) for (60) second. The reinforcing cement mortar was distributed in two approximately equal layers, and compact each layer by vibrating compactor using 60 jolts.

4. Tests
All of specimens were cured for (7, 28) days in distilled water and tested in the National Center for Construction Labs. and Researches (NCCLR).

4.1. Dry Density
Dry density of specimen was determined according to ASTM C642-97 [13]. The Archimedes method was using to obtain the dry density by determined wet weight, then immersed the specimen in water to calculate the submerged weight. After that drying the specimens in oven with temperature of (100-110°C) for 24 hours, and then moved to measured the dry weight. The dry density was calculated according to equation (1) [13]:

$$\text{Dry Density} = \frac{A}{C-D} \cdot \rho$$

Where:
A: mass of oven-dried sample in air, g
C: mass of dry sample in air after immersion, g
D: mass of sample in water after immersion, g
$$\rho_w$$: water density (1000 Kg/m$^3$)

4.2. Water absorption
Water absorption of specimen was determined according to ASTM C642-97 [13]. The procedure of the measurement of water absorption was determined by drying the specimens in oven with temperature of (100-110°C) for 24 hours, then the specimens were cooled at room temperature and weighed (Dry weight). The specimens were weighed after their surfaces were dried by dry cloth. The water absorption was calculated according to equation (2) [13]:

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

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

4.3. Porosity
Porosity of specimen was determined according to ASTM C642-97 [13]. The procedure of the measurement of porosity was similar to water absorption test except the immersed weight (third weight) is needed. Porosity was calculated according to equation (3) [13]:

$$\text{Porosity} \% = \frac{W_2-W_1}{W_2-W_3} \times 100$$

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

4.4. Compression Test
The compression test was carried out according to ASTM C109 07 [10]. The compressive strength was calculated according to equation (4) [10]:

$$f_{in} = \frac{P}{A}$$

Where:
$f_{in}$: compressive strength in (Mpa)
P: total maximum load in (N)
A: area of loaded surface (mm$^2$)
4.5. Flexural Test
This test was determined the flexural strength of specimens according to BS EN 196-1:05 [12]. The flexural test were three point loading prism specimens. The flexural strength was calculated according to equation (5) [12]:

\[ R_f = \frac{1.5 \times F_f}{b^3} \]  \hspace{1cm} (5) [12]

Where:
\( R_f \): is the flexural strength, in (Mpa)
\( b \): is the side of the square section of the prism, in (mm)
\( F_f \): is the load applied to the middle of the prism at fracture, in (N)
\( l \): is the distance between the supports, in (mm)

5. Results and Discussion

5.1. Density
The density of reinforcing cement mortar specimens were measured after (28) days of curing. The density increasing with increases iron powder percentages in all specimens with and without SBR with regard reference cement mortar as shown in figure 2. This increasing resulted from the iron powder which has higher density than other materials used. The specimens containing SBR has lower density than without it; because the effect of SBR which produce specimens with light weight.

![Figure 2](image)

**Figure 2.** Effect of iron powder waste on cement mortar density with and without SBR.

5.2. Porosity
As increasing percentages of iron powder waste porosity was increasing, but it still less than reference cement mortar which noticed in figure 3. This increasing resulted from finer particles of iron powder waste replaced sand which generated entrap air in specimens during mixing process and that led to increase pores. The SBR effect decreases pores in iron powder cement mortar more than without it; this decreasing resulted from SBR which filled the pores. The results showed very closer porosity value at high iron powder percentage (30%) with and without SBR; which explained it has the same property of anisotropy at this point.
5.3. Water absorption

The water absorption increasing with increases iron powder percentage and decreasing in specimens with SBR than without it. This increasing was coincided with the increasing in porosity results, which means increase in porosity will increase the water absorption spontaneously and vice versa with the addition of SBR [14]. On other hand, the presence of iron powder waste with different percentages in cement mortar was less water absorption than reference cement mortar as shown in figure 4.

As illustrated in table (5), the results showed an increase in density with decrease in porosity and water absorption at 28 days when compared with those at 7 days except at 30% iron powder waste with SBR. The density, porosity and water absorption depends on materials used. The increasing in density was due to the addition iron powder which higher density than other constituents. Also the addition of iron powder will create in homogeneity in the structure which increases the porosity. The water absorption depends on porosity presence; so the increasing in porosity will increase the water absorption.
Table 5: The physical properties at 7 and 28 days

| Mix with SBR | Properties at 7 days | Properties at 28 days |
|-------------|----------------------|------------------------|
| Iron powder waste | Density Kg/m³ | Porosity % | Water absorption % | Density Kg/m³ | Porosity % | Water absorption % |
| 0%          | 2084.87             | 18.67                 | 8.95                 | 2037.7         | 22.68     | 11.13          |
| 10%         | 2146.36             | 19.98                 | 9.31                 | 2198.05        | 13.52     | 6.15           |
| 20%         | 2237.38             | 19.08                 | 8.53                 | 2262.95        | 15.11     | 6.68           |
| 30%         | 2272.14             | 22.51                 | 9.90                 | 2346.36        | 18.55     | 7.90           |
| Mix without SBR | 0%                   | 2046.09               | 18.20                 | 2058.45        | 17.22     | 8.36           |
| 10%         | 1866.03             | 21.05                 | 11.28                | 2107.1         | 11.08     | 5.25           |
| 20%         | 2142.94             | 19.56                 | 9.12                 | 2190.68        | 11.06     | 5.05           |
| 30%         | 2274.94             | 14.88                 | 6.54                 | 2252.86        | 17.84     | 7.91           |

5.4. Compression Test

The compressive strength of reinforcing cement mortar specimens were measured after (7, 28) days of curing, as shown in figures 5, 6 and 7. At 7 days, the compressive strength results were different from each other in all specimens (reference cement mortar and iron powder cement mortar) with and without SBR. This changing resulted from incomplete of cement hydration process. In figure 5, the results of compressive strength for iron powder cement mortar without SBR at 28 days was higher than reference cement mortar at 7,28 days, this increasing resulted from the high density which caused by addition of iron powder waste and less pores than reference cement mortar. In figure 6, the compressive strength increases in specimens have SBR at 28 days than those with SBR at 7 days including reference cement mortar; this increasing resulted from the addition of SBR which has stability after long curing and good bonding between particles of iron powder waste and cement which make particles difficult slip apart to each other. When compared according to the cure period (28 days) with and without SBR separately, the compressive strength of iron powder cement mortar was higher than reference cement mortar as in figure 7. The compressive strength increases with increase in iron powder waste percentage without SBR than those with SBR, this increasing resulted from high density and good compatibility between cement and fine aggregate, while the addition of SBR led to drop the compressive strength through decreases the density of specimens[15].

Figure 5. Effect of iron powder waste on the compressive strength of cement mortar without SBR
5.5. Flexural Test
The flexural strength at 10% and 20% of iron powder waste cement mortar without SBR was higher than specimens with SBR as well as reference cement mortar which in figure 8. This increasing resulted from good bonding between particles of iron powder waste and matrix (cement) which give good flexural strength and the SBR was not affect at those percentages to increases flexural strength, because the anisotropy still non homogeneity. The flexural strength of specimens at 30% iron powder waste with SBR was higher than without it even reference cement mortar, because the presence of high percentage iron powder beside the addition of SBR which played an important role to increase flexural strength by its nature known to be flexible than cement hydrate, good elasticity, and good adhesion [16,17,18].
Figure 8. Effect of iron powder waste on the flexural strength of cement mortar with SBR.

6. Conclusions
An improvement in physical and mechanical properties was achieved after the addition of iron powder waste. The best results of the properties were (2109.20 Kg/m³) at 10% with SBR for dry density, and (5.05%, 11.06%) at 20% with SBR for water absorption and porosity, respectively. For compressive strength and flexural strength were (32.66 Mpa and 5.0232 Mpa) at 20% without SBR and 30% with SBR, respectively.

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