Eco-friendly Utilizing of Iron Filings in Production Reactive Powder Concrete

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Abstract. The goal of this study is to assess the opportunity of utilizing waste iron filings in altered fractions as a fine aggregate replacement to produce the reactive powder concrete. Four different fractions of waste iron filing were adopted to reactive powder concrete mixture to measure the difference, which may be achieved in the strengths of the reactive powder concrete. In order to accomplish the aim of the investigation, compressive strength, and direct tensile strength were executed to determine the effect of iron filings on the strength of reactive powder concrete. Consistent with the experimental results, it can be stated that higher fraction of waste iron filings is more effective than the other percentages in both compressive and direct tensile strength because it acquires the maximum strength properties in the shortest duration. The increasing of the compressive strength and the direct tensile strength at 28 days for 30% of the iron filings was 30.3% and 31.8% correspondingly.

1. Introduction
Iron filings are very small fragments formed locally in excessive quantities from steel factories and workshops. These products have a harmful impact on the environment. In the previous decade, there has been raised global interest on the motivation for green construction. Consequently, the use of industrial wastes such like iron filings in the production of concrete lead to enhanced environmental management of waste and commercial consumption of industrial wastes, causing to a greener world.

Reactive powder concrete is a cement-based material accompanied by ultra-high strength properties. Cement and silica fume content of reactive powder concrete, when compared to the conventional concrete, are usually rather high. Conventional Reactive powder concrete is collected of silica fume, cement, and very fine powders such as crushed quartz or crushed quartz [1][2][3].

Many researches were implemented on the effect of inclusion of the iron filing in the conventional concrete. Alzaed [4] assessed the influence of iron filings on the strength of concrete. Iron filings were utilized as incompletely substitute of cement in concrete. Results attained revealed that there is an increment in the compressive strength and indirect tensile strength of the concrete. Elamin et al. [5] tested the outcome of substituting each constituent of concrete by 30% iron fillings on the attenuation properties of concrete. The results determined that with iron fillings addition, the concrete has the preferred gamma absorption abilities and becomes heavier. Sarsaam [6] assessed the effect of nanomaterials (iron filings, coal fly ash and limestone dust) addition as partial cement replacement on some concrete pavement properties. The results obtained show that the adding of coal fly ash and limestone dust leads to reduced flexural strength while the adding of iron filings led to an increased flexural strength. Prema et al. [7] implemented a research to assess the influence of replacing sand in concrete with iron tailing. Their results revealed the strength properties of the concrete continuing iron
tailling increased above the control mix. Likewise, the utilization of waste materials, such as glass powder, ceramic powder, Rice Husk Ash, and crushed bricks have been effectively used in reactive powder concrete. Zhu et al. [8] studied depletion of the recycled fine powder prepared from the waste of cement solids and clay bricks to improve cost-saving and environmentally friendly of the reactive powder concrete by weight substituting of the silica fume at 20% to 100%. Consequently, the results exhibited that as the replacing proportions of silica fume in reactive powder concrete raised, the mechanical properties were reduced owing to the increase of the proportion of recycled powder in the reactive powder concrete. Kushartomo et al.[9] implemented a research on the outcome of the insertion of the powdered waste glass on the mechanical behavior of the reactive powder concrete. The quartz powder was substituted by powdered waste glass with fractions ranged from 10% to 30%. The outcomes designated that the practice of powdered waste glass was adequate to substitute quartz powder in reactive powder concrete. Asteray et al. [10] [11] [12] were conducted researches to inspect the behavior of reactive powder concrete modified by fine discrete waste ingredients (crushed waste glass, milled waste ceramic and fly ash). The investigational outcomes exhibited that substituting the silica fume completely by a finely crushed waste glass and fly ash is an encouraging methodology for civil engineering construction applications due to the improvement of the mechanical properties of modified reactive powder concrete.

This experimental research mainly aimed to assess the use of waste iron filings in reactive powder concrete and its influences on their properties. This objective was attained as follows: first, the effects of utilizing different fractions of waste iron filings as a replacement from sand were inspected and associated with that of a conventional mix. Subsequently, the optimum fraction of iron filings added to the reactive powder concrete to improve its properties was defined.

2. Methodology

In this study, as an inventive building raw material, an evidence of possible provincial debris was nominated as a principle on behalf of accomplishing sustainability topics for an upgrading of reactive powder concrete. Consequently, constituents and experimental parts are deliberated in this division.

2.1. Materials

In the experimental research, silica fume, Portland cement, fine sand, Iron filings, steel fibers, high range water reducing admixture and tap water were operated for the enhancement of reactive powder concrete mix and on behalf of the entire tests. Additional precisely, the constituents utilised in this investigation are titled as follows, Figure 1.

2.1.1 Cement

Sulfate-resisting Portland cement (Type V) manufactured by Karbala cement plant with the trademark of Al-Jeser was used in this investigation. Their physical and chemical property matches the criteria of ASTM C 150-15 [13].

2.1.2 Silica fume

Silica fume otherwise known as micro-silica is a byproduct of the manufacture of silicon compounds in electrical arch kilns which can be employed as supplementary cementitious material to fabricate high-performance concretes [14]. With the intention of improving all reactive powder concrete mix for this investigation, MegaAdd MS (D) type Densified Micro-silica fume was utilized from CONMIX construction chemical company. It is pozzolanic activity index at 7 days about 135.6 %. The chemical and physical requirements of the silica fume utilized in this investigation as acclaimed by ASTM C1240 [15].

2.1.3 Sand

Regionally obtainable normal sand as very fine aggregate from Al-Ukhaider, Karbala was used in the preparing of the tests samples. Normal sand was separated via 300-μm sieve and was utilized in saturated surface dry condition. Furthermore, the size particles distribution of fine sand was founded
depend on ASTM C33-13 [16]. Table 1 demonstrates the grading of the fine sand that utilized in the all reactive powder concrete mixtures.

2.1.4 Admixture
Commercially available high range water reducing admixture manufactured by BASF Company under the commercial label Glenium was used in this experimental study to achieve the desired workability. The admixture formulated to meet the requirements of Type A and type F in ASTM C 494[17].

2.1.5 Steel Fibers
Corrugated steel fibers were utilised through the experimental investigation. The steel fibers used in the present study have a diameter of 0.79 mm, aspect ratio about 22, density 7825 kg/m$^3$ and tensile strength of 1150 MPa. The reinforcing influence of steel fibers is principally critical for the mechanical properties of reactive powder concrete under tension.

2.1.6 Water
Tap water was likewise utilized for the preparation of the preferred in the mixing of the reactive powder concrete and in the curing of the test specimens.

2.1.7 Iron Filings waste
The iron filling was acquired from waste of CNC milling machine in several local workshops. It is usually produced in hundreds of tons after the processes of ironsmith. It was sieved and the fraction passing 1.18 mm was implemented in this research. The physical properties are itemized in Table 1.

| Table 1. The fine sand and iron fillings grading. |
|-----------------------------------------------|
| Sieve size | Normal sand | Iron fillings waste |
|            | %Cum. Retained | % Passing | % Cum. Retained | % Passing |
| 1.18 mm    |             |   0 100  |             |   0 100  |
| 0.6 mm     |             |   0 100  |             |    4 96  |
| 0.3 mm     |             |   0 100  |             |    8 82  |
| 0.15 mm    |    85       |   15     |    92       |    8     |
| 0.075 mm   |    99       |    1     |    99.5     |    0.5   |

2.2. Mix proportion
Reactive powder concrete is principally collected of high-volume of binder materials (silica fume and cement), very fine aggregate, and low water-to-binder ratio. In general, in the manufacture of reactive powder concrete the cement content differs from 700 to 1000 kg/m$^3$, silica fume differs from 15% to 35% by the cement weight, and the water-to-binder ratio alternates between 0.15 and 0.25 [14]. The mix proportion of the control mix in this investigation based on some local preceding studies [18] [19] [20] [21] combined with the trial experimental work to achieve the desired strength for control mix. Moreover, to attain the objective of this experimental research, the fine sand was partially substituted by volume with iron filling in different fraction. The considered iron filling fractions were 10%, 20%, and 30%. Table 2 illustrates the mixture proportions for the all mixes.
Table 2: The mix Proportions, kg/m$^3$.

| Mixture des. | Cement | Silica Fume | Fine aggregate | Iron Filings | Admixture, L fiber | Water |
|-------------|--------|-------------|----------------|--------------|-------------------|-------|
| IR00        | 830    | 290         | 980            | ---          | 15                | 200   |
| IR01        | 830    | 290         | 980            | --           | 15                | 88    | 200   |
| IR10        | 830    | 290         | 882            | 234          | 17                | 88    | 200   |
| IR20        | 830    | 290         | 784            | 467          | 20                | 88    | 200   |
| IR30        | 830    | 290         | 686            | 701          | 23                | 88    | 200   |

2.3. Experimental works

The mixing process of the materials has a significant effect on the reactive powder concrete properties (fresh properties and hardened properties). The considered mixing process adapted from an earlier study [22]. Primary, the dry ingredients (cement, silica fume, sand, and iron filling) were thoroughly mixed for 3 min. Afterward, the 80% of mixing water and full admixture dosage were added and mixed for additional 7 min. Afterthought, the lasting mixing water was added and mixed for extra 4 min. Finally, the steel fibers were added and mixed for 1 min.

The compressive strength of the reactive powder concrete was implemented agreeing to ASTM C109 [23], three 50 mm cubes specimens was adopted for each age (7, 28, and 56 days). To determine the direct tensile strength of reactive powder concrete, briquettes specimens were made and tested according to ASTM C190-85, three specimens were adopted for each age (7, 28, and 56 days), Figure 2. After completing the casting and vibration for specimens, a static pressure of 6 MPa was applied for 24 h, and all specimens were de-moulded after 1 day, and then the specimens were steam cured at around 95 °C for 48 hours in a water bath. After that they are left to be cooled at normal room temperature, and afterwards placed in water for test age as suggested by earlier study [24].
3. Results and discussion
The results can be summarized in Table 3.

Table 3. Summarize of all results in this study.

| MIX  | Compressive strength MPa | Direct tension MPa | Density (Kg/m³) |
|------|--------------------------|--------------------|-----------------|
|      | 7 days | 28days | 56days | 7 days | 28days | 56days | 7 days | 28days | 56days |
| IR00 | 67     | 78     | 84     | 4.2    | 5.85   | 6.2    | 2279   | 2315   | 2325   |
| IR01 | 72     | 89     | 93     | 5.9    | 6.9    | 7.6    | 2338   | 2375   | 2390   |
| IR10 | 81     | 94     | 100    | 7.2    | 7.4    | 8.1    | 2361   | 2420   | 2434   |
| IR20 | 86     | 104    | 113    | 7.9    | 8.6    | 9.2    | 2464   | 2512   | 2531   |
| IR30 | 93     | 116    | 126    | 8.1    | 9.1    | 9.9    | 2543   | 2595   | 2608   |
3.1. Compressive strength

From Table 3 and Figure 3, the effects of the different percentage of replacement sand by iron filings 10%, 20%, and 30% with age 7, 28, and 56 days has a significant increase in compressive strength than the 0%. The increment at age 28 days with 10%, 20%, and 30% of iron filings higher than control mix (IR01) by 5.6%, 16.8% and 30.3% respectively. The increment at age 56 days with 10%, 20%, and 30% of iron filings higher than control mix (IR01) by 7.5%, 21.5% and 35.5% respectively. The increase in compressive strength with an increase in the percentage of iron filings in mixes can be related to the toughness of iron filings and their strength. Also, iron filings have pozzolanic reaction and properties as justified by Alzaed [4] and the presence of steel fiber increase in compressive strength may be associated with the theory of the crack arrest for fibers which mentioned by Toledo et al. [25] and Cwirzen et al. [26].

3.2. Direct tensile strength

From Table 3 and Figure 4, the different percentage of replacement sand by iron filings 10%, 20%, and 30% with age 7, 28, and 56 days has a significant increase in direct tensile strength than the control mix (IR01). The increment at age 28 days with 10%, 20%, and 30% of iron filings higher than the control mix (IR01) by 7.2%, 24.6% and 31.8% respectively. The increment at age 56 days with 10%, 20%, and 30% of iron filings higher than control mix (IR01) by 6.5%, 21% and 30.2% respectively. The increasing in direct tension strength with increase the percentage of iron filings in mixes can be related to the toughness of iron filings and their strength. Moreover, iron filings have pozzolanic reaction and properties as justified by Alzaed [4] and the presence of steel fiber can increase the direct tension owing to the fact that the steel fibers be able to: (1) bridge cracking and delay their propagation as a result of tensile, (2) transfer stress over a crack and offset the crack growth [27].

Figure 3. Effects of increasing iron filings percentage on compressive strength with age
3.3. Density

From Table 3 and Figure 5, the effects of the different percentage of replacement sand by iron filings 10%, 20%, and 30% with age 7, 28, and 56 days has a significant increase in weight and density than the IR00 and IR01. The increment at age 28 days with 10%, 20%, and 30% of iron filings higher than control mix (IR01) by 1.9%, 5.7% and 9.3% respectively. The increment at age 56 days with 10%, 20%, and 30% of iron filings higher than control mix (IR01) by 1.8%, 5.9% and 9.1% respectively. The increasing in density with increasing the percentage of iron filings in mixes can be associated with the high density of fiber and iron filing than replacement material (sand) [28]. However, silica fume will improved particle filling ability by chemical reaction owing to its secondary pozzolanic reaction. This reaction gives rise to the refining of the micro-structure of the matrix of reactive powder concrete and intensification its density [14].
4. Conclusion
Based on the tests results acquired from this experimental research, the succeeding findings can be drawn:

1- There is an opportunity for the replacement of fine sand by iron filings waste in the fabrication of reactive powder concrete.

2- The usage of iron filings waste in reactive powder concrete production would motivate commercial application of industrial wastes and enhanced environmental waste management.

3- Insertion iron filings waste as a partially replacing from fine sand had enhanced thepressive strength of reactive powder concrete in the range of (5 – 35) % as related to reference mix.

4- Associated to the control mix, the direct tensile strength of reactive powder concrete improved as the replacement level of iron filings waste raised. The improvement of the strength ranged about from 7.2 % to 31.8 %.

5- Iron filings waste sand can be utilized for production of heavyweight reactive powder concrete due to the significant increase on the hardened density of reactive powder concrete. The increase percentage of the density for 30% replacement about 10 % as related to reference mix.

6- Therefore, an optimum of 30 % replacement by volume of fine sand with iron filings waste in reactive powder concrete mix is commended for reactive powder concrete production depending on the desired strength properties.

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