Mechanical Properties of Concrete Using Iron Waste as a Partial Replacement of Sand

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Abstract: The utilising of iron waste in concrete as a partial replacement of sand is attaining enormous significance nowadays, mostly because of the improvement in the strength of concrete and environmental benefits. The aim of this study is to assess the possibility of applying iron waste in different percentages (6%, 12%, 18%, 24%, and 30%) as fine aggregate replacement of sand to increase the strength of concrete. For this purpose, the mix proportion was designed as (1:2.12:2.37) for giving 33 MPa of compressive strength of concrete at 28 days of curing. In order to achieve the goal of the study, laboratory experiments, compressive strength, and flexural tensile strength were conducted to determine the influence of iron waste on the strength of concrete. Thus, based on this study, the progress of strength with the percentages of iron waste in different time was plotted. According to the results, it can be found that 12% of iron waste is more efficient than the other percentages in both compressive and flexural strength because it obtains the maximum strength in the shortest time, and it seems that increasing iron waste more than 12% leading to decrease the strength of the concrete.

Keywords: Concrete, Sand Replacement, Iron Waste, Compressive Strength, Flexural Tensile Strength

1. Introduction

Nowadays, one of the most commonly expended construction material in the world is concrete. It consists of cement, sand, gravel, and water. Additional materials could be supplied to the mixture. The concrete comprises amount of entrapped air and may have knowingly entrained air attained using an admixture or air-entraining cement (Dixon et al., 19910). Sand as fine aggregate is more extensively consumed in concrete construction. Hence, numerous developing countries have faced a struggle in providing the quantity of natural sand to enhance infrastructural development in recent years (Raman, Safiuddin & Zain, 2007). In this regard, sand could be replaced by different waste materials, which might be able to improve plasticity, workability, and increase concrete strength to enhance durability (Ghannam, Najm & Vasconez, 2016). In terms of waste materials environment impact, advancements in technology enhance not only human comforts but also damages the environment (Joshi, 2013). Although industrialization is one of the key factors for growing economy, it has led to serious troubles concerning environmental pollution. Waste materials, discharged in large quantities by industries, create serious environmental problems. To lowest possible environmental impact, the reusing of these waste materials will become an essential standard to protect the environment (Jayaraman, Shenbagamn & Senthilkumar, 2017). Regarding this, reusing unwanted remaining materials will be a popular substitute for disposaling the waste, in this waste utilization, possible pollution problems and cost are reduced or even the pollution is removed along with the achievement of environment protection. However, to use available materials most efficiently, the consideration of utilization strategy should be combined with the considerations of energy and environment (Bahoria et al., 2013). Iron waste is one of the materials discharged in great amounts by-product of the steel industry in Kurdistan Region of Iraq. Disposing this waste impacts negatively on the environment. Iron waste, due to its high strength and durability, might be able to increase a concrete strength in terms of compressive strength and flexural tensile (Ghannam et al., 2016). The presented work studies the effective of iron waste on compressive strength and flexural tensile strength of concrete based on laboratory tests. According to the past literature, during the history of the industries of iron and steel, different methods have been attempted to create operational use of the waste materials of iron and steel. Various studies have been done to use the waste material in the concrete mixture for improving concrete properties and preventing the environment from these unwanted materials. In this study, some of them will be reviewed. Dubey, Chandak and Yadav (2012) considered using the blast furnace slag powder to determine its effect on compressive strength of concrete. In this study, blast furnace slag was partially used as a replacement of cement in different percentage 5 to 30%. It has been discovered, from the experimental investigations, that the optimum substitution of Ground Granulated Blast Furnace Slag Powder to cement is 15% without changing much the compressive strength. Ugama, Ejeh and Amartey (2014) examined determining the appropriateness of using iron ore tailing (IOT) to partly replace fine aggregate for concrete which it is utilized for rigid pavement. The control mix composites a normal mixture of concrete which only sand functioned as fine aggregate, while the replaced sand in the other mixes was by 20%, 40%, 60%, 80% and 100% iron ore tailing (IOT). Strength and consistency tests were studied on all samples of concrete. It was noticed that increasing the ratio of iron ore tailing in the mixture, leads to decrease in the concrete workability. The results for tests of compressive and indirect tensile strength at twenty eight days were 43.67 N/mm^2 and 2.69 N/mm^2, respectively. They were attained for concrete when 20% iron ore tailing (IOT) was used, then the results equated to compressive strength and indirect tensile strength outcomes of 45.02 N/mm^2 and 2.64 N/mm^2 respectively, gained at 28 days as only sand as a fine aggregate was used. Alzaed (2014) studied the effect of iron filings on concrete strength as one of the portions of the concrete mixture. In the paper, the iron filing was supplied to the concrete mix in four different percentage, to determine the difference, which might be gained in compression and tensile concrete strengths at twenty eight days. In the study, numerous standard cubes and cylinders were fabricated and tested using 0% (control), 10%, 20% and 30% of iron filing in the concrete mix. It was determined that when iron filing supplemented to the concrete mix, the compressive strength of concrete increased steadily while the tensile strength showed a minor effect as the ratio of iron filing applied more than 10%. As a result, two formulas were suggested, which might be utilized to expect the quantity of increasing corresponding to each percentage of iron filing contributed to the concrete mix. Ghannam et al. (2016) carried out an experimental investigation to explore the possibility of using the iron powder (IP) and granite powder (GP) to partially replace to fine aggregate in concrete mixture. The percentages 5%, 10%, 15%, and 20% of GP and IP were added to replace sand by weight. It was found that the most effective replacement percentage of sand with granite powder in concrete was 10% by weight in increasing the compressive and flexural strength compared to other ratios. The test results showed that the compressive strength increased nearly 30%, as sand partly replaced to 10% of GP in concrete, compared with normal concrete. Similar results were also found for the flexure. It was moreover remarked that substituting of sand with up to 20% of iron powder by weight in concrete resulted in increasing in compressive and flexural strength of the concrete.

2. Study Implication

Iron waste is an industrial by-product that is produced as a result of producing steel from the steel factory. This waste material can be applied as partial replacement of sand in concrete. The aim of this study is to evaluate the suitability of using iron waste as a partial replacement of fine aggregate and to observe that iron waste leads to increase the compressive strength, and flexural strength of concrete, as used in certain proportions. The experimental research considered in this study displayed that the mechanical properties of concrete have enhanced as sand was replaced partially by iron waste in certain proportions. Furthermore, recycling of this by-product and employing it in concrete will decrease its effect on the environment and its health hazards. The usage of iron waste instead of sand will reduce using of sand in the construction industry hence maintain more of this natural resource.

3. Experimental Investigation

The experimental program included preparing concrete cubes and beams with and without iron waste replacement. The concrete mixture consists of Portland cement, sand, coarse aggregates, iron waste, and water. The cubes were prepared to evaluate the concrete compressive strength and the beams were equipped to assess the flexural strength.

4. Materials and Methodology

4.1 Materials

Materials which were used for this study comprised of cement, fine aggregates (sand), coarse aggregates (gravel), iron waste, and water. According to ASTM codes, necessary tests were carried out for the materials.

4.1.1 Cement

Cement is a binder substance that can bind other materials together. Physical properties of Ordinary Portland cement was found and compared with the code specification (ASTM C 150) which is shown in Table 1. The results are compatible with the code specification.

Table 1: Properties of cement with the code specification

No	Parameters	Values	Code Specification ASTM C150
1	Fineness	0.04	0.01 – 0.06
2	Specific gravity	3.1	around 3.15
3	Consistency	28 %	26% – 30 %
4	Initial Setting time (minutes)	70	≥ 45
5	Final Setting time (minutes)	290	≤ 375

4.1.2 Fine Aggregate (Sand)

Sand is a naturally occurring granular material composed of finely material particles. The fine aggregate passed through sieve #4 (4.75 mm) and predominately retained on sieve # 200 (75 μm) was used. The sand has a specific gravity of 2.67, bulk density 1647 kg/m^3 and the fineness modulus equal to 2.6.

4.1.3 Coarse Aggregate (Gravel)

Coarse aggregate is one of the main components of concrete composite materials. The maximum size of coarse aggregate was 12.5 mm used. The gravel has a specific gravity of 2.74, bulk density 1600 kg/m^3 and the fineness modulus equal to 6.2.

4.1.4 Iron Waste

Iron waste is a by-product material. When the waste material is disposed of, it will affect the environment. Over the past few years, the amount of this material has been increased by steel factories in the Kurdistan region of Iraq. In order to reduce the impact of waste materials on the environment, iron waste could be used instead of sand concrete mixture. The iron waste has a specific gravity, bulk density and the fineness modulus with 3.56, 2168 kg/m3, and 2.3, respectively. It should be noted that there is a difference between the density of the sand and the iron waste that will be expected to affect the density of the concrete.

Furthermore, the waste material was accumulated in a steel factory in Bazyan related (Sulaymani Province). The quantities of this waste material will increase and it will effect on our environment. Therefore, it is crucial to use this material to improve concrete properties.

4.1.5 Water

Clean water is used for mixing process and curing. The used water should be applied according to the mix proportion design.

4.2 Methodology
4.2.1 Work Plan

As it is described previously that using iron waste in concrete as replacement of sand might increases its strength. To find out that experimental method was used, both flexural tensile strength and compressive strength of concrete were considered to be tested. Regarding this, the research is planned as firstly ordinary concrete with only cement, sand, aggregate, and water as control was prepared. Then fine aggregate sand is partially replaced by iron waste in different percentage. The percentages were as follows: (6%, 12%, 18%, 24%, and 30%) for compressive strength and for flexural tensile strength. For each percentage, nine cubes and nine beams were made up. Overall, total samples were 54 cubes and 54 flexural beams. The cubes with dimensions of (100*100*100) mm samples were used for the compressive strength test, and utilizing beam specimens with dimensions of (100 × 100 × 500mm) for the flexural tensile strength test. The samples were tested after three different times of curing (7, 14, 28) days.

4.2.2 Concrete Mix Design

The mix proportions are important to a strong and durable concrete. The mix design should achieve the desired workability of concrete to prevent segregation and allow for ease of placement. In this regard, using the standard mix design according to Dixon et al. (1991) the mixture was designed for giving compressive strength of concrete of 33 MPa after 28 days of curing. The mix proportion was prepared as (1:2.12:2.37). Table 2 shows the weight of mixture components. The percentages of iron waste (0, 6, 12, 18, 24, and 30 %) were used instead of sand.

Table 2: Quantities of materials used in kg/m3

Iron Waste Percentage %	Cement kg/m^3	Iron Waste kg/m^3	Sand kg/m^3	Aggregate kg/m^3	Water kg/m^3	Water/ cement
0%	385	0	818	912	200	0.52
6%	385	49.08	768.92	912	200	0.52
12%	385	98.16	719.84	912	200	0.52
18%	385	147.24	670.76	912	200	0.52
24%	385	196.32	621.68	912	200	0.52
30%	385	245.4	572.6	912	200	0.52

4.2.3 Laboratory Tests

The concrete slump test is a practical test to measure the consistency of the concrete to check the workability of fresh concrete. In this regard, slump tests according to ASTM C143 were carried out for all mix ratios. Figure 1 (a) shows the slump test. Compression tests and flexural tests were implemented on concrete cubes, and concrete beams respectively. Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. The compressive strength samples were prepared according to ASTM C39 (2015) concerning this, nine standard compressive concrete cube specimens (100 × 100 × 100mm) were fabricated to be tested for zero percent and each proportion of iron waste. Meanwhile, the flexural strength (modulus of rupture) samples were prepared according to ASTM C293 ("American society for testing", 2010). A plain concrete beam (100 x 100 x 500 mm) was loaded in flexure at the third points of 300-mm span until it fails due to cracking on the tension face. Modulus of rupture is computed as (Fanella, 2016):

$$R = \frac{3PL}{2bd^3} \quad (1)$$

where; *R* is the modulus of rupture [MPa], *P* is a maximum applied load indicated by testing machine [N], *L* is the span length [m], *b* is the average width of specimen [mm] and *d* is the average depth of specimen [mm]. The samples were cured for 7 days, 14 days, and 28 days under standard conditions. Then the tests of the specimens were implemented. The test of the samples for a compressive strength by MPa and flexural strength by KN at 7 days, 14 days, and 28 days were carried out. Figure 1 (b) & (c) show the compression test and flexural test respectively. Regarding preparing the samples, fifty-four cubes were prepared for compressive strength, every eighteen samples were tested at 7 days, 14 days and 28 days for control and other proportions. Meanwhile, fifty-four beams were tested for the flexural strength test. Similarly, for the flexure, every eighteen samples were tested at 7 days, 14 days and 28 days for control and other proportions. Moreover, the test results of the cubes, and beams, of concrete made with IP were equated to the test results of the normal concrete (control) specimens.

(a) (b) (c)

Figure 1: (a) Slump Test, (b) & (c) display compressive and flexure strength specimen test

5. Results and Discussion

5.1. Slump Test

The outcomes show that the slump decreased slightly and gradually as iron waste increased. This means that the workability of the concrete is in an acceptable range with a good durability of concrete. Figure 2 displays the slump test for all mixing ratio.

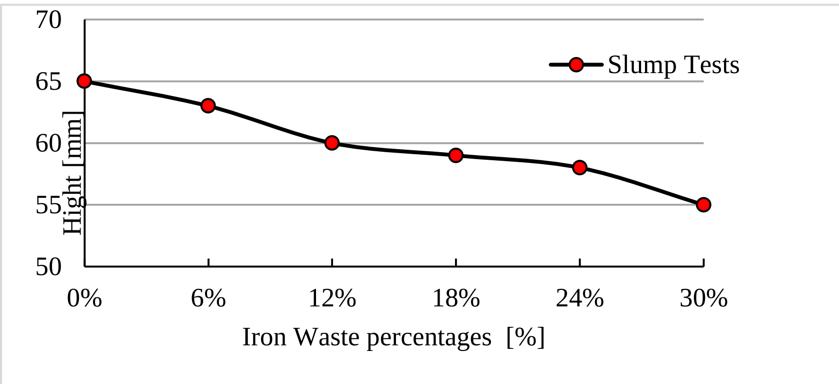

Figure 2: Presents the slump test for all mixing ratio

5.2. Compressive Strength Test

Compressive strength test was carried out to evaluate the strength progress of concrete, comprising different percentages of iron waste at the age of 7, 14, 28 days, respectively. It is shown in Figure 3 that increasing the iron waste leading to gradually gains in the compressive strength. It is observed that increasing the iron waste to 12% gives the highest strength among the results, which from this point onwards increasing the amount of iron waste decreases the strength of concrete. It can be realized that using 12% iron waste in concrete will give 15% more compressive strength in 28 days than normal concrete (control).

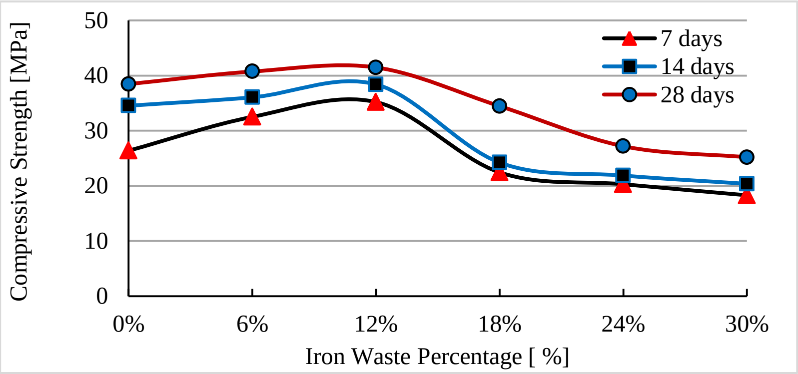

Figure 3: Compressive strength of different iron waste percentages for different time of curing

5.3. Flexural Tensile Strength Test

Regarding the flexural tensile strength, flexural samples were tested to evaluate the strength of concrete, containing various ration of iron waste. Based on the results shown in Figure 4, the flexural tensile strength gradually increases as the iron waste percentage reaches 12%. It is clear from the figure that increasing iron waste more than 12% leads to falling down the flexural tensile strength. Therefore, it can be said that iron waste can be limitedly used to be effective as a replacement of sand to increase the strength of concrete. As a result, it can be concluded that using waste materials are the benefit in terms of not only preserving the environment, but also improving the structural properties of concrete.

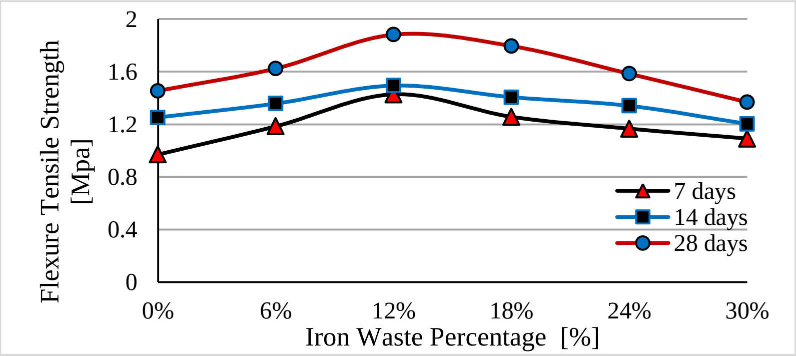

Figure 4: The flexural tensile strength of different iron waste percentages for different time of curing

6. Conclusion

In conclusion, the workability of the concrete is slightly and gradually decreased by increasing iron waste. The strength of concrete increased while curing was prolonged. The compressive and flexural tensile strength slightly increased by increasing iron waste ratio until 12%. It can be noted that using 12% iron waste in concrete gave 15% more compressive strength in 28 days than normal concrete. It should be borne in mind that the mix ratio was basically designed to give 33 MPa at 28 days but more than this can be obtained at 7 days by adding 12% of iron waste which was about 35 MPa. Thus, in case the concrete needs to reach the maximum compressive strength in the shortest time, 12% iron waste can be recommended to use in the concrete.

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