Utilization of Waste Iron Powder as Fine Aggregate in Cement Mortar

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Abstract— This paper reports about the use of recycled iron powder (IP) in producing cement mortar under normal conditions. Flow table test was performed on fresh mortar. Destructive tests were conducted on cubes of the hardened mortar to obtain the compressive and flexural strengths of the cement mortar. The effects of adding 10%, 20%, 30%, and 40% of waste IP as a natural sand replacement were assessed and compared. Waste iron are of two types: iron IP, which shows a similar particle size distribution to that of the sand used in making the samples, and fine iron powder (FIP), which contains fine particles. The compressive strength decreased with the increased amount of added IP in the mixtures, but it increased with the addition of 10% FIP and decreased gradually with the increased FIP level. By contrast, the flexural strength significantly increased with increased FIP in the mixtures. Recommendations regarding the applications of recycling to conserve resources and raw materials and prevent environmental pollution are provided.

Index Terms— Recycled materials, iron powder, waste materials, green product

I Introduction

Concrete is currently the most widely used construction material worldwide; its numerous applications include that in bridges, dams, house constructions, highway pavements, and sidewalks [1]. The use of manufactured fine aggregates has been increasing in the United States because good-quality natural sand is not economically viable in many areas. Manufactured fine aggregates differ from natural sand in terms of grading, particle shape, and texture [2].
Research and field experience have shown that good-quality concrete with proper workability and finishability can be realized using manufactured fine aggregates [3,4]. Various image analysis techniques [5,6] have been used to determine the shape and texture of aggregates.
The increasing amount of waste iron in the Gaza Strip is one of the major environmental issues in Gaza. The large amount of wastes originates from the industrial sector. These wastes are deposited in landfills. The present study investigated the utilization of the large amount of iron waste from workshops, factories, and demolished buildings in building construction. Consequently, new opportunities will be created with the use of new material in construction, thereby improving many of the overall building parameters. Moreover, the shortage of natural sand in several areas has been increasing annually [7-12]. In recent years, commonly recycled materials can be used for either building constructions or road repairs, such as that of asphalt paving. These materials include wood, gypsum wallboard, building concrete, and metals. Thus, in this study, waste iron powder (IP) was reused as a partial sand replacement in a mortar mixture to achieve higher compressive strengths and flexural strengths than those with standard mortar mixes [7-13].
The municipal waste components in Gaza City consist of organic matter (57%), paper and cardboard (15%), plastics (15%), iron metal (4%), glass (3%), and other materials (6%), as shown in Fig. 1.
This study mainly aimed to evaluate the use of waste IP in cement mortar mixtures and its effects on their properties. This objective was achieved as follows: first, the effects of adding different percentages of waste were examined and compared with that of a conventional mixture. Afterward, the optimum percentage of waste IP added to the mortar mixture to enhance its properties was determined.

This study also aimed to evaluate the effects of using waste IP as a part of the solution for environmental catastrophes resulting from disposal. The cement mortar performance was improved by using waste IP as a sand replacement in the mixture.

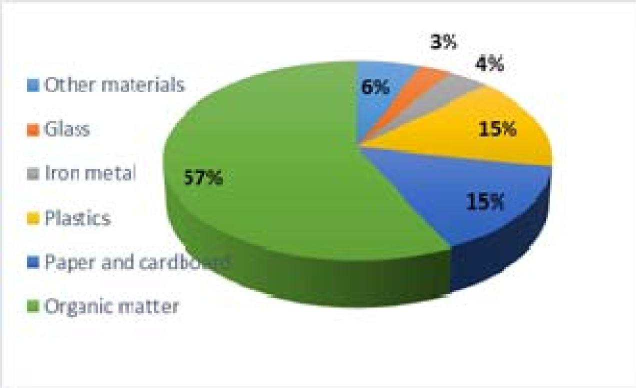

Figure 1 Municipal waste components

II Experimental Investigation

A - Testing program

The compressive and flexural strengths were determined on 50 mm cubic specimens, [14] with dimensions of 1.6 in×1.6 in×6.3 in or 4 cm×4 cm×16 cm, respectively [15]. A total of 69 cubes were used for the compression test. Three cubes were utilized for each percentage at 7, 28, and 54 days. Fifteen prisms were used for the flexural test, with three cubes for each percentage for 28 days only.

B - Material and mixture proportion

Portland cement type I 42.5 N was used to complete all the mortar mixtures [16]. The chemical compositions are provided in Table 1. Two types of waste IP were utilized: IP, which showed the same size as the sieve analysis of sand [17], and fine IP (FIP), which was passed through a 1.18 mm sieve and retained on sieve #200, as shown in Figs. 2. The measured size distributions are presented in Table 2 and Fig. 3.
Nine mortar mixtures were cast, of which one was a conventional mixture, four were IP, and four were FIP. Three specimens were evaluated for each test, and the mean values were reported. The mixture proportions are given in Table 3. This study considered different amounts of waste IP (0%, 10%, 20%, 30%, and 40%) as sand replacement.

Figure 2 Waste iron pwoder used in this study

Table 1 Chemical and physical properties of cement

Chemical properties		
Oxides composition	Content %	
Lime, CaO	66.07	
Silica, SiO_2	19.01	
Alumina, Al_2O_3	4.68	
Iron oxide, Fe_2O_3	3.2	
Magnesia, MgO	0.81	
SO_3	1.17	
Lime Saturation Factor, (L.S.F)	1.08	
Physical properties		
Specific surface area (Blaine method), (cm^2/g)	2900	Min. 2800
Setting time (vicate apparatus) Initial setting, hrs. : min Final setting, hrs. : min	2:15 3:30	Not less than 45 min Not more than 10 hrs
Compressive strength (MPa) For 3-day For 7-day	20.4 28.2	Not less than 15 MPa Not less than 23 MPa
Water demand	0.26 %	No limit

Table 2 Physical properties of fine aggregate and Iron Powder

Physical properties			
Property	Fine aggregate	IP	Specification
Specific gravity	2.884	6.584	ASTM C127-04 [11]
Absorption, %	39	-	ASTM C127-04
Dry loose unit weight, gm/cm³	1.596	-	ASTM 29/C29M/02
Dry rodded unit weight gm/cm³	1.742	-	ASTM 29/C29M/02

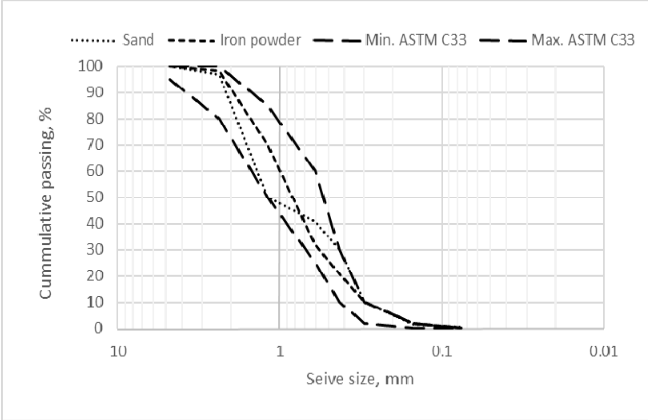

Figure 3 Grading curves of aggregates

Table 3 Mixture composition of all experiment series, kg/m^3

Mixture ID	Cement	Sand	IP	FIP	% of replacement	w/c	Water	Flow (mm)
MR	500	1500	-	-	-	0.5	250	193
MIP1	500	1350	150	-	10	0.5	250	187
MIP2	500	1200	300	-	20	0.5	250	186
MIP3	500	1050	450	-	30	0.5	250	185
MIP4	500	900	600	-	40	0.5	250	183
MFIP1	500	1350	-	150	10	0.5	250	190
MFIP2	500	1200	-	300	20	0.5	250	186
MFIP3	500	1050	-	450	30	0.5	250	187
MFIP4	500	900	-	600	40	0.5	250	176

III Experimental Results and Discussion

A - Fresh properties

Effects of IP and FIP as aggregate replacements: As shown in Fig 4., the mixtures generally showed a low flow with increased percentages of IP and FIP, which resulted in low fluidity, especially for MFIP4. Flow table test results [12] revealed a reduction in diameter with increased waste IP compared with the reference mixture; the reduction was approximately 2.95%, 3.73%, 4.41%, and 5.44% for MPI1, MPI2, MPI3, and MPI4 mixtures, respectively. The reduction in FIP diameter was about 1%, 3.1%, 3.4%, and 9.6% for MFIP1, MFIP2, MFIP3, and MFIP4, respectively, as shown in Fig 4. This trend may be due to the heterogeneity and angularity of waste IP, which was consistent with that reported by Ismail [7].

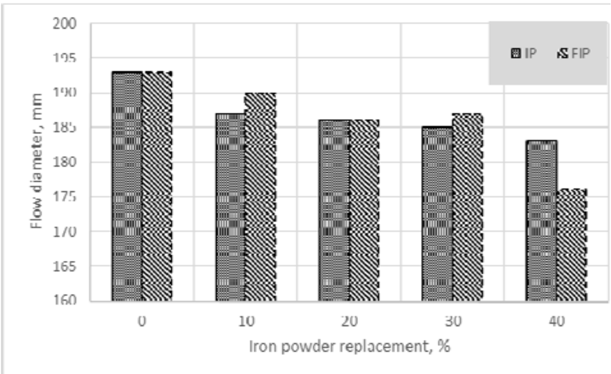

Figure 4 Effect of IP and FIP replacement on flowability cement mortar

B - Hardened properties

Figs. 5–7 show the variability (standard deviations as error bars) in hardened density, compressive strength, and flexural strength, respectively, of different mixtures. Table 5 presents the detailed results.
Effects IP and FIP as aggregate replacements on hardened density: The specimens made with IP and FIP displayed

higher densities than that of the MR mixture. This difference can be attributed to that the waste IP possessed a 2.28 times higher specific gravity (SG) than that of the sand. The unit weight of cement mortar increased with the incorporation of IP as aggregate replacement. Such replacement by FIP also decreased the air content, which consequently increased the unit weight of mixtures.

Effects of IP and FIP as aggregate replacements on compressive strength: The compressive strength decreased with the increased IP percentage. The reduction in MIP1 was 2.17%, 6.45%, and 6.69% after 7, 28, and 54 days, respectively. The corresponding values after 7, 28, and 54 days were 16.6%, 21.9%, and 33.3% for MIP2; 13.56%, 25.97%, and 42.3% for MIP3; and 10%, 17.7%, and 28.76% for MIP4, respectively.

The compressive strength of the MFIP1 mixture increased by 10.14% and 10.17% after 7 and 28 days, respectively. This trend may be due to the high density and strength of the waste IP, which was consistent with the findings in [18]. The percentage of increment was 6% for 28 days.

The compressive strength of MFIP2 after 7 days was nearly the same as that of the MR mix, but a small reduction of 4.48% was observed after 28 days. MFIP3 and MFIP4 showed significant reductions of 2.42% and 11.19% after 7 days and 10.37% and 11.17% after 28 days, respectively. These reductions may be attributed to the small voids appearing on the internal texture of the specimen after failure in the compression test or the high percentage of IP, which may affect the hydration process of cement and consequently reduce the strength [7].

The optimum percentage of FIP replacement was obtained at 10% with an increase of 10.14% and 10.17% after 7 and 28 days, respectively, compared with the reference mixture.

Table 5 Hardened properties

Mixture I	Density, kg/m^3		Compressive strength, MPa			Flexural Strength, MPa
	7 days	28 days	7 days	28 days	54 days	28 days
MR	2470	2480	27.6	33.92	39.87	4.07
MIP1	2560	2590	27	31.73	37.2	4.12
MIP2	2640	2640	23.76	29.32	35.87	4.63
MIP3	2670	2720	21.53	25.11	32.8	4.68
MIP4	2760	2760	18.4	22.23	28.4	4.82
MFIP1	2478	2480	30.40	37.37	-	4.65
MFIP2	2520	2570	27.51	32.40	-	4.93
MFIP3	2680	2720	26.93	30.40	-	4.94
MFIP4	2790	2810	24.51	30.13	-	5.21

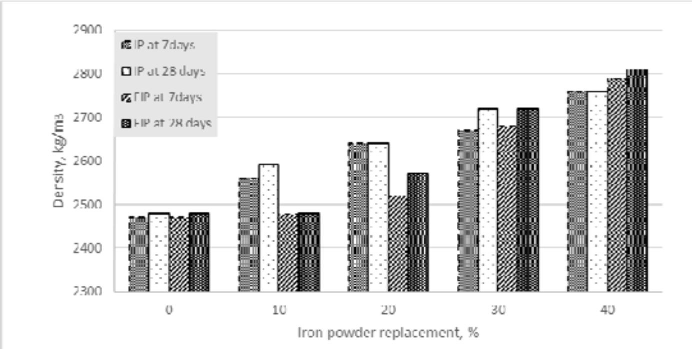

Figure 1 Effect of waste iron powder on hardended density at different age

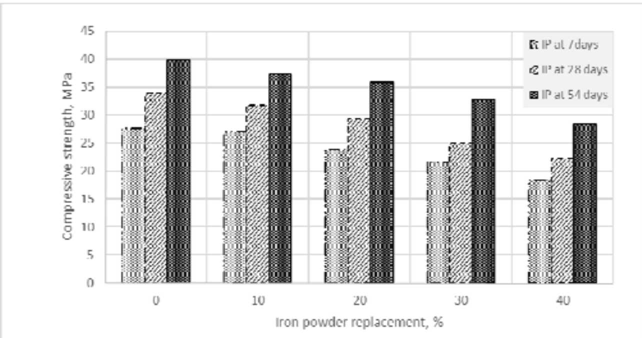

Figure 2 Effect of waste iron powder on compressive strength at different age

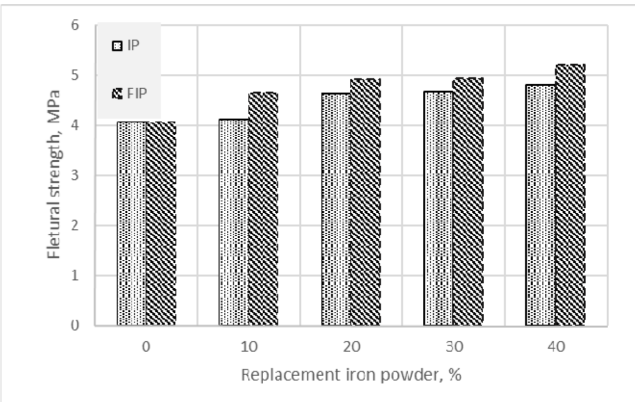

Figure 7 Effect of waste iron powder on flexural strength at different age.

Failure occurred during compression test on the specimens, and voids appeared on the internal surface texture of the specimen. The number of voids increased with the increased waste IP percentage. Thus, the reduction in the compressive strength may be attributed to this phenomenon, as shown in Fig. 8.

Effects of FIP as aggregate replacement on flexural strength: The preceding table and Figs. 8 and 9 show that the flexural strength increased with increased FIP percentage compared with that of the reference mixture. The MFIP4 mixture presented the highest flexural strength, which was 14.83% higher than that of the MR mixture. These results were consistent with those reported in [7,18]. The highest flexural strength was that of the MFIP2 mixture after 28 days; the value was 27.86% higher than that of the reference mixture at the same curing period.

Figure 8 Specimens under flexural and compressive stress

IV Conclusions

According to the present findings, the following conclusions can be drawn:

The cost showed no increase when waste IP-modified mortar mix was used compared with that using conventional mortar mix.

Flow test result revealed a reduction in diameter with increased waste compared with that of the reference mix.

The dry densities of the cement mortar specimens with 10%, 20%, 30%, and 40% IP and FIP were higher than that of the reference mix.

The compressive strength decreased with increased IP percentage. When 10% IP was added in the mixture, the compressive strength decreased by 2.17%, 6.45%, and 6.69% after 7, 28, and 54 days, respectively, compared with the control mixture. The corresponding values when adding 20%, 30%, and 40% IP decreased: 16.6%, 21.9%, and 33.3% after 7 days; 13.56%, 25.97%, and 42.3% after 28 days; 10%, 17.7%, and 28.76% after 54 days.

The cement mortar mix modified with 10% IP increased by 10.14% after 7 days and 10.17% after 28 days. With the addition of 20% FIP, the compressive strength after 7 days was nearly the same as that of the reference mix, and a small reduction of 4.48% was detected after 28 days. With the addition of 30% and 40% FIP, significant reductions of 2.42% and 11.19% after 7 days and 10.37% and 11.17% after 28 days were observed.

The flexural strength increased with increased FIP percentage. The specimens with 40% FIP showed the highest flexural strength, which was 14.83% higher than that of the reference mix.

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