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Validation of Using Mixed Iron and Plastic Wastes in Concrete

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ABSTRACT

Metals and plastics waste materials create serious environmental problems, mainly owing to the inconsistency of the wastes streams. The purpose of this paper is to evaluate the possibility of using mixed iron filings and granulated plastic waste materials simultaneously to partially substitute the fine aggregate in concrete composites. Type I Portland cement was mixed with the aggregates to produce the concrete composites. Three weight fractions (30, 40, and 50%) of iron filings waste aggregate were used with 5% of granulated plastic waste. The slump, compressive and flexural strengths as well as the fresh and hard density of the concrete mixtures were determined. The results of the mechanical properties were analyzed in comparison to the control specimens. The main findings of this investigation revealed that the mixture of iron filings and plastic waste materials could be used successfully as partial substitutes of sand in concrete composites. Increasing the granulated plastic waste in the mixed aggregate waste materials up to 10% did not seriously hinder the strength properties of the waste-concrete specimens.

INTRODUCTION

One of the main goals of sustainable solid waste management is to maximize the ability of its recycling and reusing. Metal and plastic are the most common of these materials [Hawken 1994]. With increasing environmental pressure to reduce waste pollution, the concrete industry has begun adopting a number of methods to achieve these goals [Sear 2005]. Preserving natural aggregate is a matter of sustainable development to ensure sufficient resources for future generation [Rakshvir and Barai 2006]. Reuse of solid waste as partial replacement of aggregate in construction activities results in reducing the demand for extraction of natural raw materials as well as saving landfill space. The quality of aggregate is highly important since approximately three-quarters of concrete volume are occupied by aggregate; it greatly affects the strength, durability and the structural performance of concrete [Neville and Brooks 1990]. Considering the relevance of some types of solid wastes as recyclable materials that can be reused in concrete industry, much research effort has focused on reusing waste materials from steel and plastic industries to partially replace the aggregate in concrete mixes. Akinmusuru [1991] stated that using a steel slag as an aggregate for concrete mixes have potential in the construction industry.

Soroushian et al. [1995] stated that polypropylene can be used as synthetic fibers to increase the toughness of concrete. Rebeis and Fowler [1996] found that very good flexural strength can be obtained with reinforced polymer concrete using unsaturated polyester resins based on recycled polyethylene terephthalate (PET). Ghailan [2005] stated that concrete mixes made with solid waste produced from iron and steel industry has a higher modulus of rigidity, rebound number and chemical resistance toward the exposure to acids/salts as compared with conventional concrete mixes. Pezzi, et al. [2006] proved that the addition of polymeric materials in fraction ≤ 10% in volume inside of a cement matrix does not imply a significant variation of the concrete mechanical features. Marzouk et al. [2007] reported that the plastic bottles shredded into small (PET) particles may be used successfully as sand-substitution aggregates in cementitious concrete composites which appear to offer an attractive low-cost material with consistent properties. Ismail and Al-Hashmi [2008] demonstrated that using waste iron filings as partial replacement of fine aggregate in concrete mixes offers higher strength values than that for the plain mixes. The results of the study carried out by Kou et al. [2009] revealed that the workability, compressive strength, and tensile splitting strength of lightweight aggregate concretes that are prepared with recycled plastic waste were reduced. Very limited studies explored the combined effects of mixed waste materials on the mechanical behavior of concrete mixes. In view of the fact that iron and plastic wastes are widespread types of non-biodegradable solid wastes derived as discarded materials from several industrial processes, the knowledge of their combined influence on the strength properties of concrete is worth to be considered. The current study describes the impact of utilizing mixed iron filings and plastic waste to partially replace sand on the mechanical properties of the waste modified-concrete mixes.

MATERIALS AND METHODS

Materials: Type I Portland cement was utilized in this study. The chemical analysis of cement was performed according to ASTM C114. The chemical composition and physical properties of cement are given in Tables 1 and 2, respectively.

Table 1. Chemical Composition of Cement

Compounds	% (by weight)
	64.43
SiO_2	21.14
Al_2O_3	5.78
Fe_2O_3	3.59
SO_3	2.35
MgO	1.52
Loss of ignition	0.89
Lime saturation factor	0.92
Insoluble residue	0.34
C_3S	50.83
C_2S	22.30
C_3A	9.25
C_4AF	10.90

Table 2. Physical Properties of Cement

Properties	Limit	Test Method
Fineness (m^2/kg)	269.50	ASTM C204
Initial setting time (min)	3:20	ASTM C191
Final setting time (hr)	4:15	ASTM C191
Soundness	0.19	ASTM C151
3 days age compressive strength	24.96	ASTM C109
7 days age compressive strength	30.80	ASTM C109

Natural sand of 4.75 mm maximum size was used as fine aggregate. The properties of the sand are presented in Table 3. Gradation of the fine aggregate was conformed according to ASTM C136 (Table 4). Natural crushed stone of 20 mm maximum size and 1545 kg/m^3 bulk density was used as coarse aggregate.

Table 3. Properties of Sand

Properties	Limits
Sulfate %	0.80
Finesse modulus	2.37
Absorption %	2.71
Max size (mm)	4.75
Density (kg/m^3)	1688
Specific gravity	2.57

Table 4. Gradation of Fine Aggregate and Waste Iron Filings

Sieve size (mm)	Accumulated passing %		
	Fine aggregate	Waste iron filings	Standards limits
4.75	96.50	99.93	90-100
2.36	89.16	99.34	85-100
1.18	80.70	87.14	75-100
0.60	68.40	34.24	60-79
0.30	24.97	10.18	12-40
0.15	3.81	4.14	0-10

The waste iron filings aggregate was obtained from several local workshops, it is normally generated in hundreds of tons from the iron smith processes. The gradation, chemical composition and physical properties of the waste iron filings are given in Tables 4, 5 and 6, respectively. Waste plastic was obtained from different locations. It sourced from scrapped industrial plastic waste which consists of approximately 80% polyethylene and 20% polystyrene. Table 7 presents the physical and mechanical properties of the waste granular plastic. Figure 1 presents samples of waste material aggregates.

Table 5. Chemical Composition of Waste Iron Filings

Compounds	Weight %	Test method
Fe_2O_3	93.14	Titration with potassium dichromate using diphenyl amine as indicator.
Al_2O_3	< 0.03	Auto color analyzer

Table 6. Physical Properties of Waste Iron Filings

Properties	Limit	Test method
Fineness modulus	2.65	F.M = accumulative percentage retained/100
Specific gravity	4.50	Somayaji [1995]
Density (kg/m^3)	1946.70	ASTM C 29
Color	Black gray	-

Table7. Physical and Mechanical Properties of Waste Plastic

Properties	Values
Density (kg/m^3)	386.7
Shape of particles	Granular of a broad distribution dimension with varying length of (0.15-12) mm and width of (0.15- 4)mm.
Color	Different colors
Water absorption 24 hr (%)	0.02
Compressive strength	Poor

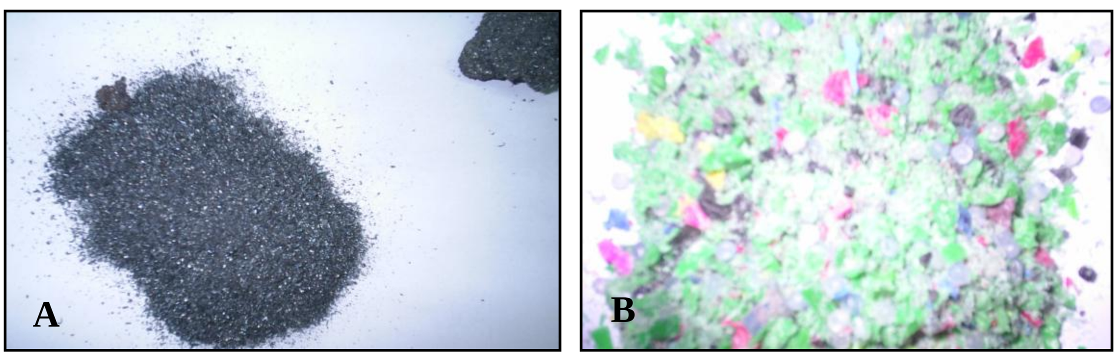

Fig. 1. Samples of Waste Materials Aggregates; (A) Iron Filings, (B) Granulated Plastic

Mixture proportioning

The plain concrete mixes (M0) were made with 715 kg/m^3 sand, 1020 kg/m^3 gravel, 380 kg/m^3 cement, and w /c ratio of 0.53 (Table 8). The waste modified-concrete composites were prepared in three mixes M1, M2, and M3 using waste iron filings to replace sand by 30, 40, and

50%, respectively with the granular waste plastic to replace sand by 5% weight fraction (Table 8). In order to investigate the influence of increasing plastic waste ratio on the strength of the concrete, another set of mixed waste-concrete specimens (data not shown) were prepared using similar fractions of waste iron filings aggregate (30, 40, and 50%) with waste plastic replacing the fine aggregate by 10% weight fraction. All specimens were water cured for 28 days.

Table 8. Mix Proportions of Waste Modified-Concrete Mixes

Mix mode	Cement (Kg/m^3)	Coarse (Kg/m^3)	Sand (Kg/m^3)	Waste materials aggregate (Kg/m^3)		W/C
				Iron filings	Plastic	
M0	380	1020	715.00	-	-	0.35
M1	380	1020	464.75	214.5 (30%)	35.75 (5%)	0.35
M2	380	1020	393.25	286.0 (40%)	35.75 (5%)	0.35
M3	380	1020	321.75	357.5 (50%)	35.75 (5%)	0.35

Specimen testing

Fifty six cubes of waste modified-concrete were cast for tests of compressive strength, hard and fresh density. Forty eight prisms were cast for testing the flexural strength. Samples of the water cured and dried specimens are shown in Figure 2. Casting, compaction and curing were conducted according to B.S. 1881. The tests of slump, fresh and dry densities, and compressive strength were conducted according to B.S. 1881. Fresh densities were measured immediately after molding and compacting the cubes. Dry densities were measured following the curing of the cubes in water, prior to testing the compression strength. A Forney-type machine was used for the compression test. The average compression strength of four cubes was recorded at 28 days. For flexural strength and toughness tests, the applied strain rate and the loading rate were 0.087 mm/min and 10 N/min, respectively. The prisms were prepared according to ASTM C192. The tests were carried out according to ASTM C 293 and the average flexural strength of three prisms was recorded at the testing curing age.

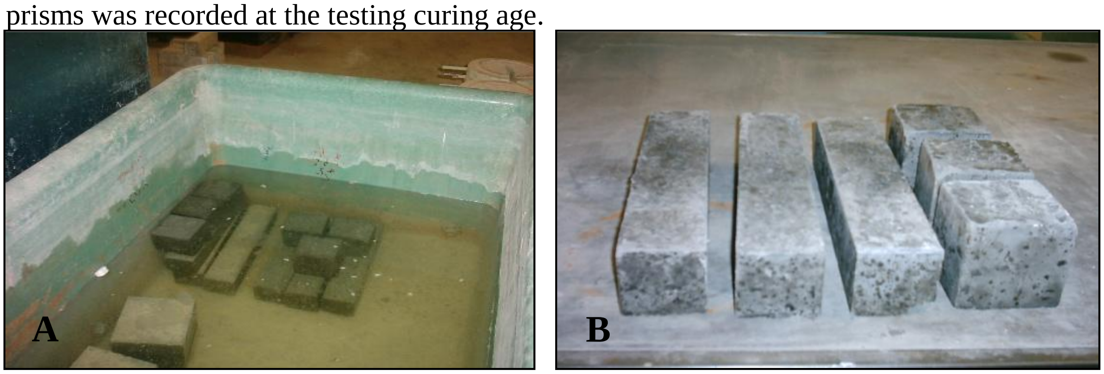

Fig. 2. Samples of Waste Modified-Concrete Specimens; (A) Water Cured Specimens, (B) Dried Specimens.

TEST RESULTS AND DISCUSSION

Effect of waste material aggregate on the compressive strength of concrete

The compressive strength tests outcome for the concrete mixes are presented in Figure 3. The results demonstrate that as the waste iron content increases in mixes M1, M2, and M3, the tendency of the strength values increase above that for the plain mix by 6.4, 9.6, and 22.5%, respectively. This tendency could be attributed to the pozzolanic activity of iron that overcomes the retardation of hydration caused by the hydrophobicity of waste plastic. Demirborga and Gül [2006] justified the increase in compressive strength due to the high density and strength of the iron content. Also, Dionys et al. [2005] reported that during hydration, the addition of polymeric materials with cement led to formation of a polymer film resulting in co-matrix during which polymer is intermingled with cement hydrate, causing the increase of compressive strength.

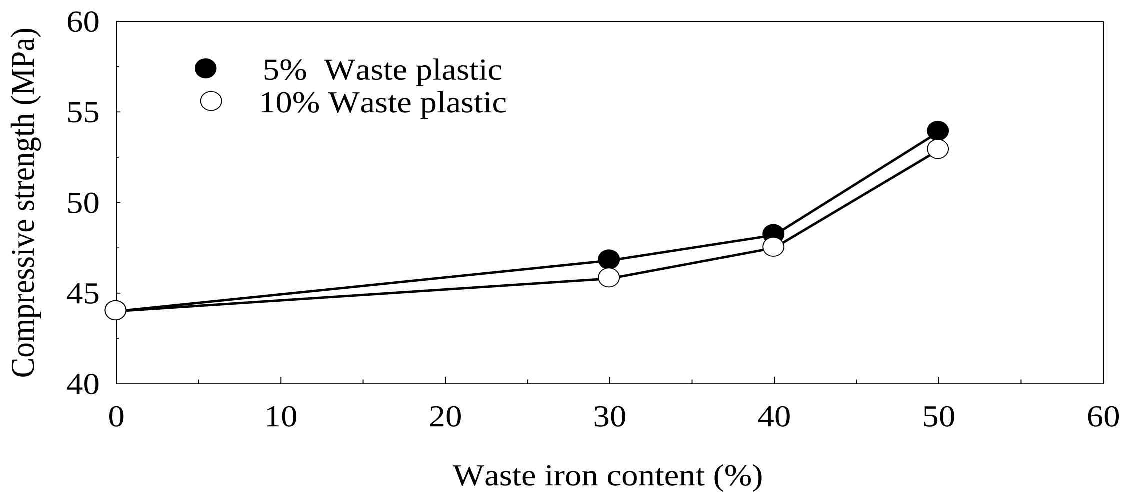

Fig. 3. Compressive Strength for Plain and Waste Modified-Concrete Mixes at 28 Days Water Curing

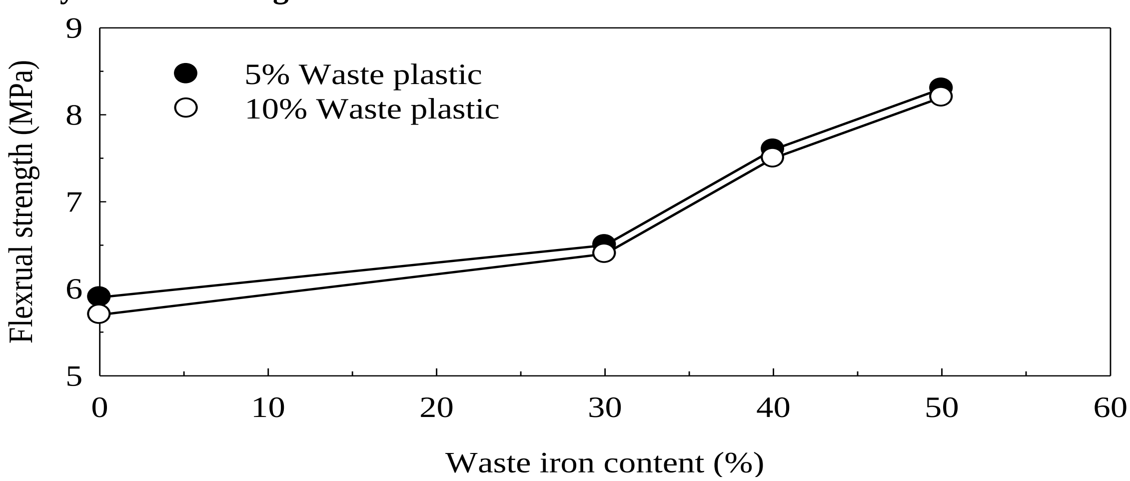

Fig. 4. Flexural Strength for Plain and Waste Modified-Concrete Mixes at 28 Days Water Curing

Effect of waste material aggregate on the flexural strength of concrete

The flexural strength was observed to follow the same trend of the compressive strength. Results revealed that as the waste content increases in mixes M1, M2, and M3, the flexural strength values are prone to increase above that for the plain mix by 10.2, 28.8, and 40.7%, respectively (Figure. 4). Interestingly, it is obvious that increasing the fraction of waste plastic aggregate up to 10% did not significantly degrade the compressive and flexural strengths of the waste modified-concrete specimens (Figures 3 and 4).

Toughness indices

The load-deflection curve of the plain concrete at 28 days age is shown in Figure 5A. This plot illustrates the sudden failure of plain concrete under center point loading on simple beams due to the brittle nature of concrete. The flexural load-deflection curves for the waste modified-concrete mixes M1, M2, and M3 are shown in Figure 5B. The plot shows the arrest of the propagation of micro cracks by introducing the heterogeneous shaped waste material particles into the mix.

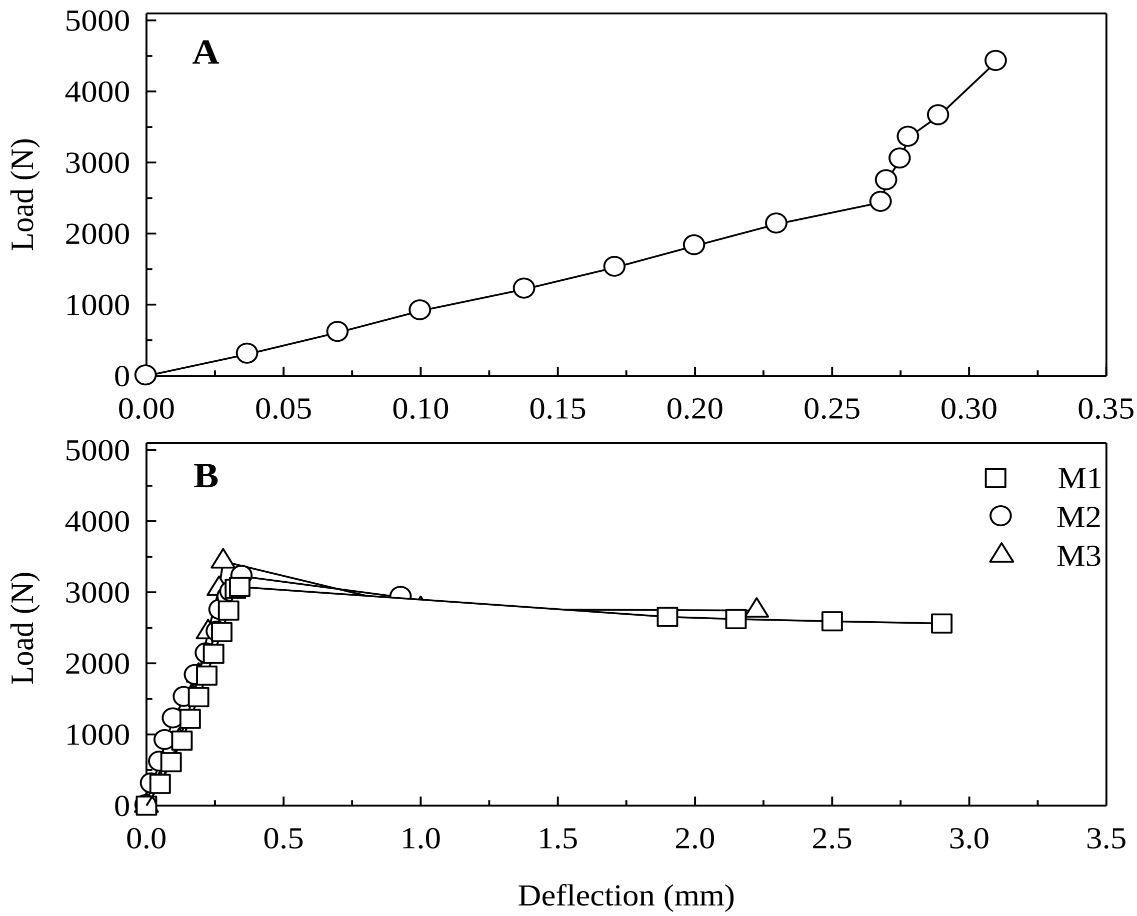

Fig. 5. Load-Deflection Curves for; (A) Plain Prisms, (B) Waste Modified- Concrete Prism

Table 9 presents the toughness indices for the waste modified-concrete mixes M1, M2, and M3. The slight differences in I_{10}:I_5 could be due to the assumption of inhomogeneous distribution of waste material aggregate. The non-uniform shapes of the waste plastic may also affects the toughness indicies values. However, for all these waste-concrete mixes, the toughness indices are comparable to the plastic behavior specified by ASTM C1018 which is desirable for many applications that require high toughness.

Table 9. Toughness Indices for the Waste Modified-Concrete Mixes

Mix mode	Indices		
	I_5	I_{10}	I_{10}:I_5
M1	5.40	10.94	2.03
M2	4.72	9.16	1.94
M3	3.00	8.99	3.00

Effect of waste material aggregate on the slump of concrete

The results of the slump tests indicate that as the content of iron filings aggregate in the waste-concrete mixes increases, the slump values increase. However, the slump values of mixes M1, M2, and M3 were relatively lower than the slump of the plain mix M0 (Figure 6). In spite of this decline in slump values, the waste modified-concrete mixes were still workable. The slump reduction could be attributed to the heterogeneous distribution of waste material as well as the sharp and angular grain shapes of the waste particles compared to the sand particles. Accordingly, as the content ratio of the mixed wastes increases, more cement paste may attach to the surface of the waste leading to less available cement paste required for concrete fluidity. These results are in line with the evidence reported by Soroushian et al. [2003] that the addition of any discrete reinforcement caused slump loss.

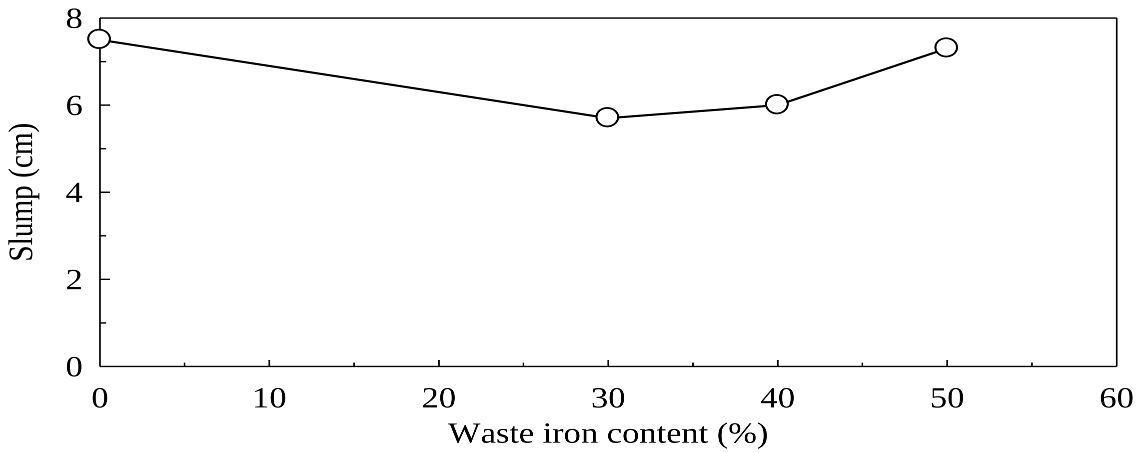

Fig. 6. Slumps for the Plain and Mixed Waste-Concrete Mixes at 28 Days Curing.

Effect of waste material aggregate on the fresh and hard densities of concrete

Results of the mean fresh and hard density tests revealed that the densities of mixed waste-concrete specimens were moderately increased with increasing the waste iron filings (Table 10). For waste modified-concrete mixes M1, M2, and M3, the fresh density values were 0.04, 1.22, and 4.46% higher, respectively, than the fresh density value of the control mix (M0). Whereby, the hard density for mixes M1, M2, and M3 exceeds that of the plain mix by 3.39, 4.17, and 8.04%, respectively. Also, it can be noticed that the hard density values are slightly greater than the fresh densities values for each mix. This could be due to the pozzolanic effect of waste iron which may produce more dense concrete at 28 days curing.

Table 10. Fresh and Dry Densities of Waste Modified-Concrete Composites

Mix mode	Density (Kg/m^3)	
	Fresh	Hard
M0	2476	2400
M1	2477	2482
M2	2507	2511
M3	2587	2593

Colors of the waste material aggregates did not have any noticeable effect on the prepared waste-concrete specimens as shown in Figure 2.

CONCLUSION

This study was conducted to evaluate the effect of using mixed iron filings and plastic waste materials as substitutes of fine aggregates on the main mechanical properties of concrete mixes. It can be concluded that those solid waste materials can be used in concrete mixes without hindering its mechanical properties up to the weight percent composition used in this study which were 50 and 10% for waste iron and waste plastic, respectively. The present study pointed out that the strength properties of the waste modified-concrete mixes demonstrated an increasing tendency along with an increase in the mixing ratio of the waste iron aggregate, whereby increasing the waste plastic ratio up to 10% did not have significant effect on the compressive and flexural strengths. The slump values of the mixed waste-concrete increased with increasing the waste aggregate content, but they were slightly below the slump values of the plain concrete mix. In spite of this decline in slump values, they remain easy to work. Both the fresh and dry density values of the mixed waste-concrete specimens tend to increase above those of the plain concrete mixes. Additionally, using colored waste plastic did not display any notable effect on the normal color of the waste-concrete mixes. Overall, the use of iron and plastic waste materials is, indeed, a viable solution to recycling such waste materials in concrete mixes. This study is exploratory, requires further work and investigations to assess the possibility of increasing the fraction of waste plastic beyond the range used in this study.

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