Mechanical and impact properties of concrete slabs reinforced with waste plastic fiber with adding recycled aggregates

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Mechanical and impact properties of concrete slabs reinforced with waste plastic fiber with adding recycled aggregates

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Abstract. In this study, demolished concrete products were used after crushed and replaced with normal coarse aggregate besides the addition of fibers produced from manual chopping of plastic bottles used to preserve soft drinks were used to improve the Impact resistance and some mechanical properties of concrete. Two types of mixes were poured; the first type contains normal coarse aggregate with different fibers ratios, while the second type the normal coarse aggregate was fully replaced by crushed concrete products by adding the same different fibers ratios to the mix. Two reference mixes made for each type of concrete without adding fibers for the purpose of comparison. The results of concrete containing natural coarse aggregate, and fiber added showed a slight decrease in concrete density and an improvement in compression resistance and bending resistance at age (28) days. And improvement in the impact resistance of slabs at age (56) days. The results of concrete containing recycled aggregates and fiber added showed a slight decrease in the density of concrete and an improvement in compression resistance and bending resistance at age (28) days respectively, the impact resistance of the slabs improved at age (56) days.
Keywords: recycled aggregate, waste plastic fibers, impact property.

1. Introduction

Due to the massive depletion of natural resources on Earth, the need to find new ways to reduce the use of these resources, or to reuse and recycle them into usable materials, whether in the same field from which they were taken or in another field [1]. For buildings and facilities, 10-30% of concrete waste is disposed of in landfills [2]. Accordingly, the environmental impact represented by these wastes is clear, as it found that 65% of these wastes are concrete pieces and coarse aggregates (gravel) [3]. In recent decades, with the aim of reducing the resulting environmental pollution and preserving the natural resources of materials that used as aggregates for concrete, concrete waste has been recycled for reuse as one of the components of concrete. [4]. besides concrete waste, polyethylene terephthalate (PET) is also the largest plastic waste producer [5-6]. PET bottles are very popular in beverage production and other industries due to their high strength in relation to weight, durability, ease of manufacture, low density, and low cost [7]. The annual consumption of plastic increased from 1.5 million tons to 332 million tons within 65 years [8]. Each year, nearly half a trillion bottles of PET are disposed of worldwide and may increase (20%) in 2021 [9]. PET bottles are difficult to dispose of due to their low biodegradability, and some disposal processes threaten the environment [10]. One of the easiest ways to recycle PET bottles is manual or mechanical shredding of PET bottles and the production of fibers in suitable sizes for using it to improve the properties of concrete mixtures [11-13]. This study aims to recycle and dispose of some wastes that threaten the environment and show their effects on concrete types.

2. Experimental work

2.1. Materials

2.1.1. Cement. Ordinary Portland cement (OPC - Type I) product of Al-Mass Company used in this study. It was adjusted to ASTM C150 [14] and IQS 5/1984 [15].

2.1.2. *Fine Aggregates.* Natural sand has used. It was clean and has no clay and no organic materials. The grade of fine aggregate adjusted to IQS 45/1984 [16].

2.1.3. *Coarse Aggregate.* Natural gravel has max size of 10 mm, it washed and submerged in water about two hours and dried in air to get saturated surface dry (SSD). The grade of coarse aggregate was adjusted IQS 45/1984 [16].

2.1.4. *Recycled Aggregate.* The recycled aggregate has max size of (10) mm made from crashed the demolished concrete by hand and graded to fitting the grade of course aggregate, Tables 1. In addition to 2. Listed the sieve analysis and the properties of recycled aggregate respectively. Figure 1 Shows the recycled aggregate. The grade of recycle aggregate adjusted to IQS 45/1984 [16].

Table 1. Sieve analysis of Recycled aggregate.

Sieve Size (mm)	passing %	IQS 45/1984
12.5	100	100
9.5	94	85-100
4.75	19	0-25
2.36	4	0-5

Table 2. Properties of Recycled aggregate.

Properties	test results	IQS 45/1984
Specific gravity	2.59	-
Sulfate content	0.09	≤0.1
Absorption %	3.11%	-

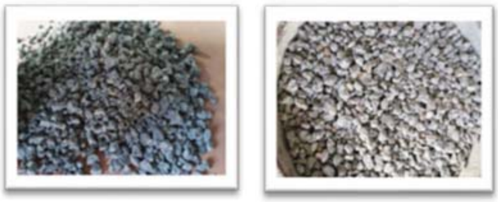

Figure 1. Recycled aggregate.

2.1.5. *Waste plastic fiber (WPF).* The waste plastic fibers that used in this study is resulting from cutting manually. The geometrical properties of these fibers illustrated in Table 3. Fiber added to the mixes as a percentage by volume of mixes by (0.6, 0.8, 1.0, 1.2 and 1.4) respectively. Figure 2. Show waste plastic fiber.

Table 3. Properties of waste plastic fibers.

Type of Fiber	Length (mm)	Width (mm)	Thickness (mm)	Aspect ratio (l/d)	Specific Gravity (gm/cm^3)
WPF	39	4	0.35	1.33	1.169

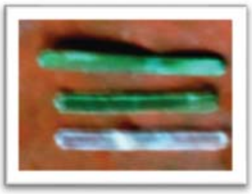

Figure 2. Waste plastic fiber.

2.2. Concrete Mixes Components

Two mixes were made in the present work of normal concrete and recycled aggregate concrete with use same mixing proportions, to arrival the required of compressive strength. Six ratios of (WPF) percentage added to the mixes (0.6, 0.8, 1, 1.2 and 1.4%) as volumetric ratios. The procedure of mixing was conforming to ASTM C I92 [17].

2.2.1. *Normal weight concrete (NWC).* The proportions of preparation the Normal-Weight Concrete mix were calculated and then mixed mechanically until all components become uniform. To produce waste-plastic concrete (WPC), the fibers of waste-plastic were added to the dry mix. All materials mixed drily until the mix becomes uniform. Then, the calculated water added and remixed all components until being homogenous. Table 4. Show mix-proportions of materials used for Normal-Weight Concrete (NWC).

Table 4. Weights of normal-weight concrete components.

Mix	Cement (kg/ m^3)	Fine Agg. (kg/m^3)	Coarse Agg. (kg/m^3)	w/c (L)	WPF (Kg/m^3)
R1	429	703.6	1128.3	188.8	0
M1	402.9	660.8	1059.6	177.3	7.01
M2	394.4	646.8	1037.3	173.5	9.35
M3	385.8	632.7	1014.7	169.8	11.69
M4	377.2	618.6	992.0	165.9	14.03
M5	368.7	604.7	969.7	162.2	16.37

Where: -

R1	Normal weight concrete without fiber
M1	Normal weight concrete with 0.6% waste plastic fiber
M2	Normal weight concrete with 0.8% waste plastic fiber
M3	Normal weight concrete with 1.0% waste plastic fiber
M4	Normal weight concrete with 1.2% waste plastic fiber
M5	Normal weight concrete with 1.4% waste plastic fiber

2.2.2. *Recycled- aggregate concrete (RAC).* To prepare the Recycled-Aggregate Concrete mix, the dry materials except the fiber were mixed mechanically until all components seem homogeneous and during the mix operation, the fiber was added to the mix. Table 5. Show mix-proportions of materials used for Recycled-Aggregate Concrete (RAC). Figure 3. shows the tested specimens.

Table 5. Weights of recycled-aggregate concrete components.

Mix	**Cement (kg/ m^3)**	**Fine Agg. (kg/m^3)**	**Coarse Agg. (kg/m^3)**	**w/c (L)**	**WPF (Kg/m^3)**
R2	418.1	685.5	1099.3	183.9	0
MR1	393.0	644.5	1033.6	172.9	7.01
MR2	384.6	630.7	1011.5	169.2	9.35
MR3	376.3	617.1	989.7	165.6	11.69
MR4	367.9	603.4	967.6	161.9	14.03
MR5	359.5	589.6	945.5	158.2	16.37

Where: -

R2	Recycled- aggregate concrete without fiber
MR1	Recycled- aggregate concrete with 0.6% waste plastic fiber
MR2	Recycled- aggregate concrete with 0.8% waste plastic fiber
MR3	Recycled- aggregate concrete with 1.0% waste plastic fiber
MR4	Recycled- aggregate concrete with 1.2% waste plastic fiber
MR5	Recycled- aggregate concrete with 1.4% waste plastic fiber

Figure 3. Tested specimens.

2.3. Curing

Specimens cured under ideal conditions. All specimens submerged in water basin with fresh water. The conditions of curing the specimen were conforming to of specimens adjusted to ASTM C 192 [17].

2.4. Tests

2.4.1. *Density test.* Density was determined by weighing the cubes after drying and dividing its weight by the measured volume of the cubes. Dry density test was computed according to ASTM C 642 [18] and that was by taking the average of three cubes of (100×100×100) mm for every mix of (NWC) and the density test of (RAC) respectively at age 28 days.

2.4.2. *Compressive Strength.* The compressive strength determined according to BS 1881 – 119 [19]. Three specimens of cubes were tested for each type of mix of concrete at ages (7 and 28) days. Figure 4 shows the tested cubes.

Figure 4. Tested cubes.

2.4.3. *Flexural Strength.* ASTM C 293 (center-point loading) defined Flexural strength as the stress applied on concrete before yield in flexure [20]. The prism dimension is (400×100×100) mm. Three specimens were tested with different ratios of fibers at ages of (7 and 28) days. Figure 5 shows the tested prisms.

Figure 5. Tested prisms.

2.4.4. *Impact test for slabs.* To determine Low-Velocity impact tests, a method of repeated falling mass was used Steel ball of (1300) gm was fallen freely with a velocity of 6.928 m/s from height 2.4 m on concrete stab of (400×400×50) mm. For each mix, six slabs were tested at age of (56) days. The number of blows to cause the first crack and failure recorded. Figure 6. shows the tested slabs of NWC and RAC respectively

Figure 6. Tested slabs.

3. Results and discussions

3.1. Density Test

Tables 6a. Moreover, 6b. Listed the density of tested specimens of both mixes of NWC and RAC respectively. The results showed that the density decreased with increasing the volume ratio of (WPF) for NWC and RAC respectively. That replacing of concrete components with plastic fibers as volume reducing the density due to the density of plastic is much less than concrete components causes this. Figure 7. Showed the changes in density of NWC and RAC respectively.

Table 6a. Density of the NWC specimens.

Mix	Density At 7 days	Density At 28 days	Development At (28) days
R1	2380	2388	**-**
M1	2368	2348	**-1.68%**
M2	2363	2345	**-1.80%**
M3	2345	2335	**-2.22%**
M4	2325	2305	**-3.48%**
M5	2293	2272	**-4.86%**

Table 6b. Density of the RAC specimens.

Mix	Density at 7 days	Density at 28 days	Development at (28) days
R2	2358	2368	**-**
MR1	2355	2338	**-1.27%**
MR2	2335	2323	**-1.90%**
MR3	2295	2280	**-3.72%**
MR4	2245	2229	**-5.87%**
MR5	2235	2218	**-6.33%**

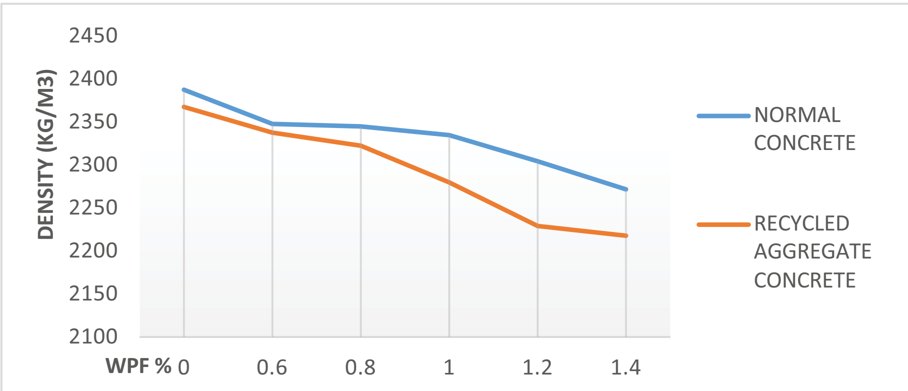

Figure 7. Development of the density for NWC and RAC at age of (28) days.

3.2. Compressive Strength Test

Test results in Tables 7a. In addition, 7b. At ages (7 and 28) days for (0, 0.6, 0.8, 1.0, 1.2 and 1.4%) of (WPF) by volume and plotted in Figure 8. Showed that compressive strength increased with compared to the reference mix without (WPF) up to (14.8 %) and (18.8 %) for NWC and RAC respectively. This increasing maybe caused by the compressive strength increased with age because of the concrete be stiffer and strength due to complete processes of hydration and reduces in porosity.

Table 7a. Compressive strength results for cubes of the NWC.

Mix	Compressive Strength (MPa) at 7 days	Compressive Strength (MPa) at 28 days	Development at (28) days
R1	27.2	40.5	**-**
M1	27.5	42.0	**3.7 %**
M2	28.0	44.0	**8.6 %**
M3	31.5	46.5	**14.8 %**
M4	30.5	44.5	**9.8 %**
M5	28.5	41.0	**1.2 %**

Table 7b. Compressive strength results for cubes of the RAC.

Mix	Compressive Strength (MPa) At 7 days	Compressive Strength (MPa) At 28 days	Development At (28) days
R2	32.0	42.5	**-**
MR1	33.0	44.5	**4.7 %**
MR2	39.5	47.0	**10.6 %**
MR3	44.0	50.5	**18.8 %**
MR4	42.0	48.0	**12.9 %**
MR5	34.0	45.0	**5.9 %**

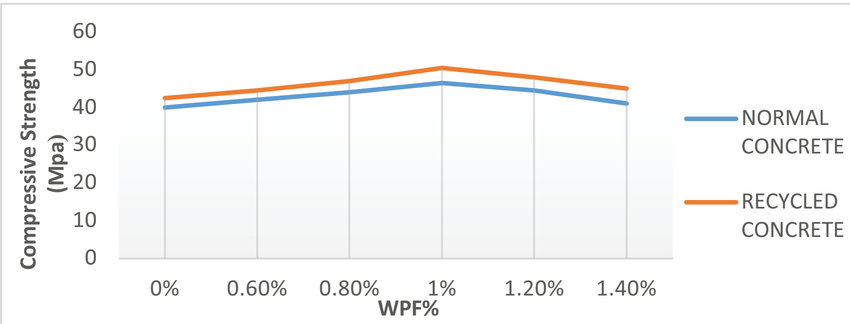

Figure 8. Development of compressive strength of NWC and RAC at age of (28) days.

3.3. Flexural Strength Test

All results for flexural test of NWC and RAC with (WPF) listed in Tables 8a. In addition, 8b. Respectively. It has plotted in Figure 9. At (7 and 28) days for (0, 0.6, 0.8, 1.0, 1.2 and 1.4%) of (WPF) as volume. Flexural strength increased with increased (WPF) also increased with curing time. Because the presence of (WPF) make tight the microscopic coracles to propagate and reinforced the concrete matrix.

Table 8a. Flexural results for prisms of the NWC.

Mix	Flexural (MPa) At 7 days	Flexural (MPa) At 28 days	Development At 28 days
R1	2.8	4.3	-
M1	3.0	4.5	**4.6 %**
M2	3.2	4.7	**9.3 %**
M3	3.4	5.1	**18.6 %**
M4	3.5	5.5	**27.9 %**
M5	2.8	4.6	**6.9 %**

Table 8b. Flexural results for prisms of the RAC.

Mix	Flexural (MPa) At 7 days	Flexural (MPa) At 28 days	Development At 28 days
2	2.6	4.4	-
MR1	3.8	4.9	**19.5 %**
MR2	4.2	5.3	**23.3 %**
MR3	4.5	5.6	**30.2 %**
MR4	4.9	6.0	**39.5 %**
MR5	4.7	5.5	**27.9 %**

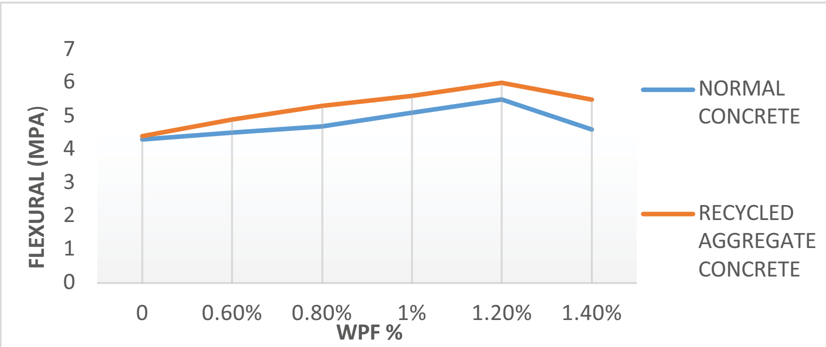

Figure 9. Development in flexural of NWC and RAC at age (28) days.

3.4. Impact Test

Results of impact resistance listed in tables 9a. Moreover, 9b. For NWC and RAC. The results showed increasing in numbers of blow with increased of (WPF) comparing to reference mixes. This increasing due to enhance in the energy absorption and toughness because of the fiber bridges the cracks and prevent it to develop. The maximum increasing of blows resistance was (228.5%) and (320%) at (1.2%) of (WPF) for NWC and RAC respectively. Figure 10. Showed the changes in numbers of blows for NWC and RAC respectively.

Table 9a. No. of blows for NWC slabs.

Mix	No. of blows (First Crack) at (56) days	No. of blows (Failure) at (56) days	Development of No. of blows (Failure) at (56) days
R1	2	7	-
M1	3	15	**114.3 %**
M2	1	17	**142.8 %**
M3	2	18	**157.1 %**
M4	3	23	**228.5 %**
M5	4	21	**200 %**

Table 9b. No. of blows for RAC slabs.

Mix	No. of blows (First Crack) at (56) days	No. of blows (Failure) at (56) days	Development of No. of blows (Failure) at (56) days
R2	1	10	-
MR1	2	22	**120 %**
MR2	2	31	**210 %**
MR3	2	35	**250 %**
MR4	2	42	**320 %**
MR5	3	29	**190 %**

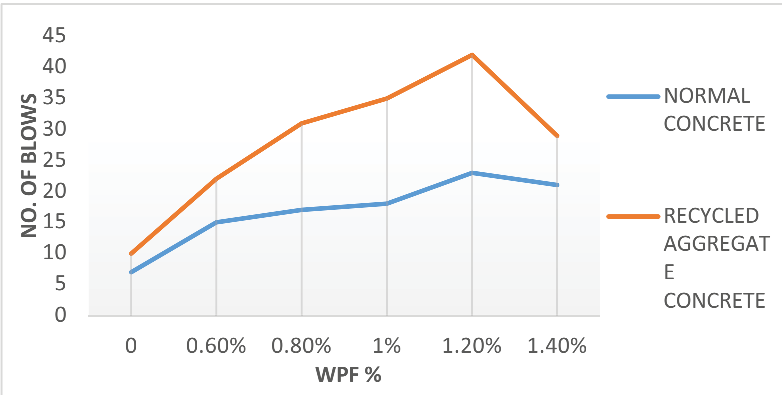

Figure 10. Development of no. of blows of NWC and RAC at age (56) days.

4. Conclusions

Based on the experimental work and results obtained in this study, the following conclusions present -

1- Waste fiber addition with different ratios enhancing the compressive strength at age of (28) days compared with both reference mixes of NWC and RAC. The magnitudes of enhancing with (1.0%) of (WPF) is about (14.8%) and (18.8%) for NWC and RAC respectively at age of 28 days.

2- Waste fiber addition with different ratios increases the flexural strength at age of (28) compared with both references mixes of NWC and RAC. The maximum magnitudes of increasing at (1.2%) of (WPF) about (27.9 %) and (39.5%) for NWC and RAC respectively at age of 28 days.

3- Waste fiber addition with different ratios decreases the density at age of (28) days compared with both references mixes of NWC and RAC respectively.

4- Waste fiber addition with different ratios increases the impact resistance at age of (56) days compared with both references mixes of NWC and RAC. The maximum magnitudes of increasing at (1.2%) of (WPF) about (228.5 %) and (320%) for NWC and RAC respectively at age of (56) days.

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