Properties of no-fines recycled aggregate concrete contains waste plastic fibers

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Abstract. The purpose of this study is to produce recycled concrete from the most common environmental pollutants, which are plastic waste and recycle concrete. Where plastic bottles were cut and used as fibers to reinforce concrete besides using the recycle concrete as an aggregate. also, it can be used in improving the various properties of concrete in terms of improving compressive strength, bending, thermal insulation, etc., because it is considered one of the most influencing disadvantages of concrete. Five mixes of concrete free of fine aggregate were poured with various volumetric proportions (0.6, 0.8, 1.0, 1.2 and 1.4) % of plastic fibers were added to them. The natural aggregate was completely replaced by a carefully graded product according to the specifications of crushed concrete residue. A comparative mix of recycled fiber-free concrete was poured. The results showed that with an increase in the fiber content, the thermal conductivity of the concrete samples decreases, the compressive and bending resistance increases at the age of (28) days, as well as, the density of concrete decreased. Besides, the results showed a slight improvement in the resistance to the impact of the slabs at the age of (90) days.

Keywords: no-fine aggregate concrete, recycled aggregate, waste plastic fibers, impact property

1. Introduction
During recent decades, the need to reuse construction and demolition waste and reduce its effects on the environment has emerged, as the biggest problem is the necessity of continuing the construction industry. The amount of solid concrete waste in all parts of the world amounts to about one-third of the solid waste, and this rate increases its growth year-by-year [1, 2]. Therefore, many methods have emerged to manufacture environmentally friendly recycled aggregate concrete and crush concrete waste to solve the construction and demolition waste accumulation crisis [3, 4]. Several experiments have been carried out on the mechanical properties of recycled concrete. Some defects appeared such as micro-cracks in the old mortar on the surface and inside the concrete due to the service life of the recycled concrete residues [5]. These defects negatively affect the properties of recycled aggregates compared to natural aggregates [6]. The production of waste plastic fiber reinforced concrete has spread widely due to its availability and cheapness [7, 8]. In addition to the environmental benefits represented by the disposal of industrial waste with harmful environmental impact [9]. This waste includes waste from plastic bottles used to store soft drinks [10]. In some countries, there has been an increasing trend towards conducting experiments to study the properties of concrete containing these fibers [11, 12]. The fracture coefficient of this concrete is lower than normal concrete that does not contain these fibers [13]. Studies showed that plastic fiber reinforced concrete has a higher resistance to impact and explosive loads compared to conventional concrete that was not reinforced with plastic fibers [14, 15]. In other researches, plastic fibers were used to produce lightweight concrete, and some of its properties were studied to see the possibility of producing this type of concrete for use in the future [16]. The behavior of recycled aggregate is of great importance in promoting the use of recycled concrete as a structural material [17]. According to previous research, studies on the behavior of adding plastic fibers to recycled concrete members using recycled concrete aggregates are very limited [18]. In this study, samples of coarse aggregate recycled concrete, free of fine aggregate, and reinforced with
recycled plastic fiber were tested to analyze some of their Mechanical and physical properties of this type of concrete. Where this study demonstrates the effects of the amount of fiber, the replacement of coarse aggregate completely, and the resistance of concrete, so that it can be used to understand the effect of concrete aggregate and plastic fibers on the properties of recycled concrete.

2. Experimental work

2.1. Materials

2.1.1. Cement. A commercial ordinary Portland cement (Type I) was used to cast specimens. This cement adjusts to ASTM C150 [19] and IQS 5/1984 [20].

2.1.2. Recycled Aggregate. This aggregate was produced from the remains of damaged concrete, where it was crushed and graded to conform to the Iraqi Standard No. 45 [21]. The size (10) mm is approved as the maximum gradient of the aggregate produced. Table 1 and 2 lists the properties of recycled aggregates. Figure 1 shows a sample of recycled aggregates used.

| Sieves Size (mm) | % Passing | IQS limits |
|------------------|-----------|------------|
| 12.5             | 100       | 100        |
| 9.5              | 88        | 85-100     |
| 4.75             | 14        | 0-25       |
| 2.36             | 2         | 0-5        |

Table 2. Properties of recycled aggregate.

| Properties     | Test results |
|----------------|--------------|
| Specific gravity | 2.31         |
| Absorption %    | 8.7 %        |

Figure 1. Recycled aggregate
2.1.3. Waste plastic fiber (WPF). This fiber was produced by cutting soft drink bottles using a paper shredder machine to produce fibers of proportional size. The properties of this fiber are shown in Table 3. Figure 2 shows the waste plastic fiber used.

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           | 40          | 4          | 0.3            | 32                | 1.17                        |

![Figure 2. Waste plastic fiber](image)

2.2. Concrete Mixes Components
All mixes were poured with a ratio of (1 cement: 5 recycle aggregate: 0.45 water cement ratio) by volume and this proportions chosen according to previous researches. One mix as a reference and five other mixes contain fiber in different proportions (0.6%, 0.8%, 1.0%, 1.2%, and 1.4%) respectively as a volumetric ratio of the concrete mix. Six specimens of cubes and prisms in addition to one slab were made for each mixing ratio. The procedure of mixing was conforming to ASTM C 192 [22]. Table 4 listed the weights of no-fines recycled aggregate concrete (NFRAC) components. Figure 3 shows the tested specimens of NFRAC.

Table 4. Weights of NFRAC components.

| Mix  | abbreviation         | Cement (kg/ m$^3$) | Recycled Agg. (kg/m$^3$) | w/c (L) | WPF (Kg/m$^3$) |
|------|----------------------|--------------------|--------------------------|---------|----------------|
| R    | NFRAC without fiber  | 342                | 1710                     | 154     | 0              |
| C1   | NFRAC with 0.6% WPF  | 340                | 1700                     | 153     | 7              |
| C2   | NFRAC with 0.8% WPF  | 339                | 1695                     | 153     | 9              |
| C3   | NFRAC with 1.0% WPF  | 338                | 1690                     | 152     | 11             |
| C4   | NFRAC with 1.2% WPF  | 337                | 1685                     | 152     | 14             |
| C5   | NFRAC with 1.4% WPF  | 336                | 1680                     | 151     | 16             |
2.3. Curing
All samples were treated until they are tested. The treatment was completed under standard conditions and according to the requirements of ASTM C 192 [22].

2.4. Tests

2.4.1. Density test. Density was computed according to BS EN 12390-7 [23]. The dry density was computed by calculating the average values of three specimens of NFRAC.

2.4.2. Compressive Strength. Cubes of concrete with dimensions of (100 x 100 x 100) mm were used to test the compressive strength with ages of (7) and (28). The results were tested and calculated for the concrete samples according to the requirements of the BS EN 12390-3 [24]. Figure 4 shows the cubes tested.

2.4.3. Flexural Strength. Flexural strength was calculated according to ASTM C1609 [25]. Where the flexural stress values range from 12-20% of the compressive strength. (400 x 100 x 100 mm) Prisms were used for the test. Figure 5 shows the tested prisms.
2.4.4. Thermal conductivity. The thermal conductivity coefficient of concrete is a measure of the thermal conductivity of the material. It can be defined as the number of thermal units that pass through a unit area of the material with a thickness equals to one unit and also within one unit of time when the difference between the temperatures of the two sides of the body is one degree. It is measured in units (W·m⁻¹·K⁻¹) and there are many methods of measuring the coefficient of thermal conductivity. The most recognized one is mentioned in ACI 523-3.9 [26]. The mathematical equation is connecting density and thermal conductivity coefficient as follows:

\[ K = 0.072 e^{0.00125 \rho} \]

Where:
- \( K \) = Thermal conductivity of an oven dryer model.
- \( \rho \) = the dry density of a sample aged (28) days

2.4.5. Impact test for slabs. The impact resistance of the NFRAC slabs was calculated by freely dropping a metal ball from a height of (1.6) m at a speed of (6.928) m/s on NFRAC slabs with dimensions (400 × 400 × 50) mm after (90) days of casting and curing. The number of blows that caused the first crack and the number of blows that caused the failure (penetration) were recorded. Figure 6. Shows the tested slabs of NFRAC.
3. Results and Discussions

3.1. Density Test
From observing the densities in Table 5. The results showed a significant decrease in the densities of NFRAC specimens, which decreased by 10.99% compared to the reference of NFRAC specimens. This could be attributed to the lower plastic density, which reduced the densities of the concrete due to the increased volume of plastic fibers with each volumetric replacement ratio. Figure 7. Showed the development in the densities of NFRAC specimens at age of (28) days.

| Mix | Density At a 28-days age | Development At a 28-days age |
|-----|--------------------------|------------------------------|
| R   | 2145                     | -                            |
| C1  | 2060                     | -1.97%                       |
| C2  | 2010                     | -3.11%                       |
| C3  | 1980                     | -5.92%                       |
| C4  | 1935                     | -8.93%                       |
| C5  | 1915                     | -10.99%                      |

Figure 7. Development of the density NFRAC at age of (28) days.

3.2. Compressive Strength Test
From Table 6, the compressive strength of the NFRAC specimens increased as the fiber content increased to the limit of (1.0) %, and then began to decrease at the proportions of (1.2 and 1.4) % of fiber. This attributed to the addition of fiber improved the homogeneity of the NFRAC components, but when increasing the fiber contents, this weakened the bond strength between cement and aggregates resulting from the lower cement content in this type of concrete.
Table 6. Compressive strength results for cubes of the NFRAC.

| Mix | Compressive strength (MPa) at a 7-days age | Compressive strength (MPa) at a 28-days age | Development at a 28-days age |
|-----|------------------------------------------|-------------------------------------------|-------------------------------|
| R   | 20.46                                    | 22.56                                     | -                             |
| C1  | 20.87                                    | 23.94                                     | 6.11 %                        |
| C2  | 21.52                                    | 25.78                                     | 14.27 %                       |
| C3  | 24.98                                    | 28.52                                     | 26.42 %                       |
| C4  | 21.19                                    | 24.63                                     | 9.17 %                        |
| C5  | 20.53                                    | 23.87                                     | 5.80 %                        |

Figure 8. Development of compressive strength of NFRAC at 7 and 28 days age.

3.3. Flexural Strength Test
The results of the bending test of (NFRAC) with (WPF) listed in Table 7 show an increase in the bending resistance of the fibers, which peaked at (0.8) % as a volumetric ratio of the mixture, and it was plotted in Figure 7. The bending strength increases with the increase in (WPF) as well. With processing time. Because the presence of (WPF) makes the bonding of microscopic layers significantly stronger, it strengthens the concrete texture.

Table 7. Flexural results for prisms of the NFRAC.

| Mix | Flexural (MPa) at a 7-days age | Flexural (MPa) at a 28-days age | Development at a 28-days age |
|-----|--------------------------------|---------------------------------|-------------------------------|
| R   | 1.514                          | 1.874                           | -                             |
| C1  | 1.758                          | 2.120                           | 13.13 %                       |
| C2  | 2.219                          | 2.389                           | 27.48 %                       |
| C3  | 1.927                          | 2.157                           | 15.10 %                       |
| C4  | 1.898                          | 2.118                           | 13.02 %                       |
| C5  | 1.876                          | 2.079                           | 10.94 %                       |
3.4. Thermal conductivity

The results in Table 8 show that the thermal conductivity of the NFRAC improved well with the increase in the fiber content and the use of recycled aggregates compared to the normal concrete, where the thermal conductivity coefficient of normal concrete is \((1.5) \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}\). This can be attributed to the good thermal insulation properties of plastic compared to concrete. Table 8 listed the thermal conductivity results of the NFRAC and Figure 10 shows the development of the thermal conductivity of NFRAC.

### Table 8. Thermal conductivity results of the NFRAC at a 28-days age.

| Mix | Dry density at a 28-days age | K factor | Development at a 28-days age |
|-----|-----------------------------|----------|-----------------------------|
| R   | 2028                        | 0.908    | -                           |
| C1  | 1988                        | 0.864    | -4.84 %                     |
| C2  | 1965                        | 0.840    | -7.48 %                     |
| C3  | 1908                        | 0.782    | -13.87 %                    |
| C4  | 1847                        | 0.724    | -20.26 %                    |
| C5  | 1805                        | 0.687    | -24.34 %                    |

![Figure 9. Development in flexural of NFRAC.](image)

![Figure 10. Development of the thermal conductivity of NFRAC at a 28-days age.](image)
3.5. Impact Test

By observing Table 9, the listed impact resistance results show an increase in the number of strikes with an increase in (WPF) compared to the reference mixture. This increase is because the fibers improved the energy absorption of the concrete models and enhanced their stiffness as the fibers prevented the development of cracks and by creating bridges between the ends of the crack that developed. The maximum increase in the impact resistance was (700) % at (1.4) % of (WPF). Figure 10 shows the improvement in the number of strokes for an NFRAC at a 90-day age.

| Mix | No. of blows (First Crack) at (90) days | No. of blows (Failure) at (90) days | Development of No. of blows (Failure) at (90) days |
|-----|--------------------------------------|-----------------------------------|-----------------------------------------------|
| R   | 1                                    | 1                                 | -                                             |
| C1  | 1                                    | 3                                 | 200 %                                         |
| C2  | 1                                    | 3                                 | 200 %                                         |
| C3  | 2                                    | 4                                 | 300 %                                         |
| C4  | 2                                    | 5                                 | 400 %                                         |
| C5  | 2                                    | 8                                 | 700 %                                         |

Figure 11. Development of no. of blows of NFRAC at a 90-days age

4. Conclusions

1- The use of recycled aggregate and the addition of waste fiber in different proportions has reduced the density well, as the maximum decrease in density at the age of (28) days was (10.99) % compared to the reference mix of (NFARC) at the proportion of (1.4) %, and also the dry density decreased by (24.34) %, when the percentage of fibers was (1.4) %, with a test age of (28) days.

2- The addition of waste fibers contributed to enhancing the compressive strength of the concrete with a lifespan of (28) days compared to the reference mixture of (NFARC), where the maximum enhancement of the compressive strength at the volumetric ratio (1.0) % of (WPF) was (26.48) % at the age of 28 days.
3- Flexural strength improved at Ages of (7) and (28) compared to (NFARC) reference mix by increasing the addition of waste fibers in different proportions. The maximum increase in (WPF) was (0.8) % volumes of about (27.48) % at a 28-days of age.

4- The use of recycled aggregates and the addition of different percentages of plastic waste fibers reduced the thermal conductivity coefficient, as the maximum decrease in the coefficient reached (24.34) % at the lifetime of (28) days compared to the reference mixture (NFARC) at the ratio of fiber (1.4) % of volume concrete mixture.

5- The use of plastic waste fibers in different proportions increased the impact resistance at (90) days lifetime compared to the reference mixture (NFARC). The maximum increase at (1.4) % of (WPF) was about (700) % of the resistance of the reference mixture.

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