Practical Study on the Effect of Partial Replacement of Coarse Aggregate with Plastic Waste on some Normal Concrete Properties

Jasim Jarallah Fahad AL- Kaabi1, Maha Al-Soudani*, Amjad Ali K. Sharba1
Civil Engineering Department, College of Engineering, Mustansiriyah University, Iraq.

*maha.al-soudani@uomustansiriyah.edu.iq

Abstract. Plastic waste management has become a burden and a threat for countries and major cities as well as a danger to environmental safety. The current report covers the ability of the concrete sector to use and recycle plastic wastes. The demand for concrete and raw materials for construction engineering has become very high in recent years because of urban development and the expansion of cities. Therefore, the use of this waste in civil and structural engineering is considered a successful way to get rid of plastic wastes properly to protect the environment. This research investigates the effectiveness of using plastic drinking water bottles (currently the highest plastic waste on the Iraqi market) as a partial substitution of the gravel in concrete. Plastic waste was added in different weight ratios of 2.5%, 5% and 10% as a partial substitute for the gravel and a cement mixture. A benchmark of 0% plastic wastes was prepared as a reference concrete for comparison purposes. The results show the possibility of using plastic waste, such as construction material. The results show a decrease in concrete strength by 12%, 29%, and 47%, and a reduction in concrete density by 10%, 16% and 31%, respectively. Research results show that this is useful to add plastic wastes for obtaining lightweight concrete.

Keywords: plastic waste, recycle concrete, aggregate, compressive strength, density.

1. Introduction
The development in large cities and an increase in the vast population witnessed by all countries creates more problems in environmental pollution. Since the plastic industry has proliferated and its product is very robust, most of which can only be decomposed after a very long time. The disposal of these waste materials after the first use is the biggest threat to the environment. The increasing demand for construction materials has become significant, and many studies have suggested emerging plastic waste in the concrete mixture[1].
Many types of research have been conducted on the concept of long-term sustainability and how to protect the environment against the dangers of pollution resulting from industrial and plastic waste in particular[2].
Rebeiz et al.[3] tested the strength of reinforced concrete polymers and non-reinforced concrete by recycling polyethylene terephthalate (PET) waste. The results obtained that the use of these waste materials can be produced precast concrete of good quality.
Choi et al.[4] studied the impact of replacing aggregates by PET plastic bottles waste in concrete properties. The results of this research showed that these wastes reduced the weight by 2 to 6% and the compressive strength by 33% as compared to the standard concrete mixture.

Ismail and Al Hashim[5] studied the effect of the partial replacement of the sand by plastic waste at ratios of 0%, 10%, 15%, and 20% in a standard concrete mixture. The results displayed that the spread of microcracks was halted by introduced the particles of plastic waste into the concrete mixtures. This study confirms that recycling plastic waste as a fine aggregate substitute in the concrete mixture provides an excellent approach to reduce the cost of materials and solve waste problems.

Pratima et al.[2] used plastic bottles after filling them with soil or sand and utilized these bottles as bricks and building units in wall construction. This study gave positive results in terms of time implementation, cost, flexibility and reduction of waste, and energy savings compared to the conventional construction.

Hosseini et al.[6] studied the reasons for the low strength of concrete pressure after implementing up to 1.25% of metalized plastic waste (MPW) fibres. The results concluded that the addition of the MPW fibers could increase the air voids in concrete and therefore, lower pressure strength.

The compressive strength of the concrete was studied at different percentages of recycled plastic waste (5 to 100%) by coarse and fine aggregates. The results of the study showed a gradual decrease in pressure strength with an increase in plastic waste[7].

In the current research, the effect of utilizing plastic waste from water bottles as a partial substitute for coarse aggregate on the density and compressive strength. This approach assists in protecting the environment and disposing of these wastes by using them in the structural engineering sector.

Natural coarse aggregate was utilized as an angular crushed aggregate from local sources. Locally available gravels were sieved and passed through 20 mm. Any material passing sieve 4.75 mm was ignored in order to confirm the standard sieves being used for coarse aggregate. These particles were then washed and cleaned by water several times and left to dry. Water absorption test revealed a value of 0.89%.

The goal of the current study is to find a proper way to dispose of plastic materials. Gravel in the concrete mixture was substituted by waste plastic waste residue and the changes in compressive strength and density were measured.

2. Experimental Methods

In this research, the gravel in the concrete mixture was replaced by plastic waste in three ratios of 2.5, 5, and 10%. A fourteen 150x300 mm concrete cylinders measuring was cast. Ten of the concrete cylinders was the benchmark reference (0% plastic waste replacement) and was cast with water/cement ratio 0.48 and mixing ratios of 1:1.5:3 (Cement: fine aggregate: coarse aggregate). Ten concrete cylinders were cast with partial replacement of coarse aggregate of 2.5%. Another ten concrete cylinders were cast with partial replacement of coarse aggregate of 5%. The last ten concrete cylinders were cast with partial replacement of coarse gravel of 10%.

Cement content, fine aggregate and water content kept constant in order to compare with the conventional concrete and to realize the effect of utilizing waste plastic. Aggregate: coarse aggregate: water. The following materials were used in this research:

2.1. Cement
Ordinary Portland cement, Type I, which conforms to the Iraqi Standards No. 5/1984[8, 9], manufactured by the Al- Najaf Cement Factory.

2.2. Coarse Aggregate
Coarse aggregates with a maximum size of 13 mm were obtained from Iraqi quarries, and the classification of coarse aggregate complies with the requirements of the Iraqi specifications No. 45 of 1984[9, 10].
2.3. Fine aggregate
Fine aggregate was obtained from Iraqi quarries Al-Akhaidher region with a maximum size of 4.75 mm. The Fine aggregate also conforms to the requirements of the Iraqi specifications No. 45 of 1984. [10]

2.4. Plastic waste
The plastic bottle was collected from plastic waste in Iraq, such as a plastic waste of packed water. Figures 1 and 2 display the plastic water before and after disposal, and how does it affect the environment.

![Figure 1. Water conservation bottles before use](image1)

![Figure 2. Quantity of water bottles after use for one of the big cities](image2)

Samples density was measured by dividing sample weight by volume. The density of concrete is an essential property in structural engineering because of its effect on many properties of the material such as resistance, acoustic insulation, thermal insulation and other features. The hydraulic generalized test machine system, shown in Figure 3, was used to test the cylinder samples under compression. The test machine has 2000KN capacity and is located in the laboratories of the Civil Engineering Department, College of Engineering, Mustansiriyah University Baghdad-Iraq, subjected to quality control.[11]
Figure 3: Universal Testing Machine for compressive strength

3. Results and Discussion

3.1. Compressive strength
The compression strength of the concrete samples was examined after hardening at the age of 28 days. The total of four groups was examined and each group had a mean of 10 samples as shown in Tables 1. The iron cylinders of dimensions 150x300 mm were used to examine the resistance to compression and according to the Iraqi standard 86 and C39 ASTM. It was reported that when the coarse substituted is replaced by 2.5%, 5%, and 10% of the plastic waste, the compressive strength decreased by 12%, 29%, and 47%, respectively, in comparison with the reference concrete samples, as shown in Figure 4.

Table 1: Compressive Strength of concrete containing plastic waste

| Batch number | Types  | Plastic waste Ratio by Weight of Gravel (%) | Average Cylindrical Compressive Strength \( f_c \) (MPa) | Reduction in Compressive Strength \( f_c \) (%) |
|--------------|--------|--------------------------------------------|--------------------------------------------------|-----------------------------------------------|
| 1            | CR     | -                                          | 26.3                                             | -                                             |
| 2            | Cwp2.5 | 2.5%                                       | 23                                               | 12                                            |
| 3            | Cwp5   | 5%                                         | 18.5                                             | 29                                            |
| 4            | Cwp10  | 10%                                        | 14                                               | 47                                            |

CR: Reference concrete.
CWP2.5: Partial replacement of coarse gravel for 2.5% plastic waste.
The relation time with load is shown in Figure 5. According to the results, the decrease in strength is due to the weakness of the properties of plastic waste as compared with the coarse aggregate. In terms of the specific weight and density for the plastic waste, they were about 1.38 and 1381 Kg/m$^3$, respectively, while the specific weight and density of the gravel as the control sample were about 2.61 and 2610 Kg/m$^3$ respectively.

Moreover, the reason for reduction may be attributed to the kind of waste causes air spaces inside the concrete. These causes air spaces were acceptable results shown in the group CWP 2.5 and group CWP 5 an observation. In group CWP 10, the results obtained prove that they could be used in secondary parts of the building. It is considered good with the observation of the decrease in density, as shown in Table 2. Finally, when comparing the results of this study with previous studies, a similar outcome of results.

### 3.2. Density

Lightweight concrete development has a positive effect on the building and maintenance costs as well as on the expense of the foundations. The use of different amounts and the impact on density was investigated for partial substitution of gravel by plastic residues. Replacement rates were conducted at 2.5%, 5%, and 10%. The results revealed that concrete density decreased by 10%, 16%, and 31% respectively, with the rise in the plastic waste ratio, as shown in Figures 6 and 7. This decrease might be due to the difference in the properties of the plastic waste from the physical properties of the gravel. The waste density was about 1381 Kg/m$^3$, while the gravel density was 2610 Kg/m$^3$.

Table 2 shows the change in density with the increasing percentage of plastic residues ratio as a partial substitute for gravel.
The concrete density depends on the specific weight of the materials of the combination and the concrete strength. Since recycled plastic waste typically has less density than coarse aggregate, it is anticipated that both fresh and dried densities should decrease in proportion to the degree of replacement [12, 13].

### Table 2: Density of waste plastic concrete.

| Specimen Designation | Length of strips (cm) | Replacement Ratio by Weight % of Gravel | Density Kg/m³ | Reduction density (%) |
|----------------------|-----------------------|----------------------------------------|---------------|----------------------|
| CR*                 | -                     | 0                                      | 2464          | -                    |
| Cwp2.5              | 0.25                  | 2.5                                    | 2218          | 10                   |
| Cwp5                | 0.25                  | 5                                      | 2069          | 16                   |
| Cwp10               | 0.25                  | 10                                     | 1692          | 31                   |

**Figure 6:** Density of plastic waste concrete

**Figure 7:** Reduction in Density of concrete containing plastic waste

4. Conclusions
The use of plastic waste as a partial substitute by coarse aggregate is considered a useful and effective method in the disposal of plastic waste and a successful manner to preserve the environment and is successful primarily that these wastes are found in large quantities and can be obtained easily. The results showed that the increase in the use of plastic waste in the concrete mixture reduced the compressive strength. Concrete density decreases as the content of the waste plastic materials increase as a result of the lightweight of the plastic material. The best ratios of partial replacement of aggregates with plastic wastes were 2.5%, and 5% as the results of compressive strength were reasonable and proved that the concrete could be used in loaded structural parts. However, when the ratio is at 10% replacement, the amount of compressive strength decreased to 14Mpa. As a result, the concrete, in this case, can be used in non-loaded structural parts.

5. Acknowledgement

The authors would like to express their gratitude and thanks to Mustansiriyah University, college of Engineering, Laboratory of Structure, Iraq for providing all facilities to achieve this research.

6. References

[1] 2018 House construction with plastic bottles, new Delhi. www.samarpanfoundation.org.
[2] Pratima A, Patel P A, Shah A and Patel H 2016 Waste plastic bottles offering innovative building materials with sustainable application International Journal of Innovative and Emerging Research in Engineering 3
[3] Rebeiz K S 1996 Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste Construction and Building Materials 10 215-20
[4] Choi Y-W, Moon D-J, Chung J-S and Cho S-K 2005 Effects of waste PET bottles aggregate on the properties of concrete Cement and Concrete Research 35 776-81
[5] Ismail Z Z and Al-Hashmi E A 2008 Use of waste plastic in concrete mixture as aggregate replacement Waste Management 28 2041-7
[6] Mohammad hosseini H, Tahir M M and Sam A R M 2018 The feasibility of improving impact resistance and strength properties of sustainable concrete composites by adding waste metalized plastic fibres Construction and Building Materials 169 223-36
[7] Tamang L W T, Wangmo T, Darjay K T, Phuntsho K S, Namgyal P and Wangchuk U 2017 Use of Plastics in Concrete as Coarse Aggregate International Journal of education and applied research 7
[8] Iraqi Standard Specifications N, Portland cement, Baghdad, 1984.
[9] Iraqi Standard Specifications IQS No. 5/1984 A C-
[10] Iraqi Standard Specifications N, Aggregate from natural sources for concrete, Baghdad, 1984.
[11] Urbanik T J 2006 Column Compression Strength of Tubular Packaging Forms Made from Paper Journal of testing and evaluation v. 34 pp. 1-7-2006 v.34 no.6
[12] Coppola B, Courard L, Michel F, Incarnato L, Scarfato P and Di Maio L 2018 Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates Construction and Building Materials 170 200-6
[13] Sosoi G, Barbuta M, Serbanoiu A A, Babor D and Burlacu A 2018 Wastes as aggregate substitution in polymer concrete Procedia Manufacturing 22 347-51