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Research Paper

The Possibility of Producing Waste Plastic Reinforced Eco-Friendly Recycled Aggregate Concrete

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Abstract

This article aims to study the mechanical properties of concrete containing the recycled and crushed aggregate instead of normal aggregate separately, and reinforced with volumetric ratios equal to (0.25,0.5,0.75,1,1.25 and 1.5)% of plastic fibers, which produced by cutting the plastic water bottles as a partial replacement from volume of coarse aggregate. Preliminary results showed that the compressive strength of recycled aggregate concrete(RAC) increased with increasing the waste plastic fibers (PET) more than the observed values of crushed aggregate concrete(CAC), while the results showed that the splitting tensile strength of concrete samples containing recycled aggregate have a higher splitting tensile strength than those containing the crushed aggregate. On the other hand, it was noted that the increasing in the proportions of PET from (0.25-1) % showed an increase in compressive and splitting tensile strength, but after the ratio of PET used equal to (1%), it was observed a decreasing in both of compressive and splitting tensile strength.

Keywords: *Recycled aggregate, crushed aggregate, waste plastic fibers, sustainable concrete, compressive strength, recycled aggregate concrete.*

1. Introduction

The productive use of waste material represents a means of alleviating some of the problems of solid waste management .The recycle of wastes is important from different points of view. It helps to save and sustain natural resources that are not replenished, it decreases the pollution. Wastes and industrial by-products should be considered as potentially valuable resources merely awaiting appropriate treatment and application (Arivalagan. S, 2016). According to the Central Pollution Control Board, the world produces nearly 150 million tones of plastics per year, which is nearly (4.8) tones per second and a per capita production of (25) kg/year (Al-Salem S *et al.*, 2016). Nowadays, recycled aggregates (RA) have been commonly used in concrete as the natural resources consumption and the associated environmental impacts can be reduced (Cui *et al.*, 2015;Yunsheng, Z. *et al., 2008*).So as the pollution got great in Iraq as a result of destroy infrastructures it become nessary to find a solution to reduce this pollution by reuse of recycled aggregate. Recycled aggregates (RA) can be a great alternative to natural aggregate for making different types of sustainable concrete. Several researches were investigating the effect of adding waste materials to concrete (Marinkovic *et al.,* 2010). Recycled coarse was used aggregate as partial replacement of coarse aggregate by different percentage for making concrete of different grade. The percentage replacement will be (0%, 10%, 20%, 30%, 40%, 50% and 60%) with natural coarse aggregate, the using of recycled coarse aggregate and glass fiber (volume of concrete) in concrete, leading to increasing of the splitting and flexural strength up to (60 %) as compare to normal concrete test result. The furthermore, the compressive strength was increased from 30% to 40% as compare to normal concrete test result (Rabadiya and Vaniya, 2015). It have been found that PET fibres, cut from the yarn with 700 µm diameter and 30 mm length, positively affected the strength of the resultant concrete. Addition of 1.5% (by volume) of the fibres causes an increase of the flexural strength of the concrete by about 30% and increase of the compressive strength by about 10%. Additionally, the fibre reinforced concrete can withstand the loads from cracking (Ochi *et al.,* 2007). The highest compressive strength was obtained for PET particle sizes of 0.5 mm and 2.5% volume and cured for 28 days, while the highest strain values were detected for 1.5 mm and 5.0% volume and cured for 7 days (Liliana *et al.*, 2013). That reduction in 28-day compressive strength varies from 11 to 72% as the percentage replacement of mixed waste plastic with sand or aggregate increases from 0 to 50% (Wong, 2010; Batayneh *et al.*, 2007; Al-Manaseer and Dalal, 1997).

2. Materials and Methods

Materials: Ordinary Portland cement conforming to the ASTM C150 was used in this work with specific gravity of 3.15 g/cm^3. Blaine fineness of this cement was equal to 300 m^2/kg. Chemical composition, physical and mechanical properties of them are given in table No.1 and 2 respectively.

Table 1: Physical Properties of Cement

Physical properties	Test result	Limits of Iraqi Specification No.5/1984
Setting time(minutes): • Initial setting • Final setting	 120 360	 45 minutes ≤ 600 minutes
Fineness by Blaine method (m^2/Kg)	300	≥ 230
% Auto Clave	0.31	≤ 0.8

Table 2: Chemical Properties of Cement

Oxide	*Weight (%)*	*Limits of Iraqi Specification No.5/1984*

CaO	62.3	-
SiO_2	20.28	-
Al_2O_3	5.55	-
Fe_2O_3	4.20	-
MgO	2.60	5.0
K_2O	0.75	-
Na_2O	0.4	-
SO_3	2.4	$\leq$ 2.8
Loss on Ignition	1.65	$\leq$ 4.0
Lime saturation factor	0.81	0.66 – 1.02
Insoluble Remains	0.5	1.5 %
F.L	0.65	-
Total	99.63	-
Compound	Weight (%)	Iraqi Specification Limits No.5/1984
C_3S	50.05	-
C_2S	20.45	-
C_3A	4.05	-
C_4AF	13.20	-

Fine aggregate of (4.75) mm maximum size was used in this investigation. Sand used is conforming to the requirements of the Iraqi Specification (IQS No. 45/1984), as shown in table No.3.

Table 3: Physical and Chemical properties of fine aggregate

Properties	*Test results*	*Limit of Specification*
Specific gravity	2.60	-
Absorption	0.75%	-
Sulphate content as SO_3 %	0.08	0.5 %

The coarse aggregate used in this work was a crushed gravel with a maximum size of (10) mm. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in table No.4, which conforms to the Iraqi specification (IQS No. 45/1984). The recycled aggregates used in this study were provided by the broking the old concrete samples or from destroyed buildings in Iraq. The test results, such as the maximum size, specific gravity and water absorption are given in table No.5.

Table 4: Physical and Chemical properties of coarse aggregate

Properties	*Test Results*	*Limits of specification*
Specific gravity	2.60	---
Absorption	0.69	---
Dry loose unit weight kg/m^3	1593	---
Sulphate content (as SO_3) %	0.08	0.5 %

Table 5: Physical and Chemical properties of recycled aggregate

Properties	*Test results*
Water absorption (%)	5.6
Specific gravity	2.32
maximum size(mm)	10

Table 6: Mixture proportions of concrete containing (PETs), (part 1 and 2)

Group	Mix Design	Cement (kg/m^3)	Sand (kg/m^3)	Crushed Aggregate (kg/m^3)	Recycled Aggregate (kg/m^3)	PET (kg/m^3)	Water (kg/m^3)
1	RAO.PET 0.25%	430	696.66	1093.9	0	2.47	192.77
	RAO.PET 0. 5%	430	696.66	1981.18	0	5.48	192.77
	RAO.PET 0.75%	430	696.66	1088.44	0	8.22	192.77
	RAO.PET 1%	430	696.66	1085.7	0	10.96	192.77
	RAO.PET 1.25%	430	696.66	1082.95	0	13.7	192.77
	RAO.PET 1.5%	430	696.66	1080.21	0	16.45	192.77
2	CAO.PET 0.25%	430	696.66	0	1093.9	2.47	192.77
	CAO.PET 0.5%	430	696.66	0	1981.18	5.48	192.77
	CAO.PET 0.75%	430	696.66	0	1088.44	8.22	192.77
	CAO.PET 1%	430	696.66	0	1085.7	10.96	192.77
	CAO.PE T 1.25%	430	696.66	0	1082.95	13.7	192.77
	CAO.PE T 1.5%	430	696.66	0	1080.21	16.45	192.77

The waste plastic fibers were obtained from cutting the bottles of soft drink as rectangular pieces by using a paper shredder with the net length of (40) mm, average width of (4) mm and thickness of (0.35) mm . The volumetric percentages of WPFs that were used are (0.25, 0.5, 0.75, 1, 1.25 and 1.5)% of the all concrete mix volume. The specific gravity of these fibers was (1.096). The mixture proportioning studied in the experimental program is shown in table No.6. Two groups of mixes were used in this research, the first group containing crushed gravel aggregate and the second group included recycled aggregate, WPFs has been added as a partial replacement from aggregate volume for each group, according to (PET) replacement level from coarse aggregate represented by crushed and recycled aggregate. For example, (RA0PET1) indicates the mixture containing 0% of recycled aggregate and 1% of WP fibers.

Types of Specimens: Steel moulds were utilized for this work. The control specimens which used in all tests were as follow:

Cubes of (100*100*100) mm were used for testing of compression concrete strength. Cylinders of (100*200) mm were used for splitting tensile concrete strength.

Concrete mixture: The details of the mixtures which used in this work are given in table No.6. The water/cement ratio of (0.488) for all concrete mixtures.

Preparing of Concrete Specimens: In this work, it was utilized a mechanical mixer of (0.1) m^3 capacity for mixing the components of concrete to get the required homogeneity. At the beginning, the interior surface of the mixer had been cleaned and moistened before placing the materials. First the coarse and fine aggregates were mixed with (1/3) of the mixing water for a period of (1) minute. Then cement and remaining water were added and the ingredients mixed for a period of 3 minutes. Finally, the fibres were added and the mixing was continued until the concrete had become homogenous and got good consistency. Then for casting stage, the steel moulds had been oiled with mineral oil according to ASTM C 192-88. Casting of concrete was carried out in layers each of (50) mm nearly. Each layer was compacted by using a vibrating table for (15-30) second until air bubbles disappeared from the surface of the concrete and the concrete is levelled off smoothly to the top of moulds and marked by name of specimen. The specimens were unmolded after 24 hours and immersed in curing water until the age of test. The specimens were tested at age of (3, 7, and 28 days).

Testing of Hardened Concrete: Compressive Strength: The average of compressive strength of three cubes was recorded for each testing age (3,7, and 28) days. The compressive strength was calculated according to ASTM C39.

Splitting Tensile Strength: The average of splitting tensile strength of three cylinders was recorded for each testing age (3,7, and 28) days. The splitting tensile strength was calculated according to ASTM C496-86.

2. Results and Discussions

Compressive Concrete Strength: Effects of adding waste plastic fibers (WPFs) to the recycled aggregate (RA) and crushed aggregate (CA) on the compressive strength are shown in Fig.1 , Fig.2

and Fig.3 respectively. Interestingly two distinct scenarios are observed. Firstly, compressive strength of the concretes continuously increased up to volumetric percentage of WPFs equal to (1%), beyond which strength began to decrease, irrespective of aggregate type. Secondly, the CA concretes had lower compressive strength compared to RA concrete, irrespective of WPFs content. The reason of this is the fiber after which (1%) had formed bulks and segregate on mix. This led to form stiff bond about these bulks.

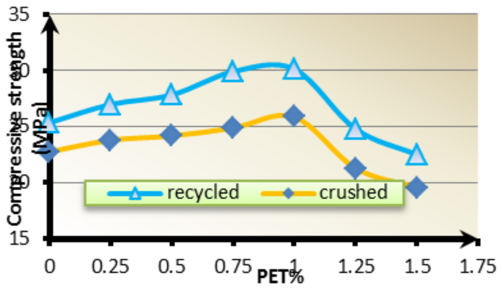

Fig. 1: The relationship between compressive strength and volume of waste plastic fibers at 3 days age.

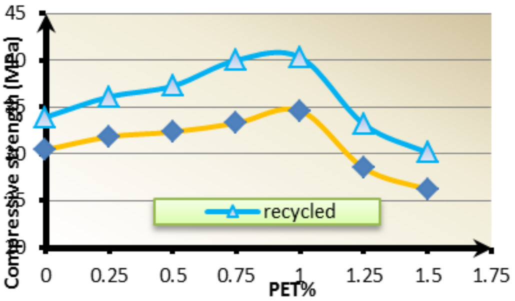

Fig. 2: The relationship between compressive strength and volume of waste plastic fibers at 7 days age

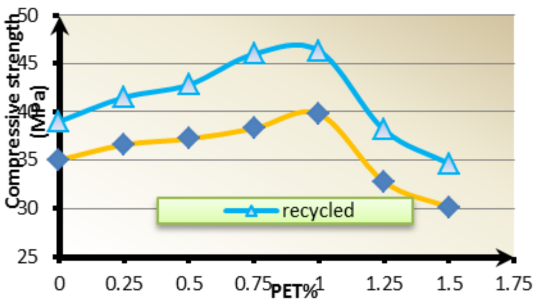

Fig. 3: The relationship between compressive strength and volume of waste plastic fibers at 28 days age.

From these figures it can be seen that, the compressive strength of all specimens increases with time, but the percentage of increasing in compressive strength differs between the reference concrete RC and the WPFs reinforced concrete. Indeed, among the different WPFs contents studied, concrete with (RA) aggregate had the highest compressive strength from (3 to 28) days which could be attributed to the greater bonding force and strength adding to this (RA) containing higher percentage of fine materials ,which was capable of filling up the voids more effectively.

Splitting Tensile Concrete Strength: When an amount of tensile stress is introduced to concrete, first micro-cracks thereafter macro cracks form. The increase in the load encourages critical crack progress at the tip of macro-cracks, which ultimately lead to concrete failure (N. Banthia ,1994). The easiest way to determine a tensile strength of concrete indirectly is by splitting tensile test. The study of tensile strength is essential to supply information regarding the maximum tensile load that concrete can withstand before cracking. The growth in splitting tensile strength versus WPFs content is presented in Fig.4, Fig.5 and Fig.6 for the concrete with RA and CA respectively. It was found that the splitting tensile strength increased with curing time and addition of WPFs up to (1%) for the two series of concretes. At the age of (28) days, adding (0.25%, 0.5%,0.75%,1%,1.25% and 1.5%) of WPFs cause an improvement of splitting tensile strength by (12.4%, 13.58%, 2.4%, 4.94%, 4.55%, 10.78% and 1.11%) compared to that with no contain of (PET). This can be attributed to great porosity, which may have been filled with concrete mix and improvement of the ITZ microstructure between RA and cement paste leading to increasing their bond strength.

On the other hand, the enhanced extents of splitting tensile strength were immediately limited after adding (1%) of WPFs by volume of coarse aggregate type. This may be because of the amount of WPFs which is greater than the amount necessary to combine with the other cementitious material particles during the process of hydration.

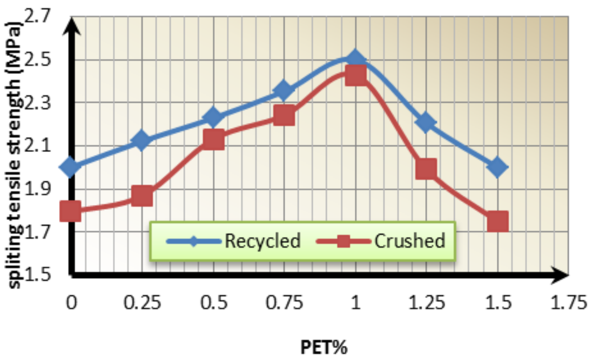

Fig.4: The relationship between splitting tensile strength and volume of waste plastic fibers at 3 days age.

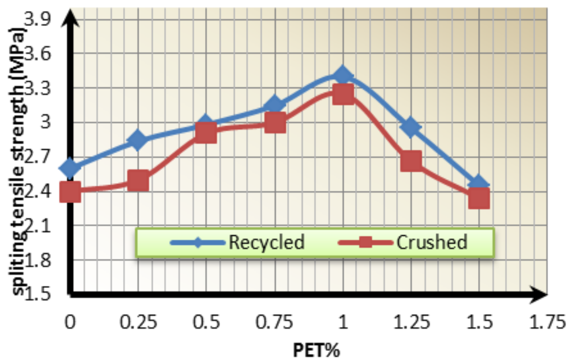

Fig. 5: The relationship between splitting tensile strength and volume of waste plastic fibers at 7 days age.

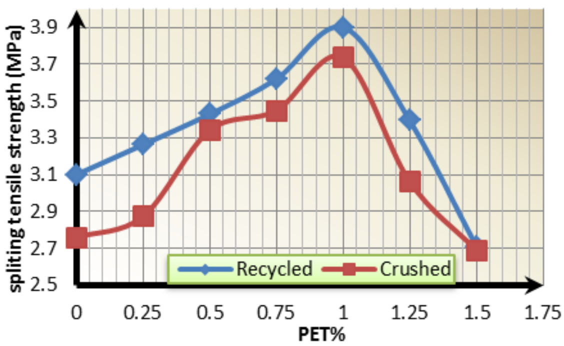

Fig.6: The relationship between splitting tensile strength and volume of waste plastic fibers at 28 days age

3. Conclusions

The following conclusions can be drawn from this study:
It was observed that the use of recycled aggregate had better performance on the characteristics of concrete compared to the crushed aggregate.
It was found that the compressive strength of concrete developed with curing time and using (PET). Adding (0.25%,0.5%, 0.75% ,1%,1.25% and 1.5%) (WPFs) improved the compressive strength with using of (RA) by (11.42%, 13.38%, 15.1%, 20.2%, 16.46%, 16.48% and 14.97%) respectively, compared to (CA) concretes.
The splitting tensile strength improved by utilizing of (RA) more than (CA) using regardless of (PET) for all ages.

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