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Research paper

Mechanical Properties of Polyvinyl Chloride Plastics Recycled Aggregate Concrete

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Abstract

The concrete prepared with Polyvinyl chloride plastics (collected from doors and windows wastes) as recycled coarse aggregates and their concrete engineering properties are studied in the laboratory in this research. The concrete blends have an expected cylinder compressive strength of 28 MPa. In this research, the concrete blends contain plasticcoarse aggregate.The ratio of this aggregate to the total aggregate volume ranges from 0 to 1. The concrete strength properties in tension and compression are greatly affected with the plastic replacement ratio. The blends density reduces with increasing replacement ratio. For low replacement ratio, the effect is practically marginal. It is not acceptable to use ACI 318 code spilt cylinder equation for plasticaggregate concrete with higher replacement ratio

Keywords: *Compressive strength, Concrete, Recycled, Tensile strength, waste plastics.*

1. Introduction

The major component of concrete blends is the aggregate which comprise 65–80% of the mix volume.The aggregate affect the properties of resulting concrete blend such as workability, strength, and durability. The use of waste or recycled materials in concrete blends can solve the problem of the large amount of waste disposal. The environmental pollution problems andaggregate scarcity in construction sites can be solved through this technique[1]. Iraq and especially, Baghdad is producing more waste each year. Over the past 40 years, the waste produced in Iraq has more than six times, from 0.5 million tons in late 1970 to about 3 million tons in 2010 around 2 kg of waste each day. The utilization of plastic waste materials as aggregate in concrete blends has an important applications because plastic material has enlarged toughness, fine abrasion resistance, lesser thermal conductivity and large heat capacity [2]. The rigid Polyvinyl chloride(PVC) has been used effectively in the different applications and generates huge waste material. It is important to dispose this waste material by reusing it in the concrete composition. This application may save energy and reduce the demand to primary mineral resources. Therefore, the reuse of plastic waste material in concrete is considered the best environmental alternative method to reduce the environmental pollution and safeguarding the natural resources.Sustainable concrete is a concept of use eco- friendly materials in concrete to make the structure more sustainable at less energy in its production and produces less carbon dioxide than normal concrete. Different waste materials are used as a partial replacement to cement or can be used as aggregate in sustainable concrete, so the environment isprotected from waste deposits. The green concrete was first originated in Denmark in the 1998 [3]. Elzafraney et al. (2005) [4] studied the thermal insulation due to using recycled plastics (polyvinyl chloride (PVC) as a partial replacement for natural coarse aggregates in structures for construction and design purposes.Jasim (2009) [5] replaced partially the natural coarse aggregate using plastic hollow aggregate (PHA) with different shape. This PHA aggregate can be utilized in nonstructural Concrete units.Mathew et al (2013) [6] investigated the utilization of recycled plastics in concrete mixes as coarse aggregate. The physical plastic aggregate properties of density, specific gravity, and crushing value of plastics were measured.Khalaf (2015) [7] used waste plastic aggregate as substitution of natural aggregate to produce sustainable concrete. The mixture content percentage were (1 : 1.2:1.8) (cement: sand: gravel) by weight of cement. The addition of (Styrene- Butadiene – Rubber) SBR in the mix enlarged the compressive, splitting tensile and flexural strength. Lafta (2017) [8] developed lightweight concrete using plastic aggregate with varying percentages 25%, 50% and 75% for four mixtures (SBR) to gain higher strength.

This research focuses on recycling waste material and using it as a coarse aggregate such as plastics and reducing cement content in the concrete mix in order to produce sustainable concrete. Therefore, the studyis devoted to evaluate the effects of using waste plastic aggregate instead of natural aggregate on themechanical properties of resulting concrete.

2. Experimental Program

2.1 Materials

2.1.1 Cement

The used Type I cement properties are given in Tables 1 and 2. They stratify to the Iraqi Specification No. 5 [9].

Table 1: Chemical testing of cement

Oxide composition	Content	Limits of Iraqi Specification No.5 [9].

CaO	63.26	-
SiO2	19.22	-
Al_2O_3	4.51	-
Fe_2O_3	3.34	-
MgO	2.62	(5) maximum
SO3	2.05	(2.8) maximum
Loss on ignition	2.40	(4) maximum
Insoluble residue	0.48	(1.5) maximum
Lime saturation factor	0.93	(0.66-1.02)
C_3S	70.60	-
C_2S	2.30	-
C_3A	6.30	-
C_4AF	10.10	-

Table 2: Physical testing of cement

Physical properties	Test result	Limit of Iraqi Specification No.5 [9]
Specific surface area (Blaine method) m^2/kg	350	230 (minimum)
Setting time (Yicale's method) **Initial setting, hrs.: min** **Final setting, hrs.: min**	 2:33 5:25	 00:45 (min.) 10:00 (max.)
Compressive strength, MPa **3 days** **7 days**	 20.5 26.5	 15.00 (minimum) 23.00 (minimum)
Autoclave expansion %	0.25	0.8 (maximum)

2.1.2 Fine aggregate

A 4.75mm maximum size of sand having fineness modulus of (2.87) was used. The sand sieve analysis is shown in Table-3 which is relevant to the Iraqi Specification No. 45[10]. Table-4 shows the sand physical properties.

Table 3: Sieve analysis of fine aggregate

Sieve size (mm)	Passing %	Limit of Iraqi Specification No. 45 for zone 2 [10]
10	100	100
4.75	96	90-100
2.36	76	75-100
1.18	58	55-90
0.6	37	35-59
0.3	9	8-30
0.15	2	0-10

Table 4: Physical properties of fine aggregate.

Properties	Test results	Limit of Iraqi Specification No. 45/1984 [5]
SO_3 %	0.35	≤ 0.5
Specific gravity	2.65	---
Absorption %	1.8	---

2.1.3 Coarse aggregate

The maximum size of (10 mm) crushed gravelhaving specific gravity (2.64)was used in the concrete blends. The coarse aggregate sieve analysis is shown in Table 5 which is relevant to the Iraqi Specification No. 45 [10].

Table 5: Grading of coarse aggregate

Sieve size (mm)	Passing %	Limit of Iraqi Specification No. 45 [10]
12.5	100	100
9.5	98.14	85-100
4.75	14.08	10-30
2.36	1.94	0-10
1.18	0.96	0-5

2.1.4 Recycled coarse aggregate

PVC plastic waste aggregate of size 10 mm and thickness of 1.5 mm is used as coarse aggregateas shown in figure (1). The specific gravity was (1.36)with (0.0%) water absorption at (24 hr) and have bulk density (800 kg/m^3).

This type of aggregate cannot be used at higher temperatures because of the melting point of this plastic is low about 200 C^0. This type of thermoplastic plastic is from the polyolefin family. It is the polymer of the vinyl chloride monomer. The molecular formula of PVC plastic is (C_2H_2Cl).The grading of recycled coarse aggregate is shown in Table 6.

Table 6: Grading of recycled coarse aggregate

Sieve size (mm)	Passing %	Limit of Iraqi Specification No. 45 [10]
12.5	100	100
9.5	94.24	85-100
4.75	60.42	10-30
2.36	2.3	0-10

Fig. 1: PVC plastic.

2.1.5 Super plasticizer

The superplasticizer used in this work was PCE 600 which has been primarily developed for applications in the precast, light weight and aerated concrete industries.

PCE 600 is different than conventional superplasticizer based on sulfonated melamine and naphthalene formaldehayde condensate, which create electrostatic repulsion of particles. Table 7 indicates the technical description of the aqueous solution of the superplasticizer used throughout this work by weight of cement.

Table 7: Properties of superplasticizer[11].

1	**Properties**	**superplasticizer**
2	Appearance	Yellow liquid
3	Specific gravity	1.06 @ 20^o c
4	Air entrainment	1% Maximum
5	Chloride content	Zero
6	Nitrate content	Zero

2.1.6 Mineral Admixture (Silica Fume (SF)):

The used silica fume satisfies the conditions required by ASTM C1240 [12]. The silica fume is used herein in order to reduce cement content and therefore producing sustainable concrete.

2.1.6 Concrete mixtures

Sixteentrial mixtures have been tested in order to study the effect of PVC waste aggregate on properties ofconcrete and to develop sustainable concrete. The blends requiredstrength in compression was (28MPa) for bothcrushed gravel concrete (NAC)and (RAC) plastic coarse aggregate concrete. The mix design suggested by ACI 211.1/1991 [13] is used to design the concretemixtures. The blends are shown in Table-8 and Table-9. The water cement ratio (w/c) is varied in order to obtain workability in the mix.

Table 8: Mix proportion of RA concrete mixtures

M ix N	Cem ent cont	San d (kg/	Gra vel (kg/	% Replace ment of	% Superplast isizer. by	%Silica Replace ment of	W/ C

o.	ent (kg/ m³)	m³)	m³)	gravel	wt. of cement	cement	
R 1	525	626	945	100	1.5	15	0.2 4
R 2	460	625	945	25	2.3	15	0.3 4
R 3	460	625	945	50	2	15	0.3 4
R 4	460	625	945	75	2	15	0.3 4
R 6	460	625	945	100	2	15	0.3 4
R 6	400	625	945	100	2	15	0.3 4
R 7	375	637. 5	1125	100	2	15	0.3 1

*where (R) mean recycled aggregate.

Table 9: Mix proportion of NA concrete mixtures

Mix No.	Cement content (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	% Superplastisizer. by wt. of cement	%Silica Replacement of cement	W/C
N1	400	700	1100	0	0	0.4 5
N2	525	625	945	0	0	0.4 1
N3	525	624.7 5	945	1.5	15	0.2 3
N4	525	625	945	1.5	15	0.2 3
N5	525	625	945	2.3	15	0.2 4
N6	300	600	1200	2	15	0.3 3
N7	250	725	1100	2	15	0.3
N8	275	800	1000	2	15	0.3 6
N9	275	700	1000	2	15	0.3 6

*where (N) means natural aggregate.

2.2 Mechanical Properties of Concrete

2.2.1 Workability (Slump Test)

The workability of blends was measured immediately after blendsof concrete constitutes in accordance with test method of ASTM C143 [14]. The w/c ratio for high strength concrete mixture was adjusted to have thesame workability (slump of 95 ± 5mm) as shown in table (9) and figure (2).

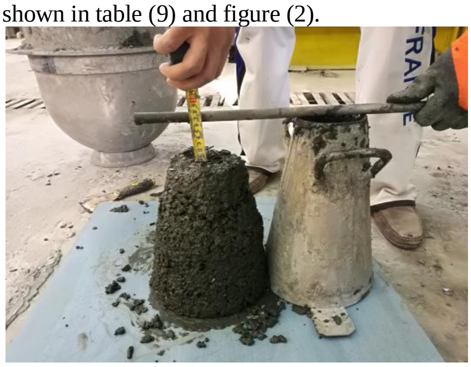

Fig. 2: Slump test

2.2.2 Fresh Density Test

The concrete fresh density for all blends was calculated immediately after blending concrete (ASTM C 138M-01) [15]. It was determined using the following equation:

$$\gamma_f = (W_c - W_m) / V_m \quad (1)$$

where:
γ_f is the fresh concrete density (kg/ m^3).
W_c is the weight of mold contains concrete blends (kg).
W_m is the weight of empty mold (kg).
V_m is the volume of the mold (m^3).
The result show that density decrease with increasing percentage of replacement to 100% and turn the mixture to light weight aggregate concrete mixas shown in table 9.

Table 9: Fresh density and slump

Mix No.	Fresh density(kg/m³)	Slump (mm)
R1	2116	-
R2	2314	85
R3	2210	90
R4	2086	98
R5	1992	-
R6	1950	100
R7	1871	60
N5	2452	100
N6	2385	60
N7	2430	60
N8	2433	190
N9	2485	60

2.2.3 Cube Compressive Strength

The universal testing machine is used for testing samples in compressionwhich relevant to BS1881-116, 1997 [16] for cubes (f_{cu}) 100mm x 100mm x 100mm as shown in figure (3). Testing was carried out at 28 days;three cubes were tested at each time.Table 10 reveals the results of tests on concrete cubes under compression. It is obvious that the compressive strength of LWA concrete will be lesser when plastic aggregate percentage increases. In case of 100% plastic aggregate was used, the compressive strengths of concrete will be lesser by about 17% (difference between mix N5 and R1). The reason for reducing concrete strength devoted to the properties of waste aggregate and waste constitutes. According to ACI 318/2014 [17] all recycled aggregate concrete mixes can be used for producing structural concrete.

Fig. 3: Compression test

2.2.4 Splitting tensile strength

This test wasmade on specimens which relevant to ASTMC496/ 2006 [18]. The testsamples were three (100×200mm) cylinders and tested as shown in figure (4).The test results (the average of three samples)are shown in Table-10. It is obvious that the tensile strength have lower values as plastic or recycled aggregate percentageenlarged. The reason for reducing tensile concrete strength is devoted to the properties of waste aggregate and waste constitutes. The natural aggregate are stronger than waste aggregate in resisting tensile stresses.The ACI 318/2014 [17] split cylinder strength equation (**$f_{ct} = 0.56\sqrt{f'c}$**)underestimate the value of tensile strength for natural or normal aggregate concrete and recycled or waste aggregate.

Fig. 4: Splitting tensile test

Table 10: Cube compressive and splitting tensile strength result

Mix No	Cube compressive strength (MPa) @ 28days	Tensile Strength (MPa)@-28days	ACI 318/2014[17] Tensile Strength Equation $f_{ct}=0.56\sqrt{f'c}$	Percentage Difference from ACI 318/2014 Equation
N1	**24.8**	**-**	**2.78**	**-**
N2	**33.2**	**-**	**3.23**	**-**
N3	**32.2**	**-**	**3.18**	**-**
N4	**37.7**	**-**	**3.43**	**-**
N5	**64.6**	**3.84**	**4.5**	**-14.66**
N6	**32.7**	**2.68**	**3.2**	**-16.25**
N7	**26**	**1.88**	**2.86**	**-34.26**
N8	**34.5**	**2.205**	**2.29**	**-3.71**
N9	**37.6**	**2.36**	**3.43**	**-31.19**
R1	**53.7**	**2.95**	**4.1**	**-28.05**
R2	**50.2**	**2.66**	**3.97**	**-33.0**
R3	**40.2**	**2.52**	**3.55**	**-29**
R4	**44.5**	**2.44**	**3.736**	**-34.7**
R5	**33.3**	**2.55**	**3.23**	**-21.05**
R6	**34.9**	**1.74**	**3.31**	**-47.4**
R7	**22.5**	**1.61**	**2.65**	**-39.2**

3. Conclusions

The following study conclusionsare obtained in the present work:
The concrete tensile and compressive strengths varied in values whichrelated on the plastic aggregate replacement ratio.This may be discarded for ratio lower than 25%. For higher replacement ratio, the mechanical properties are lowered with enlarging plastic aggregate content. It is preferred to use replacement ratio of 25% All studied concrete blends are considered as structural concrete according to ACI 318/2014.
The equation developed by ACI 318/2014 for obtaining split tensile strength equation is giving lower value than experimental one for normal aggregate concrete. For concrete blends having plastic aggregate content higher than 50%, it is not recommended to use the ACI equation.
The density of concrete decrease with increasing the percentage of PVC plastic replacement.
PVC plastic aggregate require less water in the blends than natural aggregate.

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