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MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE

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ABSTRACT

This research presents an experimental investigation on the engineering properties of concrete prepared with crushed tiles as recycled coarse aggregates. Concrete mixes with a design compressive strength of 30MPa are made using recycled aggregates with percentages ranging from 0 to 100% of the total coarse aggregate. Their influence on concrete mechanical properties is investigated. As a result, it has been obtained that using recycled aggregate to replace part of the normal coarse aggregate effects the elastic modulus, tensile strength and compressive strength with a value depends on the coarse aggregate replacement percentage. For low percentages of recycled aggregate (25%) it can be obvious that this influence is practically negligible. It may be concluded that the use of recycled aggregates in concrete may help to solve a very important environmental issue and gives a solution to the problem of inadequate concrete aggregates. The comparison of test results with ACI 318 code spilt cylinder and modulus of elasticity equations show that these equations are not recommended to be used for recycled aggregate concrete with percentage exceeding 25%.

Keywords: concrete, experimental study, mechanical properties, recycled aggregates.

1. INTRODUCTION

In Iraq, it has been recognized that destroyed building and construction waste volumes are large and increasing every year. The problem of waste accumulation and management exists in different countries. Most of construction wastes are used or left as a landfill material. Environmental side effect can be reduced by making more sustainable use of the construction waste [1]. The increasing cost of landfill coupled with the increase in aggregate production requirement for construction, has made the using of recycled aggregate (RA) to partially replace the natural aggregate is more interesting issue. While the economical and environmental advantages of using recycled aggregates are obvious, some problems related to durability aspects resulted in recycled aggregates being used practically only as base filler for road construction. Concrete, however, is one of the interesting applications where recycled aggregates can be used. The use of recycled aggregate in the production of concrete became one of the most important fields in the reuse of such waste materials in the building construction. The utilization of (RA) recycled aggregates is a good solution to problems of increasing disposable material, provided that the product good quality should be obtained. Accordingly, the performance characteristics of concrete with recycled aggregates require reassessment in relation to normal aggregate concrete [2].

Literature reports [3, 4] show that the performance of recycled concrete material is affected by the cement mortar bonding the aggregate particles. This residual mortar change aggregate water absorption and density and can have side effects on concrete material performance.

The utilization of construction waste such as crushed tiles as an aggregate in structural concrete production would have a major positive effect on the construction economy also. Namely, a preservation of available natural materials is significant for a sustainable building that would be cost effective also. This kind of building has low cost materials that can be used without any negative impact on the environment [3].

While studies on the mechanical and engineering properties of concrete made with laboratory crushed old concrete aggregate are limited [5, 6], only few data are available on grade recycled aggregate, including durability aspects, concrete mixture proportions and fresh concrete performance. Thus, this paper evaluates the effects on the mechanical properties of hardened concrete containing natural and graded recycled aggregates.

2. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (OPC) (Type-I) is used. The chemical and physical tests results of the used cement are given in Tables 1 and 2. They conform to the Iraqi Specification No. 5/1984 [7].

Table-1. Chemical composition of cement*.

No.	Compound composition	Chemical composition	(weight) %	Iraqi specification no. 5/1984 [7]
1	Lime	CaO	62.23	-
2	Silica	SiO_2	19.66	-
3	Alumina	Al_2O_3	4.66	-
4	Iron Oxide	Fe_2O_3	3.44	-
5	Magnesia	MgO	2.83	<5
6	Sulfate	SO_3	2.61	<2.8
7	Free lime	Free CaO	1.23	-
8	Loss on ignition	L.O.I	3.95	<4
9	Insoluble residue	I.R	1.27	<1.5
10	Lime saturation factor	L.S.F	0.94	0.66-1.02
11	Tricalciumsilicate	C_3S	55.23	-
12	Dicalcium silicate	C_2S	14.7	-
13	Tricalcium aluminate	C_3A	6.53	-
14	Tricalcium alumina ferrite	C_4AF	10.46	-

*All tests were made at the National Center for Construction Laboratories.

Table-2. Physical composition of cement*.

Physical properties	Test results	Iraqi specification no. 5/1984 [7]
Setting time (Vicat's Method) Initial, (hr: min) Final, (hr: min)	 3:5 4:15	 ≥45 min ≤600 min
Fineness (Blain Method) m^3/kg	351	≥230m^3/kg
Compressive Strength, MPa 3 days 7 days	 21.5 31	 ≥15, MPa ≥23, MPa

*All tests were made at the National Centre for Construction Laboratories.

2.1.2 Fine aggregate

Natural sand brought from Al-Ukhaidher region was used in the concrete mix. The fine aggregate has (4.75mm) maximum size with smooth texture and rounded particle shape with fineness modulus of (2.84). The grading of the fine aggregate is shown in Table-3. The obtained results indicate that the so_3 content and the fine aggregate grading are within the Iraqi Specification No. 45/1984[8].

Table-4 shows the specific gravity, so_3 content and absorption of the fine aggregate.

Table-3. Grading of fine aggregate*.

No.	Sieve size (mm)	% Passing	
		Fine aggregate, %	Iraqi specification no. 45/1984 for Zone(2) [8]
1	4.75	96.1	100
2	2.36	85.7	95-100
3	1.18	74.6	80-100
4	0.6	49.8	50-85
5	0.3	11	25-60
6	0.15	2	5-30
7	pan	0	0-10

Table-4. Physical properties of fine aggregate*.

Physical properties	Test results	Iraqi specification no. 45/1984 for Zone(2)[8]
Specific Gravity	2.66	-
Sulfate Content	0.08 %	≤ 0.5 %
Absorption	0.75 %	-

*All tests were made at the National Centre for Construction Laboratories.

2.1.3 Coarse aggregate

Crushed gravel with maximum size of (10 mm) from AL- Nibaee zone was used in the tests. The aggregates were washed and stored in air to dry the surface, and then stored in a saturated surface dry condition before using. The specific gravity was (2.64). The grading of the coarse aggregate is shown in Table 5. The obtained results show that the coarse aggregate grading was satisfying the requirement of the Iraqi Specification No. 45/1984 [8].

Table-5. Grading of coarse aggregate*.

No.	Sieve size	Passing %	
		Coarse aggregate %	Iraqi specification no. 45/1984 [8]
1	14	100	100
2	10	100	85-100
3	5	21	0-25
4	Pan	0	-

*All tests were made in the National Center for Construction Laboratories.

2.1.4 Recycled coarse aggregate

Only crushed mosaic tiles are used as coarse recycled aggregates with the maximum nominal size of 10 mm in this study. The specific gravity was (2.45). The characteristics of the aggregates were established in order to study their possible application in concrete production.

2.1.5 Super plasticizer

GLENIUM 51 in an admixture of a new generation based on modified polycarboxylicether. This product has been developed to be used in concrete production where the highest material performance and durability is required. It's free of chloride and low alkali and compatible with all types of cement. The product guidance suggest that the dosage of super plasticizer is (0.2 - 1 %) liter by weight of cement. Table-6 gives the properties of the super plasticizer

Table-6. Properties of the used Super plasticizer*.

Appearance	Turbid liquid
Density	1.095 kg/It.
Chloride content	Free

*Given by the manufacture.

2.1.6 Concrete mixtures

Five mixtures have been designed with different proportions to study the effect of recycled aggregate on the mechanical properties of concrete. The required compressive strength of this study was (30MPa) for natural coarse aggregate concrete (NAC). The concrete mixtures were designed according to the ACI mix design method ACI 211.1/1991 [9]. The used superplasicizer percentage was 0.4% and the water cement ratio was 0.45 as shown in Table-7. The symbol (RAC) refers to recycled coarse aggregate concrete.

Table-7. Mix proportion of concrete mixtures.

Mix symbol	Quantities (kg/m^3)				
	Cement	sand	Gravel	Recycled aggregate	Replacement ratio
NAC	350	700	1050	0	0%
RAC25	350	700	787	263	25%
RAC50	350	700	525	525	50%
RAC75	350	700	262	788	75%
RAC100	350	700	0	1050	100%

2.2 Mechanical properties of hardened concrete

2.2.1 Cube compressive strength

The universal testing machine is used for testing the compressive strength of concrete according to ASTM C39M/2003 [10] for cylinders (f_c') measuring 150mm x 300mm and BS1881-116, 1997 [11] for cubes (f_{cu}) 150mm x 150mm x 150mm. Testing was carried out at 28 days and at age of testing, three cylinders and three cubes were tested at each time.

The results of compression tests on concrete cubes and cylinders are shown in Tables 8. It can be seen from this table that the compressive strength decrease as recycled aggregate percentage increases. When 100% recycled aggregate was used, the compressive strengths concrete were reduced by about 30.9%. According to ACI 318/2014 [12] all recycled aggregate concrete mixes can be used for structural concrete. The Ratio between cylinder strength to cube strength decreased by 11 % with increasing recycled aggregate percentage from 0 to 100%,.

Table-8. Compressive strength of concrete.

Mix	Replacement ratio	Compressive strength (MPa)		Cylinder strength/Cube strength	Percentage difference from NAC for cubes
		Cubes	Cylinders		
NAC	0%	31.4	26.5	0.844	-
RAC25	25%	29.3	24.37	0.832	-6.7%
RAC50	50%	27.2	22.17	0.815	-13.4%
RAC75	75%	25.6	20.53	0.802	-18.5%
RAC100	100%	21.71	17.15	0.79	-30.9%

2.2.2 Splitting tensile strength

The splitting tensile strength tests were carried out on concrete specimens in accordance with ASTM-C496/ 2006 [13]. Split cylinder strength tests were made on two (150×300mm) cylinders placed horizontally between the loading surfaces of compression testing machine.

The results of tensile tests on concrete cylinders are shown in Table-9, where each value is the average of two measurements. It can be seen from this table that the tensile strength decreases as recycled aggregate percentage increases. When 100% recycled aggregate was used, the tensile strength of concrete was reduced by about 38.91%.

The ACI 318/2014 [12] split cylinder strength equation ($f_{ct} = 0.56\sqrt{f_c'}$)underestimate the value oftensile strength for normal aggregate concrete by 6.55% and overestimate the value by 23.14 for 100% recycled aggregate concrete. It is not recommended to use this equation for recycled aggregate concrete with percentage exceed 50%.

Table-9. Splitting tensile strength.

Mix	Repayment ratio	Tensile strength (MPa)	Percentage difference from NAC	ACI 318/2014 [12] tensile strength equation $f_{ct} = 0.56\sqrt{f'_c}$	Percentage difference from ACI 318/2014 equation
NAC	0%	2.75	-	2.57	-6.55%
RAC25	25%	2.52	-8.36%	2.47	-1.99%
RAC50	50%	2.28	-17.09%	2.35	+3.07%
RAC75	75%	2.04	-25.82%	2.26	+10.8%
RAC100	100%	1.68	-38.91%	2.07	+23.14%

2.2.3 Modulus of elasticity

The lab measurement of modulus of elasticity of concrete for concrete was carried out in accordance with ASTM-C469 /2004 [14] technique (secant to 0.4 of compressive strength), using (150 ×300mm) concrete cylinders tested in compression at constant strain. The results are given in Table-10.

The results of the modulus of elasticity test on concrete cylinders are shown in Table-10, where each value is the average of three measurements. It can be seen from this table that the modulus of elasticity decreases as recycled aggregate percentage increases. When 100% recycled aggregate was used, the modulus of elasticity of concrete was reduced by about 31.97 %.

The ACI 318/2014 [12] modulus of elasticity equation ($E_c = 4700\sqrt{f'_c}$) underestimate the value of tensile strength for normal aggregate concrete by 1.45% and overestimate the value by 16.54 for 100% recycled aggregate concrete. It is not recommended to use this equation for recycled aggregate concrete with percentage exceed 25%.

Table-10. Modulus of elasticity for concrete.

Mix	Repayment ratio	Modules of elasticity (MPa)	Percentage difference from NAC	ACI 318/2014 modulus of elasticity equation $E_c = 4700\sqrt{f'_c}$	Percentage difference from ACI 318/2014 equation
NAC	0%	2455	-	2419.4	-1.45%
RAC25	25%	2232	-9.1%	2320.2	+3.95%
RAC50	50%	2088	-14.9%	2213	+5.98%
RAC75	75%	1927	-21.5%	2130	+10.53%
RAC100	100%	1670	-31.97%	1946.3	+16.54%

3. CONCLUSIONS

From the experimental tests carried out on concrete specimens, the following conclusion can be drawn:

a) The using of recycled aggregate as partial replacement of coarse aggregate effects the tensile strength, compressive strength, and elastic modulus with value depend on the percentage of partial replacement. It is obvious that the influence is practically negligible for low percentages of substitution (25%). For higher percentages of aggregate replacement all the mechanical properties are decreased with increasing the recycled aggregate content. For the recycled aggregates, the optimum value or percentage that can be used to replace normal coarse aggregates is 25%.

b) According to ACI 318/2014 all recycled aggregate concrete mixes obtained in this study can be used for structural concrete. The ratio between cylinder strength to cube strength decreased by 11 % with increasing recycled aggregate percentage from 25 to 100%.

c) The ACI 318/2014 split cylinder strength equation underestimate the value of tensile strength for normal aggregate concrete by 6.55% and overestimate the value by 23.14 % for 100% recycled aggregate concrete. It is not recommended to use this equation for recycled aggregate concrete with percentage exceed 50%.

d) The ACI 318/2014 modulus of elasticity equation underestimate the value of tensile strength for normal aggregate concrete by 1.45% and overestimate the value by 16.54 % for 100% recycled aggregate concrete. It is not recommended to use this equation for recycled aggregate concrete with percentage exceed 25%.

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