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Shear Behavior of Waste and Natural Coarse Aggregate Concrete Beams

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Abstract: The waste concrete material recycling process is a sustainable solution for the problem of increasing construction waste disposal and resources lack of natural aggregate. The study of a concrete casted with recycled aggregates which is called waste or recycled aggregate concrete is become more interesting now a days for producing structural elements. The performed laboratory test is carried out to trace the shear response of waste aggregate concrete beams and comparing it with the behavior of same beams with Natural Aggregate Concrete (NAC) under loading applied monotonically. Two different waste aggregate contentsas a percentage to the total aggregate mass in the mixtures of concrete (0, 50 and 100%) and two ratios of shear span to effective depth (1.5 and 3) without and with stirrups were considered in the present work investigation. Small-scale laboratory tests were selected and performed on nine specimens with simple supports until collapse. The load-deflection response, crack distrbutions, failure modes, cracking deflections and ultimate loads of natural coarse aggregate and waste coarse aggregate concrete beams were compared based on the obtained test results. The results revealed that the waste aggregate beams shear response may be considered to be satisfactory or acceptable when compared to the response of natural coarse aggregate beams in terms of cracking and ultimate loads. The obtained ultimate shear strength for the tested beams (with no stirrups) exceeds the shear cracking strength by different percentages ranging from 30-43% for different waste aggregate percentage. The ultimate shear strength of the tested beams (with stirrups) exceeds the shear cracking strength by different percentages ranging from 98-126 % for different waste aggregate content and shear span.

Key words: Experimental, monotonic loading, recycled aggregate, reinforced concrete beams, shear span, strength

INTRODUCTION

The lack of area for construction waste disposal is becoming a major problem in every country (Meyer, 2002; Saravanakumar and Dhinakaran, 2013). The recycling of deposited building materials, primarily concrete may be considered to be a solution to the lack of natural resources of aggregates and construction waste problems. The obtained Recycled Concrete Aggregate (RCA) may be used for different construction applications, ranging from using waste materials in the pavement base layer to the use in the casting of structural concrete. Waste concrete recycling now became a technology of waste recycling which have environmental and economic advantages (Marinkovic *et al*., 2010; Shah *et al*., 2013). A small amount of waste aggregate was implemented in casting structural concrete members in comparison to huge quantities of waste concrete found in some countries. Waste aggregate may be used at road base layer or as a filler behind retaining walls. Also, RCA was used previously only in the concrete construction of non-structural elements. There are many technical causes for that, relating to the waste aggregate quality such as lower weight density and higher absorption of water in comparison with natural aggregate and varied impurities contents. These mentioned important concrete properties have an important effect on the properties of Recycled or waste Aggregate Concrete mixture (RAC) (Yang *et al*., 2008).

Certain researches on studying the properties of recycled aggregate were in progress, since, 2011 which consider the durability and response of waste concrete structural elements (RAC) (Marinkovic *et al*., 2012).

Al-Zahraa *et al*. (2011) investigated experimentally the shear tests on recycled concrete coarse aggregate beams. Twelve beam specimens with varied content of recycled or waste coarse aggregates, stirrups and shear spans were laboratory tested to resist two point loads until failure. Fathifazl *et al*. (2011) investigated the shear response of coarse recycled aggregate beams. The equivalent mortar volume method of mixture was used. Several beams without stirrup were designed and tested for shear based on this new mix design method. Arezoumandi *et al*. (2014) investigated the shear capacity or strength response of beams casted with full waste or Recycled Concrete Aggregate (RCA). This experimental program comprised testing 12 beams (six for each mixture of concrete). The parametric study included steel reinforcement ratio and concrete mixture or type. Knaack and Kurama (2015) studied the behavior of waste aggregate normal strength concrete beams in both shear and flexure. The experimental test results for 12 concrete beam specimens were compared with the relevant code equations. Choi and Yun (2016) investigated the shear response of concrete beams made with waste aggregate and without stirrups. The test program variables were 3 replacement ratios (0, 30, 60 and 100%) of recycled aggregate and 5 shear span to depth ratios (2.0, 2.5, 3.0, 4.0 and 5.0). The researchers work compared the laboratory results with the results obtained using relevant ACI 318 code equations and equations proposed in the literature. It was found by previous researchers that the code equations can estimate the failure shear loads of waste concrete beams very well and therefore, it is possible to use these equations to speculate the shear capacity of structural elements with waste aggregate.

Research significance: There is a lack of shear testing of waste coarse aggregate concrete beams as shown in the review of literature in the previous paragraph, particularly with higher replacement of aggregate and beams with stirrups. This research gives the major basis for safely using waste aggregate in the structural design according to ACI 318 code. The other objective is to develop a testing process to speculate the shear strength of RAC beams made with local building materials in Iraq. The experimental or laboratory test program and test results analysis for this study are presented.

MATERIALS AND METHODS

Experimental program

Properties of materials: The following materials are used in casting beams of this research. Type I (Ordinary Portland cement) which is conformed to the Iraqi Specification No. 5 (1984). The sand was of (4.75 mm) maximum size. The gravel (natural aggregate) was of maximum size of (10 mm). Only waste laboratory concrete samples of 30 MPa concrete gradeare used as waste coarse aggregates (same maximum size). It was expected that the existing of cement mortar in the used waste aggregate made the aggregate gains higher absorption of water and lower unit weight than the ordinary natural aggregate. The test results showed that the water absorption and specific gravity for recycled aggregate was 4 and 2.41%, respectively and for natural coarse aggregate was 0.6 and 2.64%, respectively. The grading of used recycled and natural aggregates is given in Table 1 which corresponds to the Iraqi specification Anonymous (1984).

The results of laboratory tensile test for steelbars applicable with the ASTM A615 (2016).

Table 1: Grading of used coarse aggregate

Sieve size (mm)	Natural aggregate percentage passing (%)	Recycled aggregate percentage passing (%)	Limit of Iraqi specification No. 45 (1984)
12.5	100.00	100.0	100
9.5	97.60	96.8	85-100
4.75	16.20	18.9	10-30
2.36	3.80	6.5	0-10
1.18	0.75	2.0	0-5

Table 2: Properties of concrete mixes

Variables	NAC	RAC 50	RAC 100
Cement (kg/m^3)	400	400	400
Fine aggregate (kg/m^3)	750	700	700
Natural coarse aggregate (kg/m^3)	1150	570	-
Recycled coarse aggregate (kg/m^3)	-	570	1150
Water/cement ratio	0.45	0.52	0.51
Superplasicizer (% by weight of cement)	0.2	0.4	0.8
Slump (mm)	70	80	110

Table 3: Compressive strength of beams at 28 days

Sample	NAC	RAC 50	RAC 100
f_{cu} (MPa)	33.70	33.200	31.500
f'_c (MPa)	27.30	26.200	25.200
f'_c/f_{cu}	0.81	0.790	0.800

Table 4: Splitting tensile strength

Sample	f_{ct}) exp (MPa)	f'_c (MPa)	$f_{ct} = 0.56\sqrt{f'_c}$ (MPa)	f_{ct}) ACI/f_{ct}) exp
NAC	2.86	27.3	2.93	1.02
RAC50	2.10	26.2	2.87	1.37
RAC100	2.05	25.2	2.81	1.37

SikaViscoCrete-5930 is the super plasticizer used in the concrete mixture according to ASTM C494 (1980) Type G and F.

Properties of beams concrete

Material proportion: The design concrete beams grade or cylinder compressive strength was (27 MPa) for all mixes. Mixture details are given in Table 2. Three mixes with 0, 50 and 100% of replacement of Natural coarse Aggregate (NA) with waste coarse Aggregate (RA) are obtained.

Mechanical properties of hardened concrete: The results of both cube (f_{cu}) and cylinder (f'_c) concrete grade or compressive strengths are given in Table 3. The laboratory tests were carried out according to BS1881-116, using three (150 mm) cubes and ASTM-C39 (2004), using three (150×300 mm) cylinders for each casted beam.

The split cylinder strength (f_{ct}) laboratory tests was carried out using two (150×300 mm) cylinders (ASTM-C496 (2011)) for each casted beam. Table 4 shows the splitting tensile strength for the tested concrete specimens (exp) and that calculated using ACI (2011) code equation. The ACI equation gives higher values of the split tensile strength than the experimental one by 2 and 37% for natural and waste aggregate concrete, respectively.

Table 5: Modulus of rupture strength

Samples	f_r) exp (MPa)	f'_c (MPa)	$f_r = 0.62\sqrt{f'_c}$ (MPa)	f_r) ACI/f_r) exp
NAC	3.72	27.3	3.24	0.87
RAC50	3.64	26.2	3.17	0.87
RAC100	3.53	25.2	3.11	0.88

Table 6: Modulus of elasticity

Samples	E_r) exp (MPa)	E'_c (MPa)	$E_c = 4700\sqrt{f'_c}$ (GPa)	E_C) ACI/E_C) exp
NAC	25.85	27.3	24.56	0.95
RAC50	22.48	26.2	24.06	1.07
RAC100	21.64	25.2	23.59	1.09

Table 7: Designation and properties of test specimens

Beam No.	Specimen designation	Recycled aggregate (%)	Ratio of shear span to effective depth (a/d)	Stirrups
1	NAS0-1.5	0	1.5	Without
2	RA50S0-1.5	50	1.5	Without
3	RA100S0-1.5	100	1.5	Without
4	NAS1-1.5	0	1.5	With
5	RA50S1-1.5	50	1.5	With
6	RA100S1-1.5	100	1.5	With
7	NAS1-3.0	0	3.0	With
8	RA50S1-3.0	50	3.0	With
9	RA100S1-3.0	100	3.0	With

NA: Natural coarse Aggregate concrete; RA50: Recycled or waste coarse Aggregate concrete with replacement 50%; S0: without stirrups; S1: with Stirrups; No: ratio of beam shear span to effective depth (a/d)

Table 5 shows the results of the modulus of rupture strength (f_r) test (exp) using 3 prisms of dimensions (100*100*400 mm) (ASTM C78, (2002)) for each casted beam and the values calculated using Anonymous (2011) code equation. The ACI equation gives lower values of the modulus of rupture than the experimental one by 12% for natural and waste aggregate concrete.

The testing of static elasticity or Young modulus of concrete (E_c) was carried out using (150×300 mm) concrete cylinders for each casted beam (Anonymous, 2002). As given in Table 6, the ACI equation gives higher values of the elasticity modulus of waste aggregate concrete by 8% and lower values for natural aggregate concrete by 5% than the experimental one.

RESULTS AND DISCUSSION

Testing of beams

Test set-up and instrumentation: Nine beams with simple supports and having a length of 2 m were casted. The beams are subjected to two-point loading test. The ratio of beam shear span to (effective) depth (a/d) was of 1.5 and 3.0 for the tested beams as shown in Fig. 1. Beam displacements were recorded through dial gages. The beams were loaded until failure. The load controlled testing method is used with load increment of 1/10 of the expected ultimate load. The study investigates the shear response of the concrete beams with almost constant compressive strength and several cases of recycled aggregate, stirrups and (a/d) ratio as shown in Table 7.

Table 8: Laboratory test results of concrete beams

Specimens designation	P_u (kN)	Δ_y (mm)	Δ_y (mm)	Ductility factor $=\Delta_u/\Delta_y$	Energy absorbed (kN mm)
NAS0-1.5	70.1	7.8	6.2	1.26	382
RA50S0-1.5	59.3	6.2	5.1	1.21	257
RA100S0-1.5	48.4	5.6	5.2	1.08	172
NAS1-1.5	120.2	23.1	15.0	1.54	2145
RA50S1-1.5	99.3	18.3	13.1	1.40	1445
RA100S1-1.5	82.4	15.4	12.8	1.20	925
NAS1-3.0	125.2	27.1	14.8	1.83	2714
RA50S1-3.0	105.4	23.3	15.2	1.53	1863
RA100S1-3.0	95.3	19.5	15.1	1.30	1400

P_u: Ultimate load capacity (kN); Δ_y; Δ_u :Beam mid span deflection at yielding load and ultimate load respectively (mm)

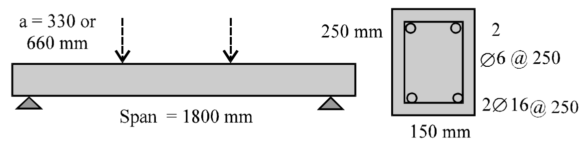

Fig. 1: Tested beams details

The ACI (2011) code is used to design beams. The design of reinforcement was carried out to ensure that the beam section failed in shear. The longitudinal or bottom tensile reinforcement was (2 φ 16 mm) and the top compression reinforcement was (2 φ 6 mm). Six of the nine beams had stirrups of (φ 6 @250 mm c/c). The beam specimen dimensions and the steel bars mesh are shown in Fig. 1.

The beams sketches after failure are shown in Fig. 2. Also, the laboratory test results of loads and deflections are listed in Table 8. For specimens without stirrups, the crack pattern and responses were similar with diagonal tension mode of failure as shown in Fig. 2. The failure happens suddenly when inclined cracks, extends and reaches the beam compression zone. Figure 3 shows the tested specimens load deflection curves in this group. It is obvious that the beams without stirrups shows or exhibits linear response until the happening of first shear cracking. After that, the specimen strength is reduced and the deformation is enlarged with different behaviors for each specimen which depends on waste aggregate content.

For beams with stirrups, the general cracking pattern and response were similar with shear compression mode of failure. The failure occurs with warning and not sudden because of using stirrups.

The ductility factor and energy absorbed were observed to be higher for natural aggregate concrete beams and they increased for beams having stirrups with increasing a/d ratio.

From Fig. 3-5, it is obvious that the natural aggregate concrete beams have higher ultimate loads than the ACI-318 theoretical load. While for waste aggregate concrete beams the ultimate loads were recognized to be lesser than the theoretical load and this is attributed to the nature of used aggregate.

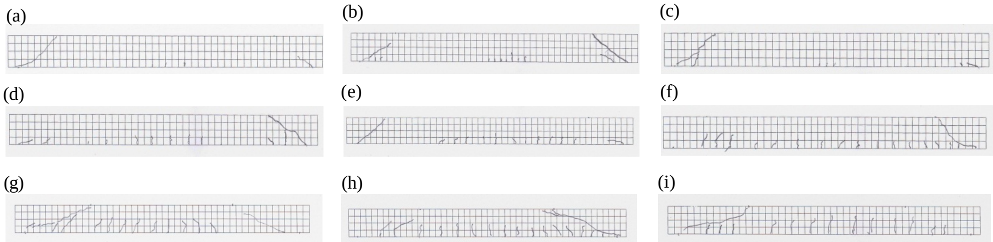

Fig. 2: Tested beams crack patterns: a) NAS0-1.5; b) RA50S0-1.5; c) RA100S0-1.5; d) NAS1-1.5; e) RA50S1-1.5; f) RA100S1-1.5; g) NAS1-3.0; h) RA50S1-3.0 and i) RA100S1-3.0

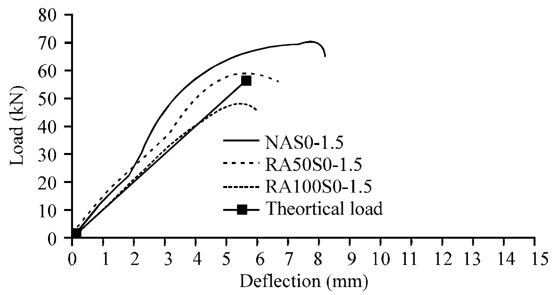

Fig. 3: Load mid span deflection curves for beams without stirrups (a/d = 1.5)

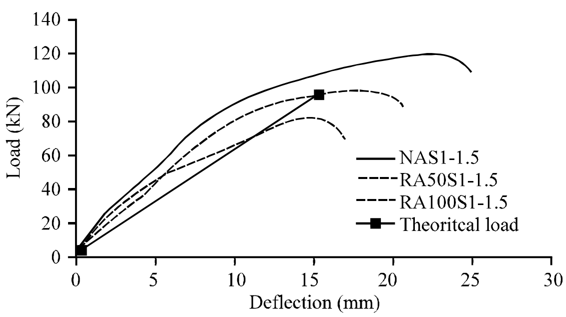

Fig. 4: Load mid span deflection curves for beams with stirrups (a/d = 1.5)

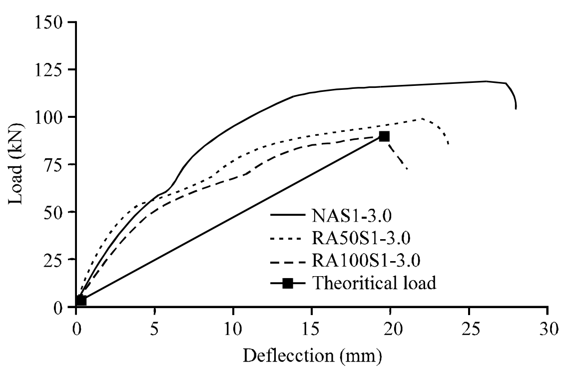

Fig. 5: Load mid span deflection curves for beams with stirrups (a/d = 3.0)

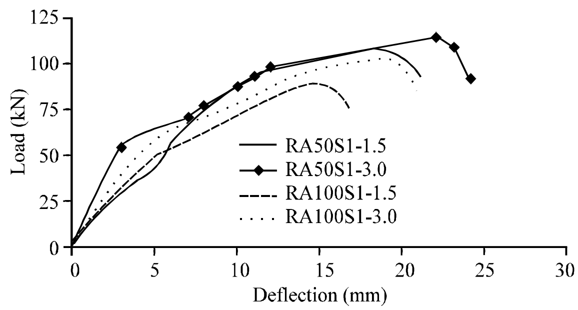

Fig. 6: Load mid span deflection curves for beams with stirrups (variable a/d)

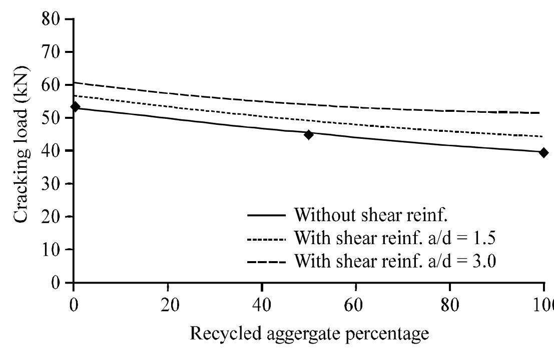

Fig. 7: Effect of recycled aggregate percentage on cracking load for different a/d ratio

It is obvious from Table 8 and Fig. 4-6 that the deflection or vertical displacement response becomes softer as the waste aggregate content increases with same other study parameters. At the same applied load level, the vertical displacement or deflection of beam for 100% replacement of RAC (RA100S1-1.5) is higher than that of beams with 50% replacement of RAC (RA50S1-1.5). Also, it had to be noted that the tested specimen cracking load and ultimate shear capacity increases as the RAC ratio decreases as shown in Fig. 7 and 8. For the natural aggregate specimen NAS1-1.5 (0% replacement of RCA), the ultimate load is larger than that of waste aggregate specimen RA100S1-1.5 (100% replacement of RCA).

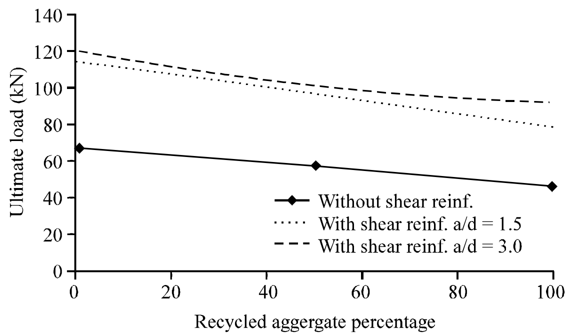

Fig. 8: Effect of recycled aggregate percentage on ultimate load for different a/d ratio

From Fig. 6 it is obvious that the shear span had a lesser effect on the beam deflection at the early loading stages. However, the beam with higher shear span shows larger inelastic deformations or deflections at failure. For beams with stirrups, the failure or ultimate shear load increases when the shear span reduces. Beams NAS1-1.5, RA50S1-1.5 and RA100S1-1.5 with lower shear span show lesser ultimate load at failure compared with NAS1-3.0, RA50S1-3.0 and RA100S1-3.0, respectively.

CONCLUSION

Based on the laboratory tests that were carried out to obtain the mechanical properties of waste coarse aggregate, the following points are concluded. The ACI 318 split tensile strength equation for natural aggregate concrete overestimates the strength by 2 and 37% for natural and waste or recycled aggregate concrete, respectively. The ACI 318 equation gives lower value by about 12% for the modulus of rupture compared to the experimental one for natural and waste aggregate concrete. The ACI 318 equation gives higher values for the elasticity modulus of recycled aggregate concrete by 8% and lower values for natural aggregate concrete by 5% compared to the experimental one.

The main conclusions obtained from the experimental work on waste aggregate concrete beams are as follows. For specimens without stirrups, the crack pattern and responses were similar with diagonal tension mode of failure. The failure happens suddenly when inclined cracks, extends and reaches the beam compression zone. The beam ultimate shear load exceeds the load that cause cracking by a percentage varies from 30-43% depending on waste or recycled aggregate content.

For beams with stirrups, the general cracking pattern and responses were similar with shear compression mode of failure. The failure occurs with warning and not sudden because of using stirrups. The beam ultimate shear load exceeds the load that cause cracking by a percentage varies from 98-126% for variable waste aggregate content and shear span.

IMPLEMENTATIONS

The implementation of stirrups in beams leads to alteration of the failure mode from diagonal tension failure to ductile shear compression failure. The cracking and ultimate loads are found to be increased by 20 and 53%, respectively for the case of beams with stirrups.

The deflection or vertical displacement response becomes softer as the waste aggregate content increases with same other study parameters. At the same applied load level, the vertical displacement or deflection of beam for 100% replacement of RAC (RA100S1-1.5) is higher than that of beams with 50 % replacement of RAC (RA50S1-1.5).

The tested specimen cracking load and ultimate shear capacity increases as the RAC ratio decreases. For the natural aggregate specimen NAS1-1.5 (0% replacement of RCA), the ultimate load is larger than that of waste aggregate specimen RA100S1-1.5 (100% replacement of RCA).

The shear span had a lesser effect on the beam deflection at the early loading stages. However, the beam with higher shear span shows larger inelastic deformations or deflections at failure. For beam specimens with stirrups, the failure shear load increases when the shear span reduces. Beams NAS1-1.5, RA50S1-1.5 and RA100S1-1.5 with lower shear span show lesser ultimate load at failure compared with NAS1-3.0, RA50S1-3.0 and RA100S1-3.0, respectively.

The natural aggregate concrete beams show higher ultimate loads than the ACI-318 theoretical load. While for waste aggregate concrete beams, the ultimate loads were recognized to be lesser than the theoretical load and this is attributed to the nature of used aggregate.

The ductility factor and energy absorbed were observed to be higher for natural aggregate concrete beams and they increased for beams having stirrups with increasing a/d ratio.

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