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Research paper

Assessment of Reinforced Recycling Aggregate Concrete Beams Under Torsional Moment

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Abstract

The recycling of aggregate concrete (RAC) is the ideal solution for reducing the natural resources. The experimental works have been carried out to investigate the torsional moment behavior and the strength of RAC beams in comparison with those beams consisting of natural aggregate concrete (NAC). Nine beams were casted with different compression strengths of concrete (25, 45, and 70 MPa), and coarse RAC of three different percentages within the full bloc of coarse aggregate in concrete mixes (0, 50, and 100%), with the same reinforcement ratio. The properties of the concrete comprised of recycled and natural aggregates were investigated. The results showed, that the difference in the torque of first crack is less than 12.5% for RAC and NAC beams, while the difference in ultimate torque is less than 7.7% for RAC and NAC. Also, it can be conclude that, the torsional moment performance of RAC beams is acceptable as compared to the conduct of NAC beams and the use of RAC is practically possible

***Keywords**: Reinforced concrete beam; Recycled aggregates; Torsional moment behavior*

1. Introduction

It has been estimated that approximately 1,111,788 tons of concrete are currently demolished each year in Iraq (the Iraqi Environmental Ministry), and the waste from construction and demolition works are of huge volumes and are only increasing with time. For the environmental reason, both abstraction quantity and ultimate size of units of waste have been limited, and the growing request for concrete in the building sites great pressure on the requirement of component materials inclusive aggregate. Consideration has formerly been moved to substitutional types of aggregates like aggregate from old concrete. Reuse of aggregates from collapse concrete structures came into workout many years ago, and from initially it has been believed for its two essential environmental benefits: resolve the growing problem of waste space, and the preservation of the given natural provenance of aggregates [1]. The use of (RAC) is one such effort at the economy of raw material and is a singular method to resolve some of the disorder in civil engineering [2]. The idea of utilizing RAC is increasingly obtaining in scalability now, and investigation in this scope is making progress. When recycled aggregates square measure made of pure materials that contain over ninety-fifth of pervious concrete, the final product can typically be clean enough to satisfy specifications for concrete aggregates while not being washed [3]. Studies relating to the characteristic of recycled aggregates, and the essential properties of recycled concrete have been orderly conducted over the latest few periods, resulting in a numeral of nation making efforts at establishing recommendations supporting their use [4]. Torsion relates to one of the master structural influence besides flexure, shear and axial compression/tension that leads to further sort of brittle failure of concrete structures.
This is a leading phenomenon that must be taken into consideration when designing the different classes of reinforced concrete structures, such as spandrel beams, horizontally curved beams, spiral staircases, skew bridges, space frames and et cetera.

2. Literature review

Previous investigators had focused primarily on the treatment of demolished concrete, the mix design, the physical and the engineering properties. Greatest of the findings are widely studied and mentioned by Hansen [3]. The reports exposed that the applicable material advantage of RAC are mostly inferior to those of traditional concrete. RCA tend to be more porous, have higher properties of absorption, and relatively lower specific gravity than normal aggregates [4]. One of the properties of concretes made with RCA yield a lower strengths than their parallel made with normal gravel [5]. A 100% replacement of coarse aggregate by recycled aggregate, will result in approximately a 9% decrease in compressive strength [6], and it is also estimated to yield a 15% decrease in the modulus of elasticity of recycled aggregate concrete. However, only a modicum studies have been conducted in the domain of structural behavior (behavior in flexure state, shear, torsion, etc.) [7]. There are some published research papers that deal

with the use of recycled aggregates in structural behavior such as those authored by Choi et al. [8] who rated the shear strength of twenty reinforced concrete beams. These beams consisted of different span-depth ratios (1.50, 2.50, and 3.25), longitudinal reinforcement ratios (0.53, 0.83, and 1.61%), and RCA replacement ratios (0, 30, 50, and 100%). Outcomes of their investigation presented that the higher RCA replacement ratio led to lower shear strength. Schubert et al. [9] studied the behavior of 14 slabs with 100% recycled coarse aggregate and reported that RAC slabs can be designed using the same design equations as for control concrete. Arezoumandi et al. [10], tested 18 beams with three different longitudinal reinforcement ratios, and the two RCA blends are various in the total of RCA permutation, (50 and 100%). Results of that research showed that the 100%RAC beam has 11% lesser shear strength parallel with the 50%RAC and NAC beams; but the 50%RAC and NAC beams showed comparable resistance of shear strength.
Many investigations have been reported on recycled aggregate, but the research of torsional strength with recycled aggregate are limited.

3. Experimental work

The experimental program based on the simile of the torsional presentation of reinforced concrete beams containing natural aggregate concrete NAC with RAC using three different level of compressive strength of concrete (25, 45 and 70 Mpa) . Also, three various proportion of coarse RAC in a full quantity of coarse aggregate in concrete mixes (0, 50, and 100 % by weight). The same reinforcement ratio, were used as the main parameters in this analysis.

3.1. Materials

3.1.1. Cement

Ordinary Portland cement (Type I) produced in Iraq from Mass Company was utilized in casting the specimens. It was tested as per Iraqi Standard Specification (I.Q.S. No. 5:1984) [11].

3.1.2. Sand

Spotless river sand is used which has fineness modulus of (2.9), specific gravity of (2.63) and sulfate content of (0.39%) by sand weight, which is minimal than the limit of Iraqi standard specification No. 45 / 1984 [12].

3.1.3. Coarse Aggregate

3.1.3.1. Natural Coarse Aggregate

The coarse mixture that was applied for this survey was traditional weight crushed mixture with most size of 14 millimeter and compliant to ASTM C33-02 [14], and the Iraqi Specification No. 45/1984 [12]. Table (1) shows the physical properties of the normal coarse aggregate consistent with limit of Iraqi specification.

Table 1: Physical properties of natural coarse aggregate

Physical properties	*Test result*	*Limit of Iraqi specification No.5:1984*
Specific gravity	2.65	-
Absorption	0.7%	-
Crushed value	15%	-
Sulfate content	0.06%	0.1% (max)

3.1.3.2. Recycled Coarse Aggregate

Recycled coarse aggregate was obtained by hand crushing the cubes salvaged from old concrete and having strength of (25-35) MPa. The particles in portions of various sizes were recombined to give a grading similar to that of the natural coarse aggregates that had a maximum size of (14 mm) (the debris having been selected, cleaned and sieved in the laboratory). The specifications were ASTM C33-02 [13], and Iraqi Standard Specification (No. 45: 1984) [12], with analysis of the sieve of this type of coarse aggregate. Table (2) shows physical properties of recycled coarse aggregate according to the limit of Iraqi specification No.5:1984

Table 2: Physical properties of recycled coarse aggregate

Physical properties	*Test result*	*Limit of Iraqi specification No.5:1984*
Specific gravity	2.4	-
Absorption	3.6%	-
Crushed value	21%	-
Sulfate content	0.08%	0.1% (max)

3.1.4. Water

Clean faucet water was used for curing and mixing of specimens.

3.1.5. Superplasticizer

The superplasticizer utilized during the mixing was “Glenium 51” the standard dosage of (0.5 liter per 100 kg of cement) as advocate by the manufacturer. This material classified as types (A) and (F) in ASTM C494-05 [14]. The aim of using this admixture was to improve workability and to reduce the (w/c) ratio to increase the ultimate compressive strength of concrete. The relative density of it is (1.1 g/cm3 @ 20º C) and PH= 6.6.

3.1.6 Silica fume

Silica fume (SiO_2) (very fine amorphous silica particles <1µm) is applied as concrete soft additive. Adding SiO_2 fills in the spaces between cement grains because of the very small particles in a concrete mixture. The (SiO_2) reacts with calcium hydroxide to form additional binder material. The properties of SiO_2, according to the manufacturer’s specifications, complies with the ASTM C1240-04 [15].

3.2. Mix proportions

Proportions of the mix were confirmed to output reinforced concrete with a workability limit by slump values range (5 and 10 cm) according to ASTM C143-00 [16]. Varied trial mixes were prepared according to the recommendations of the ACI 211.1-97 [17]. Three kinds of concrete, NAC , RAC50 (50% by mass of NAC replaced by RAC), and RAC100 (100% by bloc of NAC replaced by RAC), were used. The concrete mixes NAC and RAC were designed to get the same compressive strength and workability. The various mixes of material incorporating superplasticizer were obtained by rising the potion of admixture progressively and regulate the water-cement ratio. The mixture of concrete was designed to obtain cylinder strength of (25, 45 and 70 Mpa) at 28 days. Mixing details are given in Table (3). It was create that the used blend produces good workability and the uniform mix of concrete.

Table 3: Details of mixes

Group	Compressive strength	Specimen Notation	Cement kg/m3	Sand kg/m3	Gravel (kg/m3)		Water l/m3	Glenium51 l/m3	Silica fume kg/m3
					Normal	Recycled			
N25	25 MPa	25NC	350	700	1050	-	170	-	-
		25R50	350	700	525	525	170	1	-
		25R100	350	700	-	1050	170	1.6	-
M45	45 MPa	45NC	430	745	960	-	185	5	50
		245R50	430	745	480	480	185	8	50
		45R100	430	745	-	960	185	11	50
H70	70 MPa	70NC	450	750	1000	-	126	12.5	50
		70R50	450	750	500	500	126	16	50
		70R100	450	750	-	1000	126	19	50

Three cylinder samples of (diameter 150 mm, height 300 mm), were cast for each kind of concrete for the determination of compressive strength testing as prescribed by ASTM C39-01[18], whilst three additional cylinders (of diameter 150 mm, height 300 mm), were cast in order to test the modulus of elasticity based on ASTM C469-02 [19],. Another three cylinders of diameter 150 mm, height 300 mm were cast for the testing of splitting tensile strength, according to ASTM C496-96 [20], along with a plain concrete beam of (100 × 100 × 500 mm) loading to determine flexural strength (modulus of rupture) according to ASTM C78-02 [21]. Criterion curing process complete for all concrete segment, and the nine beams which were cured under the same situations. The properties of hardened concrete mixes are existing in Table (4) founded on normal values for three tested samples at 28 day.

3.3. The beams' specimen description

The nine beams that were cast were designed with rectangular cross-sectional dimensions of (100 mm width by 200 mm height and 1500 mm length). Beams were designed according to (ACI 318-14M) [22], with steel reinforcement of (1%) for transverse and longitudinal reinforcement. The proportion of reinforcement incorporated in the beam was a little advanced than the lowest required (minimum total reinforcement for torsion (1%)) [23]; (4 ∅10 mm) as longitudinal reinforcement was located around the edge of the beam and (∅6 @50 mm) for transverse reinforcement (Table 5 Steel reinforcement properties), was used as closed stirrups. The beam reinforcement and dimension as shown in Figure 1.The nine beams were sorted in three groups based on the compressive strength of concrete as (normal, middle and high) strengths of concrete. Each group consisted of three beams; one with NCA and two with RCA (50 and 100% replacement levels of RCA).

Table 4: Hardened concrete properties at 28 day

Group	Specimen Notation	Compressive strength f'c (MPa)	Modulus of elasticity Ec (Mpa)	Splitting tensile strength ft (MPa)	Flexural strength fr (Mpa)
N25	25N.C	25	26760	3	3.4
	25R50	24	23572	2.85	3.25
	25R100	22.3	21830	2.73	3.14
M45	45N.C	46	35373	4.3	5.1
	245R50	44	32395	4.1	4.9
	45R100	42	29235	3.8	4.6
H70	70N.C	70	42030	5.5	6.2
	70R50	68	39852	5.43	5.9
	70R100	60	36566	4.61	5.1

Table 5: Steel reinforcement properties

Nominal Diameter (mm)	**Actual Diameter (mm)**	**Modulus of Elasticity (MPa)**	**Yield Stress (MPa)**	**Ultimate Stress (MPa)**	**Elongation%**
6	5.38	204700	510	675	11
10	9.23	206000	490	654	13

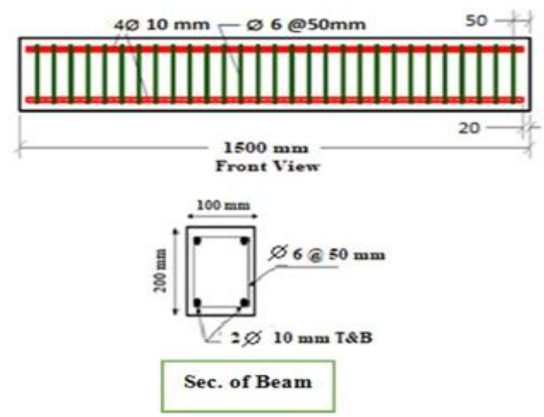

Fig.1: Details of beam dimension and reinforcement

3.4. Test program

The hydraulic universal testing machine having the amplitude of (3000 kN), was wont (used) to check the beam specimens. In order to apply pure torsional moment to the specimen as indicated in Plate (1) and Figure (2), cantilevered torsion arms (of 360 mm) with longitudinal axis of the beam were installed at both ends of the specimens which were loaded through a spreader beam by displacement control methods. The beams were placed in the machine on free supported rollers at each end with a clear span of 1300 mm. A steel girder of 3 m length and 300 mm depth was applied to convey the loads from the center of the machine to the two arms of frame as shown in Figure (3), to fulfillment pure torsion. The angle of twist was rated by two digital gauges as shown in Plate (2), linked to the bottom fiber of the end of the beam on the right, and on the left was registered the uplift and down angle at a point (30 mm) from the center of the longitudinal axis of the beam to recored the torsional angle of twist per unit length in radians. The beams had tested under pattern increasing increments of 1 kN load, and the readings were acquired manually. The torque was increased regularly up to the point of failure of the beam.

Plate 1: The testing machine and the beam setup

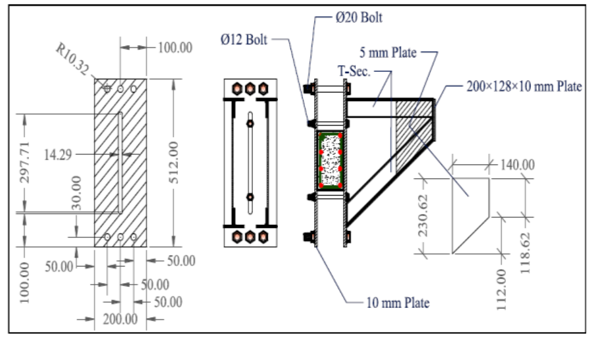

Fig.3: Details of frame of torque arm

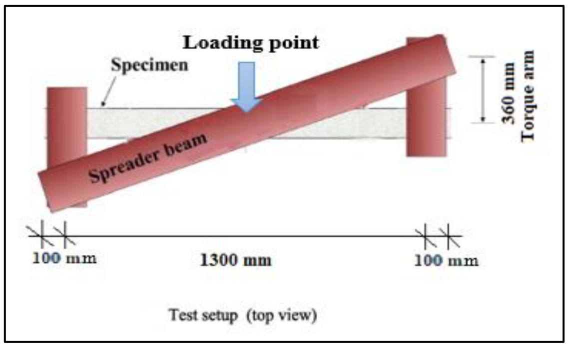

Fig.2 Test setup

Plate 2: Digital dial gage

4. Results, and discussion

For each group, the beams were designed to produce alike compressive strength in order to obtain evident contrast between the torsional strengths of NAC and RAC. However, there is a slight change in the compressive strength of concrete for each beam in the same group because the (w/c) is constant for each group. As expected, the mechanical properties of RAC are ordinarily less than those of the normal concrete, however the most significant effect was that the modulus of elasticity was lowest (18%) for the RAC with replacement level of 100% compared to the NAC.

All are displayed in Table (6). The cracking torque (Tc), the ultimate torque (Tu), and corresponding twist at cracking and ultimate stages (θc, θu), as well as longitudinal steel ratio (ρ_l) and stirrups ratio (ρ_v), are shown. For each group, the beams were designed to yield a comparable (f_c') for evaluation between the torsional strengths of both NAC and RAC.
By observing the results, for all groups, we find that there is no significant difference in the beams containing 50% RCA at cracking stage, but there is a slight difference that does not exceed 4% in the ultimate torque phase. The beams containing 100% RCA have (6.2, 8.3 and 12.5%) variation rate for the three groups (N25, M45, and H70), respectively, in cracking stage. In the ultimate torsional moment stage, the rate of variation is (7.7,
6.9 and 6.5%) for the groups (N25, M45, and H70), respectively. In general, the beams of the NAC produced higher ultimate torsional strength than the full replacement in RAC but did not exceed 7.7% in the same group of compressive strength. The percentage of deviation decreases in the stage of ultimate torque because it depends on the stirrups; and the longitudinal reinforcement of the section reaches the yielding point, and the concrete struts start to behave non-linearly.

Table 6: Summarized test results of beams

GROUP	*Beam Notation*	*Compressive strength f'c (MPa)*	ρ_l%	ρ_v%	*Cracking torque (Tc) (kN.m)*	*Angle of twist (θc) (rad/m)*	*Ultimate torque (Tu) (kN.m)*	*Angle of twist (θu) (rad/m)*
N25	25NC	25	0.0157	0.0113	1.62	0.0053	4.68	0.1155
	25R50	24	0.0157	0.0113	1.62	0.0057	4.68	0.12
	25R100	22.3	0.0157	0.0113	1.52	0.0062	4.32	0.1155
M45	45NC	46	0.0157	0.0113	2.16	0.0044	5.22	0.1288
	45R50	44	0.0157	0.0113	2.16	0.0048	5.04	0.1288
	45R100	42	0.0157	0.0113	1.98	0.0053	4.86	0.1333
H70	70NC	70	0.0157	0.0113	2.88	0.004	5.58	0.1377
	70R50	68	0.0157	0.0113	2.88	0.004	5.4	0.1422
	70R100	60	0.0157	0.0113	2.52	0.0044	5.22	0.1422

ρ_l = longitudinal steel ratio = $\frac{A_l}{b.h}$ and ρ_v = stirrups ratio = $\frac{2A_t}{b.s}$

4.1. Influence of compressive strength on torsional resistance

It can be noticed that, the H70 group of beams is the strongest group according to the cracking and ultimate torsional moment, and is followed by the M45 group, after which comes the N25 group. The torque stage, up to the first crack, increases as the compressive strength of concrete (f_c') increases because the torque of first crack depends largely on compressive strength of concrete since the effect of dimensions of the section are eliminated since it are fixed for all beams. The soft component in the RAC is the downiness aggregate-cement paste bond. Therefore, the compression strength of concrete effect effective factor in the resistance of the cracking and ultimate torque.

4.2. Effecting of compressive strength on angle of twist

The angle of twist is the two-dimensional deformation in the direction of torsional moment action. The angle of twist increases as the compressive strength of concrete increases. The result showed that, the angle of twist of the beam 70NC in the group H70 is greater than the beam notation 25NC in the group N25 by about 16.14% for NAC. The beam notation 70R100 in the group H70 is greater than that of the beam 25R100 in the group N25, which is about 18.64% for RAC.

The angle of twist (deformation) for the beams of RAC is more than NAC beams because the RAC has a lower elastic modulus, and the peak and ultimate strain of RAC is more than NAC [24].

4.3. The failure mode

Generally, the torque-twist conduct of RAC reinforcement beams is similar to that of NAC beams. The formation of the torsional crack for RAC is equal to or less than the magnitude of (Tc) of NAC. The value of first crack (Tc) is sensitive to the grade of the compressive strength of concrete used. At the stage of ultimate torque, the NAC is slightly greater than RAC due to the breakdown of concrete struts of RAC (aggregate-cement paste adhesion failure). Figures (4, 5 and 6) is a torque – twist curve for groups (N25, M45 and H70) respectively, which illustrates. The torsional behavior of three beams for each group that showed a similar approach in resisting the applied torque.

The failure patterns of the beams are shown in Plates (3, 4, and 5) for each mix group respectively. The failure manner of fully the beams presented a uniform skew bending failure. This was a principal torsion crack with an angle of inclination of around (43 to 48°) with the longitudinal axis of the beam. The failure mode was compatible with the beams of each mix group.

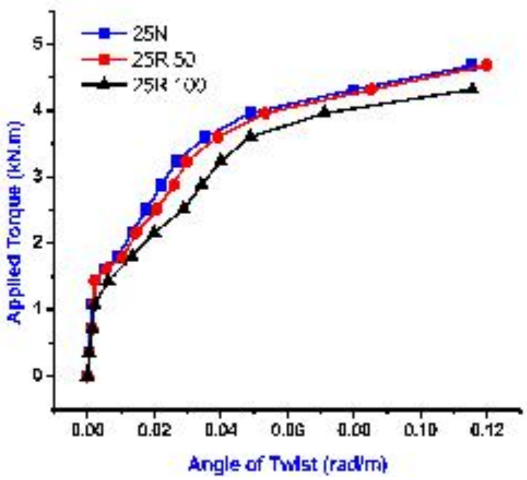

Fig. 4: Torque-twist behavior for group N25

Plate 4: The failure patterns of the beams for group N25

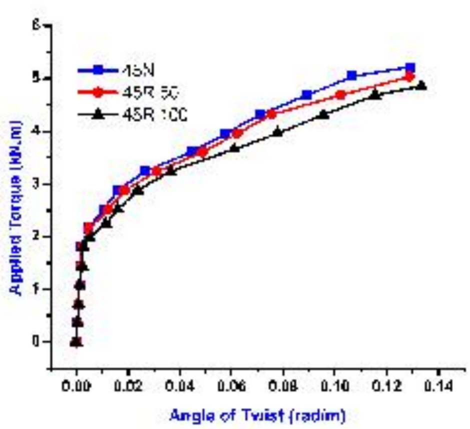

Fig. 5: Torque-twist behavior for group M45

Plate 4: The failure patterns of the beams for group M45

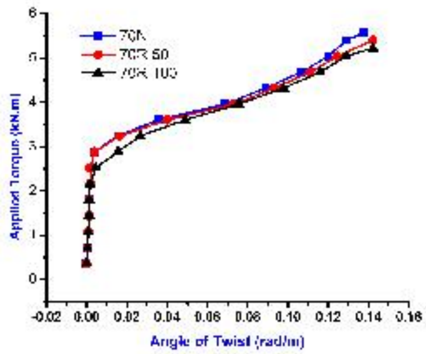

Fig. 6: Torque-twist behavior for group H70

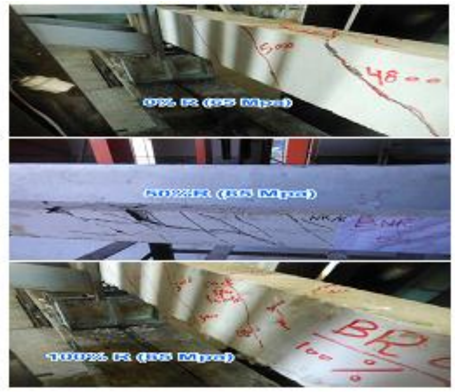

Plate 5: The failure patterns of the beams for group H70

5. Conclusions

1- Water absorption of RCA is more than the water absorption of NCA due to the older mortar that adhered to the surface of aggregate.
2- The mechanical properties of RAC are ordinarily lower to those of normal concrete, but the most significant effect is that the modulus of elasticity was lowest, at about (18%) for the RAC with a replacement level of 100%, compared to the NAC.
3- Torsional strength of the concrete beams decreases with an increase in the proportion of replacement of NCA with RCA.
4- For all groups, there is no important difference among NAC and RAC50 beams in the cracking and ultimate torque.
5- Little differences of around 7.7% were observed between NAC and RAC100 beams in the torsional behavior for ultimate torque.
6- The compression strength of concrete has significant effect on the resistance of the cracking and ultimate torque.
7- The angle of twist for beams at cracking and failure increases with increase in the ratio of replacement of NCA with RCA, due to the RAC which has a lower elastic modulus, and the peak and ultimate strain of RAC which is more than NAC.
8- The failure mode in whole the beams appear skew bending failure. Generally, the torque-twist performance of RAC reinforcement beams are similar to that of NAC beams.
Comparison of torsional behavior, (cracking and ultimate torque), crack patterns, failure modes of NAC and RAC beams, according to the above results, confirm that the employ of RAC in reinforced concrete beams is practically possible for torsional behavior.

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