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EFFECT OF LONGITUDINAL REINFORCEMENT RATIO ON THE SHEAR BEHAVIOR OF RC BEAMS MADE WITH RECYCLED AGGREGATES

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ABSTRACT

This paper presents a study into the effect of longitudinal reinforcement ratio on the shear behavior of Recycled Aggregates Concrete beams (RAC). Six beams were cast in two series: first series includes three beams with ρ=1.04% and the second series includes three beams with ρ=1.5%. The first beam of each series was cast with natural coarse aggregates (R0) to serve as control beam. The second beam was made with 50% replacement ratio of coarse aggregates (R50) and the third beam was made entirely with recycled concrete aggregates (R100). The shear span was constant for all beams a/d=3.5. The beams were subjected to four point loading test. Beams' deflection, crack patterns, yielding, ultimate shear capacity; and failure modes are all observed and analyzed. Significant increase in the shear strength was recorded as longitudinal reinforcement ratio increases by 0.5%. ACI Code provisions for predicting the concrete shear capacity tends to become more conservative with increasing ρ.

Keywords: Reinforcement ratio, shear behavior, reinforced concrete, recycled aggregates, shear span

INTRODUCTION

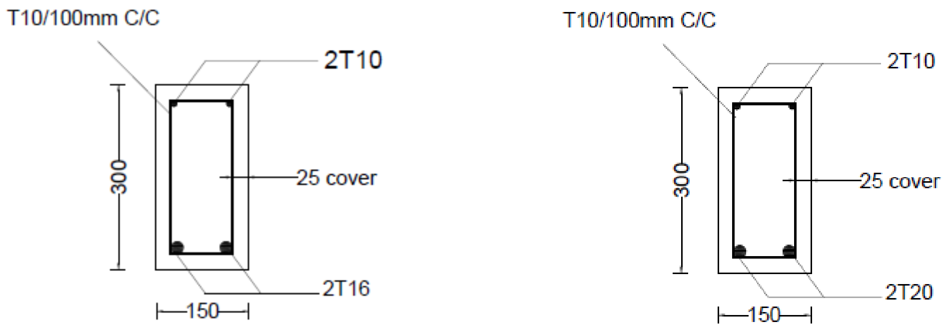
Several studies have been conducted on utilizing recycled aggregate concrete as a structural material. Research focused mostly on the mechanical properties and expanded to cover members subjected to flexure and shear. However, the work on shear still limited. Shear behavior of reinforced concrete beams is a very complex phenomenon as it is influenced by many factors such as the member size, concrete compressive strength, shear span to depth ratio and presence or absence of web reinforcement. Etxeberria et al (2007) studied twelve beam specimens with same compressive strength, constant longitudinal reinforcement ratio and constant shear span to depth ratio. Four concrete mixes using different percentages of recycled coarse aggregates were used (0%, 25%, 50% and 100%) and three different transverse

reinforcement arrangements. Results obtained indicated that the 25% substitution of coarse aggregates has negligible effects on the shear capacity of RC beams without transverse reinforcement. Beams with shear reinforcement and modified cement content achieved approximately the ultimate shear load of conventional concrete even with 100% replacement ratio. Fonteboa et al (2010) examined the behavior of recycled concrete in response to the phenomenon of shear transfer. Double-L shear specimens were designed using two types of concrete, a conventional and a recycled concrete, both made with 8% of silica fume. Without shear reinforcement, the shear friction capacity of recycled concrete with 50% replacement ratio suffers a decrease of 20%. When using any quantity of steel, this loss comes down to 10-15%. The use of silica fume led to a substantial rise in the ultimate load of recycled concrete. Fathifazl et al (2011) investigated the effects of shear span to depth ratio and beam size on the shear strength of RAC beams. They concluded that the shear strength of RAC beams had tendency to increase with decreasing a/d ratio and tendency to increase with decrease in the overall depth of the beams. Arezoumandi et al (2015) tested 18 beams with three different longitudinal reinforcement ratios: 1.3, 2.0, and 2.7%. results showed that RAC100 had 11% lower shear strength on average compared with the RAC50 and CC beams. Rahal K. N., and Alrefaei Y.T. (2018) tested a total of 18 beams. The variables were the percentage of replacement of natural coarse aggregates with RCA in concrete mixes and the amount of stirrups provided. The longitudinal reinforcement ratio in all the beams was 1.38%. the results showed negligible effects of the replacement ratio on shear cracking patterns, the critical shear cracks, the longitudinal steel strains and the mode of failure.
Based on literature, work comparing the effect of the longitudinal steel ratio on the shear strength is limited. In this paper, two percentage of steel were considered using full-scale shear testing of RAC beams.

EXPERIMENTAL PROGRAM

Test Beam Design

Two series of beams were designed to fail in shear. All beams had the same cross section 150 by 300 mm and were 3 m long. Shear reinforcement in the form of vertical stirrups was omitted. The first series was reinforced with 2T16 bars in tension giving reinforcement ratio ρ of 1.04% while the second series had 2 T 20 in tension giving ρ=1.5%. In each series, the first beam was made fully with natural aggregates, the second beam was made with 50% replacement ratio of coarse aggregates with recycled concrete aggregates. The third beam was fully made with recycled concrete aggregates. Figure 1 shows beams cross sections.



(a) Series I (b) Series II

Figure 1: Beams cross-section

Materials and Mix Proportions

The recycled concrete aggregates were obtained by crushing the control specimens tested at UOB civil engineering laboratory. All coarse aggregates were sieved into two sizes: coarse (9.5–19 mm) and medium (4.75–9.5 mm). Table 1 summarizes the test results on the physical properties of natural and recycled aggregates.

Table 1–Physical properties of natural and recycled aggregates.

Aggregates	NCA (4.75-9.5) mm	RCA (4.75-9.5) mm	NCA (9.5-19) mm	RCA (9.5-19) mm
SSD (Saturated Surface Dry)	2.6536	2.4149	2.6755	2.2896
Apparent SG	2.706	2.6883	2.7134	2.4566
OD (Oven-Dry) SG	2.6228	2.2529	2.6533	2.1749
Absorption (%)	1.1713	7.1893	0.835	5.2725
Bulk density kg/m^3	1525	1305	1552	1359

Table 2 illustrates the mix design used throughout this study. The level of coarse aggregates replacement was the only variable in the three mixes used. All constituent materials were oven dried for 24 hours at 110±5 ^{o}C. The water compensation method was used.

Table 2–Mix design

Mix	Cement (kg/m^3)	NCA 4.75-9.5 mm (kg/m^3)	NCA 4.75-9.5 mm (kg/m^3)	RCA 4.75-9.5 mm (kg/m^3)	RCA 4.75-9.5 mm (kg/m^3)	Natural sand (kg/m^3)	Free water (kg/m^3)	Super-plasticizer (L/m^3)
R0	350	444	666	0	0	741	178	3.12
R50	350	222	333	202	285	741	178	3.46
R100	350	0	0	404	569.94	741	178	3.64

All beams and the corresponding control specimens were cured for seven days; and then left for air curing in the laboratory. Beams were tested at the age of 28 days.

Instrumentation and Test Setup

To record steel and concrete strains during testing, strain gauges were attached to the main steel at three locations and on concrete on two locations as shown in Figure 2. The figure also shows the location of LVDT’s for deflection measurements. The beams were subjected to four point loading and the load was applied at a rate of 0.01 mm/sec.

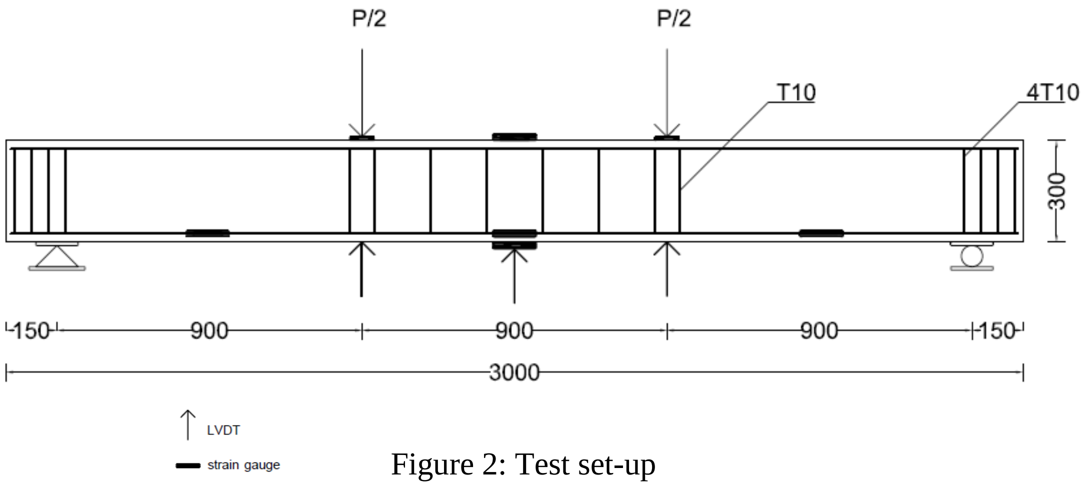


Figure 2: Test set-up

EXPERIMENTAL RESULTS AND DISCUSSION

Mechanical properties

Twelve concrete specimens were cast with each beam to measure the following mechanical properties: concrete compressive strength at 7 and 28 days, splitting tensile strength, flexural tensile strength and the modulus of elasticity. Results are shown in Table 3 including fresh concrete properties.

Table 3: Fresh and hardened concrete properties

Mix	Immediate slump (mm)	Air content (%)	7-Day Compressive strength (MPa)	28-Day Compressive strength (MPa)	Modulus of Elasticity (MPa)	Splitting tensile strength (MPa)	Flexural tensile strength (MPa)
R0	240	4.5	26.5	32.55	32,414	3.90	4.51
R50	175	3.5	24.32	37.2	32,494	3.66	3.59
R100	114	2.75	24.42	31.73	29,203	3.87	3.63

Generally, there is a decrease in the mechanical properties as the replacement level of the coarse aggregates increases. Except for mix R50, which showed slight increase in the compressive strength. Modulus of elasticity has decreased by 10% for R100 as compared to R0. This indicates the vulnerability of RAC beams to deformations. This finding is similar to results obtained by the first author in previous work (2016, 2017 and 2018).

Load vs. Deflection

Similar behavior was noticed for the two percentages of steel considered in terms of deflections, as shown in Figure 3. All beams showed linear behavior up to failure load with change in slope at the cracking level. Obviously, the increase in the percentage of longitudinal steel reduced the amount of deflections. At early stages of loading, RAC beams with R50% and R100% had approximately same deflection values, however, at higher loads, R50 beams attained higher defection levels.

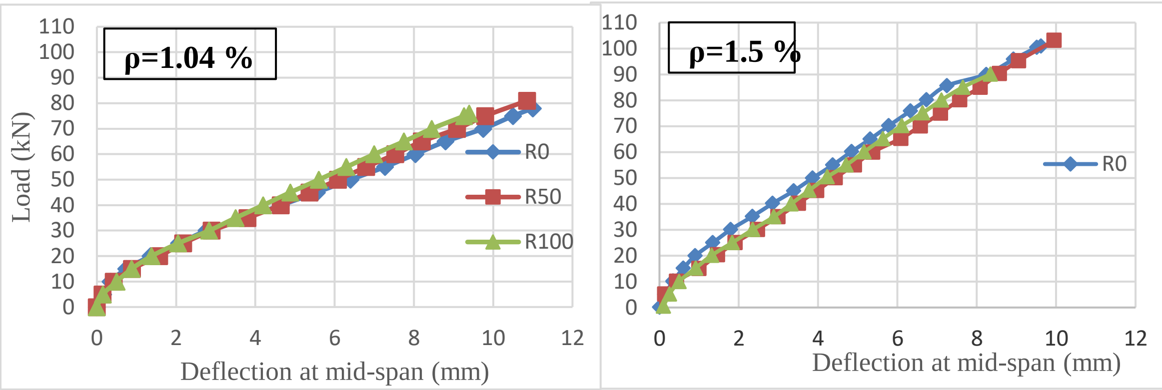


Figure 3: Mid-span deflections

Rahal et al (2018) reported maximum increase of 25% in the vertical deflections for RAC100 beams with ρ= 1.38% when compared with NAC beams (referred to as R0 in this study)

Load vs. Concrete Compression Strain

Figure 4 presents the variation of concrete compression strains against load. Comparable behavior was seen between the two series of beams. Initially all beams had the same slope till the onset of cracking. Beams with higher percentage of longitudinal steel had then higher slope as load increased to failure.

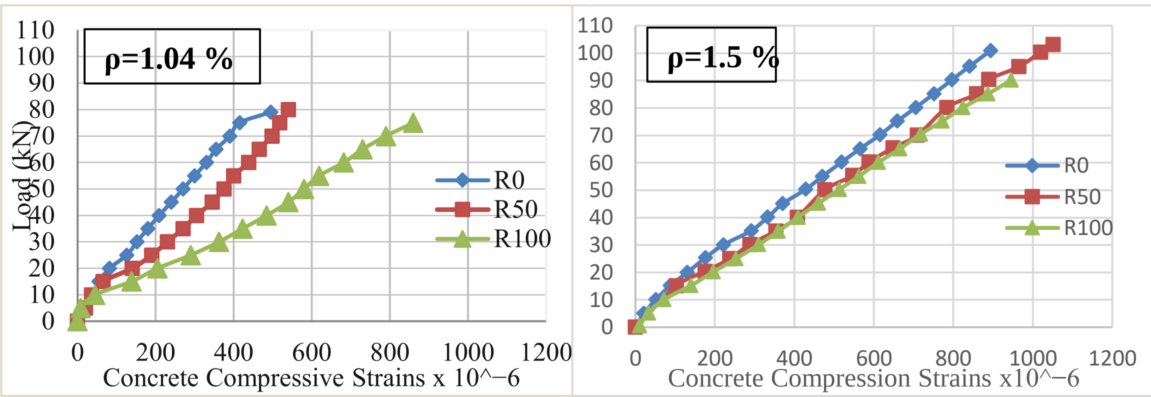
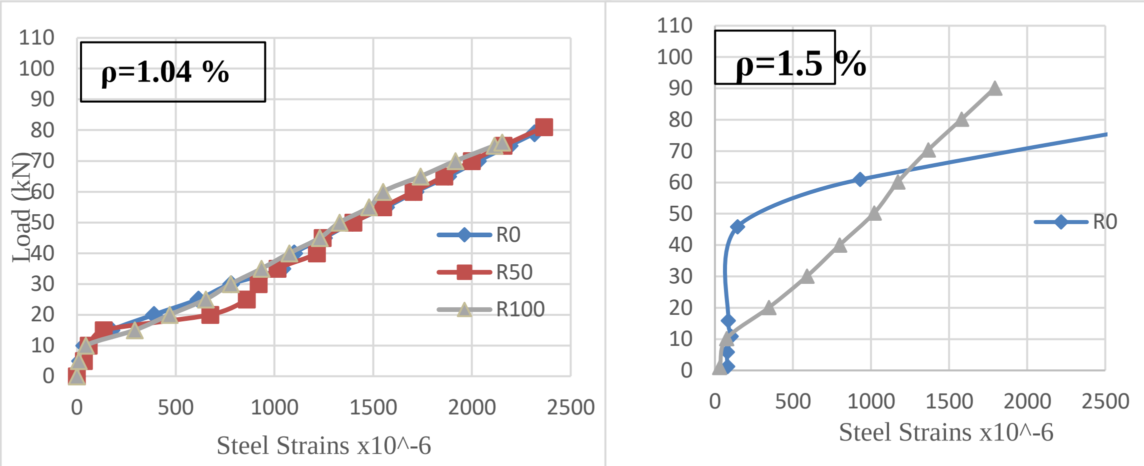


Figure 4: Concrete compressive strains at mid-span.

Load vs. Steel Strain

Variation in steel strains vs. load are presented in Figure 5. Unfortunately, a new set of strain gauges was used for R0 and R50 beams in series II. Those strain gauges were not compatible with the connection wires to the data acquisition system so no readings were obtained for these two beams. Data obtained for other beams indicate

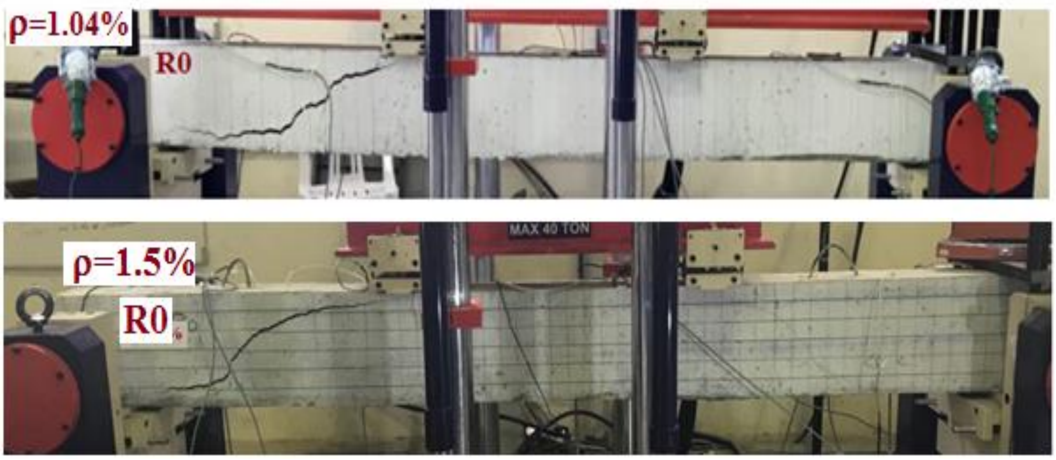


that the longitudinal steel didn't reach yielding when failure load was attained. Steel strain measurements are local measurements, hence, they are generally sensitive to the location of the gauge with respect to the nearby concrete cracks (Rahal et al 2018).

Figure 5: Load vs. steel strains at mid-span.

Crack Pattern and Failure Mode

Figure 6 illustrates the failure modes for the test beams while Figure 7 shows the cracking pattern. Cracks were initiated first in the maximum moment region at mid span, then started to get inclined towards the point loads, as the applied load was increased. A diagonal crack then formed abruptly at mid height extending from the point of load application towards the bond failure of the longitudinal steel within the shear span. This brittle shear failure was observed for all test beams. A fewer number of cracks was seen in test beams with ρ=1.5% as compared to those with ρ=1.04%. Generally, as the percentage of recycled concrete aggregates increases, the number of cracks increases too.



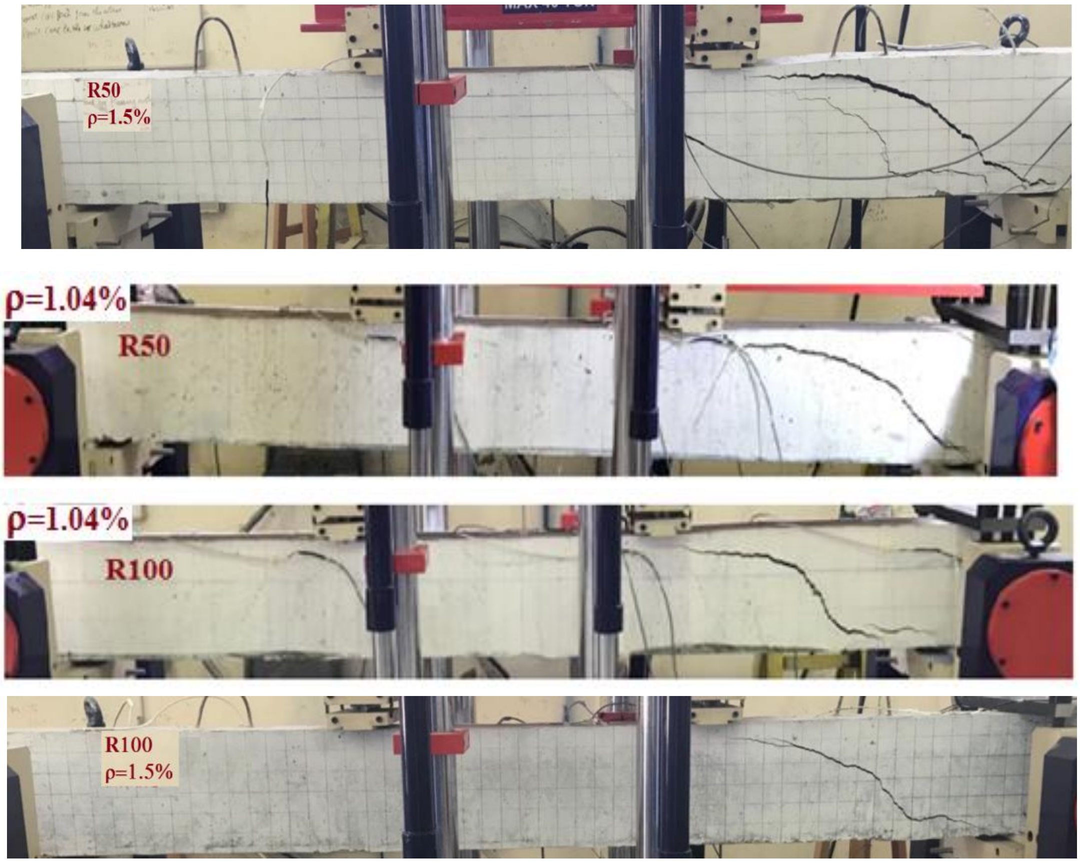
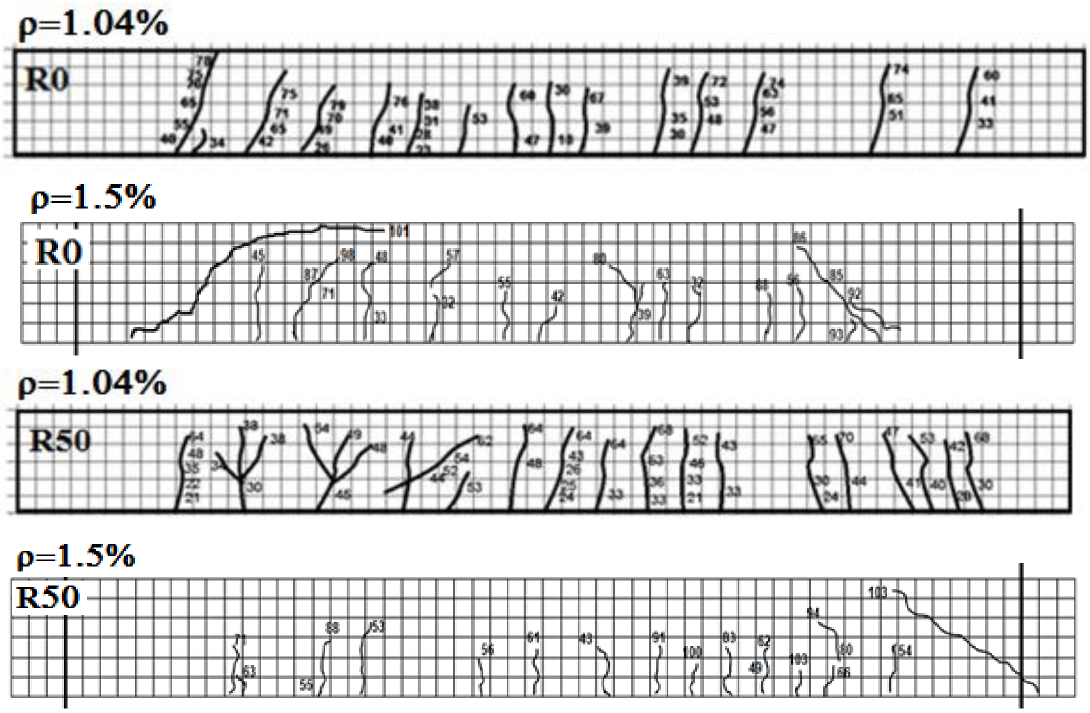


Figure 6: Failure Mode



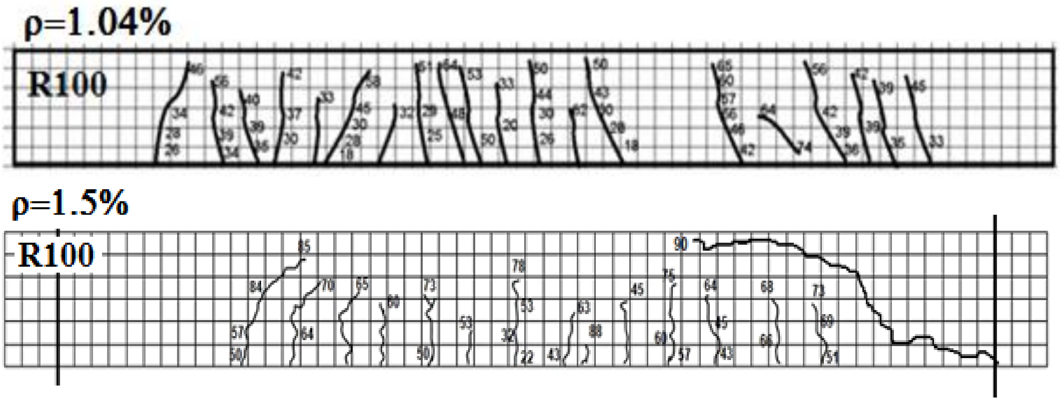


Figure 7: Crack Pattern

Comparison with ACI Shear Strength

Table 4 presents the experimental shear strength at failure V_{test}, for the test beams. V_{ACI} is the shear strength predicted by ACI equation. Although ACI equation does not include the effect of the longitudinal steel; it seems that the equation gives prediction that is more conservative as ρ increases. This margin of safety decreases as the percentage of recycled concrete aggregates increases. Arezoumandi et al (2015) who compared the test values of shear strength with different design standards concluded that the ratio *(V_{test}/V_{code})* increases for the same mix as the reinforcement ratio increases. They also stated that the *(V_{test}/V_{code})* for a given standard, is lower for RCA100 beams than for RCA0 and RCA50 for the same ρ. This is in agreement with the findings of this work.

Table 4: Shear strength results

Beam	V_{test} (kN)		V_{ACI} (kN)	V_{test}/V_{ACI}	
	ρ=1.04%	ρ=1.5%		ρ=1.04%	ρ=1.5%
R0	39.5	50.45	38.565	1.024	1.3
R50	40.8185	51.56	40.92	0.997	1.26
R100	38.192	45.07	40.11	0.952	1.27

Xu et al (2012) proposed an equation for shear capacity prediction of reinforced concrete beams without stirrups using fracture mechanics approach. The proposed formula was checked against experimental data and against ACI code provisions for shear. He observed that ACI 318 overestimates the shear strength of beams, especially those with a reinforcement ratio less than 1.0%. As can be seen in Table 4, the ACI 318 Equation appears to be much more unsafe for lightly reinforced concrete beams made with recycled concrete aggregates.

CONCLUSIONS

The following conclusions can be withdrawn:

1. In terms of mode of failure, crack pattern, load-strain and load-deflection response, the behavior of RAC100, RAC50 and RAC0 beams was similar as the longitudinal reinforcement ratio increased from 1.04 to 1.5%.
2. Shear strength of beams without shear reinforcement decreases as the replacement ratio of recycled aggregates increases.
3. The increase of 0.5% in longitudinal reinforcement ratio improves the shear strength by up to 28% for R0 and R50 and 18% for R100.
4. Although ACI provision for shear strength prediction overestimates the shear strength of beams made with high percentage of RCA, it tends to be more conservative as the ratio of longitudinal reinforcement increases.

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