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RESEARCH ARTICLE

EXPERIMENTAL STUDY OF CONFINEMENT IN BEAMS MADE OF LOW STRENGTH RECYCLED AGGREGATE CONCRETE

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ABSTRACT

It is evident from different research works that concrete made of recycled concrete aggregate produces low strength concrete thus use of this aggregate in structural concrete is much avoided. It is known that RC members increase strength and ductility when restrained laterally known as confinement. The RC design by different codes already suggests stirrups at specified spacing calculated for shear and torsional forces. But if appropriate proportion of stirrups are used, they shall increase strength, ductility and energy dissipation capacity of the member. This paper is concentrated to the possible enhancement in strength and ductility of low strength concrete beams made of recycled aggregate. This would increase the reuse of RCA reducing non-biodegradable debris landfill and also reducing carbon footprint on the environment by the industry.

INTRODUCTION

Due to consistent urbanization because of social and industrial development in Pakistan has led to quick infrastructure development. This development has undertaken different old localities for the construction of modern functionality infrastructure. Building waste from these demolitions has led to rapid landfill, reducing the land to infertile and low bearing capacity for future utilization. For a sustainable environment this rubble must also be recycled to preserve virgin aggregate resources for future generations.

Recycled aggregate extracted from this waste produces low strength concrete (Wagih, El-Karmoty, Ebid, & Okba, 2013)(Moriconi & Naik, 2016). This concrete due to low strength than the specified strength of structural design by codes, is generally avoided to be used in structural concrete. This for a long time allowed its usage limited to plane cement concrete in foundation and earthworks, street pavements and roadworks etc. Thus to extend the use of recycled aggregate in structural applications it is necessary to conduct experiments to understand its structural utilization and drawbacks.

Fabrication Plan of Samples

Reinforced concrete beams were tested to study the effect of confinement reinforcement on strength and ductility in low strength concrete (Hiroaki, Akira, & Hideo, 2008)(Agussalim, 2004) (Radni, Marki, Harapin, & Matešan, 2013). They were tested by applying mid span load to a simply supported beam. The samples were made of concrete with compressive strength of 1800 psi. The samples were denoted as e.g. B118 where B stands for beam, the first digit represents series number of specimen whereas the last two digits represented the compressive strength of concrete i.e. "18" for 1800 psi. Typical reinforcement spacing and testing setup is shown in Figure 1 and fabrication plan for beams samples is shown in Table 1. The variables under consideration of were:

1. Compressive strength of concrete
2. Variation in stirrups/ transverse reinforcement ratio (Variation for plastic hinge length i.e. middle "L/3" in case of simply supported beam is introduced)("Lecture on Plastic Analysis," Oct 2012)

Variation in negative reinforcement ratio (Coupled with extra Lateral Confining Reinforcement)(Agussalim, 2004)

Mix Design and Average Cylinder Strength

Different material properties are defined to formulate the mix design for given fresh and recycled aggregate at a replacement percentage of 30%. The cylinder strength found out at the specified mix ratio is given in table 1.

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Table 1 Fabrication plan for beam samples along with their transverse reinforcement detailing

No.	Sample No.	Concrete Compressive Strength (psi)	Longitudinal Reinforcement	Confining Reinforcement				Comments
				Configuration	Dia. (in)	Spacing (c/c "in")	ρs (%)	
Beam Samples = 2100mm*150mm*300mm (84in * 6in * 12in)								
1	B118	1800	2 # 6 bars at bottom & 2 # 4 at top	2 legged	No. 3 bar	5	0.73	
1	B218			2 legged		5 (central L/3 span 2.5")	0.73 (1.46)	Beam with extra shear reinf. in plastic hinge length
1	B518	1800	2 # 6 bars at bottom & 3 # 4 at top	2 legged	No. 3 bar	5 (central L/3 span 2.5")	0.73 (1.46)	Beam with extra shear reinf. and extra negative reinf.

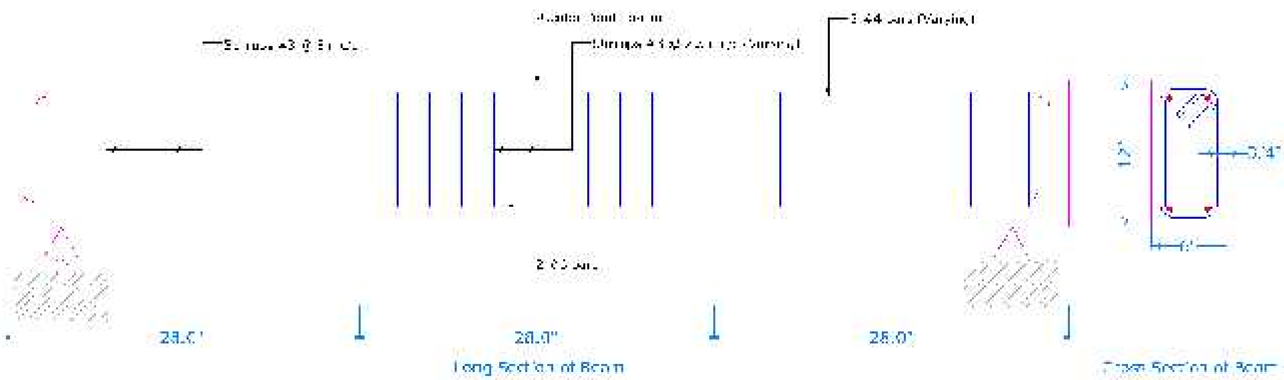

Figure 1 Showing typical reinforcement plan, testing setup and cross section of beam samples (B518)

Table 2 Calculated mix design ratio with average 7 and 28 days' strength

Mix Proportion	Cement	Fine Aggregate	Coarse Aggregate	Water	Average 7 days strength (psi)	Target 28 days strength (psi)	Average 28 days strength (psi)
1800 psi	1	2.92	3.3	0.68	1438.4	1800	1917.9

Reinforcing Steel Properties

The used steel in fabrication of beam samples exhibits properties as shown in table 2.

The load-displacement was monitored and recorded in real-time using LabVIEW software and Data Acquisition System (DAQ) from National Instruments®.

Table 3 Properties of steel used as Longitudinal Reinforcement

S. No.	NominalDia.	Yield Strength, psi	Ultimate Strength, psi	Percentage Elongation	Effective Dia., inch	Weight, lb/ft	Mean Yield strength	Standard Deviation
1	#4	71036.54	89105.07	16.40	0.48	0.595		
2	#4	70178.30	88336.32	17.19	0.48	0.600	70705.4	461.49
3	#4	70901.52	88873.09	16.40	0.48	0.598		
4	#6	80663.44	96111.60	14.06	0.78	1.627		
5	#6	80470.65	95935.09	14.06	0.78	1.625	81553.0	1710.52
6	#6	83525.07	98971.49	16.40	0.77	1.578		

Tests and results

Beams are tested for three-point flexural loading (also called center point loading) as mentioned in ASTM standard D790 Procedure A. Straining frame assembly in Structural Laboratory of Civil Engineering Department UET Peshawar was used for testing purpose. The samples were placed on an adjustable length simply supported platform.

Measurement of load and deflection

Two displacement gauges with a least count of 0.01 mm and maximum displacement capacity of 50 mm were installed at the neutral axis depth of un-cracked section i.e. 6in from bottom of sample. The resulting displacements were averaged. A load cell of 25 tons' capacity was used to apply load as shown in the Figure 2.

The beams were tested initially with force control and then after initial cracking displacement controlled loading was adopted.

Observation

During the initial stage of loading there was no cracking. Deflections were very small which can be observed from respective load-displacement curves. As whole of the section participated in resisting moment, beam behaved in elastic manner. Deflection suddenly increased at near 5 to 8 tons load in all the samples where hairline flexural cracks started to become visible. With further increase in load more flexural cracks were developed converging towards point of loading. Further increase in loading at around 15 tons' initiates cracking in compression zone along with further extension and widening of flexural cracks. The beam testing was stopped at the crushing of concrete in compression exhibiting over reinforced behavior.

Figure 2 Setup for testing of beams with Displacement Gauges and Load Cell installed at straining frame assembly

Beams with more shear and compression reinforcement exhibited closely spaced narrow cracks. Similarly, it was observed that all cracking phenomena occurred within mid half of the span of beam. As beams were over reinforced, all failed by crushing in compression zone with much deflection and widening of cracks in tension zone.

Load-Deflection And Displacement Ductility

Load-Deflection curves for a simply supported beam indicates its deformational capacity (displacement ductility from load-deflection curves) as shown in Figure 3. The idealized bi-linear load-displacement curves are used to find yield displacement Δ_y and ultimate displacement Δ_u for ductility.

$$\mu_\Delta = \frac{\Delta_u}{\Delta_y}$$

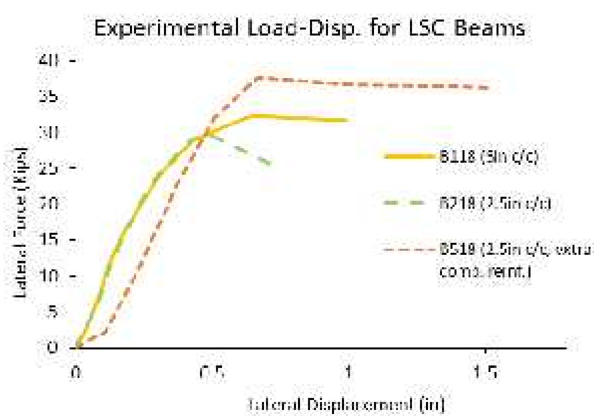

Figure 3 combined experiments load-deflection curves for 1900 psi beams

The displacement ductility is estimated using bilinear idealization to define yield and ultimate strain points using MS EXCEL.

The bilinear idealized curves were plotted using equal energy principle i.e. the area under the actual curve was equalized with that of idealized curve.

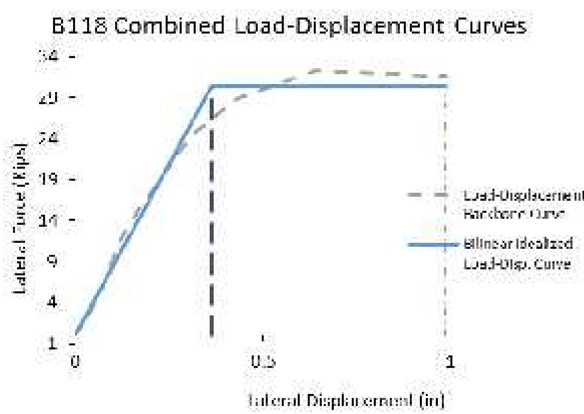

Figure 4 Actual and Idealized Load-Deflection curves of Sample-B118 (1900 psi, 5in c/c)

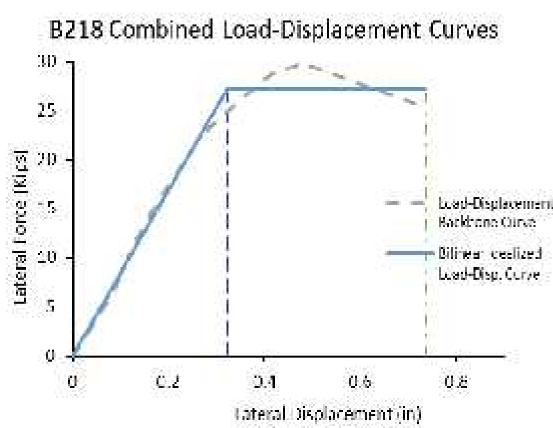

Figure 5 Actual and Idealized Load-Deflection curves of Sample-B218 (1900 psi, 2.5in c/c)

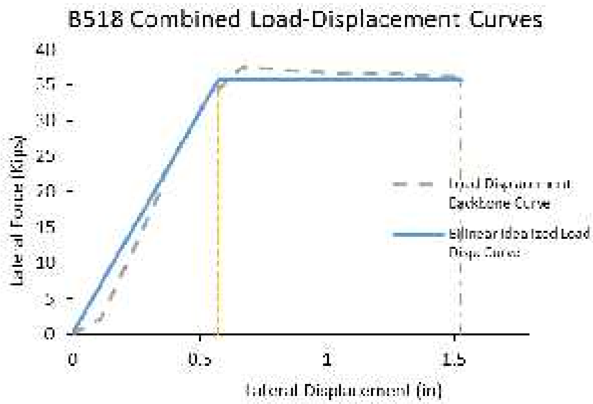

Figure 6 Actual and Idealized Load-Deflection curves for Sample-B518 (1800psi, 2.5in c/c, Extra Negative Reinforcement)

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Table 4 Experimental and idealized curve displacement ductility of different samples

No.	Long. Reinf. Ratio (%)	Compression Long. Reinf. Ratio (%)	Transverse Reinf. Ratio (%)	Flexural Load Capacity (Kips)	Increase in Flexural Capacity (%)	Displacement Ductility
B118		0.63	0.	14.64	0	2.72
B218	1.40	0.63	1.46	13.50	-8	2.28
B518		0.95	1.46	17.06	16	2.67

Table 4 shows displacement ductility of samples as observed from load-displacement curves from experiments. The effect of different parameters affecting strength and ductility of beams can be observed from table.

CONCLUSION

1. Displacement ductility increases with decrease in stirrup spacing.
2. In samples of 5in c/c, 2.5in c/c and 2.5in c/c with extra compression reinforcement the displacement ductility observed for given 1900 psi is 2.72, 2.28, 2.67 respectively.
3. Increase in compression reinforcement ratio increased flexural strength up to 16% respectively. It also increased ductility by 0.39 in low strength concrete.

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