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Structural Behavior of Reinforced Concrete Beams made with Natural Lightweight Aggregates

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***Abstract*— This paper investigates the structural behavior of reinforced concrete beams made with locally available natural lightweight scoria aggregates. A series of 4 full scale structural lightweight reinforced concrete beams 2.9 m long, with a rectangular cross-section of 250×300 mm were designed, cast and tested under 4 points bending test. The effect of varying the compressive strength from 25 to 45 MPa on the load-deflection and moment-curvature responses of under reinforced beams with a reinforcement ratio of 0.25 of the balanced steel ratio was studied. Data presented include the load-deflection and moment curvature responses of the beams tested. The investigation revealed that the flexural behavior of the lightweight reinforced concrete beams was comparable to that of normal weight reinforced concrete beams with relatively larger deflections and curvatures. Test results showed a significant reduction in ductility of lightweight reinforced concrete beams with the increase in compressive strength from 25 to 45 MPa.**

***Keywords*—lightweight concrete, flexure, reinforced concrete beam, moment, curvature, deflection.**

I. Introduction

Lightweight aggregates have been used to manufacture concretes for many years. The primary use of structural lightweight concrete is to reduce the dead load of concrete structures, which then allows the structural designer to reduce the size of the beams, columns, and other load bearing elements. Use of LWAC instead of normal weight concrete (NWC), for example, as a floor slab in a multi-story building, depends on the relative costs and the potential savings that can occur by the use of a lighter material. LWAC is about 25% lighter than normal concrete and, in a design where the dead load is equal to the live load, a saving of 15% in energy intensive steel reinforcement can result. Equal or greater savings are achieved in columns and footings. For long-span bridges, the live load is a minor part of the total load and a reduction in density is translated into reductions in not only mass, but also in section size [1-6].

Delsye et al., [7], carried out a study of the flexural behavior of reinforced lightweight concrete beams made with Oil Palm Shell (OPS). Their investigation revealed that the flexural behavior of reinforced OPS concrete beams was comparable to that of other lightweight concretes and the experimental results compare reasonably well with the current Codes of Practice.

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Karaca, & Durmus [8], investigated the usability of lightweight concrete produced with natural eastern black sea aggregates in reinforced concrete beams. Their study indicated that beams produced with lightweight concrete can be used as structural load carrying members like ordinary concrete. Wu, et al., [9], studied the flexural behavior and size effect of full scale reinforced lightweight concrete beams. Their test results indicated that the reinforced lightweight aggregate concrete (LWAC) beams had a similar load capacity and failure mode as those of normal weight concrete (NWC) beams, but demonstrated larger ultimate deflections and curvature ductility. Furthermore, they observed that an increase of the beam dimensions lead to an increase of the load and deflection at the yielding strength and ultimate strength, but reduced the ultimate deflection ratio for the beams. The main objective of this research is to explore the potential application of the natural lightweight aggregates available in the Kingdom for producing reinforced concrete beams suitable for structural purposes. The flexural response of reinforced concrete beams was investigated in terms of load-deflection and moment-curvature responses.

II. Experimental Program

The experimental program focused on investigating the flexural behavior of LWRC beams of 250×300×2900 mm. Standard 150×300 mm were also cast for determining the compressive strength and air dry density of the structural LWCs investigated.

A. *Materials and Concrete Mixes*

The materials used in this investigation include Type I Portland cement, silica sand, natural lightweight coarse and fine aggregates, silica fume, high range water reducers, and water. The LWA's were volcanic tuffs of scoria origin available at the outskirts of Al-Madina, Saudi Arabia. Two medium degree workability LWC mixes meeting the ASTM C 330 [10] standards were designed in this investigation; one had a 28-day compressive strength of 25 MPa with a corresponding air dry density of 1854 kg/m3; and another one had a 28-day compressive strength of 45 MPa with a corresponding air dry density of 1961 kg/m3.

B. *Mixing and Casting*

The concrete mixes were prepared in co-operation with a ready mix concrete producer using a truck mixer of 6 cubic meter capacity. The concrete mixes were poured in wooden molds and compacted using a poker type vibrator. After casting, the specimens were covered with wet burlap and stored in the laboratory at 23^{o}C and 65% relative humidity for

48 hours and then demolded and wrapped with wet burlap till the day of testing.

C. *Preparation of the Reinforced Concrete Beams for Testing*

The beams were designed to fail in flexure and had a length of 2.9 m long, and a rectangular cross-section of 250×300 mm, as shown in Fig. 1. The Figure also shows the various beam sections with reinforcement details, which were tested in this investigation. Parameters investigated included, two strength classes, 25 and 45 MPa, and one steel ratio, 0.25 of the balanced steel ratio, as shown in Fig. 1. Three LVDT's were placed at the bottom of the beam to measure the deflection at the loading points, and at the middle of the beam. Specially designed test setup was attached at the middle third of the beam to capture the moment-curvature response of the beam under the effect of applied load. Electrically bonded strain gages were also pasted at specific locations on the surface of the concrete and the steel bars in order to measure the strains in steel and concrete during the test. Load-deflection curves, moment-curvature responses were measured using a displacement control testing machine of 2000 kN capacity. Furthermore, failure modes, strains in steel bars and cracking patterns of the concrete were closely monitored during the test. The following designation was used for the first series of the beams tested: for example L25R25-1, L refers to lightweight concrete with 25 MPa strength, R refers to reinforcement ratio 25% of the balanced steel ratio followed by the number of specimen.

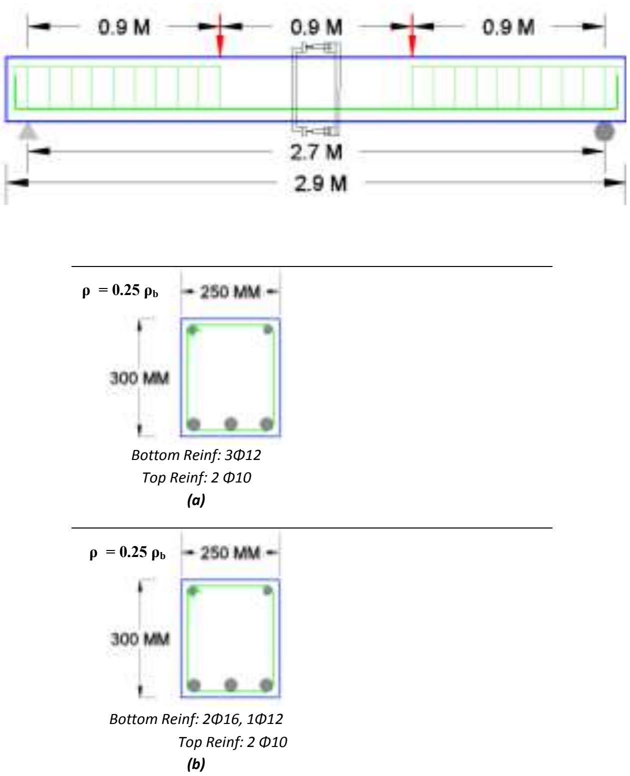

Figure 1. Schematic diagram of reinforced concrete beams investigated
a) Concrete compressive strength = 25 MPa,
b) Concrete compressive strength = 45 MPa

III. Results and Discussion

The results from the flexural tests carried out on 4 reinforced concrete beams made out of lightweight concrete have been reported. Two different concrete strengths, f'c = 25 MPa and 45 MPa, were studied and also one steel ratio ($\rho = 0.25\ \rho_{bal}$) was employed in this research. The flexural behavior was investigated based on the analysis of load-deflection data as well as the moment-curvature data from the beams tested.

A. *Load Deflection behavior*

The effect of compressive strength was studied by keeping the flexural reinforcement ratio constant. Figure 2 shows the load- deflection behavior of beams L25R25-1, 2 and L45R25-1, 2. As seen from the Figure, the increase in compressive strength has resulted in improved ultimate flexural capacities for beams. The stiffness of the LWC beams has also increased as a result of increasing the compressive strength. As seen in Table 1, which presents a summary of experimental results for flexural tests of LWC beams, the average ultimate load capacity of beams increased from 117.82 kN to 170.68 kN when the concrete strength was changed from 25 MPa to 45 MPa for beams with reinforcement ratio of $0.25\rho_{bal}$. Figure 2 also shows that the peak load mid-point deflections of 63.01 mm and 65.27 mm were observed for the two beam specimens of L25R25 series and deflections of 46.38 mm and 54.55 mm were observed for the two specimens of L45R25 series respectively. Similar to the behavior of NWC beams, this behavior indicated a reduction in ductility of LWC beams with the increase in compressive strength of the concrete.

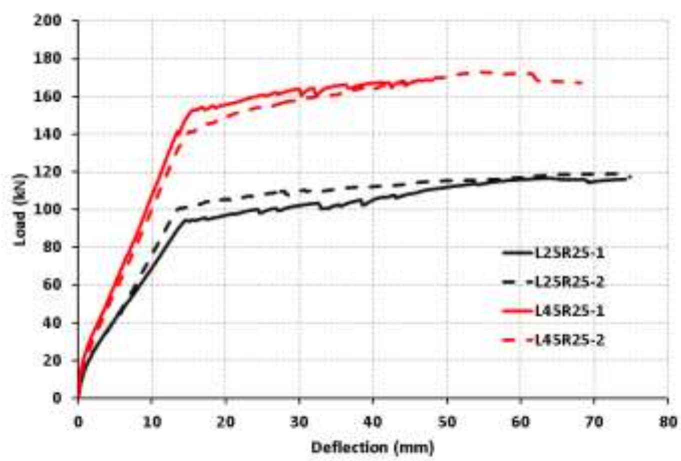

Figure 2. Load-deflection curves for LWC beams with $\rho = 0.25\ \rho_{bal}$ and varying concrete strengths.

TABLE 1: SUMMARY OF EXPERIMENTAL RESULTS FOR REINFORCED LWC BEAMS

Beam I.D.	Reinforcement Ratio	Concrete Compressive Strength	Peak Load P_u (kN)	Deflection at Ultimate Load Δu (mm)	Peak Moment M_u (kN-m)	Curvature at Peak Load ϕ_u (x10^{-6})	Stiffness (kN/mm)
L25R25-1	0.25ρbal	25 MPa	116.63	63.01	52.42	90.1	5.67
L25R25-2	0.25ρbal	25 MPa	119.01	65.27	53.44	77.76	6.19
L45R25-1	0.25ρbal	45 MPa	168.46	46.38	75.14	40.74	9.23
L45R25-2	0.25ρbal	45 MPa	172.91	54.55	74.52	47.43	8.87

B. *Moment-Curvature Behavior*

The moment curvature response of reinforced LWC beams with varying concrete strengths and a reinforcement ratio of 0.25ρ_{bal} is shown in Figures 3. As seen in Table 1, for beams with a reinforcement ratio of 0.25ρ_{bal}, the average moment capacity of the beams increased from 52.93 kN-m to 74.83 kN-m as a result of increasing the concrete strength from 25 MPa to 45 MPa. As seen in Figure 3 a peak moment curvature of 90.1 and 77.75 mm-1×10^{-6} were observed for the two beam specimens of L25R25 series respectively and curvatures of 40.74 and 47.43 mm-1 ×10^{-6} were observed for the two specimens of L45R25 series.

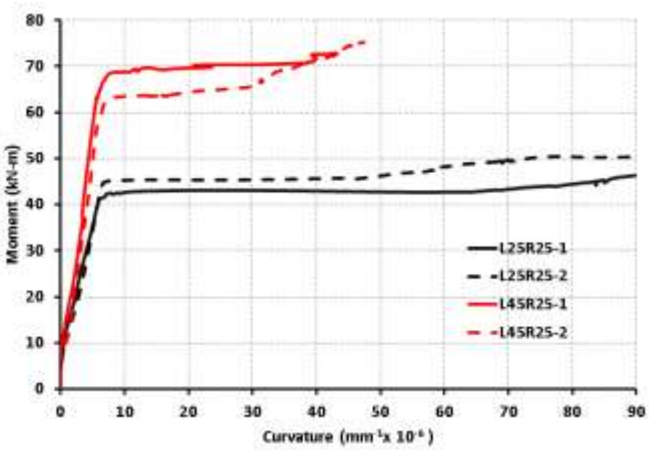

Figure 3. Moment-Curvature curves for LWC beams with ρ= 0.25 ρ_{bal} and varying concrete strengths.

C. *Crack Width and Failure Modes for LWC Beam Specimens*

Typical failure patterns of reinforced LNWC beams tested under flexural four points loading are shown in Figures 4 and 5. As shown in the Figures, the mode of failure for all beams was flexural failure caused as a result of concrete crushing in the compression zone of the beams. The concrete crushing was caused after the yielding of longitudinal reinforcement bars. Flexural cracking was first initiated in the pure bending zone near mid-span and then flexural cracks developed in other regions also. This failure behavior was similar to that observed in the NWC beam specimens. Table 2 below depicts the crack width information for light weight concrete beam specimens tested under flexure.

Figure 4. Mode of failure for beam L25R25-1

Figure 5. Mode of failure for beam L45R25-2

TABLE 2: CRACK WIDTH INFORMATION FOR LIGHT WEIGHT CONCRETE BEAM SPECIMEN

Specimen I.D.	# of cracks in Flexural Region	Weight of beam (ton)	Crack Width			
			Shear (Left)	Flexure (Left)	Flexure (Right)	Shear (Right)
L25R25-1	10	0.39	0.006	0.15	0.12	0.08
L25R25-2	6	0.39	0.03	0.19	0.034	0.1
L45R25-1	10	0.39	0.006	0.09	0.15	0.01
L45R25-2	8	0.39	0.004	0.1	0.1	0.008

IV. Conclusions

1. The experimental test results demonstrated that the scoria lightweight aggregates available in the Kingdom were found suitable for producing structural reinforced concrete beams.
2. All the lightweight concrete beams tested showed typical structural behavior in flexure with an ultimate moment capacity of 75 kN.m, ultimate curvature of 90×10-6, and mid-span deflection of 65 mm.
3. Since the beams tested were under reinforced, yielding of the tensile steel occurred prior to crushing of the compression concrete in the pure bending zone. The cracking pattern was typical of flexural beams and comparable to the one reported for normal weight concrete beams.
4. The flexural response of the LWC beams investigated was similar to that of normal weight concrete beams with relatively larger deflections and curvatures. Test results showed a significant reduction in ductility of LWC beams with the increase in compressive strength from 25 to 45 MPa.

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References

[1] H.Z. Min, and E. Gjorv, "Characteristics of lightweight aggregate for high strength concrete." ACI Materials Journal, V.88, No.2, pp. 150–158, 1990.

[2] K.F. Meyer, and L.F. Khan, "Lightweight Concrete Reduces Weight and Increases Span Length of Pretensioned Bridge Girders", PCI Journal, 2002.

[3] K.M. Hossain, "Properties of Volcanic Pumice Based Cement and Lightweight Concrete", Cement and Concrete Research, vol.34, pp. 283-291, 2004,

[4] J.M. Chi Yang, J.J. Chang, "Effect of aggregate properties on the strength and stiffness of lightweight concrete", Journal of cement and Concrete composites, 2002.

[5] M.J. Shannag, A.Charif, and S. Dghaither, "Developing structural lightweight concrete using volcanic scoria available in Saudi Arabia," Arabian Journal for Science and Engineering, 2014, DOI 10.1007/s13369-014-1019-5.

[6] A. Charif, M. J. Shannag, S. Dghaither, "Ductility of reinforced lightweight concrete beams and columns," Latin American Journal of Solids and Structures, 11, pp. 1251-1274, 2014.

[7] Karaca, Z., and Durmus, A., "Investigation of usability of lightweight concrete produced with natural eastern black sea aggregates in reinforced concrete beams," Journal of Materials in Civil Engineering, ASCE, Volume 24, Issue 7 July 2012.

[8] C.H. Wu, Y.C Kan, C.H Huang, T. Yen, and L.H., Chen, "Flexural Behavior and Size Effect of Full Scale Reinforced Lightweight Concrete Beam," Journal of Marine Science and Technology, Vol. 19, No. 2, pp. 132-140, 2011.

[9] C.L Teo Delsye, A. Mannan, J.V. Kurian, "Flexural Behavior of Reinforced Lightweight Concrete Beams made with Oil Palm Shell," Journal of Advanced Concrete Technology, 4(3), 2006, pp. 1-10.

[10] ASTM C 330-89, (1989) "Standard Specification for Lightweight Aggregates for Structural Concrete", *Annual Book of ASTM Standards*, **4.02**, 193-195.

[11] ACI 318-08, (2008), "Building code requirements for structural concrete and commentary." *American Concrete Institute*, Detroit, Michigan.

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