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USE OF RECYCLED CONCRETE AGGREGATES IN STRUCTURAL CONCRETE

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ABSTRACT

The investigation herein focuses on studying the possibility of using recycled concrete aggregates in structural concrete. The study aims in investigating the uniaxial compressive, tensile and flexural strength of recycled aggregate concrete and behaviour of reinforced RAC beams by assessing several important aspects which may influence its behaviour. These aspects include the replacement percentage of recycled aggregates used in concrete and water to cement ratio. Concrete made with recycled concrete aggregates having replacement percentage of 0%, 30% 50%, 70% and 100% was used and were tested at 28 days curing. In general, it was found that increasing percentage of the recycled aggregates resulted in decrease in the concrete compressive, tensile and flexural strengths. However, the use of RAC as structural concrete can be justified by optimizing the replacement percentage of recycled concrete aggregates and water to cement ratio to get the desirable behaviour of reinforced concrete structures.

Keywords: Recycled concrete, aggregates, cement, reinforced concrete

INTRODUCTION

Construction and demolition waste (CDW) has emerged as critical issue due to rapid growth in the construction sector and urbanization. The one of the effective way to handle this issue is by recycling CDW as aggregate for new concrete production. However, in order to use the recycled aggregate concrete (RAC), its properties and behaviour has to be investigated.

Number of studies have been conducted which focuses on investigating the behaviour of RAC both on material and structural elements level under different sets of loading. RCA produced from crushing concrete cylinders from a batching plant were used by Hamad & Dawi (2017) (Bilal S.Hamad and Ali H.Dawi 2017), to investigate the compressive behaviour of RCA. For this purpose, cylinders were used for producing RCA made up of normal and high strength concrete. It was observed that the replacement percentage used in the investigation did not significantly affected the reduction in compressive strength of the RCA when compared with its counterpart for the case of concrete with normal aggregates.

Effect of water to cement ratio on the behaviour of RAC under uniaxial compression was studied by Somna et al. (Rattapon, et al. 2012). The recycled aggregates were obtained by crushing the cylindrical specimens having strengths in the range of 25 MPa – 40 MPa. In this study the fly ash content and water to cement ratio was varied, having fly ash contents of 20%, 35% and 50% and water to cement ratios of 0.45, 0.55 and 0.65. Compressive strength of all the RAC was found to be lower than NAC. Compressive strength decreased with increase in water to cement ratio. The addition of fly ash increased the compressive strength of RAC as compared to RAC without fly ash for 20% addition, further addition of 35% and 50% had a reducing effect on the compressive strength. This reduction of compressive strength was found to be more significant on mixes with higher water to cement ratios.

It was also observed from the critical analyses of the already published studies investigating the splitting tensile strength of RCA that its decrease with the increase in recycled aggregate replacement ratio. Shi & Hou (Shi W and Hou JP 2001) and Cheng (Cheng GY 2005) used 25%, 50%, 75% and 100% replacement of RCA with NCA and observed that splitting tensile strength decreases with increase in the replacement percentage except for the case of 100% replacement Cheng (Cheng GY 2005). Similar observation was also observed in the case of flexural strength that with the increase in replacement percentage the flexural strength decreases as shown in Figure 1.

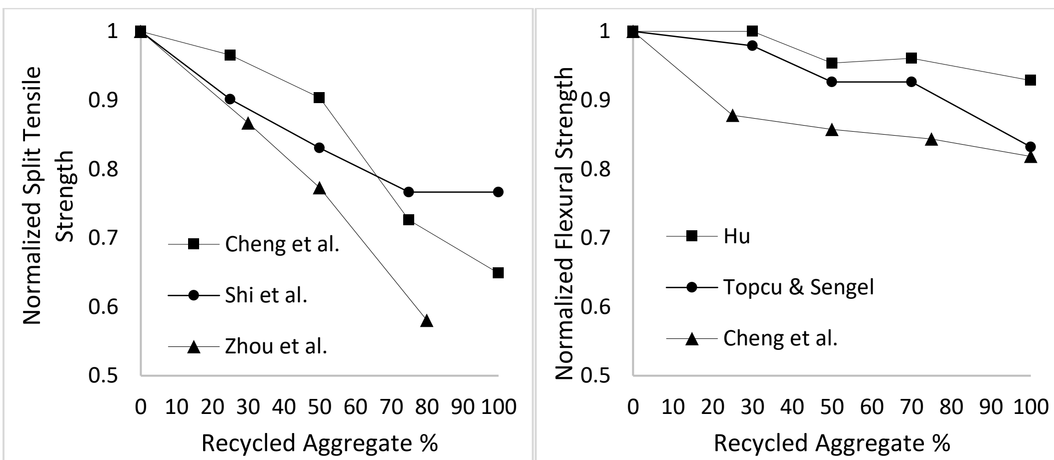

Figure 1: Split Tensile Strength *(Cheng GY 2005) (Shi W and Hou JP 2001) (Zhou JH, et al. 2010)* & Flexural Tensile Strength *(Hu 2007) (Topçu IB and Sengel S 2004) (Cheng GY 2005)*

The behaviour of simply supported beams under two-point bending was studied by Ivan et al. (S.Ignjatović, B.Marinković and Tošić 2017). For this purpose, three replacement ratios (0%, 50% and 100%) of RAC and three shear reinforcement ratios (0%, 0.14% and 0.19%) with a shear span to depth ratio of 4.2 were used. Beams having a width of 200 mm, depth of 300 mm and a length of 3500mm were used. The behaviour of beams without shear reinforcement made up of NAC and RACs exhibited diagonal crack pattern in the NAC beam whereas an 'S' shaped crack was formed in the RAC beam. This 'S' shaped crack had an angle of 45^{o} while the diagonal crack of NAC beam had an angle of 30o. Service load deflections for all replacement levels (0%, 50% and 100%) did not differ by more than 10% for same amount of reinforcement. Similarly, no significant difference in normalized shear strength was observed for all beams with shear reinforcement. For beams without shear reinforcement, 100% and 0% replacement specimens were almost equal but the specimen with 50% replacement exhibited 15% lower strength, as shown in Figure 2.

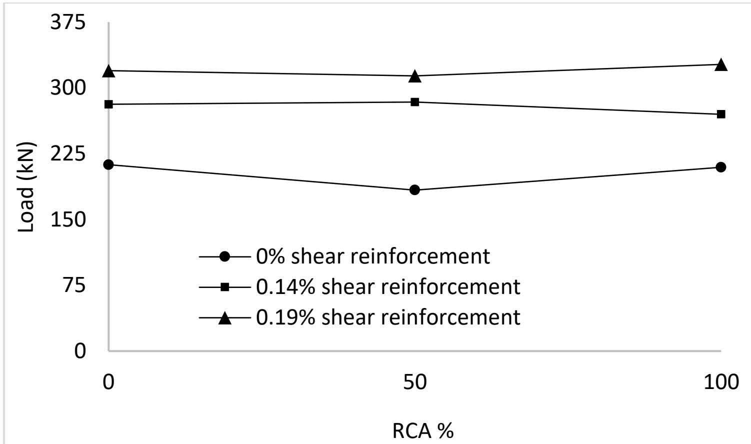

Figure 2: Shear Strength variation with replacement ratio and shear reinforcement *(S.Ignjatović, B.Marinković and Tošić 2017)*

Flexural behaviour of beam specimens was also assessed by Mahdi et al. (Arezoumandi, et al. 2015) using longitudinal reinforcement ratios 0.47% and 0.64%. Beams 300mm wide, 460mm deep and span length of 2700mm were used. The cracks patterns were observed to be similar for both types of concrete beams. The specimens showed ductile mode of failure and beams made with recycled aggregate beams exhibited lower cracking load and stiffness after cracking, and these were attributed to weakness in interfacial transition zone (ITZ) and lower elastic modulus of recycled aggregate concrete. Ultimate load deflections of recycled aggregate beams were also higher, as shown in [Fig 2.8].

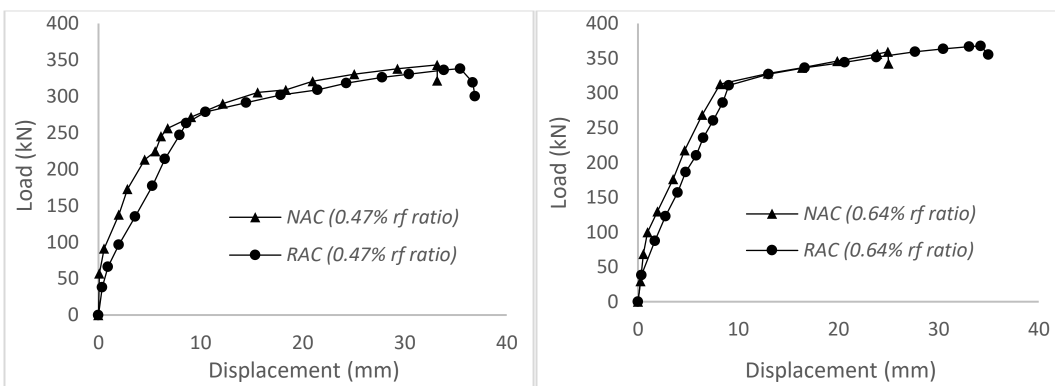

Figure 3: Response of beam specimens having reinforcement ratios *(Arezoumandi, et al. 2015)*

This study aims to investigate the uniaxial compressive, tensile and flexural strength of recycled aggregate concrete and behaviour of reinforced RAC beams by assessing several important aspects which may influence its behaviour. For this purpose, the mechanical properties of concrete made with recycled aggregates having replacement percentage of 0%, 30% 50%, 70% and 100% was used.

EXPERIMENTAL PROGRAMME

Compressive strength, splitting tensile strength and flexural strength were evaluated for investigation of mechanical properties. For compressive and tensile strength cylinders having 100 mm diameter and 200 mm length cylinders were used as per ASTM C39 (ASTM C39/C39M-16 2016) & ASTM C496 (ASTM C496/C496M 2011) standards. Flexural tensile strength was evaluated by testing 100 mm wide, 100 mm deep and 500 mm long prisms according to ASTM C78 (ASTM C78/C78M 2010).

Beams used herein were 150 mm wide, 230 mm deep, effective depth of 165 mm and 2133 mm in length and has a shear span to depth a/d ratio of 3. Beams were designed with either flexure or shear critical details having concrete made with recycled aggregates with replacement percentages of 0% and 30%. For the shear critical specimens, only tension reinforcement was provided using two 12 mm bars, while for flexure critical specimens' transverse reinforcement in the form of closed stirrups made up of 10 mm bars were used. Test specimen details can be seen in Figure 4. The tension reinforcement was selected so that the cross section remains tension controlled when failing in flexure. Hanger bars (two 10 mm) were provided to aid in stirrups placement. Region beyond supports was provided with closed stirrups in both types of specimens.

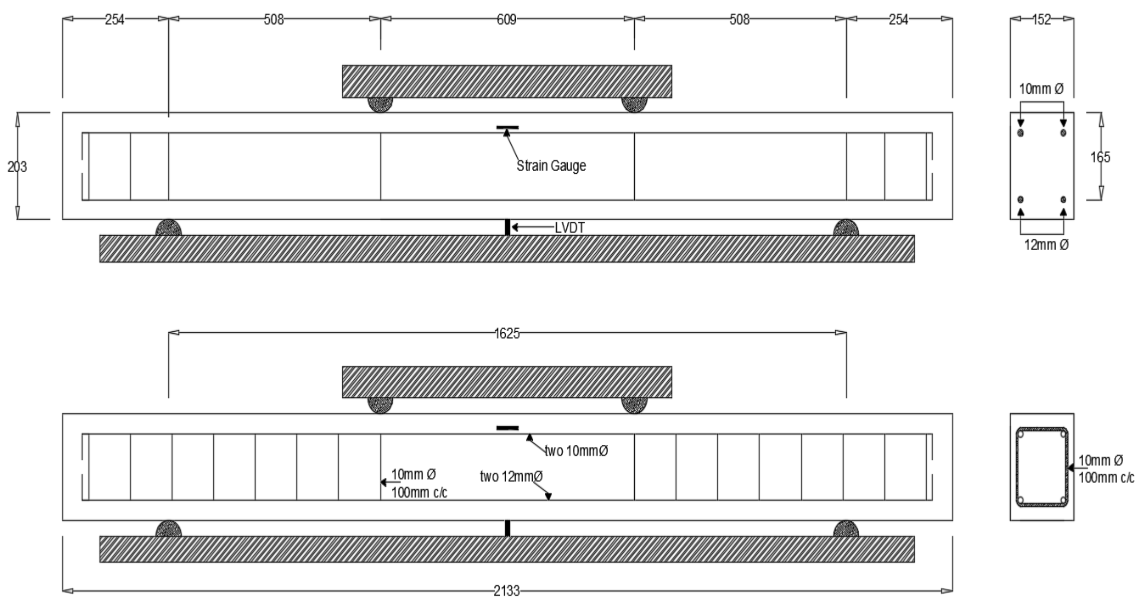

Figure 4: Reinforcement Detail for Beam Specimens.

Recycled aggregates

In order to prepare concrete with recycled aggregates, the already tested reinforced concrete beams prepared with the nominal compressive strength of 28 MPa in the Department of Civil Engineering at NED University of Engineering & Technology were crushed into pieces of concrete having approximate diameter of 100 mm. These pieces were again crushed using jaw crusher to appropriate coarse aggregate size. For preparing recycled aggregate concrete, the total weight of natural and recycled aggregates consists of 60% of aggregates retained on 9.5 mm and 40% retained on 12.7 mm sieves. These recycled aggregates have a water absorption, moisture content and apparent specific gravity of 0.3964%, 0.24% and 2.46 respectively. The recycled aggregates were washed and soaked for 24 hours and then it was also surface dry before using it in preparing recycled aggregate concrete.

Concrete mixes and replacement scheme

The specimens were prepared with concrete having a mix of 1:1.24:2.60 and water cement ratio of 0.43. Concrete mixes used in this study are named as 'RACxx', where 'xx' represents the replacement percentage of recycled aggregates. For example, RAC00 represent concrete mix having no percentage of recycled aggregates, similarly, RAC30 represents concrete with 30% recycled aggregates. Four replacements percentages (30%, 50%, 70% & 100%) were adopted in this study and compared with the reference mix of natural aggregate concrete (RAC00).
Natural aggregate concrete mix having 28-day compressive strength of 30MPa was selected as the reference mix. Mix quantities for different replacement percentages used in this investigation are given in Table 1. Water to cement ratio was kept constant of 0.43, having different quantities of super plasticizers (SP) to achieve slump between 75mm-100mm.

Table 1: Quantities for Concrete Mixes

	Quantities (kg/m^3)					
	Cement	*Sand*	*NA*	*RA*	*Water*	**SP (%)**
RAC00	454	568	1183	0	195	1.60
RAC30	454	536	783	335	195	1.50
RAC50	454	517	539	539	195	1.30
RAC70	454	500	313	729	195	1.25
RAC100	454	475	0	991	195	0

RESULTS & DISCUSSIONS

Compressive Strength

Table 2 and Figure 5 gives the compressive strength exhibited by specimens under uniaxial compression. It can be seen that strength increases for the case of RAC70 specimens when with RAC50 specimen. This may be attributed to the fact that the reduction of effective water to cement ratio due to higher absorption of recycled aggregates, and, that as the replacement ratio increases, an optimum mix is achieved that has better packing density and interlocking (Chunheng and Zongping 2017).

Table 2: Compressive strength exhibited by specimens under uniaxial compression

	Compressive Strength (MPa)					
	Samples			***Avg.***	***Std. Dev.***	***Normalized*** $f_c^{/}$
RAC00	32.07	28.99	29.60	30.22	1.63	1
RAC30	25.29	28.99	27.14	27.14	1.85	0.89

RAC50	26.03	24.42	23.56	24.67	1.25	0.81
RAC70	25.29	26.40	-	25.84	0.78	0.85
RAC100	22.20	21.59	22.82	22.2	0.61	0.735

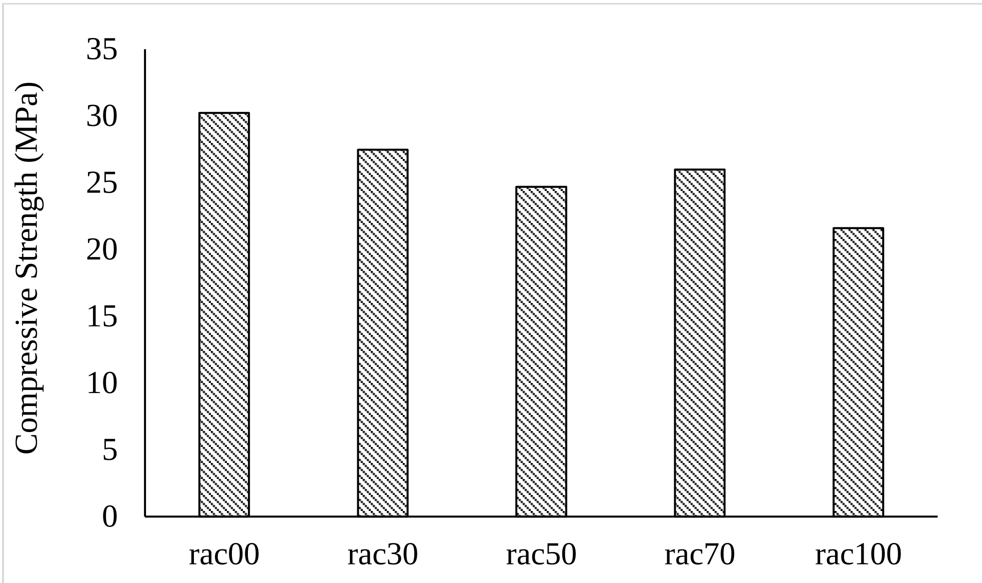

Figure 5: Variation in concrete compressive Strength for the specimens under uniaxial compression.

Tensile Splitting & Flexuarl Strength

Figure 6 shows the tensile splitting and flexural strength exhibited by specimens. Increase in flexural strength can be seen for RAC70 when compared with RAC50, this trend is similar to the trend observed in compressive strength variation. In splitting tensile strength, the decline can be observed to increase with the increase in recycled aggregate content, however, this decline is less prominent after RAC50.

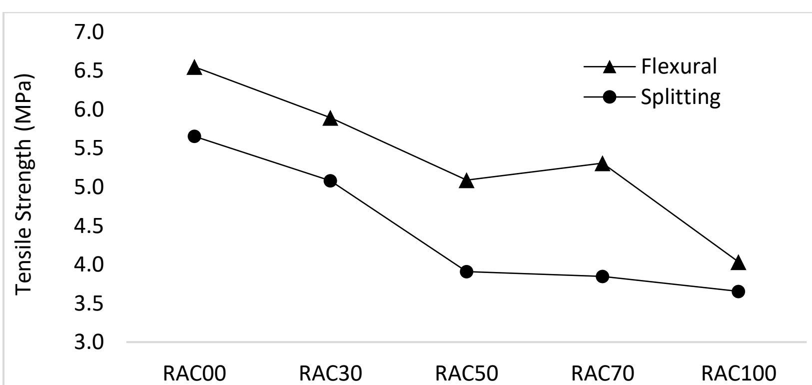

Figure 6: Variation in concrete tensile splitting strength for the specimens.

Flexure Critical Beams

For the case of RAC00 specimen, it was observed that initially no visible crack was developed till the loading level of 45 kN. However, with further increase in load (approximately 72 kN) cracks propagated the mid-depth rapidly. These crack increases in width till the failure load of 80 kN as shown in Figure 7.

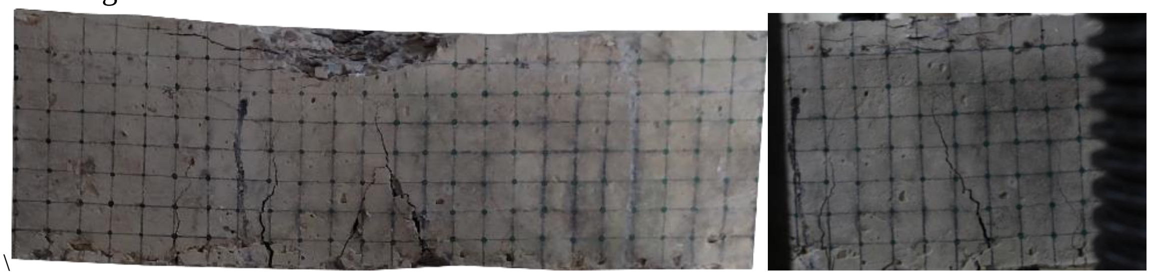

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Figure 7: Flexural Failure of RAC00

Load deflection response of RAC00 is shown in Figure 8. As can be seen that the curve has well defined yield point and significant post yield region. Yield and ultimate loads are 72 kN and 80 kN with corresponding displacements of 12 mm and 22 mm respectively. RAC00 exhibited least ultimate deflection (measuring 22 mm), this can be attributed to higher stiffness.

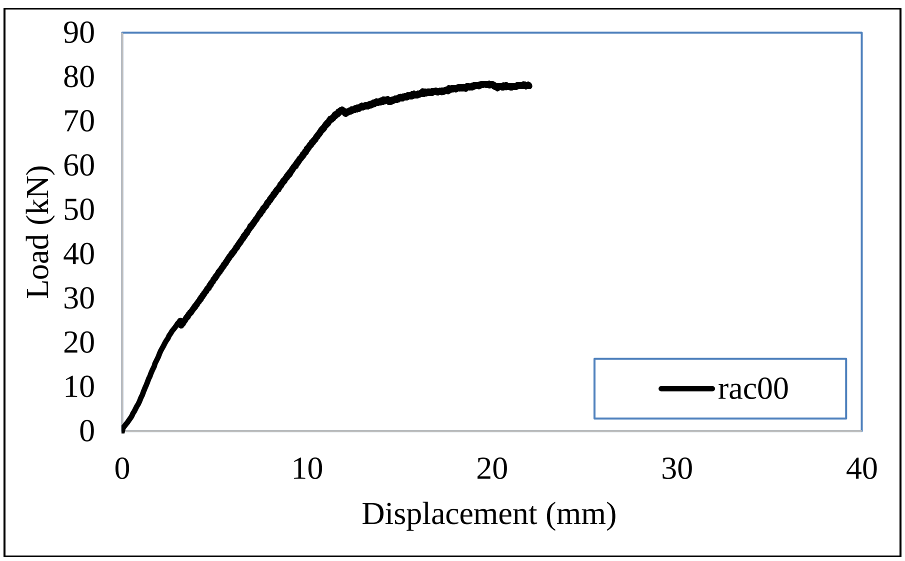


Figure 8: Response of Flexure Critical RAC00 specimen

In the RAC30 specimen, first two visible flexural hairline crack appeared almost simultaneously on 35 kN at both sides of the midspan. At around 70 kN both the cracks had propagated mid-depth of the cross section and at 81 kN another crack appeared that started vertically and then became slightly inclined. At 84 kN concrete crushing started and finally at 85 kN, specimen failed with top concrete crushing. Failure pattern can be seen from Figure 9. It can be seen that the cracks induced were flexural cracks and most of the cracks were at the same level (25 mm above mid-depth) at the attainment of failure load.

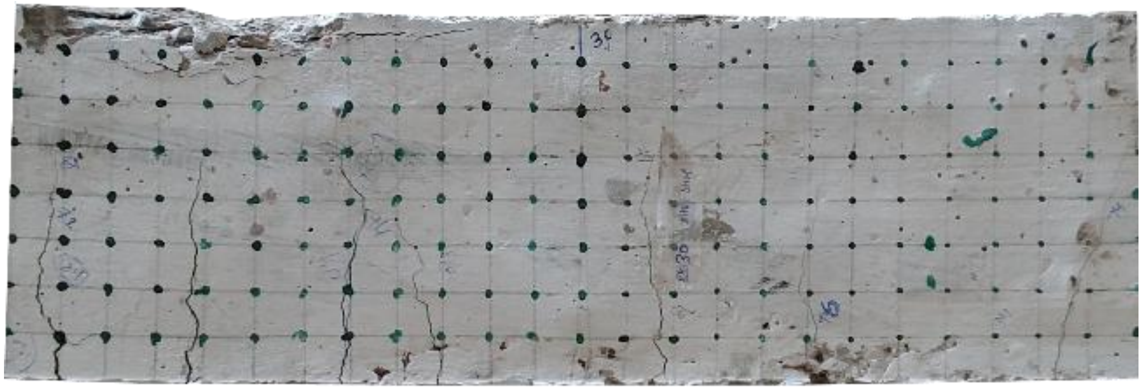


Figure 9: Flexural failure of RAC30

Load deflection response of RAC30 specimen is shown in Figure 10, the curve shows typical flexural behaviour, with well-defined yield point and then yield region. Yield and failure loads were found to be 70 kN and 85 kN while corresponding displacement are 11 mm and 27 mm respectively.

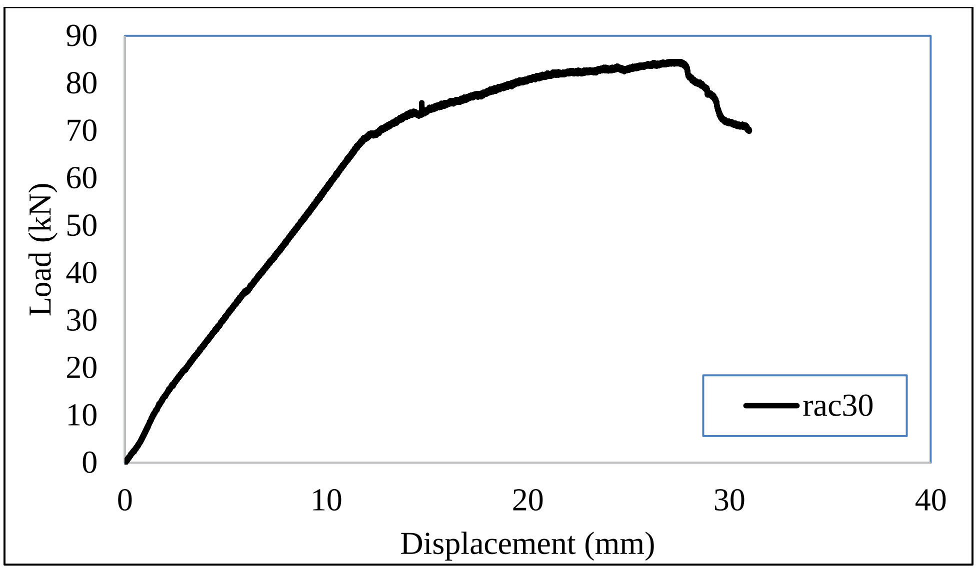


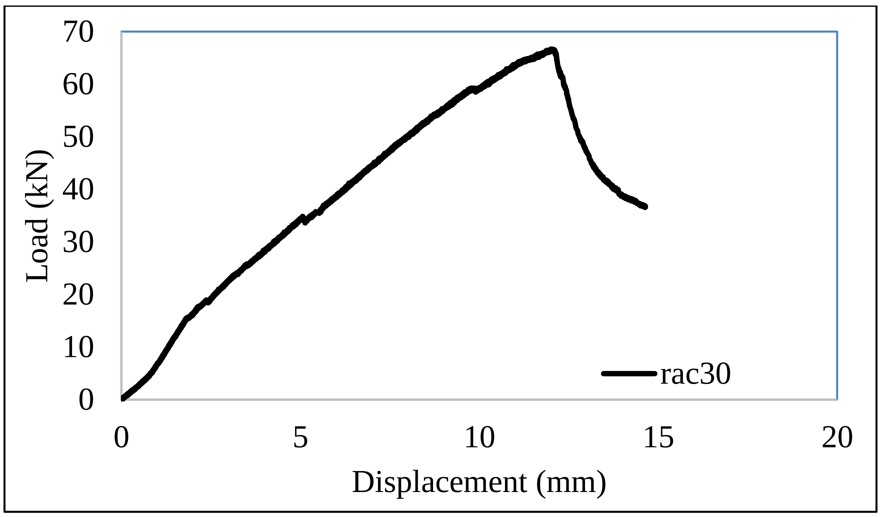
Figure 10: Response of Flexure Critical RAC30 specimen.

Shear Critical Beams

It was observed that RAC30 specimen exhibited hairline cracks at load level of 25 kN and 35 kN respectively at midspan. Shear crack appeared in the web on the right shear span of beam. This crack propagated towards the load point on the top and support on the bottom. Bottom propagation was diagonal in nature till reaching reinforcement level, after which it propagated horizontally towards the support. Top propagation of crack occurred with straight and inclined crack connecting the loading point and initial crack. Upon penetration of crack till the top fibre, specimen failed with concrete crushing on the top at 69 kN.

Some hairline flexural cracks in the shear span can also be seen in Figure 11. The crack seems to be taking form of letter ‘Z’. Crack angle at mid-depth is 49o and it reduced to 20^o in the below part and reduced to 20^o in the upper part too. Failure exhibited well-known brittleness that is associated with shear failures. Displacement at which failure occurred is 12 mm as compared to 27 mm deflection in the specimen with shear reinforcement. However, yield displacement of flexure critical RAC30 specimen was 11 mm which is very close to the ultimate deflection observed here.

(a)



(b)

Figure 11: (a) Shear Failure of RAC30 and (b) Load Deflection Response.

CONCLUSIONS

Based on the investigation carried out herein following conclusions can be drawn

- Compressive strength of all recycled aggregate concrete mixes is found to be lower than the natural aggregate concrete. This reduction in compressive strength was greatest for RAC100 (*26%*) and least for RAC30 (*11%*).

- Flexural and splitting tensile strengths of all recycled aggregate concrete mixes is found to be lower than natural aggregate concrete too. Similarly, this reduction is found to be greatest for RAC100 (*35-38%*) and least for RAC30 (*9-10%*).

- For flexure critical specimens, ultimate and yield strengths of all beam specimens are found to be close to each other, thus, recycled coarse aggregate inclusion did not seem to impart noticeable difference.

- Stiffness of all the flexure critical RAC beam specimens is found to be lower than NAC beam specimens.

- Extent of cracking for all flexure critical RAC beam specimens was found to be higher than NAC beam specimen. This can be due to lesser tensile strength of RAC than NAC.

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