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Performance of Sustainable Concrete Containing HVFA and RCA

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ABSTRACT

Utilization of waste materials in concrete instead of natural raw materials and by reduces the environmental pollution and energy consumption becomes the emerging topic of sustainable development. This study presents the experimental study of the possibility of producing structural concrete with Recycled Aggregate (RA) and High Volume Fly Ash (HVFA). Four groups of mixes were cast and the fresh and hardened concrete properties of Recycled Aggregate Concrete (RAC) with and without Fly Ash (FA) were compared with Natural Aggregate Concrete (NAC) and optimum replacement of RA and FA were found. Four reinforced concrete beams were cast, out of which two beams were control concrete and the other two were with 50% of RA and 50% of FA and its load deflection characteristics and crack pattern also studied. From the experimental results, it was concluded that use of 50% RA and 50% FA replacements are encouraging for structural concrete.

Key words: Natural aggregate, recycled coarse aggregate, high volume fly ash, recycled aggregate concrete, compressive strength, load-deflection characteristics

INTRODUCTION

The usage of Recycled Aggregates (RA) obtained from construction and demolition wastes will give considerable impact in the utilization of concrete materials and the cost of the construction.

Frondistou-Yannas (1977) reviewed the mechanical properties of RAC and compared with the NAC. The author concluded that the RAC attains 76% of compressive strength and minimum 60% of modulus of elasticity than that of NAC. Dhir *et al*. (1998) reported that the concrete with 100% coarse and 50% fine recycled aggregates have 20 and 30% lesser compressive strength of concrete than that of natural aggregate concrete.

Hansen and Narud (1983) reviewed the strength of recycled aggregate concrete by varying the water-cement ratio in the concrete mix. They found that the strength of recycled aggregate concrete was mainly affected by the water cement ratio. If the water-cement ratio is same or greater than natural aggregate concrete for recycled aggregate concrete, the strength of the RAC will be better than the natural aggregate concrete and vice versa. Hansen and Hedegkd (1984) did experiments to evaluate the recycled aggregate concretes properties as affected by admixtures in control concrete and reported that the addition of admixtures in concrete for air entraining, retarding and accelerating had lower impact or no impact on the properties of recycled aggregate concrete.

Many researchers Topcu and Guncan (1995), Van (1996), Mansur *et al.* (1999), Katz (2003, 2004), Chen *et al.* (2003), Khalaf and DeVenny (2004) and Xiao *et al.* (2005) studied the strength characteristics of RAC and reported that the compressive strength of RAC was lesser than NAC. Tavakoli and Soroushian (1996) reported that the source of the recycled aggregate and the properties of the recycled aggregate affect the strength of the concrete. They also concluded that the conventional relationships between compressive, tensile and flexural strengths are different for recycled aggregate concrete.

Ajdukiewicz and Kliszczewicz (2002) studied the strength properties of high performance and high strength recycled aggregate concrete having recycled aggregates retrieved from concrete with compressive strength 40-70 Mpa. They found that the water cement ratio in the mix design has to be adjusted to keep the same workability for NAC and RAC. They also concluded that the RAC attain 90% of strength of the NAC. Olorunsogo and Padayachee (2002) studied the durability characteristics of RAC with different percentages (0, 50 and 100%) of natural aggregate with recycled aggregate replacements. They concluded that the increase in percentage replacement of RA reduces the durability quality of the concrete in the initial age and in the long term it gets improved. They found that, after 28 days curing the water absorptivity of 100% recycled aggregate concrete was higher than natural aggregate concrete. They also concluded that this higher absorption of RAC might be due to cracks and fissures within the recycled aggregate created during processing which make the aggregate susceptible to ease of permeation, diffusion and absorption of fluid. Etxeberria *et al.* (2007) have studied the possibility of using recycled aggregate as a coarse aggregate in concrete. They conducted experiments on 12 beams with four replacements of RA for NA in concrete ranging from 0 to 100% with different transverse reinforcement. They found that less than 25% of recycled aggregate usage in concrete affects the shear capacity of Reinforced Concrete (RC) beams.

Kumar and Dhinakaran (2012, 2013) conducted extensive experimental investigations on effect of age on recycled aggregate in recycled aggregate concrete and the effect of high volume fly ash replacement for cement and recycled aggregate for natural aggregate in concrete. The authors found that the age of RA influence the compressive strength of the concrete. The strength property of the recycled aggregate concrete depends on the source of the recycled aggregate concrete. They also investigates the effects of replacing natural aggregate with recycled aggregate from 25-100% at an increment of 25% and cement with high volume fly ash from 40-60% at increments of 10% in concrete on the compressive strength and tensile strength of M50 grade concrete. The authors concluded that, the experimental results with 50% replacement of cement with FA and 50% replacement of Natural Aggregate (NA) with RA gave satisfactory results by compromising strength of 40-50% and major reduction in cost.

This study reports the workability and compressive strength characteristics of RAC with and without HVFA and also the structural behaviour such as load-deflection behaviour, flexural behaviour and crack width of reinforced RAC with HVFA which were comprehensively compared with that of concrete made with natural.

MATERIALS AND METHODS

Materials

Cement and fly ash: Ordinary Portland cement 43 grade confirming to IS: 4031 (1988) and Fly ash class F were used as cementitious materials in the concrete mixtures. Table 1 reports the chemical and physical properties of cement and fly ash.

Table 1: Chemical and physical properties of cement and fly ash

Description	Cement (%)	Fly ash (%)
SiO_2	24.50	56.60
Al_2O_3	7.00	33.71
CaO	63.00	1.07
Fe_2O_3	0.55	3.97
Na_2O	0.40	0.16
MgO	2.00	0.42
K_2O	0.60	1.02
SO_3	1.50	0.18
Cl	0.05	0.03
TiO_2	-	2.10
Specific gravity	3.15	2.45

Table 2: Physical and mechanical properties of coarse aggregate

Description	Natural aggregate	Recycled aggregate
Specific gravity	2.70	2.60
Water absorption (%)	3.00	4.50
Aggregate crushing value (%)	17.70	31.20
Aggregate impact value (%)	5.80	18.50
Abrasion value (%)	12.00	7.00
Fineness modules	7.02	6.93

Aggregates: Natural aggregates confirming to IS 383 (1970) and recycled aggregates retrieved from crushing old concrete obtained from 20 years old demolished structures was used as the coarse aggregates in the concrete matrix. The nominal sizes of the both natural and recycled aggregates used were less than 20 mm and their particle size distributions, physical and mechanical properties are shown in Table 2. River sand which passes through 4.75 mm sieve and retained on 150 µm sieve was used as the fine aggregate.

Super plasticizer: A commercially available sulphonated naphthalene formaldehyde-based super plasticizer was used to give a consistent workability.

Concrete mixtures: A total of four series of mixtures were prepares with NA and RA replacements of 25, 50 and 100% as series I, II, III and IV respectively. In each series, cement was also replaced with FA by 40, 50 and 60%. ACI mix design method was used to design the concrete mix proportion and the mix proportion arrived was 1: 0.7: 2.3 with the water cement ratio of 0.36. The addition of high range water reducing super plasticizer reduces the water cement (w/c) ratio from 0.36-0.3 and the workability was verified with slump cone test. The mix ratios and the slump values were tabulated in Table 3.

Specimen details: In each mix series 100×100×100 mm cubes in accordance with BSI (1983). were cast. The cubes were used to determine the compressive strength. In each mix series 3 cubes were cast for each fly ash mix combination and the test values were reported in Table 4. All the specimens were cast in steel moulds and well compacted. All the specimens cast were cured and tested for different periods such as 7, 28, 56 and 90 days. A total number of four concrete beams with two mix combinations were cast and tested at 29th day. Among the four beams, two were

Table 3: Mix ratio and slump value for high volume fly ash recycled aggregate concrete

Mix Idn.	Recycled aggregate as replacer (%)	Fly ash as replacer (%)	Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Recycled aggregate (kg)	Fly ash (kg)	Slump (mm)
Series 1								
M1	0	0	530	1240	389	-	-	88
M2	0	40	318	1240	389	-	212	95
M3	0	50	265	1240	389	-	265	100
M4	0	60	212	1240	389	-	318	104
Series 2								
M5	25	0	530	930	389	310	-	85
M6	25	40	318	930	389	310	212	87
M7	25	50	265	930	389	310	265	91
M8	25	60	212	930	389	310	318	95
Series 3								
M9	50	0	530	620	389	620	-	82
M10	50	40	318	620	389	620	212	83
M11	50	50	265	620	389	620	265	86
M12	50	60	212	620	389	620	318	92
Series 4								
M13	100	0	530	-	389	1240	-	78
M14	100	40	318	-	389	1240	212	81
M15	100	50	265	-	389	1240	265	83
M16	100	60	212	-	389	1240	318	85

Table 4: Experimental and theoretical values of load, deflection and moment at first crack

		Average experimental values				Theoretical value IS: 456, 2000			
Beam identification	Area of steel (%)	Load P_{cr} (kN)	Deflection Δ_{cr} (mm)	Crack width W_{cr} (mm)	Moment M_{cr} (kN m)	Load P_t (kN)	Deflection Δ_t (mm)	Crack width W_t (mm)	Moment M_t (kN m)
Control beam	1.29	50.0	3.810	0.04	17.500	15.04	0.875	0.02	5.26
High volume fly ash recycled aggregate concrete beam	1.29	42.5	3.045	0.07	14.875	15.04	0.875	0.02	5.26

control beams and the remaining two have a mix combination of 50% RA and 50% FA replacements. The length of the beam was 2.3 m and simply supported over an effective span of 2.1 m. The cross sectional dimensions of the beam were 125×250 mm and the clear cover was 20 mm. The beams were reinforced with high yield strength deformed bars of two numbers of 16 mm diameter at the tension zone and two numbers of 12 mm diameter at compression zone. Eight millimeter diameter two legged vertical stirrups spacing at 150 mm center to center were provided as shear reinforcement.

Test setup

Compressive strength: Compressive strengths were carried out as per IS: 516 (1959) using compression testing machine of 3000 kN capacity, at the applied load rate of 200 kN min^{-1}. Based on the test results, the percentage of NA and cement replacements with RA and FA were decided and the same percentage replacements were used in the further studies of flexural behavior of High Volume Fly Ash Recycled Aggregate Concrete (HVFARAC) beams.

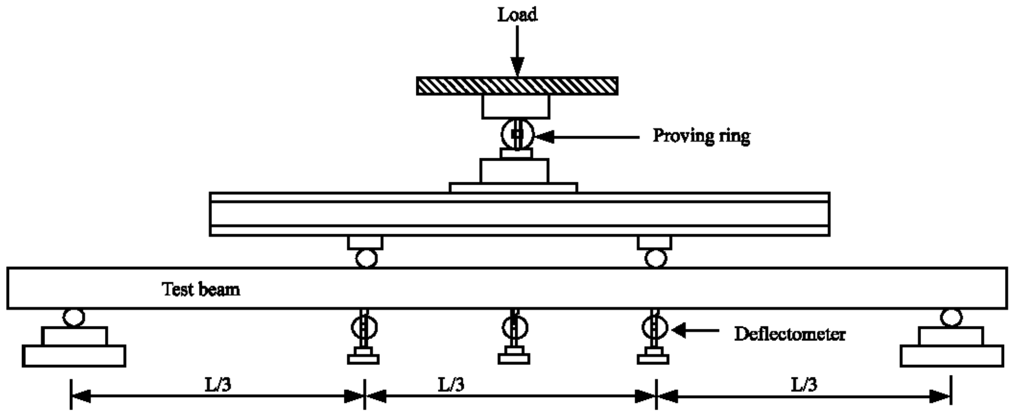

Fig. 1: Schematic diagram for flexure test on beam

Flexural test: Figure 1 shows the schematic diagram for flexure test on beam. The beams were tested for two point loading condition on 2000 kN capacity loading frame. The load was applied on two points each 700 mm away from the supports. The mid span deflection and the deflection under the load points were measured using dial gauges at different loads. The strain in concrete was measured using demec gauge. The load was applied at intervals of 2.5 kN and the deflection readings and demec gauge readings were noted. After the first crack appears the crack widths were measured for every 10 kN intervals. The performance of the beam was observed carefully and for each load increment the values were recorded until the beam fails.

RESULTS AND DISCUSSION

Workability: Slump cone test was performed for all mix proportions and the degree of workability was verified with IS: 456 (2000). Except the NAC with 60% FA, all other concrete mixes falls under the medium workability range. In accordance with Etxeberria *et al.* (2007) the fresh concrete properties like workability gets reduced when NA replaced with RA. Berndt (2009) reported that inclusion of FA in RAC has shown a considerable improvement in workability. In the present study, the replacement of NA with RA decreases the workability and the replacement of cement with FA slightly increases the workability. An average reduction of 3-11% in workability was observed for 25-100% NA with RA replacements. The reduction in workability on RAC was improved by the FA inclusion in the concrete. A maximum of 4, 7 and 9% increase in workability was observed when the cement was replaced with FA by 40, 50 and 60%, respectively.

Compressive strength: Kumar and Dhinakaran (2012, 2013) found that the compressive strength of the concrete gets reduced with the increment in RA and FA replacements. Figure 2a-d shows that, in the later age (90 days) the strength of the concrete was found to be improved in the fly ash concrete. The concrete with 40, 50 and 60 FA content reached 69, 62 and 50% strength of the concrete without FA and RA at 28 days but in later age (90 days) the strength attainment was improved as 84, 80 and 71%, respectively. The same trend was observed for all NA replacements with RA. For 25% RAC the strength improvement was from 80-91, 73-85 and 61-78%, respectively for 40, 50 and 60% cement with FA replacements. For 50% RAC the strength

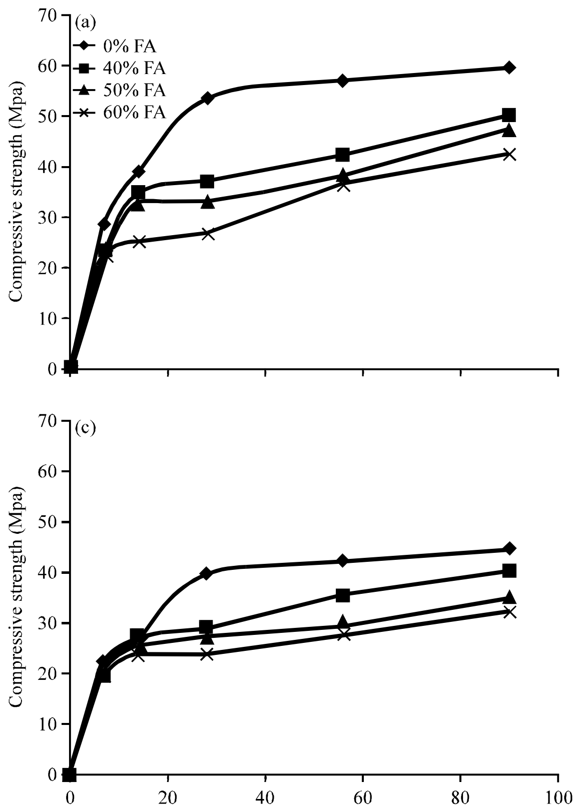

Fig. 2(a-d): (a) Compressive strength of natural aggregate concrete, (b) Compressive strength of 25% recycled aggregate concrete, (c) Compressive strength of 50% recycled aggregate concrete and (d) Compressive strength of 100% recycled aggregate concrete

improvement was from 79-91, 69-79 and 61-72%, respectively for 40, 50 and 60% cement with FA replacements. For 100% RAC the strength improvement was from 81-93, 79-83 and 66-74%, respectively for 40, 50 and 60% cement with FA replacements. From the experimental results, it was observed that the strength improvement was better in long term for all replacements of NA and cement. Kou *et al*. (2011) also studied the performance of admixed natural and recycled aggregate concrete and reported that the FA give better results on recycled aggregate concrete than NA at the later age. The above trend of the present work is found to be similar to the findings of Ishiyama *et al*. (2010). They studied the strength characteristics of recycled aggregate with high volume fly ash concrete and they concluded that though more amount of FA was used with RA, compressive strength was increased at the age of 91 days.

Load deflection behavior: Figure 3 shows the load deflection behavior at mid span for the control concrete beams (Control Beam 1 and 2) and the HVFARAC beams (HVFARAC Beam 1 and 2) having optimum percentage of FA and RA as 50% each. The behavior of HVFARAC beams which had a low compressive strength of 30 Mpa was also similar as control beam. The cracks were developed initially at tension zone and then propagated towards the compression zone when the beam was loaded. The first visible crack formation was found at around 50 kN load for the control

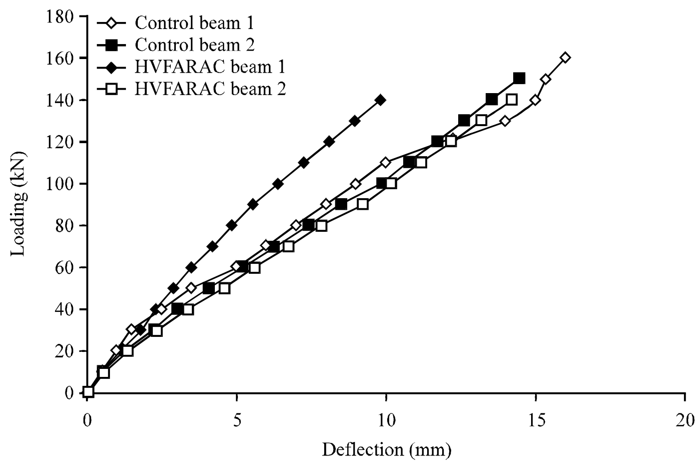

Fig. 3: Load-deflection curve for control and high volume fly ash recycled aggregate concrete beam

Table 5: Experimental values of load, deflection and moment at failure

	Average experimental values			
Beam identification	Load P_{ul} kN)	Deflection Δ_{ul} (mm)	Crack width W_{ul} (mm)	Moment M_{ul} (kNm)
Control beam	155	16.14	0.885	54.25
High volume fly ash recycled aggregate concrete beam	140	14.53	0.640	49.00

concrete beam and for HVFARAC beam it was found at 35 kN load. At first crack load the deflection at mid span of the beam was 3.81 and 3.045 mm for control and HVFARAC beam, respectively. Table 4 and 5 shows the deflection of the beams under various loads such as critical loads and ultimate loads. In all cases the experimental values are greater than the theoretical values. The ultimate load carrying capacity of HVFARAC beam was 90% of control beam and it also withstands greater load than the theoretical value. Similar results also reported by Malesev *et al*. (2010) as the deflections for a particular load was larger for reinforced concrete beams with RA than NAC beam by 5-10% for 50-100%, respectively for the replacement of NA with RA. Xiao *et al*. (2012) also reported that the structural behaviour of RAC members is generally weaker in comparison to those of structures made of natural aggregate concrete.

Flexural behavior of beams at first crack level: Table 4 shows the experimental results of both control and HVFARAC beams at first crack level. Theoretical values at first cracking moments were determined according to the IS: 456 (2000). The deflection were recorded and compared with theoretical values. The deflection at the first crack load was 3.81 and 3.045 mm for control and HVFARAC beams whereas the theoretical deflection was only 0.875 mm which is very much lesser than experimental value. Similarly both experimental and theoretical moments were compared. The experimental first crack moment was found much higher than the theoretical first crack moment and the observed moments at cracking for RAC beams with FA was lower than the control beam which is very similar to the results of Fathifazl *et al*. (2009). The Ratio of M_{cr}/M_t for control and HVFARAC beams are 3.32, 2.83, respectively.

Flexural behavior of beams at ultimate load: Table 5 shows the experimental results of both control and HVFARAC beams at ultimate load. Both NAC and HVFARAC beams showed the similar flexural behaviour and the ultimate deflection for HVFARAC beams was 14.53 mm occurs at 140 kN which was higher than control concrete beam at the same load. Qian *et al*. (2011) also reported that the flexural behaviour of reinforced RAC beam is very similar to the NAC beam and the presence of RA does not affect the structural behaviour. As per IS: 456 (2000) maximum permissible deflection was 8.4 mm which is very much lesser than both control and HVFARAC beams. Similarly the ratio of ultimate moment to theoretical moment (M_{ul}/M_t) for control and HVFARAC beams are 1.54 and 1.44, respectively. Hence, it was concluded that the replacement of NA and cement with RA and FA 50% each gives satisfactory performance.

Crack width: Crack width is an important factor from the serviceability aspect. In this study, the propagation of cracks was observed, measured and marked at every 5 kN load increment up to the failure. Final crack patterns of beams for control concrete and for concrete with HVFARAC are shown in Fig. 4a and b. The cracks were distributed symmetrically about the center. All the cracks were nearly vertical and parallel to each other. The cracks first appeared in tension zone and extended well up to top with increase in load. The vertical cracks were started at the bottom of the beam and progressed to compression zone up to the yielding. Figure 5 shows the crack width measured during experiment for HVFARAC beams and control beams at various load increments. No cracks were found in both the beams at the critical load calculated theoretically. The HVFARAC

Fig. 4(a-b): (a) Details of crack propagation for a beam with control concrete and (b) Details of crack propagation for a beam with high volume fly ash recycled aggregate

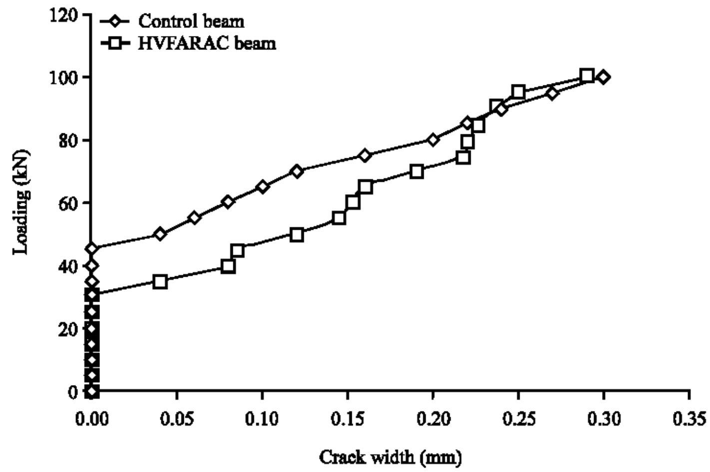

Fig. 5: Load vs Crack width for control and high volume fly ash recycled aggregate concrete beam

beams and control beams showed similar crack pattern. Fathifazl *et al*. (2009) also found that the crack pattern for both RAC and NAC beams were similar and it was distributed symmetrical about centre. In general, the failure modes of control and HVFARAC beams were identical and the crack pattern at different stages was also almost same.

CONCLUSION

Based on the Experimental study the following conclusions are made:

- The workability of RAC gets improved in HVFA replacements. The compressive strength improvement was better in long term period for all replacements of RAC than the concrete without RA in all cement with FA replacements. It is found that the 50% replacement of both cement with FA and NA with RA gives considerable increase than 100% RA replacements. Hence, it was suggested as optimum replacement percentage for NA and cement
- In the flexural strength test, the flexural strength of HVFARAC beam was higher than the flexural strength of conventional concrete beam. The load bearing capacity of the HVFARAC beam was greater than the theoretical value and it was lesser than the control beam
- The ultimate load carrying capacity of HVFARAC beam is about 90% of an ultimate load carrying capacity of control beam and the ratios between theoretical and experimental ultimate moment are 1.5 and 1.4 for control and HVFARAC beams
- The deflections and crack width of HVFARAC beam was higher than the control beam
- From the detailed experimental investigations, it was found that NA can be replaced up to 50% with RA and cement can be replaced up to 50% with FA and gives satisfactory results in addition to the benefits like reduction in cost of concrete and saving environment from pollution

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