International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Effect of Aggregate Percentage on the Fracture Parameters of Steel Fibre Reinforced Recycled Aggregate Concrete

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Abstract: ***In this study, fracture parameters are determined by conducting four point bending test on notched beams. Beams with varying percentage of 25, 50 and 75% of recycled aggregate is been used with a constant percentage of steel fibre with an initial notch depth. The peak load of the specimen with lesser percentage of recycled aggregate was higher. Deflection also decreased with increasing recycled aggregate percentage. It is found that fracture toughness is reducing with increasing percentage of recycled aggregate. The other two parameters namely fracture energy and energy release rate is also reducing with increasing percentage of recycled aggregate. So the presence of recycled aggregate actually affects the behavior of beam.***

1. Introduction

1.1 General

Concrete is the most used construction material in the world. Depending on its constituents, it can be very strong in compression, but it presents generally low bending strength and fracture toughness. In the past decade, research on applications of recycled aggregate concrete (RAC), which uses recycled concrete aggregate (RCA), has attracted world-wide interest due to their social, environmental and potential economic benefits. Either partially or totally replacing natural aggregates with recycled concrete aggregates (RCA) to produce recycled aggregate concrete (RAC) is a viable option to suppress the demand on natural resources and limit the amount of waste disposed in landfill.

Various research has been carried out to investigate the behavior of RAC in the past decades. Before that it was believed the natural aggregate performed better that RCA. Studies on the effect of the replacement percentage (i.e. RP) of RCA, which is usually defined as the mass ratio of recycled aggregate to the total natural coarse aggregate, have shown that an increase of RP leads to lower compressive and tensile strength, lower Young modulus and higher creep and shrinkage [1]. The quality of RCA has a significant effect on the probability distribution of the strength of RAC; the use of RCA with non-uniform quality may lead to a large scatter of this distribution.

The use of RCA in concrete increases its shrinkage of the resultant RAC because the RCA absorbs a large quantity of water. Adding steel fibres to form steel fibre reinforced recycled aggregate concrete (SFRAC) is an effective technique for reducing shrinkage and associated cracking, as well as increasing the energy absorption capacity of the concrete [2]. When the steel fibre content is greater than 0.25%, the crack width of steel fibre reinforced recycled aggregate mortars is considerably reduced compared with mortars without steel fibres[3]. Furthermore, it has been proved that inclusion of steel fibres can enhance the mechanical properties ,fracture properties, spalling resistance and toughness of normal concrete.

An attempt is made to study the fracture behavior including fracture energy, fracture toughness, energy release rate of SFRAC with different replacement percentage of RA.

2. Experimental Programme

2.1 Materials and sample preparation

Ordinary Portland cement of 53 grade conforming to IS 12269:1970 was used. Laboratory tests were conducted to determine standard consistency and initial setting time, final setting time and compressive strength of mortar cubes at 7 and 28 days. The results conform to IS specifications.

Table 1: Properties of cement

Sl. No.	Tests	Results
1	Standard consistency	34.6%
2	Initial setting time	150 minutes
3	Final setting time	380 minutes
4	7th day compressive strength	39.5 MPa
5	28th day compressive strength	54.4 MPa

Aggregate of size 12m and 6 mm conforming to IS 383:1970 are used. M sand conforming to zone II was used as fine aggregates. The physical properties of coarse and fine aggregates as obtained through lab tests are given in table 2 and 3 respectively.

Table 2: Properties of coarse aggregate

Sl. No.	Test Conducted	Result
1	Bulk density	1.598 g/cc
2	Specific gravity	2.67
3	Void ratio	0.66
4	Porosity	40%

Table 3: Properties of fine aggregate

Sl. No.	Test Conducted	Result
1	Bulk density	1.983 g/cc
2	Specific gravity	2.54
3	Void ratio	0.297
4	Porosity	21.8%

Superplasticizers which is also known as high range water reducers, are chemical admixtures used for well dispersion of particle suspension. Superplasticizers are used to avoid particle segregation of gravel, coarse and fine sand, and to improve its flow the addition of superplasticizers in concrete mortar reduces the water cement ratio without affecting the workability of the mixture.

Use of such admixture helps to generate self consolidating concrete and high strength concrete. It helps to improve the performance of hardened concrete. Since use of such admixtures helps to reduce water cement ratio it increases the strength properties of hardened concrete. The pH value of admixture used is 6 and volumetric mass of 1.09 kg/litre is used. It appears to be light yellow coloured with an alkali content of less than 1.5g.

Hooked end steel fibre of non-glued type is used in concrete. Properties of steel fibres provided by manufacturers are represented in figure 1. Tensile strength of fibres is given as 1100 MPa. Drinking water directly taken from water supply line was used for the entire casting work.

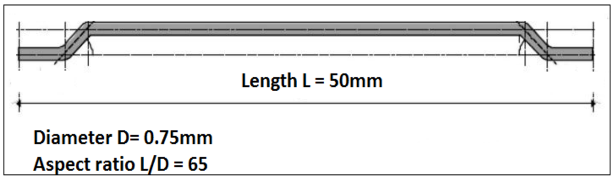

Figure 1: Details of steel fibres

2.2 Trial Mixes

Three trial mixes were prepared with the proportion given in table 4.6 Compressive strength of standard cubes at 7, 14 and 28 days were determined as shown in table 4.7. the 28th day compressive strength of these mixes were examined and found that mix designated as M3 can be used for this study.

Table 4: Trial mix proportion

Mix No.	Weight of cement (kg/m^3)	Weight of coarse aggregate (kg/m^3)	Weight of fine aggregate (kg/m^3)	w/c	Mix proportion
M1	516.9	1186.1	595.27	0.3	1:1.15:2.3
M2	520	1140	685	0.3	1:1.31:2.2
M3	479.3	1150.5	642.9	0.3	1:1.34:2.4

Table 5: Compressive strength of trial mixes

Mix No.	Compressive strength (MPa)		
	7 days	14 days	28 days
M1	47.2	60.3	65.77
M2	45.87	58.83	63.148
M3	51.3	61.7	68.3

2.3 Casting and testing of cubes

Nine different mixes were prepared with varying percentage of steel fibre and recycled aggregate along with a control mix. The size of the concrete cube were 150mx150mmx150mm. the designation given to these mixes are shown in the table below.

Table 6: Specimen details

Mix	Designation
Control mix	CL
0.5% steel+ 25% RA	5R25
0.5% steel+ 50% RA	5R50
0.5% steel+ 75% RA	5R75
1.0% steel+25%RA	10R25
1.0% steel+50%RA	10R50
1.0% steel+75%RA	10R75
1.5% steel+25%RA	15R25
1.5% steel+50%RA	15R50
1.5% steel+75%RA	15R75

The cube moulds of required size 100 mm were made in so that the two parts get separated. Cube moulds were provided with a base plate and they were as per IS:10086-1982. The tamping rod was made of mild steel and its diameter was 16±0.5 mm and was of length 600±2 mm. the rod end was rounded for the ease of tamping. The compression testing machine was used for testing recommended by code. The compression testing machine was capable of applying the uniform load manually or automatically at the specified rate. Results showing compressive strength are shown in table 7.

Table 7: 28 days Compressive strength of different mixes

Mix	28 days compressive strength (MPa)
CL	68.3
5R25	69.3
5R50	67.1
5R75	65.7
10R25	70.2
10R50	67.5
10R75	66.6
15R25	62.7
15R50	61.3
15R75	59.8

From the above graph it is clear that mix 10R25 is having the highest compressive strength as compared to the control mix and all other mixes. As the percentage of steel fibre increases the compressive strength is also increasing upto a percentage of 1% after which the compressive strength is decreasing. But in case of recycled aggregate the strength is decreasing with increase in percentage recycled aggregate. Hence it is clear that the optimum percentage of steel is 1%. With this percentage keeping as a constant beams were prepared to find the fracture properties of beam which is discussed in the next section.

2.4 Casting of Specimens

Rectangular plywood moulds of inner dimensions 100mmx150mmx1000mm were used. A rectangular cut of 3mm size was provided at the mid section so as to introduce a metallic template upto 30mm depth. 3mm metallic template is used to provide a sharp notch at the mid span of the specimen which can be removed after 5 hours of casting. Reinforced concrete beams with rectangular cross section of size 100 x150 mm and clear span of 1000mm were used to obtain fracture properties. Three beam specimens were prepared with percentage variation of recycled aggregate as 25, 50, 75% by keeping percentage of steel fibre constant as 1%. The designation is same as that given before.

The beam consists of 3 bars of 10 mm diameter as tension steel. Two legged stirrups of 6 mm diameter were provided at 90 mm spacing at the end and 100 mm spacing at the centre. Two 8 mm diameter bars were provided as stirrup holders.

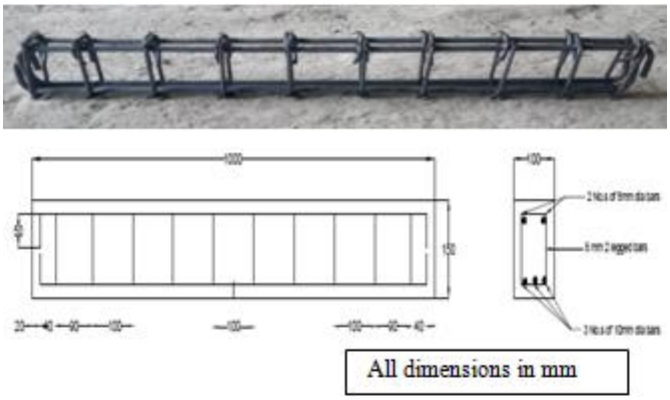

Figure 2: Reinforcement Details

Materials were batched and weighed. Mixer was wetted before mixing to prevent absorption of water. First the coarse aggregate was mixed in mixer for 5 minutes. Later fine aggregate and cement were introduced in mixer and mixed for 5 minutes. Fibers were evenly distributed in the mixer. Water and admixtures were added to obtain a uniform paste.

Inner surface of mould was oiled and a 3 mm thick steel plate was inserted in the prescribed position in each wooden mould to produce a 30 mm deep initial crack. Reinforcement cage was placed in the mould and the whole assembly was kept elevated for removal of metal template. After 5 hours of casting the metal template was removed. Specimens were unmoulded (fig. 4) after 24 hours and cured for 28 days in water at room temperature.

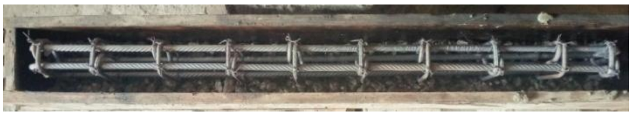

Figure 3: Reinforcement inserted in mould during casting

Figure 4: Bottom surface of beam specimen with notch

2.5 Fracture test on specimens

Specimens were taken out from water, kept for drying and then white washed. Pellets and fixtures for LVDT were glued to specimens at the location to measure strain and CMOD respectively as shown in the schematic diagram of test set up in fig. 5. Load controlled testing were done by applying two point load. Mid-span deflection, CMOD were recorded at every 0.1 tone load increment. Beams were loaded till failure and ultimate load was noted.

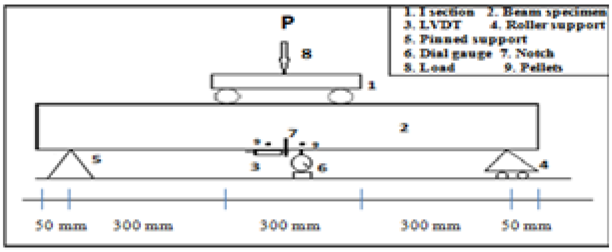

Figure 5: Schematic diagram of test setup

3. Results and Discussions

The readings and the calculated values of the fracture parameters of the beams tested under four point bending is recorded in the form of a table and is shown below.

Table 8: Fracture properties of beams

Specimen	10R25	10R50	10R75
Peak load (kN)	13.5	10.5	7.2
Deflection (mm)	0.48	0.39	0.20
CMOD (mm)	0.24	0.21	0.07
Effective crack length(mm)	51.67	42.8	41.64
Fracture toughness (MPa.mm^(1/2))	1.12	1.02	0.74
Fracture energy (N/mm)	3.15	3.01	2.53
Energy release rate (N/m)	0.829	0.64	0.59

3.1 Fracture Energy

Fracture energy is calculated from area under load-deflection curve using equation 1.1. It can be seen that specimen with 25% RA is having higher fracture toughness. Fracture toughness of beams 10R25, 10R50, 10R75 were 1.12, 1.02 and 0.74 $MPamm^{\frac{1}{2}}$

$$G_f = \frac{W_F + W_S \delta_0}{A_{lig}} \qquad (1.1)$$

3.2 Fracture Toughness

Fracture toughness of specimens was determined by set of equations from (1.2) to (1.6).

$$K_{IC} = K_{IC}^P - K_{IC}^S \qquad (1.2)$$

$$K_{IC}^P = \frac{6M\sqrt{a_0}}{BW^2} f(\alpha) \qquad (1.3)$$

f(α) is the geometric function for four point bending and is given in equation 1.5

$$f(\alpha) = 1.99 - 2.47\alpha + 12.97\alpha^2 - 23.17\alpha^3 + 24.8\alpha^4 + 60.5\alpha^{16}$$

$$\alpha = \frac{a_0}{h} \qquad (1.4)$$

$$K_{IC}^S = \frac{2F_S}{B\sqrt{\pi a_0}} F_1\left(\frac{c}{a_0}, \frac{a_0}{D}\right) \qquad (1.5)$$

Fracture energy of the beams 10R25, 10R50, 10R75 are 3.15, 3.01, 2.53 N/mm respectively. This also shows same pattern as that of fracture toughness.

$$F_1(\eta,\xi)=\frac{3.52(1-\eta)}{(1-\xi)^{\frac{3}{2}}}-\frac{4.35-5.28\eta}{\sqrt{1-\xi}}+\left[\frac{1.30-0.30\eta^{\frac{3}{2}}}{\sqrt{1-\eta^2}}+0.83+1.76\eta\right](1-(1-\eta)\xi) \quad (1.6)$$

3.3 Energy Release Rate

Energy release rate shows similar pattern as that of fracture toughness obtained from equation 1.7.

$$G_C=\frac{K_{IC}^2}{E} \quad (1.7)$$

Energy release rate also follows same patter as that of fracture toughness, since energy release rate is related to fracture toughness. Average value if energy release rates are 0.829, 0.64, 0.59 N/m.

4. Conclusions

Experimental study on the fracture behavior of steel fibre reinforced recycled aggregate concrete (SFRAC) were conducted. Based on the three-point notched beam test results, the effects of recycled aggregate on parameters associated with the facture behavior, including the peak load Pmax, the critical crack mouth opening displacement CMODc at the peak load, fracture energy (GF), fracture toughness (Kini) and energy release rate have been analyzed and discussed in detail.

The following conclusions can be drawn from the test results, analyses and discussions:

- Steel fibers were used to reduce the brittle characteristics of recycled aggregate concrete. As the percentage of steel fibre is increased the strength also increased upto certain percentage i.e., 1%.
- Adding 1.0% fiber improved the compressive strength of SFRAC to being comparable to that of the normal concrete used as a reference.
- As the percentage of RA increases, the fracture parameters show less significance.

The fracture parameters are decreasing with increase in percentage of recycled aggregate.

- Fracture parameter completely depends upon the external loading, the crack length, deflection, ligament area and the spacing of the support.
- Since the applied load causes the specimen to deflect, the rate of deflection is a measure of fracture properties.
- Fracture toughness was higher for specimen 10R25 with 1.12 $MPamm^{\frac{1}{2}}$. The fracture energy is decreased by 8.9% for 10R50 and 33.9% for 10R75 as compared to 10R25.
- Fracture energy is again decreased by 4.44% and 19.6% for specimen 10R50 and 10R75 respectively as compared to 10R25.
- Energy release rate was also higher for 10R25 with 0.829 N/m. it decreased by 22.7% and 28.8% for specimen 10R50 and 10R75 respectively.
- RA replacement upto 25% is applicable without compromising the strength and provides better crack resistance.

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