

# A Study on Fracture Parameters of Normal and Self-Compacting Concrete and High-Strength Concrete Using Normal and Recycled Aggregates

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**ABSTRACT:** The recycling of Construction and Demolition Wastes has long been accepted to have the possible to conserve natural resources and to decrease energy used in production. In some nations it is a standard substitute for both construction and maintenance, particularly where there is a scarcity of construction aggregate. The use of recycled aggregate weakens the quality of recycled aggregate concrete which limits its application. Concrete recycling gains importance because it protects natural resources and eliminates the need for disposal by using the readily available concrete as an aggregate source for new concrete or other applications. The quality of concrete with recycled aggregate concrete (RAC) is very dependent on the quality of the recycled material used.

As there is much amount of data regarding mechanical properties of recycled aggregates concrete, but few data is only available on fracture parameters of RA. A study is carried out on fracture parameters on RA in varying proportions (0%, 25%, 50%, 75% and 100%) as a replacement of natural aggregate used in Normal concrete, self-compacting concrete and high-strength concrete. An even size of 10mm coarse aggregate is used through the work.

Various fracture parameters such as fracture toughness, fracture energy( $G_f$ ), characteristic length of the material( $L_{ch}$ ), stress intensity factor( $K_I$ ) and Brittleness number are determined by measuring the maximum loads of geometrically similar single edge notched concrete prisms. Finally, a comparison is drawn by presenting graphs which shows the variation in Load- Deflection, Load-CMOD and Deflection-CMOD with variation in % replacement of recycled aggregate.

## I. INTRODUCTION

The importance of establishing the suitability of recycled aggregates has increased in recent years against the backdrop of a growing emphasis on sustainable building practices. As pointed out by Padmini et al., the rate of building demolition is constantly increasing, making it essential to effectively reuse demolition waste to conserve nonrenewable natural resources. At present a large portion of potentially useful construction and demolition waste is disposed of in landfill sites, creating environmental problems due to scarcity of such sites, unplanned disposal, and environmental cost of transporting demolition waste. The use of coarse recycled concrete aggregates (RCAs) as a replacement for natural coarse aggregates in concrete offers a sustainable solution to these problems. However, the use of RCA may potentially reduce concrete quality as coarse RCAs are generally of poorer quality than natural coarse aggregates, with greater water absorption and lower density. This reduced quality is due to the fact that coarse RCA consists of both original aggregate and adhered mortar; thus the quality of the RCA depends not only on the original aggregate, but also on the quality and quantity of adhered mortar. The use of RCA also affects the characteristics of the interfacial transition zones between aggregates and cement paste, which in turn affects the strength characteristics of concrete containing RCA. When considering the mechanical properties of concrete with RCA, most of the previous researches confirmed that the reduction in stiffness (i.e., elastic modulus) is higher than the reduction in strength. Another important consideration is the possible reduction

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in workability of concretes incorporating coarse RCA, due to the increased angularity and surface roughness of RCA when compared to natural coarse aggregates. This is of particular importance for the increasingly popular form of concrete known as Self-Compacting Concrete (SCC). The Eurocode defines SCC as concrete that is able to flow and compact under its own weight, fill formwork with its reinforcement, duct box houses, and so forth, whilst maintaining homogeneity. It is a relatively recent form of concrete construction having been developed in Japan in the mid-1980s and introduced in Europe in the mid-1990s. Despite its recent development, SCC is now widely used in industry due to the advantages of SCC which include increased on-site productivity, enhanced construction quality, and improved working conditions on-site. However, as pointed out by Tuyan et al., the cost of SCC is higher than traditional vibrated concretes due to the need for higher powder contents and chemical admixtures in SCC. Thus in order to allow SCC to reach its full potential in terms of industry uptake it is necessary to develop ways of making SCC more cost-effective. The use of coarse RCA as substitutes for coarse natural aggregates in SCC offers a means of reducing the cost of SCC, while reducing the carbon footprint of concrete production. Consequently, there are both business case and an environmental obligation to explore the use of RCA in SCCs.

This paper examines the use of varying proportions of coarse RCA in SCC. The work presented herein builds on the existing body of literature by examining the fresh concrete properties of SCCs containing RCA. This is an important area which has been examined by a number of researchers in recent years including. The primary contribution of this paper, however, lies in the examination of the hardened properties of SCCs containing various levels of RCA and, most importantly, the examination of the fracture properties of SCC containing RCA. It is recognized that the fracture properties of concrete constitute fundamental characteristics in design and safety assessment of structures, especially large-scale structures. As pointed out by Bordelon et al., examination of compressive strength and tensile strength alone does not give a complete picture of structural performance due to the interaction of the material behaviour, preexisting cracks, and geometry of the structure. Bordelon et al. thus stated that the concrete fracture properties can provide greater insight into the potential load carrying capacity of the material in a given structural system. These fracture properties are heavily dependent on the components in the mixture, with fracture energy depending largely on the quality of the ITZ and the properties of the coarse aggregate. Thus utilization of coarse RCA as a replacement for natural coarse aggregate may have a notable influence on concrete fracture energy. As stated by Butler et al. however, there are very few studies which examine the fracture energy of vibrated concretes containing coarse RCA. Even less knowledge exists for SCCs, with little or no research currently available exploring the fracture energy implications of RCA use in SCCs, which have different ITZ characteristics and mix compositions to normal vibrated concretes. The work in this paper seeks to address this important gap in the existing literature by exploring the fracture energy of SCCs with natural coarse aggregate replaced with RCA at levels of 0% (control), 25%, 50%, 75%, and 100%. SCC strength characteristics are also examined at each of the RCA utilisation levels to enhance understanding of the effect of RCA on these properties.

## II. LITERATURE REVIEW

**Hillerborg (1)** conducted a study on the determination of the fracture energy from the tests data of about 700 mortar and concrete beams obtained from different laboratories of the world. This study showed that fracture energy is apparently dependent on the specimen size.

Planas and co-workers (**Guinea et al.1992, Planas et al. 1992, Elices et al. 1992**)(2) carried several investigations on the measurement of the fracture energy using three-point bending tests and they showed that if different sources of energy dissipation during the test and analysis are taken into account, the value of GF appears to be almost size independent.

**Hillerborg et al. (1976), Bažant and Oh (3)** developed the crack band model in which the fracture process zone is modelled as a system of parallel cracks that are continuously distributed (smeared) in the finite element. The material behaviour is characterized by the constitutive stress–strain relationship. The width of the fracture process zone ( $h_c$ ) is assumed to be constant. For normal concrete it is assumed to be three times the aggregate size. The width of the crack band is held constant in order to avoid spurious mesh sensitivity. This assures that the energy dissipation due to fracture per unit length of crack is a constant which is equal to the fracture energy of the material ( $GF$ ).

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Hillerborg (1985) and RILEM Technical Committee 50-FMC (4) proposed a method using three-point bending beams to obtain the value of fracture energy. According to this method the area between the load–displacement ( $P - \delta$ ) curve obtained experimentally is corrected for eventual nonlinearities at low loads, self-weight of the specimen, and other loading due to fixtures. The fracture energy is calculated from the equation

$$GF = W_0 + W_s \delta_0 / A_{lig}$$

in which  $W_0$  is the area under the load vs displacement curve,  $W_s$  is the sum of the weight of the specimen between the supports and twice that of the part of the loading arrangement, and  $\delta_0$  is the deformation at the final failure of the beam.

### III. EXPERIMENTAL INVESTIGATION

The experimental study consists of arriving at suitable mix proportions that satisfied the plain M30 concrete and High-strength concrete and the fresh properties of self compacting concrete as per EFNARC specifications. Standard cube moulds of 150mm x 150mm x 150mm made of cast iron were used for casting and standard prism moulds of 500mm x 100mm x 100mm made of cast iron were used for casting standard prisms. The standard moulds were fitted such that there are no gaps between the plates of the moulds. If there are any small gaps they were filled with plaster of paris. The moulds were then oiled and kept ready for casting. After 24hrs of casting, specimens were de moulded and transferred to curing tank where in they were immersed in water for the desired period of curing.

The program consists of casting and testing of 30Mpa plain and 30Mpa Self Compacting Concrete and High-strength concrete(80Mpa) with the replacement of recycled aggregate in different percentages. A total of 3batches were made, out of which 1batch is of normal SCC i.e., with the percentage replacement of recycled aggregates( 0%, 25%, 50%, 75%, 100%) , 1batch of plain M30grade concrete with the percentage of recycled aggregates(0%,25%,50%,75%,100%) and 1batch of High-strength concrete i.e., with the percentage replacement of recycled aggregates( 0%, 25%, 50%, 75%, 100%).

Table 1: Details of specimens cast

GRADE OF CONCRETE	% OF RECYCLED AGGREGATE	SPECIMENS	TOTAL NO. OF SPECIMENS
M30	0%	3 PRISMS	15 PRISMS
	25%	3 PRISMS	
	50%	3 PRISMS	
	75%	3 PRISMS	
	100%	3 PRISMS	
SCC-M30	0%	3 PRISMS	15 PRISMS
	25%	3 PRISMS	
	50%	3 PRISMS	
	75%	3 PRISMS	
	100%	3 PRISMS	
HSC-M80	0%	3 PRISMS	15 PRISMS
	25%	3 PRISMS	
	50%	3 PRISMS	
	75%	3 PRISMS	
	100%	3 PRISMS	
<b>TOTAL SPECIMENS</b>			<b>45 PRISMS</b>

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## MATERIALS USED

The different materials used in this investigation are

- 53 Grade Ordinary Portland cement
- Fine Aggregate
- Coarse Aggregate
- Super Plasticizer (CONPLAST SP430)
- Fly ash.
- Water
- Silica fume

**Table 2: Proportions of Different Size Fractions of Sand to Obtain Zone-2 Sand**

Sieve size (mm)	% Passing recommended by IS 383	Adopted grading	% Weight retained	Cumulative % Weight retained	Weight retained in grams
10-4.75	100	100	-	-	-
4.75-2.36	90-100	100	-	-	-
2.36-1.18	75-100	90	10	10	100
1.18-0.60	55-90	65	25	35	250
0.60-0.30	35-59	40	25	60	250
0.30-0.15	8-30	10	30	90	300
0.15	0-10	0	10	100	100

### Cement

Cement used in the investigation was 53 Grade Ordinary Portland cement conforming to IS 12269. The cement was obtained from a single consignment and of the same grade and same source. The Specific gravity of the cement is found to be 3.10.

### Fine Aggregate

The Fine aggregate conforming to Zone-2 according to IS 383 was used. The fine aggregate used was obtained from a nearby river source. The bulk density, specific gravity, and fineness modulus of the sand used were 1.41g/cc, 2.68, and 2.90. The sand obtained was sieved as per IS sieves (i.e. 2.36, 1.18, 0.6, 0.3, and 0.15mm). Sand retained on each sieve was filled in different bags and stacked separately for use. To obtain Zone-2 sand correctly, sand retained on each sieve is mixed in appropriate proportion according to the mix design and required quantity in which each size fraction is mixed is shown in Table 2.

### Coarse Aggregate

Crushed granite Aggregate was used as coarse aggregate. The coarse aggregate was obtained from a local crushing unit having 10mm well graded aggregate is used in this investigation. The bulk density, specific gravity of the coarse aggregate sand used was 1.41g/cc, 2.65.

### Fly ash

Fly ash conforming to IS3812:1981 is used as mineral admixture. Mineral admixtures are used to improve the fresh and hardened properties of concrete and at the same time reduce the cost of concrete materials. In order to achieve the necessary viscosity to avoid segregation, additional fine materials are used.

### Super plasticizer

High range water the reducing admixtures known as super plasticizers are used for improving or workability for decreased water-cement ratio without decreasing the compressive strength. These admixtures when dispersed in cement agglomerates significantly decrease a viscosity of the paste by forming a thin film around the cement particles. In the present work water-reducing admixture Conplast SP430 is differentiated from conventional super plasticisers in that it is based on a unique carboxylic ether polymer with long lateral chains. This greatly improves cement dispersion. At the

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start of the mixing process an electrostatic dispersion occurs but the cement particle's capacity to separate and disperse. This mechanism considerably reduces the water demand in flowable concrete. Conplast SP430 combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability.

### Silica Fume

Silica fume, also known as microsilica, (CAS number 69012-64-2, EINECS number 273-761-1) is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete and high strength concrete.

**Mix Design proportions**

	Cement	Fine aggregates	Coarse aggregates	Water content	Fly ash	Silica fume	Super plasticizer
M30	425.7 kg/m <sup>3</sup>	518.05 kg/m <sup>3</sup>	1180.47 kg/m <sup>3</sup>	191.56 kg/m <sup>3</sup>	-	-	-
SCC-M30	350kg/m <sup>3</sup>	860kg/m <sup>3</sup>	788kg/m <sup>3</sup>	184.5kg/m <sup>3</sup>	175kg/m <sup>3</sup>	-	12.5kg/m <sup>3</sup>
M80	595kg/m <sup>3</sup>			217.7kg/m <sup>3</sup>	107.1kg/m <sup>3</sup>	23.8kg/m <sup>3</sup>	3.256kg/m <sup>3</sup>

### Test procedure

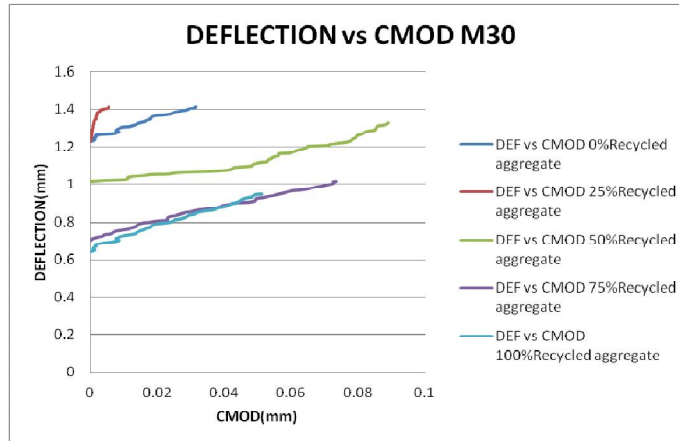
Pace the cleaned V-funnel vertically on a stable and flat ground, with the top opening horizontally positioned. Wet the interior of the funnel with the moist sponge or towel and remove the surplus of water, e.g. through the opening. The inner side of the funnel should be 'just wet'. Close the gate and place a bucket under it in order to retain the concrete to be passed. Fill the funnel completely with a representative sample of SCC without applying any compaction or rodding. Remove any surplus of concrete from the top of the funnel using the straightedge. Open the gate after a waiting period of 10 ± 2seconds. Start the stopwatch at the same moment the gate opens. Look inside the funnel and stop the time at the moment when clear space is visible through the opening of the funnel. The stopwatch reading is recorded as the V-funnel flow time, noted as T<sub>v</sub>. Clean the V-funnel after testing.

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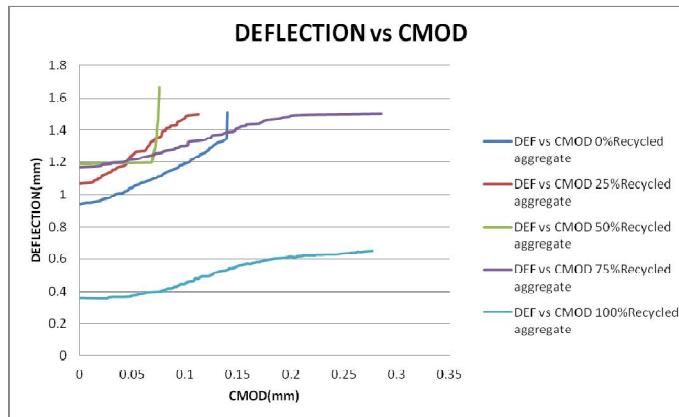
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## DEFLECTION vs. CMOD: 1. NORMAL CONCRETE M30:



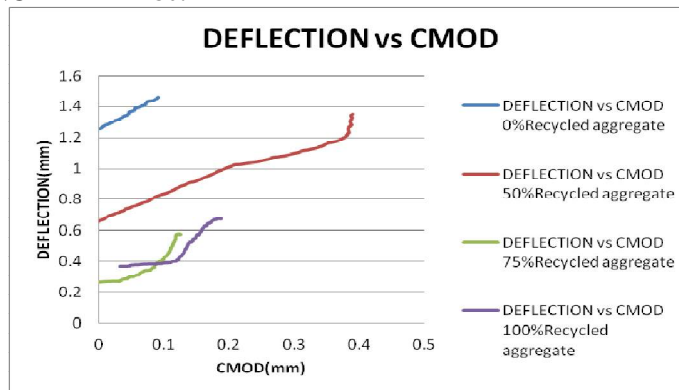
Graph 1: comparison for % replacement of Recycled aggregate

## SELF-COMPACTING CONCRETE:



Graph 2 :comparison for % Replacement of Recycled aggregate

## HIGH STRENGTH CONCRETE – M80:



Graph 3:comparison for % Replacement of Recycled aggregate



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## IV. CONCLUSION

### M30 GRADE CONCRETE:

1. From Load-deflection curve, Behavior of specimens with 50% replacement of NA by RCA is similar to that of Normal concrete. The percentage replacement levels of 25, 75, 100 behaves similarly under the application of load.
2. From Load-CMOD curve, CMOD depends on the load taken by the specimen and CMOD value starts from maximum load of specimen taken. The 25% replacement of recycled aggregate shows sudden failure. The behaviors of 0% & 75% replacement of RA are same but peak load are different.
3. For normal M30 grade of concrete the fracture energy and characteristic length decreases and Brittleness number increases with the increase in the % replacement of RA.
4. For normal M30 grade of concrete the Stress intensity factor of 25% RA increased and further decreased with increase in % replacement of RA.

### SELF COMPACTING CONCRETE:

1. From Load-Deflection curve, load taken by specimens with the % replacement of recycled aggregate shows decrement with the increase in the % of recycled aggregate, but 25% replacements of recycled aggregate specimen have taken more load than other replacements.
2. From Load-CMOD curve, Behavior of Specimens with % replacement of recycled aggregates is almost same. But, 50% replacement of recycled aggregate shows sudden failure. CMOD depends on the load taken by the specimen and CMOD value starts from maximum load of specimen taken.
3. Fracture energy increased for 25% and 75% replacement of RA and decreased for 50% and 100% replacement of RA compared with 0% recycled. Characteristic length (LCH) increases with increase in the % replacement of RA. But, in case of 100% replacement of RA it decreased. With increase in % replacement of RA, Brittleness number decreases.
4. Stress intensity factor have shown uneven results, for 25% and 75% RA Stress intensity factor increased and for 50% and 100% replacement of RA Stress intensity factor decreased.

### HIGH STRENGTH CONCRETE:

1. From Load-Deflection curve, Observed that the 0% replacement of RA to 100% RA indicates that brittleness nature of HSC specimen increases with the increase in replacement of natural aggregate with recycled aggregate. The deflection of specimens with the % replacement of natural aggregate to recycled aggregate is decreased by almost 3 times. Load carrying capacity of the specimens also decreases with increases in % replacement of natural aggregate to recycled aggregate same in same grade of concrete.
2. From Load-CMOD, 0% replacement of recycled aggregate shows sudden failure. 50% & 75% replacement of recycled aggregate shows nearly same behaviour. 100% replacement of recycled aggregate taken less load when compared with other replacements.
3. With the increase in the % replacement of RA, fracture energy and characteristic length (LCH) decreased and Brittleness number increases with partial replacement and in case of completely replaced RA Brittleness number decreased. And Stress intensity factor decreases with the % replacement of RA when compared with 0% replacement of RA.

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