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Study on Fracture Behaviour of Self Compacting Concrete Beam

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ABSTRACT- In general, the strength of concrete structures generally decreases with increasing structure size before reaching a limiting value. This effect must be taken into account in the design of the ultimate behaviour of concrete structures in order to avoid damage and crack openings. Fracture mechanics is used to predict such size effect. Stress intensity factor (SIF) is the base parameter in strength analysis regarding fracture mechanics. Hence study of fracture parameters will help to prevent catastrophic failures of structures and will be one of the important aids in material engineering. In order to investigate the fracture behaviour, 9 different mix ratios of self compacting concrete with partial replacement of Fly ash, Bottom ash, Eco-sand is used. The finite element model of beam of size1200mm×150mm×250mm with 5mm wide notch and 0.2 notch depth ratio is analysed using ABAQUS CAE. The concrete beam modelled using Abaqus software as it is capable of simulating the cracking and crushing behaviour of brittle materials. Fracture parameter considered here is Stress Intensity Factor (K), Fracture energy (Gf) and energy release rate(G). The analytical result obtained shows that Self compacting concrete made with 5% bottom ash, 25% flyash,10% eco-sand replacement levels give better result in fracture behaviour. These parameters would help in the designing of safe structures where micro cracks are given more importance.

Keywords: Fracture behaviour, Stress intensity factor(SIF), ABAQUS CAE, Fracture energy, Energy release rate

I.INTRODUCTION

Concrete occupies a distinguished position among the building materials and it has been used in construction for more than a century as a main construction material. In the reinforced concrete structures, the formworks and reinforcement are becoming more complex and extremely dense; therefore, many problems can occur due to insufficient compaction of concrete and of the inappropriate filling of the formworks.

As a consequence of this, the durability and performance of mature concrete can be lower. Improved durability of concrete and working conditions have had high preference in the development of concrete construction. Therefore, attention has been directed towards the use of concrete independent of the need for compaction, known as self-compacting concrete (SCC) which offers a better quality of concrete and improved durability.

Self-Compacting Concrete (SCC) or Self Consolidating Concrete is the present-day concrete that is being adopted the world over. Self-Compacting Concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcements. The development of Self Compacting Concrete (SCC) is an important achievement in the construction industry for overcoming problems associated with conventional concrete. SCC is the improvised concrete that partly replaces the Ordinary Portland Cement (OPC) with suitable mineral admixture (Fly ash) and filler materials (Bottom ash, Eco sand) and yet retains the qualities of the conventional cement concrete.

II.LITERATURE REVIEW

J. PLANAS (1998)describes the basic experimental and numerical results supporting an easy procedure to determine up to two fracture parameters based on numerically computed size effect curves. Furthermore, it supplies closed-form expressions to determine the initial linear segment approximation of the (stress vs. crack opening) softening curve of cohesive crack models for concrete, based only on the peak loads determined in splitting-tension tests and in three-point-bending tests on notched specimens. Knowledge of the initial segment, although not enough to describe all the fracture process of concrete structures, is enough to predict the fracture behaviour of unnotched concrete structures prior and around the peak load.

RILEM (2002)describes about the geometry of the specimen to be used for finite element modelling. The span by depth ratio of the specimen l/d should be at least 2.5. The ratio of notch depth to beam depth a_o /d should between 0.15&0.5. The notch width should be as small as possible and should not exceed 0.5 times the maximum aggregate size da. The width b and depth d must be less than 3 da. All specimen should be geometrically similar in two directions i.e., ratio of l/d, a_o/d, L/d should be same for all specimens.

Vijaykumar.H, Dr.Sakey Shamu (2012)studied the research works carried by various investigators to evolve a possible cohesive crack model for concrete. This could be used as a basis to carry out the effort to evolve a possible crack model for SCC and steel fiber reinforced SCC(SFRSCC) from the experimental results for P-CMOD curves for notched beam testing under 3-point loading using very stiff servo hydraulic deflection-controlled machine in the laboratory and to search for the possibilities to link various fracture parameters of SCC to the proposed cohesive crack model for SCC and steel fiber reinforced SCC(SFRSCC) under mode-I fracture.

I.M. Nikbin (2013) studied about the effect of volume of coarse aggregate on fracture characteristics of self- compacting concrete (SCC). Based on an experimental program, a series of three-point bending tests were carried out on 58 notched beams. SCC was prepared with coarse aggregate in varying percentages of 30%, 40%, 50% and 60% (as the percentage of the total aggregate volume).Based on the result of WFM and SEM the fracture energies of GF and Gf are significantly affected by coarse aggregate volume and increase remarkably with increase of coarse aggregate volume.Increase of coarse aggregate volume from 30% to 60% has more effect on fracture parameters of SCC than other mechanical properties.

M. Nikbin(2015) focused on influence behaviour of mineral powder content on the fracture behaviour and ductility of self-compacting concrete. This paper describes and discusses an experimental study on the effect of mineral filler on the fracture behaviour and ductility of self compacting concrete. Here 118 notched beams were tested and SCC prepared with various contents of mineral filler with W/C ratio of 0.47& 0.6. Analysis is carried out by work fracture method and size effect method. They concluded that increase in mineral filler and decrease in W/C ratio in SCC and fracture energy G_f in Work fracture method and Size effect method increase slightly.

AlperBideci (2017) described about Fracture energy and mechanical characteristics of self-compacting concretes including waste bladder tyre. The main purpose of this study is to investigate the effect of waste tyre addition on self compacting concretes mechanical characteristics and fracture properties under bending. In this study, waste bladder tyres (RA) mechanically cut in 25-, 50- and 75-mm lengths were used by volumetric replacement of coarse aggregates in self-compacting concretes (SCC).Management of solid wastes is one of the most important environmental problems in the world. Waste tyres are also one of these solid wastes. Instead of burning tyresits better to use as aggregate in concrete as partial replacement of coarse aggregate in various thickness. It is indicated that waste tyre rubber usage decreases the durability of the concrete, but makes the concrete gain elasticity and toughness.

Mehmet Gesoglu(2017) addressed about the mechanical and fracture properties of self-compacting concretes (SCCs) containing plastic waste (PW) powder as partial replacement material of cement. Partial amount of cement was replaced by PW powder at 5%, 10%, 15%, 20% and 25% by weight. Fracture characteristics of concrete were monitored via three-point bending test on notched beams.Here they analysed fracture energy by using mean compressive strength of specimen by using following relation,

$GF = 41.771f^{o}c*31$ Where GF is the total fracture energy (N/m) and fc is the mean cubecompressive strength at 28 days (MPa). Compressive strength of SCC was adversely influenced byusing plastic waste powder.Replacement should not exceed 24.6% at 25% PVC level because it seems to be negative effect.

G. Prasanth, Dr. R. Ponnudurai(2018) influences that fracture occurs due to high tensile stress, presence of notches, rapid rate of loading and calculated stress intensity factor, fracture energy, energy release rateof notched beam. The reason behind the fracture parameters is to avoid the failure of concrete. The critical load is the limiting load when the fracture parameter reaches the critical value. Under certain circumstances the load exceeding critical load of the material, the crack start to propagate. Here the determination of fracture parameters for M30 grade conventional concrete subjected to condition that notch to depth ratio of 0.15 is analysed using ANSYS software.This study concludes that crictical crack length at failure can be determine by critical stress intensity factor and critical stress, we can prevent structure from sudden failure.

Yangyang Yin1, YanminQiao, Shaowei Hu (2019) evaluates the fracture properties of concrete using four-point bending test which the beam segment near the midspan crack section is under pure bending. Five different initial crack-depth ratios varying from 0.2 to 0.6 for concrete specimens were explored. The corresponding values of load, crack mouth opening displacement and midspan deflection were simultaneously recorded. The fundamental fracture parameters of critical effective crack extension length, critical effective fracture toughness and fracture energy were analysed. More specifically, two approaches named pure bending approach and FPB approach were introduced to determine the critical effective fracture toughness. The results indicate that four-point bending test can be utilized to study the fracture properties of concrete.

Mariam Ghazy, Metwally Abd Elaty, Salah F. Taher (2021) aims to present a model suitable for analysing reinforced concrete notched beams using finite element methods. ABAQUS computer program version 6.16 is utilized in the analysis. The concrete was idealized by using the homogeneous solid elements, while the notch was modelled by using a planar shell and steel reinforcement was modelled as a wire element by assuming a perfect bond between the concrete matrix and the steel reinforcement rebar. The crack pattern is given by the finite element model similar to the experimental ones is analysed. They concluded that the average difference between the experimental and FEM results is 15% for all notch height and reinforcement ratio. The Concrete Damage Plasticity method achieved the fracture parameters of experimental results for beam specimen.

III FRACTURE PARAMETERS

The following Fracture parameters are calculated for Nine different mix of Self Compacting Concrete. Table 1 shows the different mix ratio of Self Compacting Concrete.

Table 1 Different mix ratio of SCC

MIX	BOTTOM ASH	FLY ASH	ECO SAND
M1	5	25	10
M2	5	30	20
M3	5	35	30
M4	10	25	20
M5	10	30	30
M6	10	35	10
M7	15	25	30
M8	15	30	10
M9	15	35	20

Fracture Toughness of Concrete

In the linear fracture mechanics (LEFM), the fracture toughness for mode I, K_{IC}, also called the critical stress intensity factor, is general calculated from,

$$K_{IC} = \sigma_N \sqrt{a}\, F(\alpha)$$

Where,
σ_N is the nominal applied stress,
a is the effective crack length, a =a0+Δa,
a0 is the initial notch depth,
Δa is the crack propagation at peak load and is also widely regarded as the size of the process zone or crack zone,
α is the effective notch-depth ratio and α =a/H,
H is the specimen depth,
F(α) is a geometric function.

Thus Eq. (1) is used to determine K_{IC} and σ_N in Eq. (1) is equal to the modulus of rupture of the corresponding un-notched beam and can be expressed by considering the self-weight of the beam as

$$\sigma_N = \frac{6M}{BH^2} = \frac{1.5(P_U + P_0)s}{BH^2}$$

$$\sigma_N = \frac{1{\cdot}5\left[P_U + 0{\cdot}5mg\left(\frac{L}{S}\right)^2 - \left(\frac{L}{S}\right)\right]S}{BH^2}$$

Where,
B is the width of the beam,
L is the full length of the beam,
S is the effective span,
M is the maximum moment at the middle span, given by
M = (Pu+ P0) S/4,
Pu is the maximum load at peak,
P_0 is the equivalent load due to the self-weight of the beam and
P_0 = 0.5mg (L/S) (2-L/S),
m is the mass of the beam between the supports and is calculated as m =m_0(S /L),
m_0 is the total mass of the beam,
g is the acceleration due to gravity and g =9.81 m/s^2.
Here, the factor (L/S) (2-L/S) is used to eliminate the influence of the cantilever parts of the concrete beam outside the supports.

Fracture energy

The great break strength KIC is gotten in light of a definitive load, including straight stacking and solidifying. It can be used to reflect the resistance of concrete against cracking. However, it cannot represent the crack resistance of the heated concrete. In other words, the crack resistance of concrete can be represented using load capacity and deformation ability, i.e., energy dissipation. This resistance can be well reflected using the fracture energy G_f.

$$G_f = \frac{W}{A_S}$$

where,
W= P x deflection
AS= Area of fracture = a x d a is the effective crack length.

Energy release rate

The more energy is released for unit increase in area during crack growth is given by
K_{IC}= √GE
Where,
K_{IC}= Critical Stress Intensity Factor,
G= Energy release rate,
E = Young's modulus of concrete
E = 5000 √ f_{ck} / (1-v^2) for plane strain condition,
where,
ν= Poisson's ratio
Thus, the fracture toughness related to fracture energy, KIC, can play this important role. Because KIC can represent the behaviour of concrete at both ascending and descending branches of the complete loading process including linear, hardening and softening, its magnitude can be expected to be larger.

IV.BEAM SPECIFICATION

Self-compacting concrete beam of dimension 1200mm x 150mm x 250 mm is modelled using ABAQUS software with longitudinal reinforcement of 10mm diameter and stirrups of 8mm diameter at 100mm c/c. Fig 4.1 shows the specifications of beam which is used for analysis.

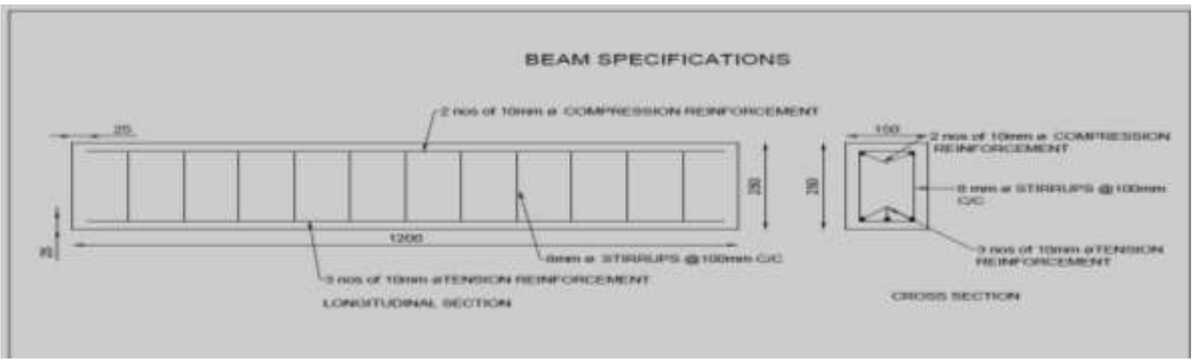

Fig. 1 Specification of Beam

V.NUMERICAL ANALYSIS

The Finite Element Method (FEM) is a numerical analysis for obtaining approximate solutions to a wide variety of engineering problems. The finite element method is now accepted as the most powerful general technique for the numerical solution of a variety of engineering problems. ABAQUS CAE is a commercially available finite element analysis software package for FEA. It is a general-purpose Finite Element Modelling Package for numerically solving a variety of mechanical problems. These problems include static and dynamic structural analysis (both linear and non-linear), steady state and transient problems, mode frequency and buckling analyses, acoustic and electromagnetic problems and various types of field and coupled-field applications.The material properties incorporated into the ABAQUS software (FEM computational platform) is key to defining the responses given by the model in the output. Inelastic behaviour of concrete is defined in FE model by using concrete damaged plasticity (CDP) model providing a general property for modelling concrete and other quasi-brittle materials in all type of structures. It considers isotropic damaged elasticity concept with isotropic tensile and compressive plasticity. Uniaxial compressive and tensile constitutive material behaviours of concrete are required to define the CDP model in ABAQUS. Table 2 presents the concrete damaged plasticity parameters.

Table 2 Concrete damaged plasticity parameters

SNO	**PLASTICITY PARAMETERS**	**RANGE**
1	Dilatation angle	30
2	Eccentricity	0.1
3	fb0/fc0	1.05
4	K	0.667
5	Viscosity Parameters	0.005

In order to achieve good results from the model, an optimum size of mesh should be used. A mesh size of 15 x 15 x 15 mm is used.

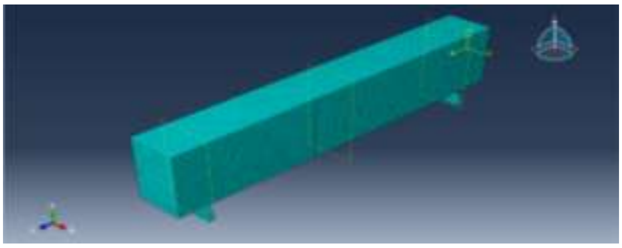

Fig. 2 Meshing of Beam

To fully imitate the experimental beams, the support conditions have to be modelled in addition. The beams are modelled for simply supported conditions (roller at one end and a pin support at the other). In order to implement these conditions, a line of nodes at the bottom of one of the supports was selected and restrained in the U1, U2, U3, UR2 and UR3. This allows the support to behave as a pinned support. The beam can then rotate about its transverse axis (x-axis). Similarly, the roller support conditions were specified. Displacement restrictions were imposed through U1, U2, UR2 and UR3 being set to 0. This allowed the support to rotate about the x-axis and to displace through the Z- axis. The deflection at the loading point is restricted to 15 mm in vertical direction by using Boundary conditions.

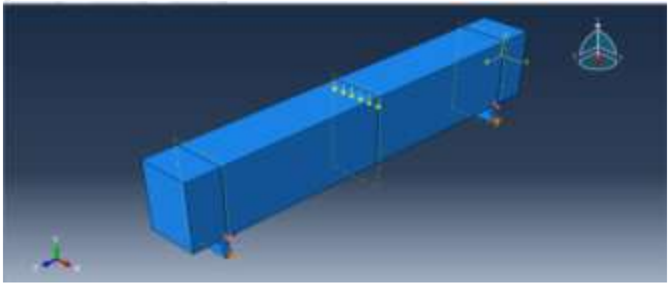

Fig. 3 Loading and Boundary Condition

VI.RESULTS AND DISCUSSIONS

This section presents the numerical results of the investigation on the flexural behaviour of self compacting concrete beam under two-point loading and beam column joint under point load and cyclic loading, by varying the proportion of fly ash (25%, 30%, 35%) eco sand (10%, 20%, 30%) and bottom ash (5%, 10%, 15%) using nine different mixes. The results which were obtained from various numerical tests are discussed in this chapter. The pattern and growth of cracks in beam at various levels of loading are discussed in this chapter. All the cracks were observed in fracture zone. Also, stress in reinforcement due to appliedload is discussed. All the beams failed due to yield in reinforced steel. The mode of failure of beams is discussed in Fig. 5.1 to 5.3 and Table 2 shows the comparison of results of nine different mixes of self-compacting concrete.

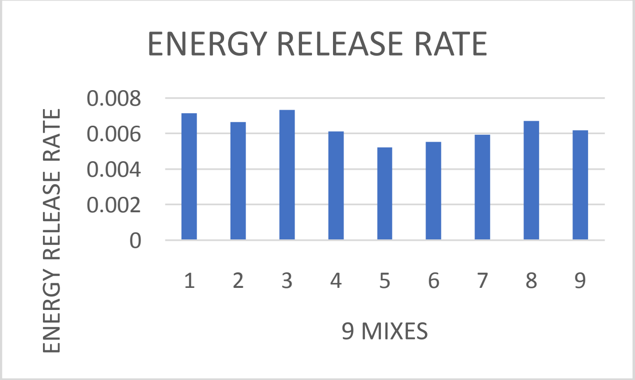

Fig 3 Energy release rate of nine mixes

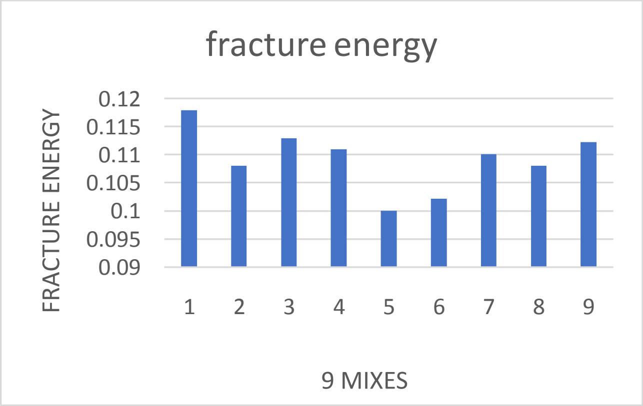

Fig.1 Fracture energy of nine mixes

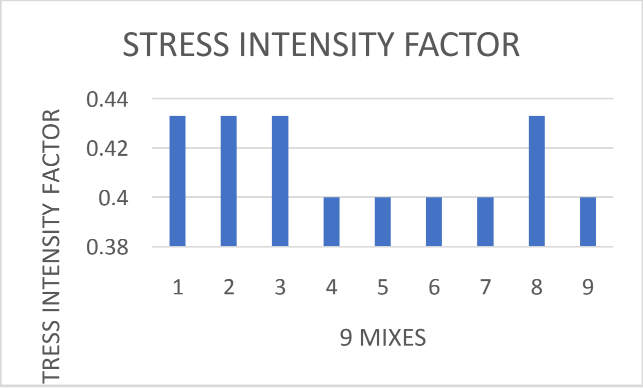

Fig 2 Stress intensity factor of nine mixes

Table 2 Comparison of Results of Nine Different SCC Mix

SNO	MIX	FRACTURE ENERGY(N/mm^2)	STRESS INTENSITY FACTOR($MPa.m^{1/2}$)	ENERGY RELEASE RATE(N/mm)
1	M1	0.1179	0.433	0.00717
2	M2	0.1080	0.433	0.00667
3	M3	0.1129	0.433	0.00736
4	M4	0.1110	0.400	0.00615
5	M5	0.1000	0.400	0.00525
6	M6	0.1022	0.400	0.00556
7	M7	0.1101	0.400	0.00595
8	M8	0.1080	0.433	0.00673
9	M9	0.1123	0.400	0.00621

VII.CONCLUSION

The following are the conclusions drawn from the present study:

- The analytical result obtained shows that Self compacting concrete made with 5% bottom ash, 25% flyash,10% eco-sand replacement levels give better result in fracture behaviour than other SCC mix because it absorbs more energy before fracture occurs. So, structures can be prevented from sudden failure.
- Since critical stress intensity factor (K_{ic}) is the material property, for any structure subjected to a crack with particular notch to depth ratio, critical stress intensity factor (K_{ic}) for the respective value notch to depth ratio could be used.
- By knowing the critical stress intensity factor for the particular notch to depth ratio, the critical stress (σ_N) at which the failure occurs can be predicted for any structure subjected to cracks.
- By increasing the load, the crack propagation occurs. The critical crack length (a) at failure stage can be predicted from the known values of critical stress intensity factor (K_{ic}) and critical stress (σ_N) and thus prevents the structure from unexpected catastrophic failures.

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