Advances in Concrete Construction, *Vol. 5, No. 6 (2017) 613-624*
DOI: https://doi.org/10.12989/acc.2017.5.6.613

Effect of fiber and aggregate size on mode-I fracture parameters of high strength concrete

Ch.Naga Satish Kumar*, P.V.V.S.S.R. Krishna and D.Rohini Kumar

Department of Civil Engineering, Bapatla Engineering College, Bapatla-522101, India

(Received June 27, 2017, Revised September 25, 2017, Accepted September 27, 2017)

Abstract. In this paper, an experimental investigation was carried out to study the effect of volume fraction of fiber and maximum aggregate size on mode-I fracture parameters of high strength concrete. Total of 108 beams were tested on loading frame with three point loading, the variables in the high strength concrete beams are aggregate size (20 mm, 16 mm and 10 mm) and volume fraction of fibers (0%, 0.5%, 1% and 1.5%). The fracture parameters like fracture energy, brittleness number and fracture process zone were analyzed by the size effect method (SEM). It was found that fracture energy (Gf) increases with increasing the Maximum aggregate size and also increasing the volume of fibers, brittleness number (β) decreases and fracture process zone (CF) increases.

Keywords: high strength concrete; mode I fracture energy; fracture process zone; brittleness number; steel fiber

1. Introduction

The safety and durability of concrete structures is significantly influenced by the cracking behavior of concrete. In order to understand the cracking behavior of concrete, it is necessary to understand the fracture properties of concrete. The study of post peak response of concrete is required to fully understand the failure criterion of concrete, which is based on the fracture parameters i.e., fracture energy of concrete, brittleness number and fracture process zone.

Quasi brittle materials like concrete have low tensile strength and strain capacity. These essential properties of concrete can be enhanced by the inclusion of short discrete steel fibers into the concrete matrix. The augmentation of Steel fibers significantly improves the engineering properties of concrete like the flexural-tensile strength and fracture toughness, thereby retarding or preventing initiation, propagation, and coalescence of cracks (Okan *et al.* 2016, Nardino *et al.* 2010, Holschemacher *et al.* 2010). Upon hardening, the randomly distributed Steel fibers which are bonded in the concrete matrix acts as stress transfer media in arresting the cracks that are developed due to internal stresses (Yazıcı *et al.* 2007, Bentur *et al.* 1990).

Mode-I fracture behavior of concrete was intensively studied by several researchers considering numerous mixture parameters like water content and aggregate size (Petersson 1980,

*Corresponding author, Professor, E-mail: nagasatish123@gmail.com

http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2287-5301 (Print), 2287-531X (Online)

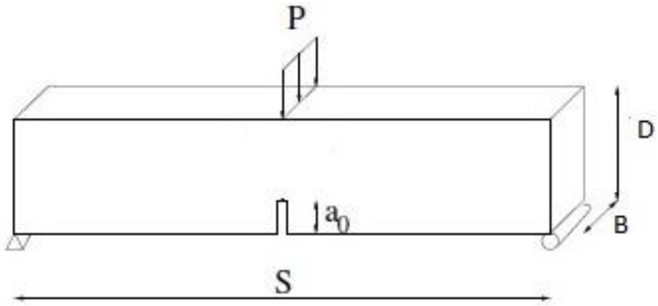

Fig. 1 Schematic view of beam setup

to the relative initial cracklength

$$\text{Where } g(\alpha) = \pi\alpha f(\alpha)^2 \tag{4}$$

In which the expression f(α) was adopted from RILEM TC 89 FMT(1990)and was given by

$$f(\alpha) = \frac{1.99-\alpha(1-\alpha)(2.15-3.93\alpha+2.7\alpha^2}{(\sqrt{\pi})(1+2\alpha)(1-\alpha)^{3/2}} \text{ for beams having geometry of S/D = 4.} \tag{5}$$

3. Experimental program

The Experimental program was designed to study the variation of Mode-I fracture parameters of concrete for different aggregate sizes and different volume fraction of steel fiber. This program consists of four series, namely Dn/d/0, Dn/d/0.5, Dn/d/1and Dn/d/1.5. In this series 'D' represents High strength concrete of M70 grade concrete, 'd' represents depth of the specimen i.e., 75 mm(Small),150 mm(Medium) and 300(Large) and 'n' represents the maximum aggregate size used in the mix i.e., 'n' equal to one that represents the maximum aggregate size is 10 mm, 'n' equal to two that represents the maximum aggregate size is 16 mm, 'n' equal to three that represents the maximum aggregate size is 20 mm. 0,0.5,1 and 1.5 represents percentage of volume fraction of steel fiber. In this investigation, for each series of beams there are three different sizes of the beams were used i.e., 350 mm×100 mm×75 mm (span is 300 mm), 650 mm×100 mm×150 mm (span is 600 mm) and 1250 mm×100 mm×300 mm (span is 1200) such that to maintain the geometrical similarity of the cross section of all the beams. The ratio of the span to the depth of the beam (S/D) was 4 for all the specimens. Fig. 1 shows the schematic representation of the beam specimen subjected to three point bending.

3.1 Material details

Crimped steel fibers of 0.35 mm mean diameter and 35 mm in length (Aspect ratio is 70) were used in this investigation. Ordinary Portland cement (OPC) of 53 grade conforming to ASTM C150 Type1 with specific gravity of 3.15 was used in concrete mix; natural river sand with specific gravity 2.60 meeting the requirements of ASTM C-33 was also used as fine aggregate in the entire investigation. Crushed coarse aggregates of size 20 mm, 16 mm and 10 mm were used for the casting of specimens. To achieve the desired workability for M70 mix naphthalene

Fig. 2 Photograph of beam setup

Table 2 Mechanical properties of concrete

Grade of concrete	Size of aggregate	Mix Proportion	% of steel fiber	28 days compressive strength f_{ck} (N/mm^2)	Split tensile strength f_t (N/mm^2)
M70	10 MM	0.265:1:1.214:1.17	0	79.3	5.75
			0.5	83.2	6.1
			1	88.8	6.8
			1.5	92.05	7.2
	16 MM	0.25:1:1.346:1.108	0	78.4	5.8
			0.5	81	6.2
			1	86.8	7.2
			1.5	95	7.1
	20 MM	0.24:1:1.346:1.103	0	78.17	5.3
			0.5	80.4	5.8
			1	84.53	6.3
			1.5	91.9	7.5

of testing setup of beam specimen is shown in Fig. 2. To find out the mechanical properties of concrete, three cubes, three cylinders and six prisms were casted for each series of the specimens and tested. The average values of the mechanical properties of concrete and mix proportions are given in Table 2.

4. Test results and discussions

For all specimens the fracture occurred by a single crack developed at the notch tip and progressed vertically towards the load point. The plain concrete specimens were certainly broken into two halves exactly over the notch (Fig. 8). The fractured specimens reinforced with steel

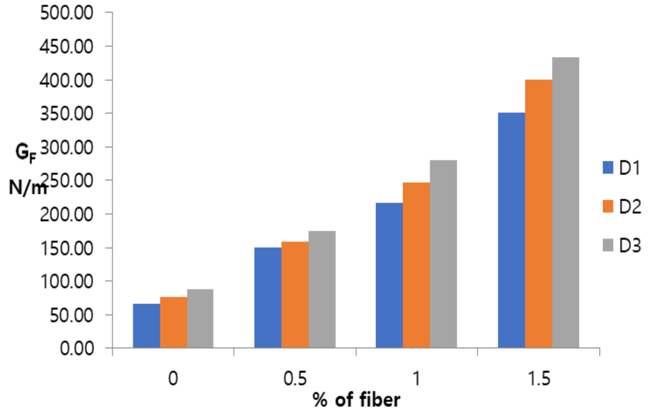

Fig. 4 Fracture Energy Vs% of Steel Fibers

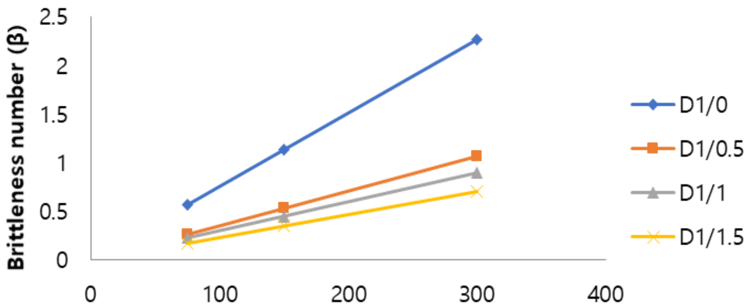

Fig. 5 Brittleness Number Vs Depth for D1 series specimens

of aggregate in cement paste matrix increases tortuosity of the fracture path. In the other words, when the concrete is under load, cracks prefer to pass weak zones such as interface transition zone (ITZ) and huge paste pores. As the aggregate size increases, the fracture path becomes more tortuous and a higher energy is required to overcome the strength of ITZ and thus fracture energy is increased. But there is no notable change in the ratio of the fracture energy of 1.5% to the plain concrete when maximum aggregate size increases from 10 mm to 20 mm.This is may be due to higher fracture energy is essential to overcome the bridging effect of fibers rather than the strength of ITZ.

Load is plotted as a function of mid-span deflection curves and crack mouth opening displacement (CMOD) curves of notched prismatic beams, and presented in Figs. 6 and 7 respectively. In the present study, we found that with an increase in MSA, A significant drop in the characteristic dimension d_o is perceived resulting in increased brittleness of the member. In other words, it can be stated that members of higher size of MSA will fail in a brittle fracture mode, even though the actual dimensions of the member being small. Fig. 5 depicts the variation of brittleness number with MSA and volume fraction of fiber. As expected, the inclusion of fibers resulted in decreasing brittleness number, representing that concrete turn out to be more ductile. Load carrying capacity, deflection correspond to ultimate load and CMOD of plain concretes increased expressively with the increase of fiber volume fraction. However, at constant fiber dosage, load carrying capacity and CMOD of composites increases with increase the size of aggregate.

Table 3 Fracture parameters

Beam	Failure Load (P)kN	Failure Stress N/mm^2	Brittleness Number (β)	Fracture Energy (N/m)	Cohesive Fracture Zone(C_F) (mm)
D_1/S/0	7	5.625	0.566		
D_1/M/0	11.8	4.766	1.133	67.01	15.23
D_1/L/0	19	3.890	2.266		
D_1/S/0.5	8	6.426	0.267		
D_1/M/0.5	14.3	5.768	0.533	150.35	32.35
D_1/L/0.5	24.5	4.993	1.067		
D_1/S/1	9	7.226	0.223		
D_1/M/1	16.5	6.648	0.446	216.25	38.70
D_1/L/1	28.5	5.793	0.892		
D_1/S/1.5	10.5	8.426	0.177		
D_1/M/1.5	20	8.048	0.354	351.22	48.76
D_1/L/1.5	34.5	6.993	0.708		
D2/S/0	7.2	5.785	0.495		
D2/M/0	12	4.846	0.990	76.13	17.43
D2/L/0	19.8	4.050	1.980		
D2/S/0.5	7.7	6.186	0.340		
D2/M/0.5	14.2	5.728	0.680	155.6	36.47
D2/L/0.5	24.2	4.933	1.359		
D2/S/1	9.5	7.626	0.208		
D2/M/1	17.2	6.928	0.415	247.76	41.58
D2/L/1	30.3	6.153	0.830		
D2/S/1.5	10.3	8.266	0.162		
D2/M/1.5	18.8	7.568	0.324	385.46	62.51
D2/L/1.5	34.8	7.053	0.648		
D_3/S/0	7.2	5.785	0.421		
D_3/M/0	12.5	5.046	0.842	87.52	20.50
D_3/L/0	20.5	4.190	1.684		
D_3/S/0.5	8	6.426	0.233		
D_3/M/0.5	14.5	5.848	0.466	163.48	37.03
D_3/L/0.5	25.2	5.133	0.932		
D_3/S/1	10	8.026	0.195		
D_3/M/1	18	7.248	0.389	280.92	44.36
D_3/L/1	32.3	6.553	0.778		
D_3/S/1.5	11.5	9.226	0.160		
D_3/M/1.5	21.2	8.528	0.320	433.07	53.98
D_3/L/1.5	38.5	7.793	0.639		

aggregate size and increases with the volume fraction of fiber.

Acknowledgments

This research work is carried out under the financial assistance from AICTE, New Delhi under RPS scheme. The authors are very thankful to the AICTE, New Delhi and also authorities of Bapatla Engineering College, Bapatla, for providing facilities for carrying out this work.

References

Amparano, F.E., Xi, Y. and Roh, Y.S. (2000), “Experimental study on the effect of aggregate content on fracture behavior of concrete”, *Eng. Fract. Mech.*, **67**(1), 65-84.

Caggiano, A., Cremona, M., Faella, C., Lima, C. and Martinelli, E. (2012), “Fracture behavior of concrete beams reinforced with mixed long/short steel fibers”, *J. Conbuildmat.*, **37**, 832-840.

Caggiano, A., Cremona, M., Faella, C., Lima, C. and Martinelli, E. (2012), “Fracture behavior of concrete beams reinforced with mixed long/short steel fibers”, *Constr. Build. Mater.*, **37**, 832-840.

Barr, B.I.G., Hasso, E.B.D. and Weiss, V.J. (1986), “Effect of specimen and aggregate sizes up on the fracture characteristics of concrete”, *J. Cement Compos. Lightw. Concrete*, **8**, 109-119.

Bazant, Z.P. and Pfeiffer, P.A. (1987), “Determination of fracture energy from size effect and brittleness number”, *ACI Mater. J.*, **84**(6), 463-480.

Bazant, Z.P. and Kazemi, M.T. (1990), “Determination of fracture energy, process zone length and brittleness number from size effect, with application to rock and concrete”, *J. Fract.*, **44**, 111-131.

Bazant, Z.P. and Oh, B.H. (1983), “Crack band theory for fracture of concrete”, *Mater. Struct.*, **16**, 155-177.

Bazant, Z.P., Kim, J.K. and Pfeiffer, P.A. (1986), “Nonlinear Fracture properties from size effect tests”, *J. Struct. Eng.*, **112**(2), 289-306.

Bencardino, F., Rizzuti, L., Spadea, G. and Swamy, R. (2010), “Experimental evaluation of fiber reinforced concrete fracture properties”, *J. Compos.*, **41**(1), 17-24.

Bentur, A. and Mindess, S. (1990), *Fiber Reinforced Cementitious Composites*, Elsevier Applied Science, London, New York, U.S.A.

Hillerborg, A. (1985), “Results of three comparative test series for determining the fracture energy GF of concrete”, *Mater. Struct.*, **18**, 407-413.

Holschemacher, K., Mueller, T. and Ribakov, Y. (2010), “Effect of steel fibers on mechanical properties of high strength concrete”, *J. Matdes*, **31**(5), 2604-2615.

Mihashi, H., Nomura, N. and Niiseki, S. (1991), “Influence of aggregate size on fracture process zone of concrete detected with 3D acoustic emission technique”, *Cement Concrete Res.*, **21**, 737-744.

Neville, A.M. (2012), *Properties of Concrete,* 5th Edition, Pearson Education, Delhi, India.

Okan, K., Erdogan, O., Cengiz, D.A., Mohamed, L. and Khandaker, M.A.H. (2016), “Effects of milled cut steel fibers on the properties of concrete”, *KSCE J. Civil Eng. J.*, **20**(7), 2783-2789.

Petersson, P.E. (1980), “Fracture energy of concrete: Practical performance and experimental results”, *Cement Concrete Res.*, **10**(1), 91-101.

Ricardo, A. and Einsfeld, M.S.L.V. (2006), “Fracture parameters of high performance concrete”, *Cement Concrete Res.*, **36**, 576-583.

RILEM FMT-89 (1990), “Size-effect method for determining fracture energy and process zone size of concrete”, *Mater. Struct.*, **23**(6), 461-465.

RILEM TC QFS (2004), “Quasi-brittle fracture scaling and size effect-final report”, *Mater Struct.*, **37**, 547-568.

Walsh, P.F. (1972), “Fracture of plain concrete”, *Ind. Concrete J.*, **46**, 469-476.

Wolinski, S., Hordijk, D.A., Reinhardt, H.W. and Cornelissen, H.A.W. (1987), "Influence of aggregate size on fracture mechanics parameters of concrete", *J. Cement Compos. Lightw. Concrete*, **9**, 95-103.
Yan, A., Wu, K.R., Zhang, D. and Yao, W. (2001), "Effect of fracture path on the fracture energy of high-strength concrete", *Cement Concrete Res.*, **31**, 1601-1606.
Yazıcı, S., Inan, G. and Tabak, V. (2007), "Effect of aspect ratio and volume fraction of steel fiber on mechanical properties of SFRC", *J. Conbuildmat.*, **21**(6), 1250-1253.
Zhang, J. and Victor, C.L. (2004), "Simulation of crack propagation in fiber reinforced concrete by fracture mechanics", *J. Cemconres*, **34**, 333-339.
Zhao, Z., Kwon, S.H. and Shah, S.P. (2008), "Effect of specimen size on fracture energy and softening curve of concrete: Part I. Experiments and fracture energy", *Cement Concrete Res.*, **38**, 1049-1060.
Zhou, F.P., Barr, B.I.G. and Lydon, F.D. (1995), "Fracture properties of high strength concrete with varying silica fume content and aggregates", *Cement Concrete Res.*, **25**, 543-552.

JK