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Fracture properties of Self Compacting Concrete for Notched and Un-notched Beams

By Hamid Eskandari, S. Muralidhara, B.K. Raghu Prasad, B.V. Venkatarama Reddy

Sabzevar Tarbiat Moallem University, Sabzevar, Iran

Abstract - The aim of this research is to obtain the fracture characteristics of low and medium compressive strength notched and un-notched plain self compacting concrete **(SCC)** beams, using **RILEM** work of fracture **(GF)** methods and compare with those of normal concrete **(NC)** and high performance concrete **(HPC)**, which is useful in engineering practice. The effect of notch-depth ratio on fracture characteristics of **SCC** beams, in bending is investigated by measuring the fracture energy **(GF)**, critical stress intensity factor **(KIC)**, critical energy release rate **(Gc)** and characteristic length **(lch)**. The results show that: (i) **GF** increases with increase in compressive strength; (ii) The values of characteristic lengths of **SCC (lch)** are more when compared with **HPC** and **NC** and therefore may be concluded that the **SCC** with air-entraining admixture **(AEA)** is more ductile compared to **HPC**.

Keywords : Self compacting Concrete; Fracture Properties; Notched; Un-notched.

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FRACTURE PROPERTIES OF SELF COMPACTING CONCRETE FOR NOTCHED AND UN-NOTCHED BEAMS

Strictly as per the compliance and regulations of:

Fracture properties of Self Compacting Concrete for Notched and Un-notched Beams

Hamid Eskandari [α], S. Muralidhara [Ω], B.K. Raghu Prasad [β], B.V. Venkatarama Reddy [ψ]

Abstract - The aim of this research is to obtain the fracture characteristics of low and medium compressive strength notched and un-notched plain self compacting concrete (SCC) beams, using RILEM work of fracture (G_F) methods and compare with those of normal concrete (NC) and high performance concrete (HPC), which is useful in engineering practice. The effect of notch-depth ratio on fracture characteristics of SCC beams, in bending is investigated by measuring the fracture energy (G_F), critical stress intensity factor (K_{IC}), critical energy release rate (Gc) and characteristic length (l_{ch}). The results show that: (i) GF increases with increase in compressive strength; (ii) The values of characteristic lengths of SCC (l_{ch}) are more when compared with HPC and NC and therefore may be concluded that the SCC with air-entraining admixture (AEA) is more ductile compared to HPC.

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I. INTRODUCTION

Self-compacting concrete (SCC) is the current research area today. Many intrinsic properties of the concrete are yet to be understood clearly. The differences between High performance Concrete (HPC) and Self compacting concrete (SCC) are essentially in the use of special admixture [16]. Due to the use of chemical and mineral admixtures, the micro cracks study are more essential in SCC compared to NC [7,31].

Many investigators have evaluated the mechanical characteristics and durability of SCC mixes. The improved pore structure and better densification of matrix have bearing on the fracture characteristics like fracture energy (G_F) and critical stress intensity factor (K_{Ic}). It has been reported in literature that increased density will increase the compressive as well as tensile strength of concrete and also fracture energy [11]. Characteristic length (l_{ch}) will decrease with an increase in density [13].

Fracture behavior of plain concrete is the basis for all the studies on behavior of reinforced concrete (RC) and prestressed concrete structures via fracture mechanics. Experimental studies have been conducted to ascertain the effect of the aggregate on the fracture behavior of concrete. It is reported that an increase in the size of aggregate decreases the brittleness of hardened concrete and increases the fracture energy as well as fracture toughness [1,2,29].

Prokopski et al. [22] from their studies on the use of silica fume and effect of water-cement ratio on concrete have concluded that the stress intensity factor increases with addition of silica fume. The variations in stress intensity factor are closely related to the variation in the concrete matrix. Chen and Liu [6] have studied the effect of aggregate on fracture behavior of HPC and have shown that G_F and K_{IC} increase with increase in the aggregate size.

Planas and Elices [21] have shown that the fracture energy, G_F is size dependent. Ries and Ferreira [24] have studied the effect of specimen notch-depth on fracture energy and have shown that the specimen dimension do effect G_F and fracture energy increases with increase of notch to depth ratio, i.e. higher the notch to depth ratio, higher will be the fracture energy. Hence it has become a contentious topic in the fracture mechanics of concrete.

II. EVALUATION OF FRACTURE CHARACTERISTIC

a) Fracture energy (G_F) from work-of-fracture

Many methods have been recommended to determine the fracture energy and characteristic length, using simple three point bending tests (TPB) [17,19,20,30,4,10,18,12,9].

One can apply the recommendation of the Technical Committee RILEM [25] to perform three-point bend tests in notched beams. The Fracture energy is defined as the amount of energy necessary to create a crack of unit surface area projected in a plane parallel to the crack direction. As the beam is split in two halves, the fracture energy can be determined by dividing the total dissipated energy by the total surface area of the crack. According to the RILEM [26] to control the fracture energy can be calculated as

$$G_F = \frac{W_0 + 2mg\delta_0}{t(b-a)} \qquad (1)$$

Where G_F = fracture energy (N/m), W_0 = area under the load-deection curve (Nm), m = weight of the beam between supports (kg), t = thickness; b = depth ;

Author [α] : Department of Civil Engineering, Sabzevar Tarbiat Moallem University, Sabzevar, Iran. Phone/Fax:+98 571 400 3526.
E-mail : Hamidiisc@yahoo.com
Author [Ω] : Department of Civil Engineering, BMS College of Engineering, Bangalore, India.
Author [β ψ] : Department of Civil Engineering, Indian Institute of Science, Bangalore, India.

δ_0= Displacement corresponding to P = 0 and a = initial notch of the beam.

i. *Intrinsic brittleness*

It is well known that the brittleness of concrete is characterized not only by the fracture toughness but also by a parameter related to it through other fracture and/or elastic constant. This parameter is a measure of the length of the fracture process zone. The smaller its value, the more brittle is the material. According to the fictitious crack model (FCM)[28], the brittleness can be expressed:

$$l_{ch}(mm) = EG_F/f_t^2 \tag{2}$$

Where E is modulus of elasticity in [MPa] and f_t is the tensile strength [MPa].

ii. *Fracture toughness*

The fracture toughness K_{IC} is calculated according to the RILEM [27] using the equation

$$K_{IC} = 3(P_0)\frac{S\sqrt{\pi}ag_1(\alpha)}{2b^2t} \quad [MPa\sqrt{m} \tag{3}$$

in which

$$g_1(\alpha) = \frac{1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)}{\sqrt{\pi}(1+2\alpha)(1-\alpha)^{3/2}} \tag{4}$$

where $\alpha = a / b$, P_0 = the measured maximum load [N] + self weight of the beam [N]. The result corresponds to the mean values of at least three tests. The critical energy release rate G_C is related to K_{IC} as:

$$G_C = (K_{IC})^2/E \tag{5}$$

III. EXPERIMENTAL STUDY

a) *Mix properties*

The cement used was 53 grade, having at 3, 7 and 28 days strength of 26.50, 33.20, and 53.40 MPa, respectively. Crushed granite aggregates of maximum size 16 mm were used. The specific gravity, dry-rodded unit weight, and water absorption of the coarse aggregate were 2.71, 1, 550 kg / m^3 and 0.5 by weight of the aggregate, respectively. River sand passing 4.75 mm was used. The specific gravity of the sand was 2.62 and the fineness modulus was 2.48. Class F fly ash from the thermal power plant near Raichur, India, was used. The CaO and loss on ignition (LOI) contents of fly ash were 59, 1.02 and 1.08, respectively. The quantity of different materials for various mixes of SCC (SCC1, SCC2 and SCC3) are listed in (Table 1).

IV. EXPERIMENTAL RESULTS

a) *Fresh properties of SCC*

The slump flow test is the most widely used method for evaluating concrete consistency in the laboratory and at construction sites. The consistency and workability were evaluated using the slump flow, U-Box, L-Box, J-Ring, V funnel and fill box tests.

The slump flow of SCC concrete was in the range of 650-750 mm, which is an indication of a good deformability. The time to reache 500 mm slump was in the range of 3-5 s, the J Ring was in the range of 3-8 mm, the funnel test flow time was in the range of 3-7 s, the funnel test flow after 5 minutes was in the range of 1-3 s, L-box, U box and Fill box were in the range of 0.8-1, 3-10 mm and 90-100% respectively. The fresh properties of SCC are summarized in (Table 2).

b) *Mechanical properties of SCC*

Compressive strength, modulus of elasticity, flexural strength and tensile splitting strength tests were conducted on all specimens of SCC mixes. The mechanical properties like compressive strength, flexural strength, split tensile and modulus of elasticity of SCC were obtained testing 150 x 150 x 150 mm six cubes, 100 x 100 x 500 mm six prism and 150 x 300 mm cylinders the results are summarized in (Table 3).

The amount of powder usually cement +fly ash + microsilica used in SCC was in the range of 400-640 kg / m^3 for different grades of concrete. The density of SCC slightly decreased with decrease in the water-powder ratio. This may be due the combination of AEA and VMA which formed large amount of air pockets in concrete specimens. The compressive strength increased with the decrease in the percentage of fly ash and water-powder ratio. The compressive strengths of SCC at 28 days varied from 15 to 45 MPa and increased by 10% at the end of 90 days.

The split tensile strength, flexural strength and modulus of elasticity at the end of 28 days also showed reduction due to addition of fly ash. This is because of the slower pozzolanic reaction of the mineral admixture, which caused slow rate of setting and hardening.

V. ANALYSIS OF RESULTS

a) *Fracture Energy* (G_F) *from work-of-fracture*

In this category, the experiments were carried out using different mixes (SCC1, SCC2, and SCC3) with different sizes (440x100x100 and 850x100x100 mm) for notched and un-notched beams. Following two types of specimens were used: (i) un notched and (ii) notched with the ratio notch/depth equal to 0.5 and 0.1 for the spans of 400 and 800 mm respectively. Three-point bending tests were conducted using a closed loop Dartec Servo Controlled testing machine with a crack mouth opening rate of 0.001 mm/sec. The details of the concrete mixes labelled SCC1 to SCC3 for batches 1, 2, and 3, respectively, are given in Table 1. Before casting the beam specimens, a notch was introduced at the mid-section. It was 0.5 depth for the 800 mm beam and 0.1 depth for 400 mm span beam. The tests were controlled by the crack mouth opening displacement (CMOD). The complete load-deflection and load-CMOD data were automatically stored on the computer. The (Figs. 1, 2 and 3) show the typical load-displacement and load-CMOD plot for SCC1, SCC2 and SCC3 with notched and un-notched respectively. In general, it is seen that as the notch to depth ratio increases, at peak load there is an increase in deflection and CMOD.

From the (Figs. 1, 2 and 3), it is evident that; (i) the pre-peak stiffness of load-deflection curve in the case of un-notched beams is more than that of notched beams. This is attributed to the presence of notch; (ii) there is a sudden drop after peak load in the load-deflection curve in un-notched beam which highlights the brittleness induced to the absence of notch. However this is not observed in notched beam; (iii) the ratio of peak loads of notched and un-notched beams is about 0.25 which satisfies the strength of material theory.

Fracture energy, G_F is the energy needed to create a crack of unit area and also called as specific fracture energy. The work of fracture was calculated by measuring the area under the load-deflection plot and the fracture energy was calculated from the (Eq. 1) as recommended in the RILEM guidelines and the values of G_F are given in (Table 4).

From the result of GF that is obtained by work of fracture, it is evident that the G_F is greatly affected by the size of beam and noth-depth ratio. Hillerborg [14] also showed that G_F increases with an increase in specimen size. The variability of G_F with specimen size and for its significant departure from G_c is mainly due to the violation of the two basic assumptions: (i) the work done by the external load goes solely into stable crack extension and (ii) the energy required to create a crack of unit area is independent of geometry and loading configuration. Several investigators have identified many processes, such as crushing of material, thermal loss, energy consumed in minor cracking, etc. other than the stable crack extension on which some energy is expended. Hence, it is clear that some errors are attributable to the determination of W_F and A_{lig}, which can explain the variability in G_F. It is also seen from the literature that for normal grade concrete, G_F varies from 40 to 130 N / m [15] and for the HPC it varies from 116 to 120 N / m [8]. From the present study, it is observed that GF for the notch/depth ratio 0.5 and span of 800 mm varies from 146 to 200 N / m and for un-notched beam varies 126 to 185 N / m. It can be seen that the fracture energy obtained with the span of 400 mm is slightly less than that of beam with span 800 mm. The value G_F of SCC in the present study is slightly more compared to that of normal concrete and HPC, this is due to the effect of porosity. SCC has higher porosity and less density compared to HPC and normal concrete.

Khalil Haidar [13] also has shown that the concrete becomes more ductile as the porosity increases (mass density decreases) and fracture energy is extremely dependent on the mass density of material.

Moreover, G_F is not constant but varies with the notch/depth ratio and G_F increase with an increase in depth of beam. (Fig. 4) shows the variation of fracture energy G_F with compressive strength. It is seen that the fracture energy increases with increase in strength as well as the increase in notch-depth ratio. As expected, the present work showed that the fracture energy, G_F, is a fracture parameter that is size-dependent [21,24]. It is found that G_F values show a definite trend to increase with increase of notch to depth i.e. un-notched depth has a lower value of G_F.

Fracture toughness (K_{IC}) is the value of critical stress intensity factor K, for which the crack starts growing. K_{IC} values for various mixes were obtained from a peak load based on LEFM approach (Eq. 3) and are given in (Table 5).

It is seen from the literature that the KIC values for various mixes varies from 0.8 to $MPa\sqrt{m}$ [23,3], while in the present study it varies from 0.58 to $0.74\,MPa\sqrt{m}$ for notched beam and for un-notched varies from 0.24 to $0.31\,MPa\sqrt{m}$ for the span of 800 mm length. It is observed from the (Table 5) and (Fig. 5) that with an increase in compressive strength of SCC, there is an increase in the fracture toughness for notch and un-notched beam. There is significant difference between K_{IC} of notched and un-notched beams. This is due to the presence of notch, which increases the ductility, when compared with an un-notched beam. It may be stated that in practice the beams are un-notched and hence the value of K_{IC} is over estimated.

For elastic brittle material $G_F = G_c$. However, for concrete, which is a quasi brittle material, G_F is higher than G_c because in the case of quasi-brittle materials there is stable crack growth before failure takes place. G_c normally varies between 3 to 20 N=m [15] for normal concrete and for HPC is varies between 17 to 40 N/m [5], while G_c varies between 18 to 20 N=m for notched beam and for un-notched beam varies between 2.9 to 3.2 N/m. The variation of K_{IC} is also reflected in the corresponding toughness value G_c, since K_{IC}, and G_c are directly related as per (Eq. 5).

The characteristic length l_{ch} of SCC or brittleness of SCC based on FCM as per (Eq. 2) is given in (Table 5). Generally for normal concrete l_{ch} is about 200 to 500 mm [15,20] and for HPC it varies between 120-450 mm [23]. In SCC, l_{ch} varies from 580 to 740 mm for notched beams and varies between 540 to 640 mm for un-notched beams. It is also seen the l_{ch} decrease with an increase in compressive strength and notch-depth ratio.

VI. CONCLUSIONS

Experiments were conducted to determine the mechanical properties of SCC and fracture characteristic of SCC beams under three-point bend notched and un-notched beams were tested at the department of Civil

Engineering of the Indian Institute of Science in order to study the fractures properties of SCC. The main conclusions that can be drawn from this study are the following:

1. The results obtained by the work-of-fracture method follow the trend of "fracture energy increasing as the compressive strength of the concrete increases".
2. As expected, the present work shows that the fracture energy, G_F, is a fracture parameter that is size-dependent [21,24], i.e dependent on the specimen dimensions. It is found that G_F values show a definite trend to increase with increase of notch to depth i.e. 50 mm and 10 mm notch depth have a higher value of G_F compared to that of an un-notched beam. The size dependence is mainly due to irrecoverable damages outside the cracking plane which tends to increase with the specimen size.
3. The range of brittleness numbers found in this study shows that SCC is more ductile than HPC. Hence can be used at least for large size structures.
4. The values of characteristic length of SCC (l_{ch}) is to be more when compared with HPC, NC and high strength concrete. It may be concluded that the SCC is more ductile compared to HPC.

References References Referencias

1. Amparano, F. E., Y. Xi, and Y.-S. Roh: 2000, `Experimental study on the effect of aggregate content on fracture behavior of concrete'. Eng Frac Mech 67(1), 65-84.
2. Appa Rao, G. and B. K. Raghu Prasad: 2002, `Fracture energy and softening behavior of high-strength concrete'. Cem Con Res 32(2), 247-252.
3. Bazant, Z. P. and E. B. Giraudon: 2002, `Statistical prediction of fracture parameters of concrete and implications for choice of testing standard'. Cem Con Res 32(4), 529-556.
4. [4] Belhamel, F., k. Hisham, and F. Kharchi: 2002, `Experimental method for the determination of the failure energy of ordinary concretes'. Mater Struct 35(3), 182-188.
5. Bharatkumar, B.: 2003, `Fracture characteristics and behaviour of high performance concrete (plain and reinforced)'. PhD thesis, IISc, India p. 235.
6. Chen, B. and J. Liu: 2004, `Effect of Aggregate on the Fracture Behavior of High Strength Concrete'. Constr Build Mater 18, 585-590.
7. Druta, C.: 2003, `Tensile strength and bonding characteristics of self-compacting concrete'. MSc thesis, Louisiana State Universityand p. 115.
8. Einsfeld, R. A. and M. S. Velasco: 2006, `Fracture parameters for High-performance concrete'. Cem Con Res 36, 576-583.
9. Elices, M., G. Guinea, and J. Planas: 1992, `Measurement of the fracture energy using three-point bend tests: Part 3-inuence of cutting the P-δ tail'. Mater Struct 25(4), 327-334.
10. [10] Elices, M., G. Guinea, and J. Planas: 1997, `On the measurement of concrete fracture energy using three-point bend tests'. Mater Struct 30(6), 375{376.
11. Giaccio, G., C. Rocco, and R. Zerbino: 1993, `The fracture energy (G_F) of high-strength conretes'. Mater Struct 26(161), 381-386.
12. Guinea, G., J. Planas, and M. Elices: 1992, `Measurement of the fracture energy using three-point bend tests: Part I-inuence of experimental procedures'. Mater Struct 25(4), 212-218.
13. Haidar, K. and G. P. Cabor: 2002, `Inuence of porosity on fracture characteristics in mortar structures'. Proc 15th ASCE Eng Mech, New York pp. 1-8.
14. Hillerborg, A.: 1985, `Results of three comparative test series for determining the fracture energy GF of concrete'. Mater Struct 18(107), 407-412.
15. Karihaloo, B.: 1995, `Fracture mechnaics and structural concrete'. Longman Scientific and technical,UK.
16. Kishi, T., A. Hosoda, C. B. Gurung, and S. Kittiwuttichusinp: 2000, `Effect of drying / autogenous shrinkage on ductility / fracture mode of beam and self-repairing function of expansive agent'. Pro JCI 22(3), 511-516.
17. Mindess, S.: 1984, `The effect of specimen size on the fracture energy of concrete'. Cem Con Res 14(3), 431-436.
18. NT Build 491: 1999, `Fracture energy (mode I)-three-point bend tests on notched beams'. Nordtest Method pp. 1{4. Available online, http://www.nordicinnovation.net/nordtest_ler/build491.pdf.
19. Petersson, P.: 1980a, `Fracture energy of concrete; method of determination'. Cem Con Res I0(1), 78-89.
20. Petersson, P.: 1980b, `Fracture energy of concrete: practical performance and experimental results'. Cem Con Res 10(1), 91-101.
21. Planas, J. and M. Elices: 1986, `Towards a measure of Gf: an analysis of experimental results'. Fracture Toughness and Fracture Energy of Concrete, Elsevier, Amsterdam pp. 381-390.
22. Prokopski, G. and B. Langier: 2000, `E_ect of Water/Cement Ratio and Silica fume Addition on the Fracture Toughness and Morphology of Fractured Surfaces of Gravel Concretes'. Cem Con Res 30, 1427-1433.
23. Raghu Prasad, B. K., B. H. Bharatkumar, D. S. R. Murthy, R. Narayanan, and S. Gopalakrishnan: 2005, `Fracture mechanics model for analysis of plain and reinforced high-performance concrete beams'. ASCE, Eng Mech J 131(8), 831-838.
24. Reis, J. and A. Ferreira: 2004, `A Contribution to the Study of the Fracture Energy of Polymer Concrete and Fibre Reinforced Polymer Concrete'. Polymer Testing 23, 437-440.

25. RILEM FMC-50: 1985, `Determination of the fracture energy of mortar and concrete by means of three-point bend tests on notched beams'. Mater Struct 18(4), 287-290.
26. RILEM FMT 89: 1990, `Size-effect method for determining fracture energy and process zone size of concrete'. Mater Struct 23(6), 461-465.
27. RILEM TC89-FMT: 1991, `Determination of fracture parameters (KIC and CTODc) of plain concrete using three-point bend tests'. Mater Struct 23(6), 457-460.
28. Shah, S., S. Swarts, and C. Ouyang: 1995, `Fracture Mechanics of Concrete - Applications of Fracture Mechanics to Concrete, Rock, and Other Quasi-Brittle Materials'. John Wiley & Sons, Inc., New York, USA p. 552p.
29. Strange, P. C. and A. H. Bryant: 1979, `The role of aggregate in the fracture of concrete'. J Mater Sci 14(8), 1863-1868.
30. Tang, T., C. Ouyang, and S. P. Shah: 1996, `Simple method for determining material fracture parameters from peak loads'. ACI, Mater J 93(2), 147-157.
31. Wittmann, F. H.: 2002, `Crack formation and fracture energy of normal and high strength concrete'. J Ind Nat Acad Sci 27(4), 413-423.

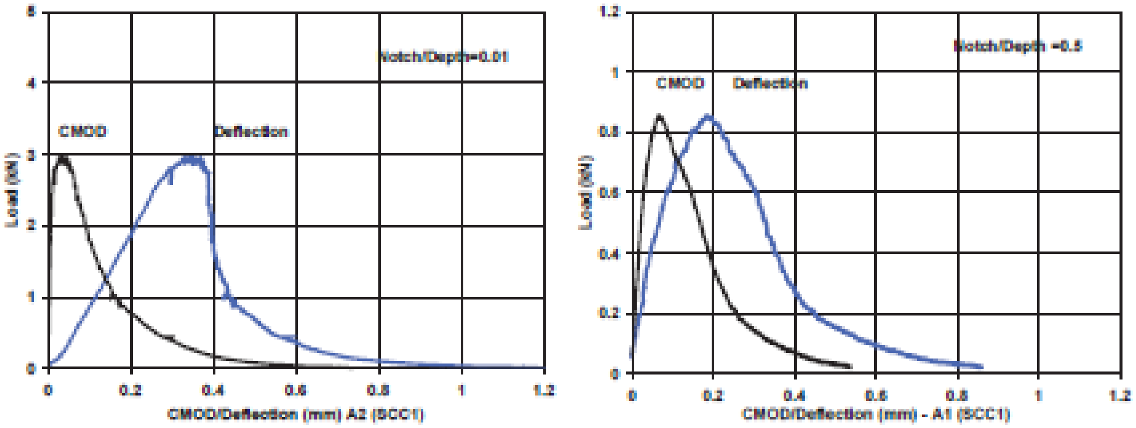

Fig. 1 : Typical load vs CMOD/Deflection for mixes SCC1

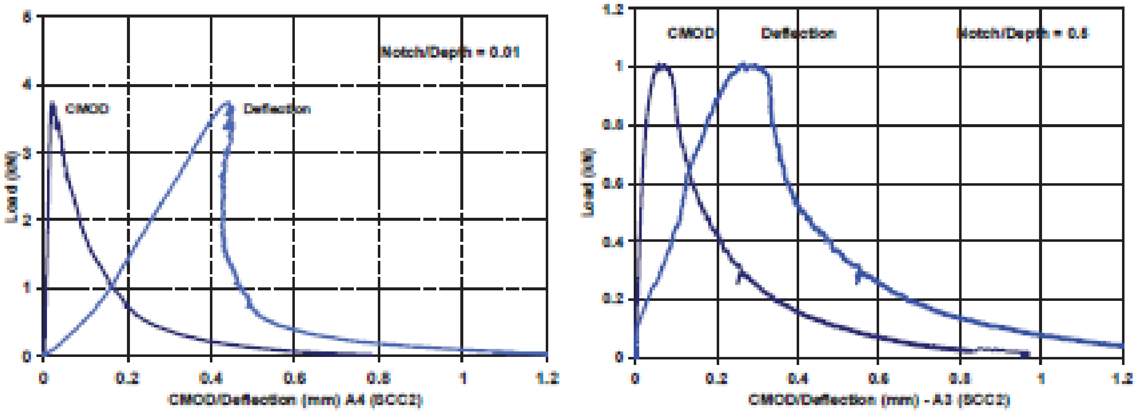

Fig. 2 : Typical load vs CMOD/Deflection for mixes SCC2

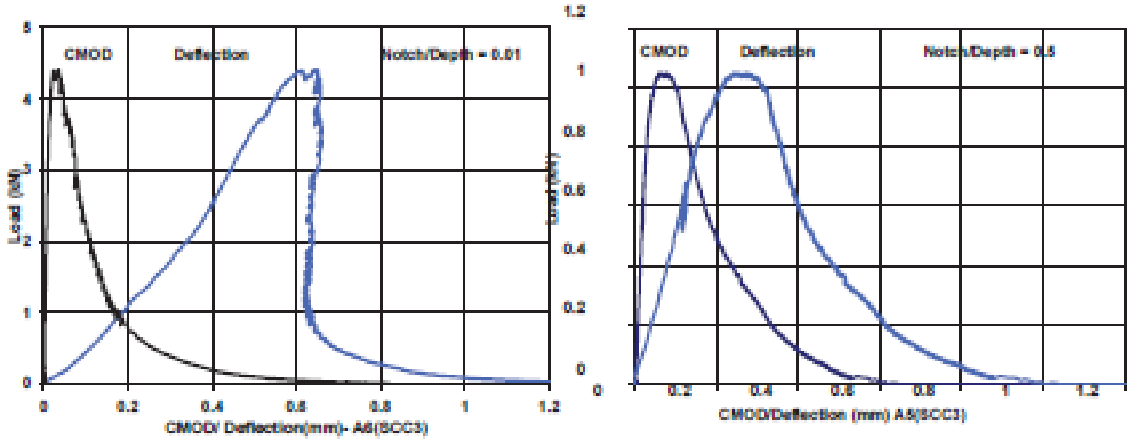

Fig. 3 : Typical load vs CMOD/Deflection for mixes SCC3.

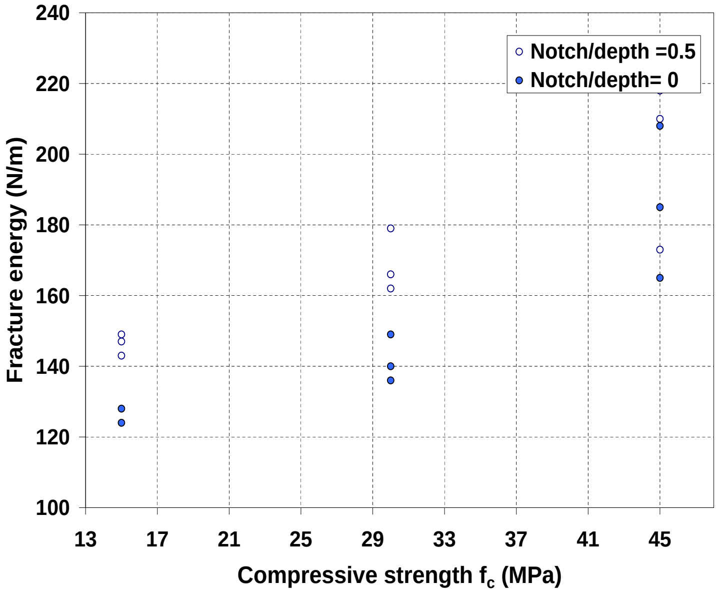

Fig. 4 : Fracture G_F vs compressive strength.

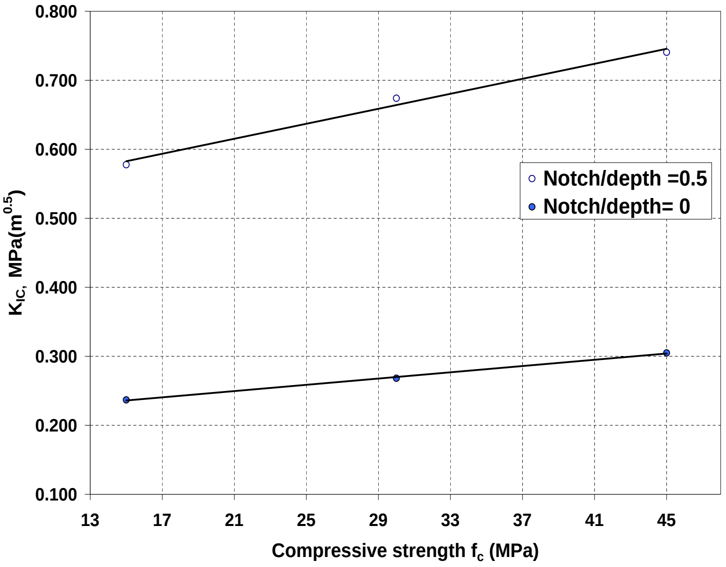

Fig. 5 : Critical stress intensity factor K_{IC} vs compressive strength.

Table 1 : Quantities of material for SCC kg / m3

Materials	SCC1	SCC2	SCC3
Cement (Kg)	240	400	360
Water (Kg)	220	180	190
Fine Agg. (Kg)	900	900	900
Coarse Agg. (Kg)	830	830	830
Fly ash (Kg)	184	200	196
Silica fume (Kg)	12	36	29
HRWR(liter)	2.00	4.00	3.50
AEA(liter)	0.20	0.24	0.40
VMA (liter)	0.50	1.50	1.25

Table 2 : Fresh properties of SCC

Tests	SCC1	SCC2	SCC3
Slump Flow (mm)	750	700	670
T50cm Slump Flow	3	4	5
J-ring (mm)	3.2	3	8
V-funnel (Sec)	4	6	7
V-funnel at T5	2	3	3
L-box ($H2/H1$)	0.8	1	0.95
U-box ($H2-H1$)	5	3	5
Fill-box(%)	95	95	95

Table 3 : Mechanical properties of SCC

Mix	Density	f_c	E	f_t	f_r
	kg/m^3	MPa	GPa	MPa	MPa
	2044	17.1	17	1.5	2.6
SCC1	2074	16.8	17	1.8	2.7
	2074	16.1	16.5	1.7	3.0
	2006	29.8	21	2.7	4.2
SCC2	1956	30.4	22	2.7	4.2
	2010	31.4	22	2.7	4.2
	2163	45	28	3.4	6.2
SCC3	2133	46	28.2	3.4	6.3
	2104	43	27	3.4	5.9

Table 4 : Value of RILEM GF for SCC

Series	f_c	a/b	b	S	G_F (N/m) Beam			Average G_F
	(MPa)		mm	mm	1	2	3	(N/m)
A1 (SCC1)	15	0.5	100	800	143	149	147	146.3
A3 (SCC2)	30	0.5	100	800	162	179	166	169.0
A5(SCC3)	45	0.5	100	800	173	210	218	200.3
A7(SCC2)	30	0.1	100	400	122	148	N/A	135.0
A9 (SCC3)	45	0.1	100	400	165	185	216	188.7
HPC*	48	0.5	100	800	125	110	147	127.3
A2 (SCC1)	15	0.01	100	800	124	128	N/A	126.0
A4 (SCC2)	30	0.01	100	800	136	149	140	141.7
A6(SCC3)	45	0.01	100	800	165	185	207	185.7
A8 (SCC2)	30	0.01	100	400	117	130	116	121.0
A10(SCC3)	45	0.01	100	400	167	184	193	181.3

*Data from [8], N/A-No result available

Table 5 : Fracture characterize of SCC

Series	*Average* $P_0(N)$	a/b	a mm	K_{IC} $MPa\sqrt{m}$	G_C N/m	l_{ch} mm
A1 (SCC1)	858	0.5	50	0.58	19.147	739.2
A3 (SCC2)	1001	0.5	50	0.67	18.428	603.7
A5(SCC3)	1100	0.5	50	0.74	18.170	584.3
A7(SCC2)	5570	0.1	10	0.6	57.784	482.2
A9 (SCC3)	5850	0.1	10	0.63	52.043	550.3
A2 (SCC1)	3200	0.01	1	0.24	3.218	636.5
A4 (SCC2)	3624	0.01	1	0.27	2.918	506.0
A6(SCC3)	4120	0.01	1	0.31	3.080	541.5
A8 (SCC2)	9893	0.01	1	0.37	21.748	432.2
A10(SCC3)	11672	0.01	1	0.43	24.718	528.9