Fracture Properties of Mixed Mode Steel Fibre Reinforced Concrete

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Abstract:- An investigation of mixed mode fracture of steel fibre reinforced concrete (SFRC) beams with 1% volume fraction of two different steel fibres SFRC1, SFRC2 having different aspect ratios and plain concrete is done here using concrete beams. The notch is considered(a/b) ratio as a constant 0.47 with different off-set ratios 0, 0.2, 0.4 and 0.6. Steel fibres used which are A)Circular corrugated hook-end type steel fibres and B) Flat Corrugated Zigzag Type Steel Fibre of two different aspect ratio viz. 46.66 (Type A) & 45.55 (Type B).

Keywords:- *Steel Fiber Reinforced Concrete, Stress Intensity Factor, Total conventional Stress Intensity Factor, Mixed Mode, Fracture Energy.*

I. INTRODUCTION

Concrete is a brittle material having low tensile strength with low strain capacity. To Improve cracking resistance, fibers reinforced has been developed.Fibers are introduced to improve tensile strength, post cracking ductility and control cracking. Fibres bridging crack faces restrict the crack from winding and propagating, thus the toughness and energy absorption capacity of composite is increased. The additions of steel fibres improve modulus of elasticity of concrete by increasing volume fraction of fibres. Steel fibre reinforced concrete (SFRC) is a cementations material reinforced with discrete fibres. Steel fibre reinforced concrete (SFRC) bring substantial benefits to the construction industry. In addition, steel fibres enhance crack control particularly when acting in conjunction with reinforcement bars.

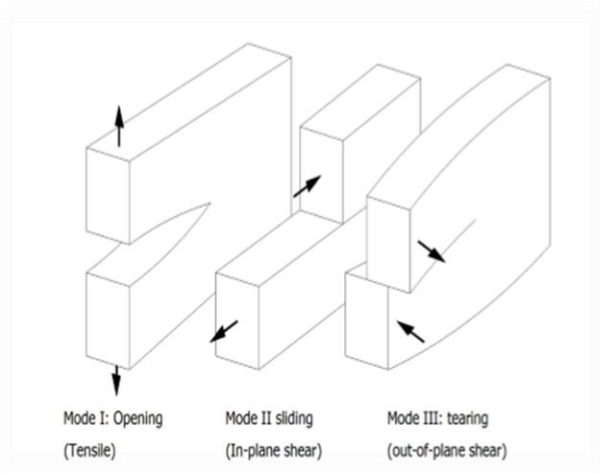

Fig 1:- Modes of Cracking

There are three modes of fracture failure: 1) Mode I 2)Mode II 3)Mode III.Mode I Opening or tensile mode, where the crack surfaces move directly apart.Mode II Sliding or in-plane shear mode, where the crack surfaces slide over one another in a direction perpendicular to the leading edge of the crack. Mode III Tearing or anti-plane shear mode, where the crack surfaces move relative to one another and parallel to the leading edge of the crack. Mode-I fracture is a clear type of crack propagation in fiber reinforced concrete. Mode-II and III are complex failure modes. In these modes the stress normal to the crack surface needs to be approximately zero and only in-plane shear stress should exist. Even when these conditions can be realized, a combination of different stresses exist (shear, tension, compression and bending) over the crack surface.

Closed loop servo controlled equipment has been used in the present work to evaluate these properties. The tests have been carried out using displacement control in order to obtain the post-peak force-displacement relationship (tensile strain-softening branch). From the test results LOAD v/s DISPLACEMENT curves have been obtained for all the specimens which were later used to evaluate the Fracture Energy .From peak load at given off-set ratio evaluate Mode I & Mode II Fracture Toughness and Total Conventional Fracture Toughness evaluated.This project work consists, the mixed mode fracture of steel fiber reinforced concrete (SFRC) beams with 1% volume fraction of two different steel fibers SFRC1, SFRC2 having different aspect ratios and plain concrete are used.In this research, different fracture parameters like Total conventional fracture toughness Kc, Mode I conventional fracture toughness K_I, Mode II conventional fracture toughness K_{II}, fracture energy Gc are evaluated.

II. MATERIAL DETAIL

Ordinary Portland cement 53 graded conforming to IS 4031 – 1988 was used for the concrete mix. The fine aggregate (sand) used in the work was obtained from a nearby river course. The fine aggregate that falls in zone–II was used. The Fineness modulus was found to be 2.81as per I.S. 383. Aggregate fraction from 80 mm – 4.75 mm is termed as coarse aggregate. For gradation of coarse aggregates (20 mm down), 2000 gm of sample is taken. The fineness modulus of coarse aggregates is found to be 3.397 as per I.S.

Fig 2:- Moulds of SENB Specimen

III. TEST PROCEDURE

The 36 specimens were given identification. Each specimen a unit code was designed. The code is a five-digit number. Specimens name first two digit are PC, F1,F2 means plain concrete, SFRC1 and SFRC2. Other two digit indicates its off-set distance for example (00,04,08,12) and last digit indicates similar specimen number. Each specimen varying with off-set ratio Y(2x/s) 0, 0.2, 0.4, 0.6 were X = distance of notch to center of beam in mm, S = loading span in mm. The length, depth, and thickness of the specimens were, L = 500 mm, b = 100 mm, and t = 100 mm, respectively. In addition, the nominal span of all the beams was S = 400 mm.

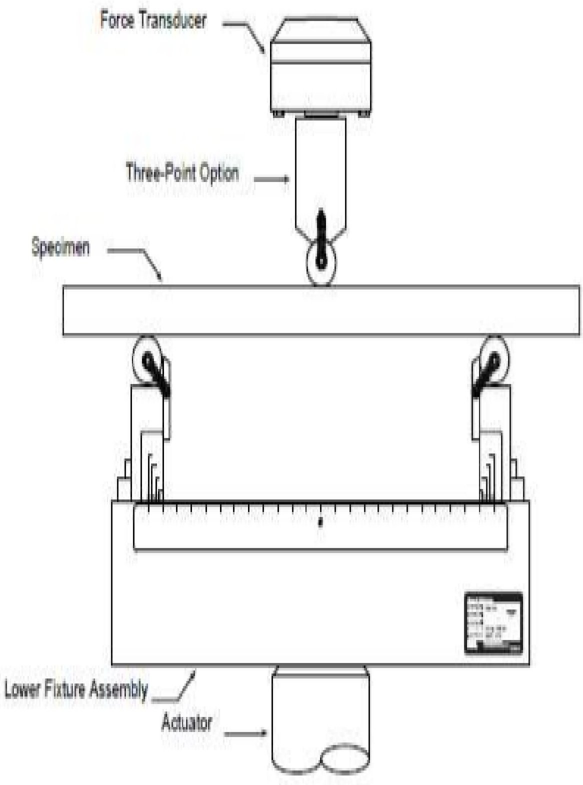

Fig 3:- Three Point Bend Fixture

The test procedure consist three-point bend load on the centrally placed beam specimen. The loading frame of the MTS was used for carrying out the experimental work, system incorporates with the set-up of bend test fixture. The height of the roller supports in the three-point loading assembly was not adequate to accommodate the clip gauge device to be attached below the beam. Steel blocks of required height and same precision groove as in the original MTS blocks were mounted on original steel blocks and fastened to them by extra-long springs locally manufactured. Also, wires were tied around them for precautionary safety purpose. This assembly is shown in Figure 3.

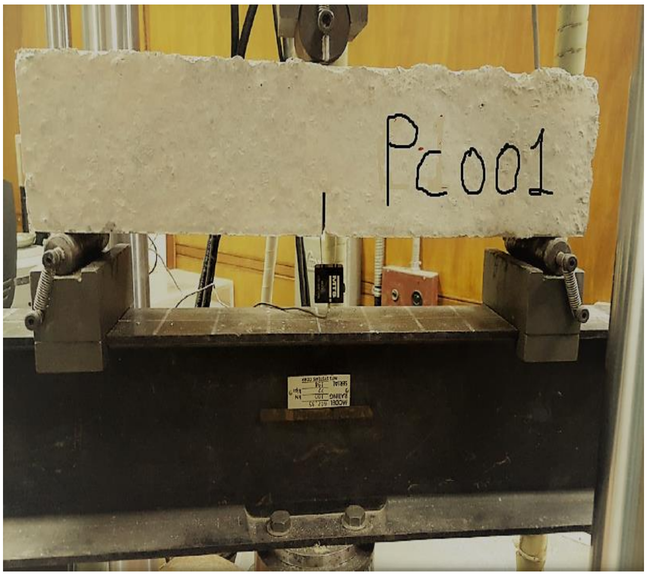

Fig 4:- Test set-up

The load was applied using the MTS system with operation was displacement controlled. Test was conducted using Test works 4 applications in the MTS. The test was so designed that after reaching peak load, drops by 90% of maximum load thus, it detects the failure of the specimen & stops test automatically. The values of load v/s actuator displacement were autographically recorded on x-y recorder. The values of axial strain (CMOD) were recorded during loading & unloading of the specimen. The beams were loaded till failure.

IV. CALCULATION &RESULTS

A. *For Stress intensity factor*

$$K_I = 6_N\sqrt{\pi a}\sqrt{b}f_I(\alpha,Y) \ldots 6.1$$

$$K_{II} = T_N\sqrt{\pi a}\sqrt{b}f_{II}(\alpha,Y) \ldots 6.2$$

Where,

$$6_N = \frac{6M}{t(1-\alpha)^2 b^2} \ldots 6.3$$

$$T_N = \frac{V}{t(1-\alpha)b} \ldots 6.4$$

M=Mp+Mw…6.5

V=Vp+Vw…6.6

Mp=p/4(S-2x)…6.7

Vp=p/2…6.8

Mw=wl/4(S–2x)-w/8(S-2x)2 …6.9

Vw=wx…6.10

$Kc = \sqrt{K_I{}^2 + K_{II}{}^2}$…6.11

i) For Fracture Energy G :

G = u-0.5mgδ/bt(1-α)…6.12

Where,

K_I&K_{II}= Mode I and Mode II stress intensity factors, 6N = Normal stress, p = point load, TN = Shear stress, w = weight per unit length of beam, V= Shear force at distance x s = nominal span, t = thickness,M = bending moment at distance(x), l = length, b = depth,α = a_0/b Notch Ratio Y = 2x/s off-set ratiof_I(α,Y)&f_{II}(α,Y) = dimensionless functions.G= fracture energy,U = area under lode vs displacement curve, mg = weight of beam b = depth of beam t = thickness of beam, δ= Value of displacement at maximum load on load v/s displacement graphα= a_0/b Notch Ratio.

Based on the experimental work performed on various Thirty-six notched concrete beam models specimens, the following results arrived.

SPECIMEN	P (kN)	K_I	K_{II}	KC
PC001	2.501	0.787	0.000	0.787
PC002	2.492	0.785	0.000	0.785
PC003	2.104	0.665	0.000	0.665
PC041	1.806	0.497	0.043	0.498
PC042	2.502	0.682	0.060	0.685
PC043	3.717	1.006	0.088	1.010
PC081	3.2	0.650	0.082	0.656
PC082	3.732	0.756	0.095	0.762
PC083	4.402	0.890	0.112	0.897
PC121	5.866	0.789	0.143	0.801
PC122	4.867	0.656	0.119	0.667
PC123	6.769	0.908	0.165	0.923

Table 1. Plain concrete

SPECIMEN	P (kN)	K_I	K_{II}	KC
F1001	2.764	0.869	0.000	0.869
F1002	2.561	0.806	0.000	0.806
F1003	1.865	0.591	0.000	0.591
F1041	3.869	1.046	0.092	1.050
F1042	2.5	0.682	0.060	0.684
F1043	3.066	0.832	0.073	0.836
F1081	4.563	0.922	0.116	0.929
F1082	3.8	0.770	0.097	0.776
F1083	4.289	0.867	0.109	0.874
F1121	5.9	0.793	0.144	0.806
F1122	9.4	1.258	0.228	1.278
F1123	5.001	0.674	0.122	0.685

Table 2. SFRC1

SPECIMEN	P (kN)	K_I	K_{II}	KC
F2001	2.4	0.756	0.000	0.756
F2002	2.1	0.664	0.000	0.664
F2003	2.5	0.787	0.000	0.787
F2041	2.52	0.687	0.060	0.689
F2042	3	0.815	0.071	0.818
F2043	2.7	0.735	0.064	0.738
F2081	3.2	0.650	0.082	0.656
F2082	3.8	0.770	0.097	0.776
F2083	4	0.810	0.102	0.816
F2121	5.2	0.700	0.127	0.712
F2122	7	0.939	0.170	0.954
F2123	4.5	0.607	0.110	0.617

Table 3. SFRC2

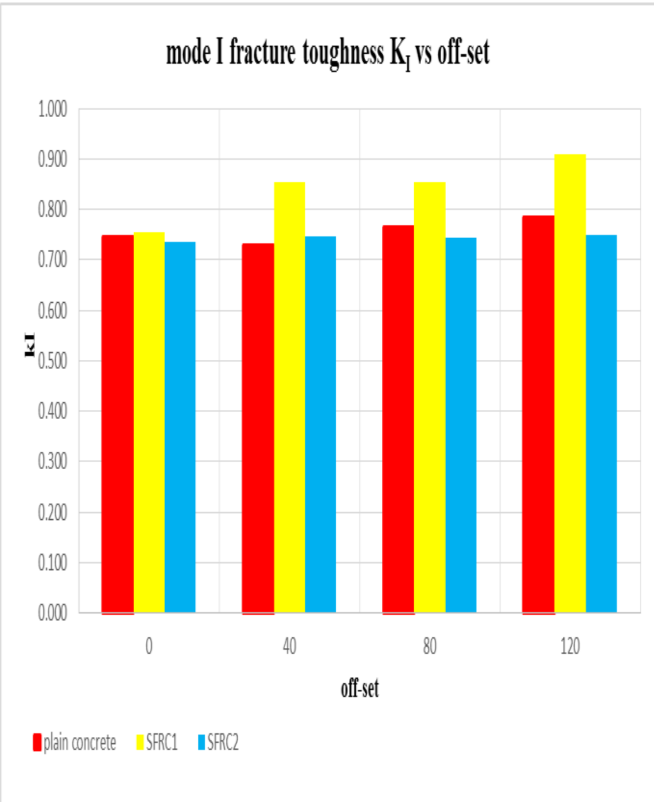

Fig 5:- mode I fracture toughness

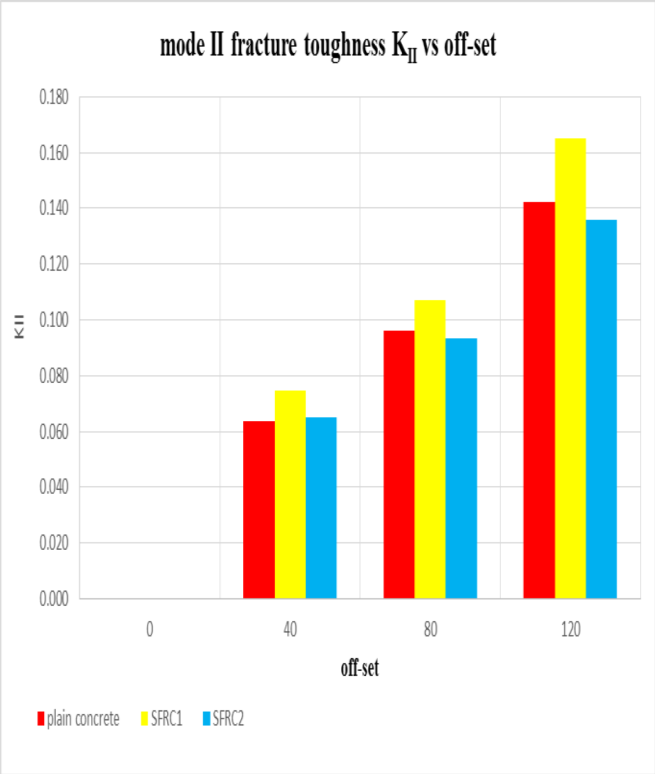

Fig 6:- mode II fracture toughness K_{II}

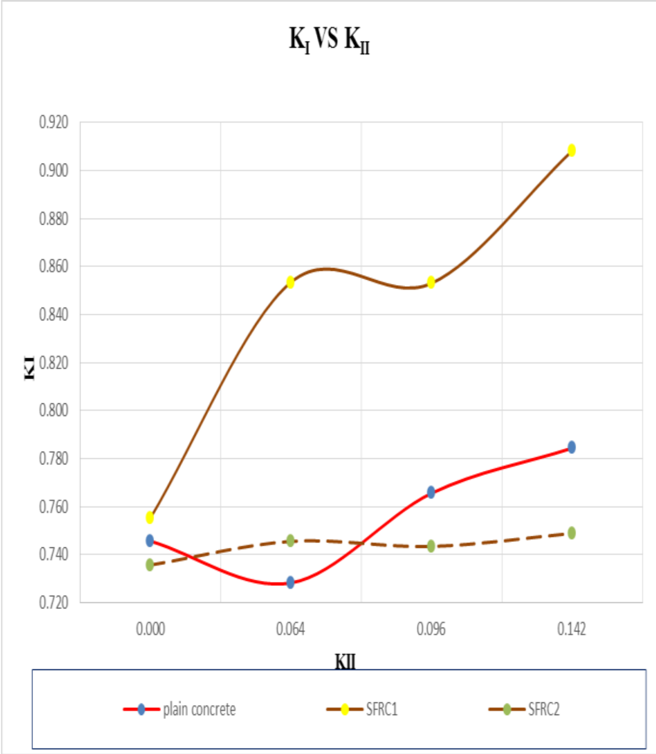

Fig 8:- mode I fracture toughness K_I vs mode II fracture toughness K_{II}

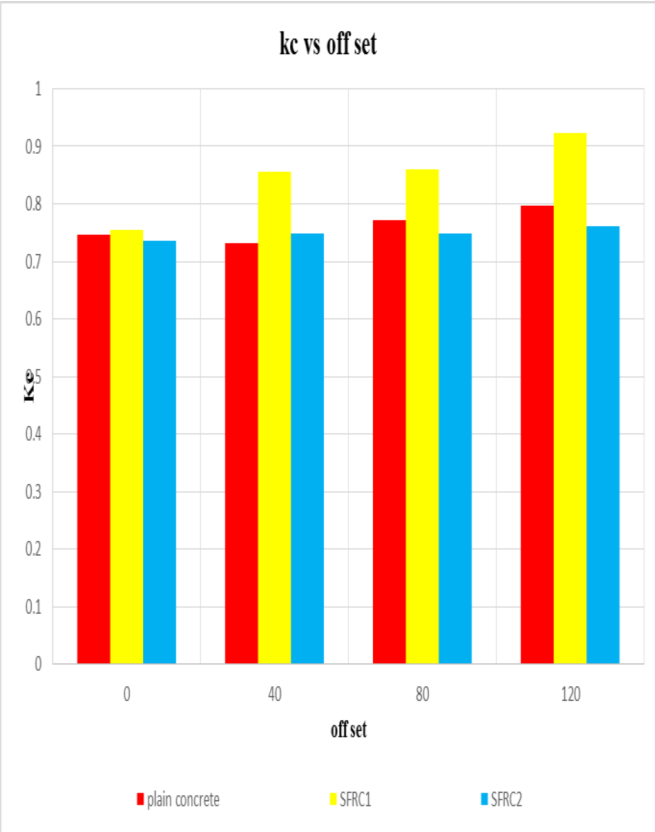

Fig 7:- Total conventional fracture toughness K_c

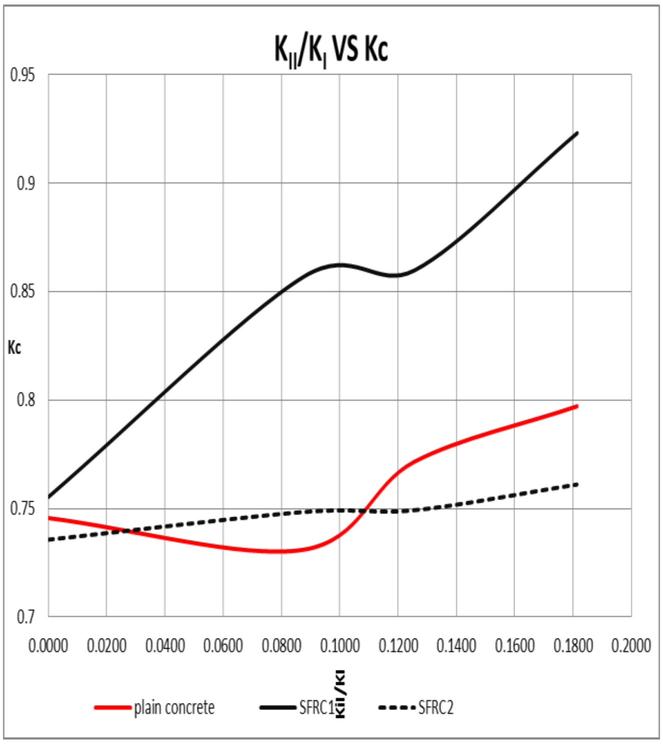

Fig 9:- Ratio of K_{II}/K_I vs Conventional fracture toughness Kc

SPECIMEN	P (kN)	u (N.m)	δ (m)	Gf (N/m)
PC001	2.502	0.24511	0.00045	41.39443
PC002	2.492	0.26506	0.00034	49.58962
PC003	2.104	0.22234	0.00055	40.34627
PC041	1.806	0.21741	0.00020	46.00113
PC042	2.502	0.26264	0.00061	48.80660
PC043	3.717	0.34017	0.00061	63.44057
PC081	3.3	-	-	-
PC082	3.732	0.41937	0.00061	78.37321
PC083	4.402	0.49829	0.00056	93.32811
PC121	5.866	0.58634	0.00061	109.88085
PC122	4.867	0.53237	0.00062	99.69075
PC123	6.769	0.69702	0.00063	130.74608

Table 4. Experimental Results of plain concrete Peak Load and Fracture Energy

SPECIMN	P (kN)	u (N.m)	δ (m)	Gf (N/m)
F1001	2.764	0.28653	0.00031	53.67840
F1002	2.561	0.26562	0.00071	49.24132
F1003	1.865	0.23136	0.00047	43.08132
F1041	3.869	0.37028	0.00061	69.11519
F1042	2.5	-	-	-
F1043	3.066	0.29801	0.00061	55.47528
F1081	4.563	0.52987	0.00058	99.26953
F1082	3.8	-	-	-
F1083	4.289	0.49829	0.00059	93.29868
F1121	5.9	-	-	-
F1122	9.4	-	-	-
F1123	5.001	0.66616	0.00054	125.03443

Table 5. Experimental Results of SFRC1 Peak Load and Fracture Energy

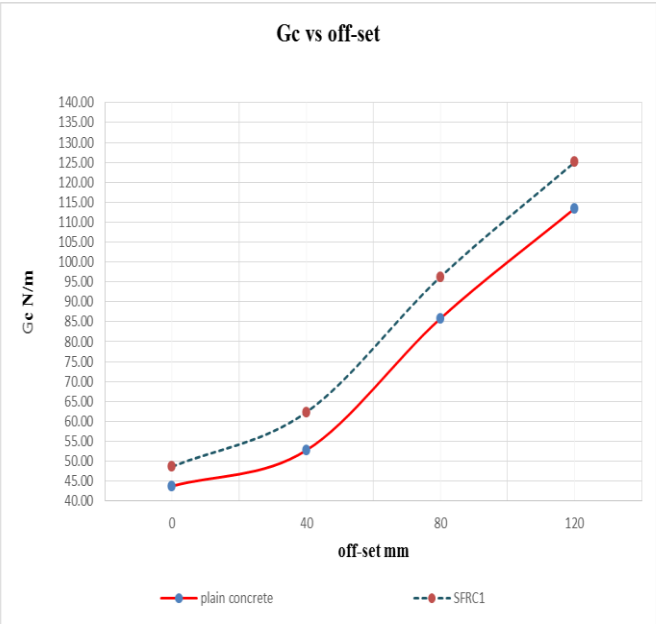

Fig 10:- Fracture energy vs off-set ratio

V. CONCLUSIONS

A. It is observed that, the graph of K_I vs off-set of Plain concrete, SFRC1 and SFRC2 the value of mode I conventional Fracture toughness K_I increases with increase in value of off-set except in case of plain concrete 40 mm off-set where the value has decreased. It is also concluded that, SFRC1 is having a good effect but plain-concrete and SFRC2 having a little effect of offset. The 1.2%, 17.17%, 11.35% and 1.81% increases in SFRC1 in value of K_1 compared to plain-concrete at off-set 0, 40, 80 and 120. The 2.5% increase in SFRC2 in value of K_I compared to plain-concrete at off-set of 40. The 1.34%, 3% and 4.5% decrease SFRC2 in value of K_I compared to plain-concrete at off-set of 0, 80, and 120 respectively.

B. It is also observed that, graph of K_{II} vsoff-set of the mode II conventional Fracture toughness K_{II} increases with increase in value of off-set and SFRC1 having good effect as compared to plain concrete and SFRC2 of off-set. The 17%, 11.5% and 16.19% increase in SFRC1 in value of K_{II} compared to plain-concrete at offset 40, 80 and 120. The 1.5% increase in SFRC2 in value of K_{II} compared to plain-concrete at off-set of 40. The 3.1% and 4.2% decrease in SFRC2 in value of K_{II} compared to plain-concrete at off-set of 80 and 120.

C. It is also observed that, graph K_I vs K_{II} the result of Plain concrete, SFRC1 and SFRC2 the value of K_I increase with increasing value of K_{II} except value of K_{II} 0.064. The value of K_I increases due to increasing value of K_{II}. The two-reason pointed out here A) By increasing K_{II} value the fibre-bridging and aggregate interlock stress will increase B) For large off-set ratio effective bending stress decrease thus K_I value increase.

D. It is also observed that, graph Kc vs off-set the result of Plain concrete, SFRC1 and SFRC2 the value of total conventional Fracture Toughness Kc increase with increase off-set except in case of plain concrete 40 mm off-set. The 12.1%, 17.23%, 11.5% and 15.8% increase in SFRC1 in value of Kc compared to plain-concrete at off-set 0, 40, 80 and 120. The 2.3% increase in SFRC2 in value of Kc compared to plain-concrete at off-set of 40. The 1.3%, 2.3% and 4.5% decrease in SFRC2 in value of Kc compared to plain-concrete at off-set of 0, 80 and 120

E. It is also observed that graph K_{II}/K_I vsKc the result of Plain concrete, SFRC1 and SFRC2 the value of total conventional Fracture Toughness Kc increase with increasing ratio of K_{II}/K_I. It shows that frictional tractions from aggregate interlock and fibre-bridging may increase by increasing ratio of K_{II}/K_I

F. It is also observed that, graph Gc vs off-set the Fracture energy increase with increasing off-set and SFRC1 have more fracture energy than plain concrete. The 11.2%, 18.1%, 12.14% and 10.21% increase in SFRC1 in value of Gc compared to plain-concrete at off-set 0, 40, 80 and 120.

G. It is also observed that the SFRC1 having good effect as compare with the plain concrete and SFRC2 because of so good aggregate interlock and fibre-bridging effect. It is also observed that the fracture energy is a more reliable property than fracture toughness Kc.

VI. ACKNOLEDGEMENT

This research has been conducted in the Fracture Mechanics Laboratory of Applied Mechanics Department at The Maharaja sayajirao University of Baroda.

VII. NOTATION

The following symbols are used in this paper:

6_N = Normal stress
P = point load
T_N = Shear stress
w = weight per unit length of beam
V = Shear force at distance x
s = nominal span
t = thickness,
M = bending moment at at distance x
l = length
b = depth
a_0 = Initial Crack Length
a = Crack Length
E = Modulus of Elasticity
$\alpha = a_0/b$Notch Ratio
o = off set
γ = off-set ratio
v =Poisson's ratio
$f_I(\alpha,\gamma)$ = Dimension less function for mode I
$f_{II}(\alpha,\gamma)$ = Dimension less function for mode II
K_I = Mode I stress intensity factors
K_I= Mode II stress intensity factors
Kc= Conventional stress intensity factor
G_f= fracture energy
u = area under lode vs displacement curve
mg = weight of beam
b = depth of beam
t = thickness of beam
δ = Value of displacement at maximum load on load v/s displacement graph

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