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Research paper

Determination of Mechanical Properties of Slurry Infiltrated Steel Fiber Concrete Using Fly Ash and Metakaolin

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Abstract

This paper reports on a wide-ranging study on the properties of slurry infiltrated fiber concrete containing fly ash, Metakaolin, and hook ended steel fibers. Properties studied include workability of fresh slurry infiltrated fiber concrete, and compressive strength, flexural tensile strength, splitting tensile strength, dynamic elasticity modulus, impact energy of hardened slurry infiltrated fiber concrete. Fly ash and Metakaolin content used was 0%, 2.5%, 5.0%, 7.5% and 10% in mass basis, and hook ended steel fibers volume fraction was 0%, 2.0%, 3.0% and 4.0% in volume basis. The laboratory results showed that steel fiber addition, either into control concrete or fly ash, Metakaolin blend slurry infiltrated fiber concrete; improve the tensile strength properties, flexural strength, impact energy and modulus of elasticity. In this experimental study, compressive strength improvement ratio is 33.60%, and Structural efficiency is 9.50 % higher in slurry infiltrated fiber-concrete with Metakaolin as compared with fly ash based slurry infiltrated fiber concrete at the 4% replacement ratio of hook ended steel fibers by volume.

Keywords: *SIFCON; Metakaolin; Fly ash; Strength improvement ratio; Structural efficiency.*

1. Introduction

Slurry Infiltrated Fiber Concrete (SIFCON) is a type of ultra-high performance fiber reinforced concrete (UHPFRC) in which mold filled with pre-placed steel fibers and pouring cement slurry on it. Slurry infiltration able by gravity flow aided by light vibration, or sometimes it can be done by pressure grouting.

For emerging of slurry infiltrated fiber concrete around two decades completed still, research is continuing on the various properties of SIFCON. Mechanical properties of slurry infiltrated fiber concrete viz. compressive strength, flexural strength, and split tensile strength has found by the different researcher [1, 2]. Crack density increases with the increase of the percentage of fiber content [3](Yan et al., 2002). Steel fibers are used in concrete to linking the gap of brittleness[4]. The crack propagation of SIFCON presents irregular multi-crack phenomenon and the density of crack increases with the increase of fiber content[5-7].

The objective of this research work is to verify the behaviors of slurry infiltrated fiber concrete after addition of fly ash and Metakaolin. Another objective is to optimize the dosage of fiber content in slurry infiltrated fiber concrete.

2. Methodology

In this section describe the various mechanical method used for determination of strength of slurry infiltrated fiber concrete. The different materials were used in this research work is mentioned below.

2.1. Materials and Slurry Infiltrated Fiber Concrete Mix Design

Mix design of slurry infiltrated fiber concrete based on packing density [8, 9]. Ordinary Portland cement, river sand 2 mm fine sand, Metakaolin, fly ash, superplasticizer, and steel fibers. Metakaolin and fly ash has replaced for cement from 5, 7.5 and 10 %. A fiber has pre-placed in the mould on the volumetric replacement for 2, 3 and 4%.quantity of fibers workout based on packing density approach [8,9] and preparation of matrix for throughout experimental work has been taken in the ratio of one part of binding material including pozzolanic material and cement and one part of fine sand.

2.1.1. Cement

Ordinary Portland cement available in the local market of the standard brand was used in the investigation. The Cement found to be conforming to specifications is IS12269-1989[10]. The specific gravity was 3.15 and fineness was 3200cm^2/gm.

2.1.2. Fine Aggregate

River sand, which is locally available passing through 4.75 mm, IS sieve used. The specific gravity of the fine aggregate found to be 2.7. The fine aggregate is confirming to as per IS 383-1970[11].

2.1.3. Hooked Ended Steel Fibers

It was procured from, Kasturi Metal Composite (P) Ltd. Amravati. The company provided the material under the trade name of DURAFLEX by ASTM-A820 [12]. The length of the fibers 35mm and diameter of fibers 0.6mm and tensile strength was 1100 MPa according to specification. Properties of hooked- end steel fibers provided in Table1 and fibers used in experimental study as shown in Fig.1

Fig. 1: Fibers used in the experimental study (hooked ended steel fibers)

Table 1: Properties of Hooked ended steel fiber

Length, mm	Diameter, mm	Aspect ratio l/d	Yield stress in MPa	Volume of fraction# in percent
35	0.6	58.33	1100	2 to 4

#assuming fibers placed primarily aligned with the loading direction.

2.1.5. Superplasticizer

To improve the workability in slurry CONPLAST SP-430 confirming to ASTMC494 [13] type- F, high range water reducing agent has been used. The addition of superplasticizer is 1% by the weight of cement.

2.1.6. Metakaolin

The natural pozzolanic materials Metakaolin (MK) has obtained from the 20 MICRON LIMITED, Mumbai. The Metakaolin was in confirming with the general requirements of properties of pozzolanic materials. The specific gravity of the Metakaolin found to be 2.56. Metakaolin (MK) confirms to IS 456-2000[14].

2.1.7 Fly ash

It is a waste product of a thermal power plant. It has obtained from eklahare thermal power plant, Nashik. Fly ash confirms to IS 3812 -1 (2003)[15]. The specific gravity of the Fly ash found to be 2.1.

2.2. Methods

The Following methodology based on for determination of hardening properties and fresh state properties of slurry infiltrated fiber concrete. Hardening properties as compressive strength, flexural strength, split tensile strength, Impact energy and dynamic modulus of elasticity.

2.2.1. Fresh –State Tests On the Slurry

Table 2.shows the results for slump flow test and L-box test for the various replacement levels of fly ash and Metakaolin. It observed that decreasing the slump flow of slurry at 10 % replacement in the case of Metakaolin and increasing in case of fly ash [16, 17]. Reported that increased the dosage of silica fume decreased the spread diameter of mini-slump and suggested the methods for measuring the fresh property of slurry. Fly ash replacement with cement brings to increase in the viscosity of slurry [2].

2.2.2. Compressive Strength and Split Tensile Strength

As per mix proportion of slurry infiltrated fiber concrete is divided into two part one part is FASIFCON (that is fly ash slurry infiltrated fiber concrete) and the second part is MKSIFCON (that is Metakaolin slurry infiltrated fiber concrete).Seventy-two cubic specimens with dimensions of 100 ×100 ×100 mm^3 [18, 19] were cast and tested to determine the compressive strength of slurry infiltrated fiber concrete including fly ash and Metakaolin as per IS 516- 1999[20].

Table 2: Results of fresh-state tests on the slurry

Designation	Slump flow test		L-Box test
	T50 (s)	df (mm)	H2/H1
5% fly ash	4.5	610	0.91
7.5% fly ash	3.5	635	0.91
10% fly ash	3.5	640	0.92
5% Metakaolin	3.0	635	0.91
7.5% Metakaolin	3.5	620	0.87
10% Metakaolin	4.0	615	0.92

Furthermore, seventy-two cylinders with 100 mm ×200 mm cylinder[21]were to cast tested for split tensile strength of slurry infiltrated fiber concrete, including fly ash and Metakaolin as per IS 516-1999[20]. The test is conducted on compression testing machine of capacity 3000 kN.

2.2.3. Flexural Strength Test

The specimens cast for the flexural strength test were of dimensions 100 × 100 × 500 mm. The useful span was 400 mm, and the samples were subjected to two points loading, the distance between the loads was 133 mm. The test procedure was carried out by IS 516-1999[20].

2.2.4. Impact Energy Test

The apparatus is used for determination of impact energy is a combine of aggregate impact value test machine and drops weight type test apparatus recommended by standards (ACI 544.2R-89)[22]. The drop hammer having weighed 13.5 kg, and it dropped from a height of 300 mm each time. Three cylindrical sample of size 150 mm diameter and 63.5 mm height tested at 28 days curing age for each type of mix, and a number of blows required causing the first visible crack and ultimate failure recorded. The first crack defined as the first visible crack. The final failure of the sample under impact test as shown in Fig.11 and Fig.12. To calculate energy absorption, the equation (1) as given

$$e_1 = \frac{1}{2} m {v_1}^2 n \quad (1)$$

Where e1 is impact energy (N-m), m, is a mass of the drop hammer (kg), v_1 is impact speed (m/s), n, is the number of blows. During the impact, the speed of the drop hammer (v_1) is measured, and it calculated as 1.8088 m/s. The impact energy test had illustrated by [23, 24].

2.2.5 Ultrasonic Pulse Velocity Test

In this test method, the ultrasonic pulse velocity is calculated by Equation 2 the pulse velocity (V) is given by the following equation (2)

$$v = L/T \quad (2)$$

Where, L= path length, T= transit time, v = ultrasonic pulse velocity. The quality of concrete based on velocity criterion as described in Table 3.

2.2.6 Determination of Dynamic Modulus of Elasticity by UPV

The following standard equation given a relationship between the dynamic modulus of elasticity and the velocity of an ultrasonic pulse traveling an isotropic elastic medium of infinite dimensions as per IS 13311 part -1, 1992[25] is given by equation (3)

$$Ed = v^2\rho\frac{(1+\mu)(1-2\mu)}{(1-\mu)} \quad (3)$$

Where, v is velocity in km/s, ρ is concrete density in kg / m3, μ is Poison's ratio (for high strength concrete μ = 0.15, for low strength concrete μ = 0.30), Ed is dynamic elastic modulus. The various researchers gave the relationship between dynamic modulus and velocity [26-28].

Table 3: Velocity Criterion for Concrete Quality Grading (As per IS 13311 part -1, 1992)

Sr. No.	Pulse velocity by cross probing (km/sec)	Concrete quality grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

3. Results and Discussion

3.1. Experimental Results of Control Specimen

The results of control specimen have listed in Table 4. Moreover, the specimen has cast with replacement without addition of steel fibers, fly ash and MK. Specimens has tested for compressive(f_c), splitting tensile(f_t), flexural(f_f), impact strength(e_1) and dynamic modulus of elasticity(E_d) for 28 days standard curing and result are given in the Table 4.

Table 4: Experimental results obtained from testing of control specimens

Designation	f_c MPa)	f_t (MPa)	f_f MPa)	e_1(N-m)	E_d (MPa)
CON	56.28	7.68	8.84	1368.02	21677.53

3.2. Compressive Strength, Spilt Tensile Strength, and Flexural Strength

Fig.2 shows that the compressive strength of slurry-infiltrated fiber-concrete with steel fibers goes on increasing up to the 4-percentage addition of steel fibers with fly ash. A higher compressive strength of 98.60MPa observed for 4% addition of steel fibers to slurry infiltrated fiber-concrete with Metakaolin. In other words, slurry infiltrated fiber-concrete with 4% steel fibers shows higher compressive strength, the percentage increase in compressive strength is 69.69%.
The experimental work performed on various mechanical properties of SIFCON and its present in Fig. 2. It is clear from the test result; strength improvement in flexural strength showed in MKSIFCON is greater than FASIFCON. This result is validated by the previous researcher reported in his experimental works [29]. The results obtained from the split tensile strength, compressive strength tests are given in Fig. 2. Fig. 2 gives as mechanical properties on Y-axis and various mix proportion of fly ash based slurry infiltrated fiber concrete (FASIFCON) with different ratio of fly ash (5, 7.5 and 10%), hook-ended steel fibers(2,3 and 4%) and Metakaolin based slurry infiltrated fiber concrete (MKSIFCON) with various proportion of MK(5, 7.5 and 10%), hook-ended steel fibers(2,3 and 4%) and Metakaolin based slurry infiltrated fiber concrete.

3.3. Impact Energy Test

Alavi Nia et al. [30] determined that a fiber showing it's an improvement in concrete impact strength; particularly steel fibers with hooked-ends present a better performance than with using polypropylene (PP) fibers because of their more substantial length. In his experimental work, the best performance under impact loading has been given by the concrete having 2.0% volume fraction of fibers reported by Farnam et al. [31]. From the Fig.4 observed that 10% Metakaolin (MK) replacement with 4 % hooked ended fiber fraction replacement on a volumetric basis that is MKSIFCON104 exhibit more impact energy as 3863.26 N-m. Rao et al. [32] studied the performance of energy-absorption capacity of SIFCON slabs increases with increased volume of fiber, and absorb more energy as compared with FRC and RCC slabs.

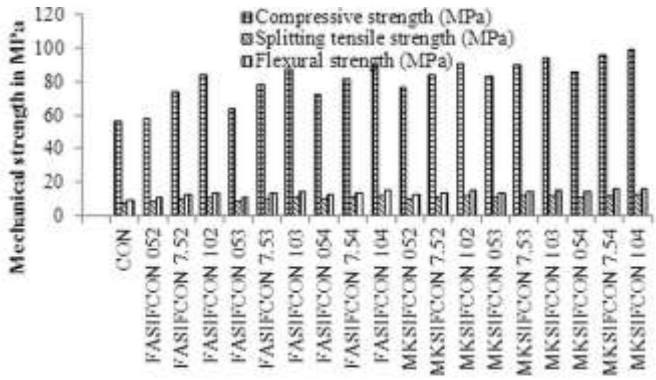

Fig. 2: Variation of Mechanical strength (Compressive, Split, Flexural Strength) of FASIFCON &MKSIFCON

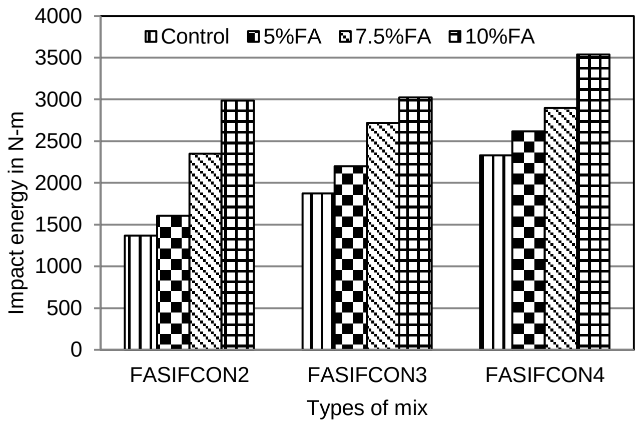

Fig. 3: Variation of Impact strength of FASIFCON

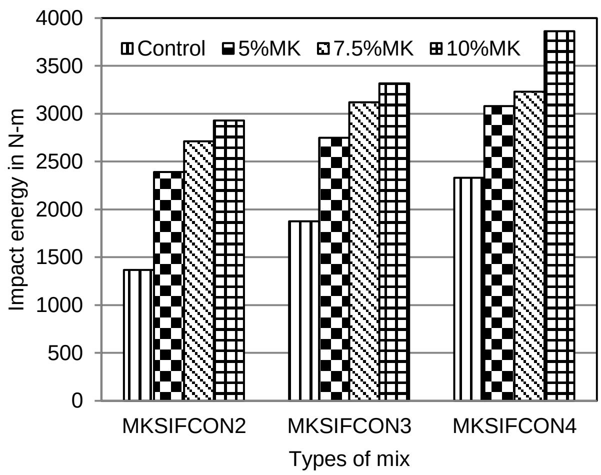

Fig. 4: Variation of Impact strength of MKSIFCON

3.4. Dynamic Modulus of Elasticity

Dynamic modulus of elasticity increase with fiber inclusion can be attributed to the higher elasticity modulus of steel fiber. Fig. 5& Fig.6 shows the results obtained from the experimental work on control, FASIFCON and MKSIFCON specimens. Variation of dynamic modulus of elasticity concerning types of the mix has given in Fig. 5 & Fig.6.

3.5 Structural Efficiency

In this section have been discussed about the structural efficiency of slurry infiltrated fiber concrete by using fly ash and Metakaolin, i.e., FASIFCON and MKSIFCON. Structural efficiency (Ste), which calculated the ratio of the compressive strength at 28 days to the density, as express in equation (4)

$$Ste = \frac{fc}{\rho} \quad (4)$$

Where Ste is the structural efficiency (Nm/kg), fc is the compressive strength at 28 days (N/mm^2), and ρ is the apparent density of the sample (kg/m^3), respectively. The structural efficiencies, as well as the densities of these eighteen mixes and their relative compressive strengths at 28 days, are shown in Fig. 7 & Fig. 8.

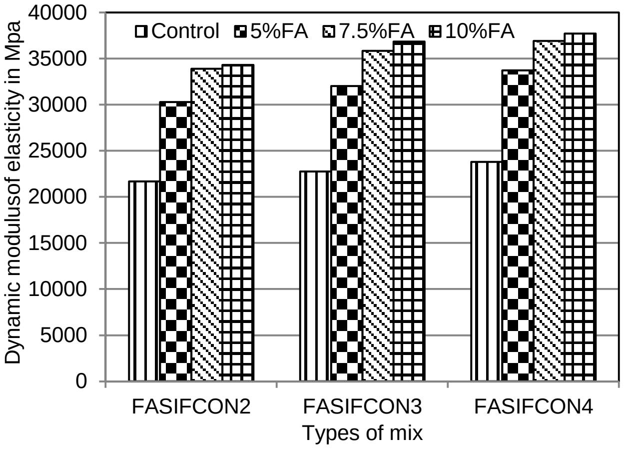

Fig. 5: Variation of dynamic modulus of elasticity of FASIFCON

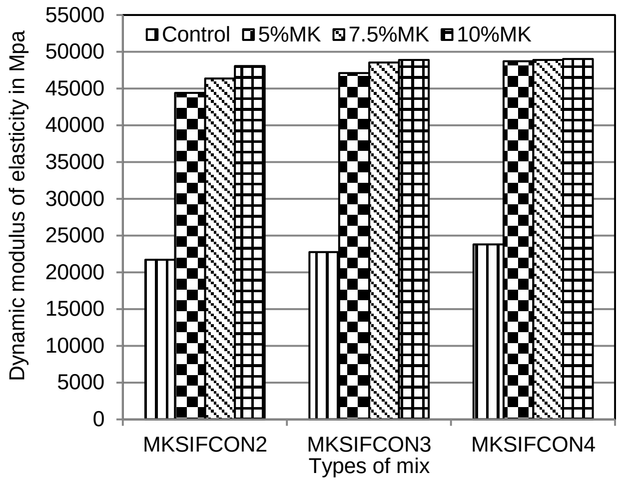

Fig. 6: Variation of dynamic modulus of elasticity of MKSIFCON

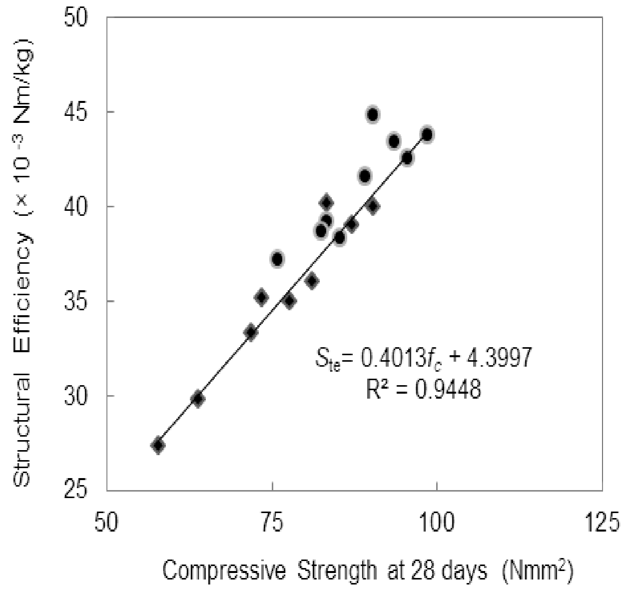

Fig. 7: Structural efficiency of FASIFCON & MKSIFCON versus compressive strength at 28 days

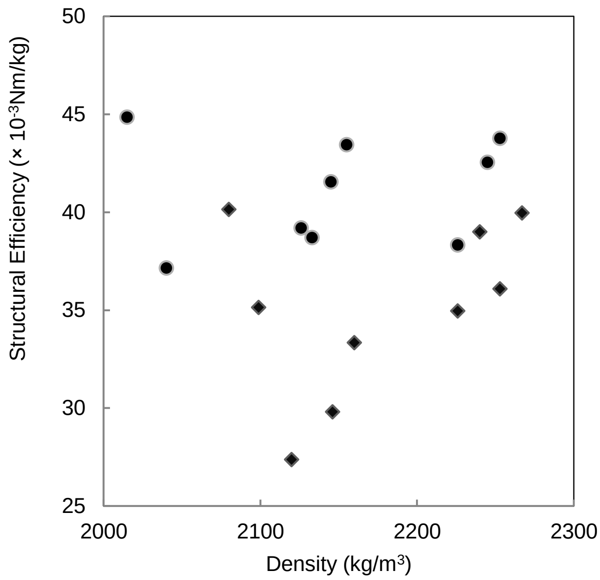

Fig. 8: Structural efficiency of FASIFCON & MKSIFCON versus density

3.6 Strength Improvement Ratio

To elucidate the efficiency of the additional steel fibers on the flexural and compressive strengths of UHPFRC. The strength improvement ratio are reported by [33], and it is given by equation (5)

$$\boldsymbol{K_t = \frac{S_i - S_0}{S_0} (i = 2, 3, 4)} \quad (5)$$

Where K_t (%) is the strength improvement ratio, S_i (MPa) is the strength of concrete with fibers, i ; means the addition of fibers (by volume) and So (MPa) is the strength of concrete without fibers.

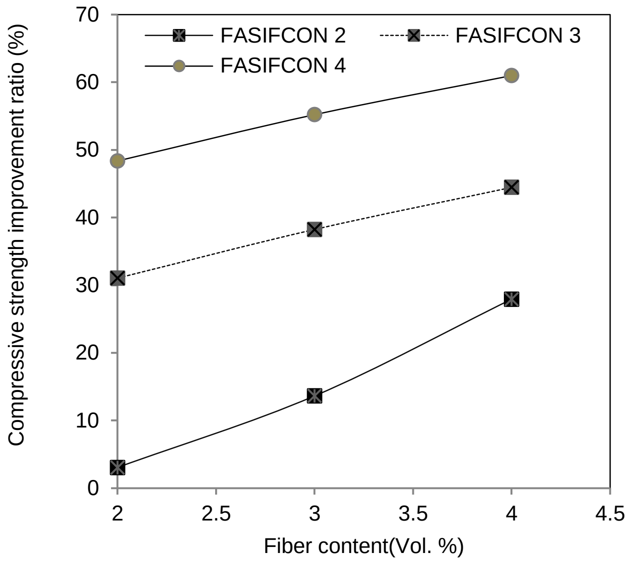

Fig. 9: Compressive strength improvement ratios of FASIFCON at 28 days as a function of steel fiber content

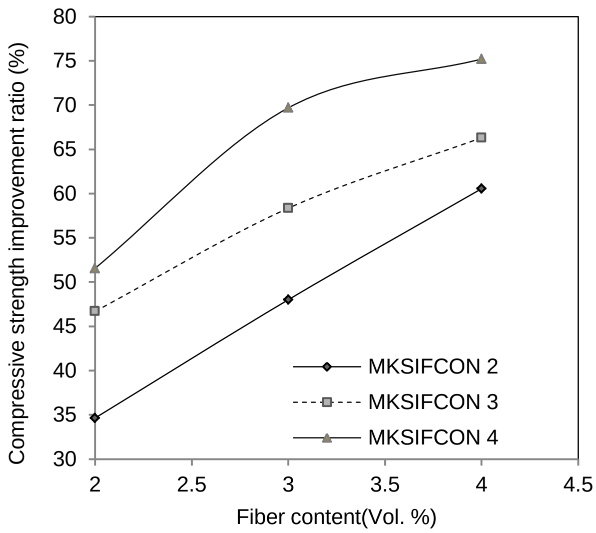

Fig. 10: Compressive strength improvement ratios of MKSIFCON at 28 days as a function of steel fiber content

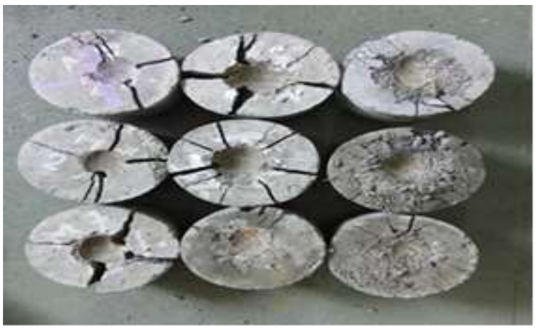

Fig. 11: Impact Strength Test of disc specimen

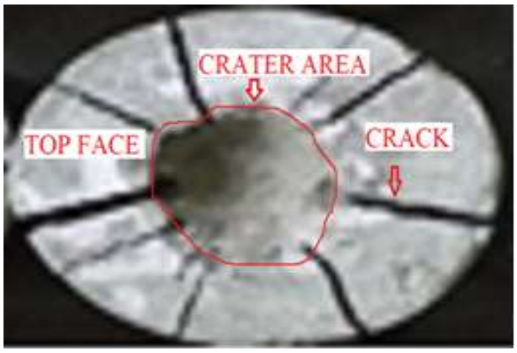

Fig. 12: The configuration of crater area and cracks on the test specimen

4. Conclusion

Based on the test results the following conclusions could be drawn:

1) The addition of hooked ended steel fiber was observed to enhance the hardened properties of slurry infiltrated fiber concrete by the addition of Metakaolin.

2) The optimum content of hooked ended steel fiber was 4% by volume while, the optimum content for Metakaolin and fly ash was 10% by cement weight.

3) Using the hooked ended steel fibers with the addition of Metakaolin increased the 28 days compressive strength, flexural strength, &splitting tensile strength, by 71.64%, 87.5%, & 67.45% respectively independent of the fiber content compared to the control concrete mix without fiber addition.

4) Using the hooked ended steel fibers with the addition of fly ash increased the 28 days compressive strength, flexural strength, &splitting tensile strength, by 60.98%, 73.11%, & 51.04 % respectively independent of the fiber content compared to the control concrete mix without fiber addition.

5) The impact resistance regarding the number of drops needed to cause the fracture of test specimens was increased by 158.80%, and 182.40% when Metakaolin and fly ash were used with hook ended steel fibers, respectively.

6) While the control mix test specimens failed suddenly in flexure and impact, the counterpart specimens contain fibers failed in a ductile manner, and failure was accompanied by several cracks

7) The dynamic modulus of elasticity pointed out increased by 84.20%, and 99% when Metakaolin and fly ash were used with hook ended steel fibers, respectively. Independent of the fiber content compared to the control concrete mix without fiber addition.

8)In this experimental study, compressive strength improvement ratio is 33.60%, and Structural efficiency is 9.50 % higher in slurry infiltrated fiber-concrete with Metakaolin as compared with fly ash based slurry infiltrated fiber concrete at the 4% replacement ratio of hook ended steel fibers by volume.

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