SORPTIVITY OF SLURRY INFILTRATED FIBER CONCRETE CONTAINING FLY ASH AND METAKAOLIN

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ABSTRACT. This paper observed the effects of replacement of fly ash and metakaolin on slurry infiltrated fiber concrete (SIFCON). Six series of test specimens were prepared using hook ended steel fiber with 4% volumes fractions along with 0 to 10 % fly ash, metakaolin replacement and one set of samples without fibers as a control specimen. All procedures on concrete subjected to fresh and hardened properties. For mechanical properties of concrete, compressive strength and durability properties performed using the sorptivity test. Fresh properties were appraised using Slump flow, L-Box, and T-50 tests. A fresh property does not show the significant effect of changing Metakaolin to fly ash replacement. Metakaolin replacement along with 4% fibers showed that 8.11% compressive strength improvement as compared to fly as a replacement along with 4% fibers. Sorptivity result for Metakaolin blend slurry infiltrated fiber concrete showed improvement over fly ash blend slurry infiltrated fiber concrete.

Keywords: SIFCON, Sorptivity, slurry, compressive strength, Metakaolin, fly ash

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INTRODUCTION

As per recent revision of ACI 318-08[1] has been specified that concrete used in structures must ensure high durability, as presented by water to binder/powder ratio(W/B). The durable concrete structure defined to equilibrium conditions during consideration of design, without deterioration, failures over the earlier life of the structures. The word durability describes the resistance offered by concrete to a variety of physical and chemical attacks due to internal or external, natural or human-made causes [1].

The use of mineral admixture as Metakaolin and fly ash – highly reactive pozzolanic materials is a comparatively effective way of improving durability properties. The durability of concrete construction is thoroughly related to the porousness of the surface layer, the one that would limit the ingress of constituents which will initiate or transmit probable destructive actions (CO2, chloride, sulfate, water, oxygen, alkalis, acids). In observing, durability depends on the material selection, concrete composition, furthermore as on the degree of supervision throughout placing, compaction, finishing, and curing.

Now a day's durability of concrete is a significant issue, from this point of view durability measurement of concrete is another critical part. Many methods are available to measure the durability of concrete. Slurry infiltrated fiber concrete, viz.. SIFCON is a one of ultra-high-performance concrete, and this concern need to verify absorption and permeability properties. In this paper primary focus on behavioral changes of SIFCON by using various pozzolanic materials by replacing cement with various percentages along with fiber replacement. In this paper correlate the compressive strength of SIFCON with sorptivity. Sorptivity test measures the rate of penetration of water into the concrete pores by capillary suction [2]. Siddique & Kaur have shown that sorptivity values decreased with increased percentage replacement of Metakaolin up to 15% [3]. Chousidis et al. [4] studied the effect of fly ash on reinforced concrete. The result shows that significant reduction in porosity/sorptivity of fly ash concrete. Badogiannis et al. [5] investigated the durability property using sorptivity, the effect of Metakaolin as a replacement material seems to be essential for the capillary pore system than for the open pore system. The water sorptivity coefficient of UHPC was found to be less than 0.044 $kg/m^2/h^{0.5}$, which is approximately 15 times lower, compared to that of typical HPC investigated by Ghafari et al.2012[6].

Turk et al. [7] presented the results of an investigation on the effect of fly ash and silica fume on compressive strength, sorptivity. They found relationships between the compressive strength and sorptivity are of exponential form whereas the compressive strength and the sorptivity of SCC with FA/SF suggested the presence of an opposite type of relationship between them with R^2 of 0.88 and 0.74, respectively. Aïssoun et al. [8] show that the sorptivity values of the concrete cover are identical to those established for the bulk concrete. Pereira de Oliveira et al. [2] observed the better performance of the self-compacting concrete appraised through the water absorption by capillarity.

Leung et al. [9] presented the results based on experimental tests on SCC mixes with various level of OPC replacement by fly ash, and silica fume reduces the surface water absorption and sorptivity. Sorptivity is a crucial parameter when assessing concrete durability, mainly developing an understanding of water transport process under the unsaturated conditions [10-14]. Bernal et al. [15] presented the result that increasing the MK content of the binder to 20 % again leads to increased water absorption at extended times of CO_2.

EXPERIMENTAL WORK

Materials and Methods

For this research throughout the work, 53 grades OPC used which procured from the locally available market and its typical physical properties given in following Table1. The cement used has been tested for various proportions as per IS 4031-1988 and found to be confirming to various specifications are IS12269-1989.

Table 1 physical properties of cement

PROPERTIES	CEMENT
Fineness	3200 cm^2/gm
Normal consistency	29%
Specific gravity	3.15
Initial setting time	34 min
Final setting time	340 min
Soundness Test	2 mm
Compressive strength (3 days)	28.90 N/mm^2
Compressive strength (7 days)	41.96 N/mm^2
Compressive strength (28 days)	52.46 N/mm^2

River sand used as a fine aggregate which confirming to as per IS 383- 1970. The properties of sand are illustrated in Table 2 and grain size distribution curve for sand as shown in Figure 1. Hook ended steel fiber was used in throughout the research having a length of the fibers 35mm, the diameter of fibers 0.6mm and tensile strength was 1100 MPa according to specification. The constant aspect ratio of hook ended steel fiber maintained in whole research. Locally available fly ash used and Metakaolin outsource for this study from Gujarat state in India

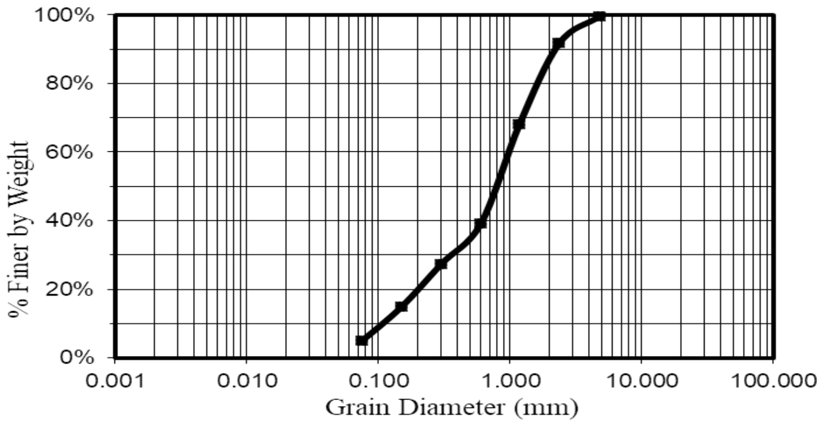

Figure 1 Grain size distribution curve for sand

Table 2 Mix proportion for FASIFCON and MKSIFCON (kg/m^3)

DESIGNATION	WATER	CEMENT	SAND	FLY ASH	FIBER
FASIFCON 054	285.71	678.57	714.28	35.71	314.00
FASIFCON 7.54	285.71	660.71	714.28	53.57	314.00
FASIFCON 104	285.71	642.85	714.28	71.43	314.00
MKSIFCON 054	285.71	678.57	714.28	35.71	314.00
MKSIFCON 7.54	285.71	660.71	714.28	53.57	314.00
MKSIFCON 104	285.71	642.85	714.28	71.43	314.00

Table3 Results of fresh-state tests on the SIFCON

DESIGNATION	SLUMP FLOW TEST		L-BOX TEST H2/H1
	T_{50} (s)	d_f (mm)	
FASIFCON 054	4.5	610	0.91
FASIFCON 7.54	3.5	635	0.91
FASIFCON 104	3.5	640	0.92
MKSIFCON 054	3.0	635	0.91
MKSIFCON 7.54	3.5	620	0.87
MKSIFCON 104	4.0	615	0.92

The hardening properties of SIFCON such as compressive strength for 28 days average water curing period, and sorptivity also determined after 28 days regular water cured sample. Sorptivity testing based on ASTM C 1585-04 consists of subjecting a particular disc-shaped specimen (100 mm in diameter and 50 mm in thickness) to a single exposure to water. To ensure that a uni-directional flow, the remaining surfaces of the specimen that not immersed must be sealed appropriately with a suitable material. The typical SEM images shown for the Control slurry, Slurry with fly ash and slurry with Metakaolin refer the Figure 2 a, b, and c

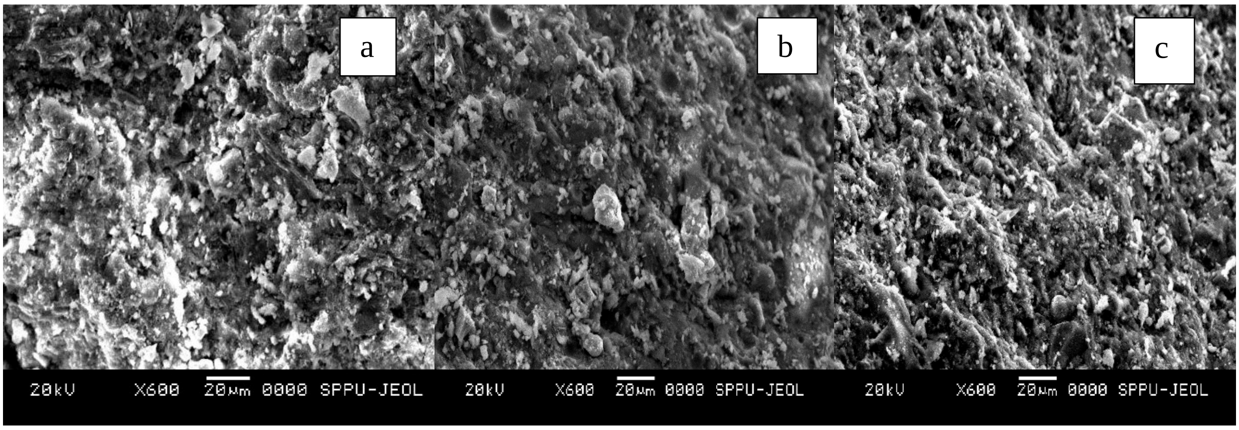

Figure 2 SEM Images for (a) Control Slurry (b) Slurry with Fly ash (c) Slurry with Metakaolin

Mix Proportioning

Six series (FASIFCON and MKSIFCON) of slurry infiltrated fiber concrete mixes prepared. The exact mix proportions presented in Table 2, and 4. FASIFCON, i.e., fly ash-based slurry infiltrated fiber concrete compare with control concrete specimen. MKSIFCON, i.e., Metakaolin based slurry infiltrated fiber concrete compare with control concrete sample. Finally, compare the sorptivity properties of MKSIFCON and FASIFCON.

Mixing and Placing

The process of making SIFCON is different, because of high steel fiber content. While in SFRC the steel fibers are mixed intimately with wet (or) dry mix of concrete, erstwhile to mix being poured into forms. SIFCON made by infiltrating low viscosity cement slurry into a bed of steel fibers "pre-packed" in forms (or) molds. Typical casting procedure of SIFCON specimen as shown in Figure 3.Mix design of SIFCON performed by fundamental of packing density approach and standard mix design illustrated in Table 2. & 3. Fresh properties of a slurry of SIFCON, i.e., workability properties, using slump flow test and L-Box test to knowing flowability and passing ability of slurry because the preplaced methodology used in the procedure of placing of concrete of SIFCON. Their typical fresh properties of SIFCON slurry given in Table 4.

Figure 3 Casting of SIFCON specimen

EXPERIMENTAL RESULT AND DISCUSSION

The result of Fresh SIFCON Slurry Test

The mixes samples designed such that the concrete possesses the UHPFRC properties notwithstanding the presence of fiber. Based on the rate, which is at least 0.8, L-box and slumps flow test was performed to evaluate the passing ability, and flowability or flowing and blocking of the concrete can be estimated.

The results of physical property assessments of the concrete presented in Table 4. At the constant 4 % of volumetric replacement of fiber in all sample of SIFCON. The effect of fly ash and Metakaolin replacement shows the lesser impact on the value of H_2/H_1 as blocking ratio is then reported. In the case of fly ash replacement flowability of SIFCON shows more as compared to Metakaolin replacements as shown in the Table 4.

Hardened SIFCON Test

Compressive strength

The results gained from the compressive strength test at 28 days, and with different % replacement of fly ash and Metakaolin is shown in Figure 4. The average compressive strength of reference mix (Control) was equal to 56.28 MPa which for other mix designs fly ash group (FASIFCON054, FASIFCON7.54, and FASIFCON104) has reached to 72, 81.3 and 90.6 MPa, respectively. Metakaolin group (MKSIFCON054, MKSIFCON7.54, and MKSIFCON104) has reached to 85.3, 95.5 and 98.6 MPa, respectively.
As shown in the Figure 4 percentage changes are compared to the control mix. As it can observe in this figure, the percentage reduction in mix designs fly ash group (FASIFCON054, SIFCON7.54, and FASIFCON104) has been equal to 5%, 7.5%, and 10% respectively.Metakaolin group (MKSIFCON054, MKSIFCON7.54, .MKSIFCON104) has been equal to 5%, 7.5%, and 10% respectively, in comparison with control mix. For example, containing 4% hook ended steel fiber; we observed that at the 10 % replacement level of fly ash and Metakaolin compressive strength slightly increased.

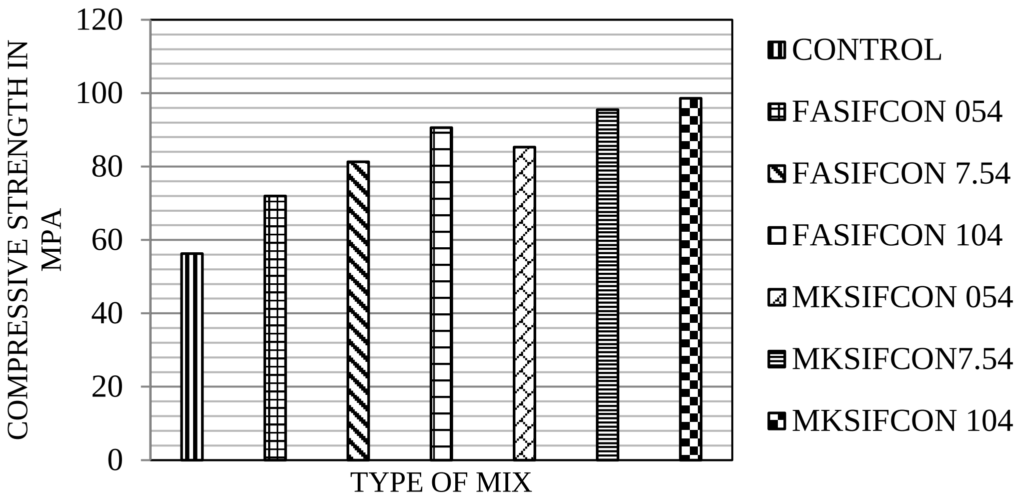

Figure 4 Compressive strength of slurry infiltrated fiber concrete

Sorptivity of SIFCON (Slurry Infiltrated Fiber Concrete)

The Sorptivity test performed as per ASTM C 1585-04 [16]. In the present study, 50 mm thick sample was cut from the top of a 100 mm diameter cylinder as shown in the Figure 4. The values of sorptivity stated with an accuracy of ±0.00005-cm^3/cm^2. $S^{1/2}$. The extreme values were lower than 0.002 $cm^3/cm^2.s^{1/2}$.

According to endorsements offered by the Concrete Society Working Halls [17, 18], sorptivity values lower than 0.005-$cm^3/cm^2.s^{1/2}$ can relate to mixtures with tolerable durability [17, 18]. All through the sorptivity test, the mass of each specimen was measured at several times using an electronic balance. From the increase in mass of the sample due to water absorption (denoted by Mt), the absorption, (I), was calculated as the change in mass divided by the product of the area of the specimen (A) and the water density (ρ). It is estimated by using the following Eq. (1)

$$I = \frac{M_t}{A \times \rho} \tag{1}$$

In general, the absorbed volume of SIFCON specimen of water per unit area of inflow surface would increase with the time as a root function of the time t. After the beginning of the sorptivity assessment, as given by the following Eq. (2), where k is that the sorptivity coefficient of the SIFCON specimen.

$$I = k\sqrt{t} \tag{2}$$

To determine concrete sorptivity S, by the mass method the mass M_t of water which penetrated into the specimen under the capillary forces through the surface area A at time t should be measured. Water penetrates through one of specimen's whole surface plane (e.g., the bottom surface of the cylindrical sample), and the movement of penetration is unidirectional. The relation is approximately linear:

$$M_t = A \times S \times t^{0.5} \tag{3}$$

Relations among water absorption and compressive strength

Table 4 shows the compressive strength and absorption of SIFCON with fly ash and Metakaolin, from the table water absorption, decreased with increased the compressive strength.

Water absorption is inversely proportional to compressive strength from the data interpretation of table.4. 10% Metakaolin with 4% of hook ended steel fiber, i.e., MKSIFCON 104 shows that 19.23% lesser water absorption as compared with FASIFCON, i.e., 10% Fly ash with 4% of hook ended steel fiber. Water absorption performed on 28 days water cured oven-dried sample and calculated as per equation (4), in this equation where w_1 is oven dry weight of cylinder in grams and w_2 is the wet weight of cylinder in grams

$$\%\, Water\ absorption = \frac{[w_2 - w_1]}{[w_1]} \times 100 \tag{4}$$

Table 4 Compressive strength and water absorption of SIFCON

SR. NO.	TYPES OF MIX	COMPRESSIVE STRENGTH IN (MPA)	WATER ABSORPTION (%)
1	Control	56.28	2.19
2	FASIFCON 054	72	1.62
3	FASIFCON 7.54	81.30	1.25
4	FASIFCON 104	90.6	0.525
5	MKSIFCON 054	85.3	0.564
6	MKSIFCON 7.54	95.5	0.462
7	MKSIFCON 104	98.6	0.424

The relation between the rate of water absorption and time

Figure 5 shows that relationship between the rate of absorption and time, in this figure initial water absorption consider up to 6 hours and after the first day consider as secondary absorption.

From fitting of the curve seven individual equations obtained for calculating sorptivity of SIFCON the comparison is tabulated in following table 5. according to ASTM C 1585-04[16] and equation state as follows: initial absorption (point measured up to 6hrs, secondary absorption after the first day)

$$I = S_i\sqrt{t} + b \tag{5}$$

Table 5 Initial and final absorption of SIFCON

SR. NO.	TYPES OF MIX	INITIAL ABSORPTION	SECONDARY ABSORPTION
1	Control	$y = 0.0033x - 0.0101$	$y = 0.0006x + 0.355$
2	FASIFCON 054	$y = 0.002x - 0.004$	$y = 0.0005x + 0.237$
3	FASIFCON 7.54	$y = 0.0024x + 0.0038$	$y = 0.0003x + 0.267$
4	FASIFCON 104	$y = 0.0007x + 0.0108$	$y = 0.0001x + 0.0802$
5	MKSIFCON 054	$y = 0.0009x + 0.0083$	$y = 0.0001x + 0.0725$
6	MKSIFCON 7.54	$y = 0.0007x + 0.0108$	$y = 0.0002x + 0.0801$
7	MKSIFCON 104	$y = 0.0007x + 0.0079$	$y = 0.0002x + 0.0701$

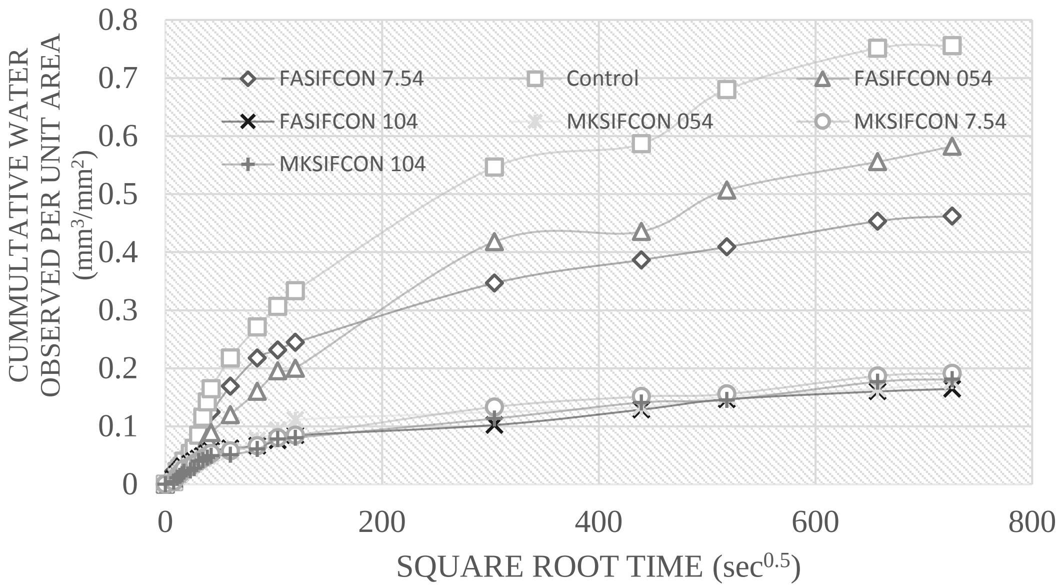

Figure 5 Typical result of water absorption as a function of square root of time

Correlation between Compressive strength and Sorptivity of SIFCON

This procedure was made to correlate the compressive strength to the sorptivity coefficient of SIFCON. Least squares method of regression analysis using was carried out based on the experimental data of compressive strength at 28 days, SIFCON mixtures with MK/FA. In statistical analyses, each mix data of SIFCON with MK/FA were separately used to find the regression line. The coefficients of the exponential regression equation with the correlation coefficient for the relation among compressive strength, sorptivity of SIFCON specimens given in Figure 6.

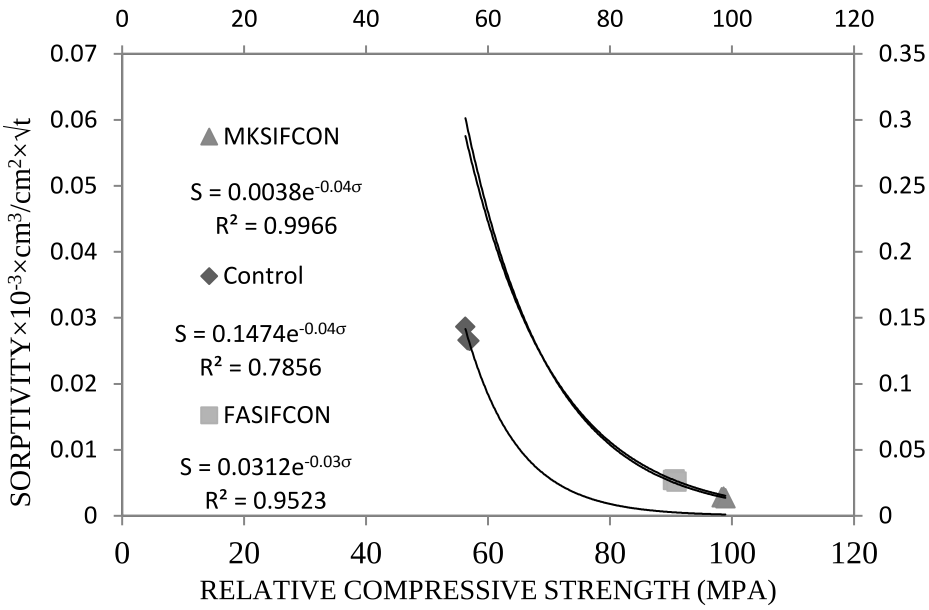

Figure 6 Correlation between compressive strength and sorptivity coefficient

It observed from Figure 6 that the relation is of exponential form for the association between both compressive strength-sorptivity. The compressive strength and the sorptivity of SIFCON with MK/FA suggested the presence of an opposite type of relationship between them; the higher the compressive strength, the lower the water absorption (19). The correlation coefficient between the sorptivity coefficient and compressive strength for SIFCON with MK and FA was R^2 of 0.99, 0.95 respectively suggesting a good correlation between them while the data obtained from control mixtures exhibited more scatter with R^2 of 0.78(see Figure 6).

Porosity and sorptivity

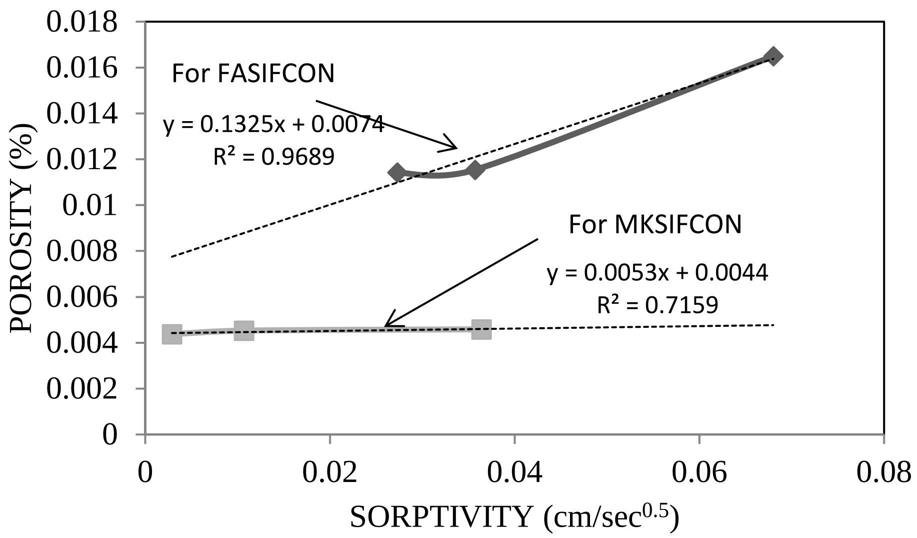

Figure 7 The relation between sorptivity and porosity

Figure 7 shows that linear relationship between sorptivity and porosity, in FASIFCON and MKSIFCON similar relationship is obtained but in MKSIFCON lesser R squared obtained as compared to FASIFCON.

CONCLUSION

By an experimental outcome presented in the research article, the following findings have summarized:

1) The addition of 4% hook ended steel fibers with fly ash, the compressive strength of concrete after 28-d curing was higher and increased sharply with the increment of fly ash content up to 10 %.
2) The addition of fly ash with 4% steel fibers minimized the sorptivity of SIFCON in 28-days of curing.
3) From regression analysis, good correlation shows that for MKSIFCON104 as compared with FASIFCON104.

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