EXPERIMENTAL STUDIES ON SLURRY INFILTRATED FIBROUS CONCRETE (SIFCON) USING M-SAND

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The current research was carried out on the effect of natural sand replaced by manufactured sand (M-sand) in fibrous concrete infiltrated with slurry under static and impact loading. The compressive strength, split tensile strength and impact strength of Slurry infiltrated fibrous concrete (SIFCON) with partial replacement of river sand by M-sand. Hooked end steel fibres of 10% by volume fraction and a constant slurry mix of 1:1 with water cement ratio of 0.4 were used. The low velocity impact response is conducted on 150 mm and 60 mm high cylindrical specimen diameters using the drop weight impact test device as per ACI Committee 544-89. By dropping a steel ball of 4.5 kg with a falling height of 457 mm with the use of a self-manufactured drop-hammer impact test setup, the replication of a low-velocity impact on the cylinder was achieved. The test results show that the strength and energy absorption capacity of SIFCON with 50% of natural sand substituted by M-sand significantly improved compared to all other replacement of M-sand. It was found that optimum replacement level of river sand by M-sand as 50%. Regression analysis has been developed from the experimental results to predict the first crack and ultimate energy absorption capacity of SIFCON. The analytical values from the regression model are well correlated with the experimental results.

Keywords: *SIFCON, M-sand, Energy absorption, Ductility index and Regression analysis*

1. Introduction

Slurry infiltrated fiber concrete (SIFCON) is an especially new composite material the usage of metallic fibers in a cement-primarily based matrix. It differs from conventional metal-fiber-strengthened concrete (SFRC) in which the metal fibers are added at once to an ordinary concrete blend inside the ratio of 0. 5 to at least one. 5 percent thru extent. While, SIFCON includes metallic fibers in the sort of 5 to 20 percent by using the use of extent. The fiber bed is then infiltrated with a low viscosity cementitious slurry. **Sudarsana Rao H.** [1] examined the energy absorption capacity of SIFCON slab containing three different fibre volume subjected to impact loading and concluded that the energy absorption of reinforced SIFCON at first crack and ultimate stage were superior than unreinforced SIFCON slab and also observed that the SIFCON containing 12% of fibre content exhibits excellent impact resistance than all other slabs. **Sudarsana Rao H.** [2] investigated the response of restrained SIFCON two-way slabs under flexure. The results showed that the energy absorption capacity and ductility characteristics are higher when compared to conventional RCC and FRC specimens and also SIFCON containing 12% of fibre content exhibits excellent performance than 8% and 10% of fibre volume. **Sudarsana Rao H.**[3] studied the performance of simply supported two way SIFCON slab in flexure under monotonic and cyclic loadings. Test results revealed that the ultimate loading carrying capacity, stiffness and ductility characteristics of SIFCON slabs are higher than plain cement concrete and fibre reinforced concrete. Also observed that the crack width lesser crack width in SIFCON compared to FRC slab subjected to cyclic loading. **Sudarsana Rao H.** [4] studied the performance of two way SIFCON slabs containing three different fibre volume in punching shear and the results revealed that the SIFCON slabs exhibits superior punching shear carrying capacity than FRC and RCC. It was concluded the punching shear strength, stiffness, loading carrying capacity with greater deflection increased with increased volume of fibre. **Elavarasi D.** [5] studied the performance of slurry-infiltrated fibrous concrete (SIFCON) slabs with and without conventional reinforcement subjected to impact loading. The test results showed that the energy absorption capacity and crack resistance of SIFCON slab with conventional reinforcement showed high than unreinforced SIFCON, RCC and PCC slabs. **V.S.Parameswaran** [6] studied the flexural performance of mortar reinforced with high volume of steel fibre. It was concluded that the SIFCON containing 8% fibre volume exhibits excellent ductility, resistance against cracking and spalling effect. It also found that the SIFCON specimen able to sustain a high load with large deflection under

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cyclic loadings. **Farnam Y.** [7] examined the performance of Slurry Infiltrated Fibre Concrete (SIFCON) subjected to tri-axial compression and concluded the peak stress, poison's ratio, energy absorption and durability were increased with increasing the volume of fibre content. **Trilok Gupta** [8] studied the impact resistance of containing waste rubber fibre with silica fume and concluded that the impact resistance and ductility were significantly improves with addition of waste rubber fibres with incorporation of silica fume. **Semsi Yazıcı** [9] investigated the influence of fibre content and aspect ratio on mechanical properties of fibre reinforced concrete subjected to impact loading and concluded that the loss of mechanical properties was significantly decreased in FRC compared to non-fibrous concrete. **Chakradhara Rao** [10] examined the impact resistance of recycled aggregate concrete and concluded that the displacement was increased with increasing the replacement level coarse aggregate by recycled aggregate and decreased the stiffness and impact resistance compared to conventional concrete. **Feng Liu** [11] studied the impact resistance of rubber reinforced concrete and concluded that the static compressive of RRC with larger diameter of rubber is higher than RRC with smaller diameter of rubber. It was also found the energy absorption capacity of RRC increases with increased fibre content upto 10%. **Wenjie Wang** [12] investigated the performance of coconut fibre reinforced concrete subjected to impact loading. The test results showed that the impact strength of coconut fibre length of 25mm and 50mm performed better than 75 mm length of coconut fibres. **Senthil vadivel** [13] studied experimentally the behaviour of waste rubber tyre aggregate concrete under impact loading and found that the 6% replacement of waste rubber for fine and coarse aggregates improves the ductility and impact resistance. **Murnal P. B**. [14] investigated fibre reinforced concrete subjected to impact loading and concluded that the impact resistance was increased due to addition of steel fibres to concrete. **Trevor D. Hrynyk** [15] examined the behaviour of steel fibre reinforced concrete slabs under impact load and found that the R/FRC slabs demonstrated superior performance when compared to non-fibrous RC slabs under impact loading. **Minsheng Guan** [16] examined the performance of axial loaded circular steel tube short column filled with M-sand concrete and concluded that the reduction of diameter to thickness ratio increased the axial compressive strength. **Huajian Li** [17] studied the influence of granite dust on strength and durability of manufactured sand. The test results revealed that the replacement of 20% of total cementitious materials showed better mechanical properties, durability and shrinkage performances.

The usage of concrete in the construction sector is very high, the construction industry will be affected due to non-availability or shortage of river sand for manufacturing of concrete. There is a necessity to identify the alternative materials such as quarry dust, bottom ash, copper slag etc. are partially or fully replaced for river sand. The main focus of the research work is to investigate experimentally the effect of natural sand replaced by M-sand in slurry infiltrated fibrous concrete subjected to static and impact loadings.

2.Experimental investigation

2.1.Materials used

2.1.1. Cement

Ordinary Portland grade 53 cement conforming to IS 12269-1987 [18] was used. Table 1 shows the physical properties of the cement used. All the results were meeting the requirements as the standard specifications.

Table 1

Cement properties

Details of test performed	Results
Standard consistency	36 %
Specific gravity	3.1
Initial setting time	30 min.
Final setting time	300 min.
Fineness test	1 % of residue

Table 2

Properties of Natural sand and M-sand

S.No.	Properties	Results	
		Natural sand	Manufactured sand
1.	Specific Gravity	2.62	2.54
2.	Density	1696 kg/m^3	1791 kg/m^3
3.	Water absorption	1.37 %	2.26 %
4.	Fineness Modulus	2.39	2.75
5.	Shape	Rounded	Angular
6.	Grading of Sand	Zone III as per IS 383	Zone II as per IS 383

2.1.2 Fine aggregate

Fine aggregates conforming to grade III as per IS 383-1970 have been obtained from a local source is used. The properties of fine aggregate are examined as per IS 2386-1975 [19] and given in the Table 2.

2.1.3 Manufactured sand

Manufactured sand particles size less than 4.75mm was used. It confirming to Zone II as per IS: 383-1970 is used. The physical properties are tested and the results are given in Table 2 in accordance with IS: 2386-1975 [19].

2.1.4 Steel fibre

Hooked end steel fiber of diameter 1.00 mm and length of 30 mm giving aspect ratio of 30 was used. The Hooks at the ends provide better bond with the matrix. This Controls cracking which occurs in the hardened state. The fiber is oriented in random manner. The mechanical properties of steel fiber are given in Table 3.

Table 3

Properties of steel fiber

S.No.	Fiber Properties	Fiber Details
1	Length (mm)	30
2	Size/Diameter (mm)	1.0 mm dia.
3	Aspect Ratio	30
4	Density Kg/m^3	7850
5	Young's Modulus (GPa)	210
6	Tensile Strength (MPa)	1056
7	Shape	Hooked ends

2.1.5 Water

Fresh water with a pH value of 7 available from local sources according to IS 456-2000[20] is used for mixing and curing.

2.1.6 Chemical admixture

CONPLAST SP430 super plasticizing admixture with sulphonated naphthalene polymers is used. for improving infiltration or penetration ability of slurry or mortar into the fibre bed.

2.2 Mix proportions

The method of fabrication of SIFCON is differs from steel fibre reinforced concrete. SIFCON is prepared by infiltrating cement slurry or mortar into the preplaced fibre bed in moulds. The matrix in SIFCON has high cementitious content and coarse aggregate is omitted. The unit weight of SIFCON is higher than conventional FRC, because of high volume of fibre content. The unit weight of SIFCON ranges between 2150 kg/m^3 to 3150 kg/m^3 for steel fibre content ranges from 5 to 20% by volume fraction. The mix proportions of SIFCON with varying replacement of river sand by M-sand are presented in the Table 4. The mix proportion of cement slurry is 1:1 and w/c ratio of 0.40 with a constant fibre volume of 10%

2.3 Mixing, placing and compaction

The ingredients are thoroughly mixed with the required quantity of water to get a uniform mix. Superplasticizer (CONPLAST 420) is added to the slurry during mixing for improving infiltration capacity, and viscosity of slurry flow into a bed of preplaced fibres. During the placement of fibres, external light vibration has to be done, and the packing density of fibre is controlled by aspect ratio and fibre length. Then, the slurry is poured into the pre-packed fibre bed with subsequent infiltration of the mortar or slurry by using the vibrator. Compaction was done simultaneously to ensure the depth of penetration of slurry to the full extent by using an external vibrator or manual compaction. The workability test (Flow table) is carried out on the flow properties of cement mortar with partial replacement of manufactured sand (0, 25, 50, 75 & 100%).

2.4 Testing of the specimens

After 24 hours of casing, the specimens were demoulded and cured in water for 28 days. The specimens were taken out from curing, clean the surface moisture and kept in room temperature for 24 hours and the specimens were tested.

2.4.1 Compressive strength

The compressive strength was conducted on a cube size of 100 x 100 x 100 mm as per BS 1881-116 [21], using a computerized compression testing system with a capacity of 3000 kN. The load is applied gradually at a rate of 140 kg/cm^2/min. till the failure of the specimens.

2.4.2 Split tensile strength

On cylinder specimens with a diameter of 100 mm and a height of 200 mm, the tensile strength was carried out in compliance with ASTM C496-96[22] using a computerized compression test system with a capacity of 3000 kN. The specimens were maintained in a horizontal position. Until the cylinder fails, the compression load is distributed uniformly and diametrically along the length of the cylinder.

2.4.3 Impact test setup

The drop weight impact testing setup was manually generated, according to ACI Committee 544.2R-89[23] for testing of slab subjected to impact loading. as shown in Fig. 1. It consists of a

Table 4

Mix proportions of SIFCON with different percentage of M-sand

Replacement of M-sand (%)	Fibre content	Cement kg/m^3	Sand kg/m^3	M-sand kg/m^3	Water lit./m^3	Fibre kg/m^3	SP kg/m^3
0	10	950	950	-	380	785	19
25	10	950	712.5	237.5	380	785	19
50	10	950	475	475	380	785	19
75	10	950	237.5	712.5	380	785	19
100	10	950	-	950	380	785	19

steel ball weighing 4.5 kg connected to a steel wire that moves over a frictionless pulley. The SIFCON cylinder's low velocity impact response was carried out by the use of drop weight impact loading. The steel ball is dropping from a height of 457 mm hits the specimen exactly at its centre. The number of blows necessary to trigger the initiation of the first crack (N_1) and the final failure (N_2) were recorded through visual observation.

Fig. 1 - Drop weight impact test setup

From the following expressions, the first crack and final absorption of energy was calculated

Energy absorption capacity

$$E = m \times g \times h \quad \text{------} \quad (1)$$

Energy absorption at first crack (E1) = E x Number of blows at first crack

$$E_1 = E \times N_1 \quad \text{------} \quad (2)$$

Energy absorption at ultimate stage (E2) = E x Number of blows required at ultimate stage

$$E_2 = E \times N_2 \quad \text{------} \quad (3)$$

Where

m - Ball mass in kg

g - Gravity-related acceleration = 9.81m/s^2

h – Dropping Height

N_1 and N_2 = Number of blows at first crack and ultimate failure.

For the analysis of post-crack resistance, the impact residual strength ratio (Irs) is helpful and could also be used as a measure of the ductility of the composite imparted by the matrix-integrated fibre. The impact residual strength ratio (Irs) is defined as the following term.

$$I_{rs} = \frac{E_2}{E_1} \quad \text{-------} \quad (4)$$

3. Results and discussion

Results obtained from the numerous tests carried out on the output under static and impact loading conditions of slurry infiltrated fibrous concrete with partial river sand replacement by manufactured sand.

3.1 Fresh properties of Slurry

Workability test (Table 4) was conducted to study the flow ability of cement mortar or slurry with constant mix proportion of 1:1 and water cement ratio 0.40 is presented in the table. The test results showed that the percentage of flow is slightly decreased with increasing the replacement level of manufactured sand.

Table 4

Workability test (Flow table)

Replacement of M-sand (%)	Initial diameter (mm)	Final diameter (mm)	% of flow
0	65	150.6	131.7
25	65	146.2	124.9
50	65	144.8	122.7
75	65	140.3	115.8
100	65	135.5	108.5

3.2 Compressive strength

Fig. 2 shows the compressive strength of SIFCON with varying replacement of river sand M-sand (0, 25, 50, 75 and 100 %). The test results showed that the compressive strength of SIFCON with partial replacement of 50 % M-sand. The compressive strength increased by 10.7% and 14.8% in 25% and 50% of M-sand respectively compared to conventional mix. The optimum dosage is obtained as 50 % of M-sand replaced for river sand. The test results revealed with 50% of natural sand replaced with manufactured sand given the maximum result towards the strength characteristics. It can be attributed due to gradation of fines, angular in shape, smooth surface textures provide better strength to the matrix by reducing voids, bleeding, and segregation. The compressive strength of SIFCON gradually decreased beyond 50% of M-sand replaced for natural sand due to reduction in infiltration of slurry into the fibre bed. It was concluded that the compressive and split tensile strength of the SIFCON had improved through better bonding by using manufactured sand.

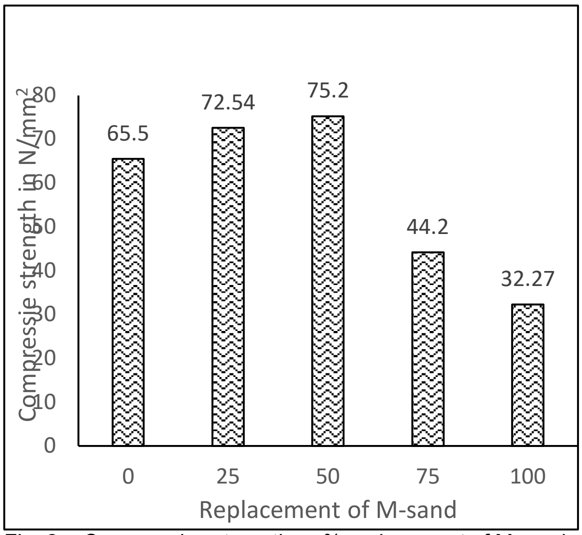

Fig. 2 - Compressive strength vs % replacement of M-sand

3.3 Split tensile strength

Fig.3 shows the split tensile strength of SIFCON containing 10 % of the fibre volume with partial replacement of river sand by M-sand. The split tensile strength of SIFCON with the addition of M-sand significantly increased by 44.6%, 52%, 41.6% and 25.7% at replacement levels of 25%, 50%, 75% and 100% respectively compared to SIFCON without M-sand. The split strength was maximum at 50% of M-sand partially substituted for natural and concluded that the replacement of river sand by 50% of M-sand is optimum dosage for SIFCON.

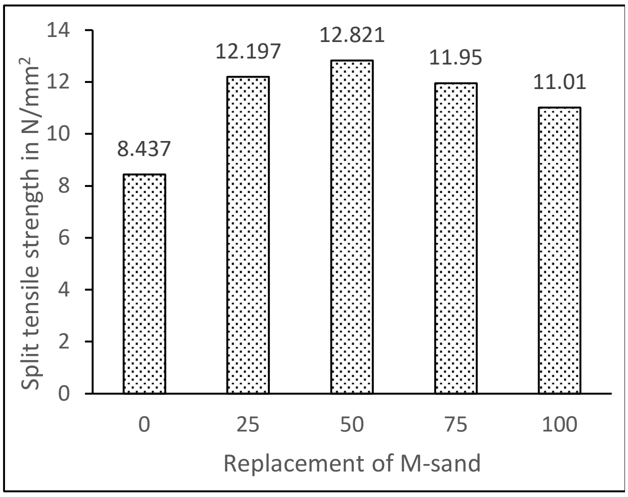

Fig. 3 - Split tensile strength vs % replacement of M-sand

3.4 Energy absorption at first crack and ultimate failure

The energy absorption capacity was determined at the first crack and final point, from the number of blows required to cause the first crack and ultimate failure. The total number of blows required to trigger the initiation of first and ultimate failures were recorded. The energy absorption capacity of SIFCON at the initiation of the first crack and ultimate failure are illustrated in Fig. 4. It is observed that the first and ultimate crack energy absorption capacity of SIFCON were gradually increasing upto 50% of M-sand replaced for river sand. It may have attributed due to good gradation of M-sand enhancing the infiltration capacity of slurry into the fibre bed thus improves the better bond between the matrix. Beyond 50% of M-sand replacement in SIFCON loses its bond strength because of decreasing the workability of the matrix due to angular particle size of M-sand. It is clearly showed that the first crack and ultimate stage energy absorption of SIFCON with partial substitution of river sand by M-sand has been substantially improved at all replacement stages. The addition of M-sand increases the matrix's filler and flow ability, thereby improving the slurry's penetration into the fibre bed. The energy absorption at the initiation of first and ultimate failure of SIFCON mix with partial substitution of natural sand by M-sand increased by 20 % and

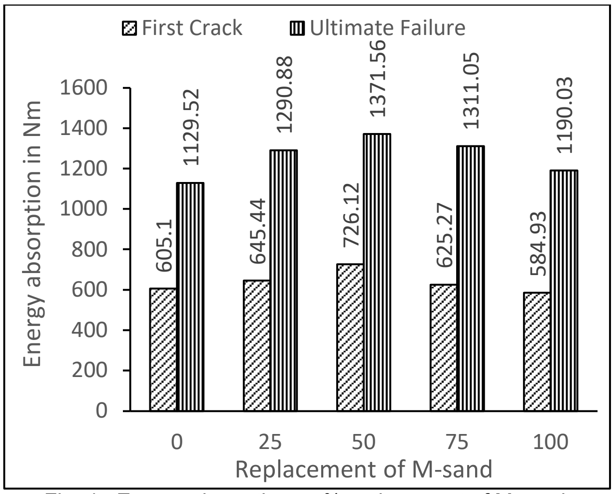

Fig. 4 - Energy absorption vs % replacement of M-sand

21.4 % respectively compared to conventional mix.

3.5 Impact residual strength ratio

Fig. 5 illustrated the ductility indices of various mixes. From the test results clearly showed that the ductility indices were decreased due to increasing replacement of M-sand.

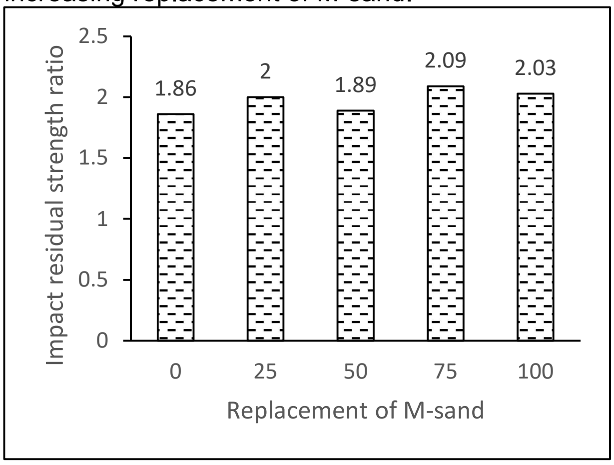

Fig. 5 - Impact residual strength ratio.

It was found that the maximum ductility index was obtained at 75% of M-sand replaced for river sand in SIFCON compared to all other replacement levels. The ductility index was getting increased with addition of M-sand in SIFCON. This can be due to the better bond between the matrix and the fibres.

3.6 Post crack resistance ratio

The post crack resistance of SIFCON with different replacement level of natural sand by M-sand are shown in Fig. 6. The post crack resistance is the ratio between the difference in ultimate and first crack energy to the first crack energy. The first crack energy absorption was higher in SIFCON with addition of 50% M-sand reduces the post crack resistance ratio. The test results clearly showed that the percentage post crack resistance increases with increasing the replacement level of M-sand in SIFCON.

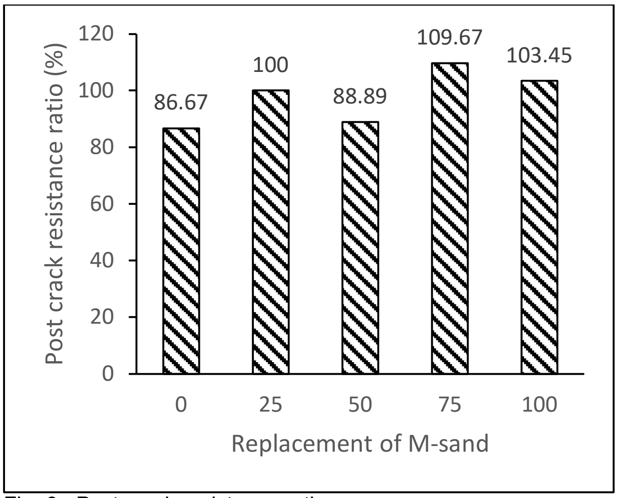

Fig. 6 - Post crack resistance ratio.

The maximum post crack resistance attained at 75% of M-sand replaced for river sand in SIFCON.

3.7 Regression Analysis for Energy absorption

In order to estimate the energy absorption at the initiation of the first crack and ultimate failure, the regression model was built from the experimental results. A multiple regression methodology was formulated for the development of the energy absorption capacity model. The equation of polynomial regression can be written in the following equation (5).

$Y = AX^2 + BX + C$ ------- (5)

Where,

Y is dependent variable

X is independent variable and

A, B and C are coefficients of regression.

Regression coefficients were formulated in line with the least square method principle. The energy absorption and eventual failure at the start of the first crack is measured in the following terms.

First crack energy absorption capacity (E_1),

$Y = -0.0392\,X^2 + 3.6767X + 600.49$ ------ (6)

Energy absorption at ultimate stage (E_2)

$Y = -0.0807X^2 + 8.6328X + 1129.5$ --------- (7)

The first crack and ultimate stage energy absorption potential of SIFCON was determined from the polynomial regression equations (6 & 7). The energy absorption at the start of the first crack and the ultimate failure from regression model were formulated with the experimental findings. Fig. 7 shows the relationship of the test results with the regression model. It has been found that the expected values are well correlated with the experimental values.

4. Conclusions

The following conclusions were drawn on the effect of M-sand substituted for natural sand in SIFCON subjected to static and impact loadings on the basis of the experimental results.

- It is observed that the usage of manufactured sand is well recognized for fabrication of SIFCON, because it will help in maintaining the ecological balance.
- The maximum compressive strength attained at 50% of M-sand replacement in SIFCON containing 10% fibre volume than all other replacement level.
- The split tensile strength was higher at 50% of natural sand replaced by M-sand in SIFCON matrix compared to all other mixes.
- SIFCON's first crack and final stage energy absorption potential with 50 % of M-sand substituted for natural sand showed higher levels than all other substitution levels.
- The impact residual strength ratio was significantly improved at all replacement level of M-sand compared to control mix. The higher

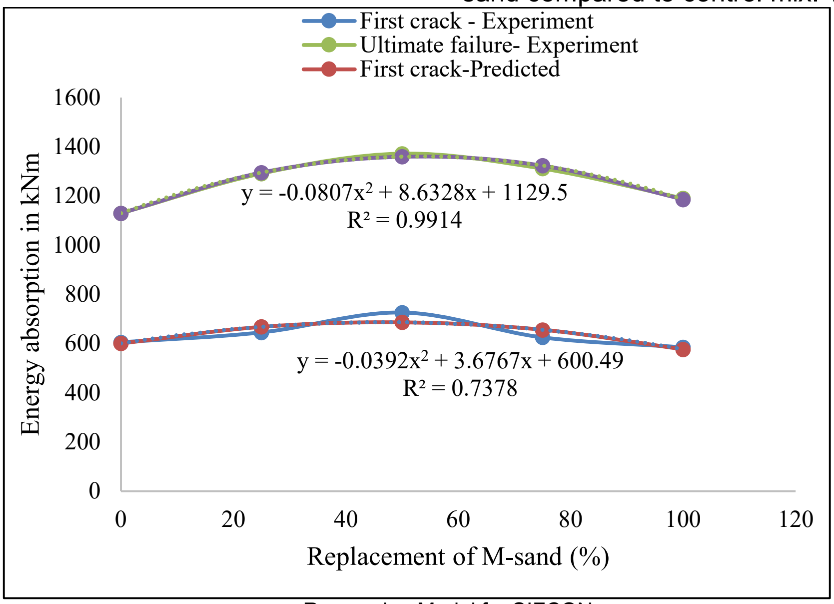

Fig. 7 - Regression Model for SIFCON

ductility index was obtained at 75% of M-sand replaced for natural sand.

- The post crack resistance ratio of SIFCON with addition of 75% of M-sand is higher than that of all other mixes.
- It was concluded that the river sand can be partially replaced by M-sand for manufacturing of concrete to conserve the natural resources. It is also found that the SIFCON with 50% of M-sand showed better strength and impact resistance than control mix.
- Based on the test results found the optimum replacement level of river sand by 50% of M-sand in SIFCON.
- In order to estimate the first crack and ultimate stage energy absorption capacity, the regression model was developed. The predicted values are well associated with the experimental findings.

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