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Behavior of Steel Fibre Reinforced Concrete subjected to Impact Loads

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ABSTRACT: Steel Fibre Reinforced Concrete (SFRC) is now a well-established construction material because of its superior resistance to cracking and crack propagation. It can hold the matrix together even after extensive cracking and these fiber composites possess increased extensibility and strength.
In this research, extensive laboratory investigations have been undertaken to study the effect of concrete with varying steel fibre contents (0%, 0.5%, 1%, and 1.5%) on mechanical, durability & impact properties. SFRC slab specimens of size 600 × 600 × 60mm (with & without reinforcement) were casted, cured and tested for 28days. Plain concrete specimens were also casted and tested for reference purposes. In this paper, the experimental results of SFRC and plain concrete are discussed for M25 Grade of concrete with hooked end steel fibre dosages of 0.5%, 1% & 1.5% by volume of concrete having an aspect ratio of 60. Simulation studies were also carried out for validation using ANSYS & LS-DYNA. The results show that the impact properties of SFRC with varying dosages of steel fibres enhanced in comparison with the conventional concrete & also the experimental results are validated with the simulation results.

Keywords: Steel fibre reinforced concrete, impact test, explicit analysis, compressive strength, split-tensile strength, flexural strength, ANSYS, LS-DYNA

I. INTRODUCTION

In accordance with desires of mankind, the civil engineering applications have been improving. Hence there is a need for more and more innovative materials. Worldwide with an annual production of over seven billion tons, concrete is the most widely used structural material due to its ability to get casted in any form and shape.

Concrete is strong under compression while it is weak under the tension. By making appropriate changes in its ingredients like binding materials, aggregates, water and special ingredients, the strength and the durability of the concrete can be change [1]. Impact is nothing but instantaneous application of load. Impact loading can occur in different types of structures such as reinforced concrete walls and slab when it is struck by the low speed objects accidentally. The impact load in the structure is due to the high loading rate and with a very short period of contact that will cause strain rate. Due to broad range of application, the research on the behavior of reinforced concrete under impact is been motivated as the researchers are not well understood so far. Usually the reinforced concrete structures are designed for static loads, but these structures fail under the impact loads [2]. To advance the performance of reinforced concrete structures exposed to impact loads, suitable work should be undertaken to develop suitable impact resistant design. There is a need to study the behavior under impact load, to discover the feasibility of the concrete for various structural applications.

Steel Fibre Reinforced Concrete (SFRC) obtained by addition of short, discrete steel fibres. The SFRC is now a well-established construction material due to its superior resistance to cracking [3]. The unreinforced concrete may be a brittle material, with a low tensile strength and low strain capability. But due to the addition of steel fibres, concrete acts as a ductile material, providing sufficient tensile strength and strain capacity [4]. The non-uniformly distributed discontinuous steel fibres hold together the cracks that developed initially and progressively under the application of loads. This successively provides ductility, which will simultaneously increase the strength of the concrete [5]. ANSYS and LS-DYNA is the most commonly used explicit simulation program, capable of simulating the response of materials to short periods of severe loading. Its many elements, contact formulations, material models and other controls can be used to simulate complex models with control over all the details of the problem. ANSYS and LS-DYNA has a vast array of capabilities to simulate extreme deformation problems using its explicit solver. Engineers can tackle simulations involving material failure and look at how the failure progresses through a part or through a system. Models with large amounts of parts or surfaces interacting with each other are also easily handled, and the interactions and load passing between complex behaviors are modelled accurately. ANSYS and LS-DYNA can perform simulations of mechanisms involving joints and articulations subjected to impacts (whether from drops or collisions). It can utilize joints and kinematic links and offers a wide choice of contact formulations to easily and automatically consider interactions between all components in the model. When this is combined with LS-DYNA's fast and efficient explicit solver scheme, it gives unrivalled simulation capabilities to study situations that could not be solved using implicit FEA methods.

In this research, experimental studies have been carried out to investigate the effect of varying steel fibres. The concrete slabs specimens of M25 grade were tested under impact for varying proportions of steel fibres i.e., 0%, 0.5%, 1% & 1.5% by volume of concrete and also validated with simulation results using ANSYS and LS DYNA software.

II. LITERATURE BACKGROUND

Jeurkar and Upase carried out experimental studies to understand the behavior of Steel Fibre Reinforced Concrete for M25 Grade [6]. The mechanic properties i.e. Compressive, Flexural and split tensile strength of Steel Fibre Reinforced Concrete are studied. In this experiment Shaktiman crimped steel fibres is used. In this research steel fibre reinforced concrete composition containing 0.5%, 1% & 1.5% fibres by unit weight of concrete were prepared concrete cubes & beams were cast using these fibres reinforced concrete to perform compressive strength & split tensile strength as well as flexural strength respectively. It is observed that there is considerable increment in the compressive strength due to addition of Shaktiman steel fibre at 7 and 28 days of age.

Krishna and Rao [7] conducted experimental studies on Steel Fibre Reinforced Concrete to understand the durability properties of M30 grade of concrete with varying percentage of steel fibres. Fibre dosages of 0.5%, 1%, and 1.5% by volume of concrete were used in the experimental study. Concrete cubes of size 150mm×150mm× 150mm were tested for compressive strength, Resistance to Acid Attack for 28 days, 56 days curing period. Hooked end steel fibres were randomly dispersed in concrete. Steel fibres were found to be effective to acid resistance.

Anes *et. al.* [8] carried out experimental investigation of Steel Fibre Reinforced Concrete subjected to Impact Loading. The study aims with the investigation of impact resistance of Fibre Reinforced Concrete, incorporated with various dosage of steel fibres subjected to sudden impact load. End hook, Crimped and flat steel fibre of length 35 mm and an aspect ratio equal to 80, 50, 77.77, 46.66 were added to concrete in proportion 1.5% with water cement ratio of 0.40. Drop test was performed on conventional concrete slab specimen and steel fibre reinforced concrete slab specimen after 28 days of curing. The experimental results showed that there was increase in number of blows in Fibre Reinforced Concrete with steel fibres compared to the Plain Conventional Concrete. In all the cases of hooked end, crimped and flat steel fibres, there was increase in impact energy at failure compared to the plain concrete specimen. Hooked End Steel Fibre showed slightly greater increase in energy compared to the crimped and flat steel fibres.

Zheng *et. al.,* [9] conducted studies on C50 and C60 steel fiber-reinforced by traditional mixing and vibratory mixing methods and then, the cube compression test, flexural test, splitting tensile test, and the bending tests were carried out. They compared the mechanical properties for traditional and vibratory mixing methods. They observed that vibratory mixing can effectively improve the distribution of steel fibers in concrete and enhance the density and thereby effectively improves the mechanical properties of steel fiber-reinforced concrete when compared to the traditional mixing method.

Bhat *et. al.,* [10] evaluated the compressive strength and split tensile strength of normal concrete (NC), steel fibre reinforce concrete (SFRC),polymer modified concrete (PMC) and polymer modified steel fibre reinforced concrete (PMSFRC) and to determine the percentage increase in strength by the addition of steel fibres and SBR. They observed that the increase in compressive strength in SFRC, PMC, and PMSFRC is 31.98%, 16.93%, and 36.16% in comparison with normal concrete cubes respectively. The increase in tensile strength of SFRC, PMC, and PMSFRC is 38.85%, 21.65% and 47.72% in comparison with normal cylinders respectively. They concluded that mechanical properties enhanced the maximum at 3% steel fibre addition for SFRC. At 15% replacement of cement with SBR, both compressive strength and tensile strength were maximum.

III. MATERIALS AND METHODS

In the present experimental work, studies on strength and durability properties of conventional and steel fibre reinforced concrete with varying fibre dosages were carried out.

The materials used for this experimental study are cement, fine aggregate (M-Sand), coarse aggregate (20mm & 10mm), water, admixture, steel fibres and super plasticizer (FosrocConplast 430).

Cement: Ordinary Portland cement of 53 grade with specific gravity of 3.15, normal consistency 29%, fineness 4%, initial and final setting times of 45 minutes and 540 minutes conforming to IS 12269-1987 was used for the study.

Fine Aggregates: Locally available M-Sand with specific gravity of 2.60, water absorption 7% and confirming to Zone II as per IS 383-1970 was used for the study.

Coarse Aggregates: Crushed granite stones of 20mm size having specific gravity of 2.72, water absorption 0.5% and fineness modulus 5.23 and of 10mm down size having specific gravity 2.70, water absorption 0.5% and fineness modulus 3.77, conforming to IS 383-1970 were used.

Admixtures: Good bye sand was used as an admixture for the concrete mix.

Steel Fibres: In this study, hooked end steel fibres 30mm long, 0.5mm in diameter and with an aspect ratio of 60 with varying dosage of 0%, 0.5%, 1% & 1.5% were used based on literature review.

Mix Design: Mix design of M25 grade concrete was carried out as per IS 10262-2009.

Table 1: Quantity of materials per cubic meter of concrete.

Contents	Values (kg/m^3)
Cement	375
Water	180
Fine Aggregates	693.12
Coarse Aggregates 20mm down	771.39
Coarse Aggregates 10mm down	428.80
Super Plasticizer	3.75
Steel fibre content	0.5%, 1%, 1.5%

The quantity of ingredient materials as per mix design are tabulated in Table 1.

IV. EXPERIMENTAL STUDIES

A. Slump Test

The slump values obtained for conventional concrete and steel fibre reinforced concrete with varying dosages of steel fibers 0.5%, 1%, 1.5% & 2% are 100mm, 80mm, 70mm, 50mm and 35mm respectively and are plotted in Fig. 1.

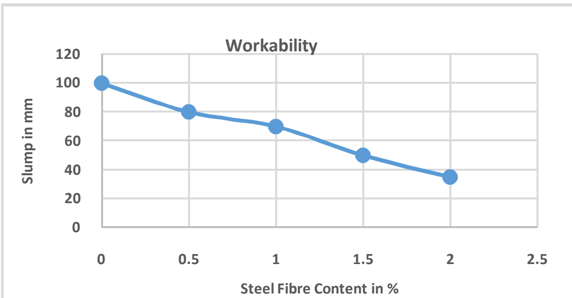

Fig. 1. Slump Test.

It was observed that the workability and consistency of the concrete mix reduced with the increase in the percentage of fibre contents. As the fibers absorb more cement paste to wrap around and there is an increase in the viscosity of mixture, it results in the loss of slump. The reason for lower slump is that adding steel fibers can form a network structure in concrete, which restrains mixture from segregation and free flow.

B. Tests conducted on Hardened Concrete

Compressive Strength and Split-Tensile Strength: A total of 24 cubes of dimension 150 × 150 × 150mm for compression test and 24 cylinders 200mm long and 100mm in diameter for split tensile test were casted and tested on a digital compression testing machine as per IS 516-1959.

Flexural Strength: Beams of dimensions 100 × 100 × 500mm were casted and tested in Flexural testing machine in accordance with IS 516-1959 to determine the flexural strength of concrete with varying steel fibres under three-point loading.

Durability: Acid Attack Test: The concrete specimens of dimensions 150 × 150 × 150 mm for varying dosages of steel fibres were casted, cured for 28 days and dried and weighed. The specimens were immersed in Hydrochloric acid of pH 2 at 5% weight of water for a period of 90 days. The resistance of concrete to acid attack was found by calculating the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in acid water [5].

Sulphate Attack Test: The concrete specimens of dimensions 150 × 150 × 150 mm for varying dosages of steel fibres were casted, cured for 28 days, dried and weighed. The specimens were then immersed in sodium sulphate and magnesium sulphate at 5% weight of water for a period of 90days. The resistance of concrete to sulphate attack was found by calculating the % loss of weight of specimen and the % loss of compressive strength [5].

Porosity: Porosity is the measure of percentage of pores or air voids present in the specimen of dimensions 150×150 × 150 mm. Air dried weight and under water weight were taken and exact dimensions of cubes were measured [5].

Oven Dried Test: The specimens of size 150 × 150 × 150mm were casted, cured for 28days and then kept in oven for one hour at 100°C. The temperature was kept constant. After one hour the cubes were removed from the oven and allowed to cool. Later on the compression strength tests were carried out. The variation in the compressive strength of oven dried cubes were noted.

Impact Test: The impact testing instrument was rigidly fixed to a Reinforced Conventional Concrete pedestal (test foundation) having a height of 1 m above ground level and the pedestal was extended up to 0.6 m giving it total height of 1.6 m, to which a frame of height 2 m fabricated with ISA 75x75x5 mm sections to support the guiding cylinder and pulley is attached. To the top of this frame a friction less pulley was attached centrally. The specimens were rested upon an I section of square frame of 600x600 mm which was made up of ISHB 160 that rests upon the pedestal extension.

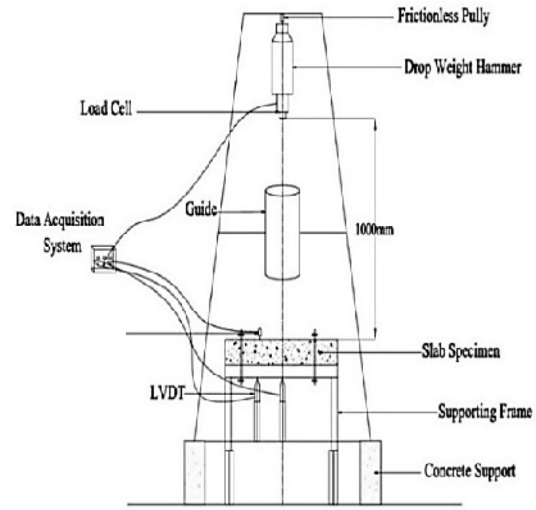

Fig. 2. Impact Testing Instrument.

Test specimens of size 600mm x 600mm with a depth of 60mm for SFRC of varying dosage of 0% - 1.5% were casted for the impact test. Slab specimens were unreinforced and reinforced with 8mm dia bars with 135mm spacing.

The impact tests were carried out by a 10.2 kg hammer with a free drop of 1 m. It has a circular head 70 mm in diameter and 180 mm long. The hammer was positioned vertically, and steel cylinder was used for guiding during impact. The circular hammer is fixed with a 10-ton capacity load cell having a diameter of 55 mm and height of 70 mm. For testing the slab specimens fixed edge condition is considered using two clamps on each side. Two numbers of LVDT's, one at ¼th and one at center of the soffit is attached to the test slab specimens.

C. Simulation Studies

Three dimensional solid elements were used to model the simulation of reinforced and unreinforced concrete slabs in finite element analysis.

Table 2: Simulation Data.

Boundary Condition	Fixed End
Meshing	Hex Dominant
Material Properties	Cylindrical Shell –RIGID Concrete – WINFRITH_CONCRETE Reinforcement – CONCRETE_BEAM
Section Properties	Concrete – SOLID Reinforcement – BEAM Cylinder – SHELL
Initial Velocity	4429mm/sec
Contact Interaction	AUTOMATIC_SINGLE_SURFACE FORCE_TRANSDUCER_PENALTY
Termination Time	0.002secs
Output	BINARY D3CRACK BINARY D3PLOT BINARY D3THDT

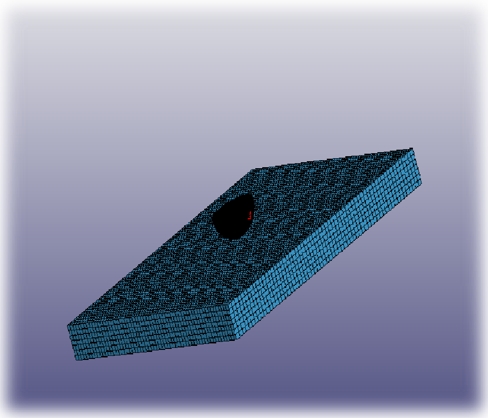

Fig. 3. Slab & shell modelling using LS-DYNA.

The modelling process includes discretized geometry, adding element section properties, assigning loads and boundary conditions, analysis type and output data. The details are mentioned in Table 2. Fig. 3 shows the slab and the hammer model obtained using LS-DYNA.

V. RESULTS AND DISCUSSION

A. Tests on Hardened Concrete

It was observed that, there was a considerable increase in the compressive, split tensile and flexural strengths due to the addition of steel fibers tested for 28 days of age are plotted in Fig. 4.

Compressive Strength and Split-Tensile Strength: The compressive strengths of steel fibre reinforced concrete with varying fibre dosages 0%, 0.5%, 1% and 1.5% when tested for 28 days were found to be 26.26 MPa, 34.21 MPa, 36.61 MPa and 39.12 MPa respectively.

The split-tensile strength values of SFRC with varying fibre dosages of 0%, 0.5%, 1% and 1.5% tested for 28 days were found to be 2.07 MPa, 3.66 MPa, 4.34 MPa and 4.97 MPa respectively.

Flexural Strength: The flexural strength values of SFRC with varying fibre dosages of 0%, 0.5%, 1% and 1.5% when tested for 28 days were 4.49 MPa, 5.68 MPa, 6.13 MPa and 6.79 MPa respectively.

The maximum increase in the strength was observed for 1.5% of fibre dosage due to the increase in fibre content in concrete.

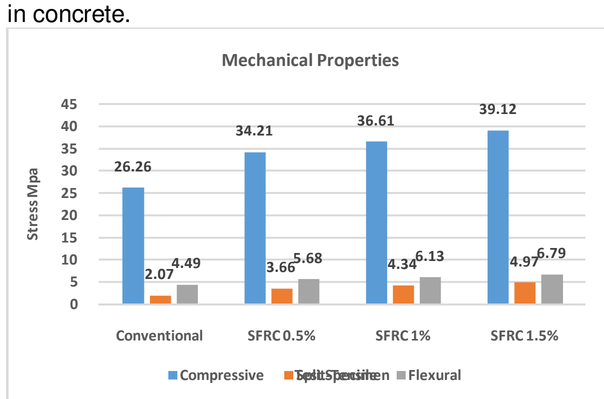

Fig. 4. Mechanical Properties.

Durability: The compressive strength results obtained after the acid and sulphate attack tests conducted on conventional and SFRC with varying fibre dosages are plotted in Fig. 5 & 6.

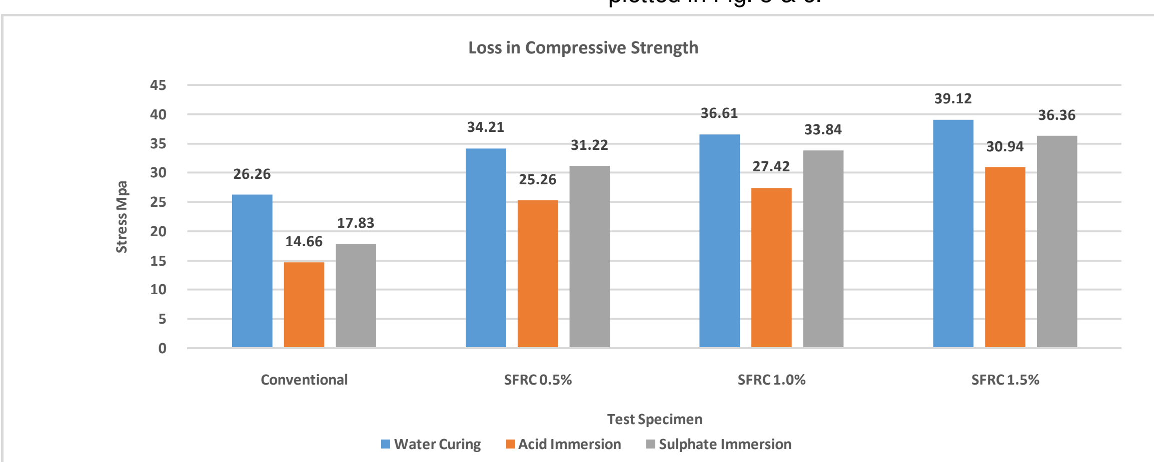

Fig. 5. Compressive strength obtained in durability tests.

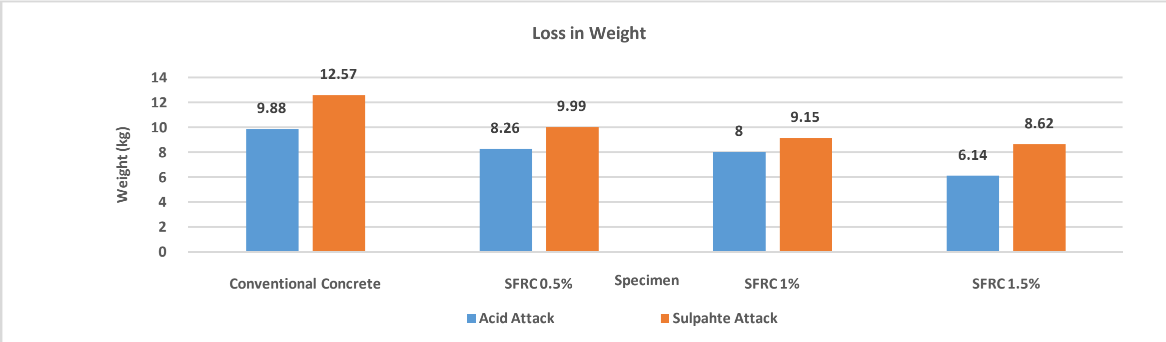

Fig. 6. Loss in weight obtained in durability tests.

Acid attack test: From the experimental test results, it is observed that, when compared to conventional concrete the steel fiber reinforced concrete was more resistant to acid attack, leading to less loss of both the weight and compressive strength for SFRC. It was observed that SFRC with the addition of 1.5% steel fibers by weight of concrete is more resistant to the acid attack compared to other dosages. i.e., due to the addition of higher dosage of steel fibres there is reduced loss in weight and compressive strength of the SFRC specimen with 1.5% dosage compared to other fibre dosage.

Sulphate attack test: When compared to conventional concrete the steel fiber reinforced concrete was more resistant to sulphate attack, leading to both less losses in weight and compressive strength. It was observed that SFRC with the addition of 1.5% steel fibers by weight of concrete is more resistant to the sulphate attack compared to other dosages. i.e., due to the addition of higher dosage of steel fibres there is reduced loss in weight and compressive strength of the SFRC specimen with 1.5% dosage compared to other fibre dosage.

Porosity: There was a considerable reduction in the porosity of steel fiber reinforced concrete when compared to conventional concrete. The percentage porosity values of conventional concrete and steel fibre reinforced concrete with varying fibre dosages of 0.5%, 1% and 1.5% when tested for 28 days were found to be 21.47%, 15.43%, 9.34% & 3.89% respectively. The maximum porosity was found in conventional concrete as shown in Fig. 7.

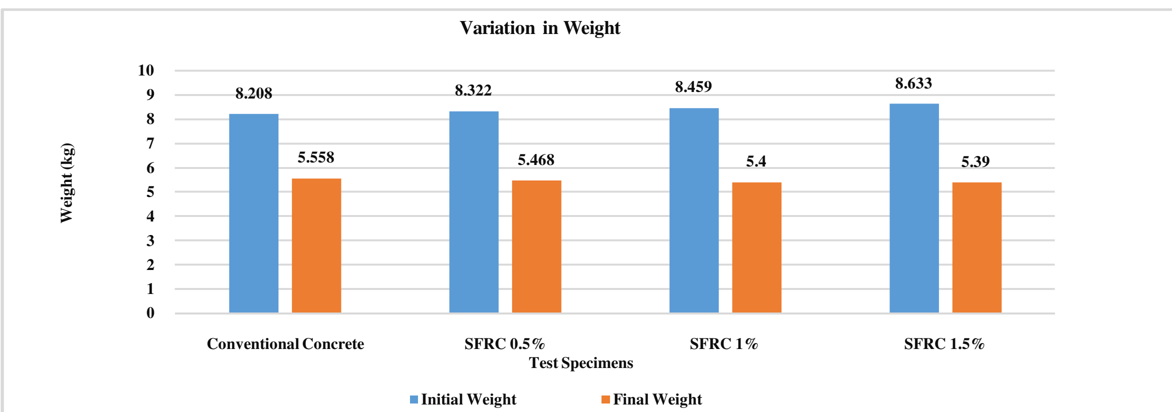

Fig. 7. Variation in weight observed in porosity test.

Due to the addition of steel fibres, the pores in the concrete is reduced i.e., the voids present in the specimens are been filled up by the randomly distributed steel fibres. Hence reducing the percentage porosity in SFRC specimen.

Oven Dried Test: There is a considerable decrease in compressive strength after curing in hot oven for both the conventional concrete and steel fiber reinforced concrete. The compressive strengths of conventional concrete and steel fibre reinforced concrete with varying fibre dosages of 0.5%, 1% and 1.5% for 28days were found to be 26.26 MPa, 34.21 MPa, 36.61 MPa and 39.12 MPa and when tested after oven drying were found to be 23.45 MPa, 31.02 MPa, 33.31 MPa and 37. 45 MPa.

The maximum percentage loss of compressive strength was observed for conventional concrete mix as shown in Figure 8. Due to the addition of steel fibres in concrete, it holds the concrete together even after heating it in an oven. Hence the higher dosage of steel fibre showed excellent compressive strength.

Impact Tests: The results obtained from impact tests conducted on steel fibre reinforced concrete with varying fibre dosages of 0% to 1.5% are plotted in Fig. 9 to 13.

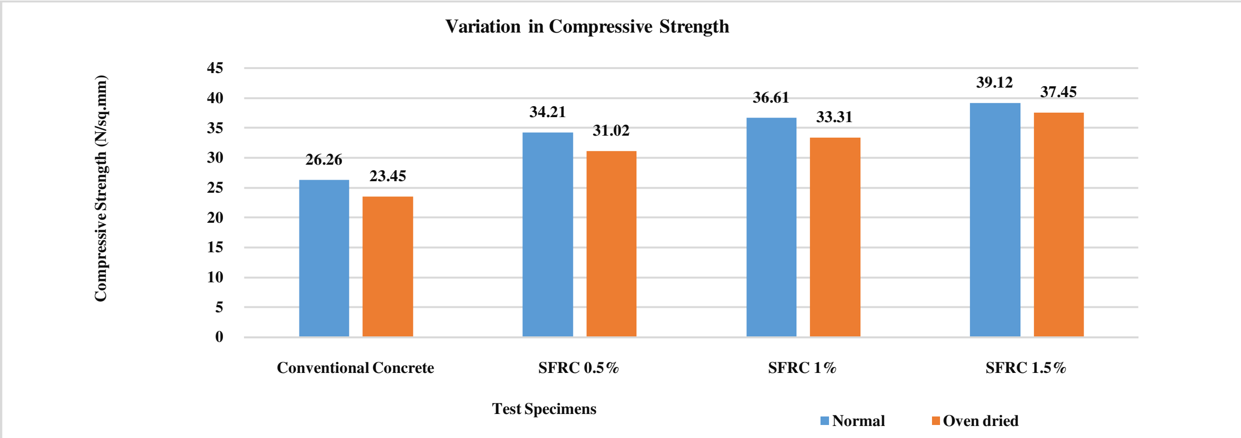

Fig. 8. Variation in compressive strength due to temperature effects.

The load time histories is expressed in terms of peak load vs time at different stages from 1st impact to the last impact blow. The peak load reduces as the number of blows increases. The midpoint displacement responses at different stages of loading were examined and represented in this section. It is observed that from Displacement-time curves the displacement increases with increase in number of impact blows.

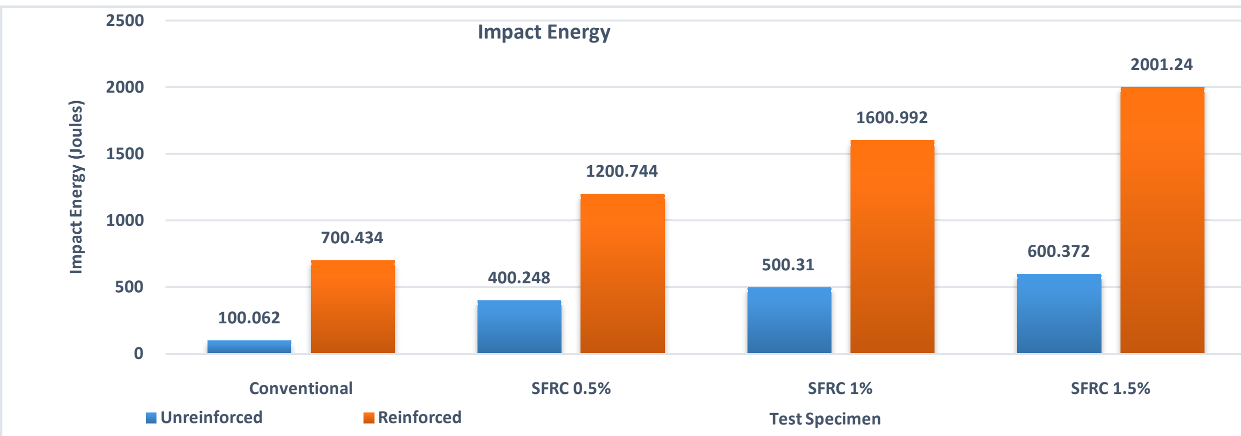

Fig. 9. Impact Energy of unreinforced & reinforced slab specimen.

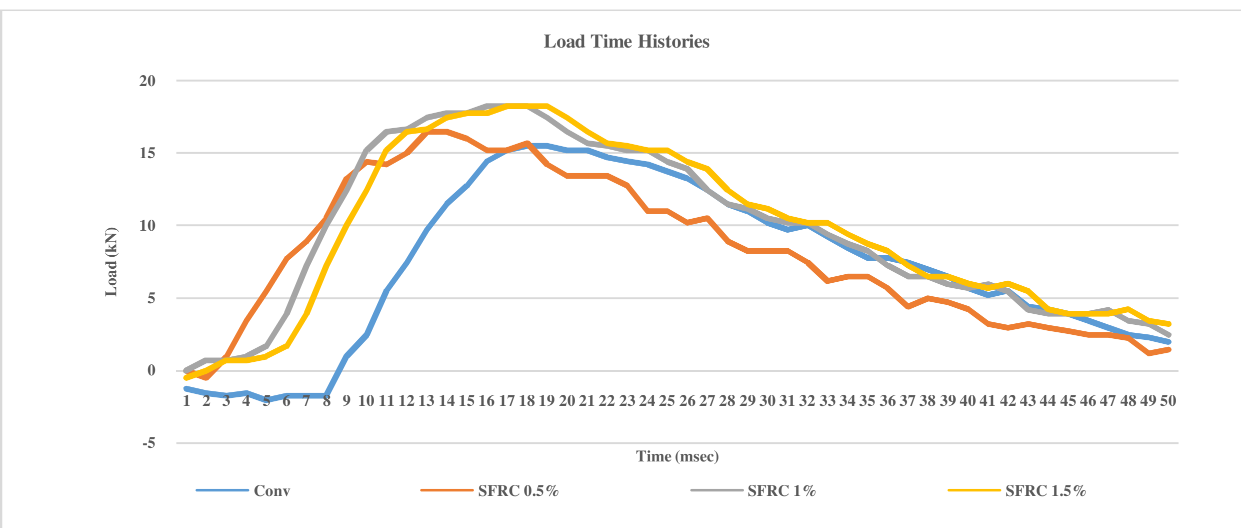

Fig. 10. Peak load for reinforced specimen.

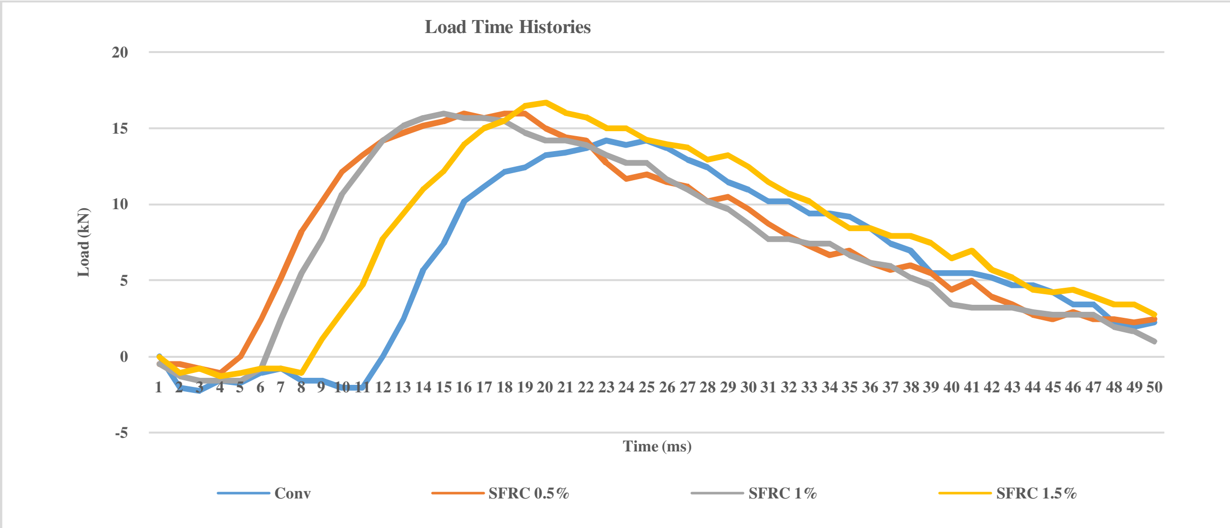

Fig. 11. Peak load for unreinforced specimen.

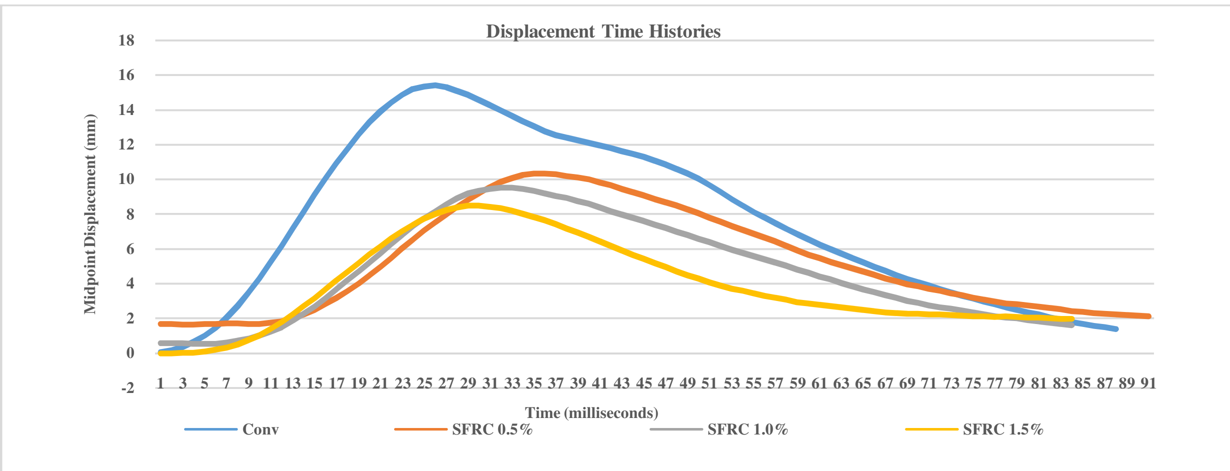

Fig. 12. Max displacement for reinforced slab specimen.

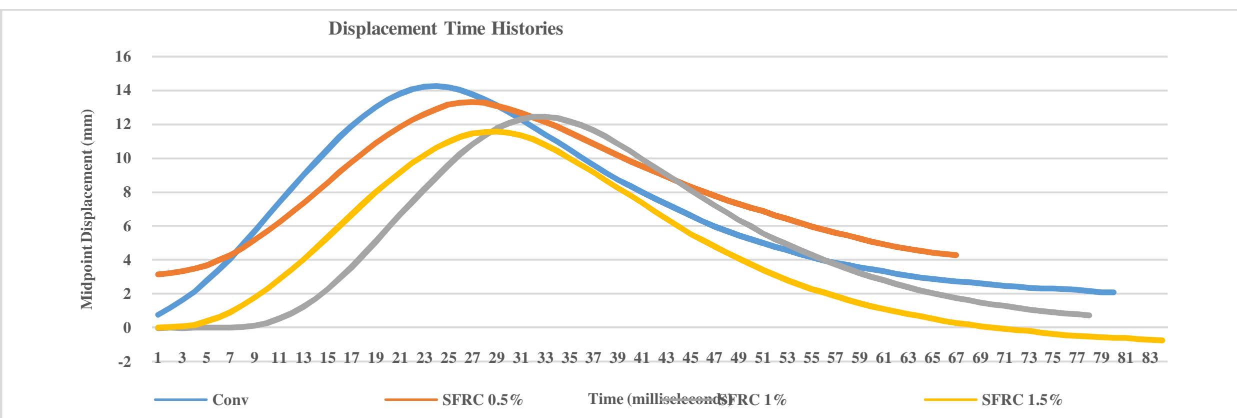

Fig. 13. Max displacement for unreinforced slab specimen.

Simulation studies: Initially hairline cracks developed. Later on diagonal cracks developed extending radially to the edges of the specimens in both conventional and SFRC slab specimens. Larger deformation is observed in case of conventional concrete slab model in comparison to the SFRC with 1.5% steel fibre dosage.

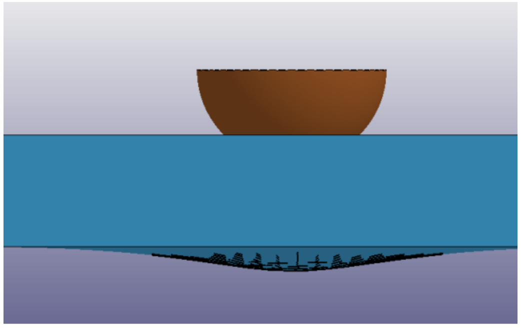

Fig. 14. Crack pattern for plain concrete.

Displacement values for reinforced steel fibre reinforced concrete slabs are obtained as shown in Fig. 16 to 19. Although maximum displacement occurs around the impact point, the values change according to support conditions, especially at the sides of the slabs. The results are presented for the final drop movement of the hammer after complete application of the impact load on the reinforced SFRC slab. Displacement is maximum at the point of impact.

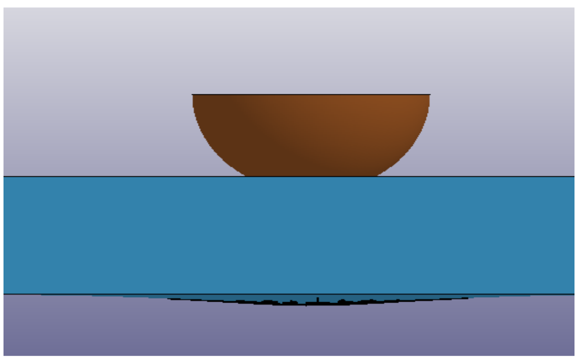

Fig. 15. Crack pattern for SFRC.

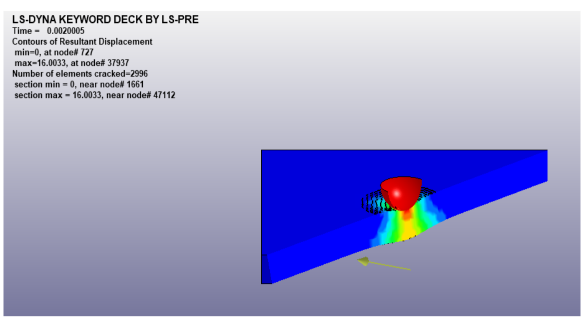

Fig. 16. Max midpoint displacement of plain concrete.

Table 3: Validation of experimental & simulation displacement results.

Specimen	Displacement (Mm)		% Variation with respect to Experimental
	Experimental	*Explicit Analysis*	
Reinforced Conventional	15.34	16.00	*4.30*
Reinforced SFRC	8.86	8.50	*4.06*

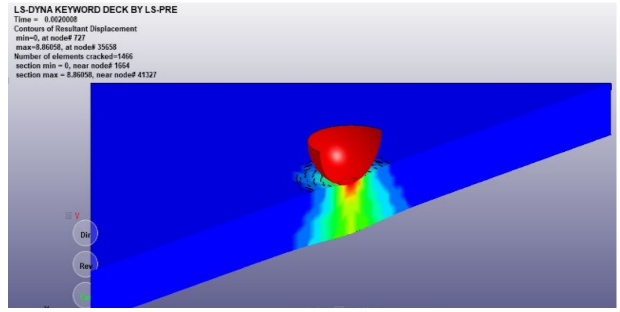

Fig. 17. Max midpoint displacement of SFRC slab (1.5%).

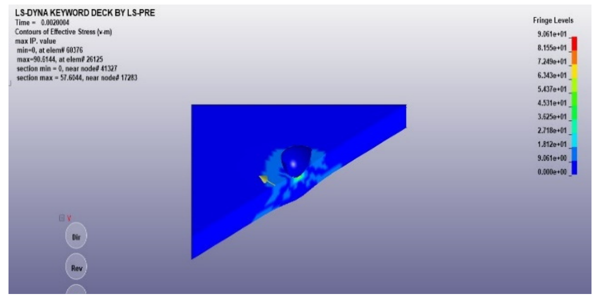

Fig. 18. Stress for plain concrete slab-90.61MPa.

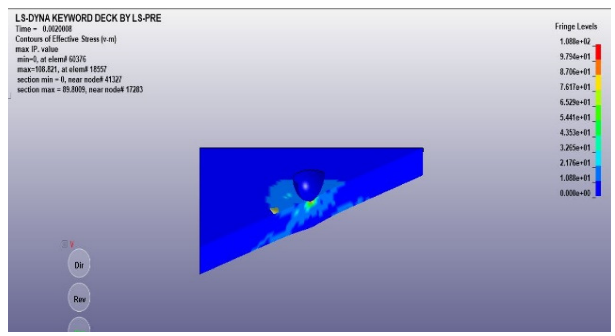

Fig. 19. Stress for SFRC slab-108.82MPa.

Stress values for reinforced steel fibre reinforced concrete slabs are obtained in MPa unit form after the conduct of explicit analyses. Although maximum stresses occur around the impact point, the values change according to support conditions, especially at the sides of the slabs. The results are presented for the final drop movement of the striker after complete application of the impact load on the reinforced steel fibre reinforced concrete slab. Stress distribution is greatly affected on the point of impact.

VI. ADVANTAGES

(i) Crack Control in concrete composite
(ii) Joint Stability in concrete composite
(iii) Fatigue & impact resistance in concrete composite
(iv) Flexural strain capacity is enhanced in concrete composite
(v) Adds ductility to concrete composite
(vi) Narrow joint width in concrete composite
(vii) Shear load transfer in concrete composite
(viii) Post crack lucidity of concrete composite
(ix) Reduces material consumption & saves cost of concrete composite structure
(x) Reduces construction time of concrete composite structure

(xi) Longer service life of structures

VII. CONCLUSIONS

The addition of steel fibres to concrete in dosages of 0.5%, 1% and 1.5% enhanced the strength, durability and impact load resistance. The following important conclusions were drawn based on the results obtained from the experimental studies

(i) The increase in compressive strength of SFRC were found to be in the range of 30.3% to 48.9% more than that of conventional concrete

(i) The increase in split-tensile strength of SFRC were found to be in the range of 86.40% to 141.12% in comparison with that of conventional concrete

(i) Flexural strength of SFRC increased in the range of 26.50% to 44.50% more than that of conventional concrete

(i) Steel fiber reinforced concrete is more resistant to acid and sulphate attacks, when compared to conventional concrete and the maximum resistance was observed in case of SFRC with 1.5% of steel fibers as indicated by lowest percentage loss in weight and percentage loss in compressive strength

(i) Porosity of conventional concrete and steel fibre reinforced concrete varied from 21.50% to 3.90%. The porosity reduced in SFRC and was least for 1.5% dosage of SFRC.

(i) Percentage loss in compressive strength due to oven drying of conventional concrete and steel fibre reinforced concrete varied from 10.70 % to 5.16%.

(i) Peak load decreases as the number of blows increases. Energy absorption and area under load-time variation for reinforced SFRC with varying steel fibre contents of 0.5%, 1.0% & 1.5% are found to be 1.25 times, 1.66 times & 2.85 times and 6.40%, 16.28% & 17.12% more compared to conventional concrete

(i) Displacement-time curves of slabs show that the displacement increases with increase in number of impact blows. Due to the addition of steel fibers, there was a reduction in displacement.

(i) From the above experimental investigations, it can be concluded that addition of 1.5% of steel fibres to concrete by weight of concrete enhances its strength and durability and impact resistance considerably.

VIII. FUTURE SCOPE

(i) Experimental studies on hybrid concrete

(ii) Experimental studies of impact test on slab specimens-Acceleration time histories

(iii) Experimental studies of static test on slab specimens

-Load deflection behavior
-Punching shear strength
-Ductility factor
-Energy absorption
-Toughness index
-Crack pattern

(iv) Simulation studies of static loading on slabs.

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