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Evaluation of Bond (Adhesive) Strength Between Conventional Concrete and Steel Fiber Reinforced Concrete Interface

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Abstract - Good bond strength between overlay and substrate is a key factor in performance of concrete repairs. This thesis was aimed at studying the evaluation of bond strength between conventional concrete substrate and steel fiber reinforced concrete. Many factors such as surface roughness, existence of micro cracks, compaction, curing etc. influence `the bond strength. The quality assurance of the bond strength requires test methods that can quantify the bond strength as well as identify the failure mode. There have been numerous investigations led to development of different test methods. The forces which are applied in each test and the failure mode are important in order to choose the proper test. An interpretive study on test methods is presented. While this study can provide individually useful information on bond strength and bond characterization.

IndexTerms – adhesive, reinforced concrete, bond, cohesive

CHAPTER 1
INTRODUCTION
1.1 GENERAL

Concrete is a predominant material used in construction and it competes directly with all other major construction materials like timber, steel, asphalt, and stone, because of its versatility in applications. However, concrete is a composite material and its properties can vary significantly depending on the choice of materials and proportions for a particular application. However, concrete does have weaknesses that limit its use in certain applications.

Now-a-days a large number of existing concrete structures worldwide are in urgent need of effective and durable repair. It has been estimated that almost half of all concrete repairs fail due to the lack of reliable and perfect bond. Good bonding between repair materials and existing concrete repair substrate is of vital importance in the concrete repairs.

- Fiber-reinforced concrete,
- Shrinkage-compensated concrete and
- Latex-modified concrete.

1.2 BOND STRENGTH

1.2.1 Definition:

The bond strength is the adhesion between overlay and substrate which can be the weakest link of the system. Good bond strength is a key factor to have a monolithic system.

According to Sprinkel and Ozyildirim (Springkel 2000), the interfacial bond strength test results may be quantified as below.

TABLE NO: 1.2.1

BOND QUALITY	BOND STRENGTH (MPa)
Excellent	>=2.1
Very good	1.7-2.1
Good	1.4-1.7
Fair	0.7-1.4
Poor	0-0.7

1.2.2 Various factors that can influence the bond strength in Concrete:

- Roughness of the old substrate.
- Bonding agent at the interface between old and new substrates.
- Mix proportions.

1.3 FIBER REINFORCED CONCRETE

1.3.1 Definition:

- Concrete containing a hydraulic cement, water, fine or fine and coarse aggregate, and discontinuous discrete fibers is called fiber-reinforced concrete.
- Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used; however, for most structural and non-structural purposes, steel fiber is the most commonly used of all the fibers.

1.3.2 Types of Steel Fibers:

The steel fibers of different shapes and sizes are shown in Fig. 1.3.2.1

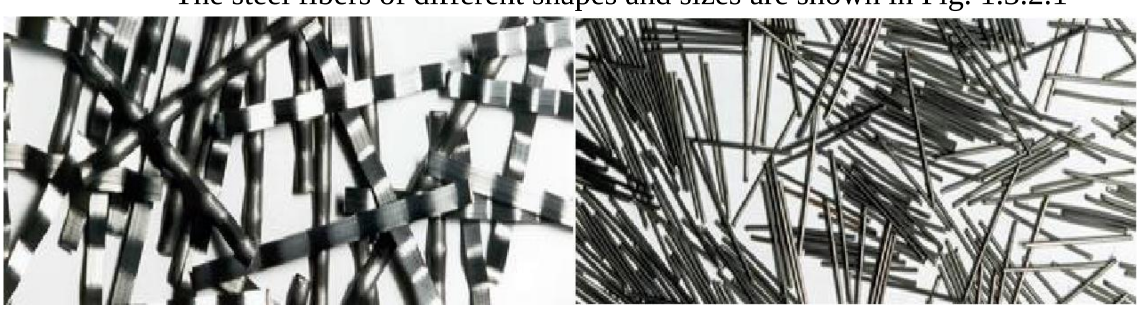


Fig.1.3.2 Typical fiber types used in concrete:

1.3.3 Advantages of SFRC:

- Improve structural strength
- Reduce steel reinforcement requirements
- Improve ductility

1.4 OBJECTIVES OF THE PRESENT WORK:

The main theme of this thesis is to study the bond strength between the concrete interfaces of Conventional concrete and steel fiber reinforced concrete.

- Concrete of different grades M20, M30 and M40 is designed and cast in to a mould of prism of dimensions 20cm*10cm*10cm up to the interface making an angle of interface 30^0 and 45^0 respectively.
- Then remaining portion is cast with fiber reinforced concrete of M20, M30, M40 grades respectively.

CHAPTER 2
LITERATURE REVIEW

2.1 RECENT STUDIES ON BOND STRENGTH BETWEEN THE CONCRETE AND CONCRETE INTERFACES:

The following points explain about research wok on the bond strength between the concrete and concrete interfaces.

Hugo costa, Pedro santos, and Eduardo julio [1] – studied the bond strength behavior of thelight weight aggregate concrete (LWAC) to the normal weight concrete (NWC) interfaces. An experimental study is conducted to characterize the shear strength and tensile strength of NWC-to-NWC, LWAC-to-NWC and LWAC-to-LWAC interfaces and stated as follows

1. Two failure modes were observed, cohesive (at the weakest concrete) and adhesive (debonding of the interface).
2. For slant shear tests, the failure mode was mainly monolithic, for very rough surfaces (HS and CD), and mainly adhesive, for very smooth and smooth surfaces (SS and WB).
3. For rough surfaces, SF and SB, both failure modes were observed.

Radhakrishnan, Syam Prakash, and Prasad varmathampan [2] – evaluated the performanceof styrene butadiene rubber as a concrete repair material in tropical climate using slant shear test and splitting tensile strength of the repaired cylinder specimens of the standard dimensions, in which SBR is used as a bonding agent are determined and stated as

1. The results of sorption test showed that the conventional weathering coat of cement mortar of 1:3 proportions did not possess adequate water penetration resistance, to function as water proofing agent. Therefore a modifier is essential to make the repairs durable.
2. SBR modified cement mortar possess very good water penetration resistance and can be used as a repair material in the case of spalled roof slabs with exposed steel reinforcement.

CHAPTER 3

EXPERIMENTAL STUDY

3.1 PROGRAM OF EXPERIMENTAL WORK

The experimental program was designed to study the bond strength between old concrete and new concrete interface. For this purpose following interfaces are created. They are:

1. M20-M20, M20-SFRC0.4%, M20-SFRC0.8%, M20-SFRC1.2%
2. M30-M30, M30-SFRC0.4%, M30-SFRC0.8%, M30-SFRC1.2%
3. M40-M40, M40-SFRC0.4%, M40-SFRC0.8%, M40-SFRC1.2%

3.2 MIX PROPORTIONS

In this experimental study all the mix design were done according to IS456:2000 and IS 383:1970 and IS 10262:2009.The following were the mix ratios used for casting:

Table No: 3.2.1 Mix proportions

Grade	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	Water/Cement Ratio
M20	320	502.4	1014.4	160	0.5
M30	380	418	874	159.6	0.42
M40	450	623.63	1084.95	180	0.4

3.3 MATERIALS

The various materials used in the experimentation namely cement, fine aggregate and coarse aggregate have been tested in the laboratory. The specifications and properties of these materials were presented in the subsequent sections. All the materials used in the study were tested in the accordance to the Indian standards.

3.3.1 Cement

Cement used in experimental work was Ordinary Portland Cement of 53 grade from Ultra tech brand conforming to IS: 12269-1987. Cement used was fresh, of uniform colour, free from any lumps and foreign matter, and from the same batch. The properties of cement used were as shown in Table 3.3.1.

Table No: 3.3.1 Physical properties of cement

S.no	**Property**	**Test values**
1	Specific gravity	3.15
2	Standard consistency	30 %
3	Initial Setting Time (min)	120
4	Final Setting Time (min)	320

3.3.2 Coarse Aggregate

The fractions from 80 mm to 4.75 mm are termed as coarse aggregate. The Coarse Aggregates from crushed Basalt rock, conforming to IS: 383:1970 is being use. The properties and test results of coarse aggregates used were shown in the Table 3.3.2.

Table No: 3.3.2 Physical properties of coarse aggregates

S.no	**Property**	**Test values**
1	Max. nominal size (mm)	20
2	Specific Gravity	2.82
3	Bulk Density (loose) in kg/m^3	1520
4	Bulk Density (Rodded) in kg/m^3	1700
5	Fineness modulus	7.867

3.3.3 Fine Aggregate

River sand conforming to Zone-II as per IS 383:1970 was used. The fine aggregate was clean, inert and free from organic matter, silt & clay. The Fine aggregate was dried before use. The properties of fine aggregate were presented in the Table 3.3.3.

Table No: 3.3.3 Physical properties of fine aggregates

S.no	**Property**	**Test value**
1	Specific Gravity	2.63

2	Bulk Density (kg/m^3)	1671
3	Fineness modulus	2.63

BASF SKY 8233 is required to improve the workability.

3.4 MOULDS AND EQUIPMENTS

3.4.1 MOULDS

Standard prism size of 400mm X 100mm X 100mm mould is used for casting the prisms.

3.4.2 EQUIPMENTS

3.4.2.1 MIXER

A standard mixer of rotating drum type of half bag capacity is used for mixing the concrete. To begin with all the dry materials (coarse aggregate, fine aggregate, cement) are mixed about two minutes then super plasticizer is thoroughly mixed with the water and this liquid component was added to the dry material mixture. This wet composition is allowed to mix for another four minutes. During this process fibers are sprinkled uniformly to the wet mixture. The care has been taken in allowing all materials to get mixed up uniformly and avoiding the material to get stuck up to walls of the mixer.

3.4.2.2 VIBRATOR

A plate vibrator was used for compacting the prisms.

3.5 CASTING

For old substrate a steel plate is kept between the two fresh concrete surfaces to create required angles of 45 and 30 degrees. The following fig.3.5.1 represents it:

Fig. 3.5.1 Process of casting prisms making required angle by keeping a steel plate

Then after 28 days these old substrates were taken for the curing tank and allowed to dry for 2 days. After this these specimens has to be chipped over the slant surface as to form a uniform grid. The following fig.3.5.2 and fig 3.5.3 represents these.

fig: 3.5.2 Specimen that had chipped at regular intervals after 28 days of curing at 45^0

For new substrate, the old substrate is kept in the mould and remaining portion has to be filled with fresh concrete. The following fig.3.5.4 represents this.

Fig. 3.5.3 Casting of new substrate over the old substrate

3.6 CURING

The specimens left in mould which possessing the ambient conditions viz. temperature of 27± 2 C and 90% relative humidity for 24 hours. These specimens are removed from the mould and submerged in clean fresh water 28 days after new substrate was added. After curing, they are removed from the water and cleaned with a cotton waste. Finally 56 days (after 28 days new substrate was added to the old substrate). The following fig. 3.6.1 and fig.3.6.2 represents it

Fig. 3.6.2 Specimen after adding new substrate to the above old substrate kept for curing

3.7 EXPERIMENTAL SETUP

The prism specimens of the concrete were tested on Compression testing machine (CTM) capacity of 40Tonnes. The bearing surface of the machine is wiped off clean and any loose sand or any other materials removed from the surface of the specimen the specimen was placed in the machine in such a manner that the load was applied to opposite vertical faces of the prism. The axis of the specimen was carefully aligned at the centre of the loading frame and the load applied was increased continuously at a constant rate until the resistance of the specimen to increasing load breaks down and could not no longer sustained.

CHAPTER 4

RESULTS AND DISCUSIONS

4.1 GENERAL

Details of the laboratory experimentation is carried out with different combinations of materials have been discussed in the previous chapter. In this chapter a detailed discussion on the results obtained from various laboratory tests are presented.

4.2 LABORATORY TEST RESULTS

4.2.1Variation of bond strength with steel fiber dosage (%) for different mixes

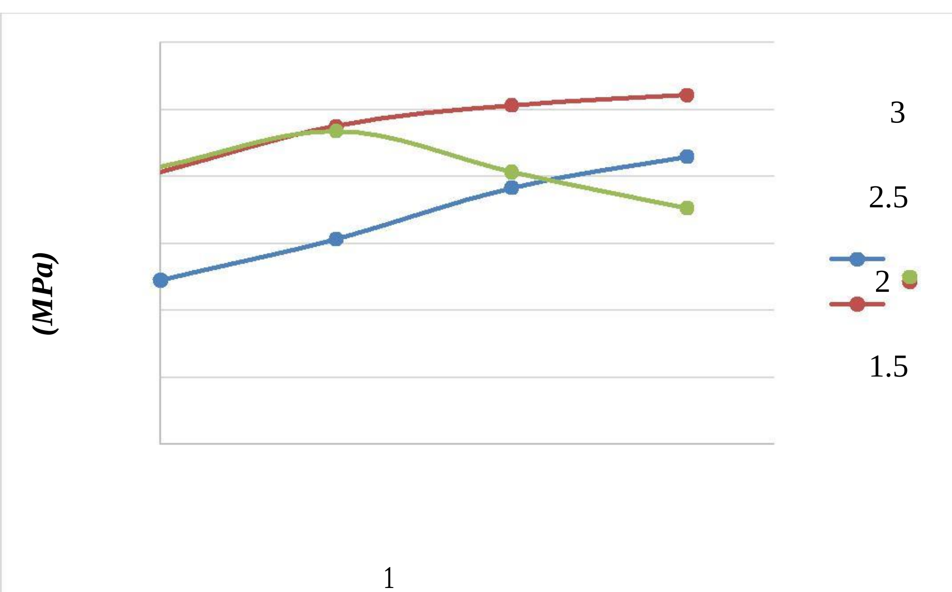
(A) For M20 grade concrete

Table 4.2.1.1 Variation of bond strength with steel fiber dosage (%) for M20 grade of concrete

	Angle of interface	45^0	30^0
Grade	Steel fiber (%)	Bond strength (MPa)	Bond strength (MPa)
M20	0	3.15	1.228
	0.4	4.80	1.535
	0.8	6.30	1.919
	1.2	7.20	2.150

Table 4.2.1.5 Variation of bond strength with steel fiber dosage (%) for different mixes at 30^0angle of interface.

Angle of interface	30^0			
Steel fiber (%)	0	0.4	0.8	1.2
Grade	Bond strength (MPa)			
M20	1.228	1.535	1.919	2.150
M30	2.035	2.38	2.534	2.611
M40	2.073	2.342	2.035	1.766



M20

M3
0

M40

0.5

0

0 0.2 0.4 0.6 0.8 1 1.2 1.4

Steel fiber (%)

Fig: 4.2.1.12 Variation of bond strength at 30⁰ interfaces

M30-M30 at 30^0 interface angle	
Load (kN)	Deflection (mm)
0	0
30	0.361
60	0.671
90	0.938
120	1.195
150	1.461
180	1.752
210	2.054
240	2.356
270	2.710
260	2.862
250	3.002
240	3.121

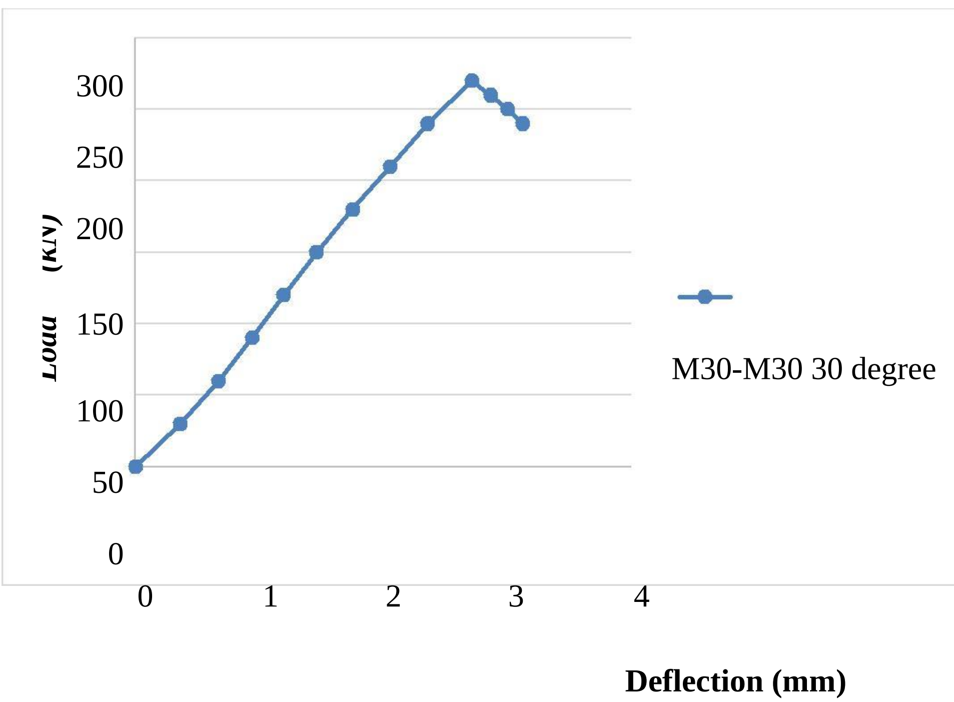


Fig: 4.2.3.25 Variation of load with deflection for M40 at 45^0 interfaces

Table 4.2.3.21 Variation of load with deflection in M40+M40 grade of concrete at 30^0 interface

M40+M40 at 30^0 interface angle	
LOAD(kN)	DEFLECTION(mm)
0	0
30	0.374
60	0.705
90	1.002
120	1.292
150	1.595
180	1.901
210	2.205
240	2.524
270	2.851
260	3.022
250	3.071
240	3.122

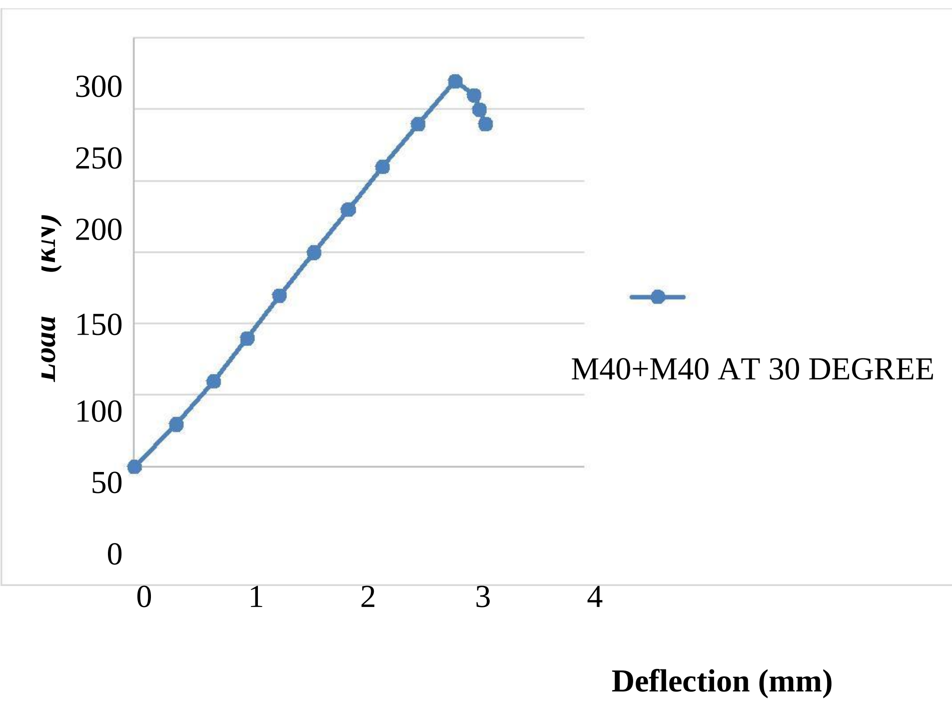


Fig: 4.2.3.26 Variation of load with deflection for M40+M40 at 30^0 interface

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Table 4.2.3.22 Variation of load with deflection in M40+SFRC0.4 grade of concrete at 30^0 interface

M40+SFRC0.4 at 30^0 interface angle	
Load (kN)	Deflection (mm)
0	0
30	0.342
60	0.654
90	0.963
120	1.256
150	1.554
180	1.865
210	2.201
240	2.522
270	2.833
300	3.157
290	3.301
280	3.413
270	3.452

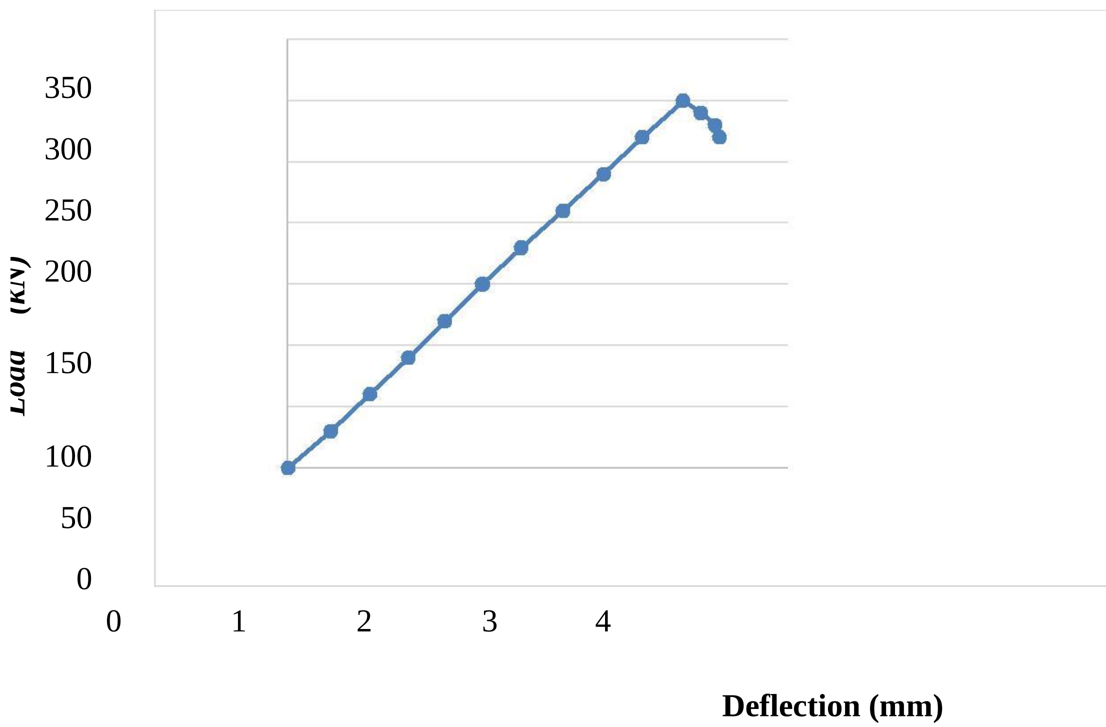


Fig: 4.2.3.27 Variation of load with deflection for M40+SFRC0.4 at 30⁰ interface

Table 4.2.3.23 Variation of load with deflection in M40+SFRC0.8 grade of concrete at 30⁰ interface

M40+SFRC0.8 at 30⁰ interface angle	
Load (kN)	Deflection (mm)
0	0
30	0.376
60	0.721
90	1.020
120	1.324
150	1.598
180	1.886
210	2.142
240	2.421
260	2.753
250	2.942
240	3.085
230	3.194

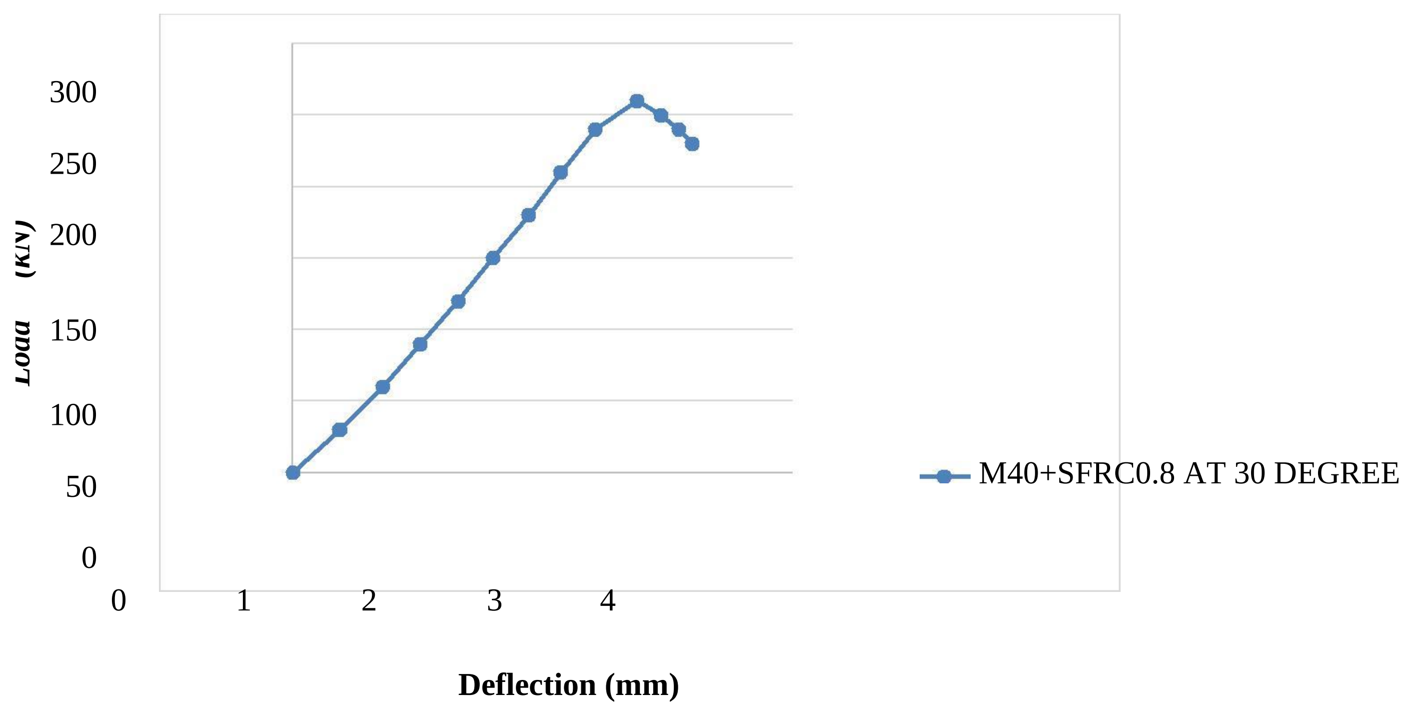
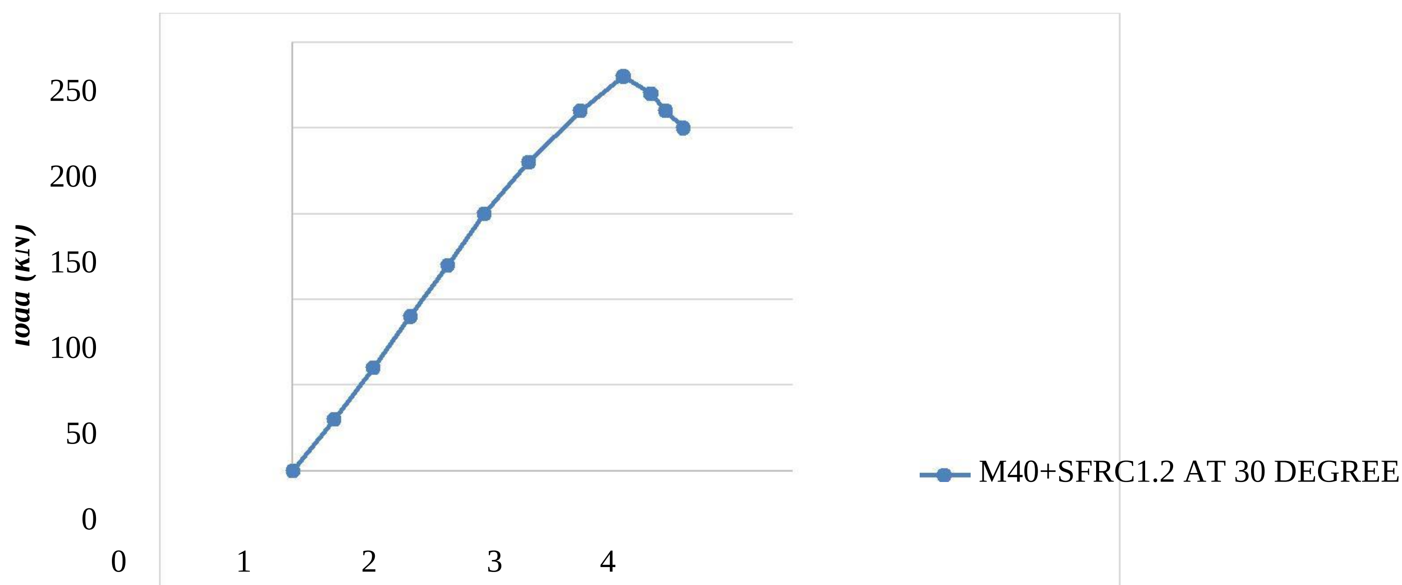


Fig: 4.2.3.28 Variation of load with deflection for M40+SFRC0.8 at 30^0 interface

Table 4.2.3.24 Variation of load with deflection in M40+SFRC1.2 grade of concrete at 30^0 interface

M40+SFRC1.2 at 30^0 interface angle	
Load (kN)	Deflection (mm)
0	0
30	0.332
60	0.645
90	0.938
120	1.241
150	1.532
180	1.884
210	2.299
230	2.643
220	2.862
210	2.981
200	3.122



Deflection (mm)

Fig: 4.2.3.29 Variation of load with deflection for M40+SFRC1.2 at 30^0 interface

4.2.5 This section shows the variation of stiffness with steel fiber dosage (%) for different grade of concrete

Table 4.2.5.1 Variation of stiffness with steel fiber dosage (%) for different grade of concrete at angle of interfaces.

Grade	Steel fiber (%)	Stiffness (kN/mm) at 45^0interface	Stiffness (kN/mm) at 30^0interface
M20	0	58.479	120.967
	0.4	119.521	129.870
	0.8	120.481	126.582
	1.2	135.746	114.942
M30	0	127.118	116.731
	0.4	131.578	103.092
	0.8	151.515	104.895
	1.2	114.942	90.634
M40	0	126.582	96.684
	0.4	137.614	102.389
	0.8	113.207	109.489
	1.2	107.913	99.009

4.2.6 This section shows variation of tensile strength with steel fiber dosage (%) for different grades of concrete.

Table 4.2.6.1 Variation of tensile strength with steel fiber dosage (%) for different grades of concrete.

Grade	Steel fiber (%)	Tensile strength (MPa)
M20	0	2.687
	0.4	3.112
	0.8	3.537
	1.2	3.212

M30	0	3.253
	0.4	2.83
	0.8	3.537
	1.2	2.97
M40	0	3.537
	0.4	3.253
	0.8	2.841
	1.2	2.405

4.2.7 Modes of failure after testing:

Fig: 4.2.6.1 Initial failure pattern in 30 degree angle of interface

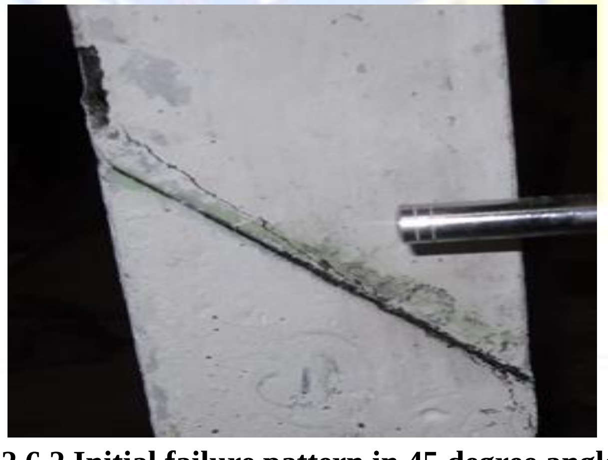


Fig: 4.2.6.2 Initial failure pattern in 45 degree angle of interface

Fig: 4.2.6.4 Failure pattern after testing in 45 degree angle of interface

4.3 DISCUSSIONS

4.3.1 From variation of bond strength with steel fiber dosage (%) for different mixes.

Referring to **Fig 4.2.1.1, Fig 4.2.1.2, Fig 4.2.1.4** and **Fig 4.2.1.5,** it is clear that there is an increase of bond strength values as the percentage of steel fiber content is increased in the over laid concrete for M20 and M30 grades of concrete at both 45^0 and 30^0 angle of interfaces. This may be due to presence of steel fibers which act as the crack closing forces against the micro cracking caused by compressive loading.

Referring to **Fig4.2.1.7 and Fig4.2.1.8,** there is an increase of bond strength values up to 0.4 percent of steel fibers and there after a decline for 0.8% and 1.2% of steel fiber is noticed in M40 grade of concrete at both 45^0 and 30^0 angle of interfaces. This decline may be due to the balling effect and low workability in steel fibers as high concentration of steel fiber presence lead to less cohesion between the steel fibers in the concrete.

Referring to **Fig4.2.1.3**, **Fig4.2.1.6** and **Fig4.2.1.9**, bond strength values have been found to be more for $45^{\mathbf{0}}$ angle of interface compared to $30^{\mathbf{0}}$ angle of interface. This may attributed to the reason that normal stresses are high for the 30^0 angle of interface as compared to 45^0 angle of interface.

Referring to **Table 4.2.4.1**, it is noticed that there is an improvement of the toughness as the steel fiber content is increasing in the overlaid concrete. So, it may be due to the improvement in the energy absorption capacity due to the steel fibers.

4.4 Limitations in using of steel fibers:

1.) There is a reduction in the workability in the concrete as the percentage of steel fibers content is increasing from the 0 to 1.2 of volume fraction.

2.) Balling of fibers is noticed as the fiber content is more than 0.8%.

CHAPTER 5: CONCLUSIONS

The following conclusions are drawn from this experimental investigation.

1. For M20 and M30 grades of substrates there is an increase in the bond strength values as the

percentage of steel fiber content is increasing for both angle interfaces of 45^0 and 30^0.

2. For M40 grade of substrates there is an increase in the bond strength values as the percentage of steel fiber content is increasing from 0 to 0.4% in both 45^0 and 30^0 angle of interfaces, but as steel fiber dosage is increasing from 0.4 to 1.2 percentages there is a decrease in the bond strength values.
3. In all grades and proportions of SFRC of the present study, the bond strength values at 45^0angle of interface are high as compared to the bond strength values at 30^0 angle of interface.
4. There is an increase of compressive strength values as the percent of steel fiber content is varying from 0 percent to 1.2 percent of volume fraction.
5. The relation between bond strength and compressive strength can be drawn as $\mathbf{y=0.3562x^{0.6254}}$where'y' represents the bond strength values and 'x' represents thecompressive strength of new concrete.
6. The lateral slip in the substrate is high at 45^0angle of interface as compared to the 30^0 angle of interface.

Further scope of study

1.) Surface roughness can be changed.

2.) Influence of longitudinal reinforcement can be studied.

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