ISSN: 2348 9510
International Journal Of Core Engineering & Management (IJCEM)
Volume 2, Issue 6, September 2015

BOND STRENGTH BEHAVIOUR OF MONO FIBRE AND HYBRID FIBRE REINFORCED CONCRETE USING STEEL AND NYLON

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Abstract
This paper presents an experimental study on the effect of hybrid fibre addition to M40 concrete mix using the steel-nylon hybrid fibre reinforced system. The study is done by comparing the bond strength behaviour of concrete beams without fibres, with steel fibres, with nylon fibres and with hybrid fibre combination of steel and nylon. M40 grade concrete was designed as the control mix. The main variables considered were the volume fraction of crimped steel fibres and nylon fibres. The mechanical properties of the mono fibre reinforced cast specimens were tested at four different volume fractions of fibre content i.e., 0.5%, 1.0%, 1.5% and 2.0%. The optimum volume fraction of steel fibre addition was obtained as 1.5% and that of nylon fibre addition was obtained as 1%. Hybrid combinations of 1.5% steel fibre along with various percentages of nylon fibre, such as 0.1%. 0.15%, 0.2%, 0.25% and 0.3%, were cast in order to find the optimum percentage of the hybrid steel-nylon fibre combination. An optimum volume fraction of 1.5% steel with 0.2% of nylon was obtained as the hybrid combination. A total of 32 pull out specimens were cast and tested. Pull-out tests were carried out to study the effect of steel and nylon fibres on the bond strength and bond stress–slip response of deformed reinforcement bars embedded in M40 concrete. The main variables considered, in the case of pull-out test, were the volume fraction of crimped steel fibres, volume fraction of nylon fibres and the diameter of reinforcement bars.

Keywords:- Index Terms-Bond stress, Deformed bars, Hybrid fibre reinforced concrete, Pullout test, Nylon fibres, Steel fibres.

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International Journal Of Core Engineering & Management (IJCEM)
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I. INTRODUCTION

Concrete is a tension-weak building material, which is often crack ridden connected to plastic and hardened states, drying shrinkage, and so on. To counteract the cracks, a fighting strategy has come into use, which mixes the concrete with the addition of discrete fibres. Plain cement concrete has some shortcomings like low tensile, limited ductility, little resistance to cracking, high brittleness poor toughness, and so on that restrict its application. The cracking of concrete may be due to economic structural, environmental factors, but most of the cracks are formed due to inherent internal micro cracks and the inherent weakness of the material to resist tensile forces. To overcome these deficiencies, extra materials are added to improve the performance of concrete.

Fibre reinforced concrete provides solutions for these shortcomings. Inclusion of fibres as reinforcement to concrete results as crack arrestor and improves its static and dynamic properties by preventing the propagation of cracks as well as increases tensile strength of concrete. Extensive research work on FRC during the last two decades has established that combination of two or more types of fibres such as metallic and non-metallic fibres increase overall performances of concrete. Investigations to overcome the brittle response and limiting post – yield energy absorption of concrete led to the development of fibre reinforced concrete (FRC) using discrete fibres within the concrete mass. The fibres were introduced to develop concrete with enhanced flexural and tensile strength. The fibres were included in the concrete is to delay and control the tensile cracking of the composite materials. The fibres, thus transform inherent unstable tensile crack propagation into a slow controlled crack growth. The fibre reinforcement delays the initiation of flexural and shear crack. It strongly influences the post cracking behaviour and significantly enhances the toughness of the composite.

Fibres of different materials such as metallic, polymeric and cellulose are presently used in high strength concrete for various infrastructural applications. Among them, metallic steel fibres contribute considerably to the improvement in tensile and toughness and to the resistance to shrinkage by arresting the crack propagation of matrix. The addition of steel fibres significantly improves many of the engineering properties of mortar and concrete, notably impact strength and toughness. Whereas low density polymeric fibres such as polypropylene, glass and nylon restrain the plastic cracks in the matrix. The nylon fibres have stepped up the performance after the presence of cracks and have sustained high stresses. However, the establishment has been awaited as to how the steel fibres compete with the nylon rivals in advancing the performance of concrete under compression, tension, flexure, etc. High strength concrete with single fibres of either type does not offer a significant improvement in mechanical properties. Hence in recent years, there has been research on hybrid fibre reinforced concrete which incorporates the advantages of both types of fibres in a single matrix.

II. AIM

In order to achieve the main research goal, a systematic approach was set out by fulfilling some main objectives. The specific objectives of the study are enumerated below.

- To find the optimum volume fractions of steel, nylon and hybrid combination of steel and nylon fibres.
- To assess the mechanical properties of mono fibre reinforced and hybrid fibre reinforced concrete, target compressive strength at the age of 28 days being around 48 MPa.

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- To study the bond strength between the fibre reinforced concrete and rebar.

III. EXPERIMENTAL INVESTIGATION

A. Materials Used

The materials used in this study were:

- Portland Puzzolona cement
- Manufactured sand
- Coarse aggregate with a maximum size of 20mm
- Superplasticizer – a High Range Water Reducing Agent (HRWRA)
- Crimped steel fibre of aspect ratio 66 (length-30mm; diameter-0.45mm)
- Monofilament nylon fibre of aspect ratio 160 (length-40mm; diameter-0.25mm)

B. Test results of Cement

Portland Pozzolana Cement, confirming to IS 1489 (Part 1) – 1991 (Reaffirmed 2005), was used throughout this investigation. The different laboratory tests were conducted on cement as per IS 12269: 1987

Table I: Properties of cement

Properties	Test Results
Standard consistency	34%
Compressive strength	33 MPa
Initial setting time	1hr 5mins
Final setting time	5hrs 20mins
Specific gravity	3.15

C. Test Results of Fine Aggregate

Commercially available Manufactured Sand passing through 4.75 mm IS sieve which conforms to IS specification was used as fine aggregate. Laboratory tests were conducted to determine the different physical properties as per IS 383 – 1970 specifications.

Table II: Properties of fine aggregate

Properties	Result obtained
Fineness modulus	2.96
Bulk density	1.8
Void ratio	0.38
Porosity	28%
Specific gravity	2.5

The test results conforms the M- sand to zone II of IS 383 – 1970 recommendations.

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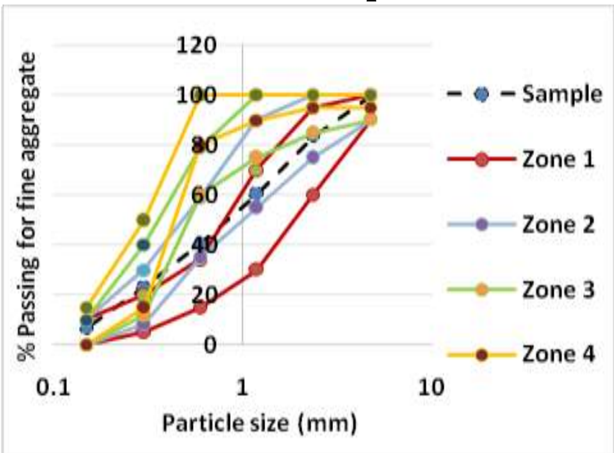

Fig. 1. Gradation curve of fine aggregate

D. Test Results of Coarse Aggregate

Crushed aggregate with a maximum size of 20 mm was used for preparing the mixes. On performing sieve analysis, it was observed that the coarse aggregate confirms to IS specification, i.e. it lies within the required zone.

Table III: Properties of coarse aggregate

Properties	Result obtained
Fineness modulus	7
Bulk density	1.6
Void ratio	0.27
Porosity	44%
Specific gravity	2.9

The test results confirm to IS 383-1970 (part III) recommendations.

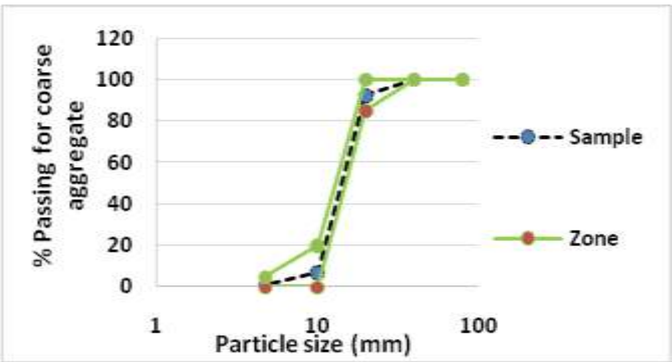

Fig.2. Gradation curve of coarse aggregate

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E. Superplasticizer

A High Range Water Reducing Agent, Cera hyperplast XR-W40, which is a polycarboxylate ether based superplasticizer was used for the work and its specification compliance is as per ASTM C 494-03, BS 5075 and IS 9103.

F. Details of the designed mix

Table IV: Mix Proportion of the Conventional Mix

Materials	By Weight	By Proportion
Cement	394 kg/m^3	1
Fine Aggregate	657.288 kg/m^3	1.668
Coarse Aggregate	1324.314 kg/m^3	3.3612
Water	157.6 kg/m^3	0.4
Superplasticer	1.527 kg/m^3	0.00387

Slump obtained: 145mm
7^{th} day Compressive Strength: 31.2 MPa
28^{th} day Compressive Strength: 48.88 MPa

IV. PRELIMINARY INVESTIGATION

Table V: Specimen Identification Details

Specimen Id	Specimen Details
CM	Control mix (without fibres)
SFRC	Steel Fibre Reinforced Concrete
NFRC	Nylon Fibre Reinforced Concrete
HFRC	Hybrid Steel- Nylon Fibre Reinforced Concrete

The effect of steel fibres was studied by adding 0.5%, 1%, 1.5% and 2% by volume of 0.45 mm diameter steel fibres with aspect ratio 66 to the designed mix. The variations in fresh and hardened properties due to the addition of steel fibre on the mix are tabulated in Table 4. The workability decreased and the hardened properties such as cube compressive strength, cylinder compressive strength and modulus of elasticity increased with addition of fibres. Since the primary objective of fibre addition was improvement in tensile and flexural behaviour, optimum performance was observed for concretewith 1.5% of steel fibre addition. Hence for further study the percentage of steel fibre addition was fixed as 1.5%.

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Table VI: Fresh and Hardened Properties of SFRC Mix

Designation of Specimen	Fibre Percentage (%)	Slump (mm)	Compressive Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
CM	0	145	48.8	3.02	3.6
SFRC1	0.5	120	50.7	3.13	4.2
SFRC2	1	114	46.8	3.25	5.4
SFRC3	**1.5**	**110**	**43.7**	**3.53**	**6**
SFRC4	2	97	30.6	2.32	4.4

The effect of nylon fibres on the properties of concrete was studied by adding 0.5%, 1%, 1.5% and 2% by volume of 0.25 mm diameter nylon fibres with aspect ratio 160 to the designed mix. Similar trend in the fresh and hard properties were observed as in the case of SFRC. The values are tabulated in Table 5. Optimum performance was observed for the mix with 1% of nylon fibre addition.

Table VII: Fresh and Hardened Properties of NFRC Mix

Designation of Specimen	Fibre Percentage (%)	Slump (mm)	Compressive Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)
CM	0	145	48.8	3.02	3.6
NFRC1	0.5	130	49.6	1.92	4.8
NFRC2	**1**	**124**	**51.6**	**2.83**	**5.2**
NFRC3	1.5	119	52.2	2.68	4.6
NFRC4	2	112	48.8	2.26	4.0

The influence of hybrid fibres on the mix was studied by adding nylon fibres at 0.1%, 0.15%, 0.2%, 0.25% and 0.3% by volume with the optimum content of steel fibre which is 1.5% by volume. From the test results tabulated in Table 6, it was found that even though workability decreased with the addition of nylon fibres, there was excellent improvement in hardened properties such as flexural strength and tensile strength. The optimum percentage of hybrid combination of steel and nylon was found to be 1.5% of steel with 0.2% of nylon by volume.

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Table VIII: Fresh and Hardened Properties of HFRC Mix

Designation of Specimen	Optimum Steel fibre percentage (%)	Nylon fibre content (%)	Slump (mm)	Compressive Strength (N/mm²)	Split Tensile Strength (N/mm²)	Flexural Strength (N/mm²)
CM	0	0	145	48.8	3.02	3.6
SFRC3	1.5	0	110	43.7	3.53	6
HFRC1	1.5	0.1	106	48.2	3.6	7
HFRC2	1.5	0.15	103	52.1	3.8	7.4
HFRC3	**1.5**	**0.2**	**100**	**50.8**	**4.3**	**8**
HFRC4	1.5	0.25	95	49.8	3.1	6.4
HFRC5	1.5	0.3	91	47.7	3	5.6

V. EXPERIMENTAL PROGRAMME

The experimental program was carried out to evaluate the pullout strength and bond stress-slip behaviour of reinforcement bars embedded in concrete containing 0% fibres, optimum percentage of steel fibre, optimum percentage of nylon fibre and optimum percentage of the combination of steel and nylon fibre. A total of 32 specimens were prepared and pullout tests were carried out as per IS 2770 Part (1):1967 (Reaffirmed 2002). The main variables were:

- CM -control mix, i.e., concrete without fibres
- SFRC-concrete containing optimum percentage of steel fibre
- NFRC- concrete containing optimum percentage of nylon fibre
- HFRC- concrete containing an optimum combination of steel and nylon fibres.
- Diameter of steel reinforcement bars (Ø) - 10mm, 12mm, 16mm and 20mm.

Two specimens were tested for each parameter and average of the results was taken for analysis.

Table IX: Number of Pullout Specimens

Mix	10mm Ø	12mm Ø	16mm Ø	20mm Ø	Total
CM	2	2	2	2	8
SFRC	2	2	2	2	8
NFRC	2	2	2	2	8
HFRC	2	2	2	2	8
				Sum =	**32**

A. Details of Pullout Specimens

The specimens consisted of concrete cubes with a single reinforcing bar embedded vertically along the central axis in each specimen. The bar was projected down by about 10 mm from the bottom of the cube for measuring the slip of the reinforcement bar. Also, the bar was projected upwards by about 1 m from the top face of the cube to provide an adequate length for gripping the specimen in the testing machine.

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Fig.3. Pullout Test Specimen

Fig. 4. Arrangement of Rebar &Helical Reinforcement

Cubes of size 100 mm were used for 10 mm and 12 mm diameter bars and 150 mm size for 16 mm and 20 mm diameter bars. Specimens were reinforced with a helix of 6 mm diameter plain mild steel bar at a pitch of 25 mm to prevent splitting failure before pullout.The details of specimens,variables andthe compressive strength of the cube specimens which were cast along with each mix are presented in Table X.

Table X: Details of Pullout Specimens

Specimen Designation	**Rebar Diameter**	**Embedded length to Diameter ratio**	**Compressive strength of Concrete cube (MPa)**
CMØ10	10	10	48.8
SFRCØ10	10	10	43.7
NFRCØ10	10	10	51.6
HFRCØ10	10	10	50.8
CMØ12	12	8.33	48.8
SFRCØ12	12	8.33	43.7
NFRCØ12	12	8.33	51.6
HFRCØ12	12	8.33	50.8
CMØ16	16	9.37	48.8
SFRCØ16	16	9.37	43.7
NFRCØ16	16	9.37	51.6
HFRCØ16	16	9.37	50.8
CMØ20	20	7.5	48.8
SFRCØ20	20	7.5	43.7
NFRCØ20	20	7.5	51.6
HFRCØ20	20	7.5	50.8

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B. Testing of Specimens

The test was conducted using a Universal Testing Machine of 400 kN capacity. The test specimen was mounted in the testing machine in such a manner that the bar is pulled axially from the specimen. For measuring the movement of the reinforcing bar with respect to the concrete at both the loaded and free ends of the bar, dial gauges having least count 0.01 mm were used at both locations. Load was applied to the reinforcing bars monotonically at a rate not greater than 22.5 kN/min. The loading was continued until the specimen failed either by yielding of the steel or by excessive slip between the bar and concrete. The test setup is shown in Figure5.

Fig.5. Test setup

VI. BOND BEHAVIOUR

Two different types of failures such as pullout failure and yielding failure were observed in the specimens. Pullout mode of failure generally occurs in confined concrete in which the bond failure is due to the pullout of the bars. In the pullout type of failure, crushing of concrete near the bar was observed. Figure 6 shows the pullout failure in which there were substantial cracking of concrete surrounding the bar.

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Fig.6. Pullout Failure

Fig. 7. Yielding Failure

In some specimens, due to the development of high bond strength, the bars yielded at the loaded end. Figure 7 shows such yielding failure in which the steel bar reached its maximum stress before reaching the ultimate bond stress. In the case of yielding failure, the bar was intact.

VII. TEST RESULTS AND DISCUSSIONS

Table XI shows the values of bond stress at free end slip of 0.025 mm and 0.25mm, which is the requirement as per IS 2770 (Part I)-1967 (Reaffirmed 2002), ultimate load and ultimate bond stress of all the specimens which failed due to pullout of reinforcement bars. In the case of specimens which failed due to yielding of steel rather than the pullout of reinforcement bars, the ultimate bond stress computed, corresponding to the load at which yielding takes place, will be actually less than the true ultimate bond stress.

It can be noted from Table XI that, for a given embedded length and mix, some bars yielded and the specimens failed before reaching its maximum bond stress. This may be because of the larger concrete cover to bar diameter ratio available in the case of smaller diameter bars which may contribute more to the bond resistance of the bar. Also the contribution of bar lugs is more effective for smaller bar diameters. All specimens with 10 mm bars failed due to yielding of bars because of enhanced bond stress. If the embedded length to the concrete is adequate, the stress in the reinforcement may become high enough to yield and even strain harden the bar. Hence, for the same embedded length, yielding failure of the bars indicates that the anchorage length of reinforcing bars can be reduced in SFRC and HFRC specimens with 12mm and 16mm diameter bars. The bond stress for 16mm bar is greater than those of 10mm and 12mm bar in different mixes.

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Table XI: Bond Stress Values

Specimen	Bond stress at 0.025mm slip (MPa)	Bond Stress at 0.250mm slip (MPa)	Ultimate Bond stress (MPa)	Failure Mode
CMϕ10	6.8	9.01	10.98 [a]	Yielding
NFRCϕ10	7.6	10.45	12.1	Pullout
SFRCϕ10	8.75	11.54	14.16	Pullout
HFRCϕ10	9.55	12.73	13.5	Pullout
CMϕ12	8.95	10.73	11.93	Pullout
NFRCϕ12	9.01	10.9	11.97	Pullout
SFRCϕ12	9.28	11.6	12.2	Pullout
HFRCϕ12	9.615	11.94	12.07	Pullout
CMϕ16	10.7	14.58	16.7	Pullout
NFRCϕ16	10.9	14.7	16.88	Pullout
SFRCϕ16	11.7	15.2	17.2	Pullout
HFRCϕ16	12.8	16.4	17.5	Pullout
CMϕ20	12.4	14.84	17.3	Pullout
NFRCϕ20	12.7	14.4	16.6	Pullout
SFRCϕ20	11.4	15.6	17.6	Pullout
HFRCϕ20	14.8	16.5	18.4	Pullout

[a] Corresponding to ultimate load at yielding failure which is less than actual bond strength

Comparing the bond stress values at 0.025 mm slip, it can be seen that the addition of fibres increased the bond stress of all the rebars marginally. Comparing the bond stress values at 0.25 mm slip, it can be seen that the addition of fibres increased the bond stress of all the rebars bars as well. In the case of fibre reinforced specimens with 10 mm, improvement in bond stress was obtained when compared to CM specimens. In the case of fibre reinforced specimens with 12 mm, considerable improvement in bond stress was obtained when compared to CM specimens. In case of 16mm diameter bars, SFRC and HFRC specimens were having greater bond stress values at 0.025 mm slip and 0.25 mm slip when compared with CM specimens. Hence the mode of failure was yielding in the above case. This shows that the contribution of fibre to the bond strength was significant for CM specimens with larger diameter bars. But the presence of hybrid fibres which gives a confining effect to concrete has a more effective contribution to the bond stress of smaller diameter bars as well.

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A. Bond Stress-Slip Response

The bond behaviour in reinforced concrete members is represented by the bond stress–slip relationship. Slip is the relative displacement of reinforcement bar with reference to the surrounding concrete. The load versus slip values were recorded continuously throughout the testing of each specimen. Figures8, 9, 10 and 11 show the monotonic average bond stress versus slip response of specimens with 10mm, 12mm, 16mm and 20mm diameter bars respectively. All the specimens exhibited the linear load slip behaviour initially until the formation of micro-cracks. Once the micro-cracks were formed, the free end of the rebar begins to slip and the stiffness of the bond stress–slip curve was reduced and the ascending portion of the curve became nonlinear.

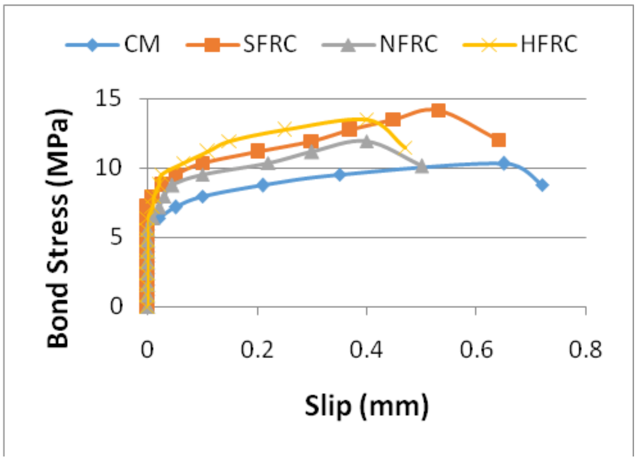

Fig.8.Bond Behaviour of Specimens with 10mm Bars

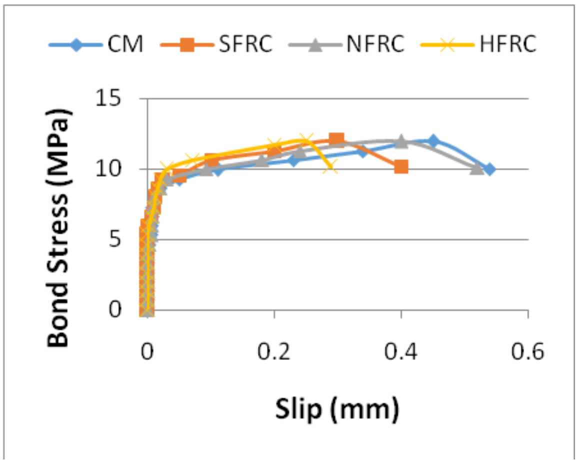

Fig.9. Bond Behaviour ofSpecimens with 12mm Bars

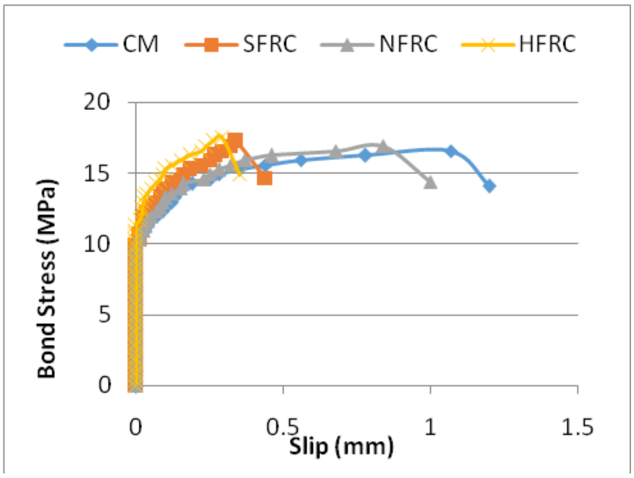

Fig.10.Bond Behaviour of Specimens with 16mm Bars

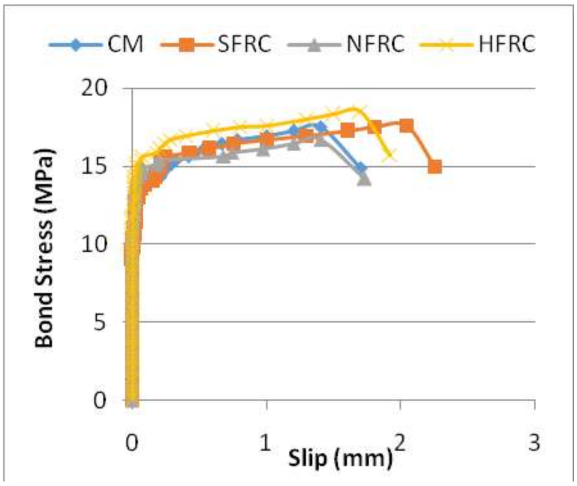

Fig.11.Bond Behaviour of Specimens with 20mm Bars

Referring to Figures 8, 9, 10 and 11, it can be seen that, the pullout type failure was characterized by a gradual increase of bond stress–slip behaviour up to the ultimate load followed by a softening branch which shows a stable failure pattern, whereas in yielding failure, the bond stress–slip behaviour, beyond peak load, could not be obtained as the bars failed before reaching the ultimate bond stress.

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B. Relative Bond Strength

The relative bond strengths of different specimens are listed in the following tables. It can be seen from the tables while comparing the values of conventional mix for all the rebars, the relative bond strength of fibre reinforced specimens are found to be increased.

Table XII: Pullout Test Data of 10mm Diameter Bars

MIX ID	CMØ10	SFRCØ10	NRCØ10	HFRCØ10
Diameter of Steel Bar(mm)	10			
Type of steel Bar	Fe 500			
Peak Bond stress(MPa) τ_{peak}	10.98	14.16	12.1	13.5
Bond stress at slip of 0.025mm(MPa) $\tau_{0.025}$	6.8	8.75	7.6	9.55
Bond stress at slip of 0.25mm(MPa)	9.01	11.54	10.54	12.73
Bond stress as per IS 456 (MPa)	3.04	3.04	3.04	3.04
$\tau_{0.025}$ / $\tau_{IS\ 456}$	2.23	2.87	2.5	3.14
τ_{peak} / $\tau_{IS\ 456}$	3.61	4.65	3.98	4.44
Relative bond strength (τ_{peak} /$f_c^{0.5}$)	1.57	2.14	1.68	1.89

Table XIII: Pullout Test Data of 12mm Diameter Bars

MIX ID	CMØ12	SFRCØ12	NRCØ12	HFRCØ12
Diameter of Steel Bar(mm)	12			
Type of steel Bar	Fe 500			
Peak Bond stress(MPa) τ_{peak}	11.93	12.2	11.97	12.07
Bond stress at slip of 0.025mm(MPa) $\tau_{0.025}$	10.47	10.27	10.93	9.615
Bond stress at slip of 0.25mm(MPa)	12.89	12.99	14.08	11.94
Bond stress as per IS 456 (MPa)	3.04	3.04	3.04	3.04
$\tau_{0.025}$ / $\tau_{IS\ 456}$	3.44	3.37	3.59	3.92
τ_{peak} / $\tau_{IS\ 456}$	3.93	4.01	3.93	3.97
Relative bond strength(τ_{peak} /$f_c^{0.5}$)	1.7	1.84	1.66	1.69

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Table XIV: Pullout Test Data of 16mm Diameter Bars

MIX ID	CMØ16	SFRCØ16	NRCØ16	HFRCØ16
Diameter of Steel Bar(mm)	16			
Type of steel Bar	Fe 500			
Peak Bond stress(MPa) τ_{peak}	16.7	17.2	16.88	17.5
Bond stress at slip of 0.025mm(MPa) $\tau_{0.025}$	10.7	11.7	10.9	12.8
Bond stress at slip of 0.25mm(MPa)	14.58	15.3	14.7	16.88
Bond stress as per IS 456 (MPa)	3.04	3.04	3.04	3.04
$\tau_{0.025}$ / $\tau_{IS\ 456}$	3.52	3.84	3.58	4.24
τ_{peak} / $\tau_{IS\ 456}$	5.5	5.65	5.53	5.7
Relative bond strength(τ_{peak} /$f_c^{0.5}$)	2.4	2.6	2.35	2.45

Table XV: Pullout Test Data of 20mm Diameter Bars

MIX ID	CMØ120	SFRCØ20	NRCØ20	HFRCØ20
Diameter of Steel Bar(mm)	20			
Type of steel Bar	Fe 500			
Peak Bond stress(MPa) τ_{peak}	17.3	17.6	16.6	18.4
Bond stress at slip of 0.025mm(MPa) $\tau_{0.025}$	12.4	11.4	12.7	14.8
Bond stress at slip of 0.25mm(MPa)	14.84	15.6	14.4	16.5
Bond stress as per IS 456 (MPa)	3.04	3.04	3.04	3.04
$\tau_{0.025}$ / $\tau_{IS\ 456}$	4.07	3.75	4.177	4.86
τ_{peak} / $\tau_{IS\ 456}$	5.69	5.7	5.46	6.05
Relative bond strength(τ_{peak} /$f_c^{0.5}$)	2.5	2.7	2.31	2.58

For all rebars, relative bond strength of HFRC is found highest followed by SFRC. The relative bond strength of NFRC is found lesser than those of HFRC and SFRC but great than CM. The bond stress values for SFRC, NFRC and HFRC were found to be 4 times more than designed bond strength values of IS 456-2000 and about 5 times for peak bond stress. Thus values of bond strengths obtained from this investigation were found to be conservative with reference to those specified in IS 456-2000 for the purpose of structural design computations. Anchorage length of steel rebars embedded in SFRC, NFRC and HFRC can be chosen as same for normal concrete under the condition of same compressive strength of concrete.

VIII. CONCLUSIONS

Following conclusions are drawn from the experimental investigations conducted to assess the influence of fibres on the flexural response of the beams.

- Fresh concrete properties of the designed mix, such as workability and flowability decreased while the hardened properties such as compressive strength, flexural strength and tensile strength improved by the addition of fibres.
- The optimum percentage of steel fibre addition was 1.5% by volume and that of nylon fibre was 1% by volume. The optimum content of the hybrid combination was 1.5% of steel with 0.2% of nylon fibre by volume.
- The confinement and bridging effects of hybrid fibres enhanced the bond stress of reinforcing bars embedded in HFRC composites when compared to the control mix.
- Contribution of fibres to the bond strength was insignificant for smaller diameter bars whereas in HFRC specimens significantly improved the bond stress for 10mm, 12 mm, 16 mm and 20 mm diameter bars by about 23%, 1.5%, 5% and 7% respectively.
- The anchorage length requirement of deformed bars can be reduced by the usage of steel fibre reinforced concrete and hybrid steel nylon fibre reinforced concrete.

ACKNOWLEDGEMENT
I hereby express my abundant and sincere gratitude to my guide **Mr. Tom George**, Assistant Professor, Department of Civil Engineering, Mar Baselios College of Engineering and Technology, for his valuable guidance, constant encouragement and creative suggestions rendered during the course of this work and also in preparing this report. I would like to extend my special gratitude toward **Mr. Azeez Khan, Mr. V. J. Vijin,** and all the lab staff of the Civil Dept. for their inspiring assistance and encouragement. I would also wish to record my gratefulness to my family and friends for their help and support rendered in carrying out the project properly. I thank God Almighty for his grace throughout the work.

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