# Effect of Hybrid Fibres on Pullout of Reinforcing Bars in High Performance Concrete

Vidhya Kanakaraj, Remya M S, Humaida Alhadi

**Abstract**— High Performance Concrete (HPC) is a concrete with enhanced properties like high - compressive strength, workability, durability etc. resulting from a very compact matrix. Hybrid Fibre Reinforced High Performance Concrete (HFRHPC) is a HPC mix that contains a mixture of two or more types of fibres to achieve both durability and ductility. The bond performance of reinforcing bars plays a major role in the behaviour of rein-forced concrete structures when subjected to static and dynamic loads. Hence the effect of hybrid fibres on the pullout behaviour of reinforcing bars embedded in high performance concrete is studied. In view of the above, an experimental program was designed to evaluate the pullout behaviour of reinforcing bars in HFRHPC as per IS 2770-1967(Part 1) reaffirmed 2002. The main variables considered in this study were steel fibres of 0.5% and 1.0% volume fraction, volume fraction of polypropylene fibres as 0.1%, 0.15% and 0.2% and diameter of reinforcing bars such as 10mm, 12mm, 16mm and 20mm

**Index Terms**— High Performance Concrete, Hybrid fibre reinforced high performance concrete, Polypropylene fibre, Pullout, Steel fibre

## 1 Introduction

High performance concrete (HPC) makes concrete a better performing material allowing designers to use it efficiently in increasingly slender structures. HPC is an engineered high tech material with high workability, high durability & high compressive strength. It is often of high strength, but high strength concrete may not be necessarily of high performance. Fibres are used in HPC whenever its intrinsic brittleness represents a limitation for its use. Hence fibre reinforced high performance concrete (FRHPC) improves the mechanical properties such as flexural toughness, ductility, impact resistance etc. The performance of reinforced concrete structures depends on adequate bond strength between concrete and reinforcing steel. Hybrid fibre reinforced high performance concrete (HFRHPC) is a relatively new technology, its pullout behaviour has to be studied extensively in order to get a clear picture about its bond performance**.**

The performance of reinforced concrete structures depends on adequate bond strength between concrete and reinforcing steel. An efficient and reliable force transfer between reinforcement and concrete is required for optimal design. The transfer of forces from the reinforcement to the surrounding concrete occurs for a deformed bar by (i) chemical adhesion between the bar and the concrete (ii) frictional forces arising from the roughness of the interface, forces transverse to the bar surface, and relative slip between the bar and the surrounding concrete; and (iii) mechanical anchorage or bearing of the ribs against the concrete surface Pullout test as per IS 2770-1967 (Part 1) reaffirmed 2002 provides a standardized procedure for comparison of bond characteristics between concrete and different types of steel reinforcing bars.

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An experimental program was designed to evaluate the pullout behaviour of reinforcing bars in HFRHPC as per IS 2770-1967(Part 1) reaffirmed 2002. A total of 96 cubes of sizes 150150150mm and 100100100mm were cast and tested for the present investigation. The main variables considered in this study were steel fibres of 0.5% and 1.0% volume fraction, volume fraction of polypropylene fibres as 0.1%, 0.15% and 0.2% and diameter of reinforcing bars such as 10mm, 12mm, 16mm and 20mm.

## 2 Experimental Programme

### 2.1 Properties of materials used

The experimental programme consists of obtaining mix proportions for HPC, casting and testing of HFRHPC specimens. The variables considered for the study are volume fractions of steel fibres (Vfs), polypropylene fibres (Vfp) and reinforcing bar diameter (φ). The specimens are tested under pullout test as per IS 2770-1967 (Part 1), reaffirmed 2002. 96 pullout specimens were cast and tested.

TABLE 1
Properties of Cement

| Sl.No | Particulars | Test Results | Requirements as per IS:12269-1987 (reaffirmed 2004) |
|---|---|---|---|
| 1 | Specific Gravity | 3.15 | - |
| 2 | Normal Consistency | 30% | - |
| 3 | Initial Setting Time | 120 min | Not less than 30 min |
| 4 | Final Setting Time | 310 min | Not more than 600 min |
| 5 | Compressive Strength | 3 day | 30.4 MPa |
| 6 | | 7 day | 40.2 MPa |
| 7 | | 28 day | 53.7 MPa |



TABLE 2
Properties of fly ash

| | |
|---|---|
| Specific gravity | 2.53 |
| Silica $SiO_2$ | 25.44% |
| Iron as $Fe_2O_3$ | 2.79% |
| Alumina as $Al_2O_3$ | 14.0% |
| Calcium as CaO | 0.67% |
| Magnesium as MgO | 0.48% |

TABLE 3
Properties of silica fume (supplied by manufacturer)

| | |
|---|---|
| Specific gravity | 2.2 |

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| | |
|---|---|
| $SiO_2$ | 90.3% |
| Moisture content | 0.60% |
| Loss on ignition at $975^0$C | 2.10% |
| Carbon | 0.80% |
| >45 Microns | 0.40% |
| Bulk Density | 640g/cc |

TABLE 4
Properties of fine aggregate

| Sl.No | Properties | Test results |
|---|---|---|
| 1 | Fineness Modulus | 2.248 |
| 2 | Specific Gravity | 2.62 |
| 3 | Bulk density | 1619 $kg/m^3$ |
| 4 | Loose density | 1535 $kg/m^3$ |
| 5 | Zone | III |
| 6 | Water absorption | 3.03 % |

TABLE 5
Properties of coarse aggregate

| Sl.No | Properties | Test results |
|---|---|---|
| 1 | Fineness Modulus | 7.387 |
| 2 | Specific Gravity | 2.81 |
| 3 | Bulk density | 1656 $kg/m^3$ |
| 4 | Loose density | 1478 $kg/m^3$ |
| 5 | Maximum size of aggregate | 12.5 mm |
| 6 | Water absorption | 0.2% |



TABLE 6
Properties of superplasticizer (supplied by manufacturer)

| | |
|---|---|
| Product Name | Conplast® SP430 |
| Specific gravity | 1.220 at $30^o$ C |
| Chloride content | Nil (IS:456) |
| Air entrainment | 1 to 2% additional air is entrained |

TABLE 7
Properties of steel fibre (supplied by manufacturer)

| | |
|---|---|
| Type of fibre | Crimped steel fibre |

| | |
|---|---|
| Length of fibre | 30 mm |
| Diameter of fibre | 0.45 mm |
| Aspect ratio | 66 |
| Ultimate tensile strength | 800 MPa |

TABLE 8
Properties of polypropylene fibre (supplied by manufacturer)

| | |
|---|---|
| Polymer | Virgin Polypropylene Homo-Polymer |
| Length of fibre | 12 mm |
| Denier per filament | 9 |
| Specific Gravity | 0.91 |
| Diameter of fibre | 37.7 μm |
| Aspect ratio | 318 |
| Tensile Strength | 550 - 600 MPa |

TABLE 9
Properties of reinforcing bars

| Sl No: | Nominal bar diameter (mm) | Yield stress (MPa) | Ultimate stress (MPa) |
|---|---|---|---|
| 1 | 10.20 | 514 | 587 |
| 2 | 12.41 | 454 | 521 |
| 3 | 16.04 | 494 | 614 |
| 4 | 20.80 | 480 | 551 |

**Spiral reinforcement**

The spiral reinforcement is provided as per IS 2770-1967(Part 1), reaffirmed 2002. 6mm diameter plain mild steel reinforcement bars of 25mm pitch is provided as spiral reinforcement. Outer diameter of the helix is equal to the size of the cube.

## 2.2 Mix for SFRHPC & HFRHPC

In the mix proportion obtained for HPC, steel fibres were added in different volume fractions to obtain SFRHPC mixes and polypropylene fibres were added along with steel fibres to obtain HFRHPC mixes. However, when fibres were added to the mix, workability got reduced and in order to increase the workability and maintain a uniform compaction factor of 0.9 for all the mixes, dosage of superplasticizer was adjusted.

TABLE 10
Mix proportion for HPC M60 grade (workability 0.9 by compaction factor)

| Particulars | Quantity |
|---|---|
| Cement | 403 $kg/m^3$ |
| Fly ash | 112 $kg/m^3$ |
| Silica fume | 45 $kg/m^3$ |
| Fine aggregate | 600 $kg/m^3$ |

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| | |
|---|---|
| Coarse aggregate | 1043 kg/m$^3$ |
| Water | 157 kg/m$^3$ |
| Superplasticizer | 24.10 litres/m$^3$ (2.1% of binder) |

## 2.3 Details of test specimens

. Experimental work includes casting of pullout specimens and testing as per IS 2770-1967 (Part 1) reaffirmed 2002. The variables considered in this study include:

i. Two different values of volume fraction of steel fibres viz. 0.5% and 1.0%
ii. Three different values of volume fraction of polypropylene fibres viz. 0.1%, 0.15% and 0.2%.
iii. Four different diameter of reinforcing bars viz. 10mm, 12mm, 16mm and 20mm.

TABLE 11
Specimen designation and variables

| Sl No: | Specimen ID | $V_{fs}$ (%) | $V_{fp}$ (%) | Cube size (mm) | Rebar diameter mm(ϕ) |
|---|---|---|---|---|---|
| 1 | S0P0ϕ1 | 0 | 0 | 100100 | 10 |
| 2 | S0P0ϕ2 | | | | 12 |
| 3 | S0P0ϕ3 | | | 150150 | 16 |
| 4 | S0P0ϕ4 | | | | 20 |
| 5 | S1P0ϕ1 | 0.5 | 0 | 100100 | 10 |
| 6 | S1P0ϕ2 | | | | 12 |
| 7 | S1P0ϕ3 | | | 150150 | 16 |
| 8 | S1P0ϕ4 | | | | 20 |
| 9 | S2P0ϕ1 | 1 | 0 | 100100 | 10 |
| 10 | S2P0ϕ2 | | | | 12 |
| 11 | S2P0ϕ3 | | | 150150 | 16 |
| 12 | S2P0ϕ4 | | | | 20 |
| 13 | S0P1ϕ1 | 0 | 0.10 | 100100 | 10 |
| 14 | S0P1ϕ2 | | | | 12 |
| 15 | S0P1ϕ3 | | | 150150 | 16 |
| 16 | S0P1ϕ4 | | | | 20 |
| 17 | S0P2ϕ1 | 0 | 0.15 | 100100 | 10 |
| 18 | S0P2ϕ2 | | | | 12 |
| 19 | S0P2ϕ3 | | | 150150 | 16 |
| 20 | S0P2ϕ4 | | | | 20 |
| 21 | S0P3ϕ1 | 0 | 0.20 | 100100 | 10 |
| 22 | S0P3ϕ2 | | | | 12 |
| 23 | S0P3ϕ3 | | | 150150 | 16 |
| 24 | S0P3ϕ4 | | | | 20 |

| | | | | | |
|---|---|---|---|---|---|
| 25 | S1P1ϕ1 | 0.5 | 0.10 | 100100 | 10 |
| 26 | S1P1ϕ2 | | | | 12 |
| 27 | S1P1ϕ3 | | | 150150 | 16 |
| 28 | S1P1ϕ4 | | | | 20 |
| 29 | S1P2ϕ1 | 0.5 | 0.15 | 100100 | 10 |
| 30 | S1P2ϕ2 | | | | 12 |
| 31 | S1P2ϕ3 | | | 150150 | 16 |
| 32 | S1P2ϕ4 | | | | 20 |
| 33 | S1P3ϕ1 | 0.5 | 0.20 | 100100 | 10 |
| 34 | S1P3ϕ2 | | | | 12 |
| 35 | S1P3ϕ3 | | | 150150 | 16 |
| 36 | S1P3ϕ4 | | | | 20 |
| 37 | S2P1ϕ1 | 1.0 | 0.10 | 100100 | 10 |
| 38 | S2P1ϕ2 | | | | 12 |
| 39 | S2P1ϕ3 | | | 150150 | 16 |
| 40 | S2P1ϕ4 | | | | 20 |
| 41 | S2P2ϕ1 | 1.0 | 0.15 | 100100 | 10 |
| 42 | S2P2ϕ2 | | | | 12 |
| 43 | S2P2ϕ3 | | | 150150 | 16 |
| 44 | S2P2ϕ4 | | | | 20 |
| 45 | S2P3ϕ1 | 1.0 | 0.20 | 100100 | 10 |
| 46 | S2P3ϕ2 | | | | 12 |
| 47 | S2P3ϕ3 | | | 150150 | 16 |
| 48 | S2P3ϕ4 | | | | 20 |



## 3 Testing Of Specimens

The test was conducted on Universal Testing Machine as per IS 2770 1967 Part 1 (reaffirmed 2002).

TABLE 12
Details of failure mode of specimen

| Sl No: | Specimen | Failure mode |
|---|---|---|
| 1 | S0P0ϕ1 | Yielding |
| 2 | S0P0ϕ2 | Pullout |
| 3 | S0P0ϕ3 | Pullout |
| 4 | S0P0ϕ4 | Pullout |
| 5 | S1P0ϕ1 | Yielding |
| 6 | S1P0ϕ2 | Yielding |
| 7 | S1P0ϕ3 | Yielding |

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| | | |
|---|---|---|
| 8 | S1P0ϕ4 | Pullout |
| 9 | S2P0ϕ1 | Yielding |
| 10 | S2P0ϕ2 | Yielding |
| 11 | S2P0ϕ3 | Pullout |
| 12 | S2P0ϕ4 | Pullout |
| 13 | S0P1ϕ1 | Yielding |
| 14 | S0P1ϕ2 | Pullout |
| 15 | S0P1ϕ3 | Pullout |
| 16 | S0P1ϕ4 | Pullout |
| 17 | S0P2ϕ1 | Pullout |
| 18 | S0P2ϕ2 | Yielding |
| 19 | S0P2ϕ3 | Pullout |
| 20 | S0P2ϕ4 | Pullout |
| 21 | S0P3ϕ1 | Pullout |
| 22 | S0P3ϕ2 | Pullout |
| 23 | S0P3ϕ3 | Pullout |
| 24 | S0P3ϕ4 | Pullout |
| 25 | S1P1ϕ1 | Yielding |
| 26 | S1P1ϕ2 | Yielding |
| 27 | S1P1ϕ3 | Yielding |
| 28 | S1P1ϕ4 | Pullout |
| 29 | S1P2ϕ1 | Yielding |
| 30 | S1P2ϕ2 | Pullout |
| 31 | S1P2ϕ3 | Yielding |
| 32 | S1P2ϕ4 | Pullout |
| 33 | S1P3ϕ1 | Yielding |
| 34 | S1P3ϕ2 | Yielding |
| 35 | S1P3ϕ3 | Pullout |
| 36 | S1P3ϕ4 | Pullout |
| 37 | S2P1ϕ1 | Yielding |
| 38 | S2P1ϕ2 | Yielding |
| 39 | S2P1ϕ3 | Yielding |
| 40 | S2P1ϕ4 | Pullout |
| 41 | S2P2ϕ1 | Pullout |
| 42 | S2P2ϕ2 | Yielding |
| 43 | S2P2ϕ3 | Pullout |
| 44 | S2P2ϕ4 | Pullout |
| 45 | S2P3ϕ1 | Pullout |
| 46 | S2P3ϕ2 | Yielding |
| 47 | S2P3ϕ3 | Pullout |
| 48 | S2P3ϕ4 | Pullout |

In the pullout mode of failure, the bond failure occurred by pullout of the bars. In this type of failure, the crushing of concrete at the toe of the bar rib and the shearing off concrete of the ribs were observed.


**a** **b**

**c**

Fig1. (a) shows pullout failure with reinforcing bar. (b) and (c) shows the cube specimen after the removal of reinforcing bar (16mm) in S2P0 and S0P2 mixes respectively. In pullout type of failure, the ultimate bond stress of the specimens is calculated.

The other type of failure observed was yielding failure. In this type the steel bar reached its maximum stress. Also the ultimate load of specimens is not calculated. Hence the bond stress @ 0.025mm free end slip of all the specimens were calculated for the study. Figure below shows the yielding type of failure obtained.

Fig 2 Yielding type of failure



## 3 Analysis Of Test Results

TABLE 13

Results of tested specimens

| Sl No | Specimen ID | Embedment length to diameter ratio ($L_b$ / ϕ) | Mean cube compressive strength of concrete (MPa) | Bond Stress @ 0.025mm slip (MPa) | Ultimate load (pullout/ yield) (kN) | Ultimate bond stress (MPa) |
|---|---|---|---|---|---|---|
| 1 | S0P0ϕ1 | 10.00 | 59.89 | 13.00 | 44 | >14.01 |
| 2 | S0P0ϕ2 | 8.33 | 59.89 | 10.20 | 58 | 15.38 |
| 3 | S0P0ϕ3 | 9.37 | 59.89 | 9.60 | 122 | 16.18 |
| 4 | S0P0ϕ4 | 7.50 | 59.89 | 8.10 | 145 | 15.38 |
| 5 | S1P0ϕ1 | 10.00 | 62.43 | 12.40 | 47 | >14.96 |
| 6 | S1P0ϕ2 | 8.33 | 62.43 | 11.80 | 60 | >15.91 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | S1P0ϕ3 | 9.37 | 62.43 | 10.40 | 126 | >16.71 |
| 8 | S1P0ϕ4 | 7.50 | 62.43 | 8.70 | 125 | 13.26 |
| 9 | S2P0ϕ1 | 10.00 | 58.80 | 12.80 | 51 | >16.23 |
| 10 | S2P0ϕ2 | 8.33 | 58.80 | 13.50 | 61 | >16.18 |
| 11 | S2P0ϕ3 | 9.37 | 58.80 | 13.60 | 106 | 14.06 |
| 12 | S2P0ϕ4 | 7.50 | 58.80 | 9.20 | 160 | 16.55 |
| 13 | S0P1ϕ1 | 10.00 | 59.78 | 11.90 | 50 | >15.91 |
| 14 | S0P1ϕ2 | 8.33 | 59.78 | 11.40 | 54 | 14.32 |
| 15 | S0P1ϕ3 | 9.37 | 59.78 | 12.80 | 110 | 14.58 |
| 16 | S0P1ϕ4 | 7.50 | 59.78 | 8.90 | 135 | 14.20 |
| 17 | S0P2ϕ1 | 10.00 | 62.50 | 11.60 | 38 | 12.09 |
| 18 | S0P2ϕ2 | 8.33 | 62.50 | 13.40 | 62 | >16.45 |
| 19 | S0P2ϕ3 | 9.37 | 62.50 | 12.00 | 126 | 16.72 |
| 20 | S0P2ϕ4 | 7.50 | 62.50 | 8.40 | 145 | 15.38 |
| 21 | S0P3ϕ1 | 10.00 | 59.59 | 12.00 | 52 | 16.55 |
| 22 | S0P3ϕ2 | 8.33 | 59.59 | 11.30 | 55 | 14.58 |
| 23 | S0P3ϕ3 | 9.37 | 59.59 | 11.70 | 112 | 14.85 |
| 24 | S0P3ϕ4 | 7.50 | 59.59 | 8.20 | 135 | 14.32 |
| 25 | S1P1ϕ1 | 10.00 | 60.20 | 13.40 | 47 | >14.96 |
| 26 | S1P1ϕ2 | 8.33 | 60.20 | 13.60 | 61 | >16.18 |
| 27 | S1P1ϕ3 | 9.37 | 60.20 | 13.20 | 120 | >15.91 |
| 28 | S1P1ϕ4 | 7.50 | 60.20 | 8.50 | 170 | 15.38 |
| 29 | S1P2ϕ1 | 10.00 | 63.10 | 14.40 | 48 | >15.28 |
| 30 | S1P2ϕ2 | 8.33 | 63.10 | 14.20 | 65 | 17.24 |
| 31 | S1P2ϕ3 | 9.37 | 63.10 | 13.50 | 119 | >15.78 |
| 32 | S1P2ϕ4 | 7.50 | 63.10 | 8.60 | 170 | 15.38 |
| 33 | S1P3ϕ1 | 10.00 | 62.60 | 13.90 | 51 | >16.23 |
| 34 | S1P3ϕ2 | 8.33 | 62.60 | 14.50 | 65 | >17.24 |
| 35 | S1P3ϕ3 | 9.37 | 62.60 | 12.50 | 116 | 15.38 |
| 36 | S1P3ϕ4 | 7.50 | 62.60 | 7.40 | 165 | 15.91 |
| 37 | S2P1ϕ1 | 10.00 | 62.80 | 12.81 | 61 | >19.41 |
| 38 | S2P1ϕ2 | 8.33 | 62.80 | 15.30 | 63 | >16.71 |
| 39 | S2P1ϕ3 | 9.37 | 62.80 | 14.10 | 119 | >15.78 |
| 40 | S2P1ϕ4 | 7.50 | 62.80 | 10.80 | 145 | 15.38 |
| 41 | S2P2ϕ1 | 10.00 | 63.30 | 13.80 | 51 | 16.23 |
| 42 | S2P2ϕ2 | 8.33 | 63.30 | 12.00 | 61 | >16.18 |
| 43 | S2P2ϕ3 | 9.37 | 63.30 | 11.30 | 108 | 14.32 |
| 44 | S2P2ϕ4 | 7.50 | 63.30 | 10.40 | 155 | 14.32 |
| 45 | S2P3ϕ1 | 10.00 | 62.70 | 12.80 | 46 | 14.64 |
| 46 | S2P3ϕ2 | 8.33 | 62.70 | 14.00 | 63 | >16.71 |
| 47 | S2P3ϕ3 | 9.37 | 62.70 | 11.50 | 108 | 14.32 |
| 48 | S2P3ϕ4 | 7.50 | 62.70 | 9.00 | 155 | 14.32 |



Fig 3 Ultimate bond stress versus slip behaviour of φ4 specimens

Fig. 4 Bond stress versus slip behaviour of S0P0φ1 & S0P0φ2

Fig. 5 Bond stress versus slip behaviour of HPC, φ3 & φ4 specimens

Fig. 6 Bond stress versus slip behaviour of φ3 & φ4 SFRHPC specimens

Fig. 7 Bond stress versus slip behaviour of φ1 & φ2 PFRHPC specimens

Fig. 8 Bond stress versus slip behaviour of φ3 & φ4 PFRHPC specimens

Fig. 9 Bond stress versus slip behaviour of SFRHPC specimens (φ1)

Fig. 10. Bond stress versus slip behaviour of PFRHPC specimens (φ1)

Fig. 11 Bond stress versus slip behaviour of HFRHPC specimens (φ1) with 1% steel fibres & varying values of polypropylene fibres

Fig. 12 Bar chart showing the bond stress values @ 0.025mm slip (φ1 bar)

Fig. 13 Bond stress versus slip behaviour of SFRHPC specimens (φ2)

Fig. 14 Bond stress versus slip behaviour of PFRHPC specimens (φ2)

Fig 15. Bond stress versus slip behaviour of HFRHPC specimens (φ2) with 0.5% steel fibres & varying values of polypropylene fibres

Fig. 16 Bar chart showing the bond stress values @ 0.025mm slip (φ2)

Fig. 17 Bond stress versus slip behaviour of SFRHPC specimens (φ3)

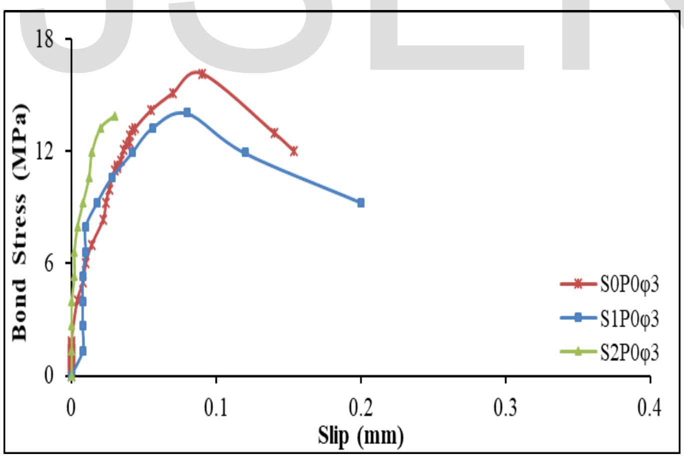


Fig 18 Bond stress versus slip behaviour of PFRHPC specimens (ϕ3)

Fig. 19 Bond stress versus slip behaviour of HFRHPC specimens (φ3) with 0.5% steel fibres & varying values of polypropylene fibres

Fig. 20 Bar chart showing the bond stress values @ 0.025mm slip (φ3)

Fig. 21 Bond stress versus slip behaviour of PFRHPC specimens (φ4)

Fig 22 Bond stress versus slip behaviour of HFRHPC specimens (φ4) with 0.5% steel fibres & varying values of polypropylene fibres

Fig. 23 Bar chart showing the bond stress values @ 0.025mm slip (φ4)

Table 14
Bond stress enhancement ratio of tested specimens

| Sl No: | Specimen ID | Bond stress enhancement ratio |
|---|---|---|
| 1 | S0P0ϕ1 | 1.00 |
| 2 | S1P0ϕ1 | 0.95 |
| 3 | S2P0ϕ1 | 0.98 |
| 4 | S0P1ϕ1 | 0.92 |
| 5 | S0P2ϕ1 | 0.89 |
| 6 | S0P3ϕ1 | 0.92 |
| 7 | S1P1ϕ1 | 1.10 |
| 8 | S1P2ϕ1 | 1.11 |
| 9 | S1P3ϕ1 | 1.07 |
| 10 | S2P1ϕ1 | 0.99 |
| 11 | S2P2ϕ1 | 1.06 |
| 12 | S2P3ϕ1 | 0.98 |
| 13 | S0P0ϕ2 | 1.00 |
| 14 | S1P0ϕ2 | 1.16 |
| 15 | S2P0ϕ2 | 1.33 |
| 16 | S0P1ϕ2 | 1.12 |
| 17 | S0P2ϕ2 | 1.31 |
| 18 | S0P3ϕ2 | 1.11 |
| 19 | S1P1ϕ2 | 1.33 |
| 20 | S1P2ϕ2 | 1.39 |
| 21 | S1P3ϕ2 | 1.42 |
| 22 | S2P1ϕ2 | 1.50 |
| 23 | S2P2ϕ2 | 1.18 |
| 24 | S2P3ϕ2 | 1.37 |
| 25 | S0P0ϕ3 | 1.00 |
| 26 | S1P0ϕ3 | 1.07 |
| 27 | S2P0ϕ3 | 1.43 |
| 28 | S0P1ϕ3 | 1.33 |
| 29 | S0P2ϕ3 | 1.25 |
| 30 | S0P3ϕ3 | 1.22 |
| 31 | S1P1ϕ3 | 1.38 |
| 32 | S1P2ϕ3 | 1.41 |
| 33 | S1P3ϕ3 | 1.30 |
| 34 | S2P1ϕ3 | 1.47 |
| 35 | S2P2ϕ3 | 1.18 |
| 36 | S2P3ϕ3 | 1.20 |
| 37 | S0P0ϕ4 | 1.00 |
| 38 | S1P0ϕ4 | 1.06 |
| 39 | S2P0ϕ4 | 1.14 |
| 40 | S0P1ϕ4 | 1.05 |

| | | |
|---|---|---|
| 41 | S0P2ϕ4 | 1.04 |
| 42 | S0P3ϕ4 | 1.01 |
| 43 | S1P1ϕ4 | 1.11 |
| 44 | S1P2ϕ4 | 1.07 |
| 45 | S1P3ϕ4 | 0.96 |
| 46 | S2P1ϕ4 | 1.33 |
| 47 | S2P2ϕ4 | 1.28 |
| 48 | S2P3ϕ4 | 1.11 |

Fig 23 Bar chart showing the bond stress values @ 0.025mm slip (φ4 bar)

## 7 Conclusions

An experimental investigation was carried out to study the effect of hybrid fibres on the pullout behavior of reinforcing bars in HPC. The effect of steel and polypropylene fibres were also a concern of the study. A total of 96 pullout specimens were cast and tested for the present study. The pullout test was conducted as per IS 2770 1967 Part1 (reaffirmed 2002).

- The confinement and bridging effects provided by fibres in HFRHPC specimens enhanced the bond stress of reinforcing bars embedded in such composites compared to plain HPC.

- Test results show that the pullout specimen with smaller bar size has greater bond stress than the specimen with larger diameter bar. So to enhance the bond stress, hybrid fibres are more effective in larger diameter bars while compared to smaller bars.

- Enhancement of bond stress in SFRHPC and PFRHPC specimens are 23% and 10% respectively. Whereas in HFRHPC specimens, with combination of 1% steel fibres and 0.1% polypropylene fibres significantly improves the bond stress upto 40% for 12mm, 16mm and 20mm diameter bars when compared to 10mm diameter bar.

- The increase in bond stress for the hybrid combination of 0.5% volume fraction of steel fibres and 0.15% volume faction of polypropylene fibres yield the same result as that of 1% volume fraction of steel fibres.

- The application of hybrid fibres can reduce the development length of deformed bars in high performance concrete.



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