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# Bond stress slip response of bars embedded in hybrid fibre reinforced high performance concrete

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## HIGHLIGHTS

- Developed a hybrid fibre reinforced high performance concrete (HFRHPC).
- Bond stress–slip response of deformed bars was investigated using pullout tests.
- Significant increase in bond stress was observed for bars embedded in HFRHPC.
- The anchorage length of bars can be reduced by the usage of HFRHPC.

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## ABSTRACT

Pullout tests were carried out to study the effect of steel-polypropylene hybrid fibres on the bond strength and bond stress–slip response of deformed reinforcement bars embedded in high performance concrete. A total of 96 specimens were cast and tested in the present investigation. The main variables considered were the volume fraction of crimped steel fibres, volume fraction of polypropylene fibres and the diameter of reinforcement bars. The combination of 1% volume fraction of steel fibres and 0.10% volume fraction of polypropylene fibres gave better performance with respect to bond strength than the other combinations considered in this study.



## 1. Introduction

Bond strength is an important structural property of reinforced concrete which is responsible for transfer of forces between concrete and reinforcing steel thereby ensuring strain compatibility and composite action. Insufficient bond can lead to a significant decrease in the load carrying capacity and stiffness of the structure when subjected to different loading conditions [1]. Basically, bond between a reinforcing steel bar and the surrounding concrete depends on chemical adhesion, friction and mechanical interaction between the ribs of the bar and the surrounding concrete. Previous studies on bond performance indicate that bond strength is governed by different factors such as the strength of the concrete, the thickness of the concrete surrounding the reinforcing bar, the confinement of the concrete due to transverse reinforcement and the bar geometry [2–8]. Several investigations were carried out to study the effect of using steel fibres on the bond between concrete and deformed steel bar. The use of steel fibre reinforced concrete is known to improve the mechanical properties, control the crack formation and increase the ductile behaviour of the concrete [9]. Researchers found that such enhanced properties lead to an increase in the bond between concrete and deformed steel bar in steel fibre reinforced concrete [10–13]. Fibres, if randomly dispersed throughout the concrete matrix, provide better distribution of both internal and external stresses due to the formation of a three dimensional reinforcing network [14]. Fibre reinforced concrete (FRC) used in practice generally contain only one type of fibre. The characteristics of fibre reinforced concrete depend upon the properties and volume fraction of fibres and each type of fibre can be effective with regard to some specific function [9]. The most important function of the fibres in concrete is to bridge across the cracks and delay the propagation of cracks which provides post-cracking ductility. However, it is known that failure in concrete is a gradual, multi-scale process. Under an applied load,

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**Table 1**
Properties of cement.

| Properties | | Test results |
|---|---|---|
| Specific gravity | | 3.15 |
| Normal consistency | | 30% |
| Initial setting time | | 120 min |
| Final setting time | | 310 min |
| Compressive strength | 3 days | 30.4 MPa |
| | 7 days | 40.2 MPa |
| | 28 days | 54.7 MPa |

**Table 2**
Properties of fly ash.

| | |
|---|---|
| Specific gravity | 2.36 |
| Silica, $SiO_2$ | 55.29% |
| Alumina, $Al_2O_3$ | 23.20% |
| Iron oxide, $Fe_2O_3$ | 10.75% |
| Calcium oxide, CaO | 5.58% |
| Magnesium oxide, MgO | 1.07% |
| Sulphate, $SO_3$ | 1.80% |
| Potassium oxide, $K_2O$ | 2.54% |
| Grade | F |

**Table 3**
Properties of silica fume.

| | |
|---|---|
| Specific gravity | 2.2 |
| $SiO_2$ | 90.3% |
| Moisture content | 0.6% |
| Retained on 45 μm sieve | 0.4% |
| Bulk density | 640 kg/m$^3$ |

**Table 4**
Properties of fibres.

| Type of fibre | Length (mm) | Diameter (mm) | Aspect ratio | Ultimate tensile strength (MPa) |
|---|---|---|---|---|
| Crimped steel fibre | 30 | 0.45 | 66 | 800 |
| Polypropylene fibre | 12 | 0.038 | 316 | 550–600 |

**Table 5**
Mix proportion for M60 grade HPC.

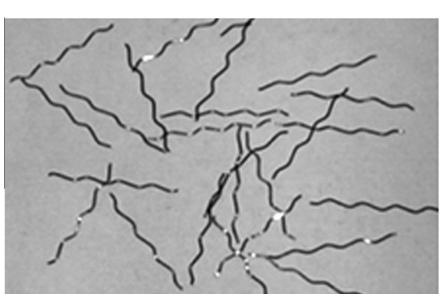
| Particulars | Quantity (kg/m$^3$) |
|---|---|
| Cement | 403 |
| Fly ash | 112 |
| Silica fume | 45 |
| Sand | 603 |
| Coarse aggregate | 1043 |
| Water | 158 |
| Superplasticizer | 11.76 |

**Table 6**
Properties of deformed reinforcement bars.

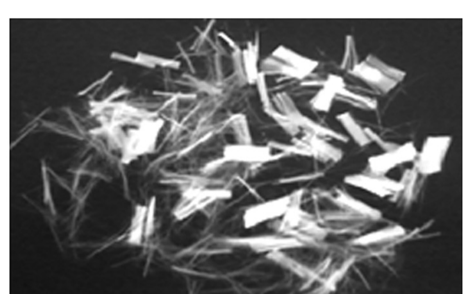
| Sl. no: | Nominal diameter of bar (mm) | Actual diameter of bar (mm) | Yield strength (MPa) | Ultimate strength (MPa) |
|---|---|---|---|---|
| 1 | 10 | 10.20 | 514 | 587 |
| 2 | 12 | 12.41 | 454 | 521 |
| 3 | 16 | 16.04 | 494 | 614 |
| 4 | 20 | 20.80 | 480 | 551 |

pre-existing microcracks in concrete grow and join together to form macrocracks. A macrocrack propagates at a stable rate until it attains conditions of unstable propagation and cause a sudden failure. The gradual and multi-scale nature of the fracture in concrete implies that a given fibre can be effective only at one level and within a limited range of strains [15]. Attempts have been made in the past to combine different types of fibres and addition of the same to cementitious composites in order to improve the cracking performance in concrete at different levels [16–18]. Small and soft fibres control initiation and propagation of microcracks and the large and strong fibres control macrocracks. Such hybrid fibre reinforced composite can also offer more attractive engineering properties because the presence of one type of fibre effectively utilizes the properties of the other fibre [19–22].

Review of literature shows that a number of studies were carried out in the past on the bond strength and behaviour of reinforcement bars in fibre reinforced concrete. The effects of steel fibres on the bond strength of deformed bars in normal and high-strength concrete was studied by Ezeldin and Balaguru [10] and they observed that adding fibres to concrete substantially improves the bond-slip behaviour of reinforcing bars after the development of splitting cracks. The slip at maximum bond stress increases with increase in fibre content and the contribution of fibres to bond strength is considerable for larger diameter bars as compared to smaller diameter bars. Harajli et al. [11] reported that the presence of fibres (steel or polypropylene) in concrete restricts the growth of the splitting cracks and leads to a much higher bond resistance. Polypropylene fibres provided about 1/3 of the increase in bond resistance provided by hooked steel fibres after the peak load. Chao et al. [1] showed that the bridging effect provided by fibres in fibre reinforced composites after cracking can effectively provide post-cracking tensile capacity to the concrete matrix and



(a) Crimped steel fibres



(b) Polypropylene fibres

**Fig. 1.** Fibres used.