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BOND BEHAVIOR OF LIGHTWEIGHT FIBER REINFORCED CONCRETE

KLAUS HOLSCHEMACHER, AHSAN ALI, and SHAHID IQBAL

Dept of Civil Engineering, University of Applied Sciences (HTWK) Leipzig, Germany

In construction industry lightweight concrete and fiber reinforced concrete are being used for many years. The former is known for brittle nature, light in weight and low thermal conductivity properties. It also offers better workability when compared to the normal weight concrete for the same slump value. These properties are however affected by addition of discrete fibers. Among the affected properties is also the bond between steel and concrete surrounding it. The integrity of a reinforced concrete member is not ensured in the absence of adequate bond. Due to limited literature on the subject matter, an experimental program was carried out to understand the bond behavior in lightweight concrete after fiber inclusion. For the purpose modified pull-out specimens made of Lightweight Fiber Reinforced Concrete (LWFC) were tested. Hooked end steel fibers having length 35 mm and diameter 0.5 mm (l/d = 0.7) were incorporated in dosages of 0, 20, and 40 kg/m^3. Besides pull-out specimens, testes were also carried out for fresh and hardened properties of LWFC. Tests results indicate higher pull-out loads for higher fiber contents. The average increase in ultimate bond strength was observed at 28% and 2% for 40 kg/m^3 and 20 kg/m^3 fiber contents respectively. The fresh concrete density, compressive strength of mixes reduced and air-content values increased with increase in fiber content.

Keywords: Pull-out, Flexure, Steel fibers, Hooked-end, Bond strength, Mechanical properties.

1 INTRODUCTION

In construction industry lightweight concrete and fiber reinforced concrete are being used for many years. The former is known for brittle nature, light in weight and low thermal conductivity properties. It also offers better workability when compared to the normal weight concrete for the same slump value (Neville 2012). These properties are affected by addition of discrete fibers; the effect being variable with the type and volume fraction of fibers.

The integrity of a structural element is not ensured in the absence of proper bond between the reinforcement and the concrete surrounding it. Current experimental work encompasses the effect of steel fiber addition on bond strength of Lightweight Fiber Reinforced Concrete (LWFC); in addition to this, effect on other mechanical properties is also discussed. It is now established, that the bond strength is influenced by different factors, categorized by structural, geometrical and material properties. ACI 408 (ACI 408R-03 2003) provides a good overview of these parameters. Many of the studies (Harajli *et al.* 2002, Holschemacher and Weiße 2004, Mitchell and Marzouk 2007, Barbosa *et al.* 2008, Harajli 2010, Kim *et al.* 2013) have discussed some of these parameters and their influence on bond behavior of different types of concrete, and in most cases normal weight concrete was used; however, little information is available on bond behavior of LWFC.

2 EXPERIMENTAL PROGRAM

2.1 Materials

Expanded clay, having particle density of 1190 kg/m^3 and particle size ranging from 2 to 10 mm was used as a coarse aggregate. Selected natural sand used as fine aggregate had particle density of 2570 kg/m^3. Ordinary Portland Cement (CEM-1/ 42.5N) was chosen as a binding material. Fibrous mixes incorporated hooked-end steel fibers (Figure 1) 35 mm in length and 0.5 mm in diameter having aspect ratio (l/d) of 70.

Figure 1. Hooked-end steel fibers used in fibrous mixes.

For controlling workability, Polycarboxylate Ether-based superplasticizer was used. 10 mm bar size having yield and ultimate strength of 500 and 600 MPa respectively was used in bond specimens. Detail of mix design used in experimental work is tabulated in Table-1.

Table 1. Concrete mix composition.

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Total Water (kg/m^3)	Superplasticizer (%*)	Effective w/c
360	772	472	204	0.5	0.35

2.2 Specimens

For bond strength evaluation through Pull-out test, RILEM (2006) guidelines suggest 200×200×200 mm^3 size of the specimen for the size of reinforcement used in current experimental work. Thus leaving concrete cover of 95 mm around reinforcement, which is not common in routine construction practice. For this reason modified RILEM pull-out specimens shown in Figure 2 were used to study the bond behavior. Besides Pull-out specimens, beam and cylinders were also cast to determine the effect of fibers on other mechanical properties. Specimens were numbered as LWFC-N1-N2, where LWFC represents lightweight aggregate fiber reinforced concrete and N1, N2 denote fiber content in kg/m^3 and specimen number respectively. Parameters like diameter of the bar (d_b = 10 mm) and bond length ($L_d = 5d_b$) were held constant throughout the testing.

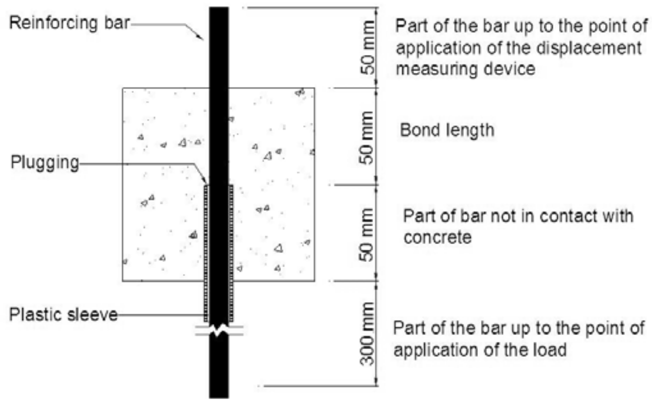

Figure 2. Pull-out specimen details.

2.3 Test Set-up

Bond tests were performed using the 600 kN displacement controlled testing machine. For recording displacement, six LVDTs, three on loaded side of specimen and three on the free side were attached. However because of the noticeable local disturbance during loading, data from free-end LVDTs only is used in the analysis. Specimens were loaded at displacement rate of 0.005 mm/s.

3 RESULTS

3.1 Concrete Properties

Fresh density for all concrete mixes was determined using 5 liter cylindrical mold. Mix with higher fiber content attained the lowest concrete density while that without fibers had the highest (Figure 3). It is because, as the fiber dosage increased, air-content also increased.

Effort required for working with fiber reinforced concrete is reduced when lightweight aggregate is used instead of normal weight aggregate (Neville 2012). In current experimental work slump cone method was used to determine the workability of both types of concrete i.e. lightweight and LWFC. Figure 3 shows the effect of fiber addition on workability in terms of slump.

28-days compressive strength for all mixes was determined using cylinders of 100 mm diameter and 200 mm height. Pressure rate of 0.25 MPa/sec was maintained throughout compression tests. In general, all the specimens with fibers had lower compressive strength when compared with controlled cylinders. Difference in compressive strength results is however not significant, for example in extreme case there was a variation of only 4 MPa.

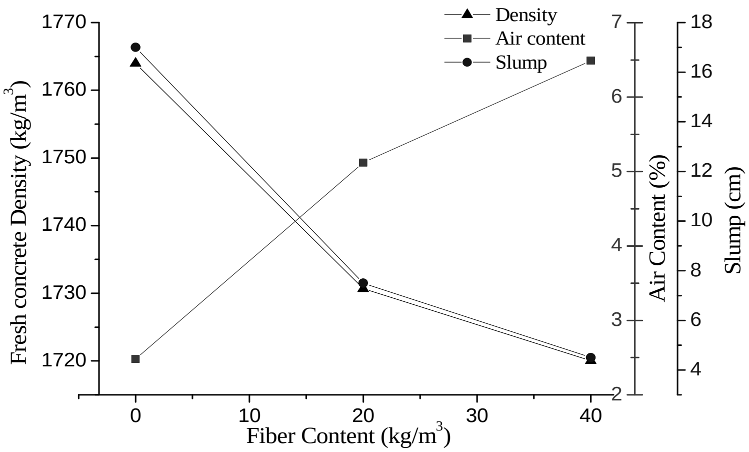

Figure 3. Effect of fiber content on fresh concrete properties.

Split cylinder tests on 100 mm by 200 mm cylinders and flexural tests on beams (150mm×150mm×550 mm) were performed to assess the tensile capacity and flexural performance. Although cylindrical specimens with fibers developed failure crack at lower loads, they kept on absorbing the energy as the fibers continued resisting crack propagation. The values in Figure 4 for split cylinder tensile strength are not the ones recorded at the first crack, but represent the maximum values logged by the testing machine for LWFC specimens. Tensile strength, when judged from modulus of rupture values at first crack, shows percent increase of 25.6 and 26.5 for specimens LWFC-20 and LWFC-40 respectively.

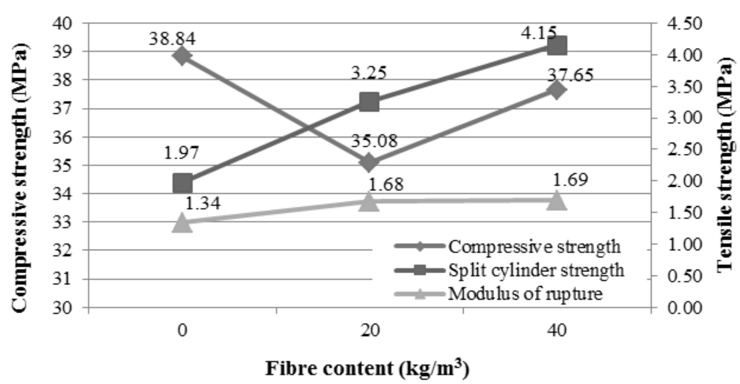

Figure 4. Effect of fiber addition on hardened concrete properties.

In terms of flexural performance, all the tested beams failed in the maximum moment region. Specimens with higher fiber content attained higher first cracking load. An increase of 26% was observed in modulus of rupture values for both 20 and 40 kg/m^3 fiber contents. Significant improvement was noted in post cracking performance of specimens with fibers, these specimens attained higher peak loads and an increase in peak strength up to 62% was observed for specimens with fiber dosages of 40 kg/m^3.

3.2 Pull-out Test Results

All the pull-out specimens failed by splitting of concrete, crack resistance offered by aggregates in specimens without fibers was of no appreciable magnitude. On slight higher loads, aggregates crushed due to their lower density and lower grain strength (around 9 MPa).

Effect of increase in modulus of rupture value was not observed in pull-out tests, the first cracking load for all the pull-out specimens was around 12 kN. This leads to conclusion that fibers did not add to the tensile strength of concrete before first crack, which is in agreement with the previous reports by Balaguru & Shah (1992) and Shah (1991). Specimens with 20 kg/m^3 fiber content had an average ultimate bond strength value of 12 MPa which is only 2% higher than specimens without fibers. Whereas 28% increase was observed in ultimate bond strength of specimens with 40 kg/m^3 fiber content. This improvement in performance can be attributed to the better confinement to concrete by fibers and increasing resistance to crack propagation, as the quantity of fibers is increased. Table 2 & Figure 5 present test results of all the pull-out specimens.

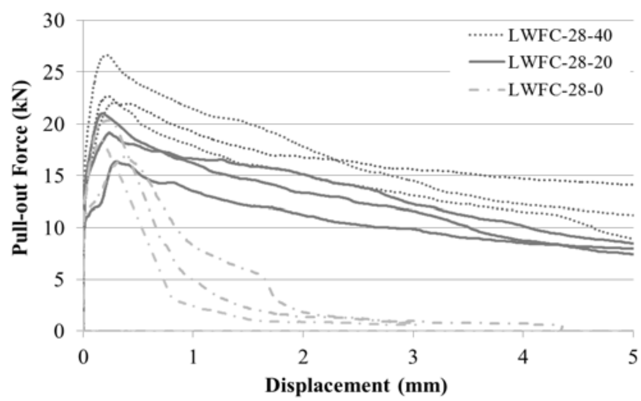

Figure 5. Load-displacement curves of Pull-out specimens.

Table 2. Pull-out test results.

Specimen	Age (days)	Fiber content (Kg/m^3)	Ultimate pull-out load (kN)	Ultimate bond strength (MPa)
LWFC-00-1	28	0	20.33	12.94
LWFC-00-2	28	0	16.85	10.73
LWFC-00-3	28	0	18.41	11.72
LWFC-20-1	28	20	19.15	12.19
LWFC-20-2	28	20	16.37	10.42
LWFC-20-3	28	20	21.05	13.40
LWFC-40-1	28	40	26.62	16.94
LWFC-40-2	28	40	22.70	14.45
LWFC-40-3	28	40	22.06	14.04

4 CONCLUSION

- Addition of steel fibers in lightweight concrete proved to be advantageous for most of its properties. Lower weight and round shape of coarse aggregate helped in minimizing the handling (workability) issue.
- Although compressive strength decreased slightly for higher fiber content, tensile strength calculated from modulus of rupture value increased.
- Splitting failure was seen in all the pull-out specimens.
- Since fiber addition results in confining concrete, this confined concrete offers better resistance to cracks once they have developed. In other words for same pull-out loads more effective concrete area is available around rebar when compared with concrete without fibers.
- Ultimate bond strength of lightweight concrete increased with the addition of fiber content. An increase up to 28% was observed with 40 kg/m^3 fiber content.

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