Construction and Building Materials 40 (2013) 299–305

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

The effect of steel fiber on the bond between concrete and deformed steel bar in SFRCs

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HIGHLIGHTS

- ▶ The concrete–reinforcement bond was increased with the increase in concrete cover thickness.
- ▶ Presence of steel fibers, the concrete–reinforcement bond increased.
- ▶ The concrete–reinforcement bond was raised with the increase in mechanical properties of SFRCs.

ARTICLE INFO

Article history:
Received 10 April 2012
Received in revised form 12 September 2012
Accepted 25 September 2012
Available online 7 December 2012

Keywords:
Bond
Concrete
Reinforcing bar
Concrete cover
Steel fiber

ABSTRACT

In this study, the effect of steel fiber amount and concrete cover on concrete deformed steel bar bond of steel fiber concretes (SFRCs) has been investigated. Steel fibers with *l*/*d* ratios of 60 and 80 were added to the concretes designed in C20, C40 and C60 classes in 10, 20, 30, 40, 60 and 80 kg/m^3 amounts. S420 deformed steel bars with 14 mm diameter were embedded at 70 mm bond length to cubic specimens prepared from the concretes produced with and without steel fiber enabling the concrete cover to be 40, 55 and 70 mm. The specimens were subjected to pullout test. Moreover, 28-day mechanical tests of the concretes produced were defined.

As a result of the studies conducted, the pullout loads are found to increase by 7–16% when the amount of steel fibers and aspect ratio in the SFRCs produced increase when compared to concretes without steel fiber. In addition, the concrete reinforcement bond was mathematically modeled using 28-day mechanical properties of the concretes and the concrete covers.

Contents

1. Introduction

The shear stress enabling the bond between the concrete and reinforcement bar is defined as bond. In reinforced concrete,

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0950-0618/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2012.09.098

concrete and reinforcement bar may deform at different levels due to factors such as load, corrosion, high temperature, creep, and shrinkage. Such deformations between the concrete and the reinforcement bar result in the transfer of stress via the bond developed between the two different materials. This bond serves as the basis for the behavior of the reinforced concrete [1,2]. The concrete–reinforcement bond is considered to stem from three main factors: molecular bond strengths which ensure the bond between steel bar and concrete, friction force forming between steel bar and concrete and the mechanical tread strengths between the deformed steel bar and concrete. The bond is known to develop in plain bars mainly due to the first two factors and mainly due to the above listed third factor in deformed steel bars. The factors affecting the bond between the concrete and deformed steel bar include the tensile strength of the concrete, yield strength of the steel, diameter of the deformed steel bar, surface geometry of the deformed steel bar, the depth at which the deformed steel bar is embedded into the concrete, the thickness of the concrete cover surrounding the reinforcement, the position of the steel bar in the concrete, the types of aggregates and admixtures used in the concrete and the use of spiral reinforcement [1,3].

The strength of the bond between the concrete and the deformed steel bar is generally calculated via pullout tests. The axial pullout load is applied to pull out the deformed steel bar embedded in the concrete during pullout tests. The bond stress formed between the concrete and the deformed steel bar is calculated via the pullout load determined in such a test.

There are several studies conducted regarding the effect of using steel fibers on the bond between concrete and deformed steel bar. The use of steel fiber in producing concrete is known to increase the ductile behavior of the concrete, decrease the crack formation and improve the mechanical properties [4–9]. Different researchers state that such effects result in an increase in the bond between concrete and deformed steel bar in steel fiber concretes [10–13].

In a study by Won et al. [10], the effect of steel fibers on the bond between concretes with high tensile strengths and glass or polymer fiber deformed steel bars were examined. The researchers reported that the steel fibers increased the concrete–reinforcement bond in ratios varying between 5% and 70%. The most effective increase in the concrete–reinforcement bond was reported to have occurred when steel fiber of 40 kg/m^3 was used.

The study performed by Haddad et al. [11] examined the effect of high temperature on the concrete–reinforcement bond in concretes with fiber. The researchers determined that the concrete–reinforcement bond in the concretes produced with steel fibers by 2% in volume increased by 23% when compared to control concrete. Furthermore, in the study, the steel fibers were reported to have a positive effect on the concrete–reinforcement bond under the influence of high temperature.

The study carried out by Campione et al. [12] analyzed the effect of repeated loads on the concrete–reinforcement bond in light fibered concretes. The researchers determined that the concrete–reinforcement bond in the concretes produced using steel fibers in volumes of 0%, 0.5%, 1% and 2% increased when compared to control concrete. This increase was reported to be between 7% and 38% depending on the embedded depth of the deformed steel bar and the amount of fibers.

In a study conducted by Söylev [13], the effect of fiber type and casting position on the bond between concrete and plain and deformed reinforcements was analyzed. The researcher produced steel fiber concrete using 40 kg/m^3 steel fibers. The bond between concrete and reinforcement was reported to have been greater by 8–22% depending on the casting position of the reinforcement when compared to the concrete without fiber.

In this study, the effects of concrete cover and use of steel fibers with different ratios on the concrete–reinforcement bond were investigated using steel fiber concretes with strength classes ranging between C20, C40 and C60. In addition, concrete–reinforcement bond and the mechanical properties of concretes and the relation amongst the amount of steel fibers, aspect ratio of steel fibers and concrete cover were mathematically modeled.

2. Experimental study

2.1. Materials

In the present study, CEM I 42.5 R type cement is used as binding material for C20 and C40 class concretes whereas CEM I 42.5 R type cement and silica fume are used for C60 class concretes. For the production of concretes, limestone-based crushed aggregates grouped into grain classes of 0/2, 0/4, 4/16 and 11/22 mm are used. Sieve analysis results and the physical properties required for concrete mixture of the study aggregates are listed in Table 1. Hooked-end bundled, and low carbon steel fibers with two different l/d ratios of 40 and 80 are used. The diameter and length of the two types of steel fibers is 0.62 and 0.75 mm and 30 and 60 mm, respectively. The tensile strength of steel fibers is 1250 and 1200 MPa, respectively. The steel fibers are used in 10, 20, 30, 40, 60 and 80 kg/m^3 by amounts of all concrete. In order to achieve the desired slump values in the mixtures, Super plasticizers are used for the concrete mixtures in C20/25 and C40/50 and hyper plasticizer is used for the concrete mixtures of C60/75.

2.2. Preparation and production of concrete mixtures

C20, C40 and C60 class concretes with and without steel fiber are produced in this study. The slump value of the produced concretes is fixed at 160 ± 20 mm. So as to achieve the desired slump value, super and hyper plasticizers are used in the concrete mixtures required. Table 2 shows the corrected material quantities required for 1 m^3 concrete and the properties of the fresh concrete.

2.3. Casting and placement of the specimens

In the production of concrete; laboratory-type and vertical-axial concrete mixer with a capacity of 65 lt. was used. First, aggregates were put into the concrete mixer and mixed for approximately 2 min; then, the cement was added on top of the aggregates and the aggregate–cement mixture was mixed for approximately 2 min. Finally, the mixture water, steel fibers and plasticizer were added, and the wet mixture was mixed for approximately 2 min. The same process was applied for all concretes. The study concretes were prepared as cubic specimens with 150 mm edge for use in compression and splitting tensile tests (234 + 234 = 468 specimens), cylindrical specimens with 150/300 mm edge for detection of modulus of elasticity (234 specimens) and reinforcement-embedded cubic specimens with 150 mm edge for bond tests (468 specimens).

The reinforcement used in the bond tests is a deformed steel bar with S420 deformed surface and 14 mm diameter. The yield strength, tensile strength and elongation ratio of the reinforcement used is 476 MPa, 542 MPa and 20.1%, respectively. The bond length of the reinforcement embedded into the concrete is fixed at 70 mm, to achieve a bond length of five times the diameter of each specimen. The total length of the reinforcement embedded into the concrete is 320 mm. In addition, the reinforcements are embedded into the concrete at three different concrete cover depths (40, 55 and 70 mm). Fig. 1 displays the guide used in the embedment process of the specimens and deformed steel bars prepared for the bond test.

Table 1
Sieve analysis and some physical properties of the aggregates.

Sieve size (mm)	Cum. pass. (%)			
	0/2 mm	0/4 mm	4/16 mm	11/22 mm
31.5	100	100	100	100
16	100	100	99	33
8	100	100	54	1
4	100	95	9	1
2	81	64	2	1
1	50	42	1	1
0.5	31	28	1	1
0.25	21	20	1	1
Physical properties				
Specific gravity (SSD)	2.67	2.70	2.71	2.72
Water absorption (%)	0.39	0.49	0.47	0.34