

Effect of Reinforcement Lap-Splices in Self-Compacting Concrete Beams

¹ B.SRINIVASA RAO, ² J.SUPRIYA

¹(M.Tech) Structural Engineering, Dept. of Civil Engineering

²Associate Professor, Dept. of Civil Engineering
Priyadharshini Institute of Tech & Science

Abstract: The advancement of self-compacting concrete (SCC) was a noteworthy step towards adequacy at building sites, reasonably delivering pre-assembled concrete basics, enhanced working conditions and better quality and development of concrete structures. By expansion of filaments to SCC, bar fortification can be supplanted and the execution of concrete structures made strides. The variety of the bond quality along the streaming way for the diverse blends was assessed. The steel-concrete bond sufficiency was assessed in light of standardized bond quality. The outcomes demonstrated that the security quality was decreased because of Portland bond supplanting with dolomite powder. The expansion of either silica fume or fly ash remains decidedly impeded further corruption as the dolomite powder content expanded. The SCC examples were cast without applying compaction, though the examples of ordinary concrete were cast by customary practice with generous compaction and vibration. The outcomes demonstrated that SCC examples created higher security to fortifying bars than ordinary concrete examples and the relationship between's security quality and compressive quality of NC is more predictable.

Keywords – Self-compacting concrete, Bond strength, Lap splice, Full-scale beam, Positive bending.

1. INTRODUCTION

Although SCC and traditionally vibrated concrete have similar hardened properties such as strength and elastic modulus, there are unavoidable differences in practical mix design (Domone, 2007), (De Schutter, Bartos, Domone, & Gibbs, 2008). Materials that constitute self-compacting concrete are the same as used for normal concrete. The most usual distinction lies in higher powder content and a low water/powder ratio in self-compacting concrete than normal concrete. The compressive strength increment of SCC depends on portion of additions. Limestone powder is an ordinary addition that contributes considerably to the rate of gain of strength. In addition, usage of viscosity modifying admixtures upgrades the stability of SCC. The types of superplasticiser define the effectualness of a viscosity material admixture.

There are three key properties of fresh SCC, namely:
1. Filling ability
2. Passing ability
3. Segregation resistance

Filling ability is the ability of the fresh mix to flow under its own weight and perfectly fill all the spaces in the formwork. Passing ability is the ability which demonstrates how well the fresh mix flow through constrained formwork. Segregation resistance, which is determined by the plastic viscosity and density of the cement paste, is the ability of fresh mix to keep its basic apportionment of constituent materials during transport, placing and compaction. Some tests, which are different than normal vibrated concrete, are performed to explore the key properties of fresh SCC. These tests are Slump-flow test, T500 time, V-funnel and L-Box. The Slump-flow test and T500 time is a test to evaluate flowability and the flow rate of self-compacting concrete in the absence of restrictions. Unlike the normal vibrated concrete, an unconfined horizontal spread of the sample is measured as the

slump-flow. T500 time is a time measured when horizontal spread of the sample reaches a circle of 500 mm diameter. The V-funnel test is used to evaluate the viscosity and filling ability of self compacting concrete. The V-funnel flow time is the period a defined volume of SCC needs to pass a narrow opening. The time measured as test result is fundamentally depends on plastic viscosity provided that blocking and/or segregation do not take place. The L-Box test is used to evaluate the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking.

Bond strength of the steel reinforcing bars has been studied by many researchers for more than 100 years. Thaddeus Hyatt (1877) is one of the first investigators, made tests to determine the bond between concrete and iron bars. In the following years, Duff A. Abrams (1913) started a project took about three years for bond between steel bars of any kind (plain and deformed) and concrete. During these years significant modifications have been done by code provisions. There are extensive numbers of researches on bond in the literature. Even, researches on bond behavior of SCC are outrageous. However, studies on bond behavior of SCC are limited with small cubical or cylindrical specimens and with pull-out tests (Canbay, 2009). In order to observe better the top-bar effect of SCC, pull-out tests were also performed on some wall or column members (Yin-Wen, et al., 2003), (Valcuende, et al., 2009). A study on small beam-end specimens was also conducted for SCC (de Almeida Filho, et al., 2008), (Desnerk, et al., 2010). There are limited studies on the literature carried out on full-scale beams with lap splices for SCC (Türk, et al., 2008), (de Almeida Filho, et al., 2008), (Pandurangan, et al., 2010). It can be concluded that there is a need for bond tests on SCC with full-scale beams to justify conclusions deduced from limited tests.

The objective of this study is to investigate the bond behavior between steel reinforcing bars and self-compacting concrete, and evaluate the effect of different parameters affecting the bond characteristics in SCC. In this study, three reports are followed; namely, ACI 408R-03 Bond and Development of Straight Reinforcing Bars in Tension, ACI R237-07 Self-Consolidating Concrete, and The European

Guidelines for Self-Compacting Concrete. Totally six full-scale bottom cast beam specimens were prepared. The parameters affecting bond behavior and considered in this study were number of transverse reinforcing bars along lap-splice region, lap splice length of longitudinal reinforcing bars, cover dimensions, and free spacing between longitudinal bars. All specimens were simply supported beams and loaded symmetrically under two points along the length of the beams. All the longitudinal reinforcement spliced at the mid-span where the shear force is zero and moment is constant. Tip and mid deflections along with strains on longitudinal and transverse reinforcement were acquired during the tests.

2. LITERATURE REVIEW

The researches and studies associated with bond behavior of reinforced normal vibrated concrete members started by Abrams (1913). Based on comprehensive literature survey, significant observations and conclusions of the previous researches and publications are summarized below. The survey is presented in chronological order to keep the historical prospective.

Sonebi and Bartos (1999) operated experimental investigation to study the properties of hardened SCC and the bond with reinforcing bars. According to the RILEM test specification, bond strength was ascertained for reinforcing bars with two types of diameter embedded in concrete. The obtained results for SCC were compared with those of a vibrated concrete as reference mix. They concluded briefly that: Self-compacting concrete had sufficient flowability and excellent deformability without blockage. The compressive strength of SCC is less dependent on curing condition than that of reference mix. The SCC showed greater stability than that of the reference mix. The drying shrinkage of SCC was lower than that of reference mix. In comparison with the reference mix, the bond stress of SCC was obtained higher.

Yien-Wen Chan, Yu-Sheng Chen, and Yi-Shi Liu (2003) performed direct pullout tests on reinforcing bar embedded in self-compacting concrete members. Full-scale reinforced concrete walls were used with a depth of 1200 mm as the pullout specimens. The reinforcing bars were set up horizontally inside the test specimens

at different elevations. Comparison of the test results between the specimens both with self-compacting concrete (SCC) and ordinary Portland concrete (OPC) was done by considering the affecting factors such as development of bond strength with age, influence of compressive strength, top bar effect and effect of high-range water-reducing admixture at early age. It was concluded that the variation in bond strength at different elevations in SCC is less significant than that of OPC which is related to the more consistent nature of SCC and the non-consolidating concreting process. SCC exhibited consequentially higher bond strength and less significant top-bar effect. Because of the possible retarding effect, more attention required to be paid to the development in compressive strength and bond strength of SCC.

Daoud and Lorrian (2003) carried out the pull-out test to investigate the impact of reinforcing bar positions on bond strength of SCC. Five different positions of reinforcement were considered: horizontal (superior, inferior and median), and vertical (loaded in casting or against casting direction). The results expressed that when the bars cast in vertical position and loaded against the casting direction, the highest bond strength was obtained. For bars cast horizontally, by increasing the depth of concrete underneath the steel bar, the bond strength decreased. The ration between the bond strength of bars cast in vertical and horizontal position was nearly 1.5. By using image analysis, a satisfying correlation was found between the bond strength and the difference between the percentage of coarse aggregate above and below the steel bar for different positions.

3. EXPERIMENTAL STUDY

In this study, six full-scale reinforced concrete beam specimens cast with selfcompacting concrete (SCC) were prepared for testing. The diameters of longitudinal and transverse steel bars were 22 mm and 8 mm, respectively. In addition, two longitudinal steel bars with 16 mm diameter were used as compression steel. All preparations including reinforcement caging, strain gauges attachment, and construction of experimental formwork were done in Structural Mechanics Laboratory; only SCC was supplied by a ready mix concrete firm.

3.1. Materials

Cement and fillers: cement type CEM I 32.5 N meeting the requirements of BS EN 197-1:2000 [23] was used. The specific gravity of cement was 3.13 and the initial setting time was 90 min. at 27.5 percent water for standard consistency. Locally produced densified silica fume was delivered in 20-kg sacks. According to the manufacturer, the light-gray powder had a specific gravity of 2.2, specific surface area of 17 m²/gm, loss on ignition of 1.5, and 93 percent SiO₂ content. Imported class F fly ash meeting the requirements of ASTM C618 [6] was used. According to the manufacturer, the average sum of SiO₂, Al₂O₃ and Fe₂O₃ is 85 percent by weight with a specific gravity of 2.1, and loss on ignition of 1.25 percent. The dolomite powder was obtained as a by-product from a local plant for ready-mix asphalt concrete. The production processes include drying the crushed dolomite used as a coarse aggregate by heating at a degree of 120 and sieving the aggregates to separate the different sizes. A small fraction of the powder that passes through sieve No. 50 (300 μm) is used in the mix, while most of the powder is a by product. This powder had a light brownish color, specific gravity of 2.72. Sieving six random samples of the powder showed that the average passing percentage through the 45-μm sieve was 63 percent. Aggregates: natural siliceous sand having a fineness modulus of 2.54 and a specific gravity of 2.65 was used. Crushed dolomite with a maximum nominal size of 16 mm was used as coarse aggregate.

3.2. Concrete mix proportions

Based on the results reported in an initial phase of research [8], seven mixes were selected to produce SCC based on compressive strength criterion. The selected mixes incorporated dolomite powder (DP) replacing up to 30% of cement along with either silica fume (SF) or fly ash[7] (FA) that replaced 10% of cement. In these mixes, the fine-to-coarse aggregate ratio was 1.13, the total content of powders (cement and fillers) was 500 kg/m³, the HRWR dosage was fixed at 10 kg/m³ (2% by weight of powders). The water content was determined by trial and error procedure to obtain consistent mixes with the required fresh rheological properties.

Table 3.1 Concrete mix design

Constituent Materials	Weight (kg/m ³)
Cement	270
Fly Ash	180
Water	185
Fine Aggregate (0-4mm)	1114
Coarse Aggregate (4-11.2 mm)	551
Super Plasticizer	6.75
Viscosity Modifying Agent	-

3.3. Configuration of push-out specimens

Push-out test specimens were used in the current work. Generally, the weak points of push-out test specimens, similar to pull-out test specimens, were the friction between the specimen and the bearing plate, and the arch-effect in the region close to the bearing plate. For these reasons, the bonded length was moved away from the bearing plate by providing a broken-bond zone next to the bearing plate as can be seen in Fig. (1). The procedure adopted by Foroughi et al. [9] to introduce a broken-bond zone and to avoid an unplanned force transfer between the bar and the concrete in this area was followed by encasing the bar with a plastic tube and sealing with a highly elastic silicone material. Also, 10 mm broken-bond zone was provided at the loading end so that the bonded length was five times the bar diameter.



Fig. 1. Preparation and testing of push-out test specimens

3.4. Casting forms

Casting forms were needed to manufacture concrete beams by casting the SCC mixes at one end and allowing concrete to flow to the other end without any compaction or vibration. The forms were designed to make it possible to split each beam into seven bond specimens with a steel dowel inserted at the center of each specimen. Specially designed wooden forms were manufactured for this purpose. The wooden forms had net internal dimensions of 120 mm depth, 150 mm width and 1400 mm length for the 10 mm steel bar diameter specimens. The corresponding dimensions for the 16 mm steel bar diameter specimens were 180 mm, 150 mm and 1400 mm. A separate plate was laid along the bottom of the form. The bottom plate was provided with seven holes at 200 mm center-to-center spacing to accommodate the lower end of the steel dowel.

3.5. Testing Procedure

A total number of 147 bond test specimens, 21 cubes and 21 prisms were tested. The bond test specimen was tested under a compression force driving down the steel dowel. A 500 kN universal testing machine was used to apply the compression force at a loading rate of 50 kN/min. The machine provided an automatic control of the loading range to ensure precise load measurements. A 20 mm thick bearing plate provided with a central hole was used to support the test specimen. The plate was supported on the edges of a rigid base allowing the penetration of the dowel. A packing plywood plate was used to ensure even contact between the bottom surface of the concrete specimen and the bearing plate[10]. To prevent buckling of the 50-mm long upper free part of the dowel under the applied load and to ensure eccentric loading, a special steel punched head was fixed in the upper platen of the testing machine. The punched head confined 30 mm of the free loaded part and thus a bar length of 20 mm was available for the dowel to penetrate through the concrete block. The 20 mm maximum penetration value was more than sufficient to achieve the ultimate bond strength knowing that the rib spacing was 4.2 mm in the 10 mm dowels and 6.9-mm in the 16 mm dowels. The test was ended once the ultimate load was recorded.

4. TEST RESULTS AND DISCUSSION

While the configuration of the push-out test specimen adopted in this work is not a standard one, some measures were considered to make the obtained results more realistic. The bonded length was shifted away from the bearing plate to avoid confinement effect due to the lateral compression stress induced in the concrete. Also, a relatively limited bond length of five times the steel bar size was adopted. These factors were expected to yield favorable bond failures due to the slip of the bar rather than due to splitting of concrete. However, splitting failures could still occur if the tensile strength is exhausted given that no radial steel reinforcement was provided to resist splitting. The test results were evaluated based on normalized bond strength obtained by dividing the average bond strength of a given mix to the square root of the corresponding compressive strength. To examine the adequacy of the obtained levels of bond strength, two approaches were adopted. The first was to check out the design bond strength requirements in the ACI 318-08 design code [11] and the second was to compare the obtained results with the results available in the literature for similar SCC mixes and bar diameters. For this purpose, the bond strength was related to the square root of the cylinder compressive strength. The cylinder compressive strength was taken equal to 80% of the corresponding cube compressive strength according to the data collected by Domone [12].

The addition of either silica fume or fly ash seemed to have a positive effect even when the DP ratios increased. The reduction of the bond strength due to the incorporation of the DP can be explained by recalling that load transfer between concrete and steel occurs through the action of three mechanisms: chemical adhesion, friction and mechanical interaction of the lugs of the deformed reinforcement bearing on the surrounding concrete. For deformed reinforcement, mechanical interaction is the dominant mechanism of response according to Zhu et al. [21]. The use of the DP as cement replacement seemed to have a softening effect on the matrix, while keeping an adequate chemical adhesion due to the improvement in the ITS as mentioned before. This behavior hindered the development of the mechanical interaction and the bond strength was dominated by their friction resistance. Another parameter contributing to the reduction of the bond strength is the reduced shrinkage of concrete upon cement replacement and consequently the reduced gripping

force exert by the concrete as reported by Sonebi et al. [13]. The observed occasional increase in the bond strength for a bigger diameter was reported by Khan et al. [14]. The increase was attributed to the increase in the friction bond component as the bar diameter increased. Also, the inconsistency of bond strength results in SCC mixes has been reported by Zhu et Al. [15] and Domone [11] and it was recommended that each concrete mix with a specified composition of the fillers should be tested to evaluate the bond behavior.

5. CONCLUSION

Splitting failure was observed in all cases causing sudden drop on structural capacity because bond capacity vanishes once the radial cracks get to outer surface of structural member. Sudden drop in slip and load confirms that cover was exhausted and large lateral pressure was accumulated around thin cover resulting splitting failure. Presence of limited clear space between parallel bars due to shift of beam reinforcement cause reduction in anchorage capacity. Reduction was significant in case of Normal Concrete (NC) whereas; no significant effect was found in Self-Compacting Concrete (SCC) and Small aggregate (SA). SCC and SA have proved good commitment of bond between reinforcement and surrounding concrete even at highly congested reinforcement regions. In SA, reduction was not significant due to uniform distribution of aggregate at congested area of reinforcement. Although mortar properties of SA can be similar to NC but better distribution of SA at congested area gives better structural performance. Whereas; in SCC, there is no segregation and bleeding which results better structural performance along with filling-ability characteristics

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