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Bond Strength of Reinforcement Lap-Splices in Self-Compacting Concrete Beams

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Abstract: The development of self-compacting concrete (SCC) was a significant step towards effectiveness at building sites, realistically producing prefabricated concrete rudiments, improved working conditions and better quality and emergence of concrete structures. By addition of fibers to SCC, bar reinforcement can be replaced and the performance of concrete structures improved. The variation of the bond strength along the flowing path for the different mixes was evaluated. The steel-concrete bond adequacy was evaluated based on normalized bond strength. The results showed that the bond strength was reduced due to Portland cement replacement with dolomite powder. The addition of either silica fume or fly ash positively hindered further degradation as the dolomite powder content increased. The SCC specimens were cast without applying compaction, whereas the specimens of normal concrete were cast by conventional practice with substantial compaction and vibration. The results showed that SCC specimens generated higher bond to reinforcing bars than normal concrete specimens and the correlation between bond strength and compressive strength of NC is more consistent.

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

1. INTRODUCTION

The specification of concrete workability is usually adopted to resolve the problems of concrete placement. The required workability for casting concrete depends on several factors, such as the type of construction, the selected methodology of placement and type of equipment for compaction, the shape of formwork, and degree of congestion of the reinforcement. With the increase in using congested reinforcements in moment-resisting reinforced concrete structures, there has been a growing interest in specifying high workability concrete. When the workability of concrete is increased, it may result lack of stability in the concrete mixture and weakening of the interface between aggregate and cement paste .It may also increase the tendency to develop local microcracking. Therefore, under the conventional practice of construction, high workability of concrete tends to increase the permeability and reduce mechanical properties. The application of SCC remarkably lowers the complexity of construction by reducing the demand for a significant amount of compacting force and skillful workmanship. Therefore, SCC allows a much easier construction task and results in a more reliable quality in concrete placement and a more homogeneous material structure. Application of SCC[2] is expected to increase the flexural behavior and loading capacity of specimens due to the superior passing and filling capability of SCC that may directly enhance the bond between reinforcements and concrete. To evaluate the advantages of SCC quantitatively, an experimental program was conducted to measure the bond strength of reinforcing bars in SCC as well as in normal concrete. For instance, the filling ability of concrete mixtures was evaluated by the slump flow test (two methods), the filling ability and segregation resistance by the discharge time in the V-funnel test (two methods) and self compatibility by the passing ability in L-box test. The workability of normal concrete (NC) specimens was evaluated by using slump test [1].

The bond strength of deformed and plain bars in SCC and in NC were measured by a series of embedded bars in pullout tests. Several variables were examined, including age of concrete, size and shape of reinforcing bars, (w/c) ratios and type of concrete materials. In the experimental program, the SCC specimens were cast by non vibration practice, while the normal concrete specimens (NC)[3], were cast by conventional procedures with substantial amount of compaction. To investigation the characteristics of bond development, reinforcing bar pull-out tests were conducted at various ages of concrete, starting from the setting time of concrete to 56 days. . Based on their experimental investigation, they found that anchorage capacity is reduced if beam reinforcement is shifted from column reinforcement at distance 0 to 1D (0 to 25mm) but on the other hand, there is no affect if bars are shifted at a distance 1.5D (37.5mm) or more from column reinforcement.

Research on this aspect is limited and only few experiments have been done so far. So, it is important to know the effect of shift of bar on anchorage performance by further investigations. So, main objective was to understand the behavior due to shift of beam bar at different distances on anchorage performance by using NC and SCC. Two different sizes of aggregate were used in NC (20mm and 10mm). At highly congested regions, it is difficult for large aggregates with maximum size of 20mm to pass through narrow spaces in NC resulting segregation and bleeding which affects structural performance.

Uniform distribution of small aggregate was expected at highly congested area. SCC has been developed to reduce the compaction problems at site in highly congested regions. But anchorage performance at highly congested area of reinforcement has not been studied yet for SCC. Better structural performance [4] was expected in SCC due to its homogeneous behavior. Pullout tests were performed to understand the behavior, where column bar was pullout and beam bars were shifted at some distances from the column bar.

2. MATERIALS AND METHODS

2.1. Materials:

1. Cement

The cement used in this experimental work is “Ultratech 53 grade Ordinary Portland Cement”. All properties of cement are tested by referring IS 12269 - 1987 Specification for 53 Grade Ordinary Portland Cement. The specific gravity of the cement was 3.15. The initial and final setting times were found as 74minutes and 385 minutes respectively. Standard consistency of cement was 30%.

2. Fine aggregate

Locally available Pravra river sand passed through 4.75mm IS sieve was used. The specific gravity 2.75 and fineness modulus of 2.806 were used as fine aggregate. The loose and compacted bulk density values of sand are 1600 and 1688 kg/m3 respectively, the water absorption of 1.1%.

3. Coarse aggregate

Crushed granite aggregate available from local sources has been used. The coarse aggregates with a maximum size of 12mm having the specific gravity value of 2.70 and fineness modulus of 6.013 were used as coarse aggregate. The loose and compacted bulk density values of coarse aggregates are 1437 and 1526 kg/m3 respectively, the water absorption of 0.4%.

4. Fly ash

Fly Ash (FLA) is available in dry powder form and is procured from Dirk India Pvt. Ltd., Nasik. It is available in 30kg bags, colour of which is light gray under the product name "Pozzocrete 60". There are no standard performance tests and procedures specified for assessing the suitability of MAs to FAC.

5. Chemical admixtures

A polycarboxylic type superplasticizer (SP) was used in all concrete mixtures. In addition to the SP, a viscosity
modifying admixture (VMA) was also used.

6. Fibers

The main variables used in the study are three different types of steel fibers i.e. hook ended steel fiber (HK), crimped type steel fiber(CR), straight type steel fiber(SF) with two values of aspect ratios (80 and 50). 2.5 % constant dosages of fibers are used by weight of cement.

2.2. Methods for Testing of Fresh Concrete

Test conducted for verifying the flow characteristics of fresh concrete are

1. Slump flow
2. V-Funnel
3. L Box
4. U Box.
5. J Ring

Deformability and viscosity of fresh concrete is evaluated through the measurement of slump flow time and diameter, JRing test, L-Box ratio test, U-Box test and V-funnel flow time. The slump flow is used to assess the horizontal free flow (deformability) of SCC in the absence of obstructions. The procedure for the slump flow test and the commonly used slump test are almost identical. In the slump test, the change in height between the cone and the spread concrete is measured, whereas in the slump flow test the diameter of the spread is determined as the slump flow diameter (D). According to Specification and Guidelines for SCC prepared by EFNARC (European Federation of National Trade Associations), a slump flow diameter ranging from 650 to 800 mm can be accepted for SCC. In the slump flow test concretes ability to flow and its segregation resistance can also be measured. To measure these properties, the time it takes for the concrete to reach a 50-cm spread circle and any segregation border between the aggregates and mortar around the edge of spread are recorded. EFNARC suggests a slump flow time (t50cm) of 2-5s for a satisfactory SCC. In addition to the slump flow test, J-Ring test, L-Box test, U-Box test[5] and V-funnel test, is also performed to assess the flow ability, passing ability and stability of the SCC. The L-box ratio was in the range of 0.80-1.0, the J-ring test values were in the range of 0-10mm. The V-funnel is filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow. The V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top. Good flow able and stable concrete would consume short time to flow out. According to EFNARC, time ranging from 6 to 12 sec is considered adequate for a SCC.

3. Experimental study

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 SiO_2 content. Imported class F fly ash meeting the requirements of ASTM C618 [6] was used. According to the manufacturer, the average sum of SiO_2, Al_2O_3 and Fe_2O_3 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 trail and error procedure to obtain consistent mixes with the required fresh rheological properties.

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.

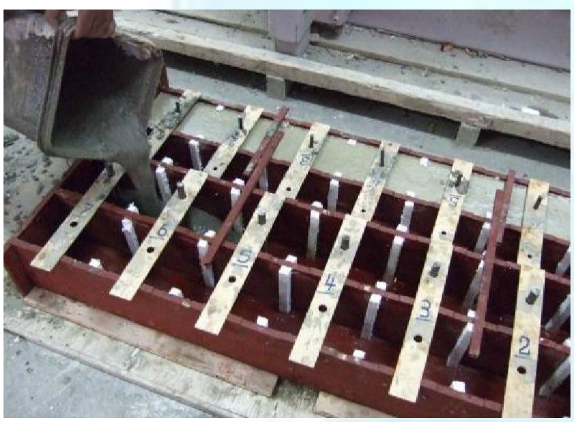

Fig. 1. Preparation and testing of push-out test specimens

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 them 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. For moderate load levels, SCC and SA performed stiffer behavior than NC. Experimental results confirmed that SCC not only reduce compaction problem at site but also, give better structural performance at highly congested reinforcement regions. Surface quality of SCC was also found better than NC. It was also found that anchorage capacity was recovered in case-05 where beam bars were shifted at distance 1.5D (37.5mm) irrespective to concrete type and aggregate size. This indicates that beam bars should be anchored at least at distance 1.5D (37.5mm) from column reinforcement for Normal Concrete (NC) otherwise, anchorage requirements for should be revised based on current situation at site. No such requirement is required for SCC and SA. Fracture pattern was not affected by concrete type and aggregate size. In all case, all the specimens made with SCC showed same failure as the NC ones so we may conclude that type of concrete has no effect on mode of failure.

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