

Bond Behaviour of Reinforcement in Self Compacting Concrete Containing Lightweight Aggregate as Coarse Aggregate

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ABSTRACT: Lightweight concrete is a special type of concrete which weights lighter than the conventional concrete. Density of this concrete is low (300kg/m^3 to 1850kg/m^3) compared to the normal concrete (2200kg/m^3 to 2600kg/m^3). Three types of lightweight concrete are lightweight aggregate concrete, aerated concrete, no- fines concrete. The lightweight aggregate self compacting concrete have so many advantages such as reduced dead loads, high insulation capacity, improved durability and resistance against fire and chemical attack. This paper presents the comparison of the bond properties of lightweight self compacting concrete (LWSCC) and normal weight self compacting concrete (NWSCC) with strength of 50 MPa.

I. INTRODUCTION

When large quantity of heavy reinforcement to be placed in a reinforcement concrete member, it is very difficult to ensure that the formwork gets completely filled with concrete. Compaction by manual or by mechanical vibration is very difficult in this situation. The typical method of compaction and vibration generates delays and additional cost in the project works. This problem can now be solved by using self compacting concrete (SCC). This type of concrete flows easily around the reinforcement and filled in all corners of the formwork. SCC describes a concrete with the ability to compact itself only by means of its own weight without the requirement of vibration. Fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure^[1]. To achieve a high workability and avoid obstruction by closely spaced reinforcing, SCC is designed with limits on the nominal maximum size (NMS) of the aggregate, the amount of aggregate and aggregate grading. When the workability is high, the potential for segregation and loss of entrained air voids increases. These problems can be reduced by designing a concrete with a high fine-to-coarse aggregate ratio, a low water-cementations material ratio, good aggregate grading, and a high range water reducing admixture^[2]. The removal of the need for compaction of the concrete reduced the potential for durability defects due to inadequate compaction. The use of SCC was also found to offer economic, social and environmental benefits over traditional vibrated concrete construction. These benefits included faster construction and the elimination of noise due to vibration. The use of self-compacting concrete in construction reduces the achievement time at 40% compared to normal concrete^[3]. One of the main drivers for the development of the technology was the reduction in the number of skilled site operatives.

In structural applications, the self weight of the concrete structure is important since it represents a large portion of the total load. When the self weight of lightweight concrete is reduced it will reduce gravity load and seismic inertia mass, resulting in reduced member size and foundation^[4]. Lightweight concrete (LWC) has been successfully used since the ancient Roman times and it has gained its popularity due to its lower density and superior thermal insulation properties. In addition to naturally occurring aggregates such as pumice aggregate, lightweight aggregates have better physical and mechanical characteristics. They can also be artificially produced using either natural raw materials or by-

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products^[5]. However, most studies on LWC concern “semi-lightweight” concretes, i.e. concrete made with lightweight coarse aggregate and natural sand. Although commercially available lightweight fine aggregate has been used in investigations in place of natural sand to manufacture the “total-lightweight” concrete, more environmental and economical benefits can be achieved if waste materials can be used to replace the fine lightweight aggregate. The main advantages of lightweight concrete are reduced seismic forces, improved structural efficiency, reduces the dead load of a structure, smaller sections as well as smaller sized foundations can be used, improved constructability, ease of transport, pumping to large distances, quick production, improved hydration due to internal curing, ease of Renovation and repair and better thermal insulation.^[6]

The utility of reinforced concrete as a structural material is derived from the combination of concrete that is strong and durable in compression with reinforcing steel that is strong and ductile in tension. The composite action requires transfer of load between the concrete and steel. This is referred to as bond. The transfer of axial force from reinforcing steel bar to the surrounding concrete produced from the development of tangential stress components along the contact surface. The stress acting parallel to the bar along the interface is called bond stress^[7]. For the reinforced concrete material, it is necessary to create suitable bond between steel bars and surrounding concrete. Bond ensures that there is little or no slip of the steel bars relative to the concrete and the means by which stress is transferred across the steel-concrete. An increase of bond length leads to decreasing of the maximum normalized bond stress^[8]. Bond resistance is made up of chemical adhesion, friction and mechanical interlock between the bar and surrounding concrete^[9]. The bond strength can be influenced by, bar geometries, concrete properties, amount of confinement around the bar and surface conditions. A loss of bond between the concrete and reinforcement could lead to failure of the structure. The bond is increases by decreasing the content of lightweight aggregate from 60-45% and the steel fiber utilization increased the bond strength^[10]. The addition of silica fumes increases the bond strength of LWC^[11]. For a high pressured steam cured concrete the bond strength is very low. The strength of concrete as a whole depends upon the bond strength of the hydrated hardened cement paste. For polluted and non-polluted steel bars, small bar sizes have greater bond strength than larger bar sizes if the embedded length is small. The bond may also be beneficially affected by the shrinkage of concrete relative to the steel.

Studies on the effect of lightweight aggregate on the bond behaviour of reinforced SCC have not yet been reported. An attempt was thus made to investigate the bond behaviour of NSCC and LWSCC specimens by carrying out pull-out tests.

II. EXPERIMENTAL PROGRAMME

Pull-out tests were carried out on 18 cube specimens as per IS 2770:1967 (reaffirmed 2002). The grade of concrete used was M50 and the steel reinforcement consisted of 10 mm, 12 mm and 16 mm diameter high yield strength deformed bars conforming to IS 1786:2008. The cube dimensions were 100 mm for the 10 mm diameter reinforcing bars and 150 mm for the 12 mm and 16 mm diameter reinforcing bars.

A. Materials and Mix Proportion

Standard mix design approaches are not available for SCC. In this experimental work, M50 grade concrete for NSCC and LWSCC was obtained by trial and error based on Nanzu et al. method. Portland Pozzolanic cement was used as the binding material. Manufactured sand passing through a 4.75 mm sieve conforming to grading zone II of IS 383:1970 (reaffirmed 2002) and having a fineness modulus of 2.86 and specific gravity of 2.46 was used. The maximum size of the natural coarse aggregate and lightweight aggregate used was 12.5 mm with a fineness modulus of 7.92 and 7.71 respectively. Silica fume was used along with cement to increase the mechanical properties. In order to improve the workability of the concrete, superplasticiser (CerahyperblastXR-W40) was employed during mixing. The objectives of the trial-and-error procedure were to obtain a desired compressive strength at the end of 28 day and to obtain a good cohesive mix with satisfactory workability. Details of the mix proportions are given in Table 1.

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Table 1. Mix proportion

	Normal SCC	Lightweight SCC
Cement	510kg/m ³	510kg/m ³
Fine aggregate	953.21kg/m ³	1008.205kg/m ³
Coarse aggregate	802.05 kg/m ³	447.638kg/m ³
Silica fume	5%	7%
Super plasticizer	1.5%	1.7%
Water cement ratio	0.301	0.264

B. CASTING OF SPECIMENS

For the preparation of test specimens, Portland pozzalano cement, manufactured sand, natural coarse aggregate, lightweight aggregate and silica fumes were used. All the aggregates were prepared in saturated surface dry condition. Superplasticiser was mixed with water and then added to the dry materials. The specimens were cast in cube moulds with specially prepared base plates. Steel bars were embedded vertically along the central axis. Each bar was projected down about 10 mm from the bottom face of the cube and projected upwards for about 900 mm from the top face of the cube as shown in Figure 1. This was to provide a sufficient length of bar extending through the bearing blocks of the testing machine and to provide an adequate length for gripping the specimen while applying the load. The cube was reinforced with a helix of 6 mm diameter plain mild steel reinforcing bar such that the outer diameter of the helix was equal to the size of cube as shown in Figure 2. The pitch of the helix was 25 mm centre to centre. The freshly mixed SCC was then poured into the mould layer by layer. The top surface was then levelled to a smooth finish. Curing was carried out for 28 days.



Fig. 1. Pullout Test Specimen



Fig 2. Helical Reinforcement

C. TESTING OF SPECIMENS

The specimen to be tested was mounted in a universal testing machine (UTM) of 400 kN capacity in such a manner that the bar was pulled axially from the cube. The bearing surface of the concrete cube was supported on a round steel plate of thickness 20 mm. The plate contained a hole of sufficient diameter to accommodate the bar and the end of the bar was projected from the top face of the cube as the pull was to be applied. Dial gauges of 0.002 mm least count were used for measuring the slip of the bar with respect to the concrete at the free end of the bar. The dial gauge was mounted on a suitable yoke, which was attached to the concrete specimen by means of screws. Figure 3 shows the test set-up for the experiment. All test specimens were loaded axially utilising the extended length of the reinforcement bars for gripping in the UTM. The slip was measured using the dial gauges placed on the loaded and free ends of the bar. The pull-out of the bar from the cube was indicated by the dial gauge readings recorded at different loads and loading was continued until

- a slip of 2.5 mm or more occurred at the free end of the bar and a dial gauge reading could not be recorded
- the enclosing concrete failed, or
- the yield point of the reinforcing bar was reached.

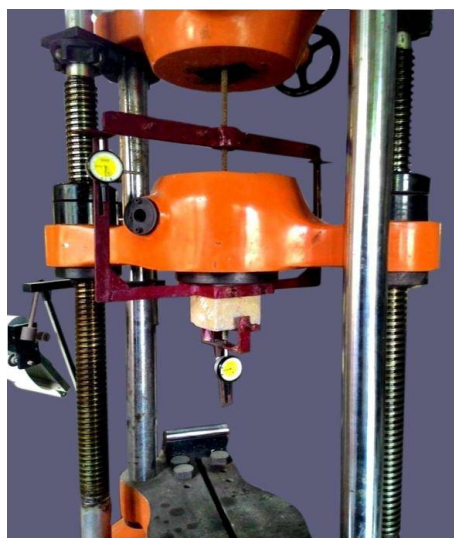


Fig. 3. Pull out test setup

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IV. RESULTS AND DISCUSSIONS

Bond strength of NSCC and LWSCC were tested using bond specimens with various diameter bars such as 10mm, 12mm, and 16mm

A. BOND STRESS

The results of all pull-out tests on the NSCC and LWSCC specimens with varying bar diameters are summarised in Table 2. The results include information on concrete compressive strength, ultimate load, bond stress and failure types. During the tests, the pull-out load and reinforcing bar displacement were recorded. The pull-out load was then converted into bond stress based on embedment length and reinforcing bar perimeter. The average bond stress along the whole anchorage length of steel bar was considered to be uniformly distributed and was computed as per IS 2770:1967 (reaffirmed 2002)^[12] as

$$\tau_b = \frac{P}{\pi d_b l_d} \tag{1}$$

where P is the force in the bar (kN), d_b is the steel bar diameter (mm) and l_d is the embedment length of the steel bar (mm).

Table 2. Bond stress values

Specimen ID	Ultimate bond stress (τ_{peak})	Bond stress at 0.025mm slip	Bond stress at 0.25mm slip	Failure mode
NSCC ϕ 10	13.36	11.45	-	Yielding
LWSCC ϕ 10	14.64	12.73	-	Yielding
NSCC ϕ 12	15.91	8.48	15.65	Pullout
LWSCC ϕ 12	17.24	14.58	17.10	Pullout
NSCC ϕ 16	17.50	12.99	16.31	Pullout
LWSCC ϕ 16	19.23	15.25	18.8	Pullout

For the specimen failed due to yielding, the ultimate bond stress was calculated corresponding to yield load which will be less than the actual bond stress. The ultimate bond stress value of LWSCC increased compared to NSCC specimen. The increments in the ultimate bond stress were 8% for 10mm &12mm bars and 9% for 16mm bars. At 0.025mm slip the bond stress was increased 11%, 14% and 15% in LWSCC for 10mm, 12mm and 16mm bars. Similarly at 0.25mm slip the increase in bond strength of LWSCC were 9% and 13% for 12mm and 16mm bars.

B. BEHAVIOUR OF SPECIMENS

Two types of failure such as yielding and pullout failure were observed. Yield failure occurs when the concrete bond strength is higher than the yield stress of steel. The steel reaches the maximum yield stress before the ultimate stress of concrete. In this type of failure the steel bar breaks due to yielding. Fig 3(a) shows the yield failure of bond specimen.

Pullout failure occurs when a specimen reaches the ultimate bond stress before the yield stress of reinforcement bar. It occurs by shear slipping of bars with concrete. Slip is followed by the cracking of concrete. In pullout failures crushing of concrete near the bar were observed. Fig 3(b) shows the pullout failure.



Fig 3. (a)Yield Failure. (b) Pullout Failure

C. BOND STRESS- SLIP BEHAVIOUR

Bond slip behaviour of LWSCC and NSCC for 10mm, 12mm and 16mm were shown in Fig 4, 5 and 6.

For analyzing the bond slip curve linearity can be seen in initial phase. The linearity is losing after the formation of first crack. As the slip increases the stiffness of the curve reduces.

Considering Fig 4, 5 and 6 the bond slip behavior of pullout specimens were characterized by a linear curve up to first crack load, then a gradual increase in slip up to ultimate load and finally a stable failure can be seen at the flat curve. Also in the small diameter bond specimen the slips were less than 0.2 mm. In larger diameter bar specimens, the slips were less than 0.6mm

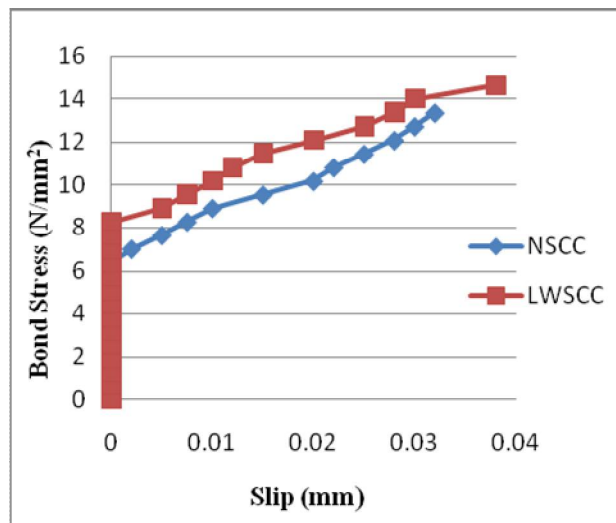


Fig 4. Bond stress versus slip behaviour of specimens with 10 mm bar

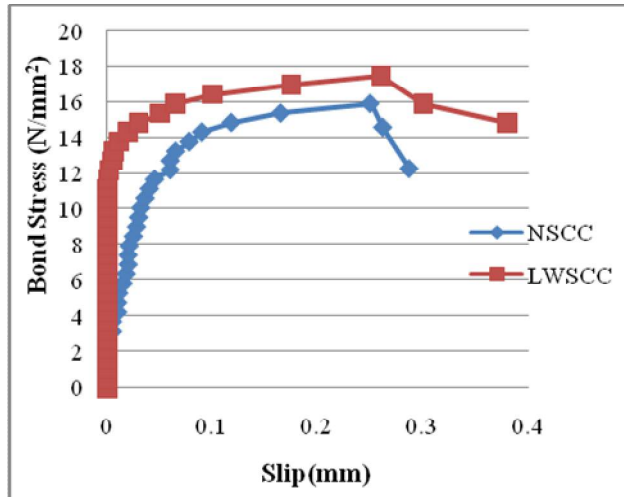


Fig 5. Bond stress versus slip behaviour of specimens with 12 mm bar

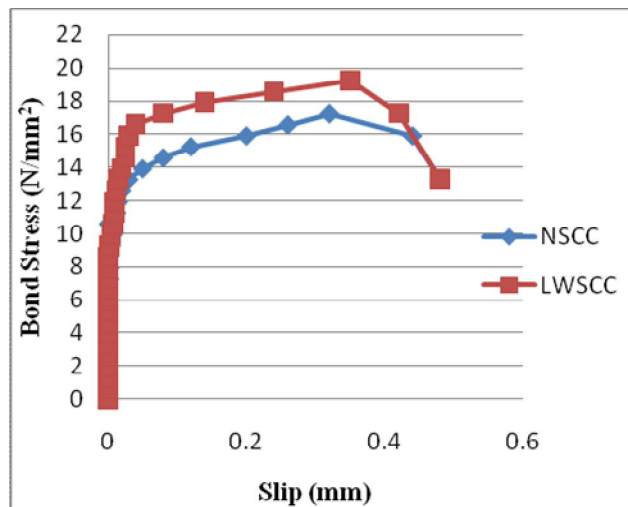


Fig 6. Bond stress versus slip behaviour of specimens with 16 mm bar

From the graph, the shape of bond slip curve shows similar pattern for both mixes. LWSCC specimens showed slight greater slip compared with NSCC. From the results it can be concluded that the bond strength behaviour of LWSCC was higher compared to NSCC. This may due to the lower water cement ratio of LWSCC.

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D.BOND STRENGTH COMPARISON

The bond strengths of different diameter bond specimens related to IS 456:2000 are listed in Table 3.

Table 3. Pullout test data of bars related to IS 456 : 2000

Specimen ID	Ultimate bond stress (τ_{peak})	Bond stress at 0.025 mm slip ($\tau_{0.025}$)	Bond stress as per IS456 (MPa)	$\tau_{peak}/\tau_{IS\ 456}$	$\tau_{0.025}/\tau_{IS\ 456}$
NSCC ϕ 10	13.36	11.45	3.04	4.39	3.76
LWSCC ϕ 10	14.64	12.73	3.04	4.81	4.18
NSCC ϕ 12	15.91	8.48	3.04	5.23	2.78
LWSCC ϕ 12	17.24	14.58	3.04	5.67	4.79
NSCC ϕ 16	17.50	12.99	3.04	5.75	4.27
LWSCC ϕ 16	19.23	15.25	3.04	6.32	5.01

From the test results it can be seen that the bond stress at 0.025 slip is 3 to 6 times more than designed bond strength values of IS 456:2000 and about 4 to 7 times for peak bond stress. Thus the values of bond strengths obtained from this investigation were found to be conservative with reference to those specified in IS 456-2000 for the purpose of structural design computations. From this result analysis, it is evident that the bond strength behaviour of LWSCC was better than SCC

III. CONCLUSIONS

The main conclusions of the study are,

- Bond specimens of SCC and LWSCC with 12mm and 16mm bars failed by pull out. But the bond specimens with 10mm bars undergone yield failure in both SCC and LWSCC. This may be due to large concrete cover to bar diameter ratio.
- The increments in the ultimate bond stress were 8% for 10mm& 12mm bars and 9% for 16mm bars. At 0.025mm slip the bond stress was increased 11%, 14% and 15% in LWSCC for 10mm, 12mm and 16mm bars. Similarly at 0.25mm slip the increase in bond strength of LWSCC were 9% and 13% for 12mm and 16mm bars.
- In the small diameter bond specimens (10mm and 12mm) the slips are less than 0.2 mm. In larger diameter bar specimens, the slips are less than 0.6 mm.
- The bond strength of LWSCC was higher compared to NSCC. This may due to lower water cement ratio.

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