

Bond Characteristics of TMT Bars in Self Compacting Concrete and Normally Vibrated Concrete

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ABSTRACT: Reinforced concrete bars will increase the flexural strength and loading capacity of structural elements. Incorporating Thermo Mechanically Treated (TMT) steel bars into the plain concrete enhances bond strength between steel bars and concrete. Resistance offered by mortar or concrete to the separation from reinforced steel with which it is in contact is called as bond strength. Nowadays, different varieties of concrete are manufactured for civil engineering construction along with varying different properties. However, bond strength is essentially a well sort after-quality of concrete for R.C.C structural elements. Bond strength of concrete is ascertained by conducting conventional standard pull-out tests. In the present investigations, bond strength is determined by Universal Testing Machine (UTM) accessed with few modified arrangements. The present paper investigates bond strength parameters in Self Compacting Concrete (SCC) specimens of M20, M25 and M30 grade. These values were compared with those of conventional Normally Vibrated Concrete (NVC) specimens of same grade. The characteristic compressive strength and tensile strength in split-tension, flexural tension and bond at 28-days for SCC and NVC are ascertained. Investigations show that SCC specimens exhibit high bond strength compared to NVC concrete specimens at 28-days curing period. It is observed that correlation between bond strength and compressive strength is more consistent for NVC compared to SCC. It is also observed that bond strength of concrete has a tendency to be decreased, when the embedment length of steel bars into concrete has been increased for both varieties of concretes.

KEYWORDS: Self Compacting Concrete (SCC), Normally Vibrated Concrete (NVC), Bond Strength, Characteristic compressive strength, Universal Testing Machine (UTM), Thermo Mechanically Treated (TMT) bars, Pull-out test.

I. INTRODUCTION

Concrete reinforced by steel bars is a composite material that has been used in civil engineering structures for about decades. Despite of its long history of use, this composite material still needs an improvement in terms of its bond strength and the interface between steel rebars and concrete. Reinforced concrete, as a structural material, is derived from the combination of concrete that is strong and relatively durable in compression along with reinforced steel that is strong and ductile in tension. Maintaining composite action between concrete and steel requires transfer of loads and stresses and bond between the concrete and steel layers. This load transfer is referred to as bond strength mechanism. Bond and development length between concrete and steel are essential for combined composite action for the transfer of stresses in reinforced concrete elements. In the present study, an experimental programme has been conducted to measure the bond strength in SCC as well as NVC to highlight the advantages of SCC quantitatively over NVC. The bond strength of steel bars in SCC and in NVC was measured by pull-out tests conducted on embedded bars. In the

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experimental programme, SCC specimens were casted by non vibration practice while those of NVC were casted by conventional procedures with substantial amount of compaction. To investigate the characteristics of development of bond in reinforced bars, pull-out tests were conducted. Because of the great difference of the properties between NVC and SCC, bond performance is expected to differ. Nowadays, few investigations were carried out to evaluate the bond performance of self compacting concrete. Results of studies suggest that SCC exhibits significantly larger values of bond strength when compared to NVC. The applications of SCC remarkably lower the complexity of construction by reducing the demand for a significant amount of compacting force and skillful workmanship. SCC allows easy construction and results in reliable quality to place concrete in formwork and to make homogeneous material structure. Application of SCC is expected to increase the flexural behaviour and loading capacity of specimens due to its superior passing, flowing and filling abilities which directly enhance bond strength between steel bars and concrete.

Nipun Verma, Anil Kumar Misra (2015) et al. [1] investigated bond strength in SCC and normal conventional concrete. They investigated about bond strength between concrete and steel bars for two varieties of concrete with varying W/C ratios (0.4, 0.5 and 0.6). Their studies reveal that SCC specimens generate high bond strength when compared to NCC specimens. Secondly, the correlation between bond strength and compressive strength of NCC is observed to be more consistent when compared to SCC. The results with Universal testing machine (UTM) were compared with those of standard pull out test and they were found to be within permissible limits. It is also observed that the bond strength values decrease with increase in water-cement ratio.

B. Nithya, P. Srinivasan, M. Suji, P. Lokesh kumar (2015) et al. [2] had studied about the use of thermal power plant wastes like bottom ash and its applications in construction industry, since it enables construction cost to be reduced and has beneficiary effects over the environment. Concrete with 40 % of fine aggregate was replaced by bottom ash used as bottom ash concrete. An experimental investigation was conducted to compare the bond strength of reinforcing steel in bottom ash concrete (BAC) with controlled concrete (CC). The experimental programme consisted of 6 pull-out specimens (three bottom ash concrete and three controlled concrete specimens). The Pull-out test was carried out for these specimens based on IS: 2770 (part I) - 1967. These comparisons indicate that BAC possesses bond strength almost same as CC. The pullout load Vs slip responses of the specimens were identified during the test.

Ioan Pop, Geert De Schutter, Pieter Desnerck, Traian Onet (2012) et al. [3] investigated on the bond behaviour between steel reinforcement bars and powder-type SCC. A total of 135 pull-out cubes were cast by using four SCC and two NVC were prepared with comparable strength characteristics. For each mix three different bar diameters were used, with three different embedment lengths for each diameter. Considering the influence of bar diameter and embedded length, it seems that SCC and NVC behave in a similar way. At the same load level, the bars in SCC tend to present a smaller slip than in NVC. The results showed that for the same slip of 0.01 mm, bond strength of SCC is higher than of NVC. It was observed that the bond strength has a tendency to reduce when the embedment length increased for both types of concretes. The slip corresponding to the ultimate bond strength decreases when the bar diameter increases for both concrete types, with SCC showing a smaller decrease. However the differences between the two types of concretes are not significant. Up to a compressive strength of 50 MPa, SCC tends to provide higher ultimate and characteristic bond strengths compared to NVC. No significant differences were observed for higher compressive strength classes up to 70 MPa.

M. Valcuende, C.Parra (2008) et al. [4] made experimental work to examine the bond strength between reinforcement steel bars and concrete. Eight different concretes were used, SCC and four NVC. Tests were conducted on 200 mm cube specimens and 1500 mm high columns. They found that, at moderate load levels, SCC performed with more stiffness, which resulted in greater mean bond stresses. The ultimate bond stresses are also somewhat greater although, due probably to the negative effects of the bleeding having less impact on failure, the differences between SCC and NVC are reduced considerably and even disappear completely for concretes of more than 50 MPa.

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Significance of the work

This paper has major significance in construction works related to reinforced concrete and selection of materials and their specifications. The experiments performed for measuring the bond strength of reinforcing bars can be used for the evaluation of the feasibility using SCC in place of normal concrete. Moreover, there are several other relevant structural performances, but in this paper, more emphasis has been given on bond strength and investigation is made in view of the extension of design rules from NVC to SCC.

II. EXPERIMENTAL PROGRAMME

The experimental programme consisted of procurement of materials for investigations, tests for physical properties of cement and aggregates, mix design procedures for NVC and SCC in accordance with I.S specifications (**SP: 23 - 1982 and I.S: 10262 - 2009**) and **Nan Su method** respectively. It also include the preparation of test specimens and making test reports for plain conventional concrete and SCC of M20, M25 and M30 grades respectively. Preliminary investigations are also made to find the compressive strength NVC and SCC specimens by accelerated curing method.

Materials

Ordinary Portland cement (OPC) of 53 grade (Ultra Tech Brand) conforming to I.S: 12269-1987, with specific gravity 3.10 and free from lumps was used in the experimental investigations. Locally available river sand with fineness modulus 3.10 and belonging to grading zone - II of I.S: 383-1970 was used as fine aggregate for NVC and SCC. Similarly, coarse aggregate of 20-mm maximum nominal size with fineness modulus 6.29 was used to prepare three types of concrete grades M20, M25 and M30 respectively for both NVC and SCC. Silica fume is used as mineral admixture to prepare SCC as it exhibits pozzolanic and cementitious properties to improve the qualities of embedded steel to protect it from corrosion effects. No plasticizer has been used to prepare NVC where as **CONPLAST SP430** with relative density of 1.21 g/cc at the rate of 1.2 % by weight of cement has been used to prepare SCC. The properties of cement, fine aggregate and coarse aggregate were summarized in Tables 1, Tables 2 and Tables 3 respectively. Potable and fresh water free from organic matter has been used for casting and curing the concrete specimens. Thermo Mechanically Treated (TMT) bars of 16-mm diameter of Grade Fe 500 were immersed in NVC and SCC concrete specimens to carry out pull-out tests.

Table 1: Properties of Cement

S. No	Characteristics	Values obtained	Standard values
1	Normal Consistency	35%	-
2	Initial Setting Time	54 min	Not less than 30 min
3	Final Setting Time	265 min	Not greater than 600 min
4	Fineness	4%	Less than 10%
5	Specific Gravity	3.1	3.1-3.5

Table 2: Properties of Fine Aggregate and Coarse Aggregate

S. No	Characteristics	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.66	2.85
2	Fineness Modulus	3.1	6.29
3	Grading Zone	II	-
4	Bulk Density	1453 kg/m ³	1330 kg/m ³

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Table 3: Physical Properties of Silica fume

Property	Result
Particle size	0.5 μ m - 1 μ m
Pack density	0.76 gm/cc
Moisture content	0.058%
Specific gravity	2.63

Preparation of specimens and Mix proportions

Six concrete mixes designated as **A/20 NVC, B/25 NVC, C/30 NVC, D/20 SCC E/25 SCC F/30 SCC** were used in the experimental investigations. Mixes designated as A/20 NVC (0.53:1:1.965:3.349), B/25 NVC (0.48:1:1.703:3.028), C/30 NVC (0.45:1:1.55:2.83) belongs to NVC where D/20 SCC (0.45:1:1.95:1.7), E/25 SCC (0.422:1:1.89:1.67) and F/30 SCC (0.381:1:1.78:1.418) belongs to SCC respectively. Each specimen was reinforced with one number of 16-mm diameter TMT steel bars of 600 mm and 750 mm length in cubes and concrete cylinders respectively.

NVC specimens were casted by conventional compacted and vibrated practice. Pull-out test specimens were designed in accordance with I.S: 2770 (Part I) - 1967. The concrete test specimens were cured in water for 28 days. The pull-out test specimens consist of concrete cubes of size 150 mm standard size and standard cylinders of 150 mm diameter and 300mm height inserted with one reinforced TMT bar of 16mm diameter. The bars were embedded vertically straight along the central axis of the specimen as shown in Figure 1 and Figure 2 respectively. The bar has been projected for a distance of 10 mm near bottom face of the cube and cylinder specimens. The bars were projected near the top surface to a length necessary to provide sufficient projected length in order to extend through the bearing blocks and the support of the testing machine as well as to accommodate the grips for testing for the application of load. In the present study for the pull out test the embedded lengths in cubes and cylinders were kept as 150 mm and 300 mm respectively. Projected upward lengths from the top face of concrete test specimen were 440 mm for cubes and cylinders.



Fig. 1 Casting of Pull-out test Specimens



Fig. 2 Pull-out test specimens before testing



Fig. 3 Position of concrete cube for bond strength in UTM

The exact proportion of cement, sand and crushed granite metal of 20-mm size were weighed and mixed thoroughly with pure water to produce SCC and NVC. Concrete was filled in the cube and cylindrical moulds. The workability characteristics of fresh conventional concrete were measured by slump and compaction factor methods and those of

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SCC were maintained in accordance with **EFNARC guidelines**. These values were recorded and noted. NVC specimens were compacted on a vibrating table for proper compaction and SCC specimens were casted in one lift. After filling the moulds with concrete, the top surface of specimens was then levelled using a trowel and kept for set for 24 hours. Specimens were de-moulded a day after casting and cured well in water till the date of testing. The mix proportions of NVC and SCC are summarized in Tables 4 and Table 5 as shown below.

Table 4 Mix Proportions of NVC and Experiment Results

Grade of concrete	Cement (kg/m ³)	Water (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	W/C ratio	Slump (mm)	Compaction Factor
M20	361.47	191.58	710.33	1210.61	0.53	10	0.91
M25	399.13	191.58	679.77	1208.77	0.48	5	0.912
M30	425.73	191.58	660.48	1204.98	0.43	5	0.927

Table 5 Mix Proportions of SCC and Experiment Results

Grade of Concrete	Cement (kg/m ³)	Silica fume (kg/m ³)	Water (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Super Plasticizer (kg/m ³)	Slump Flow Test (mm)	V-funnel (sec)	L-Box (H2/H1)
M20	360	40	180	780	680	4.8	675	8	0.875
M25	405	45	190	850	750	5.4	630	9	0.83
M30	495	55	210	980	780	6.875	605	12	0.821

Pull-Out Test Procedure

Pull out tests were carried out using the UTM by changing the position of the cube. After completion of curing period of cubes, they were attached to the UTM machine as shown in Figure 3. The reinforcing bar was held by the jaws present on the upper deck. Before loading, the system was brought in equilibrium by adjusting the distance between the upper deck and middle deck with the help of non loading motor. This was done to nullify the effect of self weight of the cube. The rate of loading of UTM was set to 2250 kg/min. Then loading was started and recording of loads was carried out. The machine automatically stops when no resistance is offered by the specimen to the tensile force being applied i.e., when specimen has failed, as shown in Figure 3. After completion of test, samples were removed from test setup and physical verification of crack. This same procedure was done for each pull-out test specimen of SCC and NVC with 16 ϕ diameter TMT bar. The pull out test is then converted into bond strength based on embedment length and reinforcing bar perimeter.

III. RESULTS AND DISCUSSION

Compressive Strength Test

Compressive strength test was carried out on concrete cube of size **150mm×150mm×150mm**. The specimens are tested after 28 days, using a calibrated compression testing machine of 2000 KN capacity as per IS: 516-1959. Compressive strength = P/A , Where P = load at failure, A = Cube area.

Split Tensile Strength Test

The cylinder specimens were tested on compression testing machine of capacity 2000 KN. The load applied on the specimen was increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained. The load at failure of the specimen was recorded.

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Split tensile strength = $2P/\pi DL$.

Where P = load at failure of the specimen, D = Diameter of cylinder, L = Length of cylinder.

Flexural Tensile Strength Test

Flexural test was carried out on beam specimens of size **500mm×100mm×100mm**. The specimens were tested for flexural tensile strength at 28 days in accordance with the IS: 516-1959.

Bond Strength

Bond strength between paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. Bond strength arises primarily from the friction and adhesion between concrete and steel. The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength up to about 20MPa.

Bond Behaviour

Three factors define the bond strength: chemical adhesion, friction, and bearing of bar deformation (ribs on bar). The adhesion is less important in magnitude and resists only small stress. Friction is a mechanical interlock between irregularities of steel surface and concrete, with magnitude superior than adhesion and occurs after the adhesion is broken and some small movement between steel and concrete take place. These two bond mechanisms are quickly lost and the tension is transferred by bearing of bar deformation. For the plain bars the bond is formed by two parcels: the chemical and friction that depends of the deformed bar surface. The ultimate bond force is proportional to lateral bar area, where occur the adhesion effect, friction and deformed surface.

For deformed bar, the strength occurs mainly by the action of these ribs. The chemical adhesion is low and friction not happen even when the slipping between the bar and concrete occurs. Bond failure on deformed bar happens by the followings modes: a) crush of the concrete surrounding to the ribs b) shear of the concrete surrounding to the bar c) or more frequently, by one longitudinal spalling of concrete cover d) one combination of these three modes. Bond can be described ideally as a shearing stress between the surface of reinforced concrete and the surrounding concrete. Moreover, concrete compressive strength, bar diameter, concrete cover, embedded length and pre-flexural crack length also affect the bond strength.

Bond Stress

The design bond stress is defined as the shear force per unit nominal surface area of reinforcing bar. The stress is acting on the interface between bars and surrounding concrete and along the direction parallel to the bars. Bond stress is calculated as average stress between the reinforcing bar and the surrounding concrete along the embedded length of the bar. In general, the bond stress corresponding to the maximum pull out load can be regarded as the bond strength or the ultimate bond.

$$\tau = \frac{V}{j * d * \sum O}$$

τ = Bond stress

V = Shear force at any section

d = embedded length

$\sum O$ = $N * \pi * \phi$ = total perimeter of bars in tension at the section

ϕ = diameter of bar

Equation gives the flexural bond stress in the tension reinforcement at any section.

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Table 6 Strength Values of Different Grades of Concrete in NVC & SCC

Grade of Concrete	M20		M25		M30	
	NVC	SCC	NVC	SCC	NVC	SCC
Compressive Strength at 28 days, MPa	29.7	30.15	33.85	33.26	41.18	40.44
Split Tensile Strength at 28 days, MPa	3.678	3.536	3.749	3.643	3.89	3.855
Flexural Strength at 28 days, MPa	3.44	4.6	3.725	4.9	5.02	5.35

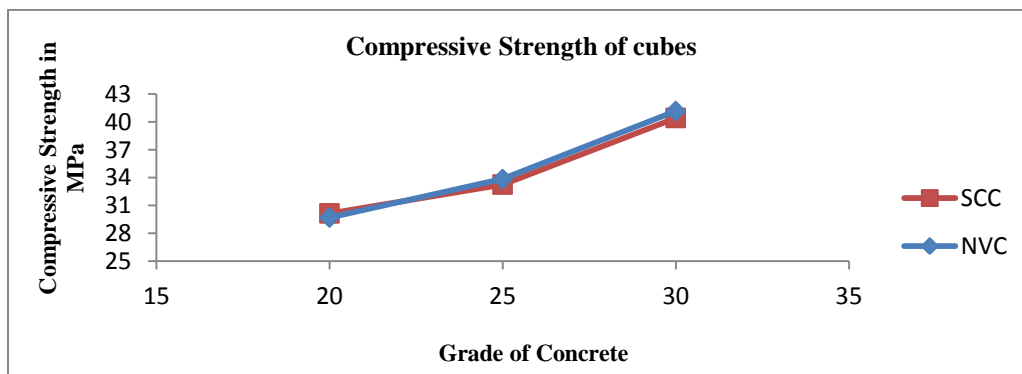


Figure 4 Comparison of Compressive Strength for different Grades of Concrete

Cube compressive strength was determined by conducting tests on standard concrete cubes (150 x 150 x 150 mm) at the age of 28 days. It was observed that the compressive strength for M20, M25 and M30 grades of concrete in NVC and SCC were more consistent. The compressive strength is observed to be maximum (41.18 N/mm²) for Mix C/30 NVC.

Split tensile strength was determined by conducting tests on standard concrete cylinders (150 x 300 mm) at the age of 28 days. It was observed that the split tensile strength for M20, M25 and M30 grades of concrete in NVC and SCC were more consistent. The split tensile strength was observed to be maximum (3.89 N/mm²) for Mix C/30 NVC.

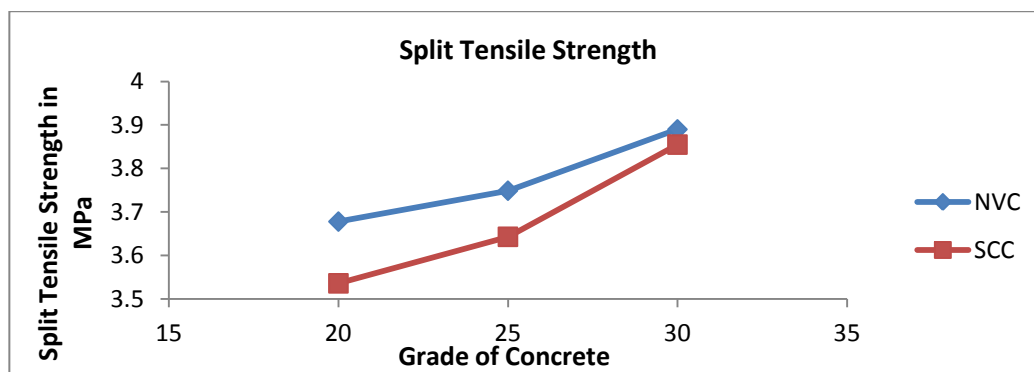


Figure 5 Comparison of Split Tensile Strength for different Grades of Concrete

Flexural tensile strength was determined by conducting tests on standard concrete prisms (100 x 100 x 500 mm) at the age of 28 days. It was observed that the flexural strength for M20, M25 and M30 grades of concrete in SCC was more than NVC. The flexural strength was observed to be maximum (5.35 N/mm²) for Mix F/30 SCC.

The values of compressive strength, split tensile strength and flexural strength at the age of 28 days for Mixes A to F are shown graphically in Figures 4 to 6 respectively and these values are tabulated in Table 6. Fracture pattern was not

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affected by concrete type and aggregate size. In all cases, the specimens made with SCC showed same failure as the NVC, so we conclude that type of concrete has no effect on mode of failure.

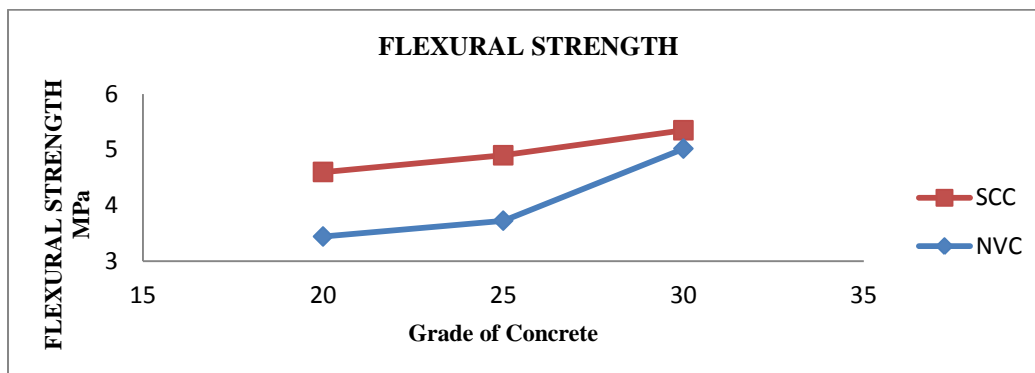


Figure 6 Comparison of Flexural Strength for different Grades of Concrete

In the present study, bond stress corresponding to the maximum pull-out load that can be regarded as the bond strength or ultimate bond strength. Bond strength varies with changes in mix design and grade of cement used. In the present work, the SCC specimens were cast in one lift without any vibration. Bond Strength increases with increase in grade of concrete in NVC and SCC, its increase is observed in cubes and cylinders as shown in Fig 7 and Fig 8. Maximum bond strength determined by the ultimate bond strength criteria was measured to be 13.64 MPa in F/30 SCC. It was observed that the bond strength has a tendency to reduce when the embedment length increased for both types of concretes. The values of bond strength at the age of 28 days for Mixes A to F in cubes and cylinders are shown graphically in Figure 7 and Figure 8 respectively and these values are tabulated in Table 7.

Table 7 Bond Strength at 28 days

Grade of Concrete	Cubes		Cylinders	
	NVC	SCC	NVC	SCC
M20	10.48	11.08	9.25	9.42
M25	11.68	12.02	9.74	10.18
M30	13.06	13.64	10.38	10.79

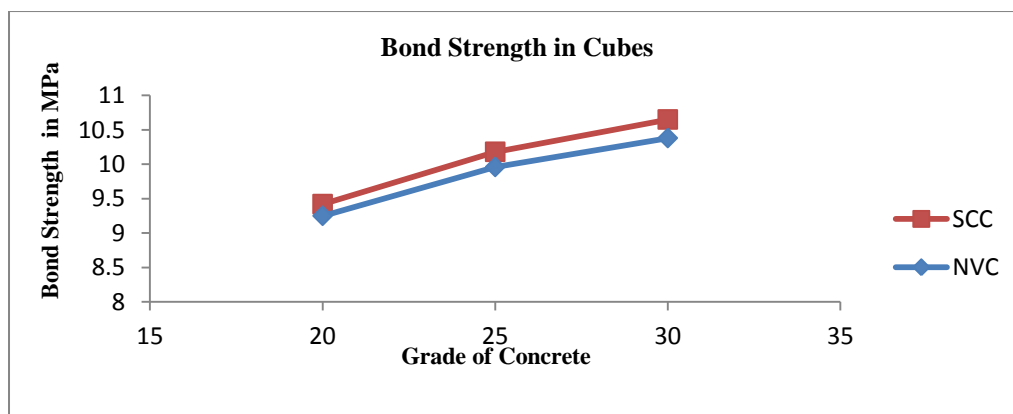


Figure 7 Comparison of Bond Strength in different Grades of Concrete in Standard Cubes

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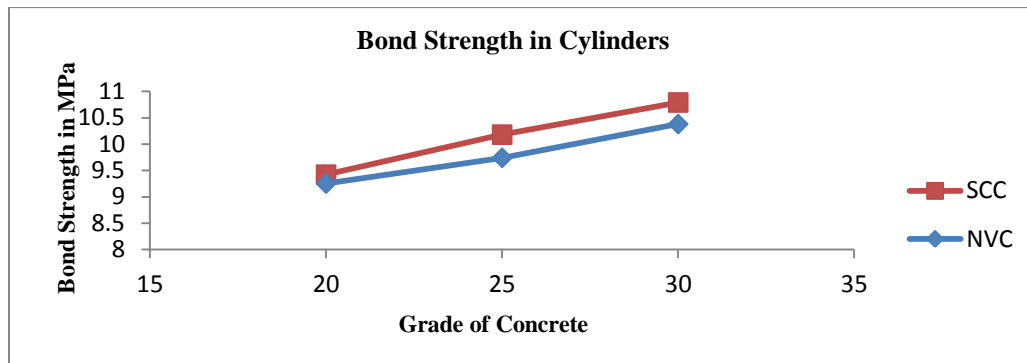


Figure 8 Comparison of Bond Strength in different Grades of Concrete in Standard Cylinders

IV. CONCLUSIONS

1. Compressive strength of M20, M25 and M30 grade specimens of NVC and SCC are consistent.
2. Bond Strength increases with increase in grade of concrete in NVC and SCC.
3. SCC specimens generate high bond strength to reinforcing bars in comparison with NVC specimens.
4. SCC exhibits better advantages than NVC for the improvement of bond strength between steel and concrete interfaces.
5. SCC exhibits better structural performance than NVC in congested reinforcement regions of concrete.
6. Bond strength in concrete is observed to have a tendency to be decreased when the embedment length of steel bars has been increased.

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