Assessing the Bond Strength of Different Reinforcement Steel in Fly Ash Blended Self-Compacting Concrete

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Abstract- Self-compacting concrete (SCC) is widely recognized as a modern and reliable concrete that effortlessly fills into the formwork without necessitating manual compaction. Its inherent ability to flow smoothly under its own weight allows it to effortlessly flow between reinforcement bars. SCC addresses the challenges of pouring concrete in conditions involving challenging formwork and congested regions satisfactorily. Reinforced concrete is a heterogeneous material constructed from steel and irregularly shaped concrete. The fundamental concept behind reinforced concrete components is that the steel resists tensile strains while the concrete carries compressive pressures. The interaction between the two materials, which is given by the connection involving concrete and reinforcement bars, is therefore necessary for effective ability to transfer force between two materials. The bond significantly affects how reinforced pieces behave during the fractured stage in structural applications, the connection between the steel reinforcement and the concrete is crucial in determining the fracture widths and deflections. This complex connection has been the subject of countless investigations due to its recognition of importance. M25 grade concrete was used in a recent study to examine the interaction between steel and concrete. The ratio of cement to water was 0.45 for both self-compacting concrete (SCC) and conventional concrete (CC). Cubic and cylindrical specimens embedded with four different types of reinforcing bars (10 mm plain, 10 mm ribbed, and 16 mm plain) were used to measure the bond strength. The results revealed an important finding: SCC showed better binding strength than CC, especially with smaller diameter bars. In particular, SCC displayed a binding strength of around 12 KN/mm^2, whereas CC registered a slightly less strength at 11 KN/mm^2

Keywords- ***Self Compacting Concrete (SCC), Compressive Strength, Bond Strength, Reinforced Bars.***

I. INTRODUCTION

The development of self-compacting concrete (SCC) has significantly improved construction efficiency, concurrently enhancing concrete placement uniformity and achieving a consistent, homogeneous material structure. Owing to the better passing and filling capabilities of SCC, the connection between reinforcement and concrete is also found be improved than that of the conventional cement concrete (CC). SCC is a result of Japanese research institutions' efforts to enhance traditional concrete (Okamura & Ozawa, 1996) SCC may be seen as a benefit to the construction world without taking casting problems into mind. Due to its features like stability, deformability, and viscosity, SCC is unaffected by the element's geometry, the kind of reinforcements used, or the caliber and experience of the workforce. Adding superplasticizers (SP), viscosity modifying admixtures (VMA) and mineral additives into the cement concrete helps in achieving SCC; however, with mineral admixtures such as fly ash (FA), limestone powder, rice husk ash, or industrial slags such as blast furnace slag (BFS), the paste quantity and subsequently the number of particles in the mixture increases. Due to its lower production costs and higher mix stability, the later (mineral admixture) has more potential for development, and was the one chosen in this investigation [2].

When compared to conventional concretes, SCC has some significant distinctions in its initial state. These variations could be attributed to the use of more powders, less bleeding and segregation, as well as the lack of vibration [19]. This positively affects the mechanical parameters, for instance the mechanical strength (Domone, 2007; Persson, 2001; Uysal et al., 2012) and elastic modulus (Craeye et al., 2014; Persson, 1999), while also leading to a more homogeneous and improved paste-aggregate contact in the microstructure [25]. However, the type, quality, and quantity of powders used in SCC have an impact on each of these characteristics (Uysal & Sumer, 2011). For instance, the compressive strength is reduced when the filler is excessively employed in place of cement in SCC

(Uysal & Sumer, 2011). However, the variations in compressive strength are negligible if the mineral admixtures are only utilized to raise the paste content in SCC (Uysal & Sumer, 2011). The tensile strength exhibits a similar tendency (Tangadagi et al., 2021). The relationship between steel and concrete in reinforced concrete, one of the most important properties that can be understood from the influences of these two attributes [20]. The structures made of prestressed and reinforced precast concrete must have a strong bond. The embedding length of reinforcing bars, which in turn influences the structural stability of elements, their capacity to support weight, the size of cracks, and their spacing, is significantly influenced by the bonding method. The bond strength [20], which is dependent on chemical adherence, friction between steel and concrete, as well as the mechanical performances of the concrete, such as compressive and tensile strengths [12], and can be used to define a good connection between concrete and reinforcing bars. According to Ahmed [50], The addition of polypropylene fibre and latex to SCC significantly improves its slant shear bond strength. When compared to cylindrical and cubic specimens, the prism configuration among the studied specimens offers a more accurate measurement of slant shear strength. The study made by Mathew and Anand [51] to evaluated the bond strength of SCC specimens made with FA, BFS, and expanded perlite aggregate (EPA) exposed to high temperatures. Pull-out tests were carried out to determine the bond strength of reference SCC specimens, and specimens exposed to elevated temperatures. The results showed that the SCC specimens made with a combination of BFS and EPA exhibited improved bond strength, both at room and elevated temperatures. Further, in another experimental investigation conducted by Looney et al. [52] compared the bond strength of reinforcing steel in SCC with CC. This study investigated two different compressive strengths of SCC as well as CC. These comparisons indicated that SCC beams possess comparable or slightly greater bond strengths than that of the CC beams. Aslani et al. [53] used reinforcing bars with a diameter varying from 12 to 40 mm to demonstrate the bond stress- slide behavior for both SCC and Conventional vibrated concrete (CVC). According to the findings, SCC has a stronger bond strength than CVC for small bar diameters, however as bar diameter increases, the bond strength falls to (1-26%). There aren't many specialized models available right now to assess the bond strength and development length of steel bars in unconfined self-consolidating concrete (SCC). Studies on steel bars in ordinary concrete by Mousavi et al. [54] don't transfer well to SCC situations. More precise and effective models are desperately needed in light of this discrepancy. We used direct pull-out tests in our study to address this. Positively, the results obtained by current study are in good agreement with the experimental data. As per the analysis made by Domone [42] published after evaluating more than 70 research on the bonding and toughness characteristics of SCC, Domone argued that the bonding capacity for SCC is not necessarily fewer than CC and, in some cases, may even be higher.

RESEARCH SIGNIFICANCE

The findings of earlier studies have underlined the critical need for a deeper investigation into the myriad variables affecting bond strength in concrete. Particularly, significant criteria needing a detailed knowledge have emerged, including variables like compressive strength, bar diameter, and embedding length. In-depth research might not give a complete picture due to the complexity of these variables and how they interact. Due to this vacuum in knowledge, the current study concentrates heavily on the bond behavior of self-compacting concrete (SCC). In order to begin this project, a thorough experimental programme was carried out. The main aim of this study is to unravel the complexities of SCC's binding strength, thereby revealing a wealth of information regarding reinforced SCC systems. The bond strengths of both SCC and Conventional Concrete (CC) were put under the investigative spotlight in an effort to present a comprehensive picture and enable direct comparisons.

It is imperative that the steel bars and surrounding concrete have a strong bond in order for reinforced concrete systems to be functional. Because of this connection, the steel bars are kept firmly in place and are not allowed to move relative to the concrete. The steel-concrete interface is therefore subject to homogenous stress transmission. This bond resistance results from a trio of forces acting simultaneously between the reinforcing bar and the concrete: chemical adhesion, friction, and mechanical interlock. The pull-out test, recommended by RILEM in 1973, is a tried-and-true technique for assessing bond strength in such systems. Even though this type of testing is extensively used, it's important to keep in mind that pull-out samples occasionally exhibit behavior patterns that differ from those of bending-reinforced components.

In this study, the bond strength was evaluated using the pull-out method after allowing the concrete to cure for a total of 28 days. Initial results revealed an intriguing picture: pull-out specimens integrated with smaller bars consistently displayed greater bonding skills compared to their counterparts fitted with thicker bars. This thorough investigation of bond behavior in SCC in comparison to CC provides priceless insights into the intricate interplay of factors that determine bond strength in reinforced concrete systems. These discoveries not only add to the body of currently available knowledge but also point out areas where additional investigation may be necessary, paving the way for additional research and advancements in the field.

II. EXPERIMENTAL PROGRAM

2.1 Materials –

In this experimental work, ordinary Portland cement (OPC-43 grade) as per Indian standard IS 8122 (IS 8112, 2013) is utilized as the binder. The physical properties of the cement based on the same Indian standard (IS 8122) are listed in Table 1. The used coarse aggregates are obtained from locally available sources and tested in accordance with IS: 383-2016 (IS 383, 2016)(Table 2). Sand from Zone III meets the requirements of IS: 383-2016 (Table 2) (IS 383, 2016). Fly ash (FA) with a defined bulk density of 2400 kg/m^3 was used in the case of SCC in order to have an improved paste volume and good cohesiveness. FA is widely used in cement-based materials due to its high pozzolanic properties and pore filling ability (Behera et al., 2021; Das et al., 2021). By maintaining the complete weight of powder (i.e., filler added to cement) at 413.34 kg/m^3 of concrete, the amount of filler was altered for each mix. The FA used in this study was collected from a thermal power plant of NALCO, Odisha, India. For this investigation, FA particles that passed through a sieve with a 300 mm aperture were employed. The tests were conducted to ascertain FA's physical characteristics are listed in Table 3.

Sikement 170 PL4 is a liquid concrete/mortar admixture that serves as a highly effective plasticizer as well as a waterproofing agent and is compliant with ISO:9001-2008 is used in this study. The plasticizer was supplied by Universal Construction Care, Bhubaneswar, Odisha. 10 mm and 16 mm mild steel bars and 10 mm and 16 mm rebars were used in this study program. The characteristics of reinforced bars are listed in Table 4, according to ISO 15630-1-2002 [13].

The following geometrical properties for each reinforcement type were found in order to compute the relative rib area (f_R):

a) The cross-sectional area of a bar when one rib projects (A_R);
b) Nominal diameter (d_b),
c) The rib spacing ratio (S_R), and
d) The height of rib (h_R).

$$f_R = A_R / (\Pi\ d_b\ S_R) \qquad (1)$$

Table1. Physical Properties of Ordinary Portland Cement

Characteristics	Experimental values	IS Specified value
Normal consistency (%)	35	NA
Fineness (m^2/kg)	332	225 (min)
initial intervals of setting(minutes)	120	30 (min)
Final intervals of setting (minutes)	425	600 (max)
Specific gravity	3.15	3.15
Strength in compression, MPa (3 Days)	31.05	23 (min)
Strength in compression, MPa (7 Days)	42.75	33 (min)
Strength in compression, MPa (28 Days)	53.39	43 (min)

Table 2. Physical Properties of coarse aggregate

Characteristics	Coarse aggregate	Fine Aggregate
Specific gravity	2.66	2.64
The Fineness Modulus	3.14	2.29
Water Absorption(%)	0.40	0.80
Zone	-----	III

Table 3. Physical Properties of Fly ash

Characteristics	Physical properties
Specific gravity	2.15
Fineness	290 m^2/kg
Colour	Light grey

Table 4. Characteristics of reinforcements

ϕ of bar (mm)	**f_y (MPa)**	h_R (mm)	S_R (mm)	f_R
10 (plain bar)	250	0	0	0
10 (Re bar)	415	0.69	7.0	0.0313
16 (Plain bar)	250	0	0	0
16 (Re bars)	415	0.69	7.0	0.0313

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2.2 Mixture Proportion –

A certain mix ratio was selected for this study's objectives in order to assess its performance and characteristics. This ratio, which was established at 1:1.63:2.9, was supported by M25 concrete, a base material that is frequently used in construction projects. The water-to-cement ratio was kept at 0.45, which is usual for concrete mixtures to have the desired workability and strength. Additional adjustments were made to this mix in order to especially cater to the needs of Self-Compacting Concrete (SCC). The addition of fly ash, a supplemental cementitious ingredient known for its capacity to improve the workability of concrete while providing possible durability benefits, was a notable modification. Superplasticizer was added to the mixture as well. A distinguishing feature of SCC, superplasticizers are high-range water reducers that are renowned for their capacity to greatly boost fluidity. Essentially, the foundational mix was based on standard ratios, but fly ash and superplasticizer were added strategically to adapt it for SCC, providing optimal performance while keeping the inherent advantages of the base M25 concrete. By being thorough, this method sought to balance the fluidity and self-compacting capabilities of improved concrete with those of traditional concrete.

Table 5. Approve mix proportion (by weight)

Water (L/m^3)	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)
186	413.34	674.211	1210
0.45	1	1.63	2.9

2.3 Preparation Of Test Specimen –

Since Self-Compacting Concrete (SCC)'s capacity to flow and settle into position without the need for vibrational consolidation makes it unique, it is crucial to ensure its workability. A multifaceted testing strategy was used to validate the SCC post-mixing's immediate viability in this investigation. To determine the workability, three main tests were used:

Slump Test: The slump test, a common technique, gauges the consistency of the concrete. The concrete's workability can be determined by how much it slumps or falls. In general, a larger slump value indicates greater workability. Slump Flow Test: Conceived especially for SCC, this test gauges the concrete's ability to flow. A crucial property of SCC is the concrete's capacity to fill formwork under its own weight, which may be determined by measuring the concrete's spread diameter. V-funnel Test: This test, which is particularly significant for structures with dense reinforcement, evaluates the flow time of SCC and can reveal information about potential obstructions.

After evaluating workability, the study went further deeper to comprehend the concrete's strength characteristics. Following EN12390's requirements [17], a number of strength metrics were assessed. Compressive Strength (fc, cub): Using typical 150 mm cubes, the compressive strengths were measured at two crucial times, 7 and 28 days. This revealed information about the concrete's resistance to axial compressive loads, which is important for structural applications. Flexural Strength (fct, fl): Using prismatic specimens, the concrete's resistance to bending was measured. These 550 mm long by 100 mm tall prisms offered information on the concrete's resistance to bending or flexural pressures. Splitting Strength (fct,sp): The tensile strength of the concrete due to applied axial loads was calculated using cylindrical samples with diameters of 150 mm and heights of 300 mm. This test provides information about how concrete behaves under tensile stress, which is particularly important for components that are subjected to bending.

These extensive tests' results were methodically compiled. A direct comparison of the attributes of SCC and its conventional counterpart, CC, is made possible by Table 6's consolidated perspective of the average test findings. This methodical methodology guarantees a thorough comprehension of SCC's performance metrics, opening the door for wise choices in its practical applications.

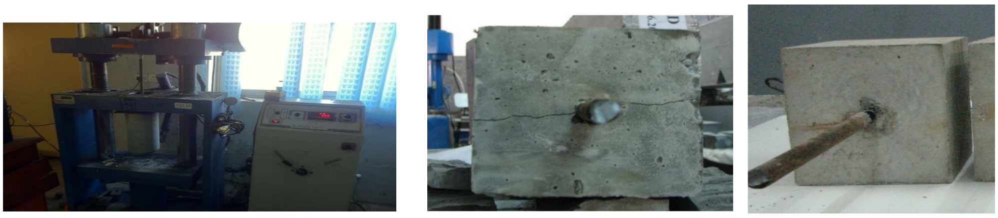
Table 6. Fresh and hardened properties of CC and SCC

Properties	**Conventional Concrete (CC)**	**Self-Compacting Concrete (SCC)**
Slump flow(mm)	-	650
Slump (mm)	75	-
V-funnel (s)	-	25
L-Box	-	0.85
fc(7days)	36.48	32.61
fc(28days)	43.23	45.03
fct, fl (7 days)	3.78	3.42
fct, fl (28 days)	4.41	4.67
fct,sp (7 days)	2.89	3.01
fct,sp (28 days)	3.48	3.12

2.4 Test Setup and Testing Procedure –

In the building industry, the strength of the bond connection between reinforcing bars and concrete is crucial. The pull-out test has established itself as a standard in the industry for precisely determining this binding strength. This test provides a measurement of the bond strength as well as a potential slide between the concrete and the reinforcement bar as well as a general indication of the bond capacity. Additionally, it is a crucial instrument for evaluating the effectiveness of new building materials or procedures as well as the standard of construction work. An investigation of the bonding dynamics between concrete and reinforcing steel was conducted using RILEM [9] criteria. The pull-out test was conducted in Universal Testing Machine (UTM). The bond strength between materials, most frequently between reinforcement bars and concrete, is precisely what this sophisticated piece of equipment is made to measure. The following are the functioning parts of the UTM such as the hydraulic jack is in charge of applying the specimen's pulling force. The load cell precisely measures the applied force to get accurate measurements. Maintains stability throughout the testing process by using a support and anchor system, which also ensures dependable and consistent loading conditions. Equipment for data acquisition captures and records important data points, such as load applied and displacement, enabling thorough post-test analysis.

The testing samples for this particular study included both cube and cylindrical samples. The diameter of the cylindrical samples was 100 mm, whilst the sides of the cube samples were 150 mm. These specimens contained reinforcement implanted at a depth corresponding to three times the diameter of the reinforcing bar. Additionally, these specimens were prepared in a consistent manner, with all reinforcement casting directions maintained parallel to the longitudinal axis. When the specimens reached the age of 28 days, which is a standard benchmark in the construction industry for evaluating concrete qualities, the critical phase of testing was started. For each reinforcing bar length, three identical specimens were examined to assure dependability and capture any potential variations. The testing was carried out with great care. The force needed to extricate the embedded reinforcement completely or cause a failure in the surrounding concrete was used to calculate each specimen's bond strength. A load cell was used to measure the force, and the applied force data was carefully recorded. In parallel, the slip at the unloaded end of the reinforcing bar was measured using a Linear Variable Differential Transformer (LVDT). The LVDT provided a remarkable level of precision, taking measurements up to 0.001 mm. The maximal force that was recorded throughout the pull-out test is what matters most. The binding strength between the reinforcing bar and the concrete is determined by this force. In summary, the pull-out test, aided by cutting-edge UTM, offers a complex understanding of the bond dynamics, guaranteeing that the reinforcing bars are optimally absorbed into the concrete and laying the groundwork for strong and long-lasting constructions.



(a) (b) (c)

Figure 1. Pull out test of concrete (a) UTM set up, (b) CC concrete specimen, (c) SCC concrete specimen

III. Experiment and Result

Self-compacting concrete (SCC) is renowned for its ability to flow and consolidate under its own weight, effectively filling formwork and encapsulating even the most intricate reinforcements without the need for mechanical vibration. This characteristic results in numerous advantages, one of which is improved surface finish, especially when compared to conventional concrete (CC). This finding, which was also made by different authors [22], demonstrates the SCC's outstanding ability to fill even small parts that only need modest amounts of concrete. The bond strength of concrete is a measure of the adhesive strength between the reinforcing steel or any embedded material and the surrounding concrete. In pull-out tests, this bond strength (fbond) is calculated based on the maximum pull-out load (P) at which either the reinforcement slips out or the concrete fails, and the surface area (A) over which this force is distributed. The standard formula to determine the bond strength is as per RILEM [9] claims in Eq. (2)

$$fbond) = P \backslash A \qquad (2)$$

Where:

P is the maximum pull-out load in MPa

A is the embedded surface area of the reinforcement

For instance, if a rebar with a circumference "C" and embedded length "l" is pulled out, the surface area A can be calculated as A=C×l.
After conducting the pull-out test, the maximum load at which failure occurs is noted. Using the above formula, this load is then divided by the embedded surface area of the reinforcement to determine the bond strength. The obtained value, fbond, provides insight into the quality of the bond between the embedded material and the concrete, which is crucial for structural performance, particularly in reinforced concrete structures. The final bond strength and the characteristic bond strength are crucial for comparing SCC with CC. The bond stress associated with the reported ultimate load is the ultimate bonding capacity. The average of the bond stresses observed for slips of 0.01, 0.10, and 1.00 mm is used to calculate the characteristic bond strength.

The test set for this evaluation experiment watermark image randomly selected from the internet. Matlab 7.0 software platform is use to perform the experiment. The PC for experiment is equipped with an Intel P4 2.4GHz Personal laptop and 2GB memory.

The proposed scheme is tested using ordinarily image processing. From the simulation of the experiment results, we can draw to the conclusion that this method is robust to many kinds of watermark images.

3.1 Bond and Slip behabiour of SCC and CC –

The bonding behavior between steel bars and two types of concrete, self-compacting concrete (SCC) and conventional concrete (CC) was thoroughly investigated in this work. In the evaluation, the binding strength of the bars' surface was evaluated, along with the associated failure mechanisms and the steel's slide. Values for final slip (Su), typical bonding capacity (M), and ultimate bonding (R) for all specimens are provided in Table 7, along with other useful information. The chart also shows the cause of failure, including splitting errors (S) and pull-out faults (P-O). For clarity, the parameters of the steel bars (diameter and embedded length) and the abbreviations used to denote each type of concrete are described.

According to Table 7's findings, SCC consistently has stronger ultimate bond strengths than CC. The difference is seen in the accompanying figure, which depicts the bond stress-slip behavior for all combinations with an embedding length three times the diameter of the bars. Notably, if we concentrate solely on the parts that suffered pull-out failure and exclude those with a predisposition for splitting, the behavior of conventional bonding appears to be consistent with the behavior found in ultimate bond strength.

The characteristic bond strength of self-compacting concrete mixtures is typically higher than that of conventional concrete (CC), with gains of up to 55% being noted, especially in the case of elements using 16 mm bars with a 3d embedded length. In contrast, because of the increased water-to-cement (W/C) ratio, the higher water content around the bars can have a considerable impact on CC's binding strength. These results are significantly influenced by the mechanical characteristics of the region between concrete and steel. The micro-mechanical characteristics around the reinforcing bars are improved in SCC because the Zone of Interfacial Transition between steel and concrete is distributed more consistently. Higher bond strength in SCC compared to CC may result from this enhancement.

Additionally, it is interesting that, with the exception of the 16 mm ribbed bars with a 3d embedded length, which demonstrate a 10% reduction, the self-compacting mixes generally show a much lower ultimate slip (Su) in comparison to ultimate bond strength. This pattern is consistent with earlier research' findings [15, 31, 34] that steel-concrete slide is less likely to occur in self-compacting concrete than in conventional concrete, particularly at intermediate stress levels of 10-15 MPa.
Table 7 shows that when subjected to a slide of 0.01 mm, all SCC mixes had stronger binding strengths than CC. At this slip value, SCC had an average bond strength that was 9% greater than CC. Both the SCC and CC failure modes were consistent. For most components, pull-out failure was the predominant mode. Splitting failure, however, was only apparent in a few instances with bigger diameters (16 mm) and an embedded length of 3d. As seen in Fig. 2, this phenomenon did not exhibit any discernible differences between SCC and CC.

Table 7. Results for bonding ability, slippage, and manner of failure for CC and SCC

Concrete	Diameter of bar (mm)	τ_R	τ_M	Su	P-O	S
CC	10 (plain bar)	6.12	4.53	1.34	3	0
	10 (rebars)	9.49	7.25	0.76	3	0
	16 (plain bar)	4.51	2.65	1.23	3	0
	16 (rebars)	3.48	1.78	0.89	3	0
SCC	10 (plain bar)	6.99	4.89	1.23	3	0
	10 (rebars)	10.36	5.43	0.65	3	0
	16 (plain bar)	5.65	2.87	0.99	3	0
	16 (rebars)	4.34	1.98	1.00	3	0

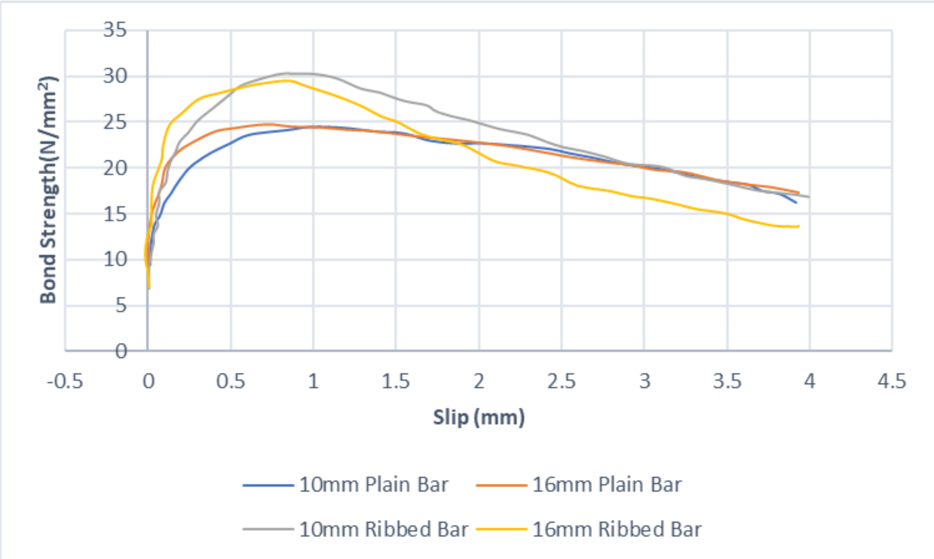


Fig.2 Bond Stress and Slip data for different diameter bars

3.2 The Effect of Embedding Length –

Particularly in the field of reinforced concrete design, the bond strength between reinforcing bars and concrete is a crucial component of structural engineering. The bar and the surrounding concrete interact mechanically to form this link by mechanisms of adhesion, friction, and mechanical interlock. In this relationship, embedded length also known as the development length is of utmost importance. Fundamentally, the bond strength normally increases together with an increase in the embedded length of a reinforcing bar within the concrete. The justification for this is simple: more surface area for the concrete to grasp or "bond" with the reinforcing bar results from a longer development length. This bigger contact results in more resistance to forces trying to pull the bar out of its position.

It is critical to take out factors like the concrete's strength and bar dimensions in order to accurately analyze the impact of embedded length. Numerous research [15,8,14,53] have shown that the strength of the concrete, which is represented by a factor of $fc^{1/2}$, has an impact on the bonding capabilities. The process to calculate normalized bond strength (n) is provided in Equation 3. The greatest bonding capacity (R) divided by the aforementioned factor yields the result.

$$\tau_{n} = \tau_R / fc^{1/2} \quad (3)$$

In structural research, the impact of the embedded length on bond strength, particularly as it applies to reinforcing bars in concrete, has received considerable study. To better understand this phenomena, Fig. 3 presents a thorough representation of the findings, arranged in accordance with bar diameter.

A curious tendency may be seen by carefully examining Fig. 3: the ultimate bonding strength appears to be decreasing as the embedded length rises. It implies that there might be an optimum range of embedding lengths for increasing bond strength, beyond which any additional length could possibly be harmful.
The research highlighted a comparison between bars with a diameter of 10mm and 16mm as one of its comparisons. For self-compacting concrete (SCC), in instance, the variation in bond strength values was found to be roughly 10%. These results highlight the role that bar diameter plays in the bond behavior of reinforced concrete elements. It's interesting how little difference there was between the performance of self-compacting concrete (SCC) and traditional concrete (CC). Both types appeared to display a generally identical bonding behavior, demonstrating that SCC's special flowable properties do not always offer a bonding advantage.
Further investigation into the effect of embedding length revealed that the bond capacity-slip connections did not appear to be significantly impacted by this variable. The bond capacity-slip connection is crucial because it sheds light on the relative slide that occurs as a load is placed between the bar and the concrete. Under various load circumstances, the structure will react reliably thanks to a consistent bond capacity-slip relationship.
A strange finding was observed, though, regarding components strengthened with 16mm bars that had noticeably long embedding lengths. These cases showed a sporadic appearance of a splitting propensity. Examining the bars with a 10mm diameter, where only a small number of radial cracks were found, as shown in Fig. 1, can help to further explain these phenomena. These radial fissures or splitting tendencies are a blatant sign of stress concentrations in the concrete, which poses a risk to the member's structural integrity.
The tensile strength of the concrete is a crucial element influencing bond behavior. It's important to notice that concrete is weaker than steel in tension than in compression. Since tensile strength differs from compressive strength, tension failure of the concrete is more likely to occur as applied loads rise. As a result, a change in the mode of failure is observed when the tensile pressures are too great for the concrete. In contrast to pull-out, which is when a bar simply pulls out of concrete, cracking or splitting begins to occur in the concrete immediately surrounding the bar. According to the reference [52] referenced, this separation turns into the predominant failure mode.
Finally, a careful analysis of Table 7 provides a further, essential discovery. Contrary to some assumptions, when the embedding length is compared to the ultimate bonding capacity, there doesn't seem to be much of an impact on the slip. This finding emphasizes how complex bond behavior is and how many variables are involved in determining it.

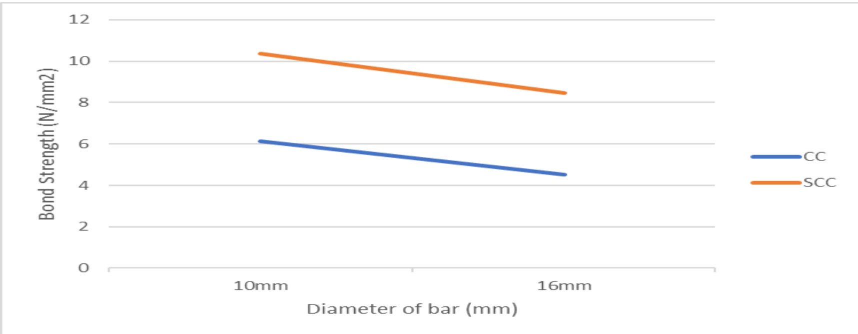


Fig3 Influence of bar diameter

3.3 Influence of the bar diameter –

When the bar diameter and the kind of concrete are taken into consideration, the bond strength of concrete in relation to reinforcing bars—a crucial metric in structural engineering—displays interesting patterns. With the use of current research and historical writing, this investigation tries to clarify these complexities and provide key takeaways.
First off, there is a continuously documented trend in numerous research, including reference [31], that the bond strength normally tends to decline as the reinforcing bar's diameter rises. The latest study unambiguously confirmed these phenomena, highlighting how common this association is.
Adding to this finding, a definite change can be seen when going from a bar diameter of 10 mm to 16 mm in self-compacting concrete (SCC). For SCC, a drop in the normalized final bond strength of 4 to 10% was specifically observed. Conventional concrete (CC) showed a more pronounced drop, varying between 10 and 15%.
These variations may be a result of the two types of concrete's inborn material characteristics and behaviors. Notably, when compressive strength increased, the size of these disparities appeared to decrease. This intriguing correlation may have its origins in the unique way that 16 mm bars fail, particularly at high compressive strengths.

Referencing further, reference [30] from the literature provides an insightful viewpoint. According to this theory, binding strengths are typically weaker during splitting failures than pull-out failures. In essence, the reported bond strength frequently appears to be on the lower side when the concrete around the reinforcing bar splits or cracks (as opposed to the bar merely becoming displaced).

As previously indicated, Fig. 4 visually illustrates these findings. The effect of bar diameter on bond strength is made clear by showing the data in terms of normalized bond strengths for both SCC and CC. The pattern is clear when averaged values for the two specified bar diameters are displayed for a constant embedded length. A rise in the bar diameter for SCC and CC is associated with a decline in bond strength. In contrast to CC, a significant linearity is seen in the case of SCC when the diameter increases from 10 mm to 16 mm. In contrast, the drop in binding strength for CC is greater. Specifically, CC showed a steeper reduction of around 15% whereas SCC showed a drop of about 10% between the 10-mm and 16-mm bar diameters.

Another interesting finding is the slide at maximal bond tension, which is in line with knowledge from reference [14]. The slip, which represents the relative displacement between the bar and the concrete at peak bond stress, steadily decreases as the diameter of the bar grows. This phenomenon provides information about how reinforced concrete members behave structurally under various load circumstances.

Although there are many variables that affect the bond strength between reinforcing bars and concrete, bar diameter emerges as a key component. As bar diameter increases, binding strength decreases for both SCC and CC, though at different rates. Despite these differences, both forms of concrete behave generally the same when other factors are consistent. It's also critical to note that, particularly in pull-out tests, the relationship between bond strength and bar diameter displays patterns that might be crucial for safety and structural design decisions

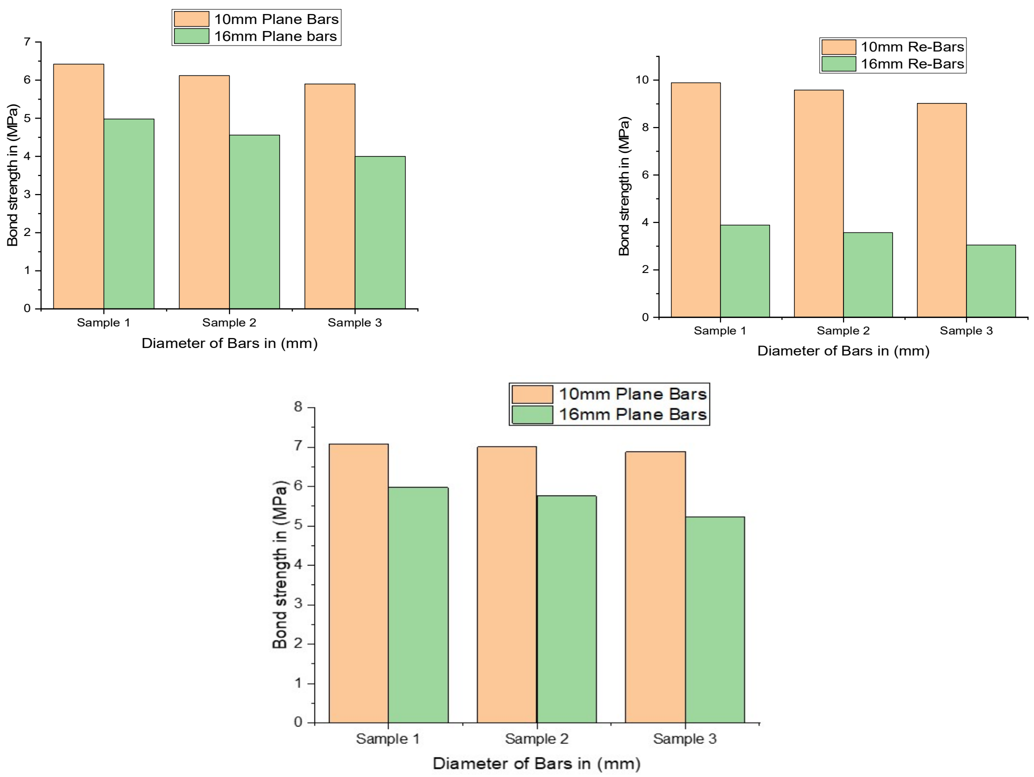


Fig.4 Bond Stress variation for SCC and CC for different diameter bars

3.4 Relation between Comptressive strength and Bond strengthfor SCC and CC –

Compressive strength is a crucial factor in assessing concrete's performance. All concrete types studied showed an outstanding increase in compressive strength over time, according to an intelligent conclusion drawn from the data. In particular, the strength at 28 days outperformed the strength at 7 days by more than 15%. This indicates that the concrete matured and gained strength in a steady and substantial manner.

Some surprising patterns are seen when Self-compacting Concrete (SCC) and Conventional Concrete (CC), the two main forms of concrete being studied, are compared. The performances of SCC and CC initially appear to be pretty similar. The variations in their test results when both types of concrete are produced using the same amount of cement are hardly ever greater than 10%. A more thorough investigation finds that SCC, as compared to its conventional equivalent, registers a slightly lower splitting tensile strength at the 28-day point.

Fig. 5 is evidence of SCC's ability to form bonds. SCC consistently performs better than CC in terms of bond strength over a wide range of mixtures. But as the quality of the material improves, an intriguing convergence in performance is noted. Consider concretes with a compressive strength of 30 MPa for a more concrete example. SCC's mean bond stress exceeds CC's by around 10%. This improved bonding in SCC may be attributable to its outstanding filling powers and less tendency to hemorrhage.

Even when blended with high water-to-cement (w/c) ratios, SCC's high viscosity gives rise to its fascinating features. Due to its high viscosity [3,19], water moves very little to the surface, preventing unwanted bleeding. CC, on the other hand, has a divergent behavior. The bleeding becomes more severe in CC as the w/c ratio increases, potentially leading to pockets of water behind the reinforcing bars. Bond strength is compromised by this buildup.

This study emphasizes an important finding: SCC behaves consistently at moderate load levels in all investigated mixes. SCC's consistency was demonstrated by the statistical insignificance of any deviation from this pattern. Additionally, as shown in Fig. 2, the relative slip between steel and concrete in SCC is substantially lower than it is in CC. As an illustration, if we carefully study the normalized stress-slip curve for a slip of 0.01 mm, SCC's slope significantly outshines CC's by 56%.

The bleeding phenomena in CC becomes strikingly obvious when the causes of this are investigated. SCC has a tighter fit between steel and concrete because of its better filling capacity and less bleeding [29]. The ribs of the reinforcing bars can contact with the concrete more effectively thanks to this tight relationship, especially at lower slip levels. The SCC and CC performance curves start to resemble one another as slip advances. SCC's bond capacity, however, continues to be clearly better even under mild loads.

The contribution of superplasticizers is another element enhancing SCC's performance. These additives, which are mostly used in SCC, disperse cement particles and stop them from clumping together. By increasing the amount of an active binding agent in the mixture, this action encourages strong bonding and significantly shrinks matrix gaps. Although SCC and CC both offer advantages, the former's traits—such as less bleeding, increased filling capacity, and greater bond strengths—make it an appealing option in situations when bond strength is crucial.

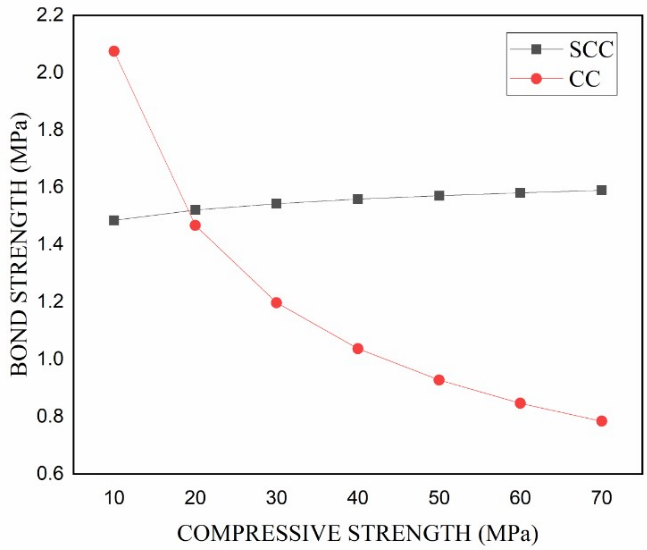


Fig.5 Relationship between Bond Strength and compressive strength

IV.CONCLUSION

In structural engineering, the complex interaction between concrete and reinforced bars, particularly with regard to their bond strength, is crucial. This study set out to investigate the relationship between bond strength and the diameter of the reinforcing bars in two widely used forms of concrete: conventional concrete (CC) and self-compacting concrete (SCC). The main conclusions from this study are that:

- SCC regularly outperforms CC in both ultimate and characteristic bond strengths when the compressive strength is benchmarked at roughly 50 MPa.
- This difference in performance suggests that SCC's behaviour and formulation make it more suited to making solid bonds with reinforcing bars when subjected to high compressive pressures.
- At a specified slip value of 0.01 mm, SCC makes a substantially stronger bond with the reinforcing bar than its conventional counterpart, highlighting SCC's bonding powers even more.
- With higher bar diameters, bond strength decreases for both SCC and CC, but SCC's rate of reduction is smoother and generally slower than that of CC. This demonstrates SCC's remarkable adaptability and resistance to modifications in the size of reinforcing bars.
- For both SCC and CC, the slip at which maximum bond strength is attained tends to decrease as the diameter of the reinforcing bars increases.
- The strength of the eventual binding decreased noticeably as this embedded length increased. The complicated relationship between embedding depth and bond strength is reaffirmed by this trend, highlighting the need of using the best design and manufacturing techniques.

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