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Influence of Corrosion on the Bond between Steel and Concrete

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Abstract - *Corrosion of reinforcing bar is now recognized as the major cause of degradation of concrete structures in many parts of the world. It causes large loss in cross section and diminished bond performance resulting in reduced performance under seismic and everyday loading. While the most obvious effect of corrosion is a reduction in cross sectional area of reinforcing bars, there are other associated effects caused by the build-up of corrosion products at the interphase between the reinforcement surrounding concrete. These corrosion products are expansive in nature and so induce radial pressures on the surrounding concrete resulting in cracking and spalling. The failure mode due to the corrosion is mostly the bond failure. The efficiency of the load transfer from concrete to steel is primarily dependent upon the bond between the steel and the concrete. Adequate bond between concrete and steel is hence one of the most important prerequisites for the concrete construction. An experimental study is conducted in this paper to investigate the effect of corrosion on the bond behavior between different steel bars and concrete. An accelerated corrosion test was used to corrode the steel bars embedded in concrete specimens. Pull-out tests were conducted on the specimens with plain and deformed reinforcing bars of different diameters. The bond behavior of the different steel bar specimens at different corrosion levels were discussed. The results showed that the bond stress increases at low corrosion level (<4%) and decreases at higher levels (>4%).*

Key Words: Corrosion, Reinforcing bars, Accelerated Corrosion Test, Pull-out Test, Bond Strength, Corrosion Loss.

1. INTRODUCTION

Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. Advantages of SCC are rapid rate of concrete placement, faster construction time., minimizes hearing-related damages on the worksite that are induced by vibration and ease of flow around congested reinforcement. Concrete has low tensile strength, which is often used in combination with reinforcing bars. It prevents the failure of concrete structures which are subjected to tensile and flexural stresses. The bond between steel reinforcing bars and concrete plays a vital role in the effective performance of reinforced concrete as a composite member.

Corrosion of reinforcement is one of the most important causes of significant damage of reinforced concrete structures. However, when reinforcement corrodes, the formation of rust leads to a loss of bond between the steel and the concrete and subsequently delamination and spalling. If left unchecked, the integrity of the structure can be affected. For the different types of reinforcing bars, corrosion has different effects on bond strength degradation due to different bond mechanisms, which is very important for the accurate prediction of bearing capacity and serviceability performance of RC members. There are different factors affecting the process of corrosion in concrete. The increase in volume of reinforcement after corrosion is one of the adverse effects on the structure apart from reduction in cross section area of reinforcement. The primary causes of corrosion are chloride penetration, and the reduction of pH of the concrete matrix due to carbonation.

Pullout test is intended to provide a standardized procedure for comparison of bond characteristics between concrete and different types of reinforcing bars. A pullout test measures the force required to pull a specially shaped steel rod or disc out of the hardened concrete into which it has been cast.

Over the past few decades, some experimental works on the bond behavior of RC member considering the reinforcement corrosion have been actively conducted. The failure mode due to the corrosion is mostly the bond failure. The efficiency of the load transfer from concrete to steel is primarily dependent upon the bond between the steel and the concrete. Adequate bond between concrete and steel is hence one of the most important prerequisites for the concrete construction. Composite action of the concrete and steel cannot be achieved without adequate bond. This makes the study of relation between the corrosion rates and the bond stress relevant. This study primarily aims to study the variation in the load bearing capacities of the real structures affected by corrosion with changes in type of steel, diameter of steel using the accelerated corrosion technique.

2. MATERIALS

2.1 Cement

Ordinary Portland Cement (53 grade) confirming to IS:12269-1987 was used for all the concrete mixtures. The physical properties of cement were tabulated in Table 1.

Table -1: Physical Properties of Cement

PROPERTY	OBTAINED VALUE
Standard consistency (%)	33
Initial setting time(minutes)	88
Final setting time(minutes)	280
Specific Gravity	3.127

2.2 Aggregates

The maximum size of coarse aggregate used in the concrete mixture is 12.5 mm. Natural fine aggregate used is Manufactured Sand. The physical properties of aggregates were tabulated in Table 2.

Table -2: Physical Properties of Aggregates

TYPE OF AGGREGATES	WATER ABSORPTION	SPECIFIC GRAVITY	BULK DENSITY
Coarse Aggregate	0.62%	2.739	1.54kg/l
Fine Aggregate	1.3%	2.68	1.48kg/l

2.3 Fly ash

Fly ash is a fine inorganic material with pozzolanic properties, which can be added to SCC to improve its properties. Class F fly ash is used for the project. Specific gravity is 2.7.

2.3 Reinforcing Bars

Reinforcing bars of 8mm, 10mm and 12mm diameters of plain and deformed bars (Fe415 and Fe500) were used.

2.4 Water

Portable water which is available at the laboratory premises was used for mixing of concrete ingredients.

3. MIX DESIGN

SCC of grade M30 was used in the study. The mix design procedure suggested by modified Nan Su et al was used, which satisfied the requirements of EFNARC guidelines. The mix proportion was obtained as 1: 2.14 : 1.9 : 0.58 : 0.66.

4. EXPERIMENTAL PROGRAMME

4.1 Tests on Fresh Concrete

The flowability, viscosity and passing ability of fresh SCC were determined by slump flow test, V-funnel test and L-box test respectively.

4.2 Preparation of Test Specimens

Concrete cubes of 150 ×150 × 150 mm dimension were casted for compressive strength. For pull-out test cube specimen of size 100×100×100mm is used. Steel bars were provided in it projecting up from the top face to a distance of 750 mm. The specimen cover on one side was 30 mm. The embedded steel bars were covered with teflon tape to a distance of 30mm into the loading end to avoid local failure. The embedment length of reinforcement was set to 100 mm.

4.3 Accelerated Corrosion Technique

The various levels of corrosion were given to the specimens through the accelerated corrosion technique. The 28 days cured specimens were dipped in 5% NaCl solution up to the top face of the concrete cube for a period of 5 days. The specimens were supplied with different ranges of direct current from a DC regulated supply by making the reinforcement as the positive electrode and a steel plate dipped in the same solution as the negative. The amount of corrosion was determined by the amount of current that passes through the reinforcement with the aid of Faraday's law which is as follows,

$I_{app} = \frac{\rho w_i \ F}{100\Pi DLWT}$, where, I_{app} = Applied current, ρ = Degree of corrosion, w_i = Initial weight of the steel in kg, F = Faraday constant whose value is 96487As, D=Diameter of the bar in mm, L = Embedment length in mm, W=Equivalent weight of the steel which is 27.925g, T = Time in seconds.

4.4 Tests on Hardened Concrete

The test conducted on hardened concrete were compressive strength test and pull-out test. Pull out tests were carried out as per IS 2770-1967- Part-1. The bond stress can be calculated from the following formula,

$\tau_{bd} = \frac{P}{\Pi DL}$, where, τ_{bd} =nominal bond stress in N/mm^2, P=Load at failure in N, D=diameter of the bar in mm, L= embedment length in mm.

5. EXPERIMENTAL RESULTS

5.1 Fresh Properties

Table -3: Fresh Properties of Concrete

SLUMP FLOW T_{500} (sec)	SLUMP FLOW DIAMETER(mm)	V- FUNNEL (sec)	L-BOX
4.15	650	9.8	0.84

5.2 Hardenend Properties

5.2.1 Compressive Strength

The compressive strength of 28 day cured specimen was obtained as 34.7MPa.

5.2.2 Pull-Out Test

(i) Bond Stress-Slip Curves for Smooth Bars

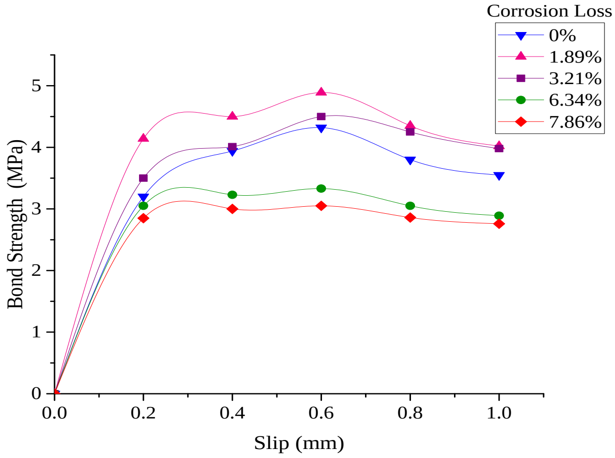

Chart -1: Bond Stress-Slip Curves for Smooth Bar Specimen of 8mm Diameter.

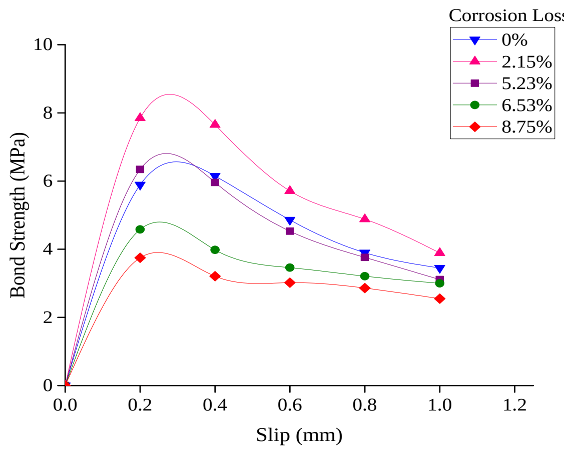

Chart -2: Bond Stress-Slip Curves for Smooth Bar Specimen of 10mm Diameter.

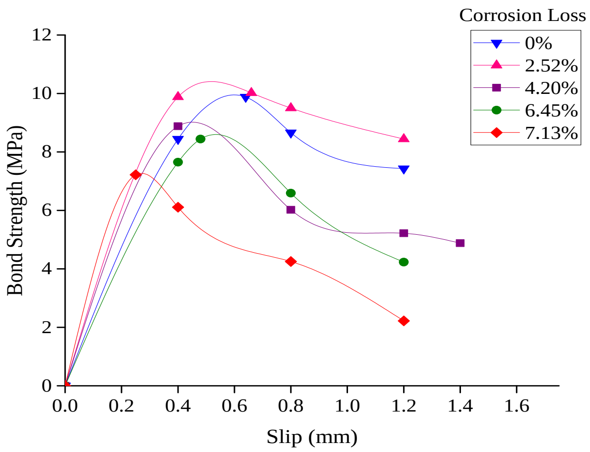

Chart -3: Bond Stress-Slip Curves for Smooth Bar Specimen of 12mm Diameter.

(ii)Bond Stress-Slip curves for Deformed Bar (Grade:Fe415)

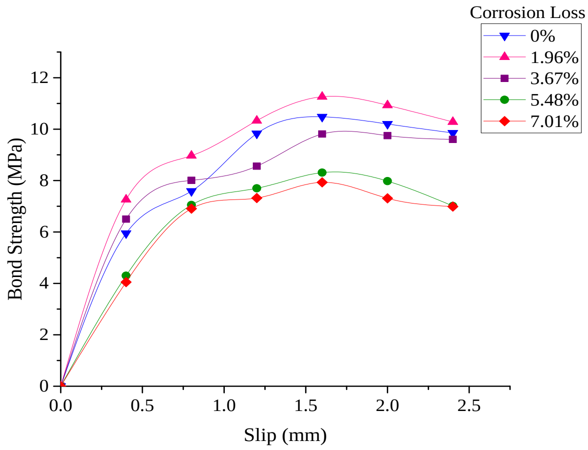

Chart -4: Bond Stress-Slip Curves for Deformed Bar Specimen of 8mm Diameter.

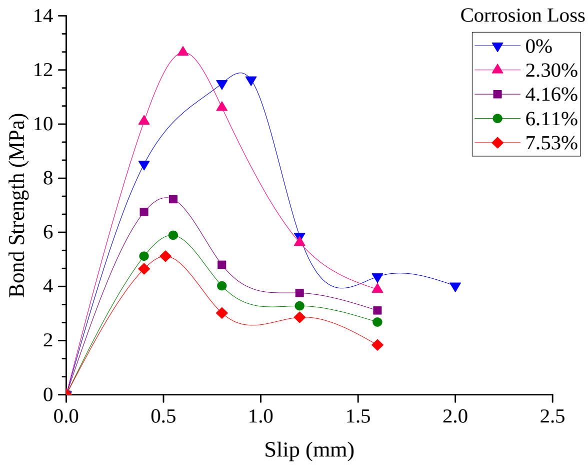

Chart -5: Bond Stress-Slip Curves for Deformed Bar Specimen of 10mm Diameter.

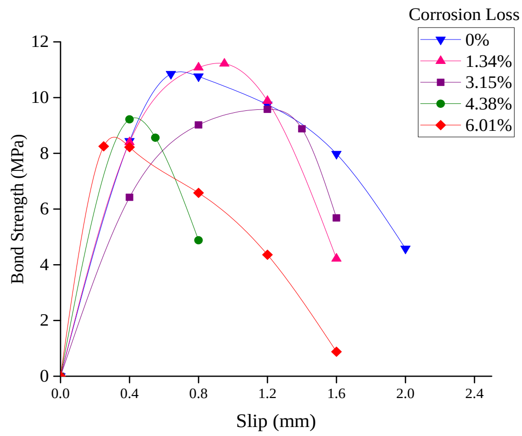

Chart -6: Bond Stress-Slip Curves for Deformed Bar Specimen of 12mm Diameter.

(iii) Bond Stress-Slip Curves for Deformed Bar (Grade:Fe500)

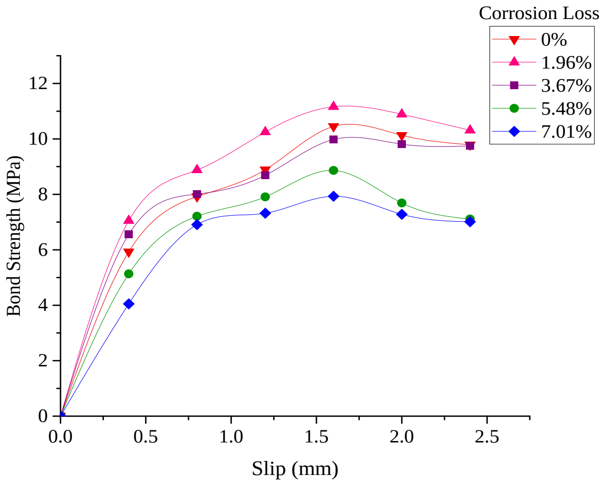

Chart -7: Bond Stress-Slip Curves for Deformed Bar Specimen of 8mm Diameter.

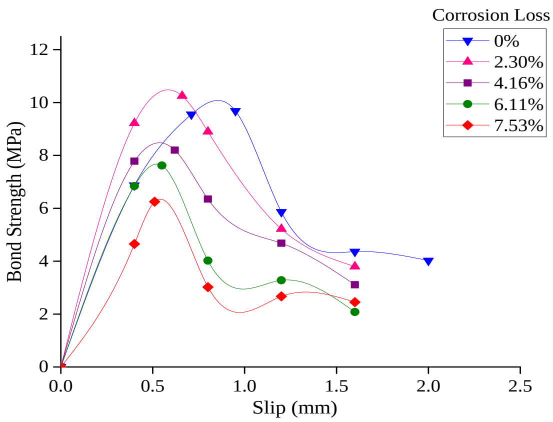

Chart -8 Bond Stress-Slip Curves for Deformed Bar Specimen of 10mm Diameter.

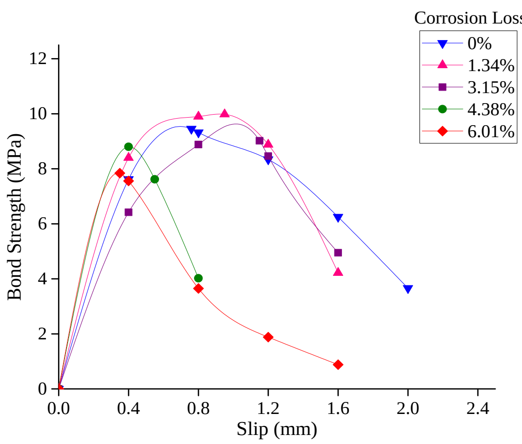

Chart - 9: Bond Stress-Slip Curves for Deformed Bar Specimen of 12mm Diameter.

6. CONCLUSIONS

The influence of corrosion on the bond between steel and concrete were studied. The following conclusions are drawn from the experimental results:

1. Accelerated corrosion technique is a feasible method to estimate the rate of mass loss of a steel bar embedded in concrete

2. It is evident that a percentage mass loss less than 2% caused the bond strength to increase before it decreased to a minimum value. This is because the rust is well adhered to the underlying steel at low levels of corrosion, which helps the bond between steel and concrete. Pressure develops at the concrete–steel interface during the initial stages of corrosion as a result of the larger volume occupied by the corrosion products. This provides some degree of confinement of the steel bar prior to cracking of the concrete cover and contributes to the initial increase in bond strength. The change in the level of roughness of the bar surface can result in an incrcase in the bond strength with increasing levels of corrosion up to about 3% corrosion. These results indicate that the strength of a reinforced concrete structure will not necessarily be negatively affected by low percentages of corrosion, and the useable life of a structure could include the time it takes for corrosion to proceed up to a specified limit.

3. At high level of corrosion the bond strength decreases. This is because the corrosion -induced crack results in a bond deterioration and accelerates the bond failure .The layer of corrosion products also broke down the friction mechanism, except for low levels of corrosion.

4. The selection of steel bars is also an alternative way to improve the bond behavior in practical design process. For the same diameter and corrosion loss the deformed bars have more bond stress when compared with smooth bars.

5. The change in the grade of deformed steel bars has not yielded any recommendable results. This indicates that for ribbed bars, the detailing of the ribs does not have any major influence on the bond capacity at different levels of corrosion.

REFERENCES

[1] Yafei Ma, Zhongzhao Guo, Lei Wang, Jianren Zhang (2017) , Experimental Study to Investigate the Effect of Corrosion and Corrosion Induced Cracks on the Bond Behavior Between Steel Bars and Concrete, Journal of Construction Building Materials152 ,240–249.

[2] Cristina Frazão, Joaquim Barros, Aires Camões, Alexandra C. Alves, Luís Rocha (2016) Corrosion Effects

on Pull Out Behavior of Hooked Steel fibers in Self-compacting Concrete. , International Journal of Cement and Concrete Research.

[3] Dharmaraj R , Dr.R.Malathy (2016) Flexural Behaviour of Reinforced Self Compacting Concrete Containing Corrosion Inhibitors, International Journal of Advanced Engineering Technology.

[4] Hana A.Yousif, Farqad F.Al-Hadeethi, Bashar Al-Nabilsy and Amani N. Abdelhadi (2015) Corrosion of Steel in High-Strength Self-Compacting Concrete Exposed to Saline Environment, International Journal of Corrosion,Vol 2014.

[5] Tondolo .F (2015) ,Bond Behaviour with Reinforcement Corrosion , Journal of Construction and Building Materials 93, 926–932.

[6] Jun Pil Hwang, Min Sun Jung, Moonil Kim, Ki Yong Ann (2015) ,Corrosion Risk of Steel fibre in Concrete, Journal of Construction and Building Materials101,239–245.

[7] Carlos G. Berrocal, Ignasi Fernandez, Karin Lundgren, Ingemar Löfgren (2016), Corrosion-induced Cracking and Bond Behaviour of Corroded Reinforcement Bars in SFRC, Journal of Composites.

[8] Cheng Jiang , Yu-Fei Wu , Ming-Jiang Dai (2017), Degradation of Steel-to-concrete Bond due to Corrosion, Journal of Construction and Building Material.

[9] Ashraf M. Heniegal , Mohamed Amin , Hassan Youssef (2017) , Effect Of Silica Fume And Steel Slag Coarse Aggregate On The Corrosion Resistance Of Steel Bars, Journal of Construction and Building Materials 155, 846–851.

[10] Beglarigale A, Yazıcı H(2016), Chloride-induced Corrosion and Bond Performance of Single Steel Fiber Embedded in Cement Based Composites, ACE 2016 12th International Congress On Advances In Civil Engineering.

[11] Ivan Holly (2013), Juraj Bilcik, Effect of Reinforcement Corrosion on Bond Behaviour, Procedia Engineering 65 (2013) 248 – 253

[12] EFNARC (2005) The European Guidelines for Self-Compacting Concrete Specification, Production and Use (May 2005).

[13] Nan Su, Kung Chung Hus, His W. Chai(2001), A simple design method for self-compacting concrete

[14] Shetty M. S., Concrete Technology Theory and Practice, S. Chand & Company Ltd., New Delhi, 2005.

[15] IS4031:1988, Indian standard– " Method of Physical Tests for Hydraulic Cement", Bureau of Indian Standards, 1988, New Delhi.

[16] IS: 2386 (Part I) – 1963 Indian standard – "Methods of test for aggregates for concrete - Part I Particle size and shape", Bureau of Indian standard, 1997, New Delhi.

[17] IS: 2386 (Part III) – 1963 Indian standard – "Methods of test for aggregates for concrete - Part III Specific gravity, density, voids, absorption and bulking", Bureau of Indian standard, 1997, New Delhi.

[18] IS: 10262:2009 Indian standard – "Concrete mix proportioning - guidelines", Bureau of Indian standard, 1997, New Delhi.

[19] IS: 383 – 1970 Indian standard – "Specification for coarse and fine aggregates from natural source for concrete", Bureau of Indian standard, New Delhi, India, 1970.

[20] IS: 456 – 2000 "Plain and Reinforced concrete – Code of practice", aggregates from natural source for concrete", Bureau of Indian standards, New Delhi, India,1970.

[21] IS 12269:2013 "Ordinary Portland Cement, 53 Grade – Specification", Bureau of Indian standards, New Delhi, India.

[22] Robert F. Blanks and Henry L. Kennedy, The Technology of Cement and Concrete, Volume 1, Concrete Materials, John Wiley & Sons, Page 52.

[23] Properties of Concrete, A.M. Neville, Addison Wesley Longman Ltd., Page126.

[24] IS : 2770 (Part I) – 1967, Methods of Testing Bond in Reinforced Concrete, Bureau of Indian Standards, NewDelhi.