Review on the Effects of Sodium Chloride on Bond Strength between Steel & Concrete

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Abstract — The corrosion of steel strands due to the chloride contamination is one of the most common causes for the degradation of pre-stressed concrete infrastructure. In this project, an experimental study was performed to investigate the bond behaviors between steel strands and concrete after suffered the chloride corrosion. Total nine central and off-center pull-out specimens with different corrosion levels were prepared and tested on UTM. The effects of corrosion rate, concrete to the steel strands on the bond behaviors of steel strands were studied and compared, in terms of the failure mode, bond-slip relationship, bond strength. In this Project, total nine cube has casted of size of 15m×15cm×15cm. The grade of the concrete was M40 and Mineral Admixture was fly ash, chemical admixture was super plasticizer and the proportion of the mineral admixture was 20% of the cementious material 0.6 % of super plasticizer. Steel bar of diameter of 8mm and length is 1m is used for providing inside of the cube at a depth of 100mm. Proper Mix design has done and all material required has collected before casting the cube. For casting, Material is prepared with proportion for first three cube and mixing has done for that three cube and that process has done every three cube and the prepared concrete has filled in cube with proper compaction after determining the slump of that prepared concrete and steel bar is immersed up to 100mm from top in concrete. After painting, testing has been performed that is pullout test and calculation has been done. The result was, bond strength was more than mentioned in the IS 456-2000 and development length was 100mm for every cube that was same as actual provided and development length was 350mm to 400mm for different cube. So we are on safer side as guidelines of the IS code.

Keywords: Sodium Chloride, Bond Strength, Steel & Concrete

I. INTRODUCTION

Tremendous increase in demand for resources and acute shortage of the same is like a double edged sword. Codes and construction practices are emphasizing durability to cope with the situation. One of the most important concerns with reinforced concrete construction is deterioration due to reinforcement corrosion. Corrosion effects on structures cannot be ignored and replaced.

Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. In case of corrosion formation, an oxide of iron due to oxidation of the iron atoms in solid solution is a well-known example of electrochemical corrosion, commonly known as rusting. These oxides are usually weaker than steel. Chloride ingress into the concrete is a major cause of steel corrosion. Presence of chloride ions at the rebar level leads to the breakdown of passive firm thin film layer and consequently initiates the corrosion (Pradhan and Bhattacharjee, 2009). Rust produced as a result of corrosion increases its volume 2 to 6 times than that of original steel; it causes increase in volume of tensile stresses in concrete (Bhaskar et al. 2010).

The process of corrosion is initially slow and later it progresses exponentially. Corrosion initiation process in RC structures depends on the atmospheric conditions, thickness of cover, quality of concrete present at the cover depth, stress levels of corrosion in rebar, cracking effect etc. Macro corrosion cell-both the anodic and cathodic reactions frequently take place in different places with some distance apart (Browne, 1975). Physical model for steel corrosion in concrete sea structures is proposed by Bazant, (1979). Effects of reinforcement corrosion on the performance of RC elements are summarised in Fig.given below

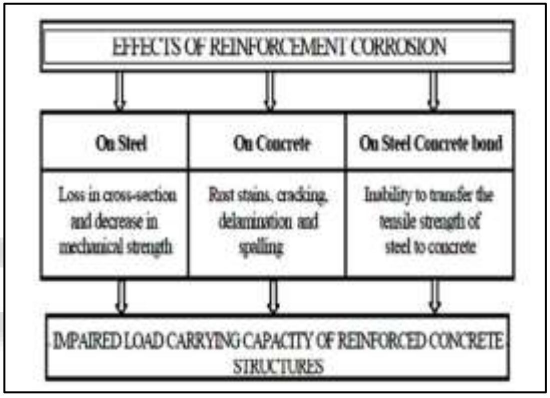

Fig. 1: Effect of Reinforcement Corrosion on the Performance of RC Elements

The basic cycle of micro cracking, cracking of concrete and influence of various environmental factors, resulting in the corrosion of embedded steel contribute to further Cracking and reprocessing, until the steel corrodes extensively and/or concrete gets deteriorated or delaminated

II. CONCLUDING REMARK OF LITERATURE

A. Charles Kennedy, Akatah Barry Mark, Ishmael Onungwe, Akpan Paul Paulinus

In this study investigated the effect of corroded and inhibited reinforcement on the stress generated on pullout bond splitting of non-corroded, corroded and resins / exudates paste coated steel bar of 150µm, 250µm and 350µm thicknesses from three trees extract of symphonia globulifera linn, ficus glumosa, acardium occidentale l. Uncoated and coated members were embedded into concrete cubes and exposed to laboratory severely / corrosive environment and enumerated the effects on surface condition of reinforcing steel for 90 days after initial 30 days curing and 60days ponding in an accelerated medium. Results obtained showed potentiality of corrosion on uncoated concrete cube members. In comparison, failure loads of Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l are 36.47%, 32.50% and 29.59% against 21.30% corroded, bond strength are 64.00%, 62.40%, 66.90 against 38.88% and maximum slip are 89.30%, 84.20%, 74.65% against 32.00% corroded. Entire results showed values increased in coated compared to corroded specimens resulted to adhesion properties from the resins / exudates also enhances strength to reinforcement and serves as protective coat against corrosion.

B. Amadou Sakhir Syll and Toshiyuki Kanakubo.

In this study Corrosion of the reinforcement affects more than the cross-sectional area of the rebar. The volume of steel also increases due to expansive corrosion products, leading to the cracking, delamination, and spalling of concrete. As a result, the bond capacity between concrete and rebar is affected. Researchers have extensively examined the impact of corrosion on the bond strength between concrete and rebar to propose empirical, theoretical, or numerical predictive models. Therefore, research programs on this topic have increased rapidly in recent years. This article presents a systematic literature review to explore experimental methods, outcomes, and trends on this topic. The Web of Science search collected 84 relevant research articles through a rigorous selection. Key factors that affect bond strength degradation, including concrete cover, concrete strength, and stirrups, have been documented. However, a general model is still unavailable due to discrepancies caused by differences in testing methods to evaluate the effect of corrosion on bond strength.

Furthermore, researchers attempted to clarify the degradation mechanism of bond strength affected by corrosion. As a result, new alternatives have been proposed to build a practical model to assess the bond strength deterioration of corroded structures.

C. Akshatha Shetty

Corrosion of reinforcing steel is the most detrimental effect endangering the structural performance. Present investigation has been taken up to study the detrimental effect of corrosion on bond behaviour. Anchorage bond strength and Flexural bond strength characteristics are studied in this research. Two types of cements namely Ordinary Portland Cement (OPC) and Portland Pozzolona Cement (PPC) have been used. Bond strength study has been carried out for controlled beam specimen and for specimens subjected to different levels of corrosion. Loss in mass of reinforcement bar has been taken as the basis to fix corrosion levels. Accelerated corrosion technique has been adopted to control corrosion rate by regulating current over predetermined durations. For the study of anchorage bond strength, cylindrical specimens have been adopted. Concrete grade of M20 and Fe-415 grade of 16mm diameter bar have been used. From the study it has been observed that for corrosion levels upto 2.5%, bond strength is unaffected. But for corrosion levels beyond 2.5%, there is considerable decrease in bond strength. For understanding the performance of flexural bond strength, National Bureau of Standard (NBS) beams have been investigated. Concrete grade M30 and steel Fe-415 have been used. From the experimental investigation it has been observed that load carrying capacity drops by about 1.6%, for every percentage increase in corrosion level. Bond strength degradation of 2.6% at slip initiation and 2.1% at end of slip have been observed for every percentage increase in corrosion level for OPC concrete beam specimens. For PPC concrete, bond strength degradation of 2% at slip initiation and 2.1% at end of slip have been observed. In numerical study, finite element method was used. ANSYS commercial software is used for the study. From the numerical modelling it has been observed that load carrying capacity drops by about 1.8%, for every percentage increase in corrosion level. The bond strength degradation values are 3% and 2.4% at initiation of slip and end of slip respectively per percentage increasen in corrosion level. Lastly, an attempt has been made to apply the proposed prediction equations to estimate corrosion in real life structure.

D. Zhao-Hui Lu. Shi-Yu Wu. Zhuo Tang. Yan-Gang Zhao. Wengui Li.

The corrosion of steel strands due to the chloride contamination is one of the most common causes for the degradation of prestressed concrete infrastructure. In this paper, an experimental study was performed to investigate the bond behaviors between steel strands and concrete after suffered the chloride corrosion. Total twenty central and off-center pull-out specimens with different corrosion levels were prepared and tested, in which the electrochemical acceleration method was employed to induce various corrosion levels. The effects of corrosion rate, stirrup configuration and holding condition of concrete to the steel strands on the bond behaviors of steel strands were studied and compared, in terms of the failure mode, bond-slip relationship, bond strength, and bond toughness. The results show that both the ultimate bond strength and characteristic bond strength decreased with the increase of corrosion degree. The presence of stirrups can significantly enhance the bond performance, indicating the more ductile failure characteristic and increased bond toughness. Moreover, the prediction results using empirical and analytical models are also compared with the experimental results to verify their applicability and accuracies in predicting the bond strength of steel strands after corrosion.

III. METHODOLOGY:

A. Cement:

OPC 43 cement shall conform to IS: 8112-1989 and the designed strength of 28 days shall be minimum 43 MPa or 430 kg/sqcm. Even though 43 Grade cements early strength is less as compared to that of 53 Grade, with time it will attain the same ultimate strength as that of 53 Grade cement. In the case of 43 Grade cement, the initial setting of cement is slower as compared to 53Grade cement. In other words, the hydration process and consequently, the release of heat is moderate and therefore, occurrence of micro cracking is much less and can be easilycontrolled by proper curing of the concrete / masonry work. Unless a project requires very high strength cement, the use of 43 Grade OPC is generally recommended in general civil construction work such as residential, commercial and industrial structures. It is used in RCC works, preferably where the grade of concrete is up to M-40.

B. Aggregates:

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and portland cement, are an essential ingredient in concrete. Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered include: Grading, Durability, particle shape and surface texture, abrasion and skid resistance, unit weights and voids, absorption and surface moisture .Needless to say, the selection of these aggregates is a very important process.

1) Size of Coarse Aggregate

Materials that are large enough to be retained on the 4.7mm sieve size usually constitute coarse aggregates and can reach a maximum size of 63mm. The size of coarse aggregates affects several aspects of the concrete, mainly strength andworkability, and the amount of water needed for the concrete mix. It also helps determine how much fine aggregate is needed to produce a concrete batch. The bigger the size, the smaller is its bondable surface area for cement, sand and water; the less water and fine aggregate is needed with concrete mixes The size of the coarse aggregate determines the cement to water ratio Less water means a stronger mix, but it also becomes less workable. One important factor is the space between TMT Bars. The aggregate needs to be smaller than the space between internal reinforcements. This will allow the aggregate to pass between the rebar and settle evenly throughout the structure.

In this project, two sizes of the coarse aggregate have been used. The size of the coarse aggregate is 20mm and 10mm. The proportion of the coarse aggregate of size of 20mm is 60 percent of the total quantity of coarse aggregate required. In the case of 10mm size of coarse aggregate, proportion was 40 percent of the same and the specific gravity of coarse aggregate is 2.74.

C. Fine Aggregate:

Fine aggregate is the essential ingredient in concrete that consists of natural sand or crushed stone. The quality and fine aggregate density strongly influence the hardened properties of the concrete. The concrete or mortar mixture can be made more durable, stronger and cheaper if you made the selection of fine aggregate on basis of grading zone, particle shape and surface texture, abrasion and skid resistance and absorption and surface moisture.

1) Grading Zone of Fine Aggregate

A good concrete mix must include aggregates that are clean, hard, strong and free of absorbed chemicals or coatings of clay and other fine materials. Ignorance of these characteristics can cause the deterioration of concrete, thus regulatory authorities have decided grading zone of fine aggregate, where each zone defines the percentage of fine aggregate passed from the 600 microns sieve size.

Zone I: 15% to 34%, Zone II: 34% to 59%, Zone III: 60% to 79%, Zone IV: 80% to 100% .In this project, fine aggregate in zone I is used and specific gravity of that fine aggregate is 2.67. The fine aggregate used is crushed artificially in crushing machine

D. Fly ash:

The use of fly ash in portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of portland cement may be reduced.

Benefits to Fresh Concrete. Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits are as follows: Improved workability, the spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. This same effect also improves concrete pumpability by reducing frictional losses during the pumping process and flat work finishability, Decreased water demand. The replacement of cement by fly ash reduces the water demand for a given slump. When fly ash is used at about 20 percent of the total cementitious, water demand is reduced by approximately 10 percent. Higher fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations. Reduced heat of hydration. Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements. Fly ash is used 20 % of cementious material.

E. Super plasticizers:

When superplasticizer is used, concrete tends to lose workability rapidly. High strength concrete containing such materials must therefore be transported, placed, and finished before they lose their workability. Many modern superplasticizers can retain reasonable workability for a period of about 100 min, but care is still needed, particularly on projects where ready-mixed concrete delivery trucks require long journey times. Often, to avoid drastic reduction in slump and resultant difficulty in placing, only part of the superplasticizer is mixed during batching with the balance being added on site prior to pouring. The same production and quality control techniques for normal strength concrete should also be applied to high strength concrete. In fact, the importance of strict control over material quality as well as over the production and execution processes cannot be overemphasized for high strength concrete. In general, production control should include not only correct batching and mixing of ingredients, but also regular inspection and checking of the production equipment, e.g. the weighing and gauging equipment, mixers and control apparatus. With ready-mixed concrete supply, this control should extend to transport and delivery conditions as well. The main activities for controlling quality on site are placing, compaction, curing and surface finishing. Site experience indicates that more compaction is normally needed for high strength concrete with high workability than for normal strength concrete of similar slump. As the loss in workability is more rapid, prompt finishing also becomes essential. To avoid plastic shrinkage, the finished concrete surface needs to be covered rapidly with water-retaining curing agents.

F. Epoxy Paint:

Epoxy coatings are used to protect concrete and steel marine structures as formulations are available to adhere to wet substrates. The use of epoxy paint is to resist the water or moisture to enter inside the cubes, It has applied on all side, except top side because it is required to calculate the bond strength from top side of the cube.

Typical applications for the protection of marine structures include:

- Coating piles, piers, sea walls and abutments in the splash zone.
- Coating water tanks, fish ladders, dams, and outfall structures.
- Coating piles, piers, seawalls and abutments underwater.

G. Steel bar:

Reinforcement for concrete is provided by embedding deformed steel bars or welded wire fabric within freshly made concrete at the time of casting. The purpose of reinforcement is to provide additional strength for concrete where it is needed. The steel provides all the tensile strength where concrete is in tension, as in beams and slabs; it supplements the compressive strength of concrete in columns and walls; and it provides extra shear strength over and above that of concrete in beams. In this project, the deformed bar of size of 8mm has been used and total number of bar was Nine. Each bar has been cut at 1m length and marking of 10cm has been made from one side for immersion into concrete up to marking.

H. Water:

Potable water was used for making concrete available in Material Testing laboratory. This was free from any detrimental contaminants and was good potable quality.

1) Test on hardened concrete:

From each concrete mixture, cubes of size 150mm x 150mm x 150mm have been casted for the determination of compressive strength. The concrete specimens were After applying the epoxy paint on each cube on all side excluding top side,All nine cube have put in water for 28 days , Six cube have been cured in salty water and Three cube in normal water. The proportion of salt in salty water was 300gm/litre of water.So in this manner, All cube have been kept submerged in clear fresh water andsalty water until taken out prior to test. curing conditions as per IS 516-1959 and were tested at 28days for determining compressive strength as per IS 516-1959 and splitting tensile strength as per IS 5816-1999.

IV. CONCLUSION

In this project The bond strength for every cube is varying in the range 11.50 N/mm^2 to 12N/mm^2 and as par IS 456-2000 The bond strength for deformed bar and for M40 grade of concrete it is 3.04 N/mm^2, so the actual bond strength between steel and concrete is conservative by approximately 4 by factor of safety.

Similarly in the case of development length, The development length provided is 100mm and As per IS 456:2000, After doing of calculation the development should be in the range of 350mm-425mm, But As we have provided the development length of 100mm, Then Also the bond strength is in the range of 11.50 N/mm^2 to 12N/mm^2 which is grater than As per IS456:2000 provisions. So, Here the bond strength and development length is safe side or conservative by factor of safety of 4.

The width of surface cracking on concrete due to corrosion of steel reinforcement is closely related both to the cover thickness and to the amount of stirrups or their absence in RC element.

Existence of stirrups contributes to bond behavior, and subsequently, greater density of stirrups affects both the reduction of bond loss' degradation rate due to steel corrosion, as well as the increasing of bond stresses values due to greater confinement.

The development of surface cracking in concrete is associated with an exponential reduction of bonding forces.

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