Durability Characteristics of Reinforced Concrete Column

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Abstract: ***The corrosion of steel reinforcement in concrete is the most significant durability problem encountered in reinforced concrete structures. In moist air reinforcement corrosion is an obvious cause of deterioration of concrete structure, which affects the durability and service of reinforced concrete structure. The deterioration of concrete structures caused by corrosion of reinforcing steel bars is not always directly related to strength reduction of reinforcing bars. When corrosion of reinforcing bars takes place crack formation in concrete could lead to greater reduction in strength and durability.***
Keywords: Durability, column, reinforced concrete, corrosion

1. INTRODUCTION

A composite material in which concrete is relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength or ductility is known as Reinforced concrete (RC). The reinforcement is usually, though not necessarily, steel reinforcing bars (rebar) and is usually embedded passively in the concrete before the concrete sets. Reinforcing schemes are generally designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking and/or structural failure.

Modern reinforced concrete can contain varied reinforcing materials made of steel, polymers or alternate composite material in conjunction with rebar or not. Reinforced concrete may also be permanently stressed (in tension), so as to improve the behaviour of the final structure under working loads.

For a strong, ductile and durable construction the reinforcement needs to have high relative strength, high toleration of tensile strain, good bond to the concrete, irrespective of pH, moisture, and similar factors, thermal compatibility, not causing unacceptable stresses in response to changing temperatures and Durability in the concrete environment, irrespective of corrosion or sustained stress for example.

1.1 Reinforcement in construction field

Many different types of structures and components of structures can be built using reinforced concrete including slabs, walls, beams, columns, foundations, frames and more. Reinforced concrete can be classified as precast or cast-in-place concrete. Designing and implementing the most efficient floor system is key to creating optimal building structures. Small changes in the design of a floor system can have significant impact on material costs, construction schedule, ultimate strength, operating costs, occupancy levels and end use of a building. Without reinforcement, constructing modern structures with concrete material would not be possible.

1.2 Behavior of reinforced concrete

1.2.1Materials- Concrete

Concrete is a mixture of coarse (stone or brick chips) and fine (generally sand or crushed stone) aggregates with a paste of binder material (usually Portland cement) and water. When cement is mixed with a small amount of water, it hydrates to form microscopic opaque crystal lattices encapsulating and locking the aggregate into a rigid structure. The aggregates used for making concrete should be free from harmful substances like organic impurities, silt, clay, lignite etc.

Typical concrete mixes have high resistance to compressive stresses (about 4,000 psi (28 MPa)); however, any appreciable tension (e.g., due to bending) will break the microscopic rigid lattice, resulting in cracking and separation of the concrete. For this reason, typical non-reinforced concrete must be well supported to prevent the development of tension.

1.2.2 Materials-Steel

If a material with high strength in tension, such as steel, is placed in concrete, then the composite material, reinforced concrete, resists not only compression but also bending and other direct tensile actions.

A reinforced concrete section where the concrete resists the compression and steel resists the tension can be made into almost any shape and size for the construction industry.

1.3 Reinforced concrete column

A reinforced concrete column is a structural member designed to carry compressive loads, composed of concrete with an embedded steel frame to provide reinforcement. For design purposes, the columns are separated into two categories: short columns and slender columns.

1.3.1 Anti-corrosion measures

In wet and cold climates, reinforced concrete for roads, bridges, parking structures and other structures that may be exposed to deicing salt may benefit from use of corrosion-resistant reinforcement such as uncoated, low carbon/chromium (micro composite), epoxy-coated, hot dip galvanised or stainless steel rebar. Good design and a well-chosen concrete mix will provide additional protection for many applications.

Uncoated, low carbon/chromium rebar looks similar to standard carbon steel rebar due to its lack of a coating; its highly corrosion-resistant features are inherent in the steel microstructure. It can be identified by the unique ASTM specified mill marking on its smooth, dark charcoal finish. Epoxy coated rebar can easily be identified by the light green colour of its epoxy coating.

Hot dip galvanized rebar may be bright or dull grey depending on length of exposure, and stainless rebar exhibits a typical white metallic sheen that is readily distinguishable from carbon steel reinforcing bar.

Reference ASTM standard specifications A1035/A1035M Standard Specification for Deformed and Plain Low-carbon, Chromium, Steel Bars for Concrete Reinforcement, A767 Standard Specification for Hot Dip Galvanised Reinforcing Bars, A775 Standard Specification for Epoxy Coated Steel Reinforcing Bars and A955 Standard Specification for Deformed and Plain Stainless Bars for Concrete Reinforcement.

Corrosion inhibitors, such as calcium nitrite [$Ca(NO^2)^2$], can also be added to the water mix before pouring concrete. Generally, 1–2 wt. % of [$Ca(NO^2)^2$] with respect to cement weight is needed to prevent corrosion of the rebars. The nitrite anion is a mild oxidizer that oxidizes the soluble and mobile ferrous ions (Fe^{2+}) present at the surface of the corroding steel and causes them to precipitate as an insoluble ferric hydroxide ($Fe(OH)^3$). This causes the passivation of steel at the anodic oxidation sites. Nitrite is a much more active corrosion inhibitor than nitrate, which is a less powerful oxidizer of the divalent iron.

1.3.2 Surface Treatment

There are three generic type of surface treatment are available for the decoration and protection of concrete surface, designed to control chemical ingress as well as moisture movement

Hydrophobic impregnation treatment such as silicone impregnated, which line the pores of the concrete. They repel water and therefore prevent it from entering the concrete, but continue to allow water vapour to escape is known as pore liner.

Materials that partially or completely block the concrete. They may accomplish this by either reacting with concrete to produce pore blocking products or by physical blocking in the pores is known as pore blocker.

Coating systems based on either organic resins such as styrene butadiene and acrylic copolymer or inorganic resin such as potassium silicate, which form a protective / decorative film on the surface of the concrete is known as film formers.

2. REVIEW OF LITERATURE

Biqin Dong, et.al., (2017) X-ray microcomputed tomography (X-ray μCT) method is proposed to trace steel corrosion and corrosion-induced cracking in cement paste. Experimental results show it can track the time-dependent development of steel corrosion and corrosion products, as well as the subsequent initiation and propagation of corrosion-induced cracks. The time-dependent corrosion process can be quantitatively analyzed by using X-ray μCT measurement. Good linear relationships exist between the volume loss of steel, corrosion products, and corrosion-induced cracks. The mass loss of steel obtained by X-ray μCT measurement correlates well with the mass loss estimated by Faraday's law when compared with gravimetric results.

Bo Yu, et.al., (2017) An improved numerical model for steel reinforcement corrosion in concrete was developed to investigate the influences of temperature and relative humidity on process control and corrosion rate of steel reinforcement in concrete. Corrosion rate of steel reinforcement in concrete increases with increasing temperature under both resistance control and cathodic reaction control. As a result, corrosion rate of steel reinforcement first increases and then decreases with increasing relative humidity. Corrosion rate of steel reinforcement in concrete increases gradually with increasing water-to-cement ratio and chloride content, since they may decrease the resistivity of concrete.

Hongfang Sun, et.al., (2017) In this research, a micro X-ray computed tomography (μCT) technique was used to investigate the distribution of steel corrosion embedded in cement paste non-destructively. An electrochemical method was used to accelerate the corrosion of steels for two designed levels of corrosion (2% and 18%).The actual corrosion level was found to be related to the immersion depth in NaCl electrolyte. i.e., with the increase in the depth of immersion, the steel corrosion level increased. For both corrosion levels of 2% and 18%, the distribution of corrosion products is not significantly related to the position of cathode electrode but is related to the distribution of cracks.

Jinjie Shi, et.al., (2017) In this study, the corrosion behavior of reinforcing steels in concrete under simultaneous flexural load and chlorides attack was studied by means of linear polarization resistance (LPR), electrochemical impedance spectroscopy (EIS) and cyclic potentiodynamic polarization (CPP) measurements. It was proposed that the tensile stress effect and the possible steel-concrete interfacial defects are mainly responsible for this difference. The results of LPR and EIS reveal that, as the stress ratio of flexural load increases, the uniform corrosion rate of steels increases gradually. CPP measurements show that the probability of pitting corrosion for steels with 0.5 stress ratio is markedly higher than those with 0.3 stress ratio.It is concluded that the chloride-induced corrosion of steel adjacent to the concrete with tensile stress is more severe than that subjected to compressive stress.

Raoul François, et.al., (2017) This paper investigates the influence of corrosion degree and corrosion morphology on the mechanical properties of the steel reinforcement .The ultimate strain of the corroded steel reinforcement was reduced in an exponential curve with the corrosion degree when its maximum value was smaller than 30% by mass; but it stayed stable when the maximum corrosion degree was over 30%. Corrosion reduced the ductility of the steel reinforcement. The rupture of the steel reinforcement was changed from ductile to brittle failure gradually with the increase of the corrosion degree.

Wenjun Zhu et.al., (2017) In this paper, the propagation of chloride-induced corrosion of bars embedded in reinforced concrete (RC) beams exposed to a chloride environment was examined. the cracking of the RC beams was observed and the corroded reinforcements were extracted from the beams in order to investigate the corrosion distribution and propagation. the pitting factor was close to 1 when the corrosion degree of the reinforcement was above 20%. The vast majority of experimental results retrieved for accelerated corrosion experiments and the corrosion of bars embedded in corrosive soil were located in the zone between the envelope curve and the asymptote.

Jinjie Shi, et.al., (2017) In this paper the different corrosion behaviors of top part and bottom part of horizontal steel (with respect to casting direction) in mortars after exposure to 3.5% NaCl solution were investigated. The combination of EIS and X-CT techniques allows nondestructively distinguishing the corrosion behaviors of steels in mortars with different steel-mortar interface conditions when exposed to 3.5% NaCl solution. The results of SEM and EDS highlight the dual negative effects of the defects at the bottom steel-mortar interface on steel corrosion behavior.

Xiaofei Pei, et.al., (2017) The viability of cementitious capillary crystalline waterproofing materials for corrosion protection of steel reinforcing bars for civil engineering infrastructure was evaluated using the half-cell potential method according to ASTM C876.The test program monitored the corrosion activity of 102 reinforcing bar samples embedded in mortar and immersed in a 3.5% concentration sodium chloride solution for one year. The average corrosion potential value for the test group with a W/C ratio of 0.7 remained within the non-active range for only the first 2 months before dropping sharply to -500 mV Ag/AgCl.

Chunhua Lu, et.al., (2016) In this study A 4-year natural corrosion experiment coupled with a cyclic wetting-drying process with 5% NaCl solution and an indoor natural corrosion process was carried out for pre-cracked reinforced concrete elements. The degree of corrosion of the corroded bar samples evaluated by average mass loss, was in a range from 1.87% to 5.77%.A new non-uniform coefficient, S, which was established directly based on diameter loss, was proposed to describe the mechanical properties of corroded bars therefore the value of S is in a range of 1–5 in this study. The degradation models of yield strength, ultimate strength and percentage elongation were derived based on the coefficient, S.

Abd El Wanees, et.al., (2016) Initiation and inhibition of pitting corrosion on reinforcing steel in saturated naturally aerated Ca(OH)2 solutions, under natural corrosion conditions, are followed through measurements of corrosion current, electrochemical impedance spectroscopy and SEM investigation. Pitting corrosion currents initiated after an induction period, which depends on the concentration of the aggressive salt, as well as, its cation and anion-type. Benzotriazoles inhibit pitting corrosion by adsorption and displacement of water molecules at steel/solution interface.

Zhao-Hui Lu, et.al., (2016) This paper aims to investigate the degradation of mechanical behavior of corroded steel stirrups. It is found in the experiment that both the strength and ductility of corroded stirrups decrease with the increase of corrosion and that the hemispherical model for the pit shape is more appropriate for the prediction of strength reduction of corroded stirrups. The ductility of corroded stirrups reduces with the increase of corrosion rate in particular after the corrosion rate is larger than 50%.It can be concluded that the constitutive model for corroded stirrups developed in the paper can be used to predict the mechanical behavior of corroded stirrups accurately.

Antonio Bossio, et.al., (2015) In this paper preliminary FEM analyses were performed in order to simulate pitting corrosion or general corrosion aimed to demonstrate the possibility to extend the results obtained for a cylindrical specimen, reinforced by a single bar, to more complex RC members in terms of geometry and reinforcement. Quasi-brittle behavior leads to higher corrosion penetration compared to a brittle behavior, considering rigid or deformable concrete assumptions. crack propagation, results obtained indicate that propagation depends still on the same parameters, but with a major dependency from the concrete cover.

Mainier, et.al., (2015) This article describes the mechanisms of corrosion that occur in reinforced concrete deterioration observed in an industrial plant by the action of direct emissions of sulfur dioxide. Chemical corrosion of concrete is driven by the reactions and transformations of calcium silicates ($xCaO{\cdot}SiO_2$) and calcium oxides (CaO) as new products with a volume far superior to initial volumes of these constituents in the concrete, thus favoring the fragmentation of concrete. It is recommended that reinforced concrete structures in industrial areas (high aggressiveness) have a covering thickness of 50 to 55 mm.

Vahid Afroughsabet, et.al., (2015) This study investigates the effect of the addition of steel and polypropylene fibers on the mechanical and some durability properties of high-strength concrete (HSC). The results also indicate that incorporation of steel and polypropylene fibers improved the mechanical properties of HSC at each volume fraction considered in this study. The electrical resistance of concrete with 10% silica fume increased by 3.1, 6.7, and 5.3 times at 7, 28, and 91 days, respectively, compared to those of plain concrete. The addition of steel fibers significantly decreases the electrical resistivity of concrete due to conductivity characteristics of the fibers.

Tang, et.al., (2015) This paper reviews and discusses recent research activities on the durability of concrete, including: major durability problems such as alkali aggregate reaction, sulfate attack, steel corrosion and freeze–thaw; durability of concrete in marine environment; coupling effects of mechanical load and environmental factors on durability of concrete. The study of natural green inhibitor for steel corrosion also opens a promising research direction in the near future. The case of steel corrosion, the self-power steel corrosion monitoring from tiny corrosion energy leads toward a new horizon of durability assessment.

Bulu Pradhan, et.al., (2014) In this paper the outcome of a comprehensive experimental investigation is presented wherein corrosion performance of steel reinforcement in concrete exposed to composite solutions of chloride and sulfate ions has been evaluated. The half-cell potential values were more negative than 270 mV (SCE)/350 mV (Cu/CuSO4 electrode) for both types of cement at all w/c ratios and in all exposure solutions, thus indicating the initiation of steel reinforcement corrosion in concrete. The results of analysis of variance it is found that except concentration of sulfate ions; cement type, w/c ratio and chloride ion concentration are affecting both relative resistivity and corrosion current density in composite solutions of sodium chloride and magnesium sulfate.

Daniel Matias, et.al., (2014) This study is to evaluate the effect of standard and high-performance superplasticizers on the key durability-related properties (shrinkage, water absorption by immersion and by capillarity, carbonation and chloride penetration resistance) of concrete made with different percentages of recycled coarse aggregates (RCA) from crushed concrete and compare the findings with the corresponding effect on conventional concrete. Mixes with RA and superplasticizers had better chloride penetration resistance than the RC. Adding superplasticizers can help to compact the cement paste, hindering the chloride penetration; however, there were some discrepancies in this test and further work is needed. High-performance superplasticizer always had lower carbonation depth than the one with the standard superplasticizer.

Naga Chaitanya, et.al., (2014) This study is to analyze the strength, experimentally; of corroded beams using Ordinary Portland cement. Accelerated corrosion technique was adopted to corrode the beam experimentally. The corrosion was measured using Applied Corrosion monitoring instrument. From the experimental investigation it is observed that the load carrying capacity of the beam is more for control beams, but Deflection is less for Control beams with respect to Corroded beams (2.5%, 5%, and 7.5%). It is observed that for Control Beams (i.e., Non-Corroded Beams),Peak load taken was maximum compared with 2.5%,5%,7.5%.Deflection observed for Control Beam was less than Corroded Beams. It is observed that for 7.5% Corroded Beams, the Peak load taken by the Beam was less compared with (i.e., 2.5%, 5%), Control Beams and Deflection was also less.

Kumar, et.al., (2013) The study reveals that through calcium palmitate and its combination with calcium nitrate reduces the concrete strength but inhibition to the corrosion of the rebar increases the service life of the reinforced concrete by 8 to 10 times. It is concluded that the use of 3% calcium palmitate reduces the compressive strength of the concrete by 41% but enhance the inhibition capacity of reinforced concrete considerably increasing the service life of RC structure almost 10 times.

Sagoe-Crentsil, et.al., (2012) The influence of commercial superplasticizers on the mechanism of corrosion of steel reinforcements embedded in concrete has been investigated by the impedance spectroscopy technique using Portland cement mortars with and without added chloride. The influence of CI- ions on electrochemical processes at the steel: mortar boundary are inferred from the impedance plots for the chloride bearing specimens cured at 40°c for up to 240 days. calcium lignosulphonate gives markedly lowered corrosion rates in the presence of chloride; the other plasticizers corrode at essentially the same rate as the control without plasticizer

Sung-Ho Tae, et.al., (2012) This study is to assess the corrosion resistance of a reinforcing concrete bar from chloride attack when the concrete is blended with a natural inorganic mineral admixture. The improved corrosion resistance is attributed to the fact that the concrete blended with a natural inorganic mineral admixture could bind chloride ions and inhibit bleeding, thus prohibiting the formation of pores in the lower part of the reinforcing bar. The half-cell potential and polarization resistance of the reinforcing bar in the 10% reMEUM concrete were larger than those of the plain concrete. It is concluded that the 10% reMEUM-blended concrete was indicated to be better than the plain concrete in preventing reinforcing bars from being corroded and protecting them from a chloride attack.

Manoharan, et.al., (2009) In this work, the corrosion rate of mild steel rod, CTD (Cold Twisted Deformed) rod and TMT (Thermo Mechanically Treated) rod were observed by adding water reducing admixture in concrete mix. By varying the percentage of admixture, the study was carried out. According to the results obtained from ACI measurement test, rods in concrete added with 0.5% - water reducing admixture gave better corrosion resistive character. Data obtained from OCP test reveals better corrosion resistance was offered by 0.75% admixed concrete to all the rods, especially to TMT rods.

Apostolopoulos, et.al., (2008) In the case of the significant corrosion-induced mechanisms, such as concrete carbonation and chloride penetration there are reliable predictive models. The experimental results from the accelerated corrosion tests on bare steel bars are in a good qualitative agreement with results from steel bars embedded in aged concrete. It was observed in both cases, that bars subjected to corrosion may suffer a relatively modest loss of strength but a significant loss of ductility.

Sanju ´An, (2000) Calcium Aluminate Cement (CAC) can be used successfully in mortars and concretes for special applications such as refractory and sulphate-resistant materials. This paper presents the characteristic values of corrosion rate, corrosion potential and resistivity and the relationship between them. Corrosion potential vs. corrosion rate relationship, Corrosion potential vs. resistivity relationship, Resistivity vs. corrosion rate relationship. The increase of porosity with time in CAC mortar and concrete leads to an easier external aggressive agent's penetration.

3. Conclusions

➢ For industrial areas (high aggressiveness) the covering thickness of 50 to 55 mm should be provided.

➢ 3% calcium palmitate enhances the inhibition capacity of reinforced concrete considerably increasing the service life of RC structure.

➢ Corrosion resistance was offered by 0.75% admixed concrete (conplast sp430) to TMT rods.

➢ High-performance superplasticizer always had lower carbonation depth than the one with the standard superplasticizer

➢ The degree of corrosion of the corroded bar samples evaluated by average mass loss, was in a range from 1.87% to 5.77%.

➢ The chloride-induced corrosion of steel adjacent to the concrete with tensile stress is more severe than that subjected to compressive stress.

➢ The 10% reMEUM-blended concrete was indicated to be better than the plain concrete in preventing reinforcing bars from being corroded and protecting them from a chloride attack.

➢ The pitting factor was close to 1 when the corrosion degree of the reinforcement was above 20%.

➢ The ultimate strain of the corroded steel reinforcement was reduced in an exponential curve with the corrosion degree when its maximum value was smaller than 30% by mass; but it stayed stable when the maximum corrosion degree was over 30%.

➢ The bars subjected to corrosion may suffer a relatively modest loss of strength but a significant loss of durability.

➢ Calcium lignosulphonate gives markedly lowered corrosion rates in the presence of chloride.

➢ The ductility of corroded stirrups reduces with the increase of corrosion rate in particular after the corrosion rate is larger than 50%.

➢ The specimen made with OPC showed higher value of relative resistivity and the lowered values of corrosion current density in composite solution of sodium chloride.

➢ Corrosion levels of 2% and 18%, the distribution of corrosion products is not significantly related to the position of cathode electrode but is related to the distribution of cracks.

➢ The average corrosion potential value for the test group with a W/C ratio of 0.7 remained within the non-active range for only the first 2 months before dropping sharply to -500 mV Ag/AgCl.

➢ The self-power steel monitoring from tiny corrosion energy leads toward a new horizon of durability assessment.

➢Corrosion rate of steel reinforcement in concrete increase gradually with increasing water to cement ratio and chloride content, since they may decrease the resistivity of concrete.

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