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A COMPREHENSIVE REVIEW ON EFFECT OF CRACK PROPAGATION OF CORRODED STEEL IN CONCRETE

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Abstract

Steel corrosion in reinforced concrete structures can lead to cracking of concrete cover when corrosion products expand. Corrosion of steel reinforcement is a serious problem for durability and serviceability of reinforced concrete. It is generally recognized that cracks provide easy access to ingress of chlorides in concrete and hence, the initiation of corrosion of steel in cracked concrete occurs at early stage. As the reinforcing steel corrodes, it expands and exerts pressure on the surrounding concrete cover, causing tensile stresses in concrete. This ultimately leads to cracking and spalling of the concrete cover, further exacerbating the durability problems of a structure and increasing the rate of its deterioration. The durability of structure cannot be guaranteed when a corrosion expansion crack reaches the surface of the reinforced concrete member. This paper critically reviews predictive models for crack initiation and propagation in concrete due to corrosion of the reinforcing bars and also focuses on the possible gaps and scope of advanced work to do for identifying the effective solution to reduce this problem. This paper also imparts a review study on the causes and factors responsible for corrosion. This study employs all necessary information related to the corrosion activity, fostering the researchers towards explicating some productive outcome to enhance the durability characteristics as well as the service life of reinforced concrete structures.

Key Words : *Reinforcement, Concrete, Corrosion, Durability, Crack*

Introduction :

Concrete has been proved to be a vital element in the construction field since majority of the construction industry involves design of reinforced concrete structures to accommodate with the convenience of every sections of human habitants and the materials of which is easily and widely available in the market. Reinforced concrete members are made up of three main ingredients: coarse aggregate, fine aggregate, and cement. Corrosion is similar to cancer for the reinforced concrete structure because it degrades reinforcement which affects its strength, life span. Because of corrosion, the rust product formed in the surrounding zone of reinforcement occupies a larger volume leading to a development of tension cracks in that zone leaving behind a reason for sudden collapse or menace to the structure. Different type of concretes need different type of precaution depending upon the climatic and material factors. As time and load increase, durability of structure decreases because of the action of salts, climatic condition, corrosion etc.

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This Review paper deals with all areas of possible crack propagation and corrosion of steel and the measures taken for preventing etc.

Ali S. Al-Harthy, Mark G. Stewart, and John Mullard [1] reviewed previously reported predictive models on corrosion-induced crack initiation and propagation and presents new additional results of ongoing accelerated corrosion tests conducted. It was found that predictions of time to crack initiation are highly scattered and can differ by as much as two orders of magnitude. It was also found that crack initiation and propagation times increase with increasing cover and decrease with increasing reinforcing bar diameter and compressive strength.

M.B. Otieno, M.G. Alexander, and H.-D. Beushausen [2] Studied about Cracks influence the durability of reinforced concrete (RC) structures in aggressive environments by accelerating the ingress of corrosive agents to the embedded steel. Their study investigated the influence of crack width (0·7 mm, 0·4 mm and incipient cracks), binder type (100% CEM I (ordinary Portland cement – OPC) and 50/50 OPC/Corex slag blend), water-to-binder (w/b) ratio (0·40 and 0·55) and crack reopening on chloride-induced corrosion in RC specimens with constant cover of 40 mm. Over the study period (31 weeks), corrosion rates varied from passive values of 0·01 $\mu A/cm^2$ to active values of 1·50 $\mu A/cm^2$. It is also identified that Crack reopening increased the corrosion rate in the cracked specimens.

J. A. González, E. Ramírez, and A. Bautista [3] The behaviour of highly polarized steel embedded in concrete was analysed using small mortar specimens and concrete beams, as well as slabs of considerable size, in the presence and absence of chloride additions. Electrochemical impedance spectroscopy (EIS) was used for the small samples, and polarization resistance was measured in the large ones. The measurements at corrosion potential provide information about the corrosion kinetics of steel embedded in concrete.

Ahmed M. Diab, Ali A. Aliabdo, and Ismail A. Mohamed [4] discussed about corrosion of steel bars embedded in concrete made of Portland cement replaced partially with ground limestone is studied. Three variables are considered: replacement ratios with ground limestone (0, 10, 15, 20 and 25% of cement by weight), level of cement content (300, 350 and 400 kg/m^3) and fineness of ground limestone (345, 530 and 720 m^2/kg). Reinforced concrete specimens are immersed in a 5% sodium chloride solution by weight up to 9 months. The corrosion rate is measured by potentiodynamicpolarisation technique. The corrosion behaviour of steel bars and the resistivity characteristics of Portland limestone cement concrete are also found essentially to depend on the cement content of the concrete.

JianfengDong, YuxiZhao, KunWang, WeiliangJin.[5] Presented a paper by investigating the cracking behaviour and flexural capacity of beams under simultaneous sustained loading and steel corrosion. Chloride ions were electro-migrated into the concrete beams, and then DC current, coupled with wetting and drying cycles, was applied to accelerate the steel corrosion. During the steel corrosion, the beams were subjected to sustained loading at different levels. The cracking maps were drawn and crack width was measured periodically. The flexural capacity and the steel corrosion degree were measured after seven wetting and drying cycles. The results show

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that simultaneous loading and corrosion lead to more severe and faster cracking damage on the beams and reduce the beams' ductilities.

MohammedElghazy, AhmedElRefai, UsamaEbead, AntonioNanni [6] Reports on the flexural behavior of corrosion-damaged reinforced concrete (RC) beams strengthened with different fabric-reinforced cementitious matrix (FRCM) composites. Three groups of beams were subjected to accelerated corrosion for 70, 140, and 210 days to obtain theoretical mass loss in their tensile steel bars of 10%, 20%, and 30%, respectively. The test parameters included the fabric type (PBO and carbon), the number of FRCM layers (two, three, and four), and the strengthening Scheme (end-anchored and continuously wrapped). Test results showed that FRCM composites governed the failure of the strengthened beams rather than the damage level to which the beam was subjected due to corrosion. The reported load-carrying capacities of the corrosion-damaged beams confirmed that the contribution of FRCM composites significantly offset the impact of corrosion damage on strength.

Garyfalia, G.Triantafyllou,Theodoros, C.Rousakis, AthanasiosI.Karabinis [7] presented the experimental and analytical behavior of four reinforced concrete beams with corroded steel reinforcements with low mass loss (around 7.5%), yet in need of removal of cracked concrete cover, treatment of steel bars, application of cement-based repair patch and of externally bonded EBR or NSM FRP laminates. Their study also demonstrates that assessment of contribution of corroded steel and treatment in the above cases requires partial uncovering in order to apply inhibitors and better calibrate the actual mass loss with corresponding cover concrete damage.

FabioDi Carlo, AlbertoMeda, ZilaRinaldin [8] In this paper, the behaviour of corroded columns under cyclic loads is studied with a three-dimensional Finite Element Analysis, accounting for steel and interface decay and including buckling effects. The model is validated through a comparison with the results of experimental tests developed at the Bergamo University. Finally, a parametric survey is carried out to highlight the main parameters governing the global response.

MehdiZomorodian, AbdeldjelilBelarbi, AshrafAyoub [9] Developed the FE model for predicting the shear behavior of FRP strengthened reinforced concrete (FRP strengthened RC) membrane elements can be predicted by developing logical models that satisfy the principles of mechanics of materials namely stress equilibrium, strain compatibility, and constitutive relationships of concrete, steel and, FRP reinforcements. The Softened Membrane Model (SMM), which was developed for predicting the shear behavior of reinforced concrete (RC) membrane elements, is extended to FRP strengthened RC members subjected to shear.

YuxiZhao, JiangYuBingyanHu, WeiliangJin [10] investigated a reinforced concrete specimen that had deteriorated in an artificial environment for 2 years. The crack width and the rust distribution were observed by digital microscopy. The variation of the total circumferential crack width along the radial direction is presented using a linear function. Observation reveals that rust does not penetrate into the corrosion-induced cracks before concrete surface cracking. After concrete surface cracking, rust fills the cracks, lining the edges of the cracks due to the circulation of the outer solution.

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BrankoŠavija, MladenaLuković JoséPacheco, ErikSchlangen [11] Studied cracking mechanisms due to reinforcement corrosion, mechanics of the problem was implemented in a two-dimensional lattice model. Heterogeneous nature of concrete was taken into account in the mechanical analysis. Firstly, the case of uniform corrosion was tested, and successfully verified using experimental data from the literature. Also, it was found that cracking pressure is not a deterministic value, and depends on local mechanical parameters. Secondly, two pitting scenarios were tested and compared to the uniform corrosion case.

Mullard, John A.; Stewart, Mark G [12] Their paper presents an improved model that will be used to predict the timing of corrosion-induced cover cracking for reinforced concrete (RC) structures in chloride environments. An accelerated corrosion experimental program measured concrete cover cracking for RC slabs based on various concrete covers, concrete tensile strengths, and reinforcing bar diameters. It is noticed that a new empirical crack propagation model based on the test data was then developed.

E.Chen, Christopher K.Y, Leung [13] Discussed about the Steel corrosion. Steel corrosion in reinforced concrete structures can lead to cracking of concrete cover when corrosion products expand. In this study, a finite element model has been developed to study crack propagation in concrete as corrosion progresses. The developed model considers the practical situation of chloride penetration from the member surface, which leads to non-uniform corrosion distribution around the steel cross section. To highlight the necessity to consider non-uniform corrosion in practical situations, the evolution of crack width under non-uniform corrosion for concrete with different boundary conditions is compared with that under uniform corrosion.

DiQiao, HikaruNakamura, YoshihitoYamamoto, TaitoMiura [14] investigated the effects of corrosion distribution, specifically non-uniform and localized corrosion, on cracks propagation in concrete. Different corrosion distributions along rebar length were simulated using a sodium chloride pond with various sizes set on the concrete cover, and a direct current was applied to accelerate the corrosion process. The test results showed that the crack pattern is more influenced by corrosion distribution than by concrete cover thickness. The cracking mechanism was analyzed using the Rigid Body Spring Method with a corrosion-expansion model, which utilized a set of experimental data relating to corrosion distribution. The crack patterns are simulated reasonably well. The analysis also indicated that the internal crack pattern is closely related to concrete surface deformation.

Jian Cao,Liangfang Liu, and Shangchuan Zhao [15] In this paper, firstly, based on the existing theoretical model of steel corrosion degree, the calculation process of the model and the determination of the relevant parameters in the model were analyzed and discussed. Secondly, the stiffness reduction factor of concrete in the model was calculated according to the existing experimental data, and the engineering formula of the steel corrosion degree was established, which was related to the surface crack width of reinforced concrete. Moreover, the experiments

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of steel bar corrosion were carried out with different components of surface crack width, in which the parameters of the bar diameter, concrete protection layer thickness, and water-cement ratio were taken into consideration.

E. Chen, Carlos G. Berrocal, IngemarLöfgren, Karin Lundgren [16] presented results on corrosion characteristics of 66 rebars extracted from un- and pre-cracked plain concrete and fibre-reinforced concrete (FRC) beams suffering from corrosion for more than 3 years. The influences of fibre reinforcement, flexural cracks, corrosion-induced cracks and loading condition on the maximum local corrosion level (defined as the maximum cross-sectional area loss percentage) and pit morphology were examined. With 3D-scanning, the corrosion characteristics were analysed, and pit types were classified based on the maximum local corrosion level and geometric parameters of pits. Corrosion pits were observed near some flexural cracks, while the bars at other cracks were free from corrosion.

Vidal et al. [17] measured corrosion crack widths and mass loss in the steel reinforcements in two beams that had naturally corroded in a saline environment and were subjected to wetting–drying cycles over periods of 14 and 17 years. As the authors did not report an estimate of the corrosion rate, a corrosion rate of 1 . 4 _A/cm 2 was inferred from corrosion penetration data (beam A). Using this corrosion rate in Equation 3 yields k R ¼ 0 . 91. A more elaborate estimate assuming a pit factor of 6 will only result in a small change, k R ¼ 1 . 1. In order to illustrate the importance of the loading correction factor and how it can be used to extrapolate data from laboratory corrosion tests to real corrosion rates.

Alonso et al. [18] pointed out that the presence of stirrups does not influence the time to crack initiation or propagation. A concrete member with corroded transverse reinforcing steel such as stirrups will show signs of corrosion cracks earlier (due to a smaller cover) than a member with no transverse reinforcements. The effect of corroded stirrups will be on the bond strength of the members. The large scatter in model predictions of time to crack initiation and propagation is due to different experimental procedures and environments used in the laboratory and field testing and also to different assumptions and parameters used when deriving the analytical models. Additionally, the specimens studied in many of the experiments were of different sizes and were often reinforced with only a single reinforcing bar.

Ali S. Al-Harthy et al [19] reviews previously reported predictive models on corrosion-induced crack initiation and propagation and presents new additional results of ongoing accelerated corrosion tests conducted at The University of Newcastle. In addition to eight concrete specimens previously tested, six new specimens were tested to study the effect of reinforcement confinement, concrete strength (24 and 8 MPa), cover (10 and 20 mm) and reinforcing bar diameter (16 and 27 mm) on corrosion-induced cracking. Time-dependent crack widths were measured for different reinforced concrete slabs for corrosion rates up to 169 _A/cm2 . It was

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found that predictions of time to crack initiation are highly scattered and can differ by as much as two orders of magnitude.

X P Zhong, Y Li, C B Yuan, Z Yang and Y Chen [20] Performed the tests on 13 pieces of reinforced concrete beams with HRB500 steel bars under long-term sustained loads, at time of corrosion-induced initial crack of concrete, and corrosion-induced crack widths of 0.3mm and 1mm, corrosion of steel bars and time-varying behavior of corrosion-induced crack width were studied by the ECWD (Electro-osmosis - constant Current – Wet and Dry cycles) accelerated corrosion method. The results show that when cover thickness was between 30 and 50mm,corrosion rates of steel bars were between 0.8% and 1.7% at time of corrosion-induced crack,and decreased with increasing concrete cover thickness, when corrosion-induced crack width was 0.3mm, the corrosion rate decreased with increasing steel bar diameter, and increased with increasing cover thickness;its corrosion rate varied between 0.98% and 4.54%;when corrosion-induced crack width reached 1mm, corrosion rate of steel bars was between 4% and 4.5%;when corrosion rate of steel bars was within 5%, the maximum and average corrosion-induced crack and corrosion rate of steel bars had a good linear relationship.

Zhang *et al.*[21] also built relationship between the average cross-section loss area of reinforcement and corrosion-induced crack width by experimental study.However,the effect of long-term sustained load on corrosion-induced crack and crack width of cover has not been considered in above experimentalstudies.Infact,the actual structure is working under load and environment interaction,so,studyingcorrosion-induced crack behavior of reinforced concrete members under load has very importantpractical value for durability design and service life prediction of structure.

Andrade *et al.*[22] conducted accelerated corrosion experiments on 4 group different specimen ofsteel bars position,steel bars diameter and cover thickness,found that reinforcement corrosion depth ofthe first visible surface crack(crack width was 0.05~ 0.10mm)was usually 10~50μm;

Inamullah Khan et al [23] studied the evolution of reinforcement corrosion in comparison to corrosion crack width in a highly corroded reinforced concrete beam. Cracking and corrosion maps of the beam were drawn and steel reinforcement was recovered from the beam to observe the corrosion pattern and to measure the loss of mass of steel reinforcement. Maximum steel cross-section loss of the main reinforcement and average steel cross-section loss between stirrups were plotted against the crack width. The experimental results were compared with existing models proposed by Rodriguez et al., Vidal et al. and Zhang et al. Time prediction models for a given opening threshold are also compared to experimental results. Steel cross-section loss for stirrups was also measured and was plotted against the crack width. It was observed that steel cross-section loss in the stirrups had no relationship with the crack width of longitudinal corrosion cracks.

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Q.T.Nguyen et al [24] As per their work it is discussed about Corrosion effect. Corrosion is enhanced by the combined effect of chlorides and sometimes by carbonation of concrete that renders the pH low rebar corrode. The corrosion products during active corrosion induce a mechanical pressure on the surrounding concrete which leads to cover cracking along the rebars. The objective of this work is to study the cracking of concrete due to the corrosion of the reinforcements. The phenomenon of corrosion/cracking is studied in experiments through tests of accelerated corrosion on plate and cylindrical specimens. A CCD camera is used to take image every hourand the pictures are analyzed using the Correli – LMT software to derive the displacement and strain field.

J. H. Castorena-González et al [25] 3D FEM model is proposed using the corrosion damage function by measuring the concrete cover crack width, which is a function of the free concrete cover depth, the steel rebar diameter, the mechanical properties of the concrete, and the length of the anodic zone. A significant aspect to evaluate service lifetime conditions in corroded reinforced concrete structures (RCSs) is the concrete cover crack width. Surface cracks originate due to the pressure exerted by the volume expansion of the corrosion products and oxide layer formed on the rebars. In this work, concrete cover crack width on corroded RCS is analyzed by means of finite element method allowing a corrosion damage model to be proposed. The model obtained was used to find a theoretical relationship between the dissolved steel (corrosion process) and the concrete cover crack width. The results were validated using three experimental data sets.

Khoa KimTran et al [26] discussed about Cracking behavior due to rebar corrosion in concrete specimens having a single rebar is evaluated experimentally and analytically. In the experiments, in which corrosion was induced electronically, the propagation of cracks (including internal crack patterns and surface crack widths) was monitored. In addition, deformation of the specimen surface was measured using a laser displacement meter. In the analysis, a three-dimensional Rigid-Body-Spring Method (RBSM), combined with a three-phase material corrosion–expansion model, is proposed to simulate crack propagation due to rebar corrosion. The effects of the properties of corrosion products such as elastic modulus, penetration of corrosion products into cracks, and local corrosion after cracking of the concrete are investigated.

Faiz Uddin Ahmed Shaikh [27] presented a comprehensive review and summarised the results on the effect of cracking on corrosion of steel in concrete. The effect of crack widths on the diffusion of chlorides ions andcarbon-dioxide is also discussed in their studies. Among all available results, a correlation between the corrosion current and thecrack widths up to 0.3 mm can be established, however, no distinct trends are observed beyond that crack width. Conflictingresults on the effect of crack widths on chloride ion diffusion are also reported. The longitudinal crack causes more severecorrosion of steel in concrete than transverse cracks of same width. Cracked concrete containing supplementary cementitiousmaterials exhibited superior corrosion resistance than cracked ordinary Portland cement concrete of same width of transverse aswell as longitudinal cracks. The same is also true in the case of lower water–binder

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ratios of cracked concrete. The increase incrack depth increased the chloride diffusion; however, the corrosion test shows an opposite trend. Conflicting results on the effectof crack frequency on corrosion of steel are also reported.

AminJamali et al [28] critically reviewed a number of empirical, analytical and numerical models to predict the time to cracking due to corrosion of reinforcing bars in reinforced concrete structures. The empirical models are generally based on simple mathematical expressions and primarily depend on corrosion rate, cover depth and diameter of reinforcing bars. The analytical and numerical models, on the other hand, involve more refined, mechanistic considerations and include strength and stiffness parameters of concrete and type of corrosion products. It was observed that the majority of the investigated models were only capable of adequately predicting the time-to-cracking for the experiments to which they were fitted.

JuhuiZhang et al [29] proposed a numerical model to study the cracking of cover concrete. The physical model was focused on the middle-located rebar corrosion, and the effect of the neighboring longitudinal reinforcing bars on the cracking of cover concrete was mainly considered. A damaged plasticity model for the study on the failure behavior of concrete cover was built. The non-uniform radial displacement distribution was adopted to simulate the corrosion expansion behavior of the rebar. The cracking propagation process of cover concrete with two neighboring longitudinal reinforcing bars embedded was simulated and monitored with the level of corrosion build-up. The present approach was verified by the available experimental observations. The influences of concrete cover thickness, rebar diameter and rebar spacing on the failure patterns of concrete cover and crack width propagation were examined.

AntonioBossio et al [30] In their work 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. Furthermore, a mechanical analytical model to evaluate the stresses in the concrete surrounding the reinforcement bars is proposed. In addition, a sophisticated model is presented to evaluate the non-linear development of stresses inside concrete and crack propagation when reinforcement bars start to corrode. The relationships between the cracking development (mechanical) and the reduction of the steel section (electrochemical) are provided. Finally, numerical findings reported in work were compared to experimental results available in the literature and satisfactory agreement was found.

J.Ozbolt et al [31] deled with a 3D numerical model for transient analysis of processes after depassivation of reinforcement in concrete, which are relevant for calculation of corrosion rate. The aim of the study is to investigate the influence of the concrete quality, cracking and water saturation in concrete on the current density. The results show that the corrosion rate is higher in poor quality concrete than in good quality concrete. The model predicts that cracks do not influence corrosion rate for the case where the only influence of the crack is on the rate at which oxygen can reach the steel.

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K.G.Papakonstantinou et al [32] Developed probabilistic model for chloride induced corrosion of the reinforcing steel in concrete structures is presented in this work. The main purpose of this model is to simulate the complex phenomena involved in a detailed yet simple way, appropriate for implementation on large-scale, real structures. Addressing this problem a time-dependent model is developed that can simulate all stages of reinforced concrete corrosion, i.e. corrosion initiation, crack initiation and propagation. The novelties of the formulation include a new empirical model for the crack propagation stage, which combines corrosion crack width with steel-bar cross sectional loss, based on published experimental results, and the dynamic influence of propagating cracks on the corrosion mechanism. Probabilistic concepts are also employed due to numerous sources of uncertainty in the degradation model and the extent of damage is quantified by considering the spatial variability of the various parameters.

KukritToongoenthong, Koichi Maekawa [33] aimed to numerically simulate corrosion induced cracking, its propagation over sections of reinforced concrete members and the penetration of corrosive gel product into crack gaps. A coupled steel core and surrounding corrosion product are mechanically represented by a fictitious growing composite, with which the corrosive cracking initiation and subsequent propagation are simulated by 2D nonlinear crack analysis. The injection of corrosive gels into evolving cracks is substantiated in cases where corrosive cracks stably propagate such as large covers and/or comparatively small diameters of steel, and the coupled system of gel formation, migration and crack propagation is newly presented.

Yuxi Zhao et al [34] investigated four reinforced concrete mixtures with different replacement percentages of recycled coarse aggregate (RA). The corrosion rate was measured using an electrochemical workstation, and the corrosion-induced cracks on the concrete surface were observed using digital microscopy. The results show that the use of RA introduces more interfaces in concrete, which accelerates the steel corrosion process and corrosion-induced crack propagation in concrete cover. However, steel corrosion and the corrosion-induced cracking process in concrete are not significantly influenced by replacing a small amount (33% in the study) of coarse aggregate with RA.

Balafas.I et al [35] examines the environmental conditions under which the time to cracking of concrete, due to pressure caused by rust production on the surface of steel bars, is short. To determine this time, volume compatibility is assumed, which allows for compaction of all materials affected by the pressure, including the rust itself. A fracture mechanics concept is also used to signal cover failure. The model reveals that time-to-cover-cracking is a function of the rust production and the strength of the system to resist the resulting pressure. It is found that the highest corrosion rates are towards the end of autumn and the beginning of spring, when humidity reaches relatively high values with moderate temperatures. On the other hand the highest resistance of the system to corrosion production is during summer, since the humidity is low.

Stefania Imperatore et al [36] influence of the current density on the degradation of a reinforced concrete element is investigated with particular reference to the kind of formed oxides and to the crack width is discussed in their work. As the corrosive attack propagates, the oxides

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accumulated on the steel-concrete interface cause a radial internal pressure in the structural element and induce a tensile stress state in the concrete with the consequent cracking. Except for few cases, the main outcomes on the behavior of reinforced concrete structures damaged by corrosion come from experimental results on artificially corroded specimens. For many years, the scientific community has been discussing the feasibility of artificial techniques to simulate the corrosion process in structural element.

Zhongzhao Guo et al [37] investigated the corrosion fatigue crack propagation mechanism of high-strength steel bar HRB400 in various corrosive environments. Fatigue crack growth (FCG) tests were conducted under different fatigue loading types, environments, and stress ratios. The fatigue loading type included the constant and stepwise decreasing load amplitude. The environments were air, distilled water, 3.5% NaCl solution, and an artificially accelerated corrosive environment. The stress ratio ranged from 0.1 to 0.7. The threshold stress-intensity factor range and FCG rate under various test conditions were obtained. The FCG path and fracture morphology were examined by optical microscopy and scanning electron microscopy, respectively. The threshold stress-intensity factor ranges, FCG rates, FCG paths, and fracture features under different conditions were compared.

Wenjun ZHU et al [38] investigated the influence of non-uniform corrosion in the transversal direction of the steel reinforcement on the cracking propagation of the concrete cover. An analytical model is proposed for the prediction of the corrosion-induced cracking performance. Both the thick cylinder theory of the concrete and the effect of transversal non-uniform corrosion of the steel reinforcement are involved by considering the corrosion layer of the corrosion products and a layer of concrete with the corrosion products filled with the pores. A three-stage corrosion-induced cracking of the concrete is proposed: corrosion without expansive stress to the concrete, corrosion with expansive stress to the adjacent concrete, as well as the corrosion-induced cracking of the concrete. By considering the non-uniform corrosion of the steel reinforcement and the tensile stress induced by the volumetric expansion of the corrosion products, the cracking initiation resulting from the non-uniform corrosion was involved in the prediction model. The models were also validated by the experimental results from both the corroded specimens and the existing literature, which would be helpful for the evaluation of the existing reinforced concrete constructions in the marine environment.

Michel et al.[39] investigated the penetration of the corrosion products into the concrete around the steel reinforcement based on the X-ray attenuation method and found a corrosion-accommodating region to hold the corrosion products during the time-dependent development

Wong et al. [40] also found a similar phenomenon and named it as the corrosion layer and corrosion product-filled pasted layer between the steel-concrete interface, respectively. The experimental results also found that the corrosion layer was smaller than 100 μm, and the corrosion product-filled pasted layer was usually smaller than 180 μm.

Lu et al.[41] investigated the cracking process of the concrete cover with the corrosion product and proposed a prediction model based on the uniform corrosion according to the Faraday's Law. In Lu et al.'s model, the corrosion-induced crack was supposed to be full of corrosion products.

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IoannisBalafas et al [42] In this paper, a model is developed to determine the time span of the second period. The model includes a volume compatibility condition thatallows for the proper introduction of compaction of all materials that contribute to cover spalling, including the rust. A new condition formarking failure of the cover is also established, based on fracture mechanics and strain energies. Finally, a new formula is proposed for therate of rust production, which allows for the constant rust production at early and nonlinear diffusion dependant rates at latter stages ofcorrosion.

Hossein M.Shodja, KeivanKianiAlireza, Hashemian[43], In this study, a nonlinear mathematical model for determining the displacement and stress fields in RC structures subjected to reinforcement corrosion is introduced. For corrosion products, a nonlinear stress–strain relation which has been previously confirmed by experimental data is incorporated in the present analysis. In formulation of the governing equations for steel–rust–concrete composite, the rational behavior of corrosion products and penetration of rust into the microcracks are considered. An analytical approach as well as an innovative meshless method, gradient reproducing kernel particle method (GRKPM), are employed for solving the nonlinear boundary value problem. A reasonably good agreement between the results of the two methods is achieved. The performance of the proposed model is then investigated through various comparisons of predicted values with experimentally observed data, and again good agreement is obtained. Moreover, the effects of the crucial parameters associated with the mechanical behavior of rust and concrete on time to cover cracking and some measures of deterioration are studied for different values of rust penetration into the micro cracks.

Conclusions

Corrosion of reinforced concrete is a major issue for construction work all over the world. Thousands of paper are being published every year in different journals only to know every possible behavior, factors, monitoring technique, different simulation and other phenomena so that possibility of more accurate results can be obtained which shows full behavior of structure. According to all studies which were done by several authors, give conclusion which shows different forms of results because all the studies are not done with same properties, section, admixture, salts, process and different factors for corrosion process. All information will be gathered from all the review which are added in this paper like factors, behavior, condition, corrosion description used by different authors. Cracking is also unavoidable in RC structures during itsservice life, which adversely affects its corrosion durability. While this is an important durability issue for RC not much research are reported in the literature especially in archival journals. Within available articles conflicting results on the effect of cracking on corrosion of steel in concrete are also reported. Based on all these studies it is observed that there is a gap in performing the advanced finite element analysis methods to attain better outcomes. So researchers can focus in these areas for quality research.

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