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A Contemporary Review of the Effects of Corrosion of Damaged Concrete Cover on the Structural Performance of Concrete Structure Using CFRP Strengthened Corroded Beam

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***Abstract* -** This research work reviews the experiment of the effect of damaged concrete cover on the structural performance of concrete structures using CFRP sheets. The experiment involves exposing a R.C beam specimen to an accelerated corrosion through a direct connection of electricity to the specimen. The rate of the corrosion varies by 5 to 6.5%. The exposed beam was damaged and repaired by a sheet fibre (CFRP sheet) to restore the damages caused by the corrosion exposure while the other beams were clean from the infected concrete cover and replaced with a new layer. However, the study found that the strength and stiffness of the corroded beam is higher than that of the control beams which implies that the CFRP sheet enhance the performance of concrete structure from corrosion.

***Keyword* -** *CFRP sheet, control beam, corroded beam, corrosion*

Literature review

Introduction

Concrete as emerge as the only means of solving the challenges of nature and its environs especially when faced with a construction tasks that involved technical expertise. According to V. Kumar (2013) concrete has clearly emerged as the materials of choice for the construction of a large number and variety of structures in the world today. This has lead to high usage of concrete in this modern construction industry for making barriers, beams, column, culverts, bridge e.t.c. previous occurrences of building collapse in developing country has shown that the compressive strength of concrete and its service life are not given much cognizance since what most designers focus on is the present task and not what may transpire later in the lifespan of the structure. Al-saidy (2009) found that every year building owners and managers are faced with the cost of repairing concrete that spalls when the reinforcing steel corrode, usually due to the presence of salt. Corrosion of reinforcement and the corresponding strength reduction, but also due to the volume of the rust products in the form of ferric oxides or hydroxides whose volume is 3-6 times more than the volume of steel (Kumar, 2013). Reinforcement corrosion is a major cause of deterioration which nevertheless disrupts the cover zone (concrete cover) of concrete. Al-saidy (2009) found that as steel corrodes, there is a corresponding loss in cross sectional area and in turn reduction in the flexural strength capacity of concrete. As a matter of fact when steel corrodes, its occupy a larger parts than the original steel because its spread into stages and exert a substantial tensile forces on the concrete environment causing it to crack and spall off, hence reducing its service life. The service life of concrete has been previously investigated to exceed 50yrs but sometimes concrete does not perform adequately as a result of poor construction and design, poor materials selection and environment factors (john p, 1997). In a related development Bloomfield, (1996) found that if concrete carbonates to the depth of the steel and chloride is present at above critical threshold the protection can be compromised. Product of corrosion generally occupy a larger volume than the uncorroded steel, unhydrated ferric oxide is about twice the volume once hydrated it may be up to 6 to 10 times the volume. This has created difficulties when attempting to repair the concrete, the deterioration of R.C structure is a major problem in the construction of today. The cost of repairing or replacing dilapidated structures has become a major obligation and liability to the clients. The prominent cause of this deterioration is the corrosion of steel reinforcement bars due to chlorides. The two main sources of chlorides are deicing chemicals and seawater. In Nigeria most local contractors fail to understand the effects of using sea water for mixing concrete, yet this has increase the amount and severity of structural damages without any noticeable observations by the contractors. John p (1997) observed that steel embedded in concrete can show a high amount of resistance to corrosion because the cement paste when in good quality in concrete can provides an alkaline environment with PH 12.5-13.5 that can protect the steel from corrosion by protective ferric oxide film formed on the surface steel when embedded in concrete. The protective ferric oxide film is immune to mechanical damage of the steel surface, it can, however, be destroyed by carbonation of concrete or by the presence of chloride ions, however when the PH falls below 10 for any reasons corrosion may occur (paul T, 2000). Previous research has shown that building built with black reinforcing steel are showing progressive deterioration as the concentration of chloride ions increases, this has brought about several measures to prevent the chloride ions but for most corrosion protection measures, the principle is to prevent the chlorides ions from reacting with the steel surface and also to increase the time needed for the chloride ions to penetrate through the concrete cover. Janotka etal (1989) carried out a study on the corrosion resistance of steel fibres and steel bar reinforcement in cement mortar incorporating various amount of calcium chloride from 2-10%. The results of his experiments reveal that by addition of calcium chloride while the bar reinforcement display corrosion at 2% calcium chloride, the fire did not indicate any harmful corrosion until the chloride content was 6%. Hence, these measures do not generally stop corrosion from eventually initiating; they do increase the service life of reinforced concrete structure by slowing the corrosion process. This paper aims at providing a brief review of past experimental studies on corrosion of steel bars and its effect on the service life of concrete structures.

Corrosion process

The corrosion process of reinforcement steel bars is similar to that of electrochemical process which requires several chemical reactions and a flow of electric current. In electro chemical process, the 3 important components of galvanic corrosion cells are (1) Anode (2) cathode and (3) electrolyte. For the sake of this study, the anode and cathode can be in the same reinforcing bars. The anode is the location on a steel reinforcing bar where corrosion is taking place and metal is being lost. Experiments have shown that at anode fe^{+} atom lose electrons to become ionized or iron ions (fe^{2+}). (Falah and Mohammed, 2008) observes that these iron ions, dissolve in the pore water and gives up electron, the two electrons (2^{e-}) erected in the anodic reaction must be consumed elsewhere on the steel surface to preserve electricity neutrality. This oxidation reaction is referred to as the “anodic reaction”. The pore solution is rich in oxygen with a high PH value, so that (fe^{2+}) can stay in the form of $fe(OH)_2$ or $fe(OH)_3$ due to hydrolysis or oxidation of (fe^{2+}). According to khan (1991) at the initial stage after concrete is cast and subjected to moist curing, the passive film can not be formed so quickly if the concrete is completely immersed in water. The cathode is the location in a steel bar where metal is not consume, unlike at the anode where metal is lost. At the cathode, oxygen in the presence of water, accept electrons to form hydroxyl ions OH- , in other words it is not possible for large amounts of electrical charge to build up at one place on the steel, another chemical reaction must consume the electrons. (Perez N, 2004 cited by Falah.k and Mohammed, 2008) explains its as the reactions that consume water and oxygen. These hydroxyl ions (2OH-) generated in the cathodic reaction increases the local alkalinity and strengthened the passive layer, minimizing the effects of carbonation and chloride ions at the cathode. If the iron (fe^{+}) is just to dissolve in the pore water, cracking and spalling of the concrete cannot be seen, several more stages must occurs before rust can be formed. The electrolyte is the medium that facilitates the flow of electrons (electric current) between the anode and the cathode. When concrete is exposed to wet dry cycles, it has sufficient conductivity to serve as an electrolyte. John p (1997) observes that if steel is embedded in concrete, it can show a high amount of resistance to corrosion, it improve the alkaline environment (PH between 12.5-13.5). Both the anode and the cathodic reaction are necessary for the corrosion process to occur which is required to take place redundantly. The cathode and the anode can either be located next to each other or separated. As explained by John p (1997) the initiation and carbonation of the corrosion process are influenced by the environment surrounding the steel reinforcement bars. The presence of chlorides in concrete usually enters the concrete from the top surface which exposes the reinforcement to higher concentration of chloride. The concrete serves as the electrolyte while the steel bars serves as metallic conductors. Concrete become alkaline due to the presence of $Ca(OH)_2$, KOH and NaOH and has an alkalinity between 12 and 13 due to the high alkalinity of concrete pore water, the steel reinforcing bars are passivated by an iron oxide film (Fe_2O_3) that protect the steel. The oxide product initiates the corrosion of steel reinforcing bar at the initial stage. The oxide product initiates the corrosion of the steel reinforcing bars at the initial stage of corrosion, a ferrous hydroxide $Fe\ (OH)_2$ conform is formed. $Fe(OH)_2$ has low solubility while in the presence of oxygen and water, is oxidized to iron oxide (Fe_2O_3) to form passivation film as the film is formed, the oxygen diffusion rate is reduced , which in turn reduces the corrosion rate. Once the passive layer breaks down, the area of the rust will start appearing on the steel surface (Falah, 2008). The following are several step steel corrodes without chlorides

(1a) At the anode, iron is oxidized to the ferrous state and release electrons

$$Fe \longrightarrow fe^{2+} + 2e^- \quad (1)$$

(2) These electrons migrate to the cathode where they combine with oxygen to form hydroxyl ions

$$2e^- + h_2O + {}^1/_2O_2 \longrightarrow 2OH^- \quad (2)$$

Hydroxyl ions ($2OH^{-)}$ are generated in the cathode reaction; this ion increases the local alkalinity and strengthened the passive layers

(3) The hydroxyl ions combine with the ferrous ions to form ferrous hydroxides

$$Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2 \quad (3)$$

(4) In the presence of water and oxygen, the ferrous hydroxide is further oxidized to form

$$Fe_2O_3 4\ Fe(OH)_{2\,+}O_{2\,+}H_2O\ \ 4Fe(OH)_3 \quad (4)$$

$$2\ Fe(OH)_3 \longrightarrow FeO_3.2H_2O \quad (5)$$

Experimental studies of corrosion process of reinforcement

The experimental study of reinforcement corrosion is very important because it allow for thorough observation of the gradual process which has effects on concrete structure. Regarding the corrosion process of reinforcement and its effect on the service life of structures, various studies have been carried out in the past years regarding the effects of corrosion on concrete structure with experimental proofs and results. Some of the notable experiments are highlighted below

Av.Benin and A.semenor (2010)

Av. Benin and A. semenor (2010) carried out an experiment on the modeling of fracture process in concrete reinforcement under steel corrosion through a numerical and experimental methods, this experiments includes a 2-dimensional finite element analysis of concrete cracking under reinforcement corrosion. A reinforced concrete structural component caused by expansion of corrosion predicts was modeled by a plane with periodical holes corresponding to the component cross section, the plane was loaded with an internal uniform pressure P, applied along the hole circumference to stimulate the corrosion products smell. The volume of corrosive materials is about 2.0-2.5 times of the reduction bars cross section which generated a high pressure in the concrete resulting in original cracks and their propagation through concrete cover. [2] Observed that the concrete media was free of micro-cracks, the cracks system growth was further assessed which was found also along with the increasing pressure the new cracks were generated at free surface of cover and extended toward the hole [3] uses several constructive models to test the reliability of the results through multi-model and multi variant analysis. In the model inelastic behavior analysis, concrete was assumed to be a linear elastic media (homonymic theory of plasticity and flow theory). Elasto-damage model was also applied based on the continue damage mechanical concept. The experiment results in a smaller strain using the corrosion pressure p, for various materials model.

Y.H cho (2008)

Similarly, Y.H cho, (2008) carried out an experiment on the mechanism of cracking using concrete model, a corrosion failure analysis was carried out using concrete model, a corrosion failure analysis was carried out using a commercial non-linear program package ABA QUS 6.5. In experiment, material non-linearity and non uniform pressure was applied in order to consider the real state of corrosion failure. To model the concrete, 4 modes of quadrilaterals methods were used. A numerical approach of two dimensional models using plane stress element were applied. The diameter of reinforcement was assumed as 25mm, 32mm, spaced between 150mm thickness of concrete, a simulation case of 100mm and 150mm of cover thickness was carried out. Because of the varying temperature a tensile strength of 3 different cases was used which varied from 1.308 mpa-2.545mpa, the corrosion product was assumed to be formed uniformly around the steel bar which results that the higher concrete strength and the thicker cover depth product allow the steel to constraint corrosion expansion, which means that the possibility of concrete surface cracking is at minimal diameter under the same condition is the same with the cover depth of 50mm regardless of the concrete strength and steel diameter which implies that when steel diameter is decreased. It is of benefits for structure safety under consideration of concrete surface cracking.

Matlob (2008)

In a related development mat lob (2008) carried out an experiment on concrete inhibitors, he uses materials such as OPC (ordinary Portland cement) which was relatively tested in a cement test laboratory, a washed graded sand was also used with an aggregate size of 20mm sieve according to specification IQS54:984 two type of anodic, inorganic corrosion inhibitors were used such as sodium benzoate (SB) (C6H5COONa), potassium dichromate $k_2cr_2O_7$ (PD) to serve as an inhibitors. The potassium dichromate was added to water, mix and stirred until it diffuse completely, which was later added to the concrete mix. Likewise a steel reinforcement of 0.5cm in diameter was used which was cleaned with wetted grinding paper. A concrete mix in accordance with American mix design (AC1211) and a compressive strength of 25mpa (28days) in ratio of 0.48 was prepared for the casting specimen. The specimen were immersed partially in aggressive solution(3.5% Nacl soluble for 3 month, through this period of recording of data) various test such as the compressive strength test, splitting tensile test, flexural strength test, electrochemical test were carried out to analyze the result of the specimen. The results of the compressive test shows that sodium, benzoate admixture in concrete does not show any reduction in compressive strength in ages 18, 60 and 90 days which gives a higher results than the reference mix (C25) by approximately 12%, 15% and 14%, hence using sodium benzoate as corrosion inhibitors in concrete affect the compressive strength at early ages by 2% and 3% while potassium dichromate admixture affect the compressive strength through reduction of 8% and 4% respectively. With the splitting test results, sodium benzoate admixture reveal an increase in splitting tensile strength of about 10%, 16.6% and 17%. The results of the electrical resistance test show a significant high electrical resistance due to a good quality cement mix. However the result of the experiment reveals that if some kind of anodic corrosion inhibitors like potassium dichromate are used in low dosage, they will act as corrosion accelerators not as corrosion inhibitors (matlob, 2008)[2] the sodium benzoate admixture in dosage 2% and 3% by weight of cement has no significant effects on concrete properties it only has an effects on concrete strength [3] potassium dichromate admixture in dosage of 1% weight of cement act as corrosion accelerator [4]potassium dichromate admixture in dosage of 2% and 3% by weight of cement has no detrimental effects on concrete properties.

Kumar (1999)

Kumar (1999) also carried out a study on the effects of strength of concrete in corrosion of reinforcement bar, 3 grades of steel bar, HYSD bars of grade Fe 415, and CRS (corrosion resistant steel). The steel were tested in a laboratory accelerating a corrosion test to determine the mass loss and assess the corrosion quality and the thickness of concrete cover largely determines the effectiveness of general defensive shield against corrosion. The mass loss of the steel are significantly influences by strength of the concrete. The rate of decrease of the mass loss for all type of steel is maximum 35 to 40mpa concrete strength. The study also reveals that the higher carbon content of the steel exhibit relatively large amount of corrosion, when compared to HYSD steel and CRS bars. The performance index of CRS lies in the range of 1.3 to 1.5 and increases as the quality of concrete increases and decrease. Janatka etal (1989) studied the corrosion resistance of steel fibres and steel bar reinforcement in cement mortar incorporating various amount of calcium chlorides from2-10%. The results showed that by addition of calcium chloride while the bar whiles the bar reinforcement display corrosion at 2% calcium chloride, the fibre did not indicate any harmful corrosion until the chloride content was 6%. All of the corrosion process described above required oxygen in the absence of oxygen the corrosion rate is appreciably reduced even with chloride concentration above the threshold level. However, keeping oxygen from reinforcing steel in the field is extremely difficult, if not possible when corrosion of reinforcing steel occurs, the corrosion products or rust can occupy several times, the volume then the original steel, causing tensile force to develop in the concrete. Steven. F (n.d) explain that since concrete is relatively weak in tension; cracks can develop exposing the steel to even more chlorides, oxygen and moisture while the corrosion process accelerates.

Laboratory experiment

This experiment is similarly to that of Al-saidy, as al-harthy and Al-jabri (2009) but the findings of the results are different, since this research focus on the effects corrosion has on concrete structure. However, this experiment is based on that of Al-saidy (2009) but the purpose of the test is different

- Materials **-** Cement: ordinary Portland cement (OPC) was used complying with IS: 1489-1991 (part1). The specific gravity was around 2.89-2.90 for OPC.
- Aggregates**:** a maximum aggregate size of 10mm was used in accordance with IS: 2386(party)-1963. The test samples collected were sieved to separate then into single size. The concrete was mixed in the ratio of 1:2:4 of sand: water: cement (proportioned by volume) with a water/cement ratio of 0.45. The concrete has a 28days compressive strength of 1.6 and a tensile spitting strength of 3.9mpa
- Reinforcement**:** A 10mm diameter reinforcement bars was used and measured to be 400 mpa and modulus of elasticity of 200Gpa. A stirrup of 6mm was also used with yield strength of 250mpa
- Water**:** For preparation of mix and curing of concrete samples, portable water was used for the experiments collected from a pure water factory along ikorodu road
- CFC (carbon fibred sheet): A CFC (carbon fibre sheet) was used for the experiment with a thickness of 0.11m and a manufacturer specification of 3800mpa tensile strength, modulus of elasticity of 240Gpa and 1.55% elongation. The carbon fibre sheet has a compressive thickness of 1m (fibre and epoxy).

Tests methods and discussion

A 4 R.C beam of size 1.5m long, 150mm wide and 150m high were used for the experiment with a reinforcement bar of 12mm (at the top which serves as tensile bars) and 10mm (at the bottom which act as compressive bars). A stirrups of size 6mm epoxy coated plain bars spaced at $250^{c}/_{c}$ (6nos) were used to link the top bars (tensile) and the bottom bars (compressive). The purpose of the epoxy coat is to prevent or delay the ingress of chlorines, oxygen, and moisture through the concrete cover to the reinforcing steel. A concrete cover of 25mm spaced at each ends of bars were used. In order to allow for the rapid corrosion process, an allowance was made at the bottom of the steel bar (compressive bar) for the purpose of electrical connections to the steel which was extended beyond 50mm. The beams were given a label of A, B and C respectively. Beam C (0%) serves as the control beam with no corrosion, beam C(5%) and C(5%) are also a control beams with 5% and 6.5% corrosion, while beam B1 and beam B1 (5% and 6.5% respectively) were repaired through the application of CFRP sheet at the bottom of the beam, the beam were damaged with 5% and 6.5% corrosion and then replaced with a new layer of concrete attaching the CFRP sheet at the bottom. For the purpose of repairing the damaged beam of B1 and B1, the beams were replaced with a new layer of concrete while the CFRP sheets were laid at the bottom of the beams. The casting of the beam were done in 3layers, firstly the concrete was placed at the first layer(tensile steel bars) of beam A and B while a reasonable quantity of salt of about 1.5% by weight of cement was spread along the first layer(tensile sides) except beam C(0%, which is the control beam). The beams were immersed up to 1/3rd of the height of water. Practically, salts have a reasonable amount of chloride when in contact with a metal (especially in the presence of oxygen). The purpose of the salt is to facilitate the chloride ions attacks and accelerate corrosion. The concrete were cured for 28days of volume of resistivity (in room conditions), two of the beams (beam B1 and B1) were placed inside a tank which has already been mixed with salt (as mentioned earlier), and the salt concentration was about 4% by weight of the water. The rebar were then connected to a power voltage source where current was applied to accelerate the corrosion process. The two parallel steel bars (in the tank) acts as the cathode since they are both connected to the negative charge of the power source. Similarly to that of al-saidy (2009) experiments, it took 14days of continuous application of current to each beams to achieve a 5% theoretical corrosion, but at 13days the beams were already showing a rapid increase in corrosion which was estimated to be in the range of 13.45%.

Table 1- Showing the specimen corrosion rate

Specimen	Corrosion	Remark
C (5%)	0%	Control beam
C (5%)	5%	Control 5% corrosion beam
C (6.5%)	6.5%	Control 6.5% corrosion beam
A (5%)	5%	5% corrosion strengthened with CFRP sheet
B1 (5%)	5%	5% corrosion patch repaired and strengthened with CFRP sheet
B1(6.5%)	6.5%	6.5% corrosion patch, repaired and strengthened with CFRP sheet

Note: The research work is similar to that of A.H. Al-Saidy, A.S. Al-Harthy & K.S. Al-Jabri (2009)

Previous experiments adopt various strategies for strengthening the damaged beam but this experiment adopt that of Al-saidy (2009) which uses two common methods of (1) CFRP sheets which was laid on the tension side of the beam A and B1 (5% and 6.5 % respectively) due to accelerated corrosion (2) and by removing the concrete cover zone from the contaminated concrete below the corroded rebar's before replacing the contaminated concrete with a new layer, the repaired beam was left for weeks for curing before applying the CFRP sheet and then tested

Fig. 1.

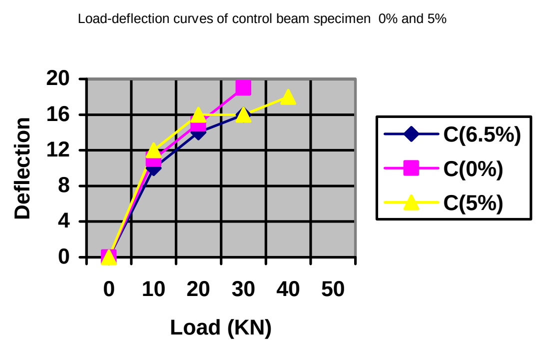


Figure 1.0 shows the load-midspan-deflection curves for the control specimens (Beams C (0%), C (5%), and C (6.5%). The graph reveals that the yield and ultimate strength decreased with the increase in corrosion reduction of the cross-section of reinforcement, Beam B1(5%) was strengthened by one layer of CFRP sheet without removing the damaged concrete due to corrosion, this beam nevertheless was able to sustain load higher than beam C(0%) (Beam with no corrosion) by 4.5% and higher by 10% than beam C (5%) (Control beam with 5% corrosion). The yield strength was higher in the strengthened beam B1 (5%) than both control beams (C0% & C5%). Beam B1 (5%) failed by CFRP at mid span which was mainly due the opening of the diagonal corrosion crack that pushed the concrete cover against the CFRP sheet reinforcing bars. The CFRP sheet was

pushed away from the beam surface but finally failed by shear at the tip of the cracked area. The beam had large deflection before failure indicating an increase in ductility due to the addition of CFRP sheet.

Modeling the results of the experiments

To analyze the effects of the corrosion products on the cover, the ring around the bars is analyzed. Since the thickness of the stirrups or ring is equal to the minimum concrete cover, this is where the critical crack is expected to be formed. From the experiments, the bottom of the beam is reinforced with 2 tensile steel bars, the concrete stirrups around the bar is highlighted, the bar is assumed to corrode uniformly along its length which means that only a 2D plain strain analysis can be performed. Experimentally when the corrosion initiates, the original radius of the bar R_b reduces to R_{rb}; but because the rust possess higher volume than the original metal, the effective radius of the steel bar increases to R_t prompting a significant pressure on the cover. However, at initials the rust products fill the pores in the concrete around the steel bar which means the pressure is at minimal until the pores is filled up. The experiment shows that the concrete cover is elastic until the stress at the steel concrete interfere reaches the tensile strength which initiated the cracks and prevent where the stress at the tip of the crack can be sustained by the concrete, parts of the rust formed by the corrosion fills the pore that surround the bars until the rest causes more pressure on the concrete. As pressure increases, cracks develop through the cover. According to Nguyen etal (2006) when these cracks appear, the internal stresses relax which stops the propagation of other internal cracks. According to balafas and Chris J, (2009) the mass of rust formed is given from

$$M_r = {}^1/_7 m_r \text{ (kg/m)} \qquad (1)$$

In which M_e and Mi are the mass of rust and consumed steel, respectively. The corresponding volume of steel consumed is

$$Vt = {}^{Mt}/_{Pt} \text{ (m}^3\text{/m)} \qquad (2)$$

$$Vl = {}^{Ml}/_{Pl} \text{ (m}^3\text{/m)} \qquad (3)$$

Where pt and pl = density of steel (7850kg/m^3) and rust (4,115kg/m^3). The steel radius R_{rb}, reduces to

$$R_{rb} = \sqrt{R^2 b - {}^{vcs}/_{\pi}} \text{ (m)} \qquad (4)$$

Where Vcr= the steel volume consumed and Rb = The original bar radius. The total bar radius, R_l

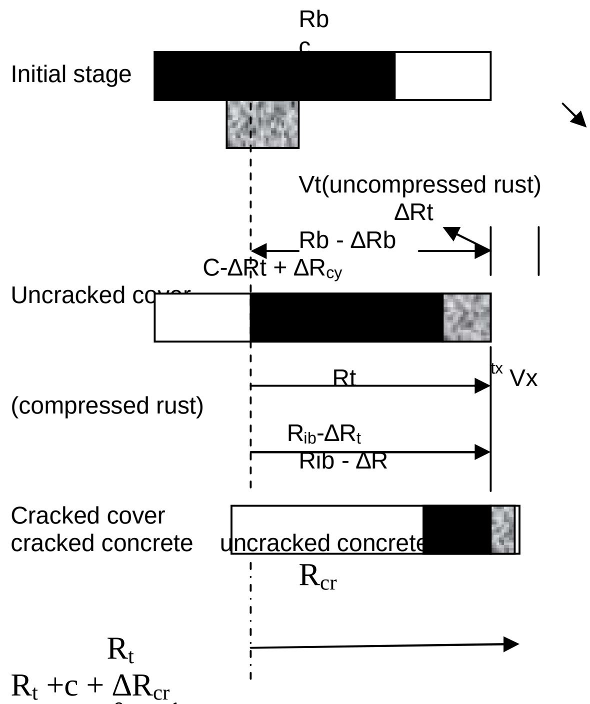
$$Rt = R_{rb} + t_t\text{(m)} \qquad (5)$$

The volume of oxide generated, Vt is

$$Vt = \pi\ (Rt_2 - R_{2rb})\ \text{(m}^3\text{/m)} \qquad (6)$$

By substituting 5 and 6

$$Vt = \pi t_t\ (2R_{rb} + tr)\ \text{(m}^3\text{/m)}$$



$: b_1 = \sqrt{R^2_{rb} + {}^{v1}/_{\pi}} - R_{rb}$ (m)

Thickness of the passivity and exposure when $t_r \le t_f$

$tr = \sqrt{R^2_{rb} + {}^{Vr}/_{\pi}} - R_{rb} - t_f$(m)

If the concrete porosity is known, the thickness of the porous zone can be calculated as

$tr = {}^{(R_b + t_p)v_p}$ (m)/R_b

The presence of rust will increase the bar radius by

$\Delta R_b = R_b - R_{rb} + t_r$(m)

The pressure that acts in the cover because of the rust can be calculated as

$\Delta v_s + \Delta v_s = V_{rc}({}^{m3/}{}_{m})$

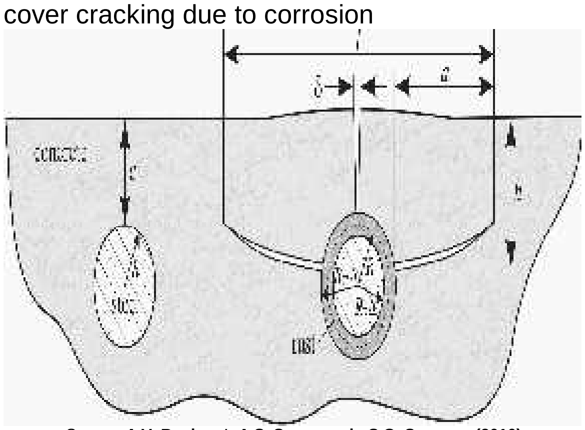
The volume change of the steel is calculated as the function of the direct stress volume reduction to rust production and compression which can be calculated as

$\Delta R_c = {}^{Pc\ (Rb\ +rc)/}{}_{Ecr}\ {}^{\{(c+Rb)\ 2\ +\ R2ci\ +\ Vc\}}/_{(c+Rbc)}{}^2 - R^2_{ci}$ (m)

Where c = the cover depth and E_{cr} = the elastic modulus of concrete the pressure on the concrete cover is reduced from P to p_c

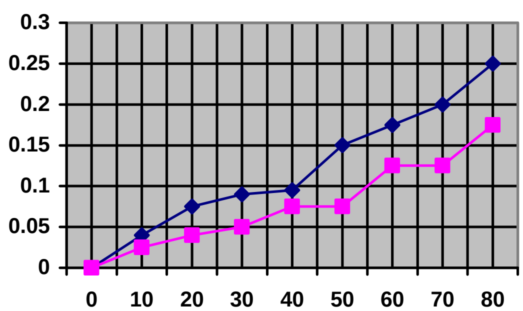
$Pc = {}^{P}{}_{Rrb}/{}_{Rci}\ (N/m^2)$
Similarly, the concrete volume change is
$\Delta vc = 2\pi\ (R_{ci} + {}^{\Delta Rc}/_{2})\ \Delta R_c\ ({}^{m3}/_{m})$

Fig 2.0 showing the characteristic of concrete cover cracking due to corrosion



Source: **A.V. Benin a,*, A.S. Semenov b, S.G. Semenov(2010)**

Degree of induced corrosion results for 28days



Test results

The study reveals the following results of the test on structural member (beam) damaged by corrosion

1. Corrosion usually results in a weakened bond which usually takes place at the interface of concrete and corroded bars
2. the impressed current procedures used to accelerate corrosion in steel can be concluded as a good technique to facilitates corrosion in concrete specimen in a short period of time
3. the study also reveal that when a contaminated concrete is replaced with a new layers of concrete (cover) it is more efficient and effective in repairing a damaged concrete
4. if the concrete is mixed in compressive strength of 25mpa with high thickness of concrete cover, good curing, low water/ cement ratio, better compacting, good workability and high cement contents, the reinforcement bar will have a good protection against corrosion when present in an aggressive environment
5. Corrosion is the major causes of failure in concrete structure and mostly affected through the cover zone, the modeling of the study reveals that the more the cross section of the steel is corroded, the higher the resulting expansion stress. When the expansion stress exceeds the tensile strength of the concrete cover, cracks will develop
6. CFRP sheet is an effective methods of strengthening a damaged concrete structures

Conclusion

The corrosion mechanism of steel and its effects in concrete has been investigated to some wide extents. However, the research still lacks detailed information on how chloride attacks the passive film in the reinforcement in concrete. Previous research believed that concrete cover could protect the embedded steel reinforcement from corrosion which draw out a conclusion that R.C structure has a high resistance to corrosion but site experience and practice has shown that RC structure do not usually perform so well due to poor methodology of construction or deficiency in design, these factors usually have a significant effects on their service life. The steel bars in concrete are always prone to corrosion attack due to the failure of the concrete cover as observed through this research experiment. Since concrete will continue to have a pore in it, detriment species can penetrate into the concrete, making the concrete solution more corrosive to the reinforcement and initiating the corrosion of the reinforcement. In conclusion, the study reveal that since concrete structures always contain defect which would indirectly or directly initiate the corrosion of the steel bar, the occurrence of corrosion of steel in concrete is only a matter of time because the concrete cover will act as a shortcut for the ingress of detrimental species spalling off the concrete and exposing the interior of the concrete to corrosion.

Recommendation for further studies

The study opens opportunity for further research, first, research should be carried out on the process of how chloride ion attack the passive film in the reinforcement steel bars in concrete and also on how environmental temperature, permeability of the concrete cover affects the interaction of concrete structures. Investigating the highlighted point will be of significant benefits to the study of corrosion, however it is of paramount to note that the basic principles of most corrosion protection measures is to prevent chloride ions from reacting with steel bars surface and also to increase the time needed for chloride ions to penetrate through the concrete cover zone, these measures only increase the service life of R.C structure by slowing the corrosion process but not stopping it. Hence, the experiments in this study and previous research work has shown that this protection measures do not stop corrosion from initiating and commencing its attack on the steel bars but they can slow its process for a long period of time, though this research work only initiate the corrosion process and observed the cover zone and the corrosion protection material (CFRP sheet)

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