Corrosion impact on mechanical properties of earth quake reinforced steel bar

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Abstract - Corrosion of steel reinforcement is one of the most severe problems in durability of earth quake resistant reinforced concrete structures. Hence forth a good understanding of the corrosion effect on the mechanical properties of these steel used in constructional purpose in seismic zone need to be adequately assessed.

In the present study two different compositional reinforced steel specimens with varying degree of corrosion that developed after exposure in brine solutions were studied. The corrosion problem associated in the material due to the formation of pit on the exposed surface and corrosion rate increases as the depth of penetration increases. Also, it was observed that the degree of corrosion strongly affect mechanical properties of the steel, particularly the yield and ultimate stress. Interestingly, the yield strength of all the corroded steel bars remained almost constant while their true ultimate strength was considerably increased. At this juncture specifically relationship between corrosion penetration and the mechanical properties of reinforcing steel bars were identified and presented. The reduction in diameter, yield strength and pit depth penetration has been observed in both the specimen. In addition, a study of the influence of the depth of pit penetration on deterioration and mechanical properties were presented. A severe non-linear reduction in the mechanical properties related to the corrosion degree was observed. These phenomena can be pertinent to estimate the life of the earth quake resistant steel used in severe acidic conditions.

Keywords:* *Corrosion, Ductility, Earth quake resistant reinforced steel, yield stress

I. INTRODUCTION

Corrosion is one the biggest threats currently faced by the reinforced concrete industry. One of the most frequent problems that arise in the earth quake resistant (EQR) reinforced concrete structures is the corrosion which significantly affects the mechanical properties of the materials. Usually, corrosion of the reinforcing steel bars weakens the bond between steel and concrete and hence can reduce the service life of the structure. Many researchers have investigated the impact of corrosion on the mechanical properties of steel and most of these studies deal with accelerated corrosion induced by impressed current applied to the surface of the reinforcement embedded in the concrete. Also some of the literatures reported that rusting did not affect the strength of the bars however, in presence of chlorides ions pit and depth of the pit crack and its propagation may cause reduction in area and strength of the bar.

Thus the studies of structural effects arises due to corrosion of these steel bars are essentially required to prevent that causes sudden failure or collapse of the material under aggressive environment. The study of the corrosion effects of these steel bar structures is crucial to observe the structural performance and strength of impaired structures. Usually, the corrosion products developed on the steel bar surface resulted in the volumetric expansion that may induce split stresses along corroded reinforcement and ultimately damage to the surrounding material. The splitting stresses are not well tolerated by concrete, resulting in cracking and eventually spalling of the concrete cover. As the surface of reinforcement becomes more exposed, the corrosion rate may increase due to pitting and facilitate the deteriorate process. The pitting corrosion affects in some specific part of the bar due to that loss in mass observed and can be

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expressed as the corrosion penetration in percentage of cross-section reduction.

II. Literature Survey

The corrosion of reinforcement is one of the major deterioration mechanisms for reinforced concrete structures in aggressive acidic environment. Once reinforcement steel bar starts to corrode, its mechanical properties affected significantly and as a consequence the durability and serviceability decreases. In order to promote the effective application of reinforced concrete and to ensure that structure has good performance during its service life, it becomes necessary to understand the mechanisms of how reinforcement corrodes in a given environment and how its deterioration affects the performance of the structure. Corrosion is one the biggest threats and currently facing the problem worldwide in the reinforced concrete industry. Due to corrosion the steel bar reinforced in the concrete structure are used in various kinds of applications particularly in the seismic zone under severe conditions exert a pressure that easily surpasses limited tensile strength of the concrete and thus leads to cracking and spalling of the concrete cover from the surface. In addition, corrosion of the reinforcing steel bars weakens the bond between steel and concrete and hence can reduce the service life of the structure. Many researchers investigated the impact of corrosion on the mechanical properties of steel and most of these studies deal with accelerated corrosion induced by impressed current applied to the surface of the reinforcement embedded in the concrete which is different from natural corrosion [1]. C.A. Apostolopoulos and V.G. Papadakis studied the tensile behavior of reinforcing steel bars and observed that yield stress and effective and apparent ultimate stress decreased as the corrosion rate increased due to significant loss of ductility [2]. Han-Seung Lee and Young-Sang Cho reported that, decrease in nominal yield point and nominal elastic modulus as the degree of reinforcement corrosion increased [4]. Chloride corrosion of reinforcement bars is the major cause of deterioration in reinforced concrete constructions, especially when the structures are exposed to a marine environment. The corrosion occurs due to the diffusion of chloride ions, oxygen and water through the concrete cover to reach the reinforcing bars. Following are some of the important parameters that affect corrosion and consequently reduce the mechanical properties.

A. Chloride effect on corrosion of steel bar

Generally, chlorides are acidic in nature and can come from different number of sources. The most common being, de-icing salt, use of unwashed marine aggregates, sea water and certain accelerating admixtures. In the presence of chlorides localized pitting corrosion occurs which does not always have associated with it the early warning signs of surface cracking. Chlorides induced corrosion is potentially more dangerous than that resulting from carbonation. Like most of the aspects of concrete durability, deterioration due to corrosion of the reinforcement can take over significant number of years to manifest over the surface. In the many literatures it has been reported that, the basic reason for corrosion to be initiated due to or in presence of aggressive chloride ion penetration through the passive layer that formed over the surface [1]. Initially, the passive layer must to be accumulated over the surface and due to or in presence of aggressive chloride ion penetration the damage of the surface layer occurred in some specific portion. Thus chloride ions activate the surface of the steel to from an anode and the remaining passivated surface being act as the cathode. The reactions involved are as follows:

$Fe^{++} + 2Cl^{-}$ - > $FeCl_2$ (a)

$FeCl_2 + 2H_2O$ - > $Fe(OH)_2 + 2HCl$ (b)

Pitting corrosion initiates when the penetration of chlorides in the concrete cover is such that a threshold value is reached at the steel surface. The risk of chloride-induced corrosion is usually associated with the penetration of chlorides through the depth of the concrete cover thickness. The rate of chloride penetration depends on many factors, the main ones being related to the concrete properties, the mechanisms of transport of chloride bearing solutions, the moisture content of concrete and most important are the concentration of chlorides in the environment. Transport of chlorides through the concrete cover may take place due to a

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combination of different transport mechanisms such as diffusion, capillary suction and permeation. When a structural element is exposed to wetting-drying cycles, it is subjected to capillary absorption of the chloride-bearing solution during wetting, possibly followed by diffusion during the wet period, while during dry periods, evaporation of water brings about accumulation of chlorides near the surface. Conversely, during exposure to precipitations, the chloride may wash out from the surface of concrete. Chloride penetration in a reinforced concrete structure is thus a complex function of quality of the steel used, geometry, position, environment, and composition of concrete.

B. Corrosion mechanism

Most metal corrosion occurs via electrochemical reactions at the interface between the metal and electrolyte solution. A thin film of moisture on a metal surface forms the electrolyte atmospheric corrosion [1-2]. Corrosion normally occurs at a rate determined by equilibrium between opposing electrochemical reactions. The first is the anodic reaction, in which a metal is oxidized, releasing electrons into the metal. The other is the cathodic reaction, in which a solution species is reduced, removing electrons from the metal. When these two reactions are in equilibrium the flow of electrons from each reaction is balanced, and no net electron flow occurs. The two reactions can take place on the one metal or on two dissimilar metals that are electrically connected. Since corrosion is actually a process involving electrochemical oxidation and reduction reactions. In order for the reaction to occur, the following condition s must exist:

I. A chemical potential difference must exist between adjacent sites on a metal surface (or between alloys of a different composition).

II. An electrolyte must be present to provide solution conductivity and as a source of material to be reduced at the cathode.

III. An electrical path through the metal or between metals must be available to electron flow.

During the test an ionic conduction path is provided through the solution separating the working electrode and the counter electrodes while the electrical conduction path is provided through the potentiostat. This potentiostat is then used to control the driving force for electrochemical processes taking place at the working electrode. The magnitude of the driving force indicates which processes is taking place at the anode and at the cathode as well as their rates. Electrons flow from the anode to the cathode by the electrical path as stated above. Anode is thought to be a negative electrode and cathode the positive one.

At the anode oxidation takes place, which can be represented as:

$$M = M^{2+} + 2^{e-}$$

Where M represent the metal or alloy, M2+ represent the ion of the metal and 2e- represent the number of electrons transferred in the

processes. At the cathode reduction takes place, reaction such as reduction taking place at the cathode surface may takes place as:

$$2H^{+} + 2^{e-} = H_2$$

The corrosion occurs when metal atoms detach themselves from the metal surface at the anode and enters the solution as ions, leaving behind the negatively charged electrons in the metals. The electrons flow through the metal to the cathode and neutralize positively charged hydrogen atoms that collect at the surface. The neutral hydrogen atoms combine to form hydrogen gas. In solution where hydrogen tends to evolve to slowly, oxygen is reduced and combines with hydrogen ions or water to form water or hydroxyl ions [6, 7]. Corrosion can be attacking the overall surface or be a local phenomenon, depending on the relative proportion of anodic and cathodic areas. When the areas are approximately equal, corrosion is usually uniform over the whole surface. However when the cathodic area is large compared to the anodic area, the localized attack at anodic sites can be intensified [8].

III. Experimental work

In the present work two different compositional thermo mechanical treated earth quake resistant steel bars in the form of long rod of diameter 16 mm were obtained and prepared for different tests. The sample of the specimens

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for corrosion test, mechanical test and hardness test were prepared separately in different dimension as per ASTM standard. The metallographic samples were cut in cross-section from the stock materials of about 2.5 cm along the length. The faces of cross-sectioned samples were ground in a grinding wheel. Then, these faces were subjected to progressive polishing with a series of emery papers of different grit of emery paper size ranging from 120-1000 consecutively following the standard procedure. After that, wet polishing was done in rotating cloth wheel at 300 rpm with alumina powder of size 0.05 µm mixed with water. After smooth polishing, the samples were washed in water and dried with acetone. The dried samples were etched using 2% Nital solution (2% HNO_3 acid in Ethanol) as etching reagent for these steel rebar to reveal right microstructure. Similarly the tensile specimens were prepared and the tests were conducted before and after the exposure.

Fig.1: sample preparation of as received steel bar

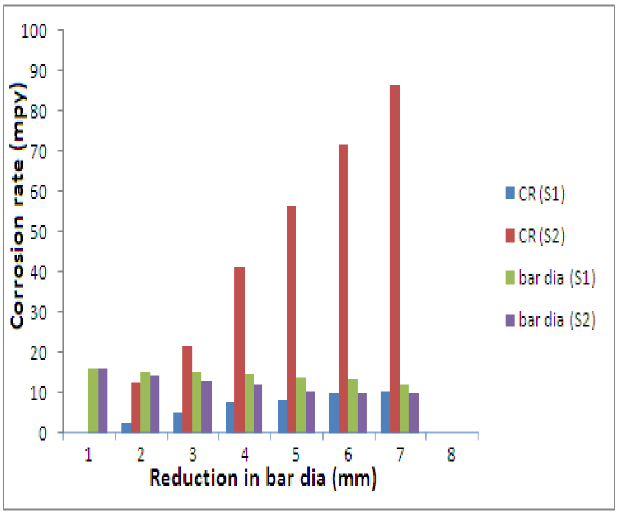

Fig.2: Reduction in bar diameters of steel 1 and steel 2 with varying corrosion rate

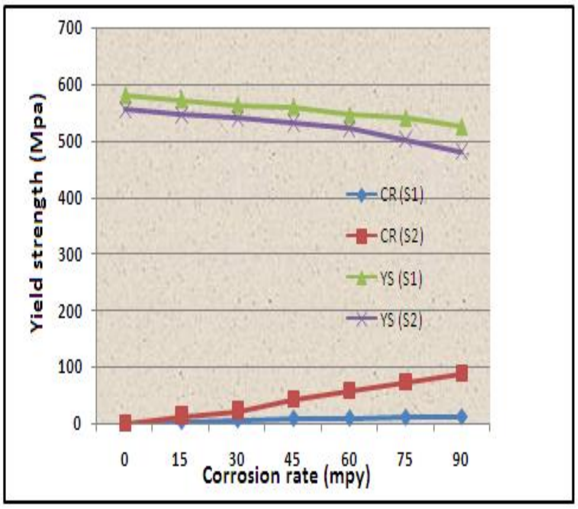

Fig.3: Yield strength variation in steel 1 and steel 2 with varying corrosion rate

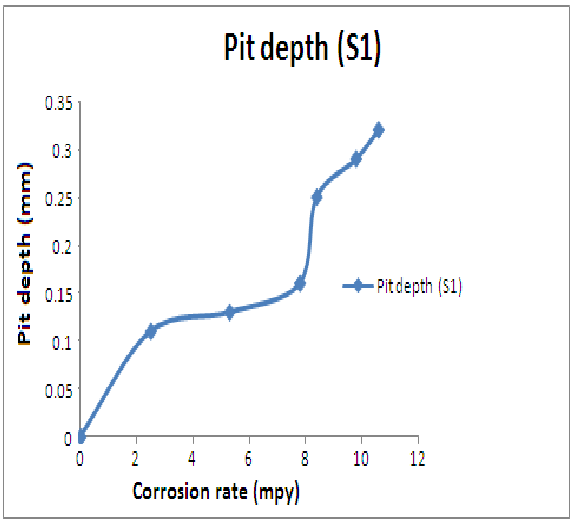

Fig.4: Pit depth variation in steel 1 with varying corrosion rate

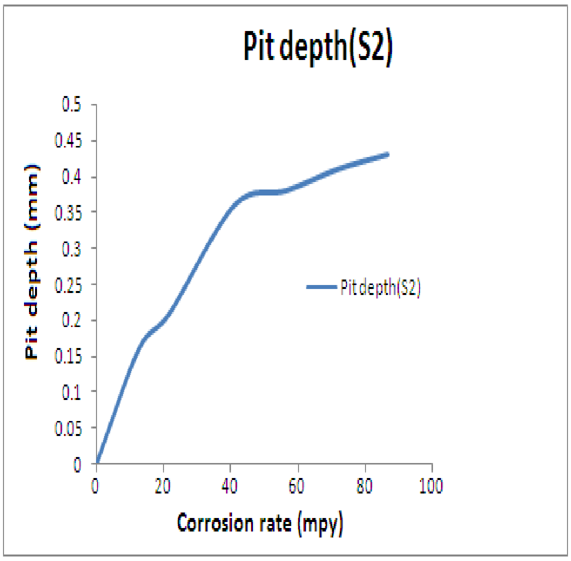

Fig.5: Pit depth variation in steel 2 with varying corrosion rate

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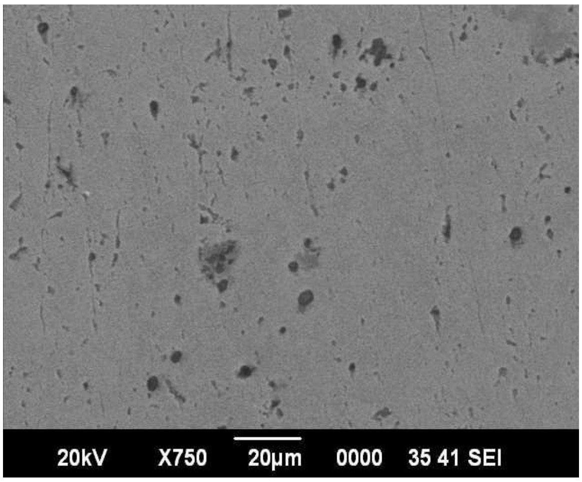

Fig.6: Pit depth variation in steel 1 with varying corrosion rate

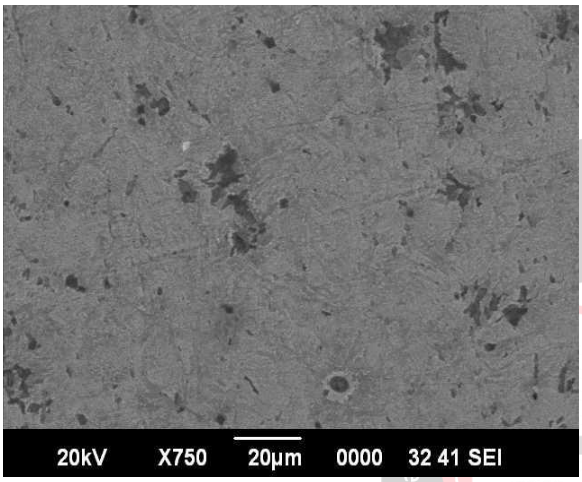

Fig.7: Pit depth variation in steel 2 with varying corrosion rate

The different micrographs of some aggressive portions of the deterioration were observed by using scanning electron micrographs.

IV. Results and Discussions

The effect of corrosion of steel reinforcement on the tensile strength and yeild strength has been studied and shown in the above figure. As the degree of corrosion level increases the bar diameter deteriorates resulted in decrease in mechanical properties such as load carrying capacity. It is also observed that for every percentage increase in corrosion level there is about 0.04 % decrease in load carrying capacity. Also the corrosion rate increases due to different concentration of the pit depth and it increases in the steel sample 2 in comparison to steel 1. Corrosion pits were simulated by removing a section of bar using different techniques. It found that reduction of the load was proportional to the damaged area while reduction in the force at the yield point was slightly less proportional to the cross-section. The pit formed exposed surface of the samples were observed using scanning electron microscope and shown in Fig. 6 and 7 for steel 1and 2respectively.

V. Conclusions

The diameter of the steel bar and Yield stress depends on the corrosion rate which significantly affects the mechanical properties. The depth of the pit formation increases as the corrosion rate increases. Usually the corrosion due to aggressive condition of steel bar reduces the yielding stresses. Modulus of elasticity and measured strains present a higher dispersion than yield stresses and strength. In addition, a premature failure was observed resulting in a severe reduction in ductility. The theory of uniformly corroded cross section based may be different on the actual corrosion penetration due to pitting corrosion and depth of penetration that affects the reliability of the steel bar. This may vary the results of the mechanical properties significantly. Pit depth has a higher impudence on the mechanical properties of the steel materials used in reinforcing structures.

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