FLEXURAL BEHAVIOR OF REINFORCED BEAMS BY USING CORROSIVE REBAR

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ABSTRACT

At this research, the effect of pre corrosion rebars on the flexure behavior of beams is investigated. The corrosion is induced at rebars, before using for reinforcing beams, by two methods. The first method is putting rebars in water with 10% salt concentration inside lab. The second method is surrounding rebars by salt outside the lab and leaving them to weather changing, like rain and different relative humidity. The second method is given more corrosion rate compared to first method. The beam are subjected to two loading test. Three ages of beams are investigated which are 30, 90 and 120 days. Two size of rebars (10 mm, 12 mm) are exposed to corrosion and used at this research. The results are shown that high corrosion rebars of 10mm carried maximum load with maximum deflection at mid span for all ages. The percentage of increasing load for this corrosion bar is 144.3%,141.7%, 124.3% for 30 days, 90 days and 120 days respectively compared with low corrosion of same bar size. This percentage is 126.1%, 127% for 30 days and 120 days respectively compared with no corrosion of same bar size.

Key words: corrosion, load, displacement, moment, curvature, flexural behavior.

1- INTRODUCTION

Corrosion of reinforcing steel is widely accepted as the primary cause of premature deterioration in the reinforced concrete (RC) structures. Corrosion is defined as the destruction or deterioration of a material because of its reaction with environment. In case of corrosion, formation of an oxide of iron due to oxidation of the iron atoms in solid solution is a well-known example of electrochemical corrosion, commonly known as rusting. These oxides are loosely attached and spall off from the surface of steel.

During the process of corrosion, weight of material decreases as depth of corrosion layer/pits increases. The magnitude of reinforcement corrosion has a significant effect on flexural strength, deformational behavior, ductility, bond strength and mode of failure of RC structures.Therefore, a reinforcement corrosion cell is formed.

2- BEHAVIOR OF CORRODED STEEL REBARSS

Corrosion damages the superficial layer of steel rebars, causing a worsening of their mechanical properties, in terms of strength and ductility. In (Maslehuddin et al., 1993)[1] the effects of atmospheric corrosion are analyzed. According to the authors, after 16 months of exposition, no significant variations of mechanical properties of reinforcing steel could be observed. On the contrary, in (Almusallam, 2001) [2], the corrosion caused by penetration of chlorides on reinforcing steel rebars embedded in concrete appeared to affect in a significant way the behavior of the bars. Apostolopoulos et al. (2006)[3] assessed the effects of artificial corrosion damage on the mechanical properties of tempcore reinforcing steel rebars. In both the cases, even if the influence of the corrosion on the steel tensile behavior is clearly highlighted, no relationships of deterioration of steel mechanical properties are given. Azher (2005) [4] found that where concrete has been carbonated to the depth of the steel reinforcement and a small but uniform amount of moisture is present, the steel is likely to corrode fairly uniformly. If chlorides are concentrated near the surface of the steel or access of water and oxygen is restricted to a single location on the steel, severe pitting corrosion may occur. This reduces considerably the cross-sectional area of the bars at these locations, while the remainder of the bar may be left uncorroded. Structural cracking, or honeycombing, can also create conditions favorable to pitting corrosion by allowing the localized ingress of aggressive agents. The effects of corrosion on the behavior of reinforced concrete elements are schematically shown in Figure.(1).

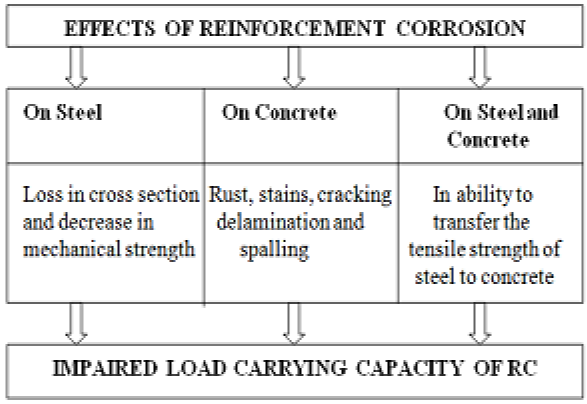

Figure 1. Effects of reinforcement corrosion on reinforced concrete structures [4].

3- INFLUENCE OF THE CORROSION ON THE BOND CHARACTERISTIC

Bond between reinforcement and concrete is necessary to ensure the composite interaction of the two materials. For very low stress, bond strength is assured from chemical bond between steel and concrete. Once slip occurs, bond is assured mainly by mechanical interlock between ribs and concrete. On corroded elements, the chemical adhesion is lost, then the bond is given only by the friction contribute.At higher corrosion levels, the steel bars display localized pitting and loss of some of the ribs over the bar length, thereby weakening the rib-concrete mechanical interlocking force transfer mechanism (Amleh&Mirza, 2000) [5]. Studies conducted by Auyeung (2001) [6] assessed that loss of bond is very critical; for a 2% of diameter loss he found an experimental bond reduction of about 80%.

Many researchers carried out studies on the influence of corrosion on bond, generally developed onthe basis of experimental tests in specimens subjected to artificial corrosion [7, 8, 9, 10, 11, 12, 13]. The current density applied to accelerate the corrosion influences the bond strength [[14]; according to (Coronelli, 1997) [15], it is necessary to adopt a maximum current density of 0.05 mA/cm^2.

4- SIGNIFICANCE OF THE RESEARCH

The rebars which is used at reinforcing concrete, may be stored at bare places. This storing is caused corrosion of rebars as a result of exposure to high humidity or water at open space. The rate of corrosion may be high or low which is depended on the period of storing at open space. This corrosion rebars are always used at different reinforced concrete structures, so the effect of them on behavior of these structures needs to be investigated. This research is done to determine the effect of pre corrosion rebars on flexural behavior of reinforced concrete beams.

5- EXPERIMENTAL PROGRAM

The experimental work consists of two stages. At the first stage, two artificial treatments are used to corrode rebars. The first one is putting rebars at water and salt with 8% concentration for 30 days inside the lab. The second one is putting rebars surrounded by salt outside lab and exposed to rain and different humidity for 40 days. Two sizes of rebars are used (10 mm, 12 mm) for these artificial treatments. These artificial corrosion rebars are used for longitudinal reinforcing beams at second stage. This stage consists of casting sixteen reinforced concrete beams of dimension (150 mm× 150 mm× 750 mm). Table (1) shows the materials used for all concrete samples.The beams are named by one letter and number. The letter is namely high, low or non corrosion and the number is namely diameter of rebars. The properties of reinforcing steel is given at Table (2). The method of testing beams is illustrated in Table (3).

Material	Weight kg	Type
Cement	326	Tasloja Ordinary Portland Cement (ASTM Type I)
Sand	652	Koya city sand grading and limits of ASTM C33 [8]
Gravel	1304	Koya city gravel grading and limits of ASTM C33 [8]
Water	146.7	Potable

Table 1: Concrete’s components

Material	fu MPa	Stress at failure MPa	Fy MPa
Steel	703	539	420

Table 2: Properties of rebars[+]

+ The properties of rebars are found by testing them at the lab.

Beams (150mm× 150mm× 750 mm)	Age of testing days	Longitudinal Steel Bars	Stirrups bars
H10	30	2 - φ 10	φ 10 @ 70 mm
L10	30	2 - φ 10	φ 10 @ 70 mm
NC10	30	2 - φ 12	φ 10 @ 70 mm
H12	30	2 - φ 12	φ 10 @ 70 mm
L12	30	2 - φ 12	φ 10 @ 70 mm
NC12	30	2 - φ 12	φ 10 @ 70 mm
H10	90	2 - φ 10	φ 10 @ 70 mm
L10	90	2 - φ 10	φ 10 @ 70 mm
H12	90	2 - φ 12	φ 10 @ 70 mm
L12	90	2 - φ 12	φ 10 @ 70 mm
H10	120	2 - φ 10	φ 10 @ 70 mm
L10	120	2 - φ 10	φ 10 @ 70 mm
NC10	120	2 - φ 10	φ 10 @ 70 mm
H12	120	2 - φ 12	φ 10 @ 70 mm
L12	120	2 - φ 12	φ 10 @ 70 mm
NC12	120	2 - φ 12	φ 10 @ 70 mm

Table 3: Detail of tested beams[#]

H means high corrosion, L means low corrosion and NC means not corrode

5-1 Preparation of samples

For two artificial treatments, the corrosion ratio was measured by weighing three samples of rebars of same length before and after removing the corrosion layer and calculating old and new diameter of rebars as follows:

$$\text{Diameter} = (4 * \text{weight of rebar} / (7800 * \text{length of rebar} * \pi))^{1/2} \quad (1)$$

$$\text{Corrosion ratio} = ((\text{old diameter} - \text{new diameter}) / \text{old diameter}) * 100 \quad (2)$$

Also, two arbitrary rebars of two artificial treatments are used for measure the mechanical properties after corrosion which include stress- strain curve. After lifting rebars from salty sol for low corrosion rebars and from outside of laboratory for more corrosion rebars, they was used, without any cleaning of corrode layer, in reinforcement the beams. All concrete components are weighed by electronicbalance and mixed in a horizontal pan mixer for about 10 minutes. Then, they are compacted manually because lack of vibrating table. Three 100×100 mm cubes were prepared from each batch and used for determining the compressive strength (f'_c)at an age of 28 days. The approximate value of f'c for all beams is 30 MPa. After 24 hours, all specimens were stripped and cured for 28 days in a water bath. Then, the beams are brought out a water bath and let them at lab till testing. Figure (2) and figure (3) show the casting of beams and failure of one of them.

Figure 2. Casting of beams.

Figure 3. Flexural failure of H10 at 120 days.

5-2 Loading Setup and Measurements

All beams are tested by using universal testing machine type MIE with capacity 10 ton. The beams are tested under increasing two point loads at mid one-third span till failure. They are supported under two rollers laid 25 mm from their end edges. The vertical deflections of beams at mid span and at 120 mm from the right support were measured by using dial gage. The details of loading, deflection positions and assigning of beams are set out at Fig. (4).

Figure. 4. Details of testing beams

6- TEST RESULTS

The tests have shown that bare bars, after the artificial treatment, exhibit an almost uniform corrosion, comparable with bars naturally corroded by carbonation. On the contrary, steel rebars embedded in a concrete prism, are generally affected by localized corrosion, with marked pits. The bare bars with the same corrosion degree, instead, have a section almost constant on all their length. In this research, 16 RC beams were tested. The corrosion ratios for high corrosion are 8 %, 6% for 12 mm, 10 mm respectively and for low corrosion are 3 %, 2% for 12 mm, 10 mm respectively. The results of beams testing are illustrated in Table (4). Load-displacement curves are shown in Figs. (5, 6 and 7).The curvature-moment curves are indicated in Figs.(8, 9, 10).

Type of beam & its age (days)	Max. deflection @ mid span (mm)	Max. Load (kN)	Max. Curvature (rad)	Max. Moment (kN m)	% Increase of load
H10 (30)	4.6	88	0.0283	10.34	147.34
L10 (30)	2.76	61.9	0.0226	7.27	103.64
NC10 (30)	4.5	69.3	0.03666	8.14	116.03
H12 (30)	2.95	78	0.0214	9.165	98.18
L12 (30)	1.8	52	0.0231	6.11	65.45
NC12 (30)	4.65	99	0.0389	11.63	124.61
H10 (90)	7.15	83	0.0344	9.7525	138.96
L10 (90)	2.84	59	0.024	6.9325	98.78
H12 (90)	3.7	85	0.0177	9.9875	106.99
L12 (90)	2.8	57	0.02666	6.6975	71.75
H10 (120)	8.04	86	0.055	10.105	143.99
L10 (120)	4.4	70	0.017	8.225	117.2
NC10 (120)	4.4	69	0.03666	8.1075	115.52
H12 (120)	3.77	73	0.0165	8.5775	91.87
L12 (120)	5	76	0.013	8.93	95.66
NC12 (120)	3.91	81	0.01866	9.5175	101.96

Table 4: Experimental Results

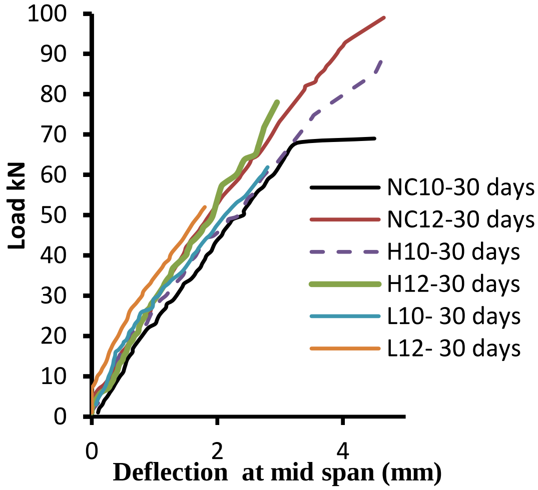

Figure 5. Load-displacement for 30 days

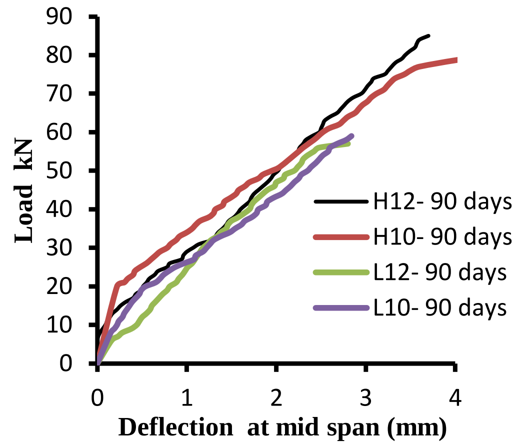

Figure 6. Load-displacement for 90 days

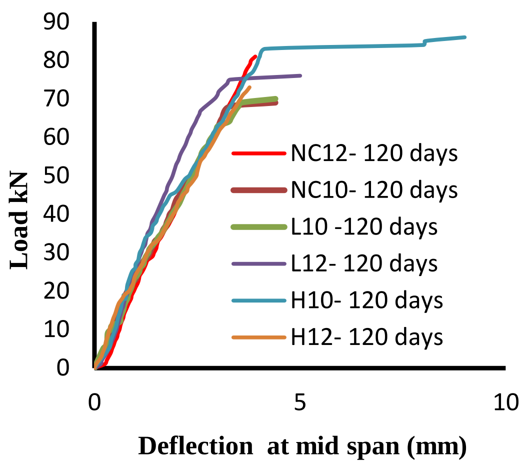

Figure 7. Load-displacement for 120 days

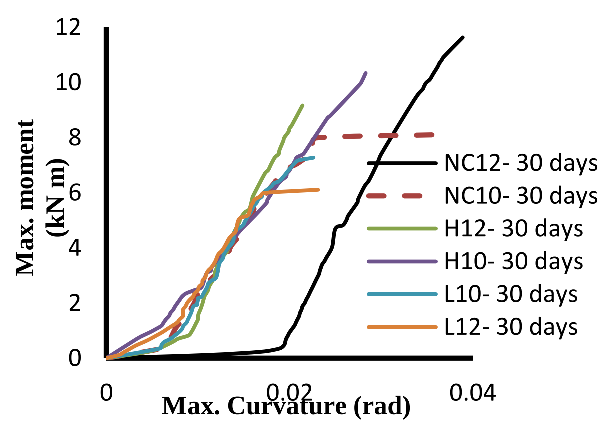

Figure 8. Max. Moment- Max. Curvature for 30 days

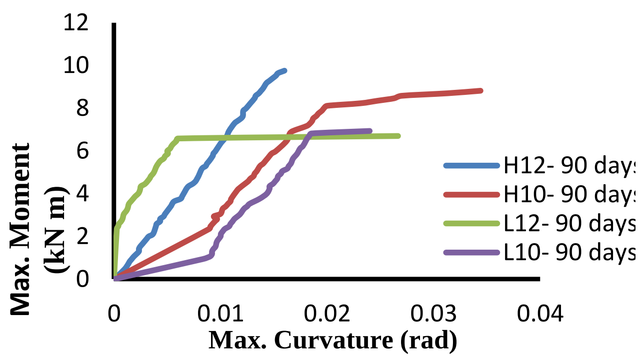

Figure 9. Max. Moment- Max. Curvature for 90 days

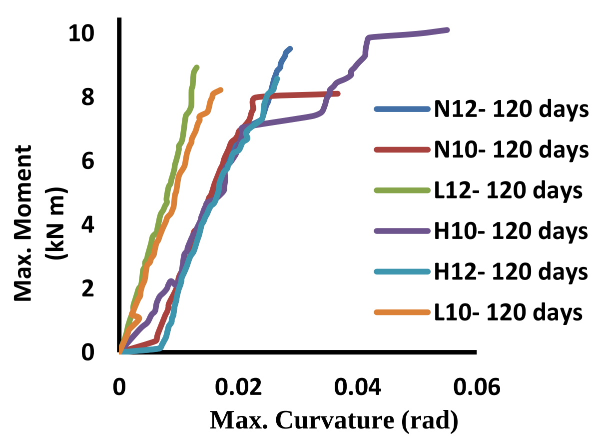

Figure 10. Max. Moment- Max. Curvature for 120 days

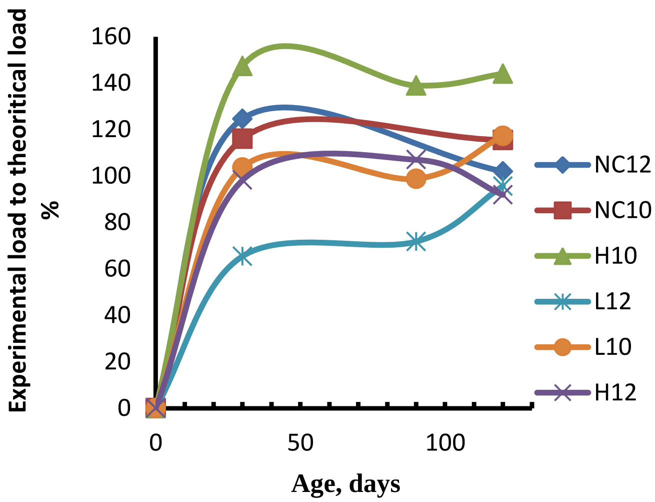

Figure 11. $P_{exp.}/P_{theory.}$ % with time

It can be seen from curves of load-displacement, that beams of high corrosion gave maximum load and maximum displacement at all ages except at age 30 days, where beams of non corrosion rebars gave the maximum results of load and displacement. The same observation is found for curves of maximum moment-maximum curvature. It can be remarked the ductile behavior at age 120 days for beams of high corrosion. This behavior could be resulted from increased bond between high corrosion rebars and concrete, where layer of eroding did not remove when rebars used at concrete. When experimental load compared with theoretical load ($P_{exp.}/P_{the.ory}$), it can be noticed at Fig.(12) maximum ($P_{exp.}/P_{theory}$) for H10 and this ratio is increased with time for beams of low corrosion rebars and decreased with time for beams of high and non corrosion rebars, where at age 120 days theses beams have related ratios. This increasing of L10 and L12 could be redounded from salt used for corrosion which was exuded with time and this was legible by white surface layer of beams.

7- CONCLUSIONS

At this research, there was an attempt to simulate the circumstance of usual storage of rebars which includes exposure rebars to different humidity, rains and different corrosion ratios as a result. The selection of two sizes of rebars (10 – 12) mm is because these sizes are smaller sizes that may be used in reinforcement of structural elements and corrosion ratio is more effect on them than larger sizes. It is found ductile behavior of high corrosion 10 mm bar at 120 days for load-displacement and moment-curvature. At early age, non corrosion rebar beams gave maximum load, moment, displacement and curvature, but this situation changed at late age. Beams of high corrosion rebars gave better results compared with beams of low corrosion rebars and high corrosion rebar 10 mm gave better results than same corrosion rebar 12. This could be produced from improving the bond characteristics at the steel-concrete interface for this high corrosion where the detritions layers of these bars were not removed when using them at beams. The behavior of corrosion rebars beams are improved with time. It can be seen the decreasing of load, moment capacity of non corrosion rebar beams with time and this could be result from using local sand, gravel of high percentage harmful salt. This fact is not clear for corrosion rebar beam because they contained more percentage of salt which exuded with time and this was legible by white surface layer of beams. The failure condition is governed by the concrete; the reduction of the steel sections increases the ductility of beams. It can be concluded that using of corrosion rebars at beams is useful and this advantage is clear at late age. But, this result needs more investigation on different diameter sizes and different structural elements.

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