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Experimental Study Of Reinforcing Steel Bars Behaviour Under Corrosive Conditions

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Abstract: In this study, corrosion behaviour of steel reinforcing bars was investigated in the laboratory. A total of eight concrete mix groups were established. The procedure of molds and samples (steel reinforcement) preparation were described. Steel bars were analyzed using corrosion rate and hardening tests, and the results obtained were compared. Effects of parameters such as steel coating and using different ratios of sulfuric acid in the concrete mix have been examined. This study implies that corroded environment conditions have significant influence on the behaviour and strength of the steel reinforcement, and the results may provide reference for future design of concrete structures in such surrounding environment.

Key words: Corrosion, Steel bars, Corrosion rate test, Hardening test, Concrete mix.

INTRODUCTION

A correct concrete technology can help to increase the structure service life, but it cannot ensure an overall protection against reinforcement corrosion, especially in aggressive environments.

Concrete as known is strong in compression but weak in tension and cannot withstand exceeding tensile stress without cracking. Therefore, reinforcement is needed to resist the tensile stresses resulting from the applied loads

The protection that concrete provides to the embedded steel and, more in general, its ability to withstand various types of degradation. Due to the protective nature of concrete, it takes a reasonably long time for initiation and progress of reinforcement corrosion even in the case of severe corrosive exposure conditions.

However, these reinforcements suffer severe corrosion problems when the reinforced concrete structure is exposed to chloride-contaminated environments and/or when the concrete cover is carbonated.

Corrosion of steel rebar damages the reinforced concrete structures in two ways: First, it reduces the cross-sectional area of the steel rebar. Secondly, it produces corrosion products with a larger volume than the steel itself. The volume increase induces the tensile stress in concrete, which results in cracking and eventual structural failure.

In moist environments, carbon dioxide present in the air forms an acid aqueous solution that can react with the hydrated cement paste and tends to neutralize the alkalinity of concrete (this process is known as carbonation). The permeability of concrete has a remarkable influence on the diffusion of carbon dioxide and thus on the carbonation rate. A decrease in the *w/c* ratio, by decreasing the capillary porosity of the hydrated cement paste, slows down the penetration of carbonation.

The advantages of a lower *w/c* ratio can only be achieved if concrete is properly cured, since poor curing hinders the hydration of the cement paste and leads to a more porous cement matrix. It should be stressed that poor curing will mainly affect the concrete cover, i. e. the part that is aimed at protecting the reinforcement. In fact, the outer layer of concrete is the part most susceptible to evaporation of water (resulting in poor curing).

In the presence of moisture and oxygen, chloride ions at the interface of steel and concrete can destroy the passive film locally and initiate local corrosion. Chloride ions in concrete can be bound by concrete leading to the formation of calcium chloroaluminate (Friedel's salt), a complex between the hydration products of cement and chloride.

In the experimental investigation by Liu (1996), reinforced concrete members were cast with different amount of chloride mixed into concrete in order to simulate different corrosion rates. The water-cement ratios were between 0.43 and 0.45. The specimens were stored outside. The observed time to cover cracking ranged from few months to about 4 years depending of chloride content and concrete cover thickness. Table (1) shows measured corrosion rates, weight loss of reinforcement and observed time to cracking (Liu 1996).

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Table 1: Experiment results by Liu (1996)

No of specimens/ Admixed chlorides (kg/m3 concrete)	Steel diameter (mm)	Cover depth (mm)	Measured corrosion rate (μA/cm2)	Weight loss (mg/cm2)	Observed crack (year)
3 / 5.7	16	48	2.41	39.3	1.84
3 / 5.7	16	70	1.79	60.1	3.54
4 / 7.2	16	27	3.75	29.8	0.72

Study of the literature indicates that the influence of sulfuric acid on corrosion of reinforcing steel in concrete has not been well documented.

MATERIALS AND METHODS

Concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate. In hydraulic cement concrete, the binder is formed from a mixture of hydraulic cement and water.

Effective production of concrete mixes is achieved by more stringent requirements on materials selecting, controlling and proportioning the entire ingredients. Optimum proportions must be selected according to the mix design methods, considering the characteristics of all materials used. The flowchart in Figure (1) shows the materials used in concrete casting.

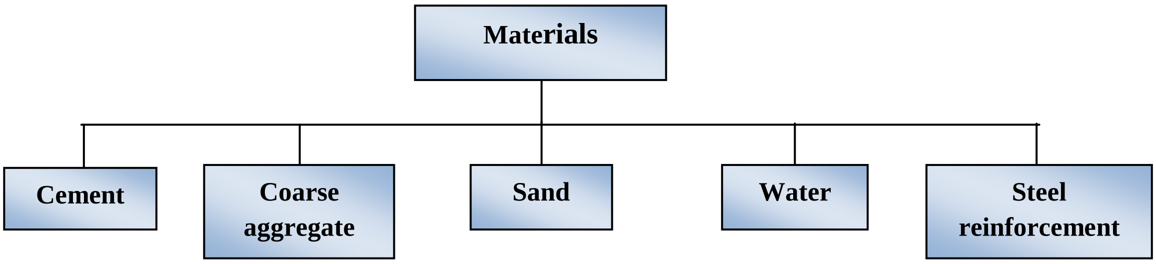

Fig. 1 Materials used in the reinforced concrete

Portland cement manufactured by Tasluga cement factory at the Republic of Iraq is used throughout this study. To avoid exposure to different atmospheric conditions, the whole quantity of cement is brought to the laboratory; each bag of cement is put inside nylon containment and stored in a dry place. The same procedure is used to store the sand at the laboratory.

Aggregate maximum aggregate sizes 10 mm from Samara Al-Niba'ee region are used. For mixing and curing of concrete without any additives, Distilled water is used throughout this work. Water is an essential ingredient because it controls the strength and workability of the mix. The water reacts with the white Portland cement in a process known as hydration to form a cementitious paste that hardens with time. The hydration reaction is a complex chemical reaction which physically alters the character and properties of the white Portland cement. In order to achieve the desired result, Details of the concrete mix proportions used are shown in Table (2).

Table 2: Conventional Concrete mixture

Material	Cement	Sand	Aggregate	Water
Weight (g)	200	400	600	120

To obtain the corrosion rate, different solutions of sulfuric acid are added to the concrete mixture to make 4 different testing groups for both sets of bars (with and without coating), as shown in Table (3). Coated Bars are checked for minimum average dry film thickness, uniformity of thickness, defects such as cracks, peeling, bulging and uncoated areas etc. 60 days will be the period of keeping the specimens in the laboratory, see figure (2).

Table 3: Sulfuric acid concentration

Solution	Sulfuric acid concentration (g)
A	12
B	18
C	24
D	30

Fig. 2: Concrete mix specimens

The rate of corrosion will be calculated by cracking the specimen and extracting the bars in which bars weight will be measured before casting and after extracting. A digital weight balance will be used to record the values of these weights as shown in the figure (3). The following formula will be used to calculate the rate of corrosion:

Corrosion rate = missing mass (g) / time (sec).

Fig. 3: Digital weight balance

After calculating the corrosion rate for the first group, same process will be repeated with the epoxy coated bars.

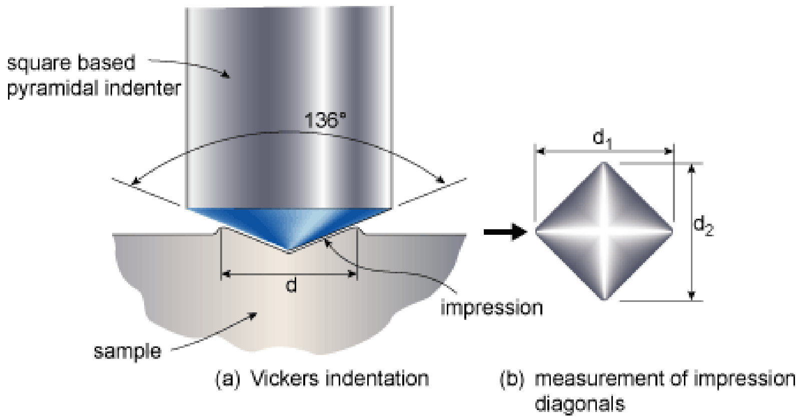

Fig. 4: Vickers hardness test

Vickers hardness test will be used to measure the hardness of the steel bars. The common Vickers hardness measurement is made using a 136° diamond pyramid indenter and variable loads enabling the use of one hardness scale for all ranges from highly soft materials such as lead to extremely hard materials such tungsten carbide. The diamond does not deform at high loads so the results on extremely hard materials are more reliable. As illustrated in Figure (4) two diagonals, d1 and d2, are measured, averaged and the surface area calculated then divided into the load applied. The load may range from 1 to 120kgf and is applied for between 10 and 15 seconds.

QualiTip (Vickers hardness measurement) a pocket sized tester were used to obtain the hardness readings of the steel rebar. Standardized testing according to DIN 50156 and ASTM A956, This stand-alone tester does not require a separate indicating display, or PC hardware. Through its light and compact design, the QualiTip as show in figure (5) is ideal for quality control and testing for incoming inspection and throughout production. Its user-friendly operating interface and its practical function make the QualiTip the most ergonomic integrated rebound hardness tester available.

Fig. 5: portable digital hardness tester

RESULTS AND DISCUSSION

This study begins with the attempt to observe the effect of corrosion on coated/noncoated steel Bars properties embedded in concrete which have been tested in the laboratory. Both of corrosion rate test and hardness test are conducted to obtain the effect of corrosion with the presence of sulphuric acid in the concrete.

The mixing process is repeated several times to get several readings for different concentration of sulfuric acid. Thus, diagram can be made to show weight loss with time and corrosive mediums. The related laws are applied to find corrosion rate of steel Bars in different solutions, see table (4).

Table 4: Corrosion rate result for non-coated rebars

samples	Acid solution	W1(g) the weight before let in acid solution	W2(g) the weight after let in acid solution	TIME (sec)	Corrosion rate (g/sec)
1	A	216	210.1	5184000	12*10-7
2	B	218	204.2	5184000	27*10-7
3	C	217.3	201.55	5184000	30*10-7
4	D	220.5	200	5184000	40*10-7

The increase the corrosion rate of noncoated steel bars is proved to be related to the increase of solution acidity as shown in figure (6).

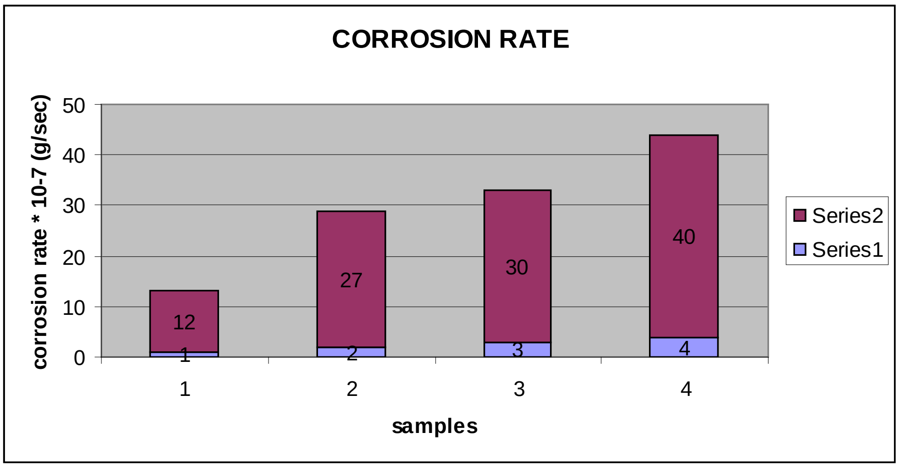

Fig. 6: The value of corrosion rate for the different samples of non-coated steel bars

Corrosion rate results of epoxy coated bars samples in different solutions is presented in table (4).

Table 4: Corrosion rate result for epoxy coated bars

Samples	Acid solution	W_1(g) {the weight before let in acid solution}	W_2(g) {the weight after let in acid solution}	TIME (sec)	Corrosion rate (g/sec)
1	A	230	226.1	5184000	$8*10^{-7}$
2	B	234	229.4	5184000	$9*10^{-7}$
3	C	228.7	223.33	5184000	$10*10^{-7}$
4	D	233	227.2	5184000	$11*10^{-7}$

The decrease and increase of the corrosion rate for of epoxy coated rebar samples is related to the increase of solution acidity.

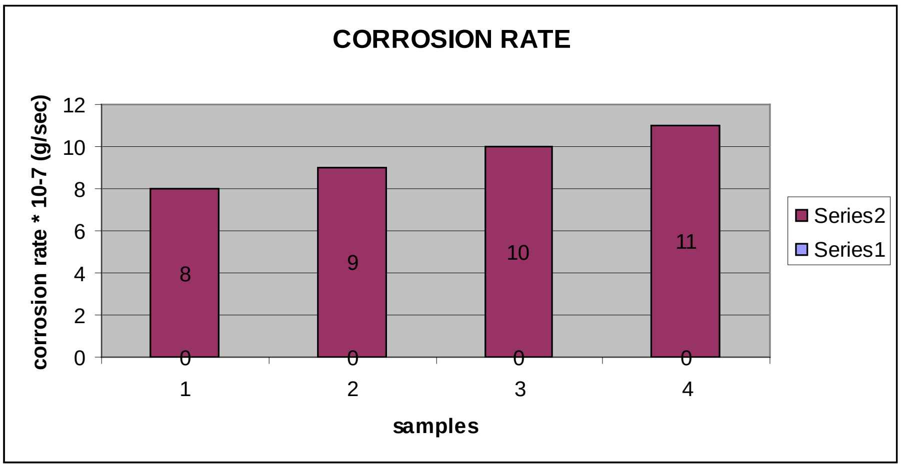

Fig. 7: The value of corrosion rate for the different samples of coated steel rebars

Figure (8) below shows the relation between the values of corrosion rate for coated and noncoated steel bars.

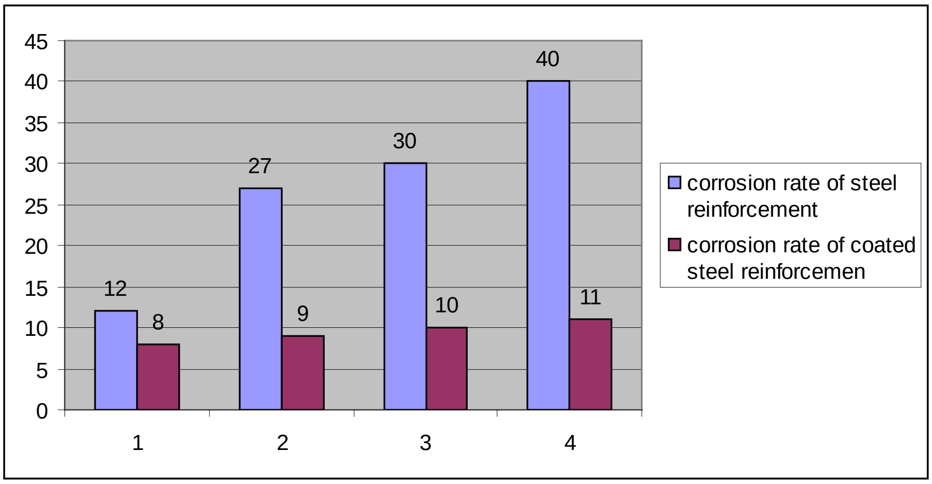

Fig. 8: The relation between corrosion rate for steel reinforcement and coated steel reinforcement.

Note that there is considerable disparity between the values of corrosion for coated steel reinforcement by epoxy and noncoated steel reinforcement, and this is due to the epoxy material that provides a protection from corrosion effects significantly and therefore it is preferably to be used as a coating for steel bars.

Table 5: Hardness test results

Samples	HV1 (before adding acid solutions)	HV2 (after let acid solutions)
1	103	102.2
2	103	101.7
3	102.5	102
4	101	100

Hardness test results before and after adding the acid solutions is presented in table (5). Note from the above table that there is a remarkably simple variation in the values of Vickers hardness and that is because the time is not sufficient to change the mechanical properties.

Conclusion:

The test results indicate that fatigue life of steel bars is reduced significantly due to increase of sulfuric acid concentration in the concrete mix and caused corrosion pits; steel bars decayed according to the negative power exponent law approximately. Fatigue of corrosion reinforcement is quite complex, which is affected by environment, loading conditions, steel rebar type, steel rebar coating, and so on.

Experiment survey revealed that bar coating provides the most effective corrosion protection to the rebar. Epoxy coated Bar has been generally rated in excellent condition, despite high sulfuric acid contents in surrounding concrete. Based on the deterioration rate and life expectancy, epoxy coated bar have performed better than bar with no coating in both calculated rates of hardness and rate of corrosion. Authors' recommendation for future work is to involve a detailed study in corrosion mechanics and to expose test material to different acidity environments with time longer than the current one in this work to study the evolved behavior of the corrosion. Pertinent research has key significance. There is before us a heavy responsibility and a long way to go.

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