Effect of DC Current and NaCl Ratio on Accelerated Corrosion at Different Diameter of Steels

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Abstract— The purpose of placing steel in reinforced concrete structures is to increase the tensile strength of concrete. The diameters of the reinforcements steel in the concrete decrease as a result of electro-chemical reactions. Therefore; corrosion of reinforcement steels is the most important problem in the buildings. As a result of some experimental study, the ductility and ultimate load-carrying capacity decreases as the corrosion rate was increased. In this study, reinforcements steel with diameters of ø12, ø14 and ø16, respectively, were exposed to accelerated corrosion by applying 18 V DC stress intensity for 18 hrs. The solutions whose NaCl ratios are 3, 3.5 and 4%, respectively, were prepared to investigate the effect of NaCl on accelerated corrosion on reinforcement steel. As a result; it has been observed that as the NaCl ratio decreases and reinforcement steel diameter increases, the corrosion rate decreases.

Index Terms— Reinforcement steel, Accelerated corrosion, DC current, Ratio of NaCl.

I INTRODUCTION

The tensile strength of concrete is low. In order to increase the tensile strength of the concrete, steel reinforcements of different diameters are placed in the concrete. The reinforcement steels in the concrete corrode over time and depending on various factors. Corrosion of steel reinforcements in concrete may cause deterioration of reinforced concrete structures over time and even structural collapse [1-2]. Thus one of the main major reasons for the deterioration of reinforced concrete structures is the corrosion of steel rebar [3-5]. Corrosion of steel in concrete takes long time. Some accelerated techniques is need because of difficult to achieve a significant degree of reinforcement corrosion. Galvanostatic methods are used to determine corrosion ratios [6]. In order to study the accelerated corrosion characteristics of steel rebar, three laboratory research methods are widely used, such as natural exposure (chloride diffusion, H_2SO_4, biological etc.) [7-8], artificial climate acceleration [9-11], electrochemical technique [12]. Austin et al. [13] have found that current can be used for accelerated corrosion. The corrosion rate with current application, is reducing the initiation period for depassivation from years to days [13]. Yuan et al. [14] have concluded corroded reinforcement steel ratios are different when current application and nature corrosion of steel bar. This differences lead to different corrosion distribution on the surface of the bar [12].

Some investigations have been reported about accelerating corrosion of reinforced steel. Husain et al. [15] have been used AC current for the evaluation and prequalification of concrete materials prepared with chemical corrosion inhibitors and pozzolanic admixtures of GGBS slag. They have found that the AC current allows detection of performance of the steel reinforcement and the breakdown of passivity in concrete within a much shorter time than with DC current. Wang et al. [16] were prepared eight different reinforced concrete and corroded different accelerated corrosion setup such as wet-dry cycling, half-immersion, full-immersion etc. They found that however wet-dry cycling seems to be the best, the impressed current density is recommended to be kept below 50 IA/cm^2. Sarıbas et al. [17] have investigated the short term effects of Na2SO4 and NaCl concentrations on the strength and durabilility characteristics of hardened mortars. They found that mortars with high water/cement ratio and then exposed to Na2SO4 and NaCl concentrations has lower strength and durability characteristics. Paulson et al. [18] have investigated the capacity of penta sodium triphosphate (PST) to avert the steel reinforcement corrosion in contaminated concrete,by putting specimens in NaCl solutions for 480 days. Their investigations proved that, PST can be used as a competent admixture for inhibiting the corrosion of steel reinforcement.In this study, DC stress intensity was applied on different diameters of reinforcement steels. Different proportions of solutions were prepared to investigate the effect of NaCl on accelerated corrosion. The effects of accelerated corrosion on weight loss and tensile strength of steels were investigated.

II EXPERIMENTAL STUDY

Reinforcement steel diameters of ø12, ø14 and ø16, respectively, were weighed and recorded before the experiment). Then reinforcement steels have been put into sodium chloride solution at the ratio of 3, 3.5 and 4%). 18 V constant DC stress intensity was applied for 18 hrs on the reinforcement steels (Figure 1). At the end of the experiment, the rebars were cleaned with Clarke solution and their weight was measured). When the amount of water used in the experiments is determined to be high during the experiments, the current drawn from the DC power supply becomes very high and causes the cable to burn). For this reason, 2000 liters of water were used in all NaCl solution (Table 1). It has been observed that the diameters of rebars have decreased after

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accelerated corrosion test (Figure 2). Tensile strengths of steels is shown in Figure 3.

TABLE 1
NaCl Solution Mixing Ratios.

Ratio of NaCl (%)	The amount of water (l)	The amount of NaCl (g)
3,0	6000	180
3,5	6000	210
4,0	6000	240

Figure 1 Acceleration corrosion setup

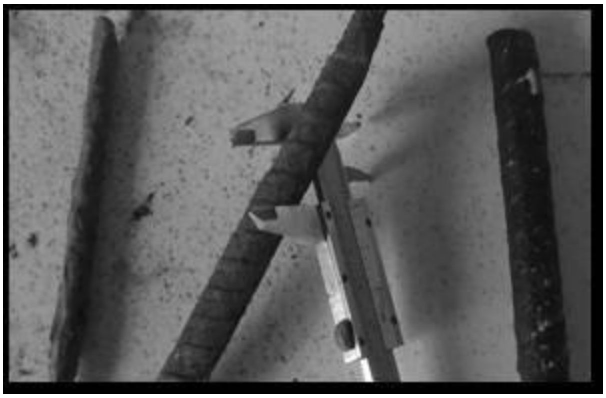

Figure 2. Rebars After Accelerated Corrosion

Figure 3. Tensile strenght tests of steels

III RESULTS AND DISCUSSION

III.I Weight Loss in Accelerated Corrosion

18 V DC stress intensity was applied for 18 hours to the reinforced steels that were put into a 3, 3.5, and 4% NaCl solution, respectively. Table 2 has been prepared in order to compare the weight loss rates of the samples due to accelerated corrosion test.

For all solution ratios, it was observed that as the reinforcement diameter increased, the corrosion rates decreased. When the solution containing 3% NaCl in the mixture is examined, corrosion in the diameter of the reinforcement steel of ø12 poses more risk than the others. However, it has been observed that raising the reinforcement steel diameter to ø14 and ø16 does not pose corrosion risk. As a result of the some experimental study, it was found that when corrosion ratio at 3% increased, the ductility of structural members but decreases the ductility and ultimate load-carrying as the corrosion rate was increased [19]. With the increase in sodium chloride ratio, it causes an increase in corrosion rate and causes a decrease in reinforcement steel diameter. As the amount of NaCl in ø12 reinforcement steels increased from 3% to 4%, the corrosion rates of the samples become 4.14%, 11.40 and 11.61% respectively. As the NaCl ratio increased in solutions, with ø14 reinforcement steel diameters, weight loss due to accelerated corrosion test were calculated 2.57%, 9.22 and 11.00%, respectively. Weight loss ratios for bars with reinforcement steel diameter of ø16 were calculated as 1.42%, 2.66 and 6.69%, respectively. It has been determined that as the NaCl ratio decreases and the reinforcement steel diameter increases, the corrosion rate decreases (Figure 4).

TABLE 2
Weight Loss Rates Of The Reinforcement Steels due to Accelerated Corrosion Test.

Ratio of NaCl (%)	Diameter of Steel	Weight before corrosion (g)	Weight after corrosion (g)	Weight loss (g)	Weight loss ratio (%)
3,0	12	1375	1318	57	4,14
3,0	14	1945	1895	50	2,57
3,0	16	2380	2346	34	1,42
3,5	12	1490	1320	170	11,40
3,5	14	2005	1820	185	9,22
3,5	16	2435	2370	65	2,66
4,0	12	1515	1339	176	11,61
4,0	14	2180	1940	240	11,00
4,0	16	2540	2370	170	6,69

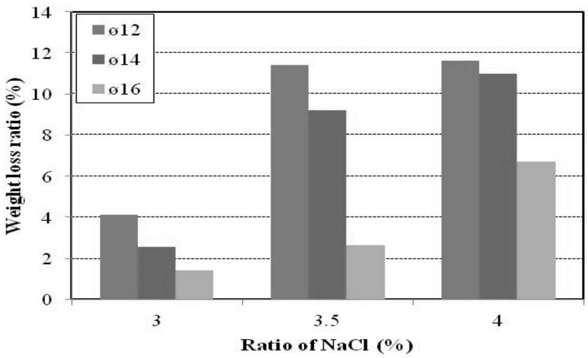

Figure 4. Weight Loss Ratios of Rebars Depending Upon NaCl Ratio and Diameter of Steel

III.II Results of Steel Tensile Strength

Steel tensile tests were carried out on rebars that 18 V DC stress intensity applied for 18 hours in different proportions of NaCl solution. In general, as the diameter and NaCl ratio increases, it is observed that decreases of steel values (Figure 5). This situation can be explained by the cross section losses occurring in diameters as a result of accelerated corrosion in the reinforcement steel. Table 3 has been prepared in order to compare the steel tensile strength values according to the reinforcement diameter of steel NaCl ratio in solution. When the reinforcement steel diameters of ø12, ø14 and ø16 are put in 3% NaCl solution and constant 18 V stress intensity is applied, the tensile strength were decreased by 2.29%, 4.15 and 11.36%, respectively.

TABLE 3

The Tensile Strength Values Depending Upon Diameter of Steel and the Ratio of NaCl

Dimension of steel	Ratio of NaCl (%)			
	0	3	3.5	4
ø 12	670,23	654,64	538,93	536,54
ø 14	612,35	586,90	535,16	529,31
ø 16	655,93	581,41	527,47	496,07

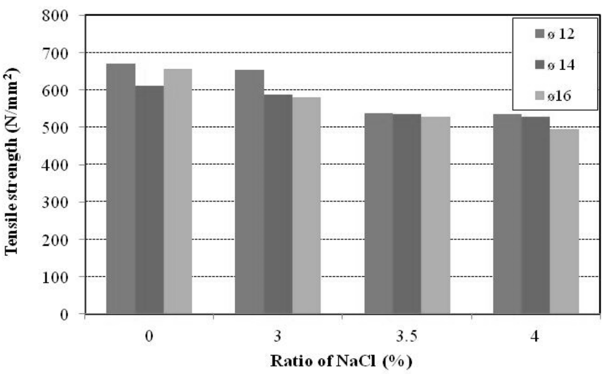

Figure 5. Tensile strengths of steels depending upon NaCl ratio in solutions

The tensile strength of the samples in 3.5% NaCl solution decreased by 19.59%, 12.60% and 19.58%. Reinforcement steel diameters of ø12, ø14 and ø16 were placed in 4% NaCl solution and DC tension was applied, resulting in tensile strength of 19.94%, 13.56 and 24.37%, respectively (Figure 6).

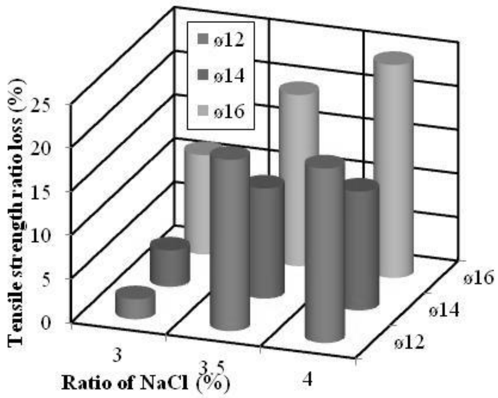

Figure 6. Tensile strength ratio losses depending upon NaCl ratio and diameter of steels

Determining the tensile strength of reinforcement steel is of great importance in reinforced concrete structures. In some studies, it has been tried to establish a relationship between reinforcement steel corrosion and steel tensile strength. Moreno et al. [20] obtained the tensile strength of the steel of 525.59 MPa for ø16 size steels which were corroded 7.43. In this study, for the 6.69 corrosion ratio it is reached 496.07 MPa tensile strength for the same dimension of steels. In order to establish relation between tensile strength and weight loss ratio in terms of NaCl ratio (3, 3.5 and 4%) on reinforcement steels whose dimensions are ø12, ø14 and ø16, graphic has been prepared (Figure 7). As it shown in Figure 7, when the corrosion ratio of steels has increased, tensile strength has decreased for the all dimension of reinforcement steels. Relationship between accelerated corrosion ratio and tensile strenght on different dimension steels which is put into 3 %, 3.5 and 4 % NaCl solutions have can be calculated as given in Table 4.

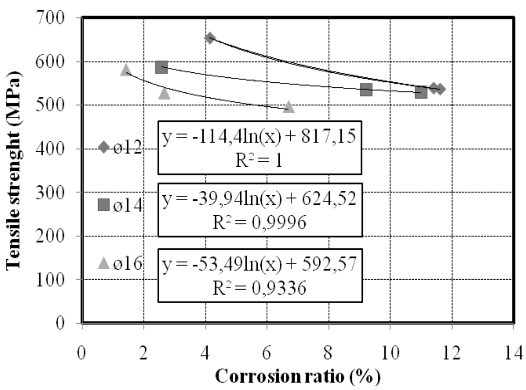

Figure 7. Relationship between tensile strenght and weight loss ratio of steels whose dimensions are ø12, ø14 and ø16

TABLE 4.

Equation and correlation coefficient for relationship between corrosion ratio and tensile strenght of different diameters of steel

Dimension of steel	Equation	R^2
12	y = -114,4ln(x) + 817,15	1,00
14	y = -39,94ln(x) + 624,52	0,9996
16	y = -53,49ln(x) + 592,57	0,9336

III.III The Relationship between DC Current Transition and Corrosion Ratio of Steel

Because of liquid phase of NaCl solution electrical current is easily passes from one electrode to other electrode. The values of current have been measured by ampermeter. Ampermeter has been directly connected to the reinforcement steels. It has been seen that, by increasing NaCl ratio in general it is observed that current passage is increased, too (Figure 8).

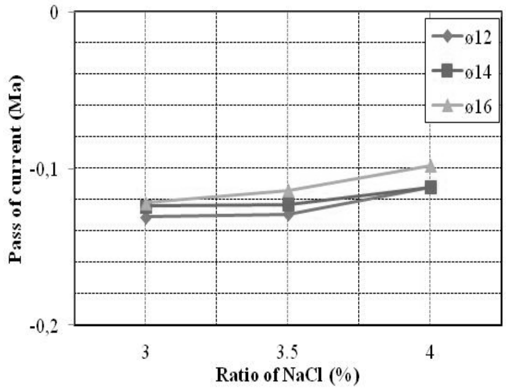

Figure 8. Electrical current change depending upon dimension of steel and NaCl ratio

In order to establish relation between current passages at the end of 18 hours and weight loss ratio in terms of NaCl ratio (3, 3.5 and 4%) on reinforcement steels whose dimensions are ø12, ø14 and ø16, graphics have been prepared (Figs. 9-11). In Figs. 9-11, X axis represents corrosion weight losses and Y axis represents current pass at the end of 18 hours. As a result of forming trend line, equations of weight loss ratio by corrosion have been obtained depending on the NaCl ratio (3 %, 3.5 and 4 %) of the steels which dimensions are ø12, ø14 and ø16. It is concluded that the weight loss of the steels can be estimated by measuring at the end of the current passage of the reinforcement steels. Although most of the sea waters have NaCl values of 3.1 % to 3.8 %, the NaCl rate in the seas varies around the world [21]. In Figure 9 it has been observed that the current passages on steels has been measured -0.131 Ma, -0.129 and -0.112 Ma, respectively (Figure 9).

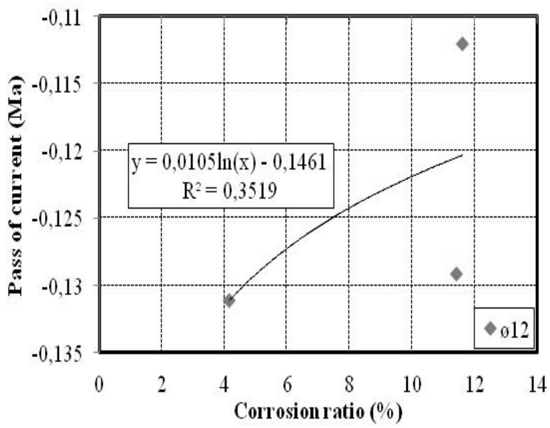

Figure 9. Relationship between current and weight loss ratio of steels whose dimension are ø12

In Figure 10, for the ø14 steels, the current passages on bars have been measured as -0.124 Ma, -0.123 and -0.112 Ma, respectively. It has been observed that when the NaCl ratio increased, the corrosion ratio of reinforcement steels have been increased too.

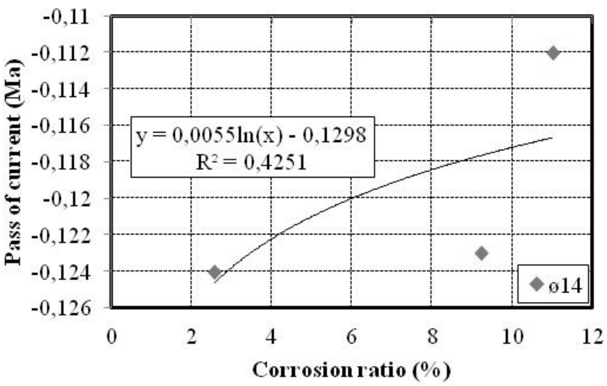

Figure 10. Relationship between current and weight loss ratio of steels whose dimensions are ø14

In Figure 11, for the ø16 steels, the current passages on steels have been measured as -0.122 Ma, -0.114 and -0.098 Ma, respectively. In Figure 11, has been observed to the uniform increase in corrosion rate depending upon the NaCl ratios.

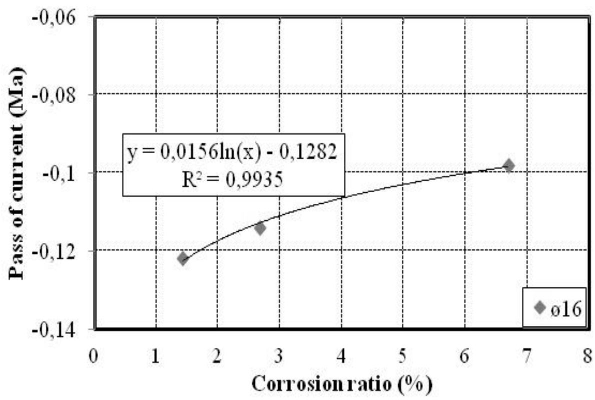

Figure 11. Relationship between current and weight loss ratio of steels whose dimensions are ø16

This study is important because for the determination of corrosion rate of construction steels directly exposed to NaCl solution such as sea water. Relationship between accelerated corrosion ratio and current passage on different dimension steels which is put into 3 %, 3.5 and 4 % NaCl solutions have can be calculated as given in Table 5.

TABLE 5.

Equation and correlation coefficient for prediction of corrosion ratio of different diameters of steel and the ratio of NaCl as a result of application of 18 V DC stress intensity

Dimension of steel	Equation	R^2
12	y = 0,0105ln(x) - 0,1461	0,3519
14	y = 0,0055ln(x) - 0,1298	0,4251
16	y = 0,0156ln(x) - 0,1282	0,9935

IV CONCLUSIONS

The diameters of the reinforcements steel in the concrete decrease as a result of corrosion. Therefore; corrosion of reinforcement steels is the most important problem in the buildings. Determining the corrosion rate of steels at the buildings is extremely important to prevent damage to the structures.

The results being obtained by the research study are given below:

- It has been determined that as the NaCl ratio decreases and the reinforcement steel diameter increases, the corrosion rate decreases.
- Generally, as diameter of steel and NaCl ratio increased, steel tensile strength values decreased.
- The most efficient results in terms of steel tensile strength loss have been achieved with ø14 reinforcement steels.
- Relationship between accelerated corrosion ratio and current passage on different dimension steels which is put into 3%, 3.5% and 4% NaCl solutions have can be estimated as using equation in Table 5.

Consequently, reinforcement steels corrosion ratio can be accelerated by applying DC current. In order to make the study more detailed, it is recommended to test it with different amounts of NaCl ratio and applying different voltage intensities. It is recommended to compare the same experiments by applying AC current and applying current at different frequencies.

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