Effect of Various NaCl Concentration on Corrosion of Steel in Concrete Produced by Addition of Styrofoam

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ABSTRACT

In this study, the corrosion of reinforced steel in the concrete samples with various concentrations of NaCl and with the addition of styrofoam which was replaced 15% of the aggregate volume in the concrete structure was investigated. Additionally, the change on the corrosion of steel in the concrete samples with styrofoam and/or with silica fume 10% in the cement volume was explored. Three groups of concrete samples containing various NaCl concentrations were prepared. In the first group, the samples were without any additional material, the second group was produced by addition of styrofoam (15%) and the third group of samples prepared with the addition of styrofoam plus silica fume (10%). The corrosion rates were measured according to the galvanic current method on the samples. The corrosion potentials have been measured by applying the ASTM-C-876-91 method for 90 days and using $Cu/CuSO_4$ reference electrode. As a result of these experiments, it was found that the corrosion rate of steel in the concrete samples with styrofoam increased with the increasing of the portion of NaCl. However, the corrosion rate of steel in the samples decreased with the addition of silica fume.

Key Words: Corrosion, Styrofoam, Silica fume, Reinforced concrete, Steel.

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1. INTRODUCTION

The concretes that are used as building materials in many structures are chemically and physically very durable against the external effects. Steel reinforced concretes are used in order to increase the tensile and bending strength of the concrete which has very high compressive strength.

Concrete and steel have been the most important building materials in the last century. Reinforced concrete structures are preferred for various kinds of structures because of their high tensile and compressive strength, mouldability for desired shapes and dimensions and cheapness. These kinds of structures are practically advantageous because they are durable against fire and require less care [1].

Concrete is a building material that is used very widely in many kind of constructions in civil engineering. Lower specific strength is particularly more important at the constructions having long distance without support such as bridges whose load ratio of dead load value to total load are enormous. It has been well known that structures are affected from an earthquake because of excessive load on the supporting constituents. Light weight materials should be used in order to reduce its effect to a minimum level. Accordingly, usage of light weight concrete is, nowadays, getting more attention in the construction of concrete buildings [2].

Light weight concretes are classified according to their formations; with artificial or natural light aggregate, with traditional coarse aggregate, and cell or gas concrete obtained by expanding of cement paste. Additionally, they can be classified according to the purpose of their usage; insulation concrete and structural concrete [3].

The steel used in the reinforced concrete has a low corrosion resistance in an atmospheric or humid environment. However, they endure a long time in the concrete against to corrosion because of the high alkali property of concrete. In the alkali environment, a passive oxide film occurs on the surface of steel and, therefore, the corrosion rate decreases [4, 5, 6].

The passive layer which forms on the reinforced steel in clear concrete which is not contaminated with ions and is a character of a quite strong film prevents the contact between steel surface and harmful ions. However, active ions like chloride infiltrating into the concrete contaminate the passive layer and cause initiation of corrosion [1].

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Chloride ions are able to penetrate into the concrete from various sources.

- Set accelerating additions such as $CaCl_2$,
- Sea sands or aggregates extracted from salty medium,
- The salts which are used to melt ice on the concrete in winter, such as sodium chlorides or calcium chlorides,
- Sea water and
- Fog adjacent to the sea.

When chlorides reach a critic level(0,6-1,2 Cl^-/m^3 into the concrete, the corrosion of steel starts [7].

It is very important that chloride ion is diffused into the concrete during the producing of concrete or later. The effects of the chloride ions that diffused by both ways into the concrete are different. A part of the mixture substances (water, aggregate or additons) and chloride ions diffusing into concrete during the hydration of it are bonded together with tricalcium aluminant (C_3A), therefore a insufficiently solved salt that is called friedel ($3CAO.Al_2O_3.xH_2O$) is formed. Consequently, a part of the chloride is bonded together. The chloride ions that are diffused later into the concrete are more effective from the point of corrosion because they are not involved in this reaction [8, 9].

One of the most important precautions for reducing the corrosion is to manufacture impermeability concrete. Therefore, finer grain mineral additions such as silica fume are added into concrete. So, the entrance of components increasing the corrosion rate such as oxygen and carbon dioxide are difficult. In this case, it can be expected that the puzzolans decrease the harmful effects of chloride ions diffusing later into concrete and the carbonation event [1, 10]. However, it has not yet been exactly explained in the literature the effect the puzzolan addition on the chloride ions which diffused into concrete during the casting has. Consequently, the NaCl was added directly into the mixture water and experiments were performed in this study for the determination effects of silica fume addition on the chloride ions which exist in the lightweight concrete.

In this experimental study, the variations of the corrosion rate of steels which were in the lightweight concrete samples that were prepared to replace 15% rate of aggregate in volume with styrofoam in order to maintain lightweight concrete was investigated. Additionally, silica fume (10% by weight of cement) was added into the lightweight concrete including styrofoam and the corrosion variations on the steels were examined.

The corrosion rates of steels in the concrete were measured with the galvanic current measurement method that was developed by Jang and Iwasaki [11]. This method is based on the measurement of galvanic current by ampermeter between electrodes that are dipped into different electrolytes. Jang and Iwasaki used two different ways to apply this method. Initially, two reinforcement concrete steel samples, one of them including chloride and the other one without chloride, were embedded into the solution having concrete pieces. The solutions have been touched with each other by saturated ammonium nitrate salt bridge. The reinforcement concrete steels were connected with each other by a cable and current values passing from cells were measured by an ampermeter. Secondly, two concrete block samples were used instead of concrete pieces. A curtain was been emplaced between concrete blocks in this experiment. One of the concrete samples was embedded into water and the other one into the solution containing chloride. Concrete blocks were connected with each other by a salt bridge and galvanic current between the concrete steels were measured by an ammeter.

In 1996, Asan who was one of the practicers of the galvanic current method investigated the effects of chloride ions, acetate ions and fly ash on the corrosion of steel in concrete [12].

In this study, aforementioned studies were referenced and the variation of the corrosion rate of steel was measured by using the galvanic current method.

2. MATERIAL AND METHOD

A total of 15 batches of concrete (each batch contained three samples) was prepared to investigate different NaCl concentration effects on the accessory corrosion of styrofoam added into the concrete. Variation of the corrosion rate of steel in the concrete was measured according to the galvanic current method.

Moreover, the corrosion potentials have been measured according to ASTM-C-876-91 every day throughout 90 days and the diagram was drawn to determine whether reinforcement concrete steels were in the active or passive condition.

2.1. Preparation of Electrodes

SAE 1010 steel bars that were produced in an Iron and Steel Company in Ereğli have been used in this experimental study. The chemical composition of steel is given in Table 1.

Table 1. The analysis of steel

Element	Carbon (C)	Manganese (Mn)	Silicon (Si)	Phosphorus (P)	Sulfur (S)
Weight, %	0,17	0,249	0,051	0,005	0,044

90 pieces of steel bars were cut into 8 mm diameters, 14 cm length and their surfaces were cleaned mechanically and finally their surfaces were polished with 1200 mesh sandpaper. The polished surfaces were cleaned with ethylene alcohol. A total of 10 cm^2 surface area of the electrodes were uncovered to be embedded into the concrete. the other side of the electrodes were grooved for seeking simpler measurement and the cables were connected to the screws of electrodes. The remaining areas of the electrolytes were firstly covered with epoxy then bandaged with polyethylene to protect against external effects.

2.2. Preparation of Concrete Blocks

In this study, 10x10x10 cm attached concrete blocks were prepared. Preprepared steel electrodes were embedded into the concrete blocks. One of the blocks was in normal composition and the other contained various amounts of NaCl concentrations.

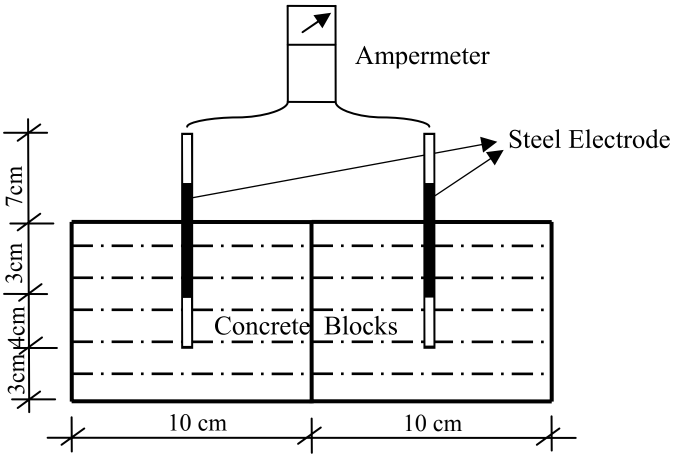

Figure 1. Attached concrete blocks

The black areas on the electrodes shown in the Figure 1 are protected areas. The concrete samples were held in the laboratory for 24 hours then the molds were removed. Samples were held in 90% relative humidity medium during the experimental study for more sensitive measures.

2.3. Compositions of Concrete Block

A total of 45 batches of concrete block samples were prepared for the experimental study.

Group A: In this group, one of the adherent block was of normal composition and the other block was obtained with the addition of NaCl replaced by 1%, 2% and 3% of mix water.

Group B: Concrete blocks in this group were obtained with the addition of styrofoam which was replaced by 15% of aggregate volume. Also, one of the blocks consisted of NaCl 1%, 2% and 3% of mix water.

Group C: Concrete blocks in this group, were obtained with the addition of styrofoam which was replaced by 15% of aggregate volume like Group B. But in this group, silica fume was replaced 10% of cement volume which is different than that of Group B. In this group, one of the blocks consists of NaCl with 1, 2 and 3% of mix water.

If silica fume is used in the concrete, 1 lt water must be added into the concrete for every 1 kg silica fume in the concrete [13]. Additional material with solidification slacken have not been used because of the addition water as silica fume ratio.

Concrete compositions of A, B and C samples are given in Table 2.

Table 2. Mix design of concrete blocks

Sample	Left Block	Right Block
A1 Samp.	Normal Concrete	Normal Concrete + 2,47 kg Cl^-/m^3
A2 Samp.	Normal Concrete	Normal Concrete + 4,94 kg Cl^-/m^3
A3 Samp.	Normal Concrete	Normal Concrete + 7,41 kg Cl^-/m^3
B1 Samp.	Normal Concrete + %15 Styrofoam	Normal Concrete + %15 Styrofoam + 2,47 kg Cl^-/m^3
B2 Samp.	Normal Concrete + %15 Styrofoam	Normal Concrete + %15 Styrofoam + 4,94 kg Cl^-/m^3
B3 Samp.	Normal Concrete + %15 Styrofoam	Normal Concrete + %15 Styrofoam + 7,41 kg Cl^-/m^3
C1 Samp.	Normal Concrete+ %15 Styrofoam + %10 (S.F.)	Nor. Conc. + %15 Styr. + %10 (S.F.) + 2,47 kg Cl^-/m^3
C2 Samp.	Normal Concrete+ %15 Styrofoam + %10 (S.F.)	Nor. Conc. + %15 Styr. + %10 (S.F.) + 4,94 kg Cl^-/m^3
C3 Samp.	Normal Concrete+ %15 Styrofoam + %10 (S.F.)	Nor. Conc. + %15 Styr. + %10 (S.F.) + 7,41 kg Cl^-/m^3

The chemical and mechanical properties of PÇ 42,5 cement provided from a local Cement Company were given in Table 3. Mineralogy component of silica fume produced in Antalya Eti Electro Metalurgy was given in Table 4. Silica fume that was used in concrete mix. has 2,2 kg/dm^3 specific gravity. Drinking water was used in the concrete blocks as mix water.

Table 3. Mechanical and chemical properties of cement

Chemical Properties	
Components	**Values (%)**
Silicium Dioxide (SiO_2)	20,04
Aluminum Oxide (Al_2O_3)	5,61
Ferrite Oxide (Fe_2O_3)	3,27
Calcium Oxide (CaO)	63,01
Magnesium Oxide (MgO)	2,49
Sulfur Trioxide (SO_3)	2,26
Chloride (Cl)	0,006
Loss on Ignition	1,64
Unknown	1,68
Mechanical Properties	
Specific Gravity, (g/cm^3)	3,08
Specific Surface, (cm^2/g.Blaine)	3470
Soundness (Le Chatelier), (mm)	7
Initial Setting Time, (h/m.)	03:10
Final Setting Time, (h/m)	04:15
2 Days Compressive Strength, (N/mm^2)	24,2
7 Days Compressive Strength, (N/mm^2)	43,5
28 Days Compressive Strength, (N/mm^2)	54,5

Table 4. Mineralogical component of silica fume

Components	**Values (%)**
Silicium Dioxide (SiO_2)	91
Aluminum Oxide (Al_2O_3)	0,58
Ferrite Oxide (Fe_2O_3)	0,24
Calcium Oxide (CaO)	0,71
Magnesium Oxide (MgO)	0,33
Sulfur Trioxide (SO_3)	1,06
Chloride (Cl)	0,09
Loss on Ignition	1,84
Unknown	-

General properties of styrofoam were demonstrated in Table 5.

Table 5. General properties of styrofoam

Technical Properties		**Standard**	**Unit**	**Values**		
Density		DIN 53420	kg/dm^3	0,015	0,020	0,030
Compressive Strength		DIN 53421	N/mm^2	0,07-0,12	0,12-0,16	0,18-0,26
Flexural Strength		DIN 53430	N/mm^2	0,15-0,23	0,25-0,32	0,37-0,52
Shear Strength		DIN 53427	N/mm^2	0,09-0,12	0,12-0,15	0,19-0,22
Bending Strength		DIN 53423	N/mm^2	0,16-0,21	0,25-0,30	0,42-0,50
Young's Modulus		-	N/mm^2	0,6-1,25	1,0-1,75	1,8-3,1
Extension Coefficient		-	1/K	5-7.10^{-5}	5-7.10^{-5}	5-7.10^{-5}
Specific Heat Capacity		DIN 4108	J / (kg.k)	1500	1500	1500
Permability of Steam		DIN 53429	g/ m^2.d	40	35	20
Steam Diffusion Resistance Coefficient, (μ)		DIN 4108	1	20/50	30/70	40/100
Under the Water State Water Absorption	7 Days	DIN 53428	In Volume, %	3,0	2,3	2,0
	1 Year		In Volume, %	5,0	4,0	3,5

Some values of styrofoam used in this experiment are; density is 0,024 kg/dm^3, compressive strength is 0,15 N/mm^2, tensile strength is 0,30 N/mm^2, E-Module is 1,70 N/mm^2 and water suck portion under the water (1 year) is 4,1%. These values were determined by the producer company.

In this study styrofoam having 4-8 mm diameterse were used.

Mix proportions of the concrete samples with 10cm x 10cm x 10cm are shown in Table 6.

Table 6. Mix proportions of samples

	A1	A2	A3	B1	B2	B3	C1	C2	C3
Cement, kg/dm^3	0,465	0,465	0,465	0,465	0,465	0,465	0,419	0,419	0,419
Sand(0-4 mm), kg/dm^3	0,907	0,907	0,907	0,771	0,771	0,771	0,771	0,771	0,771
Gravel(4-8 mm), kg/dm^3	0,863	0,863	0,863	0,863	0,863	0,863	0,863	0,863	0,863
Water, kg/dm^3	0,247	0,247	0,247	0,247	0,247	0,247	0,280	0,280	0,280
Styrofoam, kg/dm^3	-	-	-	0,00225	0,00225	0,00225	0,00225	0,00225	0,00225
Silica Fume, kg/dm^3	-	-	-	-	-	-	0,03278	0,03278	0,03278
NaCl, kg Cl$^-$/m^3	2,47	4,94	7,41	2,47	4,94	7,41	2,8	5,6	8,4
Water/Binder	0,53	0,53	0,53	0,53	0,53	0,53	0,61	0,61	0,61

3. EXPERIMENTAL METHOD AND RESULTS

3.1. Experiment of Compressive Strength

The highest strength of the concrete is compressive strength [14]. If concrete has high compressive strength; (compasity), hardness, impermeability and durability against the external effects of concrete increases and abrasion of concrete decreases. Most of the studies which investigated the relationship between the compressive strength of concrete and its other properties showed that compressive strength and other properties of concrete changed proportionally [15]. Compressive strength of concrete shows proportionality with its other properties. Compressive strength test of concrete is the simplest one among the other experiments.

Therefore, in addition to the corrosion tests, the compressive strength of the samples were also determined and the results were interpretated for the samples prepared for 28 days.

Loading rate is 3.00 kN/s during the experiment. The results are demonstrated in Figure 2.

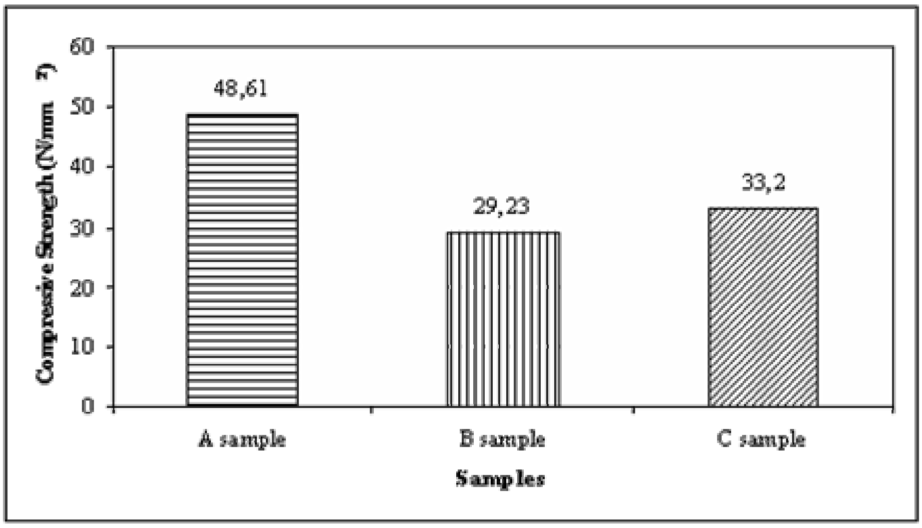

Figure 2. Compressive strength of the samples

3.2 Measuring of Corrosion Potential

Saturated Cu/CuSO$_4$ reference electrodes were used in the measurement of corrosion potential. The corrosion potential was measured daily and for 90 days according to the ASTM-C-876-91 standard. Fluake 45 Dual Display Multi-meter were used in the measurements. The change on the corrosion potential versus time was drawn on the diagrams to determine whether the steel was active or passive.

The change of the steel depending on corrosion potential were explained by Van Daveer as in Table 7 [16].

Table 7. State of the steel depending on corrosion potential

Ecor, (V), (SCE)	State of Steel
> -0.220	Passive
< -0.220 with > -0.270	Active or Passive
< -0.270	Active

Corrosion of the steels in the concrete were qualitatively examined according to this method. The results obtained according to the ASTM-C-876-91 were given in Table 8 and also presented in Figure 3, 4 and 5 in the graphical form.

Table 8. Corrosion potential value of samples

Corrosion Potential Value of Samples, (mV)									
Day	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
1	-365	-482	-522	-487	-545	-559	-430	-517	-548
5	-292	-350	-367	-344	-410	-434	-330	-405	-440
10	-276	-315	-353	-246	-327	-420	-301	-309	-367
15	-259	-270	-316	-284	-284	-400	-220	-238	-333
20	-230	-250	-307	-262	-245	-385	-145	-220	-336
25	-219	-260	-298	-241	-270	-360	-136	-246	-318
30	-250	-239	-297	-257	-267	-383	-122	-164	-297
35	-207	-217	-284	-234	-247	-373	-109	-205	-262
40	-194	-212	-264	-238	-253	-372	-102	-175	-225
45	-156	-200	-256	-180	-237	-373	-105	-195	-191
50	-172	-237	-258	-242	-281	-371	-118	-123	-187
55	-123	-201	-253	-182	-225	-369	-121	-156	-183
60	-101	-233	-269	-153	-221	-362	-112	-132	-203
65	-75	-203	-242	-131	-277	-363	-100	-123	-182
70	-77	-197	-239	-125	-272	-361	-90	-121	-181
75	-103	-192	-221	-126	-266	-361	-75	-118	-175
80	-110	-183	-195	-145	-287	-323	-80	-108	-160
85	-105	-141	-227	-165	-276	-330	-73	-112	-171
90	-95	-139	-225	-173	-285	-335	-75	-114	-180

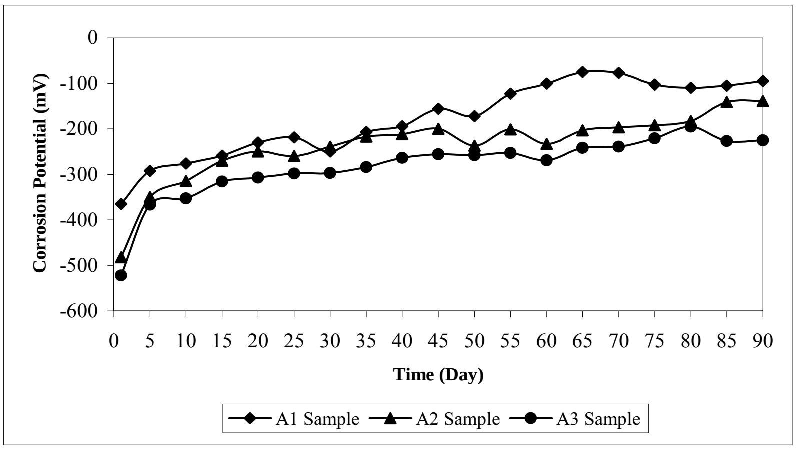

Figure 3. The change of the corrosion potential on the A samples

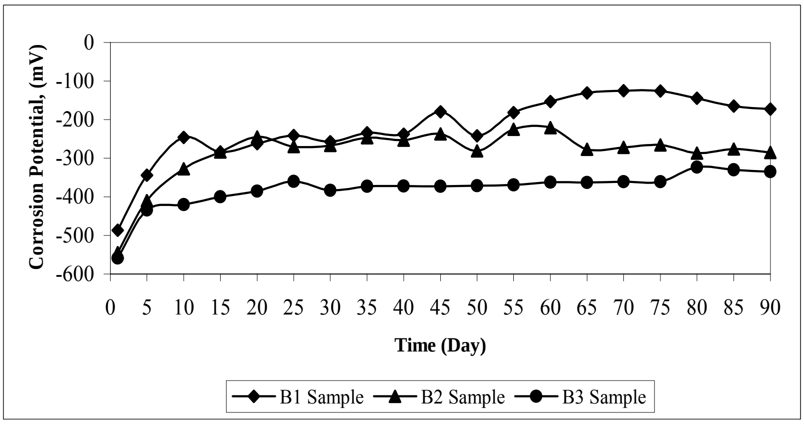

Figure 4. The change of the corrosion potential on the B samples

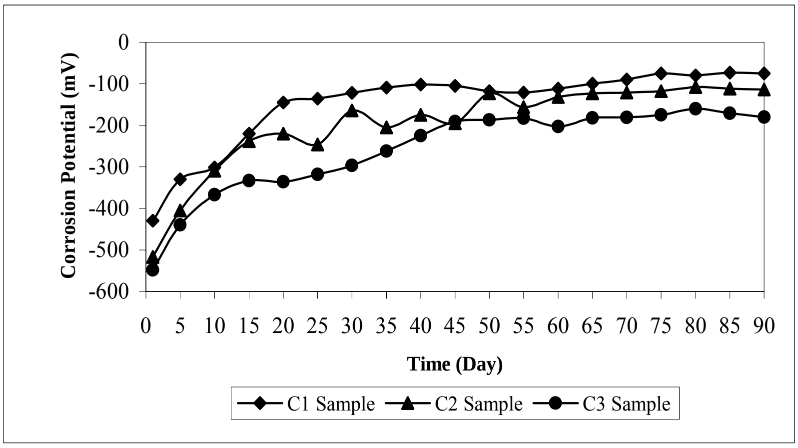

Figure 5. The change of the corrosion potential on the C samples

3.3. Measurement of Galvanic Current

The galvanic current value of A, B and C samples were measured daily and for 90 days. The relative corrosion rate was determined by dividing galvanic current passing through galvanic cell to surface area of the electrode. Fluake 45 Dual Display Multimeter were used in this experiment. The results are given in Table 9 and presented in Figure 3, 4 and 5.

Table 9. Galvanic current value of samples

Galvanic Current Value of the Samples, (µA/10 cm^2)									
Day	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
1	22,6	42,0	44.4	42,2	53,9	64.3	31,0	39,0	48.0
5	16,0	29,3	34.0	27,4	51,0	41.6	25,0	36,0	39.2
10	17,9	25,0	26.0	23,0	38,5	34.8	22,6	29,2	32.0
15	14,0	21,4	25.0	22,2	32,2	32.8	14,3	19,4	17.1
20	11,1	20,5	20.3	14,2	34,8	30.6	12,7	12,1	16.7
25	9,5	10,3	12.5	13,4	23,3	28.3	13,1	17,7	16.9
30	10,7	11,4	10.7	14,1	22,0	28.5	9,0	11,2	11.1
35	11,6	8,7	9.6	18,3	23,1	25.0	8,3	9,7	9.6
40	8,5	8,4	8.6	12,6	22,1	24.0	6,8	8,4	9.2
45	6,1	8,1	7.4	10,8	15,9	21.9	8,3	6,8	8.9
50	5,5	6,0	7.2	6,8	14,0	20.9	5,6	4,3	7.6
55	6,0	5,2	7.0	8,5	12,2	18.2	3,9	3,9	6.9
60	3,9	3,9	6.7	5,2	11,8	18.4	3,0	3,0	5.9
65	2,8	5,4	6.8	4,6	9,7	14.6	2,3	2,4	5.6
70	3,1	4,9	5.4	4,1	8,6	11.6	1,1	2,0	4.9
75	1,8	4,7	5.3	3,8	8,5	9.3	1,3	2,5	4.9
80	1,4	2,9	5.3	4,1	8,8	9.0	1,5	2,1	3.8
85	1,7	3,0	5.0	4,3	7,8	8.7	1,1	2,3	3.8
90	1,6	3,4	4.8	4,6	8,0	8.8	0,9	2,4	3.5

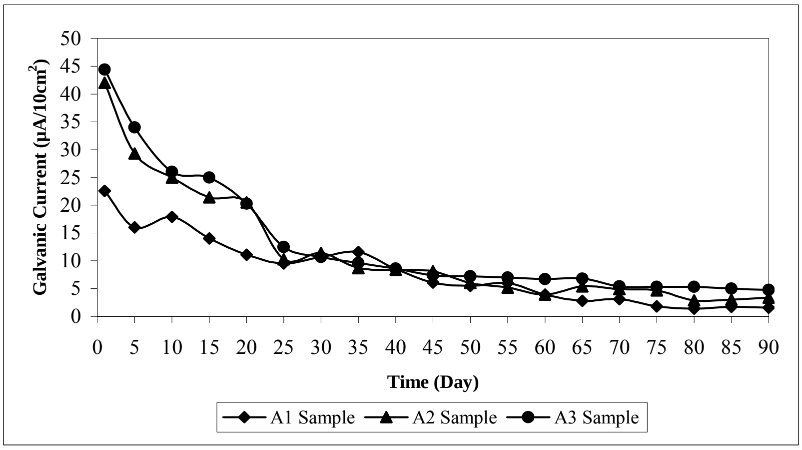

Figure 6. The change of the galvanic current on the A samples

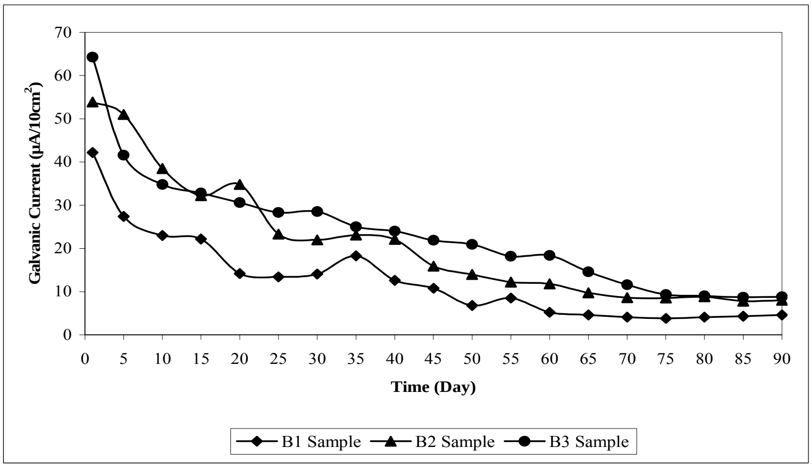

Figure 7. The change of the galvanic current on the B samples

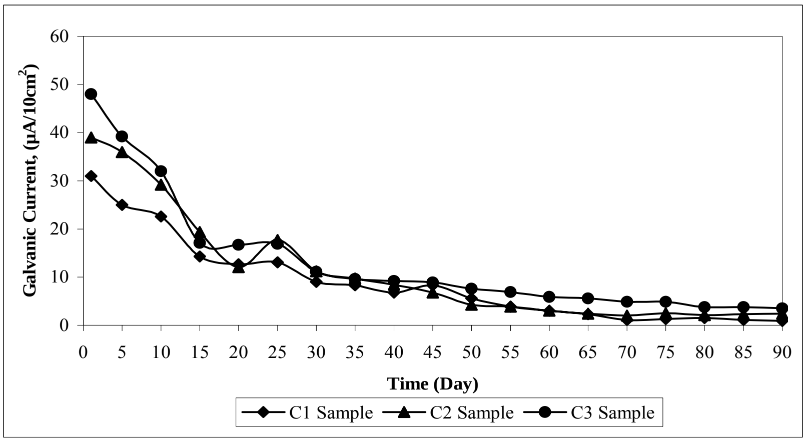

Figure 8. The change of the galvanic current on the C samples

4. DISCUSSION

The compressive strength of the control sample was 48,61 N/mm^2 according to the compressive strength test. The Compressive strength was reduced to 29,23 N/mm^2 with addition of styrofoam replacing 15% of the aggregate volume in the samples to reduce the unit weight of concrete. The compressive strength was increased to 33.2 N/mm^2 with the addition of silica fume replacing 10% of the cement volume in the samples with styrofoam. The increase in the compression strength has occured as a result of increasing the water rate in the mixture despite addition of water in the amount of silica fume.

As a result of corrosion potential experiments, the corrosion rate of reinforced concrete steels increased with the addition of styrofoam into concrete consisting of various NaCl concentrations. At the end of ninety days, it was observed that B2 and B3 reinforced concrete steel samples were in the active zone. It was considered that this case occurred because of reducing the unit weight of the concrete with the addition of styrofoam into the concrete and the increasement of the NaCl ratio. But, the corrosion rate of steels in these samples have reduced with the addition of silica fume replacing 10% of cement volume into the samples with styrofoam and these steels became passive in a short period of time. At the end of the 40th day, reinforced steels in the C3 sample have passiveness with the addition of silica fume to the samples.

Furthermore, the increase of the corrosion rate of steel reinforcement depending on the amount of NaCl concentration in the samples have been determined with the measurement of corrosion potential. A3, B3 and C3 samples in which their mix water consisted of 3% NaCl had the maximum corrosion rate. Steels in the C3 samples with the addition of silica fume had passiveness from the 40th day in spite of the active zone of reinforced steels in the A3 and B3 samples at the end of the 90th day. Active or passive states of reinforced steels have been able to be determined with the corrosion potential values.

Galvanic current measurement have shown that the corrosion rates of all samples have been rapidly reduced in the first day. Gradual increase in the concrete resistivity causes this state. But, decrease of galvanic current values of all samples is not at the same degree.

As a result of the galvanic current measurement, it is clearly observed that the galvanic current values have increased with the addition of styrofoam into the concrete consisting of various NaCl concentrations. This has pointed out that steels in the concretes including styrofoam are more active than in the concretes without styrofoam. However, the galvanic current values of styrofoam added concrete samples have reduced to nearly zero level by addition of 10% silica fume. This case shows that passiveness rapidly occurs in the lightweight concrete with the silica fume.

In this study, it is proved that the biggest corrosion rate has occurred at the A3, B3 and C3 samples including 3% NaCl in their mix water comparing with other NaCl concentrations. Although steels in B3 are more active, the galvanic current values of the steels in C3 including silica fume reduce gradually and finally they become passive in a short time.

Both the compressive strength values and corrosion rate values of this study are identical. The Corrosion rates have increased and the compressive strength has reduced with addition of styrofoam in the concrete. Besides, the compressive strength of samples have increased, corrosion rates have reduced with addition of silica fume together with styrofoam. These results are related to the ultra fine structure of silica fume which both fills the gaps in the concrete and also has very high puzzolanic activity [10].

5. CONCLUSIONS

The results of this study are summarized as follows;

- The corrosion rate of all concrete samples have reduced depending on the increase at the resistivity of concrete in a period of time.
- The Corrosion rates of steels have increased depending on the increase of the NaCl rate in the mix water.
- The highest corrosion rates have occurred in the Group B samples containing styrofoam. Steel samples in this group have not been passive at the end of 90th day.
- It is observed that the addition of silica fume by 10% volume of cement in Group B makes reinforced steels passive in a short period of time.
- Variation of the corrosion rates and compressive strength values of the concrete are exhibited similarily. It is observed that the corrosion rates of steels increases although compressive strength decreases with addition of styrofoam in the concrete. But, the corrosion rate decreases although compressive strength increases with addition of silica fume in the concrete together with styrofoam.
- As a result of this study, it was found that silica fume should be used to increase the compressive strength and resistance of corrosion that is caused by NaCl penetrating during the cast of concrete .

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