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The Effect of Mineral Admixtures on Behavior of Reinforced Concrete against Attack Chloride Salt

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Abstract : *The effect of mineral admixtures on behavior of reinforced Concrete against attack chloride salt was investigated experimentally. The program of the study consisted of casting, curing and testing of three mixes. Mix one contains ordinary Portland cement. Mix two contains ordinary Portland cement and 10% fly ash. Mix three contains ordinary Portland cement and 10% silica fume. For every mix cubes (100*100*100 mm) and cylinders (100*200 mm) without and with 16 mm steel reinforcement were molded. Samples were exposed to sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9% until time periods 28, 60 and 90 days. The mechanical properties concrete compressive strength, splitting tensile and rate of steel corrosion were measured. The results show that the values of compressive and splitting tensile strengths increase when the chloride ratio 5% more than 0%. Moreover the values of compressive and splitting tensile strengths decrease when the chloride ratio 7% and 9% respectively. Increasing the chloride ratio increase the corrosion rate. The compressive and splitting tensile strengths of silica fume show the highest result as compared to the fly ash and ordinary Portland cement. The corrosion rate of silica fume shows the lowest result as compared with the fly ash and ordinary Portland cement.*

Keywords - *sodium chloride; mineral admixtures; steel corrosion; strength; resistance. About five*

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I. Introduction

Steel in concrete is normally in a passive state, which means that the corrosion rate is low due to the high pH of the pore solution. An early study showed that steel in chloride free solutions with pH levels from 11.6 to 13.2 does not corrode. The steel surface in the passive state has a protective layer where the composition of the layer is determined by pH, the electrochemical potential over the steel surface and the oxygen concentration [1]. The corrosion of steel reinforcement is the main enemy of the durability of concrete structures. It is chiefly caused by penetration of chlorides (Cl_) in the concrete mass. All researchers have been developing electrochemical treatments aimed at preventing the penetration of chlorides in concrete and to remedy its effects. Some patents have been registered and its techniques have been applied to many infrastructure works with good results, as a rule. Therefore, it is generally accepted that bothelectrochemical chloride extraction (ECE) and cathodic protection (CP) are appropriate and efficient methods to improve the durability of reinforced concrete structures [2-6].

Carmona and others [7] carried out regarding the application of cathodic prevention (CPrev) and cathodic protection (CP) in some cases with a pre-treatment of electrochemical chloride extraction (ECE), on representative specimens of reinforced concrete structures, using an anodic system consisting of a graphite–cement paste applied as a coating on the surface. This research was found out the competence of this anode for the aforementioned electrochemical treatments. Yanjuan Chen and others [8] studied the combined solution of chloride and sulfate was investigated for three different mixtures, including fly ash and slag. Chloride penetration depths, dynamic modulus of elasticity, and mass change, were tested in the different solution. From results, specimens with fly ash and slag showed lower deterioration compared OPC specimens exposed to combined solution attack under drying–wetting cycles. Additional, higher sulfate contend in combined solution retarded damage for OPC under drying–wetting cycle. Deformation of samples and concerning the microstructure, XRD-analyses is in accordance with TG/DSC-analyses, moreover, DSC/TG could quantified the results from XRD analyses.

II. Materials And Methods

2.1Aggregates

Properties of aggregates used are shown in table 1.

Table 1: Properties of Coarse Aggregate (Basalt) and Sand

Type of test	value
Maximum Aggregate size	22.00
Fineness Modulus of Sand	2.63
Absorption of Coarse Aggregate	2.00%
Specific Gravity of Coarse Aggregate	2.72
Specific Gravity of Fine Aggregate	2.55
Unit Weight of Coarse Aggregate (t\m3)	1.65
Unit Weight of Coarse Aggregate (t\m3)	1.70

2.2 Mineral Admixtures

2.2.1 Fly ash

Properties of Fly ash used are shown in table 2.

Table 2: Physical properties of the fly ash

Color	Whitish grey
Specific gravity	2.288
Bulk density (kg/m^3)	994
Moisture (%)	3.14
Average particle size (μm)	6.92
Color	Whitish grey

2.2.2 Silica fume

Properties of silica fume used are shown in table 3.

Table 3: Properties of Silica Fume

Constituent	Content %
SiO_2	97
Fe_2O_3	0.5
Al_2O_3	0.2
CaO	0.2
MgO	0.5
K_2O	0.5
N_2O	0.2
SO_3	0.15
Cl	0.01
H_2O	0.5

2.2. Concrete Mix Proportions, Samples, and Experimental Program

Three mixes of concrete were produced to cast a series of test specimens divided from mix M1 to mix M12. M1, M2, M3, and M4 were contained ordinary Portland cement and exposed to sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9% until time periods 28, 60 and 90 days. M5, M6, M7, and M8 were contained ordinary Portland cement and 10 % fly ash, and exposed to sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9% until time periods 28, 60 and 90 days. M9, M10, M11, and M12 were contained ordinary Portland cement and 10 % silica fume, and exposed to sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9% until time periods 28, 60 and 90 days. All mixes are shown in Table 4. For each mix 12 cubes (100*100*100 mm), 12 cylinders (100*200 mm), and 12 cylinders (100*200 mm) inside it ϕ16 steel reinforcement as shown in in figure 1 were molded. The Concrete was cast in steel cubes and cylinders. They were demolded after approximately 24 h, were initially cured in water for 7 days, and were transferred to tanks containing sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9% until their testing ages 28, 60 and 90 days.

Table 4: Concrete Mixes

Mix Type	Mix	Water	Cement	Fine Aggregate	Coarse Aggregate	Fly Ash	Silica Fume	Curing Condition
		(kg/m^3)						
Ordinary Portland Cement	**M1**	175	350	747	1121	-	-	Water+0% NaCl
	M2	175	350	747	1121	-	-	Water+5% NaCl
	M3	175	350	747	1121	-	-	Water+7% NaCl
	M4	175	350	747	1121	-	-	Water+9% NaCl

Ordinary Portland Cement + 10% Fly ash	**M5**	175	315	747	1121	35	-	Water+0% NaCl
	M6	175	315	747	1121	35	-	Water+5% NaCl
	M7	175	315	747	1121	35	-	Water+7% NaCl
	M8	175	315	747	1121	35	-	Water+9% NaCl
Ordinary Portland Cement + 10% Silica fume	**M9**	175	315	747	1121	-	35	Water+0% NaCl
	M10	175	315	747	1121	-	35	Water+5% NaCl
	M11	175	315	747	1121	-	35	Water+7% NaCl
	M12	175	315	747	1121	-	35	Water+9% NaCl

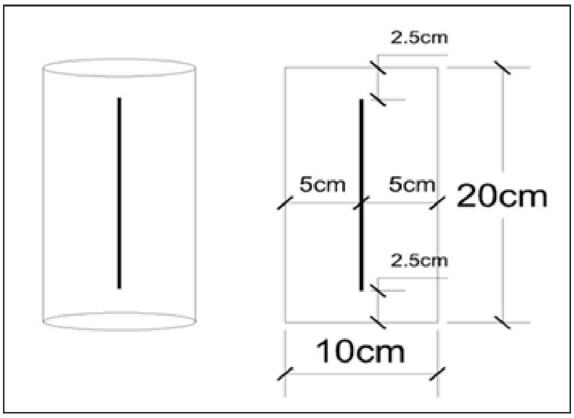

Figure 1: The Corrosion Specimen

2.3. Experimental Tests

Compression tests were carried out on 100 mm cubic and splitting tensile test carried out on 100*200 mm cylinder using a 2000 KN compression machine. The loading rates for the machine applied in the compression and splitting tensile tests were 0.6 and 0.03 N/mm2/sec respectively. Compressive strength and splitting tensile strength were measured at the ages of 28, 60, and 90 days. The high impedance voltmeter was used to measure the corrosion potentials and noting the potentials against a saturated calomel electrode (SCE). Half-cell potentials more positive than-270 mV represents a passive state of corrosion while potentials more negative than -270 mV represent an active state of corrosion (figure 2).. After age 28, 60, and 90 days the rate of steel corrosion was measured

Figure 2: The Half-Cell Potential Test

III. Results And Discussion

Results of compressive strength, splitting tensile strength, and rate of corrosion for all mixes of concrete ware shown in the table 5 to 7.

3.1 Compressive Strength

The compressive strength of specimens was determined after exposure time periods of 28, 60 and 90 days of sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9%. The values of average compressive strength for each mix ware shown in Table 5, Figure 3, Figure 4 and Figure 5. It was observed that the compressive strength of concrete decreased with the increasing of percentage (NaCl) until at 5% of (NaCl) was increased. The relation between the period of chloride exposure and percentage of average decrease in compressive strength for Portland cement, 10% fly ash, and 10% silica fume were shown in Figure 6. It was observed that after 28, 60, and 90 days of exposure to 5, 7, and 9% sodium chloride solution (NaCl) the percentage of decreasing in compressive strength of specimens with Portland cement ware 2.4, 2.5, and 2.4%, 10% fly ash ware 4.4, 6.5, and 4.3%, and 10% silica fume ware 5.2, 6.9, and 4.2%. The mineral admixtures were improved the compressive strength of concrete against the sodium chloride solution 5, 7, and 9% (NaCl) by averaging about 1.8, 8.9, and 4.6% for Portland cement with 10% fly ash, and 10.9, 18.3, and 14.1% Portland cement with 10% for silica fume after 28, 60, and 90 days of exposure respectively as shown in figure 7.

Table 5: Compressive Strength for Average 3 Cubes at 28, 60, and 90 Days

Cement Type	Mix	Compressive Strength (Kg/cm^2)			Curing Condition
		28 days	60 days	90 days	
Ordinary Portland Cement	M1	350	359	425	Water+0% NaCl
	M2	354	380	438	Water+5% NaCl
	M3	344	352	420	Water+7% NaCl
	M4	339	348	410	Water+9% NaCl
Ordinary Portland Cement + 10% Fly ash	M5	360	397	449	Water+0% NaCl
	M6	365	445	468	Water+5% NaCl
	M7	347	375	432	Water+7% NaCl
	M8	341	367	427	Water+9% NaCl
Ordinary Portland Cement + 10% Silica fume	M9	398	443	498	Water+0% NaCl
	M10	405	500	520	Water+5% NaCl
	M11	385	420	480	Water+7% NaCl
	M12	370	405	474	Water+9% NaCl

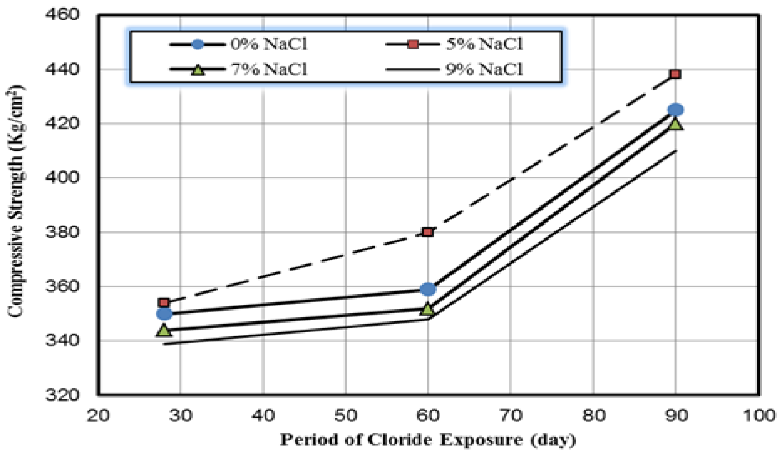

Figure 3: Relation between Period of Cloride Exposure and Compressive Strength for Ordinary Portland Cement

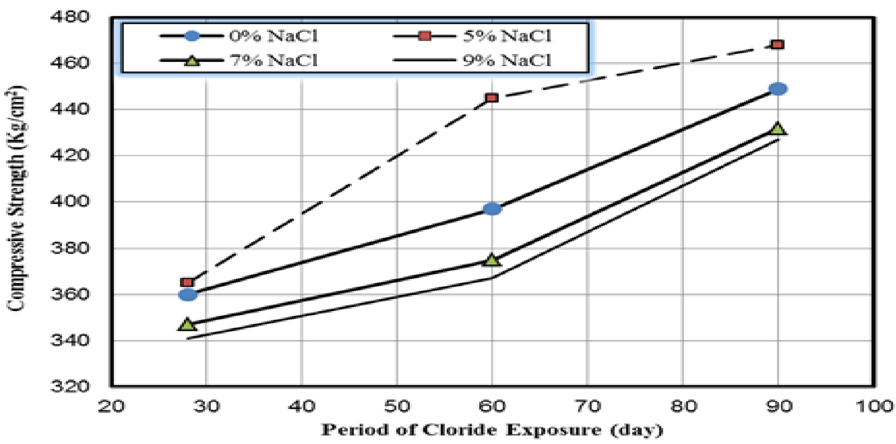

Figure 4: Relation between Period of Cloride Exposure and Compressive Strength for Odinary Portland Cement and 10% Fly Ash

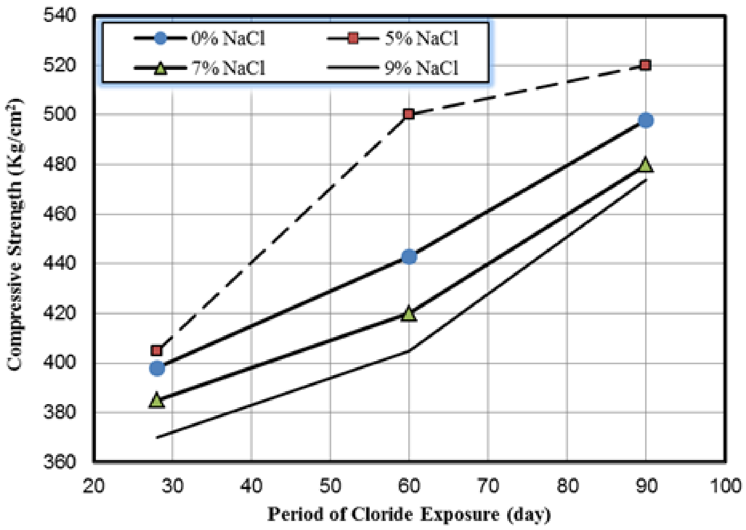

Figure 5: Relation between Period of Cloride Exposure and Compressive Strength for Odinary Portland Cement and 10% Silica Fume

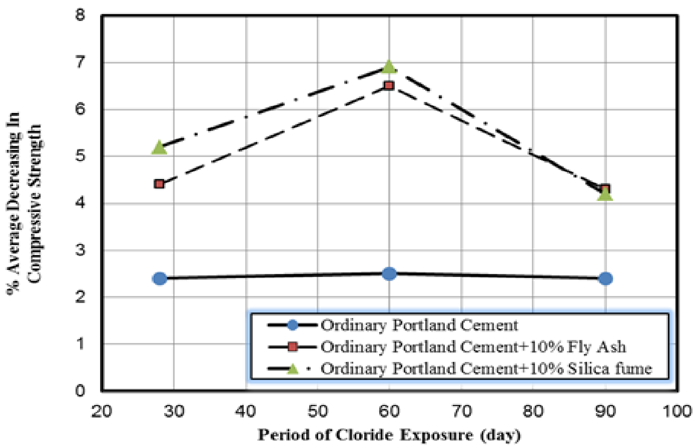

Figure 6: Relation between Period of Cloride Exposure and Percentage of Average Decreasing in Compressive Strength

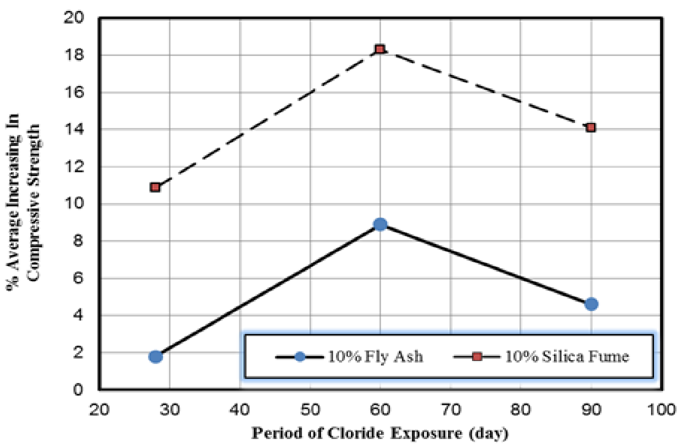

Figure 7: Relation between Period of Cloride Exposure and Percentage of Average Increasing in Compressive Strength Than Ordinary Portland Cement

3.2 Splitting Tensile Strength

The splitting tensile strength of specimens was determined after exposure time periods of 28, 60 and 90 days of sodium chloride solutions (NaCl) with concentration of 0%, 5%, 7%, and 9%. The values of average splitting tensile strength for each mix ware shown in Table 6, Figure 8, Figure 9 and Figure 10. It was observed that the splitting tensile strength of concrete decreased with the increasing of percentage (NaCl) until at 5% of (NaCl) was increased. The relation between the period of chloride exposure and percentage of average decrease in splitting tensile strength for Portland cement, 10% fly ash, and 10% silica fume were shown in Figure 11. It was observed that after 28, 60, and 90 days of exposure to 5, 7, and 9% sodium chloride solution (NaCl) the percentage of decreasing in splitting tensile strength of specimens with Portland cement ware 1.6, 7.7, and 3.2%, 10% fly ash ware 6.9, 6.9, and 5.1%, and 10% silica fume ware 5.1, 5.6, and 4.8%. The mineral admixtures were improved the splitting tensile strength of concrete against the sodium chloride solution 5, 7, and 9% (NaCl) by averaging about 8.6, 11.2, and 4.8% for Portland cement with 10% fly ash, and 17.1, 15.1, and 10.3% Portland cement with 10% for silica fume after 28, 60, and 90 days of exposure respectively as shown in figure 12.

Table 6: Splitting Tensile Strength for Average 3 Cylinders at 28, 60, and 90 Days

Cement Type	Mix	Splitting Tensile Strength (Kg/cm^2)			Curing Condition
		28 days	60 days	90 days	
Ordinary Portland Cement	M1	21	26	31	Water+0% NaCl
	M2	24	29	34	Water+5% NaCl
	M3	20	23	29	Water+7% NaCl
	M4	18	20	27	Water+9% NaCl
Ordinary Portland Cement + 10% Fly ash	M5	24	29	33	Water+0% NaCl
	M6	26	31	35	Water+5% NaCl
	M7	22	27	30	Water+7% NaCl
	M8	19	23	29	Water+9% NaCl
Ordinary Portland Cement + 10% Silica fume	M9	26	30	35	Water+0% NaCl
	M10	28	32	38	Water+5% NaCl
	M11	24	28	32	Water+7% NaCl
	M12	22	25	30	Water+9% NaCl

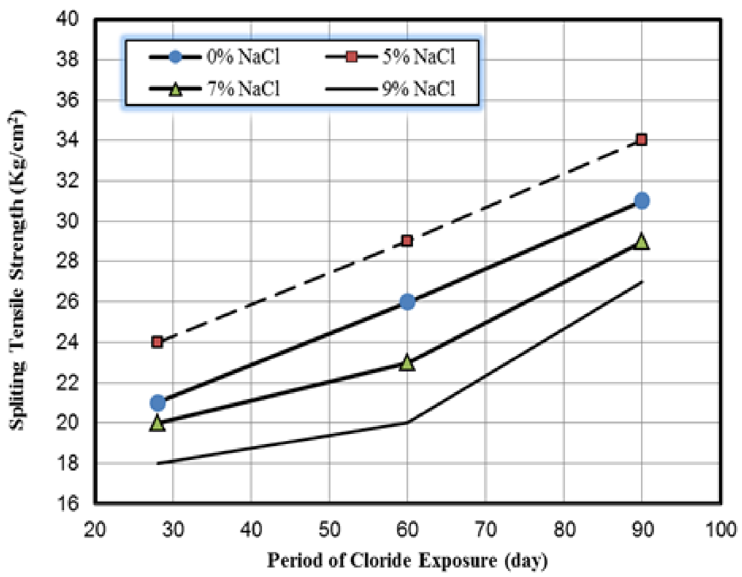

Figure 8: Relation between Period of Cloride Exposure and Spliting Tensile Strength for Ordinary Portland Cement

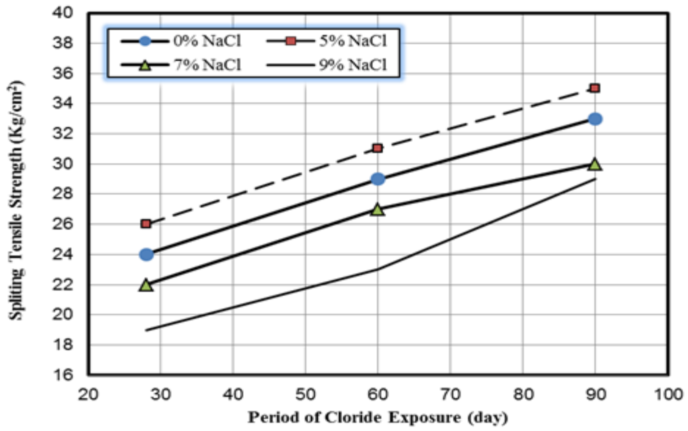

Figure 9: Relation between Period of Cloride Exposure and Spliting Tensile Strength for Odinary Portland Cement and 10% Fly Ash

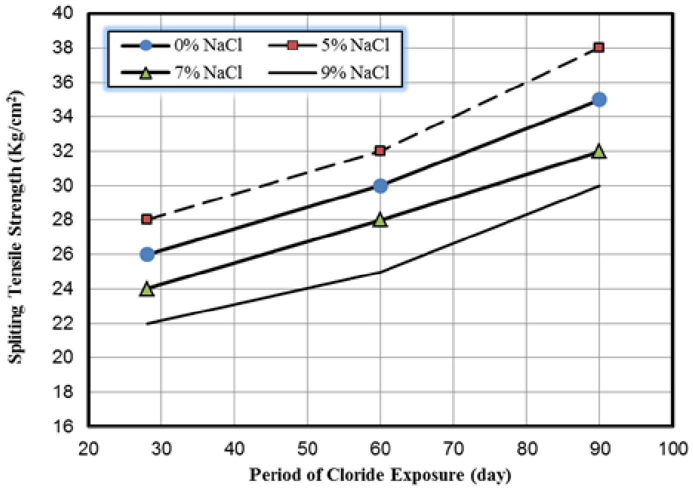

Figure 10: Relation between Period of Cloride Exposure and Spliting Tensile Strength for Odinary Portland Cement and 10% Silica Fume

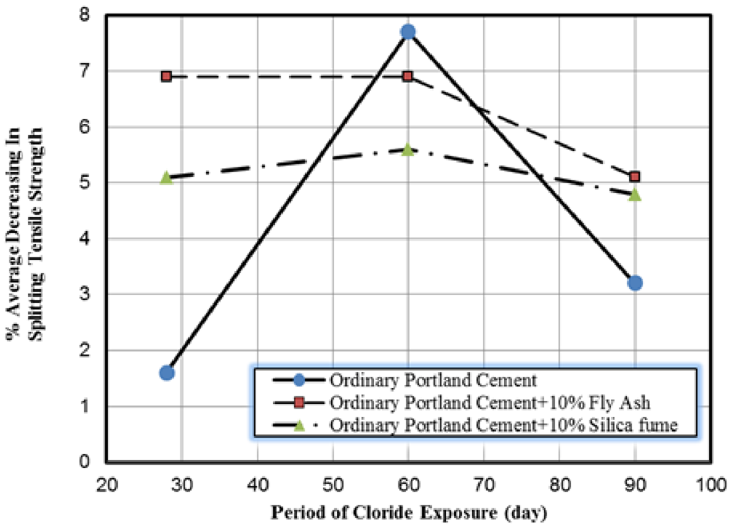

Figure 11: Relation between Period of Cloride Exposure and Percentage of Average Decreasing in Splitting Tensile Strength

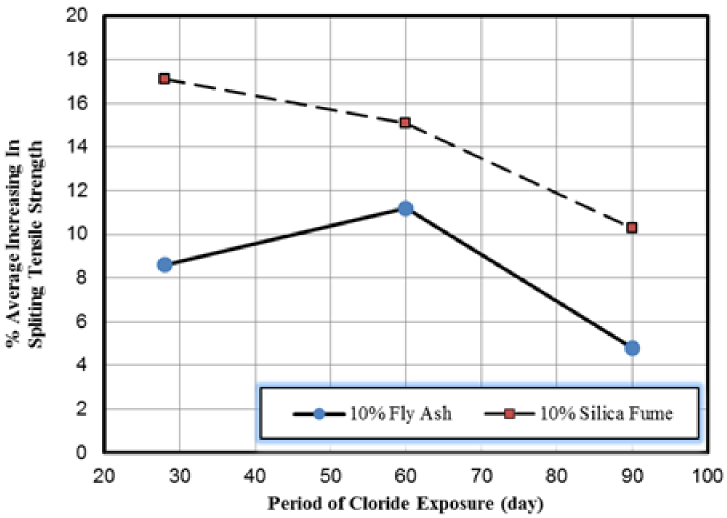

Figure12: Relation between Period of Cloride Exposure and Percentage of Average Increasing in Spliting Tensile Strength Than Ordinary Portland Cement

3.3 Rate of Steel Corrosion

The rate of steel corrosion for specimens was determined after exposure time periods of 28, 60 and 90 days of sodium chloride solutions (NaCl) 5, 7, and 9%. The average rate of steel corrosion values for each mix was shown in Table 7, Figure 13, Figure 14, and Figure 15. It was observed that the rate of steel corrosion were increased with the increasing of percentage (NaCl). The relation between the period of chloride exposure and percentage of average increase in the rate of steel corrosion for Portland cement, 10% fly ash, and 10% silica fume were shown in Figure 16. It was observed that after 28, 60, and 90 days of exposure to 5, 7, and 9% sodium chloride solution (NaCl) the percentage of increasing in rate of steel corrosion of specimens with Portland cement ware 2.3, 3.3, and 4.7%, 10% fly ash ware 2.5, 3.2, and 5.0%, and 10% silica fume ware 5.0, 4.8, and 5.4%. The mineral admixtures were decreased the rate of steel corrosion against the sodium chloride solution 5, 7, and 9% (NaCl) by averaging about 7.3, 9.1, and 9.1% for Portland cement with 10% fly ash, and 20.6, 24.2, and 27.9 % for Portland cement with 10% silica fume after 28, 60, and 90 days of exposure respectively as shown in figure 17.

Table 7: Rate of Steel Corrosion for Average 3 bar at 28, 60, and 90 Days

Cement Type	Mix	Rate of Steel Corrosion (um/year)			Curing Condition
		28 days	60 days	90 days	
Ordinary Portland Cement	M1	188	182	176	Water+0% NaCl
	M2	190	185	180	Water+5% NaCl
	M3	192	188	185	Water+7% NaCl
	M4	195	191	188	Water+9% NaCl
Ordinary Portland Cement + 10% Fly ash	M5	175	167	161	Water+0% NaCl
	M6	177	170	165	Water+5% NaCl
	M7	179	172	170	Water+7% NaCl
	M8	182	175	172	Water+9% NaCl
Ordinary Portland Cement + 10% Silica fume	M9	153	145	137	Water+0% NaCl
	M10	155	148	140	Water+5% NaCl
	M11	160	153	144	Water+7% NaCl
	M12	167	155	149	Water+9% NaCl

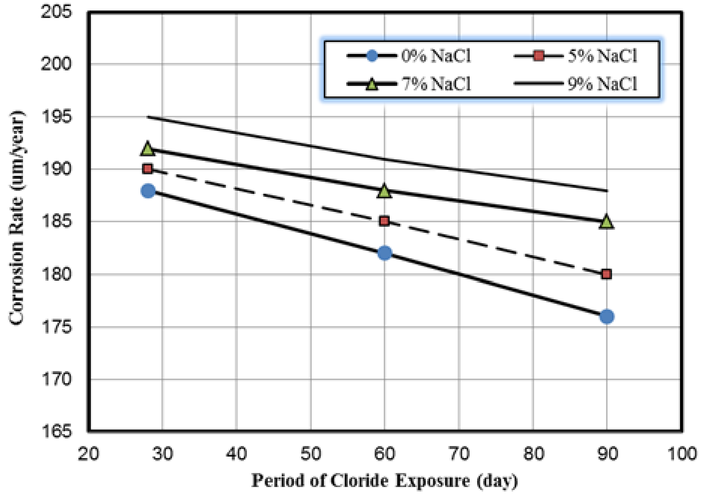

Figure 13: Relation between Period of Cloride Exposure and Corrosion Rate for Ordinary Portland Cement

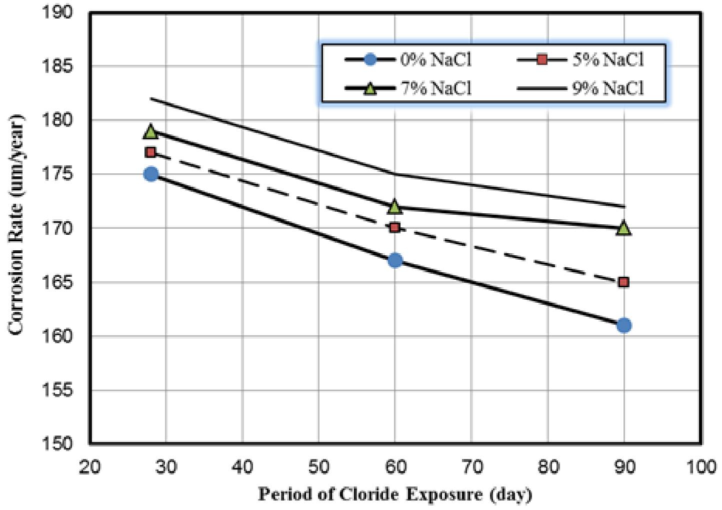

Figure 14: Relation between Period of Cloride Exposure and Corrosion Rate for Odinary Portland Cement and 10% Fly Ash

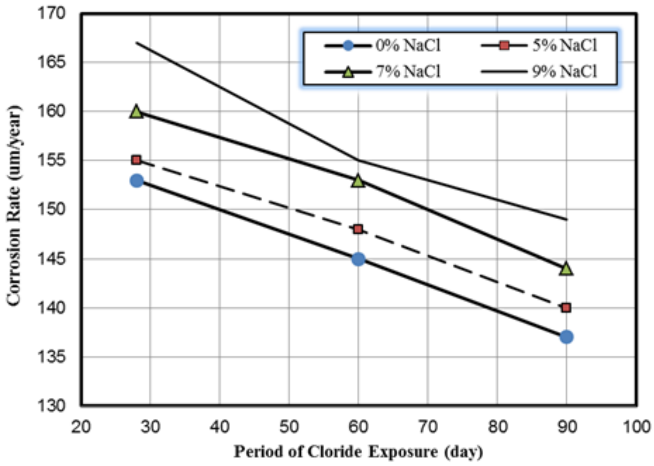

Figure 15: Relation between Period of Cloride Exposure and Corrosion Rate for Odinary Portland Cement and 10% Silica Fume

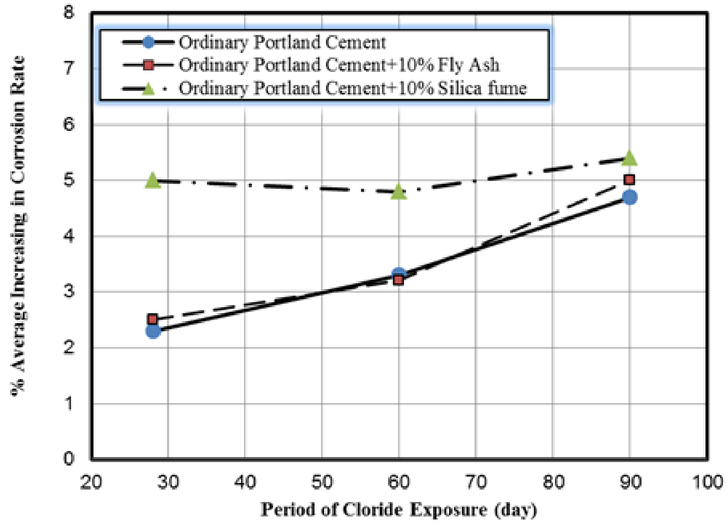

Figure 16: Relation between Period of Sulfate Exposure and Percentage of Average Increasing in Corrosion Rate

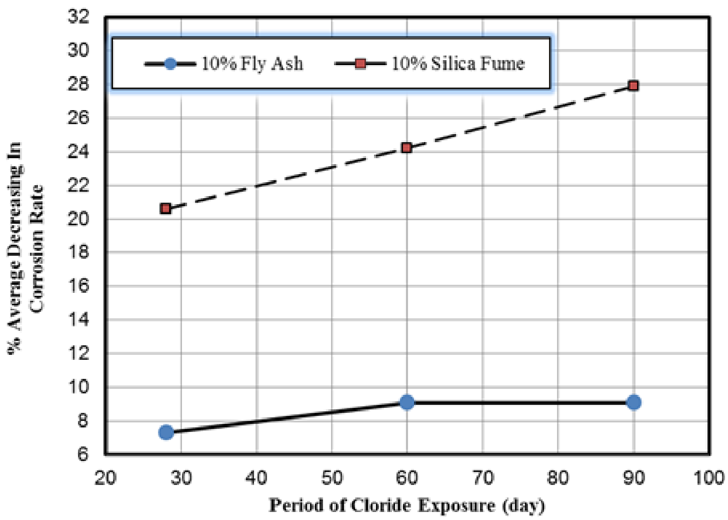

Figure17: Relation between Period of Cloride Exposure and Percentage of Average Decreasing in Corrosion Rate Than Ordinary Portland Cement

IV. Conclusion

Based on the experimental results presented in this paper, the main conclusions are as the follows:

1- Chloride attack process decreases the mechanical properties of the concrete due to change the chemical and physical properties of the cement.

2- A decrease in strength, with a period of exposure, was noted in all types of specimens in sodium chloride solution (NaCl) expect for 5% of (NaCl) was increased.

3- A higher reduction in strength was noted in specimens immersed in 9% (NaCl) solution ,and followed by 7% (NaCl) solution after 90 days of exposure.

4- The mineral admixtures were improved the compressive strength of concrete against the sodium chloride solution 5, 7, and 9% (NaCl) averaging about 1.8, 8.9, and 4.6% for Portland cement with 10% fly ash, and 10.9, 18.3, and 14.1% Portland cement with 10% for silica fume after 28, 60, and 90 days of exposure respectively.

5- The mineral admixtures were improved the splitting tensile strength of concrete against the sodium chloride solution 5, 7, and 9%(NaCl) by averaging about 8.6, 11.2, and 4.8% for Portland cement with 10% fly ash, and 17.1, 15.1, and 10.3% Portland cement with 10% for silica fume after 28, 60, and 90 days of exposure respectively.

6- The mineral admixtures were decreased the rate of steel corrosion against the sodium chloride solution 5, 7, and 9% (NaCl) by averaging about 7.3, 9.1, and 9.1% for Portland cement with 10% fly ash, and 20.6, 24.2, and 27.9 % for Portland cement with 10% silica fume after 28, 60, and 90 days of exposure respectively.

7- Silica fume is improved the mechanical properties of the concrete, and the rate of steel corrosion against the sodium chloride solution (NaCl) than the other mineral admixtures.

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