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The Effect of $MgCl_2$ and NaCl Salts in Concrete

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Abstract — **In this study, the effect of NaCl and $MgCl_2$ salts in lightweight concrete (LWC) with raw perlite aggregate was investigated. For this purpose, a total of 360 concrete samples with Ø100/200 mm cylindrical shape were produced. In concrete mixture, the micro silica fume (MCF) and fly ash (FA) were replaced with cement at the rate of 10% and 20% of its weight in 90 samples for each, respectively. The obtained concrete samples were subjected to Sodium Chloride and Magnesium Chloride solutions at the rate of 3.5% and 5.0% further in mixtures of these at the rate of 1.75%+1.75% for 28, 90, 56 days. But firstly, the standard water curing was applied to samples for 28 days. The compressive strength, unit weight and ultrasonic pulse velocity (UPV) standard tests were made on three each sample to investigate effect of these salts in lightweight concrete and average results obtained from tests were given in this paper.**

The obtained results showed that; the effect of $MgCl_2$ solutions on samples with additives of 10% MCF and 20% FA was fewer compared to standard samples. Besides, NaCl solution and the mixture of these two salts had little effect on LWC. On the other hand, the more $MgCl_2$ solution penetrated into the concrete; because of the specimens with 20% fly ash can absorb more water. As a result, in $MgCl_2$ solution for 90 days, the standard samples were most affected; meanwhile the samples with 20% fly ash and the samples with %10 micro silica fume were affected the least, respectively.

Keywords — **lightweight concrete, perlite, micro cilica fume, fly ash, sodium cloride, magnesium cloride**

I. Introduction

It is known that about 85-90% of structure production in the world is realized about 85-90% as reinforced concrete structural system. In this case; information about reinforced concrete and concrete materials has gained importance a lot. This information is deal with the production of concrete, molding and protection conditions based on the strength of concretes well as mainly aggregates, binders and additives. In the recent years; many advances have arisen in the areas of concrete production and using. The quality of concrete and strength and durability of reinforced concrete system in Turkey which is located on earthquake zones are remarkable [1].

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Concretes of marine structures such as harbors and piers can be damaged by the seawater and affected adversely. Sometimes to take measures against it; the existent mineral admixtures are used. Examples of these materials are blast furnace slag, silica fume, fly ash and other natural pozzolans.

Concrete and reinforced concrete structures are under the influence of salts which is found in their environment and atmosphere. In case of not taking some necessary measures in the concretes happening structures; the structure has been damaged in a very short period of time and cannot realize its function. Although chlorides are not as dangerous as sulfates, in some cases of various types can have some dangerous effects on concrete and reinforced concrete structures. Calcium chlorides, potassium chloride (KCI), magnesium chloride ($MgCl_2$) are chlorides damaging in concrete [2].

In this study; examined salts ($MgCl_2$, NaCl) are mostly found in sea water environment. Majority of structures which expose to the sea water carries the salt on the agenda in terms of effects in the structures and some studies have been realized and will be realized to decrease the effects.

All measures (w/c rate is low (w/c≤0.45), decreasing the effects of salts (NaCl, $MgCl_2$, Sulfate etc.) are valid measures so as to paint the upper surface of concretes (using pozzolanic substance) and to reduce the effect of sea water. Generally; the salinity of the seas and oceans is 36-39 g/l. So, in this thesis in the light of literature; $MgCl_2$ and NaCl solution were produced in the rates of 3.5%, %5 and 1.75% $MgCl_2$ + 1.75% NaCl.

II. Material and Method

A. *Material*

As binding material of perlite aggregate concrete produced for experiments; Portland cement (PÇ 42.5) produced in 2012 by Aşkale Cement Plant and Erzurum city water were used. Perlite is a naturally occurring siliceous volcanic rock. In this study, Erzincan Mollaköy raw perlite aggregate for 100% of the tests were used. Perlite aggregates were sieved in the range of 0-8 mm. Aggregates was separated by 0-2, 2-4 and 4-8 mm sieve and cumulative passing % values for 2, 4 and 8 mm square sieve were 40, 61 and 100%, respectively.

Chemical and physical properties of the material were given in Table 1.

Table 1. Chemical and Physical properties of Perlite [3, 4]

Chemical Properties		Physical Properties	
Component	**(%)**	**Properties**	**Value**
SiO_2	71-75	Specific gravity (g/cm³)	1.999
Al_2O_3	12.5-16	Density (g/cm³)	2.2-2.4
Fe_2O_3	0.3-0.50	Water absorption (%)	4.6
CaO	0.4-0.82	Loose unit weight (kg/m^3)	1116
MgO	0.02-0.03		
SO_3	0-0.2	Tight unit weight (kg/m^3)	1225
Ignition Loss	2.5		
Na_2O	3.2	Water absorption for 30 minutes (%)	2.43
K_2O	4-5		
Free CaO	-		
H_2O	2-6		

In this study; super plasticizer additive Glenium C303 which has capable of high-range water reducer as 1.5% of the cement was used.

The silica fume is gained during the production with melting method of silica or silicon-iron alloy. Although silica fume is a waste material; it entered both to a position of by-product material and it became the most valuable materials among other pozzolanic materials because silica fume has high pozzolanic activity.

Behavior of silica fume in concrete is physicochemical. Physical part of this behavior is reducing the size of the space system in the cement paste matrix, in particular in the aggregate-cement interface [5]. Silica fume chemical composition was given in Table 2. The unit weight of silica fume is 245 kg/m³.

It is a valuable concrete additive having pozzolanic concrete with fly ash and affecting positively a lot of features of the concrete. Because of the global nature of fly ash; it improves the workability of concrete. In this thesis study; fly ash which was taken from Orhaneli thermal power plant in Bursa was used. The physical, chemical and mechanical properties of fly ash were given in Table 2.

Table 2. The chemical and physical properties of silica fume and fly ash [6]

Component / Properties	Silica Fume (%)	Fly Ash (%)
SiO_2	94.6	42.14
Al_2O_3	1	19.38
Fe_2O_3	0.50	4.64
CaO	1.40	26.96
SO_3	0.21	2.43
Specific gravity (g/cm^3)	2.36	2.18
Specific surface (cm^2/g)	200000	-
Insoluble residue	2.16	-
Ignition loss	-	1.34
Free CaO	-	4.34
MgO	-	1.78
K_2O	-	1.13

B. *Method*

The raw perlite obtained from Erzincan Mollaköy in Turkey was used as aggregate in this study. The percentage of fine aggregate should be among 40% and 60% for an aggregate which has the smallest grain size 8 mm in practice according to dry loose volume basis. With this arrangement, the ratio of the units of class respectively were determined as 40% 0-2 mm, 21% 2-4 mm, 39% 4-8 mm.

Additionally; in the calculation of light concrete mixtures and so as to make strong the cement matrix, silica fume (10%) and fly ash (20%) instead of some amount of cement were used according to the cement weight. The objective of these pozzolanic materials using is to increase the ultimate strength and workability.

The PÇ 42.5 cement dosage is 350 kg/m^3 and S/Ç rate is 0.35 and the water amount is 122.5 kg/m^3. Also 10% silica fume and 20% fly ash amount was determined according to the cement amount. The plasticizer admixture was used the amount of 1.5% of the cement weight in mixtures.

For determining the unit weight of hardened concrete; it was determined according to ASTM C 567. Firstly; samples were dried till 105±5°C unchanging weight in an oven and later samples balanced in 1 g precision poise; dry unit weight was calculated by dividing the sample weights to the volumes. To calculate saturated unit weight of the same samples; they were waited in the water for 24 hours. After 24 hours; the samples were balanced and their weights were divided to their volumes and saturated unit weight was determined.

Standard experiment method is provided in TS 500, TS 3114 ISO 4012, ASTM C 31 and ASTM C 39. For uniform distribution of the load over the whole area in the samples; a hood was done. These samples were broken under the pressure load via test press equipment in the end of 28, 56 and 90 days.

III. Result and Discussion

In this chapter; results obtained from aggregate and concrete experiments are shown as Tables and Figures.

The grading of perlite aggregate, i.e. percentage values of passing the sieve for 8, 4, 2 mm and pot sieves were determined as 100, 61, 40 and 0%, respectively. It was realized that this grading is accord with reference grading for the maximum grain size of 8 mm in TS 802.

Unit densities of mineral-based aggregates do not excess 2000 kg/m^3 or loose mass densities of some aggregates do not excess 1200 kg/m^3 are to be identified as light aggregates [7]. The dry unit weights of perlite aggregate for different grain class ranged from 1129 – 1154 kg/m^3. The wet unit weights of produced fresh concrete samples were determined and were showed in Table 3.

Table 3. The unit weight of fresh concrete

Mixture Type	Unit Weight (kg/m³)
Light concrete with 10% Silica Fume	1.910
Light concrete with 20% fly ash	1.900
Light concrete without mineral additive	1.885

A. *Compressive Strength*

Two kinds of salt ($MgCl_2$ and NaCl) were solved in the water with 3 ratios (3%, 5%, mix 1.75%+1.75%) and samples were waited in water for 28, 56, 90 days. Also; normal sample (without additives) was waited in 10% silica fume and 20% fly ash standard water and 9 normal samples were left in each water obtaining water for every experiment samples were removed from water at the end of 28, 56, 90 days; experiments were carried out. Samples which were with additives were added 10% silica fume of cement weight and 20% fly ash; they were waited it salty waters. For concrete samples prepared in this study; hardened concrete experiments such as compressive strength, ultrasonic pulse velocity, unit weight and water absorption were carried out in this experiment program.

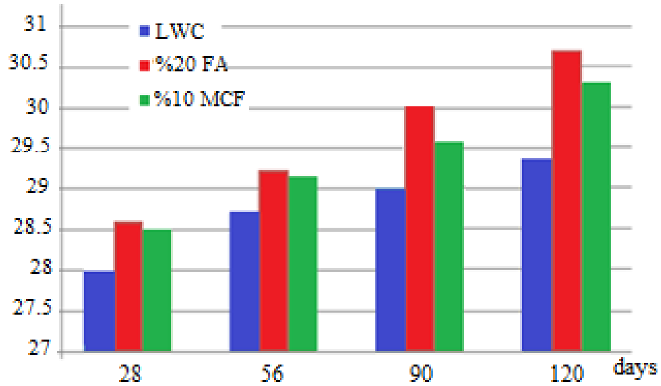

Figure 1. Compressive strength of concrete samples in standard curing

When investigated 28 days compressive strength in Figure 1; concrete samples with 20% fly ash showed the highest strength. The compressive strength of samples which was with the addition of 10% silica fume without mineral additive followed respectively this. There is an increasing in the samples by the addition of 20% fly ash and in the samples by the addition of 10% silica fume. The reason of this increasing is that the strengths of concrete samples under normal curing conditions increase normally day by day.

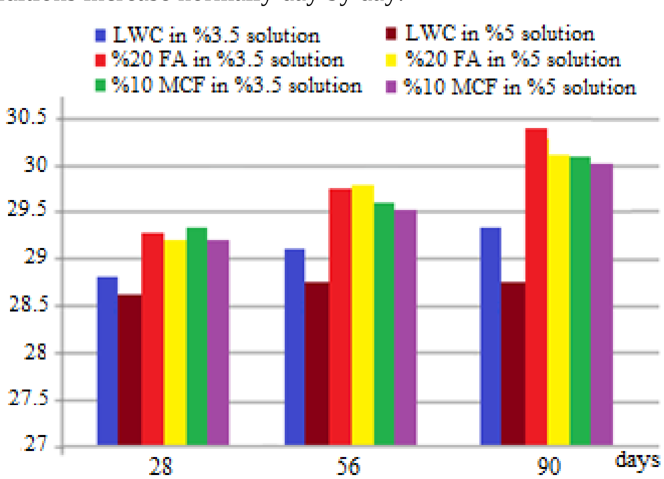

Figure 2. The compressive strength of concrete samples subjected to 3.5% and 5% sodium chloride solutions

The compressive strength test results of concrete specimens which are exposed to 3.5% and 5% sodium chloride solutions were graphically shown in Figure 2 for 28th, 56th and 90th days. When the compressive strengths for 28 days were investigated in Figure 3; concrete samples with 10% silica fume gave the highest strength for 3.5% NaCl solution. As a result; the effects of NaCl solution on concrete samples are so low or sometimes there are no effects of NaCl. However; day by day, more NaCl enters into the concrete and this case causes a lot of spaces in concretes.

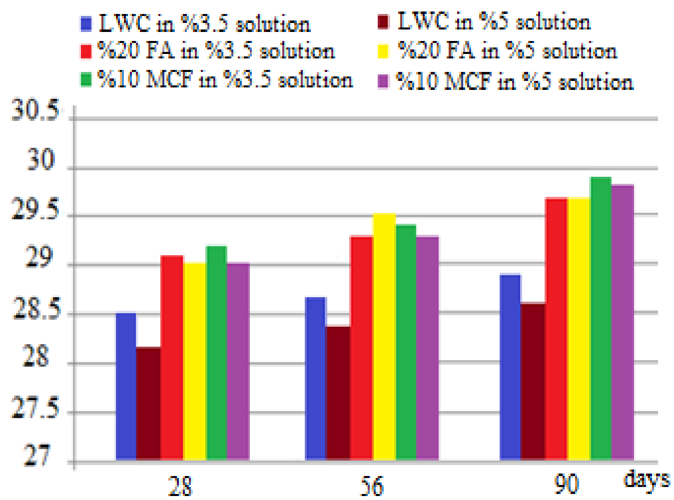

Figure 3. The compressive strength of concrete samples subjected to 3.5% and 5% magnesium chloride solutions

The compressive strength test results of concrete specimens which are exposed to 3.5% and 5% magnesium chloride solutions were graphically shown in Figure 3 for 28th, 56th and 90th days. When the compressive strengths for 28 days were investigated in Figure 4; concrete samples with 10% silica fume gave higher strength than fly ash samples for 3.5% $MgCl_2$ solution.

Briefly; 10% silica fume samples were less affected from magnesium chloride solution than fly ash and witness samples. Also, it was determined that the effect of magnesium chloride is harmful on the concrete surfaces.

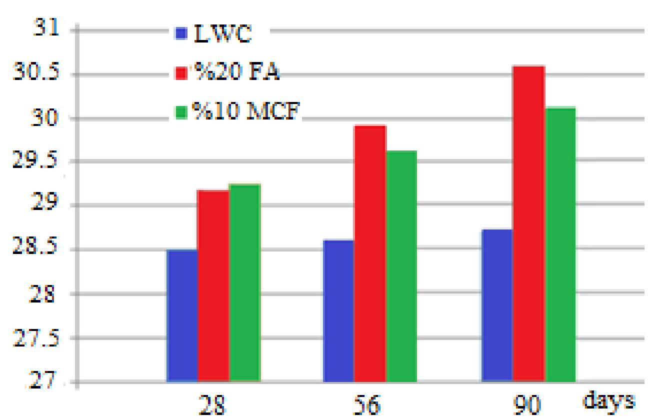

Figure 4. The compressive experiment of concrete samples subjected to 1.75% $MgCl_2$ and 1.75% NaCl.

When the compressive strengths for 28 days were investigated in Figure 4; concrete samples with 10% silica fume gave the highest strength but 20% fly ash samples gave higher strength in 56th and 90th days and the reason of this case is that it used more filler (20% fly ash) silica fume. Additionally; 1.75% magnesium chloride and 1.75% sodium chloride solutions had less effect over the concrete surfaces.

B. *Unit weight (UW)*

The dry unit weights of concrete samples were also measured for standard curing and effect of salt solutions. According to obtained results; in the standard water, the unit weights of normal samples increase day by day. It was seen that the UW increased more in samples with 10% silica fume, 20% fly ash and in standard curing. The UW values of without mineral additive samples in solutions of 3.5% NaCl, 5% NaCl and in mixture (1.75% $MgCl_2$+1.75% NaCl) dropped very few.

In solutions of 3.5%, 5% $MgCl_2$ solutions; UW of concrete samples without mineral additives are so less than NaCl and as the curing time increases; UW increasing decreases. In samples of 10% silica fume and 20% fly ash, 3.5%, 5% NaCl and mixture (1.75% $MgCl_2$+ 1.75% NaCl) solutions seem that they have no effects. Unit weights of samples of 10% silica fumes and 20% fly ashes are less than samples without additives in 3.5% and 5% $MgCl_2$ solutions.

C. *Ultrasonic pulse velocity*

Ultrasonic pulse velocity test results of concrete samples in standard curing were graphically shown in Figure 5 for in 28th, 56th, 90th and 120th days.

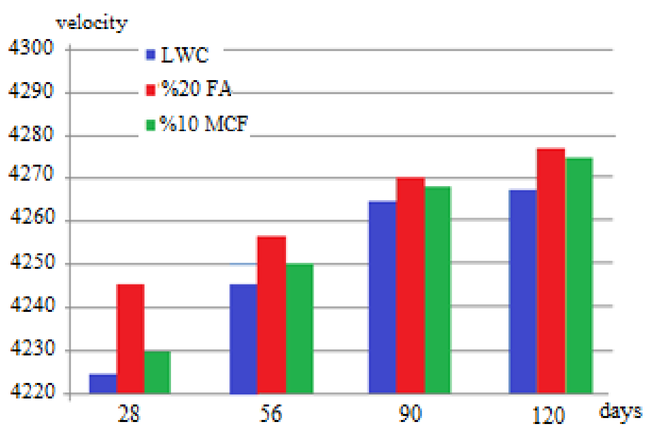

Figure 5. Ultrasonic velocity of concrete samples kept in standard curing (m/s)

The lowest ultrasonic velocity of samples kept in standard curing pool in Figure 6 in 28th days is in samples without mineral additives and in the highest samples with 20% fly ash.

The lowest velocity of samples in 28th, 56th, 90th and 120th days was in samples without mineral additives. Since silica fume and fly ash are filler materials; there is less space on concrete surfaces and the velocity also increases.

After 28 days; an increasing can be seen and this explains that the concrete keeps the surface very well. If the spaces of concrete decreases; the ultrasonic velocity increases.

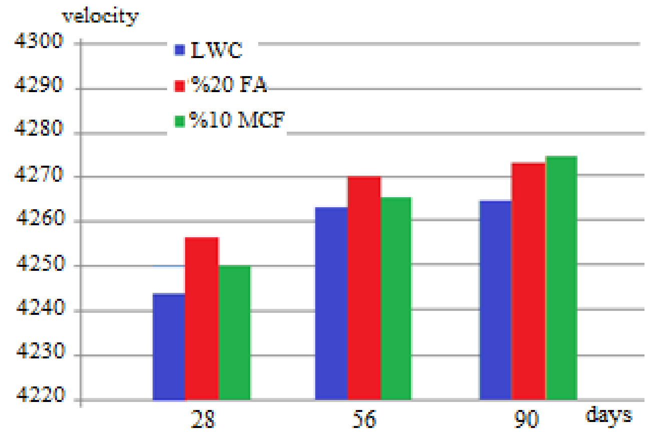

Figure 6. Average ultrasonic velocity of concrete samples exposed to 3.5% and 5% sodium chlorides (m/s)

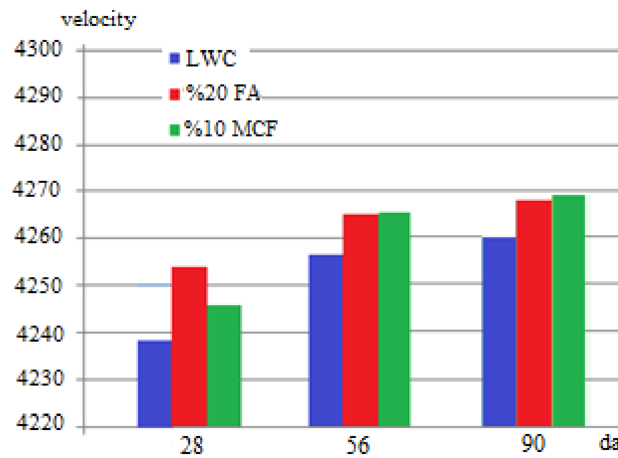

Figure 7. Average ultrasonic velocity of concrete samples exposed to 3.5% and 5% magnesium chlorides (m/s)

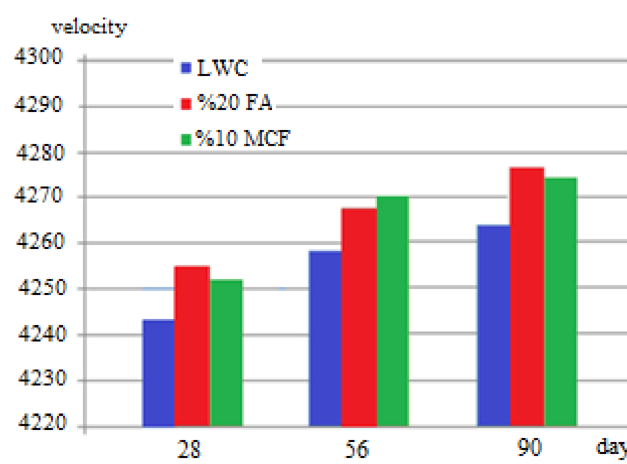

Figure 8. Average ultrasonic velocity of concrete samples exposed to 1.75% NaCl and 1.75% magnesium chlorides

The average of ultrasonic pulse velocities which were exposed to 3.5% and 5% sodium and magnesium chloride solutions, are graphically shown for 28th, 56th and 90th days in Figure 6 and 7. They are samples which do not contain the lowest rate mineral additives in concrete samples in the 28th day and they are the highest samples with 20% fly ashes. In samples in 28th, 56th, 90th days; they are samples without lowest velocity mineral additives. These values show that they are less than normal and NaCl waters.

$MgCl_2$ salt less harmful than NaCl for the concrete and it creates more space and crack in the concrete surfaces or it leads more damages to the concrete. Thus; ultrasonic pulse velocities of concrete samples which are exposed to $MgCl_2$ solution are less.

Ultrasonic pulse velocities of concrete samples which are exposed to 1.75% sodium chlorides and 1.75% magnesium chlorides are shown graphically in 28th, 56th and 90th days in Figure 8. They are samples which do not contain the lowest rate mineral additives in concrete samples in the 28th day and they are the highest samples with 20% fly ashes. These values show that they are less than normal and NaCl waters.

As the time passes; since fly ash and silica fume unit classes are so thin, it was determined that they filled the spaces more and decreased the space rate in the concretes and also provided a high ultrasonic pulse velocity value.

IV. Results

When the experimental results obtained from test studies for 28, 56 and 90 days were compared with together; the following consideration may be said;

1. The compressive strength of the samples allowed in the standard curing showed increasing within 120 days free from mineral additives. While the highest strength value was obtained from samples with 20% FA, the samples with 10% silica fume and without mineral additive was followed them, respectively.

2. It was observed that for both solution rates, the NaCl salt and mixture solution had not significant effect on compressive strength and ultrasonic pulse velocity of concrete, especially in short time.

3. But, $MgCl_2$ salt showed more effects than NaCl in terms of compressive strength and ultrasonic velocity for both solution rates. Because; Na+ and K+ ions are kept by silica surface in the cement. In gel composition; this gel mixes in the case of hydrate by increasing the rate of alkali and starts to separate. Magnesium chloride ($MgCI_2$) causes calcium chloride formation ($CaCI_2$). With increasing the rate of calcium chloride in the concrete surface; it provides the formation of calcium chloric aluminate; so this material is so dangerous for the concrete surfaces.

$$MgCI_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCI_2$$

When the calcium chloride is in a little water as solution; it accelerates increasing of strength by accelerating set of concrete. In addition, it can be harmful a certain degree for cement due to $CaCI_2$ condensation.

4. $MgCl_2$ get decreased the compressive strength increasing acceleration of samples as the time passes and this explains that $MgCl_2$ is so dangerous for the concrete.

5. When the evaluation in terms of mechanical strength was made; it can be said that fly ash and silica fume increase the strength till a certain point. Using of fly ash had a positive effect on the strength of concrete against $MgCl_2$. However; other physical and chemical effects of the concrete with the observation of long-term performance would be useful.

6. In sea structures and wet places in which alkali-aggregate reaction develops fast; using of perlite aggregate concrete should be increased. Maximum aggregate dimension (D_{max}), W/C rate and aggregate grading are so important during production of concrete by using perlite aggregate.

7. A decrease was observed in ultrasonic pulse velocity of concretes exposed to 3.5% and 5% $MgCl_2$ solutions for 90 days. There was a reduction in ultrasonic pulse velocity compared with samples without mineral additives exposed to 3.5% and 5% NaCl solutions. This case shows that $MgCl_2$ solution can damage more than NaCl solution.

8. The loss of strength in samples without mineral additives for 90 days was more. This situation showed that; the concrete samples with mineral additives have better performance in $MgCl_2$ medium.

9. In concrete samples with silica fume and fly ash; these provides durability and resistance against to salts that affect to durability negatively such as $MgCl_2$ because those fill spaces in concrete.

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