

# An Investigation of the Durability Increasing of Concrete in Sulfate Environment with Limestone Powder

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## ABSTRACT

Durability of concrete in vicinity of sulfate ion like structures in the routes and piers is one of issues that always had special concerns. In this research, durability of concretes containing limestone powder in the environments with 5 percent magnesium sulfate, 5 percent sodium sulfate, and net water was investigated. Moreover, we investigated the effect of sulfate ion type with different parentage of water, limestone powder in cement, along with parameters of time in reduction of weight and compressive resistance. To do this, 27 mixing plan of concretes including 15 and 30 percent of limestone powder were replaced with three cement types of without slag, 10 percent slag, and 20 percent slag. To create these concretes, three 0.3, 0.4, and 0.5 water to cement ratios were used. We examined 243 samples with 70\* 70\* 70 mm dimensions in two periods of 70 and 140 days. The results showed that, the mixture of 10 percent slag and 15 percent limestone powder substituted with cement increase the durability of concrete while making it more economical. Therefore, such mixture of cement is recommended for constructing concretes in sulfate ion environments including routes and piers.

**KEYWORDS:** concrete, durability, limestone powder, magnesium sulfate, sodium sulfate, pier

## 1. INTRODUCTION

Since one of the basic problems of reinforced concrete structures is chemical corrosion, due to sulfate ions available in soil and water adjacent to concrete members, there is an effort to improve durability of concrete near corrosive environments with use of additives materials. With attention to the low concentration of sulfate ion in soil and water, and therefore corrosion needs more time, in order to investigate the effect of sulfate ion on concrete in a very short period in laboratory environment, it is required to use acceleration tests by increasing sulfate ion concentration. Researchers like Bonen and Cohen [1] believe that, increasing sulfate ion concentration will not resulted in accelerated corrosion process; but some others like Santhanam et al. (2005) believe in reverse. Powder concrete permeability is lowering agent that has been produced based on fatty acids. The design and manufacture of concrete structures that are exposed to atmospheric conditions and injuries, permeability of concrete is a decisive factor for the prediction and assessment of its durability. The feature size is less water is more concrete durability and strength (Narayanan and Roberts, 2010). Until now, many researches had been done about the effect of additive and pozzolanic materials on destruction process caused by sulfates corrosion especially silica and limestone powder while, adding limestone powder attracted less attention. Hekal et al. (2002) investigated durability of cement pastes containing 10% of slag and limestone powder in  $MgSO_4$  solution and concluded that, in magnesium sulfatesolution, cement pastes containing 40% of slag have more durability than Portland cement. Moreover, adding only 5% of limestone powder increases concrete durability in these environments (young et al., 2001). These Applications are as below:

- The construction of impermeable concrete is required.
- Sewer.
- The sealed tanks, dams and tunnels.
- Channel, eyebrows.
- Launching some docks offshore foundations.
- Floor coverings.
- Concrete and prefabricated structures.
- Different types of cement mortar.
- To prevent the penetration of chemical solutions.
- Concrete water tanks and dams where water is required (Boswel and D'Mello, 2011).

Mostofinejad and Raisi investigated durability of concrete containing limestone powder at sulfated environment and concluded that, the best durability is associated with concrete containing 15% of limestone powder (Young et al., 2002). Young et al. (1999) investigated to investigated weight reduction and compressive resistance of samples subjected to environments with 10% sodium sulfate and 20% magnesium sulfate. Their results showed that, both magnesium and sodium sulfates environments reduced the resistance of samples but the samples within magnesium sulfate had more resistance reduction. In addition, weight changes of samples within net water and

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sodium sulfate were negligible after 90 days; but sample within magnesium sulfate had obvious weight change. Since previous researches, did not specifically offer an appropriate combination of cheap limestone powder and slag materials for durable concrete against sulfate ion, this work aims for determining an appropriate combination of limestone powder and slag to increase durability of concrete against sulfate ion.

## 2. METHODOLOGY AND DATA

### 2.1 Constructing samples

Three 0.3, 0.4, and 0.5 water ratios were used to construct samples. Since concretes with 0.3 and lower water to cement ratios considered as high resistance concretes and there is no specific code for mix plan of high resistance concrete, we benefitted ACI 363R and ACI 211.4R-93 recommendations along with methods of Okamura [8] and Mostofinejad & Nezhati [9] to construct samples. In mixing plan, we used super lubricant materials to the extent that slump will be at 80 to 100 mm. Limestone powder and slag with softness level near to Portland type I cement (220 m<sup>2</sup>/kg Blaine) was used.

Table (1) exhibits the amount of used materials in mix plans. In this table, the W/CM, C, SL, LP, CA, FA, and SP<sub>liquis</sub> variables stand for water to cement materials ratio, cement weight, slag, limestone powder, coarse grains weight, fine grains weight, and super lubricant weight, respectively. Moreover, W<sub>modified</sub> symbol shows the amount of added water to mixture concerning the almost dry state of grains and f<sub>c</sub> represents 28-day compressive resistance of concrete and expressed for each mix plan.

### 2.2. Experiments

In order to investigate the effects of sulfate ion on concrete in intensified manner at laboratory in short time, magnesium sulfate solution with 5% concentration, and sodium sulfate solution with 5% concentration were used. In order to investigate destruction process of samples, after processing, the rate of compressive resistance reduction of sample submerged at water examined after 140 days and weight changes of samples examined once after 70 days and then after 140 days.

Figures (1), (2), and (3) show the effects of sulfate ion on compressive resistance reduction of samples within 5% sodium sulfate and 5% magnesium sulfate environments compared with samples subjected to net water after 140 days. Table (2) shows the weight change rates of samples submerged in above-mentioned environments after 70 and 140 days.

## 2. RESULTS

According to figures 1, 2, and 3 it can be seen that, in both magnesium and sodium sulfate environments, with increase of water to cement materials ratio, the number of compressive resistance reduction of mix plans will increase. This is due to increase of permeability and consequently, more permeation of sulfate ion into these concretes.

Table (1) - Used material in mix plans (kg/m<sup>3</sup>) and compressive resistance in 28 days

Mix plan	W/CM	C	SL	LP	CA	FA	W <sub>modified</sub>	SP <sub>liquid</sub>	f <sub>c</sub> (MPa)
H <sub>1</sub>	0.3	530	0	0	1106.7	612.8	157.7	15.00	77.8
H <sub>2</sub>	0.3	450.5	0	79.5	1107.4	600.5	159.3	11.93	77.1
H <sub>3</sub>	0.3	371	0	159.0	1107.6	587.7	159.6	10.60	16.4
H <sub>4</sub>	0.3	477	53	0	1106.7	605.9	157.7	14.58	76.8
H <sub>5</sub>	0.3	397.5	53	79.5	1107.4	594.6	159.2	10.87	72.9
H <sub>6</sub>	0.3	318	53	159	1107.6	582.8	159.6	10.34	71.3
H <sub>7</sub>	0.3	424	106	0	1106.7	598.8	157.7	13.25	76.2
H <sub>8</sub>	0.3	344.5	106	79.5	1107.4	588.5	159.2	10.47	72.8
H <sub>9</sub>	0.3	265	106	159	1106.6	577.8	162.0	9.54	69.8
H <sub>10</sub>	0.4	400	0	0	1106.9	717.7	162.6	10.30	70.6
H <sub>11</sub>	0.4	340	0	60.0	1107.2	708.2	163.1	8.80	68.0
H <sub>12</sub>	0.4	280	0	120.0	1106.6	698.6	162.0	7.80	64.2
H <sub>13</sub>	0.4	360	40	0	1106.9	712.5	162.5	10.00	64.7
H <sub>14</sub>	0.4	300	40	60	1107.2	703.7	163.1	8.30	63.6
H <sub>15</sub>	0.4	240	40	120	1107.2	695.0	163.1	7.50	57.3
H <sub>16</sub>	0.4	320	80	0	1106.6	707.1	162.0	9.80	63.7
H <sub>17</sub>	0.4	260	80	60	1106.9	699.2	162.5	8.50	61.6
H <sub>18</sub>	0.4	200	80	120	1107.2	691.2	163.1	7.20	56.9
H <sub>19</sub>	0.5	320	0	0	1107.2	782.9	160.3	8.96	56.8
H <sub>20</sub>	0.5	272	0	18.5	1107.0	775.0	163.5	8.00	53.5
H <sub>21</sub>	0.5	224	0	96.0	1107.5	767.5	164.2	7.20	48.6
H <sub>22</sub>	0.5	288	32	0	1108.2	779.7	162.3	8.80	55.7
H <sub>23</sub>	0.5	240	32	48	1107.1	771.5	163.5	4.60	49.5
H <sub>24</sub>	0.5	192	32	96	1107.3	764.4	163.7	7.20	46.8
H <sub>25</sub>	0.5	256	64	0	1107.2	774.4	163.5	7.20	51.6
H <sub>26</sub>	0.5	208	64	48	1107.3	767.9	163.7	6.80	47.7
H <sub>27</sub>	0.5	160	64	96	1107.6	760.7	164.4	6.25	40.1

Table (2) – Weight change percent of samples after 70 and 140 days

Mix plan	Net water		Sodium sulfate 5%		Magnesium sulfate 5%	
	70 days	140 days	70 days	140 days	70 days	140 days
H <sub>1</sub>	0.34	1.39	0.34	1.93	0.25	0.55
H <sub>2</sub>	0.42	1.94	0.39	2.03	0.30	0.65
H <sub>3</sub>	0.50	2.03	0.51	2.23	0.35	0.74
H <sub>4</sub>	0.30	1.18	0.34	1.93	0.23	0.51
H <sub>5</sub>	0.36	1.66	0.36	2.02	0.23	0.61
H <sub>6</sub>	0.47	2.00	0.48	2.17	0.27	0.65
H <sub>7</sub>	0.63	1.79	0.58	2.13	0.37	0.64
H <sub>8</sub>	0.80	2.52	0.69	2.23	0.45	0.68
H <sub>9</sub>	0.99	2.89	0.76	2.53	0.57	0.83
H <sub>10</sub>	0.49	1.98	0.70	2.36	0.38	0.95
H <sub>11</sub>	0.52	2.38	0.75	2.42	0.42	0.97
H <sub>12</sub>	0.58	2.53	0.84	2.66	0.50	1.09
H <sub>13</sub>	0.43	1.69	0.68	2.27	0.35	0.85
H <sub>14</sub>	0.45	1.95	0.70	2.41	0.39	0.94
H <sub>15</sub>	0.52	2.08	0.77	2.74	0.46	1.08
H <sub>16</sub>	0.75	2.74	0.72	2.40	0.71	1.00
H <sub>17</sub>	0.86	2.91	0.83	2.62	0.72	1.16
H <sub>18</sub>	1.02	3.32	0.99	2.71	0.74	1.22
H <sub>19</sub>	0.53	2.46	1.55	2.93	0.65	1.10
H <sub>20</sub>	0.73	2.50	1.60	3.03	0.68	1.33
H <sub>21</sub>	0.96	2.77	1.65	3.17	0.77	1.51
H <sub>22</sub>	0.45	2.25	1.46	2.88	0.71	0.93
H <sub>23</sub>	0.62	2.26	1.47	3.00	0.79	1.18
H <sub>24</sub>	0.83	2.51	1.57	3.10	0.89	1.37
H <sub>25</sub>	0.85	3.21	1.74	2.92	0.94	1.31
H <sub>26</sub>	0.95	3.53	1.89	3.13	1.08	1.35
H <sub>27</sub>	1.04	3.58	2.07	3.31	1.25	1.56

In addition, for a specific mix plan, the samples within magnesium sulfate 5% environment showed higher resistance reduction than sodium sulfate 5% environment. This approves the higher destructive effect of magnesium sulfate than sodium sulfate. This process was true for all mix plans.

With a closer look at figures 1, 2, and 3 for samples within sodium sulfate, 5%, it can be seen that, with increase of slag to cement materials ratio, the compressive resistance reduction percent will be increased. This inappropriate performance of slag in compressive resistance of samples within sodium sulfate could be a result of cement amount reduction and consequently lesser production of cement gel. But the sample within magnesium sulfate environment, the highest compressive resistance reduction belong to concrete without slag, concrete with 20% slag, and concrete with 10% slag substituted with cement, respectively, indicating the proper performance of slag for samples within magnesium sulfate environment. This is due to reaction of slag with calcium hydroxide and consequently reduction of its amount in concrete, because magnesium sulfate have relatively higher reaction desire with calcium hydroxide available in concrete, creating calcium sulfate that its tensional reaction leads to destruction of concrete.

Moreover, in the samples within sodium sulfate 5%, the highest compressive resistance reduction belong to concrete without limestone, concrete containing 30% limestone powder, and concrete containing 15% limestone powder, respectively. This indicates that, for all concretes submerged in sodium sulfate solution, concretes containing 15% limestone powder have best durability.

However, for samples submerged in magnesium sulfate 5% environment, the highest resistance reduction belong to concrete containing 30% limestone powder, concrete without limestone powder, and concrete containing 15% limestone powder. It is due to contribution limestone powder in hydration reaction that leads to formation of mono-carbo-aluminate (mono carbonate) instead of hydrated mono-sulfo-aluminate (mono sulfate) - that created by hydration of normal cement. In normal cement during sulfate attack, mono sulfate reacts with sulfate ion and produces ettringite increases the volume, but in cements containing limestone, due to lesser formation mono sulfate, lower ettringite will be produced in sulfated environment, resulting in increasing of cement's resistance against sulfate attack. In addition, coupled using of limestone powder and slag while assuming the limestone powder amount is constant, highest resistance reduction belong to concrete without limestone powder, concrete containing 20% limestone powder, and concrete containing 10% limestone powder.

Other parameter that used to investigate the durability of samples is the rate of weight change of concrete samples. Table (2), exhibits weight changes of all concretes submerged in sodium sulfate 5%, magnesium sulfate 5% and net water after 70 and 140 days. With a closer look at this table, one can see that, all sample submerged in all environments, gained weight in first 140 days. It can be due to the hydration reactions in this period. For samples

within sulfated environments, highest weight increase belong to concrete with 20% limestone powder, concrete without limestone powder, and concrete with 10% limestone powder. To investigate the effect of sulfate on reduction of samples weight, the weight increase percentage of samples in net water deducted from weight increase percent of samples within sulfated environment. Results show that, all sample within magnesium sulfate 5% environment lost more weight than similar samples within net water at both 70 and 140 days periods, indicating the existence of corrosive reactions.

However, samples in sodium sulfate environment gained weight more than similar samples in net water at first 70 days and also after 140 days, they have lesser weight loss than samples in magnesium sulfate environment. It indicates that, from weight loss viewpoint, magnesium sulfate environment is more corrosive than sodium sulfate environment. Highest weight loss ratio is equal to 2.18 percent for H<sub>26</sub> concrete sample.

In the environments containing sulfate ion, since the concrete with 10% limestone powder has minimum weight change, the optimized amount of slag consumption from weight change viewpoint is 10%. In addition, for all sample, with increasing limestone powder to cement ratio, weight increase percentage has ascending order.

Figure 1: Compressive resistance reduction percent of concretes with different ratios of SL/C and LP/C for W/C = 0.3 state, submerged in sodium sulfate and magnesium sulfate after 140 days.

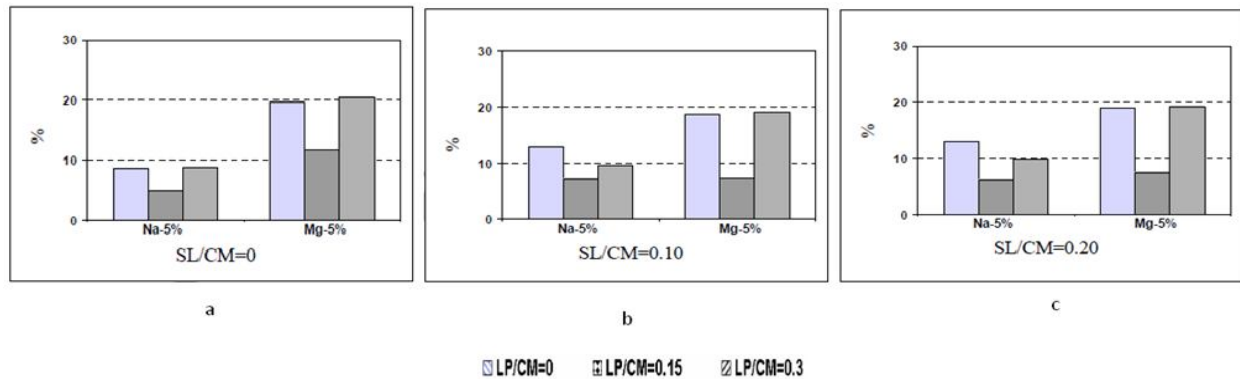


Figure 2: Compressive resistance reduction percent of concretes with different ratios of SL/C and LP/C for W/C = 0.4 state, submerged in sodium sulfate and magnesium sulfate after 140 days.

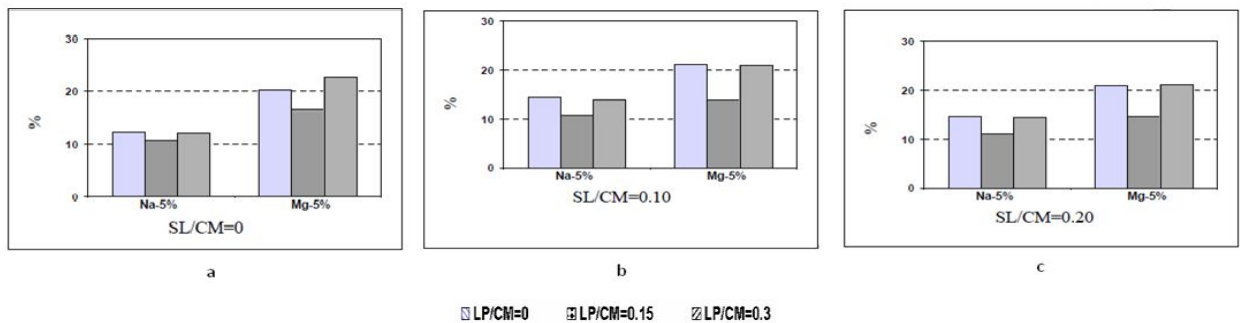
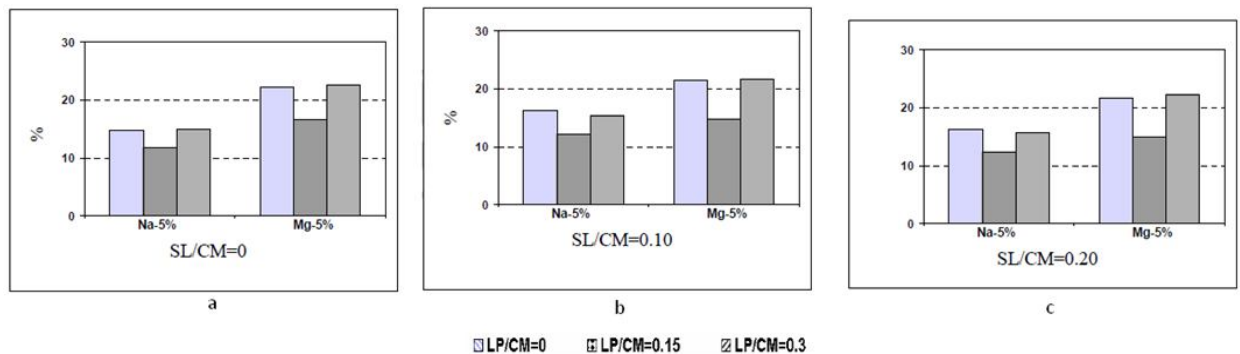


Figure 3: Compressive resistance reduction percent of concretes with different ratios of SL/C and LP/C for W/C = 0.5 state, submerged in sodium sulfate and magnesium sulfate after 140 days.



#### 4. Conclusion

In this work, to determine the appropriate combination slag and limestone powder as alternative for a portion of cement to improve durability for concretes subjected to magnesium sulfate and sodium sulfate environment, 27 different mix plans were used. The concentration of sulfate solution was selected to be 5%. The results of this research are as follow:

- With increase of water to cement materials ratio, resistance is reduced and weight change is increased.
- From resistance reduction and weight change viewpoint, magnesium sulfate is more destructive than sodium sulfate.
- From resistance reduction viewpoint, in sodium sulfate environment, adding slag reduces concrete durability, but it increases by 10 % in sulfate magnesium environment.
- From resistance reduction viewpoint, in sulfated environments, adding 15% limestone powder to concrete results in lesser resistance drop in sulfate environments and therefore, improves durability of samples.
- From weight change viewpoint, adding 15% of limestone powder improved concrete durability but adding 30% limestone powder reduced samples durability.
- From weight change viewpoint, adding 10% limestone powder resulted in lesser destruction and weight loss of sample and improved their durability.
- The highest compressive resistance reduction (22.3%) belongs to concrete with water to cement ratio of 0.5 and containing 30% limestone powder and 20% slag submerged in magnesium sulfate 5% environment and after 140 days. Moreover, highest weight loss (2.2%) belongs to concrete with water to cement materials ratio of 0.5 and containing 15% limestone powder and 20% slag in magnesium sulfate 5% environment and after 140 days. According to this, it can be concluded that, coupled using of relatively high amounts of limestone powder and slag as cement substitute, reduces the concrete durability in sulfated environments.
- According to results of this research, to obtain a durable concrete against different types of sulfate ions, using relatively low ratio of water to cement materials and also 15% of limestone powder and 10% of slag as cement substitute is suggested. Utilization of this combination in concretes adjacent to sulfate like the concretes of piers not only improves durability of concrete but also is economical. It is obvious that, for practical and safe utilization of this composition, other independent experimental researches and observations is required.

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