Effects of $MgCl_2$ with Weight on Concrete

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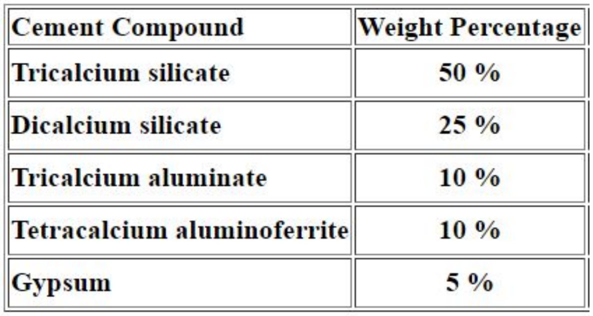
Abstract

The use of salt such as magnesium chloride ($MgCl_2$) or sodium chloride (NaCl) is common within cold climates as a method of snow and ice removal, but studies have shown that concrete infrastructure deteriorates more when exposed to $MgCl_2$. This experiment examines the effect of $MgCl_2$ on concrete over an extended period of time under different temperatures. Reinforced concrete samples were created with pieces of rebar and exposed to varying levels of salt solutions and temperatures where weight was placed on these samples to test for the structural integrity of the concrete. Once finished with the data collection of the concrete samples, the reinforced concrete samples were broken open to observe any changes in concrete or rebar. The data obtained from the experiment revealed no definitive conclusion on the effects of $MgCl_2$ on concrete. Neither the amount of cracks nor final rebar data illustrated a clear pattern due to prolonged exposure to $MgCl_2$. For example, Figures 3 and 4 indicated that the average number of cracks of the undersaturated refrigerator sample was significantly higher than that of the control and saturated solution, however the average number of cracks of the saturated room temperature sample was higher than the undersaturated and control. The rebar samples underwent physical changes over the period of the experiment, but the increase in mass did not show a pattern in terms of the exposure to different solutions and temperatures.

Introduction

The practice of using salt, usually magnesium chloride ($MgCl_2$) or sodium chloride (NaCl), for snow and ice control on roads is common in cold climates. The roads, which are made from reinforced concrete, can be negatively affected both physically and chemically by the added salt. Studies on this topic suggest that specifically $MgCl_2$ degrades concrete's integrity and leads to physical deterioration. Concrete scaling, which is the degradation to the exposed surface of concrete, occurs as a result of water expansion as it freezes on, or in, the concrete surface. The addition of salt increases the frequency of the freeze-thaw cycle, and the degree to which cement scales. $MgCl_2$ also causes an increase in porosity, making the cement more permeable, and allowing more salt and H_2O to penetrate and enter the cement pores. When water freezes, its volume increases by nine percent. This causes hydraulic pressure inside the concrete to increase, creating cracks and scaling. $MgCl_2$ thus leads to accelerated damage to the concrete (America's Cement Manufacturers, 2017).

Concrete is made up of cement, water, and aggregate. Cement consists of five different compounds as shown in the table, but only the tricalcium silicates and dicalcium silicates contribute to concrete strength. When water is added to the cement, the compounds undergo hydration.



Cement Compound	Weight Percentage
Tricalcium silicate	50 %
Dicalcium silicate	25 %
Tricalcium aluminate	10 %
Tetracalcium aluminoferrite	10 %
Gypsum	5 %

Tricalcium silicate + Water → Calcium silicate hydrate (CSH) + Calcium hydroxide + heat

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 4H_2O + 3\ Ca(OH)_2 + 173.6kJ$$

Dicalcium silicate + Water → Calcium silicate hydrate (CSH) + Calcium hydroxide +heat

$$2Ca_2SiO_4 + 5H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 4H_2O + Ca(OH)_2 + 58.6\ kJ$$

As the hydration reactions proceeds, and more CSH is formed, the cement paste begins to attach to the aggregate particles which are made of coarse gravel and sand. Cement is the glue that holds the aggregate together. The aggregate makes up 70 to 80% of the volume of concrete to decrease cost and to provide particular density and porosity qualities (Department of Materials Science and Engineering University of Illinois Urbana-Champaign).

When dissolved in water, $MgCl_2$ has three ions, compared to NaCl's two ions, increasing its ability to lower the freezing point of an aqueous solution. Positive and negative ions are produced when $MgCl_2$ and NaCl dissolve in water, causing a strong attractive force to occur with the polar water molecule. An increase in ions in solution requires a colder temperature to freeze the solution in order to overcome the vibrational energy within the solvations attractive forces. More ions result in increased attraction between the solvent (H_2O) and the ions of the solute ($MgCl_2$ or NaCl). While NaCl also depresses the freezing point depression, $MgCl_2$'s higher attractive forces outweigh NaCl's. $MgCl_2$ can melt ice up to negative fifteen degrees celsius, whereas NaCl can only melt ice as low as negative ten degrees celsius. $MgCl_2$ requires lower application amounts to achieve comparable results, melts ice faster, and is effective for a longer period of time (Mussato et. al., 2004). However, when $MgCl_2$ is exposed to calcium hydroxide $Ca(OH)_2$ present in concrete, the calcium diffuses as the Magnesium displaces it, or leaches out, creating larger pores within the concrete and decreasing its strength.

$$Ca\,(OH)_2 + MgCl_2 \rightarrow CaCl_2 + Mg(OH)_2$$

Furthermore, the addition of $MgCl_2$ leads to the decalcification of the calcium silicate hydrate (C-S-H), compound that comprises more than fifty percent of the volume of cement paste (Sumsion and Guthrie, 2013).

$$CSH + MgCl_2 \rightarrow CaCl_2 + MSH$$

Magnesium silicate hydrate (M-S-H), is non-cementitious and therefore causes deterioration of concrete. Overall concrete strength is thus negatively impacted (Michigan Tech Transportation Institute, 2008). Finally, the $MgCl_2$ penetration of the concrete and diffusion of $Ca(OH)_2$ results in a decrease in pH level within the concrete. As the acidity of the concrete increases, the rebar within the concrete loses passivation allowing corrosion to occur (Mussato et. al., 2004). Corrosion occurs as iron ions come into contact with water ions, making the iron the anode and the forming rust the cathode. The iron is losing electrons as rust forms, thereby weakening the rebar. The purpose of rebar in concrete is to reinforce the concrete and prevent excessive cracking under service conditions. (America's Cement Manufacturers, 2017). The corrosion of rebar leads to an increase in susceptibility to cracking within concrete.

A conclusive study funded by the South Dakota Department of Transportation but conducted by the Michigan Tech Transportation Institute, shows that $MgCl_2$ causes strength loss in cement. After 568 days of of $MgCl_2$ saturation, the concrete psi (pounds per square inch) decreased 57%, from 6311 psi to 2718 psi (Michigan Tech Transportation Institute, 2008). Many studies conducted do not address concrete strength when exposed to road salt; however, this is essential to understanding the effects of road salts on concrete durability. Validating the study completed by the Michigan Tech Transportation Institute is crucial to understanding the effect of $MgCl_2$ on concrete.

The following experiment will address the impact of different concentrations of $MgCl_2$ on concrete roads at varying temperatures over time. Concrete roads show signs of deterioration and depressions in the structure after repeated, prolonged exposure to the weight of cars and other vehicles.

Methods:

Before creating any samples or solutions, goggles and aprons were worn as a protective measure to the effects of $MgCl_2$. Consumption and exposure to $MgCl_2$ were carefully avoided. If contact occurred hands were washed to prevent skin irritation.

Following the *Reinforced Concrete Sample Development*, 18 samples of concrete were made with ¾ in. bars of rebar and put into 3 ounce paper cups. 500 mL of Solution One was made with 273 g $MgCl_2$, which served as the solution that was saturated at room temperature. 500 mL of Solution Two was made with 150 g $MgCl_2$, which served as the solution that was undersaturated at room temperature. 500 mL of Solution Three was made with 270.5 g $MgCl_2$, which served as the solution that was saturated at 15℃ (refrigerator temperature). 500 mL of Solution Four was made with 148.6 g $MgCl_2$, which served as the solution that was undersaturated at 15℃ (refrigerator temperature). Two samples of the controlled variables, which consisted of distilled water, were placed in room temperature and 15℃ (refrigerator temperature). Concrete samples in solutions one, two and the distilled water sample are exposed to room temperature while concrete samples in solutions three, four, and the remaining distilled water sample are exposed to refrigerator temperature (15℃).

Each concrete sample was weighed before exposing the samples to the solutions. After the creation of the concrete samples and their corresponding solutions, 100 mL of each solution was measured and placed into cups with their concrete sample. Concrete samples were placed into 100 mL of distilled water, as the controlled variables. After leaving the concrete samples within the solution until the next data collection, each concrete sample, both refrigerator temperature and room temperature was removed from its cup and were tested for structural integrity with a standard red brick (2267.96 g), given forty-eight hours. The standard red brick was placed on top of the three concrete samples of each individual solution. After forty-eight hours, the concrete samples were observed for any changes in structure or form, specifically cracks. The mass of the concrete samples were weighed following the weight test to observe any changes in mass. Five trials of the weight test were performed on every concrete sample within this experiment.

Once the data collection of weight and cracks was completed, the concrete samples were taken outdoors and struck with a hammer to reveal the rebar. The amount of strikes to break open the concrete samples were recorded to observe the structural integrity of the concrete samples. The interior of the concrete samples were observed as well as the rebar to see the effect of salt penetration into the concrete. Once the rebar was removed from the concrete, the rebar was observed for any concrete attached to the rebar and weighed for further analysis on possible changes in mass.

Data Analysis:

For the remainder of this study, Solution 1 refers to the saturated room temperature solution and Solution 2 refers to the undersaturated room temperature solution. Solution 3 refers to the saturated refrigerated solution and Solution 4 refers to the undersaturated refrigerated solution. Control 1 is the room temperature distilled water, while Control 2 is the refrigerator distilled water.

According to both Figure 1 and 2, a sharp increase in weight was observed from the initial concrete mass (day 0), to the 5th day weigh-in mass. This is observed in all of the concentrations because the initial mass was collected when the cement was dry. Cement masses were collected after submersion into varying concentrations from the fifth through sixty-second days. The mass of all solutions from Day 5 to Day 28 show a decrease in mass as seen in Figure 1 and 2 due to the initial submersion in water and subsequent increase in mass from the added water. The average weight loss for concentrations in room temperature (Figure 1) was 0.891 grams between Day 5 and 28. This is a 1.171% average weight loss. The average weight loss for concentrations in the refrigerator (Figures 2) was 3.11 grams between Day 5 to 28. This is a 4.326% average weight loss. This result illustrates the effect of the frequent freeze thaw cycles that occur when the cement is taken from the refrigerator to ambient conditions, and back again. This mimics what would happen to concrete in actual winter conditions.

However, following the initial decrease in mass from Day 5 to Day 28, the mass of the concrete samples increased and continued to increase as more data was collected over the course of 34 days. This is seen from the positive line of best fit for each solution in Figure 1 and 2. The least steep slope was 0.013, however the steepest was 0.75, proving that, though they increased at varying rates, each solution experienced some level of penetration by the salt solution. It was hypothesized that prolonged exposure to the salt solutions caused a buildup of brucite within the concrete samples, increasing the mass.

For both the refrigerated and room temperature concrete samples, the slopes of the graphs in Figures 3 and 4 indicate a general increase of average number of cracks with the steepest slope increasing at a rate of 0.467 and the least steep increasing at a rate of 0.0146. However, some samples experienced extreme cracking, while others averaged a low number of cracks. Solution 4 saw the largest increase in average number of cracks for the refrigerated group, but Solution 2 experienced a much lower increase in average number of cracks. This indicates that the freeze thaw cycle negatively affects the structural integrity of concrete exposed to $MgCl_2$, however this conclusion cannot definitively be drawn, because this trend was not observed with Solution 1 and Solution 3. While both control groups (C1 and C2) average number of cracks remained low, the refrigerated sample underwent slightly more damage, further supporting that the freeze thaw cycle, in addition to $MgCl_2$, weakens concrete's structure. Despite this evidence, Solution 1 saw a much greater increase in number of cracks than Solution 3. Overall, however, the graphs indicated that $MgCl_2$ does cause concrete degradation; the slopes of the saturated and undersaturated solutions, at both room temperature and in the refrigerator, tend to be steeper than those of the control groups.

The slopes of the average mass and the average number of cracks in the concrete show no correlation as seen in Table 1. This indicates the increase in cracks did not affect the increase of mass.

Figure 1: Samples at Room Temperature: Control, Saturated, Undersaturated

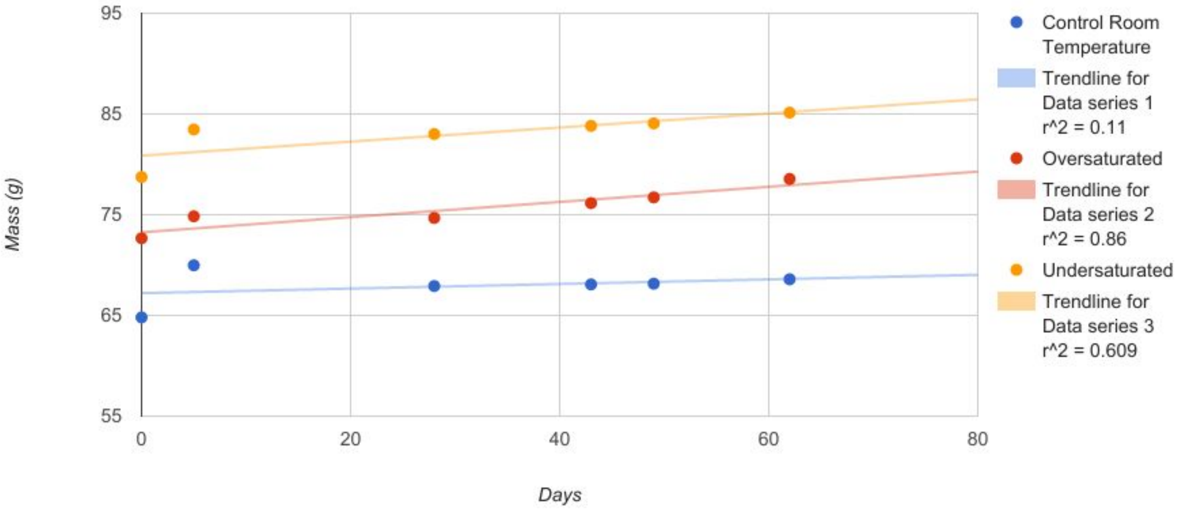


Figure 2: Samples in Refrigerator: Control, Saturated, Undersaturated

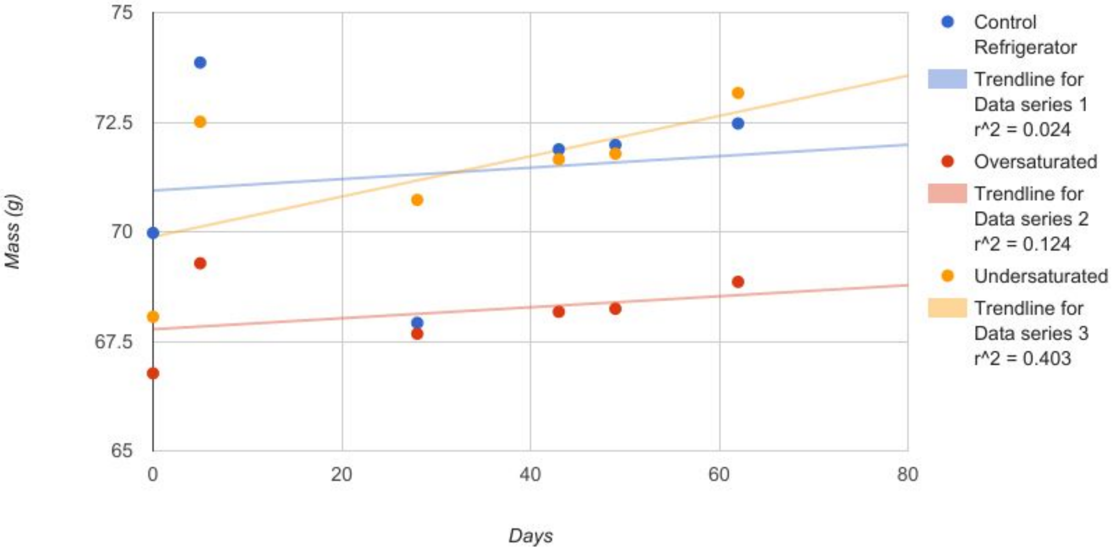


Table 1: Slopes from Line of Best Graphs from Mass Increase and Cracks in Concrete Samples

	Room Temperature			Refrigerator		
	Control	Undersaturated	Saturated	Control	Undersaturated	Saturated
Mass (g)	0.023	0.07	0.075	0.013	0.046	0.013
Cracks	0.024	0.0814	0.391	0.048	0.467	0.0146

Figure 3: Average Number of Cracks In Refrigerator - Concrete Samples Over Data Collection Period

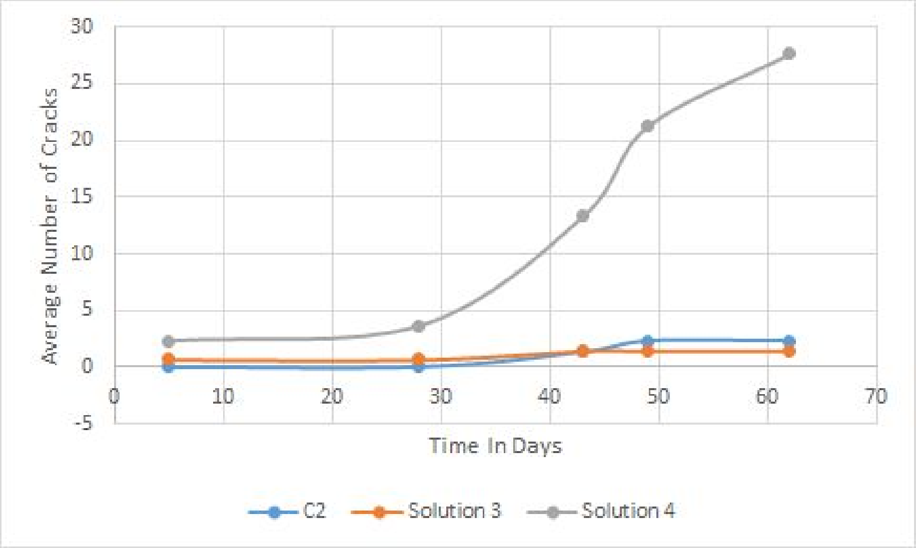


Figure 4: Average Number of Cracks in Room Temperature - Concrete Samples Over Data Collection Period

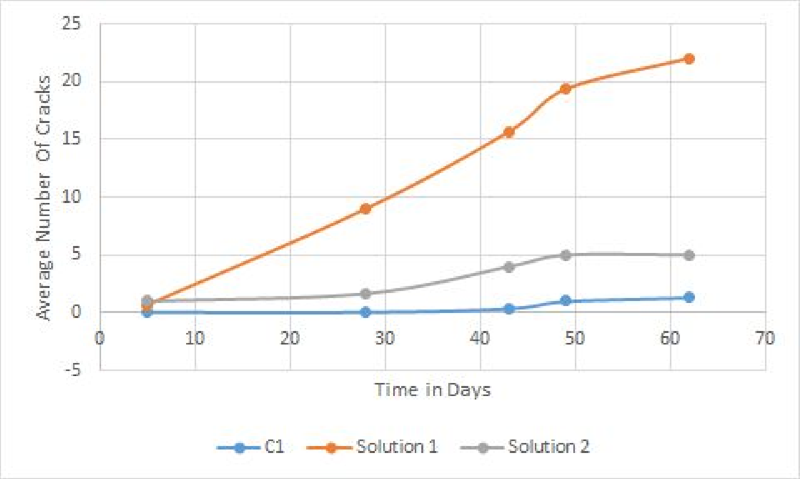


Figure 5: Average Number of Hits to Concrete Samples - Room Temperature

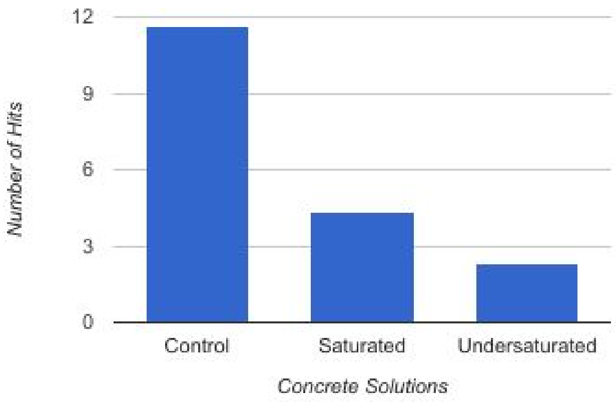


Figure 6: Average Number of Hits to Concrete Samples - Refrigerator

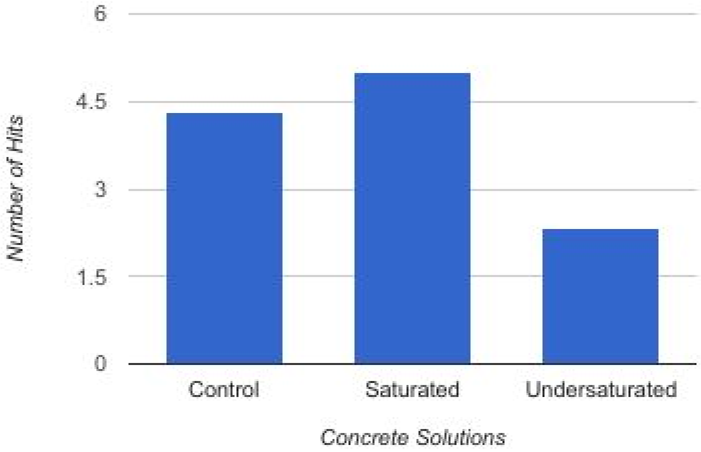


Table Two: Rebar Data

	Control Room Temperature (C1)	Control Refrigerator (C2)	Solution 1	Solution 2	Solution 3	Solution 4
Average Decrease in Mass (g)	.1597	.0344	.1978	.1544	.0654	1.946
Rebar Observations	Bit rusty, some residue,	Some rust, no bumps,	Little to no rust,	Very rusty, bumpy,	Some rust, no bumps,	Very rusty, white salty

	no bumps	little residue	bumpy	white patches	no residue	residue,
Concrete on Rebar	Some concrete stuck to rebar	None	Little to none	Very little to none	None	Little to none

Discussion:

It is hypothesized the $MgCl_2$ penetrated the concrete, causing a buildup of brucite ($Mg(OH)_2$) on the concrete samples, thereby decreasing the mass as a result of cracking and flaking of the concrete samples. However, the concrete samples began to increase in mass over the data collection period. While the cracks on the concrete samples continued to increase, the mass did not decrease, because it was absorbing the salt solution. To determine the effects of brucite upon the concrete samples, further testing and observation would be done on the concrete samples. Consistent observation of the increase in cracks would allow further discovery of the build up of brucite. Fluctuation and changes in mass would be measured daily to determine the amount of buildup on the concrete samples and how it correlates to the amount of cracks.

All collected data showed no definitive pattern, revealing that no conclusion can be drawn about the effects of $MgCl_2$ with weight on concrete. The data in Table 1 displayed no clear correlation between amount of $MgCl_2$ and increase in mass; the undersaturated solutions tended to have the steepest slope, however it was hypothesized that the saturated solutions would undergo the most change, because the greater amount of salt in the solution, the more damage the salt could do. It was expected that the saturated solutions would penetrate the concrete more, therefore causing a greater change of mass. Additionally, the data on the average number of cracks in Figures 5 and 6 provided no conclusive results; in the refrigerated samples the control experienced more degradation than the saturated solution, while the saturated solution in the room temperature samples saw the greatest increase in average number of cracks. Although it was hypothesized that the saturated solutions in both the refrigerator and room temperature would undergo the most change in mass, because the higher concentration of salt would lead to quicker degradation, the data in Table 2 revealed no clear pattern; the saturated solutions experienced minor changes in mass, whereas the undersaturated solution in the refrigerator saw the greatest decrease in mass, but the undersaturated solution in room temperature's mass decreased very little.

The samples also varied in durability at the end of the data collection with no definitive pattern. Originally, it was expected that the control samples would be the most difficult to break, because they had no salt degrading the structural integrity, and then the undersaturated solutions would be easier to break than the saturated solutions, because they had less salt degrading the structural integrity. However, this was proved wrong as seen in Figures 5 and 6; the undersaturated solution was consistently the easiest to break and in Figure 6 the saturated solution was the hardest to remove the rebar from. It was hypothesized that the rebar samples in the saturated solutions would have corroded the most due to the higher salt concentration in the solutions, however Table 2 indicates that there was minimal change in rebar mass following data collection. The undersaturated refrigerator solution showed an average mass change of 1.946 grams which is significantly higher than the average mass changes of the other solutions that were all below one gram. The rebar within the undersaturated refrigerator sample was not expected to undergo a serious decrease in mass, however, the large decrease indicates that the metal showed a large amount of rusting, which did not correlate with the hypothesis that the undersaturated solution would experience a significant decrease in mass.

In future experiments, prolonged testing and scheduled data collection would allow a more structured experiment, ultimately providing more accurate data. Additionally, testing more types of salt, including NaCl and $CaCl_2$, would further expand data on the overall effects of salts and weight on concrete.

References

The Deleterious Chemical Effects of Concentrated Deicing Solutions on Portland Cement Concrete. (2008, April). Retrieved from Michigan Tech Transportation Institute website: http://www.sddot.com/business/research/projects/docs/SD2002-01_Final_Report_Final.pdf

Mussato, B. T., Gepraegs, O. K., & Farden, G. (2004). *Relative Effects of Sodium Chloride and Magnesium Chloride on Reinforced Concrete*. Washington DC: National Research Council.

Reinforced Concrete. (2017). Retrieved March 30, 2017, from http://www.cement.org/concrete-basics/buildings-structures/design-aids/reinforced-concrete

Scientific principles. (n.d.). Retrieved May 8, 2017, from MAST website: http://matse1.matse.illinois.edu/concrete/prin.html

Sumison, E. S., & Gutherie, W. S. (2013, July). *Physical And Chemical Effects of Deicers on Concrete Pavement: Literature Review*. Retrieved from Utah Department of Transportation Research Division website: https://www.udot.utah.gov/main/uconowner.gf?n=8081525197623431

Appendix

Independent Variable: change in temperature (different amount of $MgCl_2$)
Dependent Variable: concrete strength and change in mass
Negative Control: room temperature
Control Variables:

a. Temperature
b. Amount of salt
c. Weight on top of concrete
d. length/amount of rebar
e. Amount of concrete
f. Amount of time concrete is exposed to salt solution

Materials list:

a. Concrete
b. Dixie cups
c. 18 oz (532 ml) plastic cups

d. Refrigerator
e. Water
f. $MgCl_2$
g. Thermometers
h. Rebar
i. 500 mL Volumetric flask
j. Brick (11339.8 g) weight

Safety Concerns:

a. Wear goggles to protect from $MgCl_2$. Can cause redness.
b. Do not consume solution ($MgCl_2$) or concrete
c. If $MgCl_2$ gets on skin, it can cause irritation. Wash hands after exposure.
d. Wear rubber gloves when handling solution, because it is extremely exothermic.

Procedure:

1. Following the Reinforced Concrete Sample Development, make 18 of the Concrete Sample Mold Type 1.
2. Measure the mass of the rebar and record in the data table
3. Make concrete and pour into 18 3 oz. paper cups, adding ¾ in. bars of rebar to all of the 3oz. paper cups.
4. Let the concrete dry and remove from 3oz paper cups.
5. Measure the mass of the concrete and record in the data table.
6. Make Solution One: This will be the saturated room temperature concrete sample.
   a. Weigh out 273 g of $MgCl_2$ in a weigh boat using the electric balance.
   b. Add the $MgCl_2$ to a 500 mL volumetric flask.
   c. Add distilled H_2O slowly into the volumetric flask while swirling until the solute has dissolved.
7. Make Solution Two: This will be the undersaturated room temperature concrete sample.
   a. Weigh out 150 g of $MgCl_2$ with the electric balance.
   b. Add $MgCl_2$ to a 500 mL volumetric flask.
   c. Add distilled H_2O slowly into the volumetric flask while swirling until the solute has dissolved.
8. Make Solution Three: This will be the saturated refrigerator (15℃) concrete sample. b

   a. Weigh out 270.5 g of $MgCl_2$ with the electric balance.
   b. Add the $MgCl_2$ to a 500 mL volumetric flask.
   c. Add distilled H_2O slowly into the volumetric flask while swirling until the solute has dissolved.

9. Make Solution Four: This will be the undersaturated refrigerator concrete sample.
   a. Weigh out 148.6 g of $MgCl_2$ with the electric balance.
   b. Add $MgCl_2$ to a 500 mL volumetric flask
   c. Add distilled H_2O slowly into the volumetric flask while swirling until the solute has dissolved.
10. Take Solution One and measure 100 ml of solution with a graduated cylinder and pour into three 532.3 mL cups. Add a concrete sample to each cup.
11. Take Solution Two and measure 100 ml of solution with a graduated cylinder and pour into three 532.3 mL cups. Add a concrete sample to each cup.
12. Take Solution Three and measure 100 ml of solution with a graduated cylinder and pour into three 532.3 mL cups. Add a concrete sample to each cup.
13. Take Solution Four and measure 100 ml of solution with graduated cylinder and pour into three 532.3 mL cups. Add a concrete sample to each cup.
14. Measure 100 mL of distilled water and pour into six 532.3 mL cups. Add a concrete sample to each cup.
15. Leave the concrete samples with Solution One and Two in room temperature (20℃) until next data collection to see short term effects of $MgCl_2$ on the integrity of concrete.
16. Take the concrete samples with Solution Three and Four in the refrigerator at a temperature of 15℃ until next data collection to see short term effects of $MgCl_2$ on the integrity of concrete at lower temperatures.
17. Take three of the concrete samples with 100 mL distilled water and place into the refrigerator at a temperature of 15℃ (C2) until next data collection to see short term effects of $MgCl_2$ on the integrity of concrete at lower temperatures.

18. Take the remaining three concrete samples with 100 mL distilled water and leave them in room temperature (20℃) (C1) until next data collection to see short term effects of $MgCl_2$ on the integrity of concrete.
19. Remove all concrete samples and solutions from the 532 mL cups
20. Place a standard red brick weight (5 pounds) on top of the three concrete samples from Solution One and record observations in data table.
21. Repeat step 20 for C1, C2, Solution Two, Three, and Four.
22. After 48 hours, observe changes to the concrete samples from Solution One and record in the data table. The time the weight is applied to the concrete samples is slightly longer to account for the reduced weight per sample across three samples (3x surface area).
23. Repeat step 22 with concrete samples from C1, C2, Solutions Two, Three, and Four.
24. Measure the mass of each concrete sample using the electronic balance. Record in the data table.
25. Repeat step 24 with concrete samples from C1, C2, Solutions Two, Three, and Four.
26. Return concrete samples into their respective 532.3 mL cups and locations until next data collection.
27. Once data collection is finished, take the concrete samples from C1 and place onto a flat surface. Take a hammer and strike until the rebar has clearly broken away from the concrete. Record the amount of strikes, rebar, and concrete observations in the data table.
28. Repeat step 27 with concrete samples from C2, Solutions Two, Three, and Four.

		Control Room Temperature (C1)	Control Refrigerator (C2)	Solution 1	Solution 2	Solution 3	Solution 4
Rebar Mass (g)	1	15.5970	22.0654	21.7684	19.4228	27.1681	25.3437
	2	23.6323	23.6447	27.6047	27.7288	19.4618	19.9804
	3	19.1515	25.9265	21.4733	28.4851	19.6838	19.0991
Cement	1	59.12	66.99	72.52	67.59	73.97	66.28

Mass (g) Before	2	60.16	61.66	70.9	79.5	66.1	72.16
	3	75.13	81.27	74.57	89.14	60.24	65.74
Cement Mass (g) After **Trial 1**	1	64.28	70.84	74.07	71.77	76.34	70.47
	2	64.48	65.33	73.82	84.06	68.65	76.69
	3	81.17	85.41	76.63	94.56	62.87	70.37
Number of Cracks	1	0	0	1	0	0	3
	2	0	0	0	2	1	2
	3	0	0	1	1	1	2
Observations	1	Powdery	Flakey, dry	Dry, flakey	Really salty, dry, powdery	flakey, dry	Flakey, dry
	2	Powdery, flakey	Flakey, dry	Dry, flakey	Really salty, powdery	Flakey, dry	Flakey, dry
	3	Powdery, flakey	Flakey, dry	Dry, flakey	Really salty, powdery	Flakey, dry	Flakey, dry
Cement Mass (g) After **Trial 2**	1	62.07	68.66	73.37	71.12	74.57	68.85
	2	62.71	**82.7**	74.68	83.28	66.77	74.84
	3	78.98	**63.07**	75.98	94.63	61.68	68.49
Number of Cracks	1	0	0	4	0	0	2
	2	0	0	16	4	1	3
	3	0	0	7	1	1	6
Observations	1	light gray, powdery	Powdery, light gray	Dark gray, some white residue on the bottom	Very, very salty	Dark gray, rough patches	Salty on the top
	2	Light gray,	Powdery,	Layer of	Lots of	Dark gray,	Salty on

		powdery, flat	light gray	white on top, residue on bottom, very cracked	white residue on bottom and top	rough	the top
	3	Light gray, powdery	Powdery, light gray	Gray, layer of white on top and bottom	Extremely salty	Dark gray, some white residue on bottom, a little dry and flakey	Salty on the top
Cement Mass (g) After **Trial 3**	1	62.38	68.97	74.49	71.76	74.99	69.76
	2	62.99	83.22	76.61	83.96	67.26	75.74
	3	78.87	63.45	77.34	95.74	62.27	69.46
Number of Cracks	1	0	1	9	0	2	12
	2	1	2	26	4	1	13
	3	0	1	12	8	1	15
Observations	1	Light grey, powdery	Light grey, a little powdery	Dark grey on bottom/sides, white powdery substance on top	Covered in brucite, white	Dark grey, some white specks, some rust	White, powdery, rusty
	2	Light grey, powdery	Light grey, a little powdery	Powdery, white all over, extremely cracked	Covered in brucite, white	Dark grey, some white specks on the bottom, some rust	White on top, grey on sides, white on bottom
	3	Light grey, powdery	Light grey, powdery on the top	Medium grey, powdery, rust patch on top	Covered in brucite, white	Dark grey, white specks on top,	White on top, powdery, light grey on sides

Cement Mass (g) After **Trial 4**	1	62.43	69.09	75.17	72	75.02	70.08
	2	63.06	83.34	77.28	84.1	67.31	75.61
	3	78.96	63.52	77.7	96.1	62.4	69.65
Number of Cracks	1	2	2	10	1	2	19
	2	0	2	28	4	1	24
	3	1	3	20	10	1	21
Observations	1	flakey , grey	Light grey, powdery	Grey, some brucite	Covered in brucite	Extremely bumpy, dark grey, tiny cracks	Brucite on top, dark grey on bottom
	2	Light grey, powdery	Light grey, powdery	Very cracked, light grey	Covered in brucite	Dark grey, bumpy, rusty	Some chipping
	3	Light grey, powdery	Light grey, powdery	Rust spots, grey powdery	Covered in brucite	Dark grey bumpy	Brucite on top, grey on bottom
Cement Mass (g) After **Trial 5**	1	62.84	69.53	76.79	72.96	75.58	71.39
	2	63.46	83.92	79.90	85.04	67.87	76.88
	3	79.47	63.97	78.96	97.4	63.12	71.23
Number of Cracks	1	2	2	12	1	2	34
	2	1	2	32	4	1	25
	3	1	3	22	10	1	24
Observations	1	Flakey, grey	Light grey, powdery	Grey, some brucite, powdery	Covered in brucite, very white	Extremely bumpy, dark grey, tiny cracks	Brucite on top, dark grey on bottom
	2	Light grey, powdery	Light grey, powdery	Very cracked, light grey,	Covered in brucite	Dark grey, bumpy, rusty	Some chipping

				white on bottom			
	3	Light grey, powdery	Light grey, powdery	Rust spots, grey, powdery	Covered in brucite	Dark grey bumpy	Brucite on top, grey on bottom

Rebar Samples

		Control Room Temperature (C1)	Control Refrigerator (C2)	Solution 1	Solution 2	Solution 3	Solution 4
Number of hits	1	20	7	3	2	9	1
	2	1	5	1	3	2	2
	3	14	1	3	9	4	4
Interior	1	White and grey splotches. Dry all over.	Wet. white spots. Rust around where rebar was	Wet, dry where rebar was	Wet and rusty. Rebar detached from concrete	Dry and rusty where rebar was. White splotches	Wet, dry where rebar was
	2	Wet inside. Rust spots. White splotches	Wet, dry where rebar was. Concrete is splotchy	Wet	Rusty. Salty. Rebar detached from concrete	Dry where rebar is. Red rust spots	Wet, dry where rebar was
	3	Dry inside, white splotches. Rust spots	Wet, dry where rebar was	Wet, dry where rebar was	Dry. rust spots. Rocks inside. Lighter gray on inside. Rebar detached from	Rebar is dry. Areas around rebar is dry	Wet

					concrete		
Rebar Observations	1	Rusty with gre residue. No bumps	Rusty, no bumps	Clean	Rusty. Greyish residue. Bumpy all over	Rusty. Some bumps. No white residue	Rusty. Rough texture. White salty residue
	2	Bit rusty, no bumps	Rusty. Small bit of grey residue	Very bumpy, white residue. Not a lot of rust.	Very rusty on ends. Bumpy. Alot white residue all over	Bumpy, not rusty. No residue	Rusty. Rougher texture. White salty residue
	3	Clean	Some rust. No bumps	Some rust on ends.	Large white rusty patch.	No bumps. Small amount of rust.	Rusty, bumby where rust is. Some white residue. White brucite formed
Final Mass	1	15.93	22.11	21.99	19.62	27.25	25.56
	2	23.69	25.96	27.92	27.81	19.54	25.53
	3	19.24	23.67	21.53	28.67	19.72	19.17
Concrete stuck to rebar?	1	A Lot of concrete	None	Small amount	Small amount	None	Small amount
	2	Tiny line	None	Small amount	None	None	Small amount
	3	Small amount	None	None	None	None	None