EcoConcrete – The search for and study of viability of ecofriendly alternative to current highly-energy intensive and carbon-positive cement production

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Abstract

Cement production is responsible for eight percent of all the carbon dioxide that humans put into the atmosphere every year. The reason is that Calcium Oxide, the main ingredient of Portland cement, is obtained by heating limestone at 2,200 degrees Fahrenheit. No directs ores of Calcium Oxides exist and do not have a choice. This project took a comprehensive look at the periodic table and searched for alternate cementitious materials that are viable and eco-friendly at the same time. While several candidates were initially identified, Magnesium was identified as the single best alternative element. Many of the other candidates were found not to be practical due to factors such as cost, toxicity, relative abundance, presence of natural ores, ease of mining access, among others. In the next step of the project, analogous Chloride, Sulphate, and Phosphate were studied as possible cementitious counterparts. Magnesium Chloride was identified to be the best alternative. Some additives were tried to improve the tensile, compressive. and flexural properties of the concrete samples. Then, a water resistance study revealed a chloride leaching problem. Binding materials were tried, and Slag was found to improve water resistance. Possible direct sources and indirect non-carbonate sources of Magnesium Oxide were identified. The project showed that Magnesium based cement could be a viable eco-friendly alternative and could play a significant role in the future of construction materials.

Rationale

Commercial cement contains about 5% Ferric Oxide, 6% Aluminium Oxide, 22% Silicon Dioxide, 7% Calcium Sulfate, and the rest, about 60% is Calcium Oxide. The Calcium Oxide comes from heating limestone that is mined from open quarries. The limestone is heated to more than 2200 Degrees F. The Calcium Carbonate in limestone decomposes to Calcium Oxide and Carbon Dioxide. Every year, 4.4 billion tons of concrete is made, and it is projected to increase to 5.5 billion tons per year as developing nations industrialize. So, the preparation of Concrete generates about 2.5 billion tons of Carbon Dioxide. Cement is generally created by mixing Calcium Oxides with Calcium Sulfate, or other compounds. When the cement is hydrated, it combines with Silicon Dioxide to make several kinds of compound crystals that interlock with each other to create the strong structure that we associate with concrete.

Several Group II elements are similar to Calcium chemically and often create analogous compounds. Some transition elements like Zinc and post-transition elements like Aluminium also present some similarity in analogous compounds. So, there must be other candidates for an ecofriendly alternative to Portland cement.

Societal Impact

Calcium Oxide is made primarily from Limestone by heating it and expelling Carbon Dioxide. Calcium Oxide does not occur naturally. However, Magnesium Oxide occurs naturally as Periclase. Magnesium Hydroxide exits naturally as Brucite. Zinc Oxide occurs as Zincite and together with other elements as Franklinite and Calamite. Magnesium Oxide can also be made by heating Brucite with is Magnesium Hydroxide. Heating it would produce just steam and not a greenhouse gas like Carbon Dioxide. If Magnesium concretes became mainstream, it will lead to a huge reduction in the amount of Carbon Dioxide we put into the atmosphere - possibly the entire 2.5 billion tons that we pump into the atmosphere for cement production could be done away with.

Hypothesis

The hypothesis is that we should be able to make cements (with at least limited use) using other Group II elements or neighboring elements with similar properties.

Research Questions

1. What will be the composition of the ingredients that will make the concrete with the highest tensile and flexural strength?
2. What composition will lead to highest compressive strength?
3. Will the concrete leach out over time?
4. Will it preserve strength underwater?

Goal

To make commercially viable or special use concrete that can be made from raw materials in an environmentally friendly way and still have tensile, compressive and flexural strength comparable to regular Calcium based concrete.

Procedure

The elements the periodic table were analyzed systematically to find candidate elements for the alternative cement, based on cost, abundance, crystal strength, toxicity, among others. 13

candidates were identified. They were further analyzed and Magnesium was identified as the best candidate.

1. Find which of Magnesium Oxide – Chloride/Sulfate/Phosphate cements is the best.
    a. Mix Magnesium Oxide with Magnesium Chloride and Silicon Dioxide
    b. Start with 50% Magnesium Oxide and vary Silicon Dioxide and Magnesium Chloride concentration in steps or 5% with Magnesium Chloride percentage between 5 and 25%
    c. Find strength of concrete in each of the sample cores created in previous steps.
        i. Compressive strength
        ii. Tensile strength
        iii. Flexural strength
    d. Repeat Steps 1a to 1c with Magnesium Sulfate instead of Magnesium Chloride.
    e. Repeat Steps 1a to 1c with Magnesium Phosphate instead of Ammonium Phosphate Monobasic
2. Find if addition of Ferric Oxide or Aluminium Oxide or both improve strength of best candidate from Step 1.
    a. Add 2.5 % Iron III Oxide to 50% Magnesium Oxide, 30% Silicon Oxides, 17.5% Magnesium Chloride
    b. Add 2.5 % Aluminium Oxide to 50% Magnesium Oxide, 30% Silicon Oxides, 17.5% Magnesium Chloride
    c. Add 2.5 % Iron III Oxide and 2.5 % Aluminium Oxide to 50% Magnesium Oxide, 27.5% Silicon Oxides, 17.5% Magnesium Chloride
    d. Find strength of concrete in each of the sample cores created in steps 2a-c.
        i. Compressive strength
        ii. Tensile strength
        iii. Flexural strength
3. Test for participles of raw cement in the cured concrete
    a. Use large quantity of the best cement from Step 3.
    b. Shape the concrete to maximize the surface area.
    c. Leave it in warm water for more than 3 days.
    d. Use water test strip to check for presence of chloride or iron in water.
4. Find if addition of slag and/or fly ash to Magnesium Oxide – Chloride – Ferric Oxide cement will increase strength and water resistance. Prepare samples with composition listed below and compare it with Magnesium Oxide - Silicon Dioxide - Magnesium Chloride – Ferric Oxide from previous step.
    a. Add 2.5 % Slag to 50% Magnesium Oxide, 27.5% Silicon Oxides, 17.5% Magnesium Chloride, 2.5 Ferric Oxide
    b. Add 2.5 % Fly Ash to 50% Magnesium Oxide, 27.5% Silicon Oxides, 17.5% Magnesium Chloride, 2.5 Ferric Oxide

c. Add 2.5 % Slag and 2.5% Fly Ash to 50% Magnesium Oxide, 25% Silicon Oxides, 17.5% Magnesium Chloride, 2.5 Ferric Oxide
d. Find strength of concrete in each of the sample cores created in steps 2a-c.
   i. Compressive strength
   ii. Tensile strength
   iii. Flexural strength
e. Test all the samples in water.

Data

Step 1:

Tensile Strength

		7%	10%	15%	20%	25%
MPA	Portland	3				
	MgO-MgCL2		2.9	3.1	3	2.7
	MgO-MgSO4		2.3	2.4	2.5	1.9
	MgO-NH4HPO4		1.9	2.3	2.4	1.6

PSI		7%	10%	15%	20%	25%
	Portland	435				
	MgCL2		420.5	449.5	435	391.5
	MgSO4		333.5	348	362.5	275.5
	NH4HPO4		275.5	333.5	348	232

Compressive Strength

MPA		7%	10%	15%	20%	25%
	Portland	26				
	MgO-MgCL2		23	27	26	21
	MgO-MgSO4		22	25	23	23
	MgO-NH4HPO4		19	22	16	11

PSI

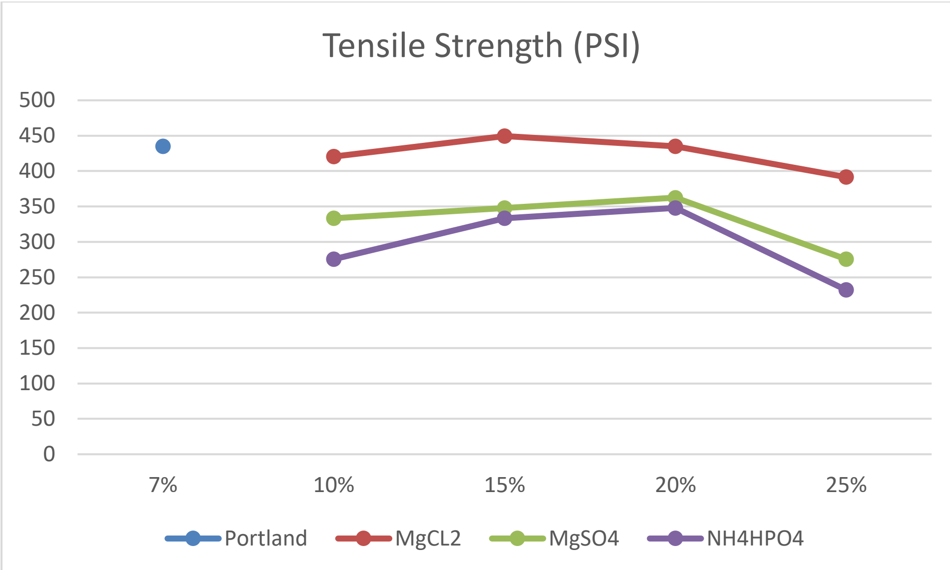
		7%	10%	15%	20%	25%
	Portland	3770				
	MgCL2		3335	3915	3770	3045
	MgSO4		3190	3625	3335	3335
	NH4HPO4		2755	3190	2320	1595

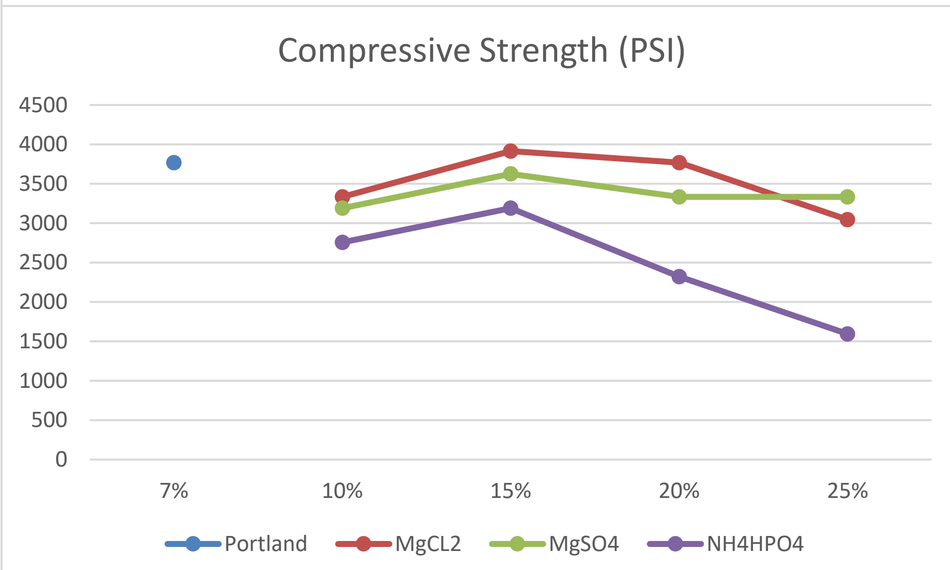
Flexural Strength

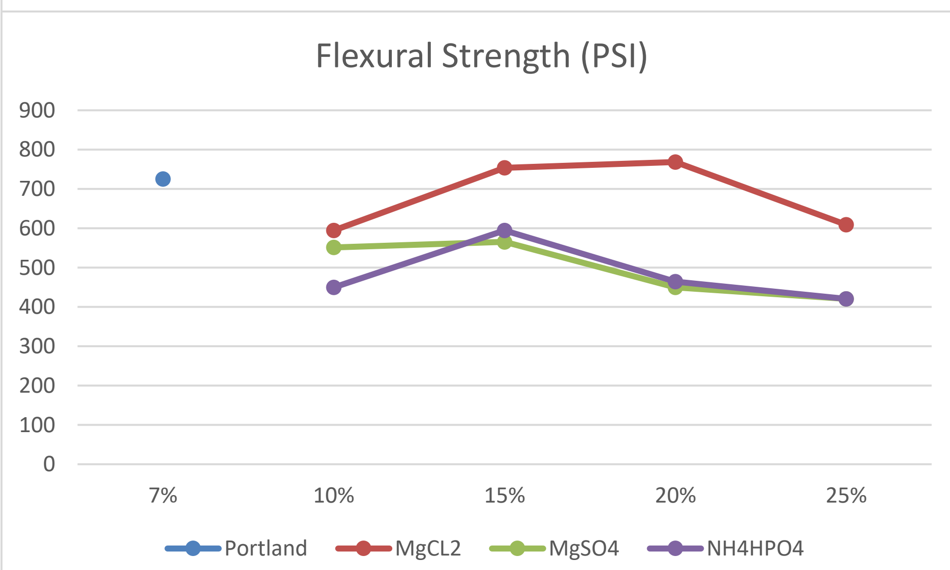
MPA		7%	10%	15%	20%	25%
	Portland	5				
	MgO-MgCL2		4.1	5.2	5.3	4.2
	MgO-MgSO4		3.8	3.9	3.1	2.9
	MgO-NH4HPO4		3.1	4.1	3.2	2.9

PSI

		7%	10%	15%	20%	25%
	Portland	725				
	MgCL2		594.5	754	768.5	609
	MgSO4		551	565.5	449.5	420.5
	NH4HPO4		449.5	594.5	464	420.5


Tensile Strength (PSI)
500
450
400
350
300
250
200
150
100
50
0
7%
10%
15%
20%
25%
Portland
MgCL2
MgSO4
NH4HPO4


Compressive Strength (PSI)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
7%
10%
15%
20%
25%
Portland
MgCL2
MgSO4
NH4HPO4


Flexural Strength (PSI)
900
800
700
600
500
400
300
200
100
0
7%
10%
15%
20%
25%
Portland
MgCL2
MgSO4
NH4HPO4

Step 2:

Compression Test

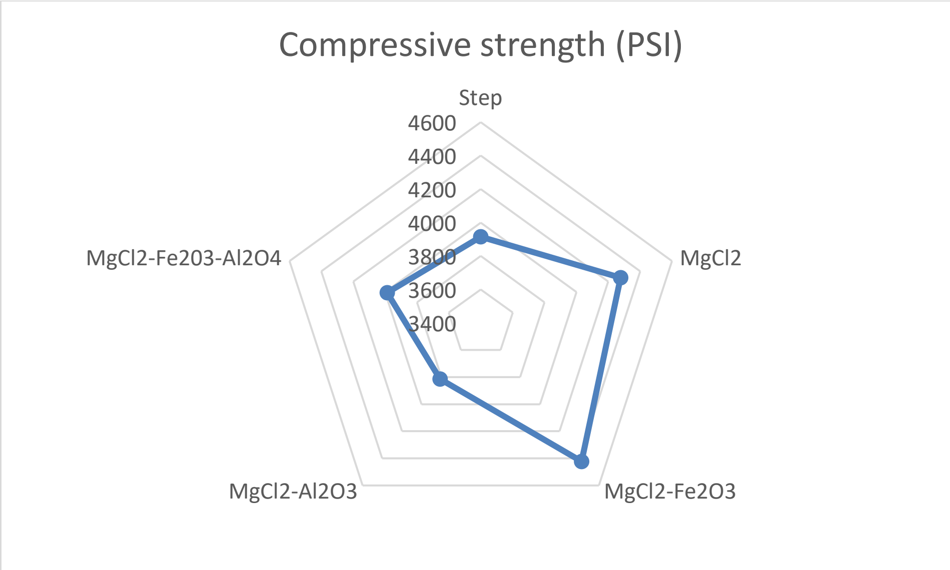
Step	**PSI**	MPa
MgCl2	4278	29.5
MgCl2-Fe2O3	4423	30.5
MgCl2-Al2O3	3814	26.3
MgCl2-Fe203-Al2O4	3988	27.5

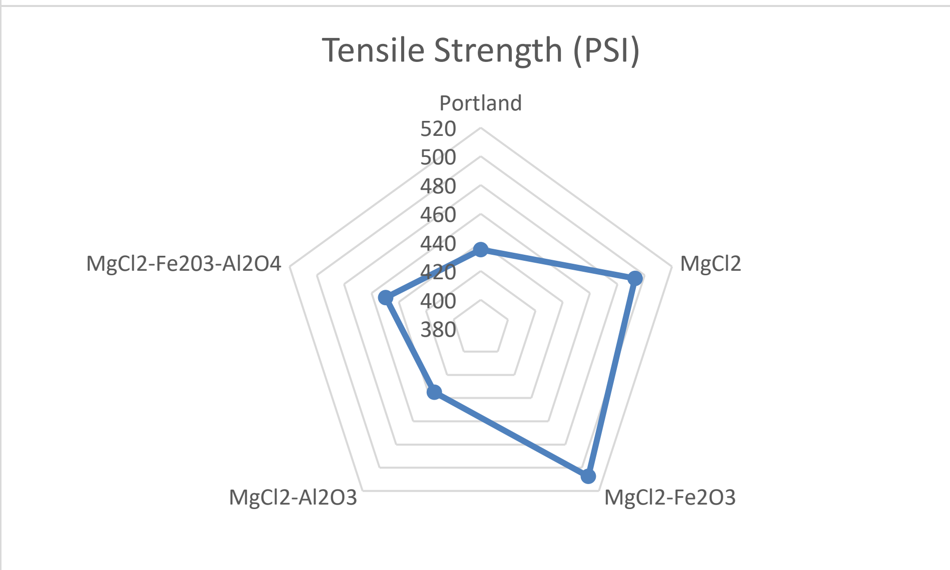
Tensile Test

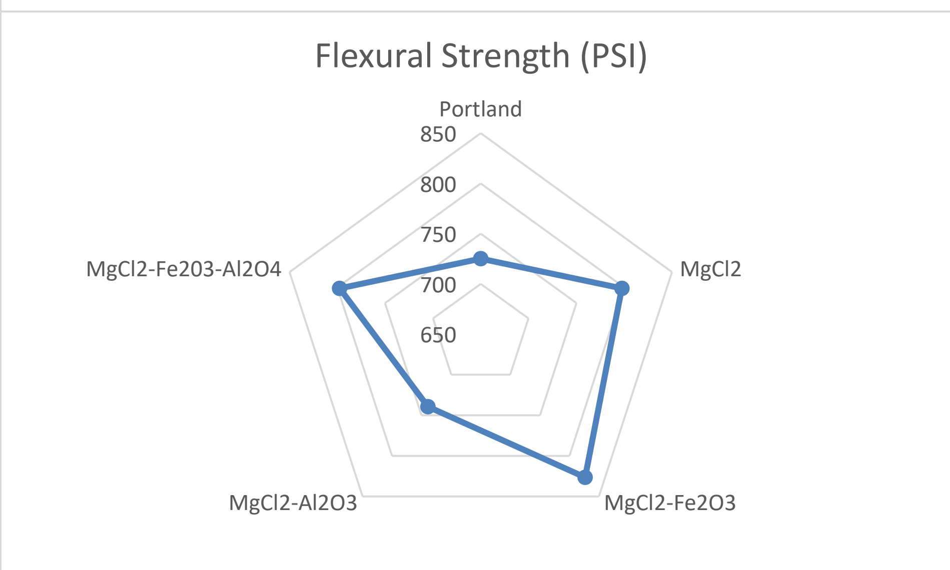
Portland	435	3
MgCl2	493	3.4
MgCl2-Fe2O3	508	3.5
MgCl2-Al2O3	435	3
MgCl2-Fe203-Al2O4	450	3.1

Flexural Test

Portland	725	5
MgCl2	798	5.5
MgCl2-Fe2O3	827	5.7
MgCl2-Al2O3	740	5.1
MgCl2-Fe203-Al2O4	798	5.5


Compressive strength (PSI)
Step
4600
4400
4200
4000
3800
3600
3400
MgCl2
MgCl2-Fe2O3
MgCl2-Al2O3
MgCl2-Fe203-Al2O4


Tensile Strength (PSI)
Portland
520
500
480
460
440
420
400
380
MgCl2
MgCl2-Fe2O3
MgCl2-Al2O3
MgCl2-Fe203-Al2O4


Flexural Strength (PSI)
Portland
850
800
750
700
650
MgCl2
MgCl2-Fe2O3
MgCl2-Al2O3
MgCl2-Fe203-Al2O4

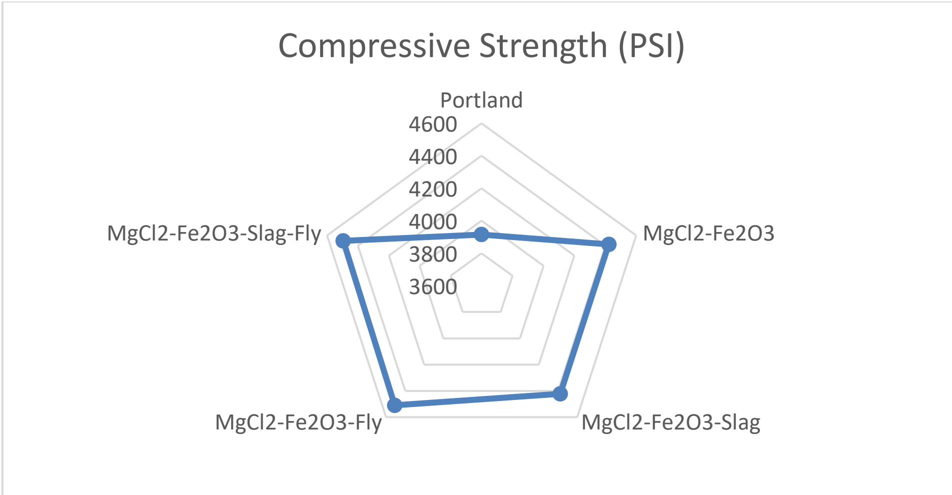
Step 3: Water test found chloride leach

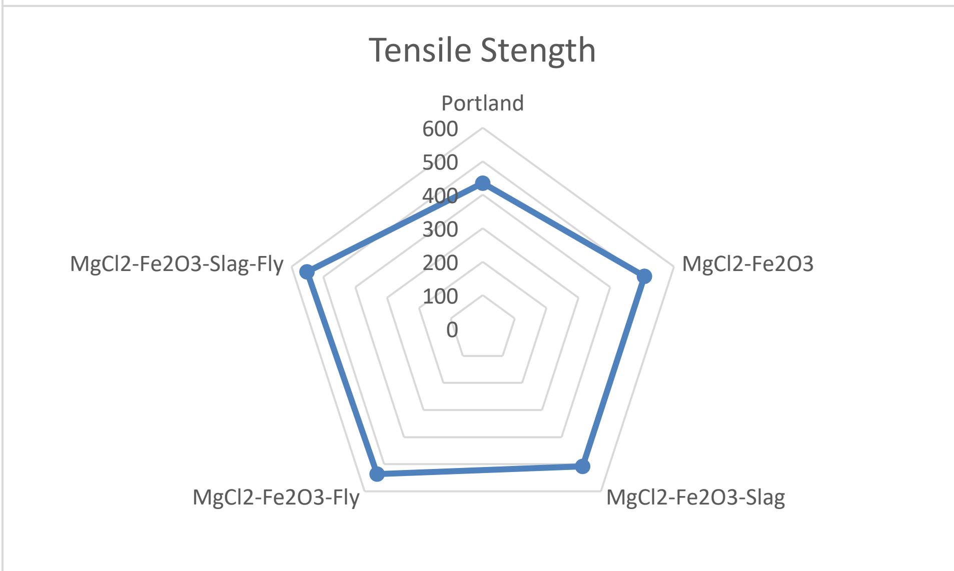
Step 4:

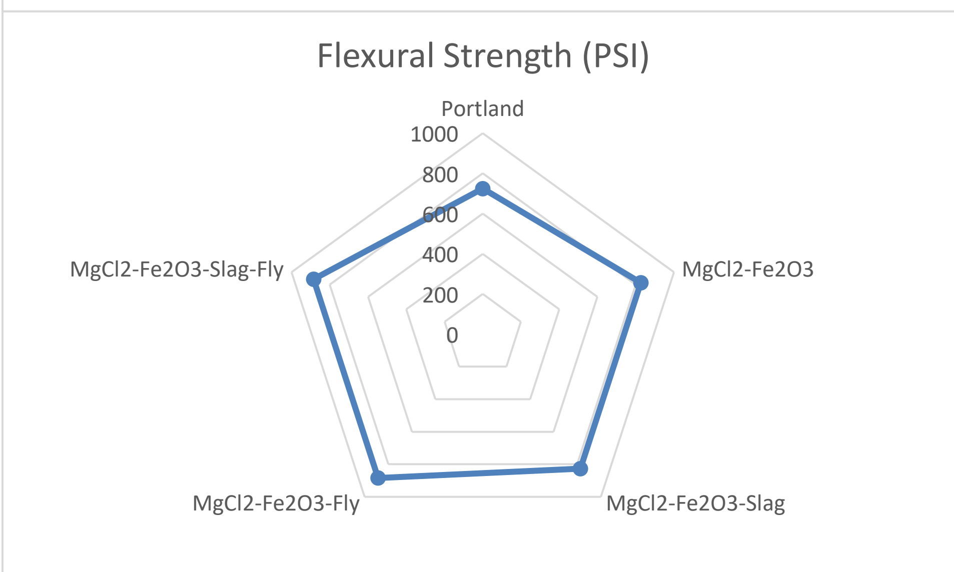
Compression Test	**PSI**	MPa
Portland	3915	27
MgCl2-Fe2O3	4423	30.5
MgCl2-Fe2O3-Slag	4423	30.5
MgCl2-Fe2O3-Fly	4510	31.1
MgCl2-Fe2O3-Slag-Fly	4495	31

Tensile Strength	**PSI**	MPa
Portland	435	3
MgCl2-Fe2O3	508	3.5
MgCl2-Fe2O3-Slag	508	3.5
MgCl2-Fe2O3-Fly	537	3.7
MgCl2-Fe2O3-Slag-Fly	551	3.8

Tensite Stength	**PSI**	MPA
Portland	725	5
MgCl2-Fe2O3	827	5.7
MgCl2-Fe2O3-Slag	827	5.7
MgCl2-Fe2O3-Fly	885	6.1
MgCl2-Fe2O3-Slag-Fly	885	6.1


Compressive Strength (PSI)
Portland
4600
4400
4200
4000
3800
3600
MgCl2-Fe2O3
MgCl2-Fe2O3-Slag
MgCl2-Fe2O3-Fly
MgCl2-Fe2O3-Slag-Fly


Tensile Stength
Portland
600
500
400
300
200
100
0
MgCl2-Fe2O3
MgCl2-Fe2O3-Slag
MgCl2-Fe2O3-Fly
MgCl2-Fe2O3-Slag-Fly


Flexural Strength (PSI)
Portland
1000
800
600
400
200
0
MgCl2-Fe2O3
MgCl2-Fe2O3-Slag
MgCl2-Fe2O3-Fly
MgCl2-Fe2O3-Slag-Fly

Data and Analysis

$$\text{Tensile Strength (Pa)} = \frac{Force}{Length \ * Breadth}$$

$$\text{Compressive Strength (Pa)} = \frac{Force\ (N)}{Length \ * Breadth}$$

$$\text{Flexural Strength (Pa)} = \frac{3 * Force * Length}{2 * Width * Depth^2}$$

$$\text{Strength (PSI)} = Strength\ (Pa) * 6894.76$$

Step 1: Tensile, Compressive and Flexural Strength will be calculated for Magnesium Chloride, Magnesium Sulfate and Ammonium Phosphate cement with Magnesium Chloride, Magnesium Sulfate and Ammonium Phosphate concentrations 10%, 15%, 20% and 25%.

Step 2: Tensile, Compressive and Flexural Strength will be calculated for samples without Ferric Sulfate, Aluminium Oxide and both.

Step 3: Water Test involves not calculation.

Step 4: Tensile, Compressive and Flexural Strength will be calculated for samples without Slag, Fly Ash and both.

Results

0. Element Search
   a. Magnesium was found to be best alternate to Calcium cement.
1. Compound Search
   a. Magnesium Oxide with Magnesium Chloride was found to be the best among Magnesium Chloride, Magnesium Sulfate and Ammonium Monophosphate and all three counts.
   b. Magnesium Chloride at 17.5% was selected based on Step 1 results. Magnesium oxide was 50% and Silicon Dioxide was 32.5%.
      i. Tensile
      ii. Compression
      iii. Flexural
2. Additive Search
   a. Ferric Oxide improved strength
   b. Aluminium Oxide reduced strength.
3. Water Test
   a. While no Iron was found
   b. No Magnesium was found
   c. Chloride was found to be leaching into the water.
4. Binder Search
   a. Fly ash improved strength.
   b. Slag stopped Chloride leaching.

Final samples displayed significant strength when compared with regular concrete.

Best composition was found to be 50% Magnesium Oxide, with 25% Silicon Dioxide, 17.5% Magnesium Chloride, 2.5% Ferric Oxide, 2.5 % Slag and 2.5 % Fly Ash

Tensile strength for the sample was around 540 PSI.

Flexural strength for the sample was round 850 PSI.

Compressive strength for the sample was around 4500 PSI.

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