EcoConcrete - The search for and study of a viable alternative to highly energy-intensive and carbon-positive Portland cement

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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 - so we 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.

The Problem

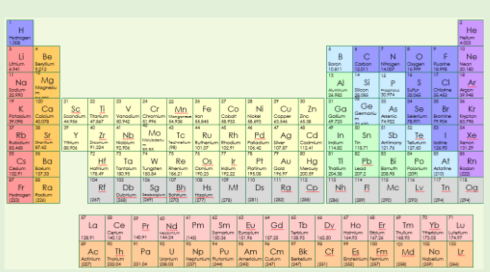
Currently 4.4 billion tons of concrete is manufactured in the world every year and it is projected to go up to 5.5 billion tons as developing nations industrialize. Commercial Cement, called Portland Cement, is mostly Calcium Oxide (60%). Calcium Oxide is made by heating limestone ($CaCO_3$) which produces **Carbon** Dioxide ($CaCO_3$ + heat → $CaO + CO_2$). Just the making of concrete puts 2.5 billion tons of Carbon Dioxide into the atmosphere every year. That is 8% of all the Carbon Dioxide that we put into the atmosphere every year comes from making of cement and its use!

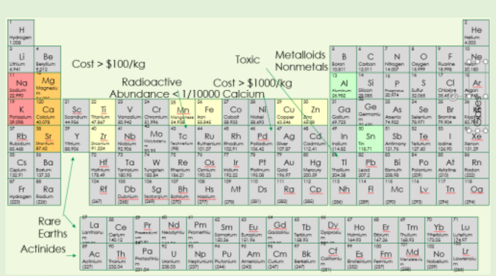
Hypothesis

There are several kinds of cements, but they are all generally large quantities of Metal Oxides mixed with Chlorides, Sulfates or Phosphates with some additives to change some properties of the concrete. My 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.

Potential Candidates

Candidates were identified based on relative abundance, availability of ores, price, easy of mining, strength of crystals formed, radioactivity and toxicity.



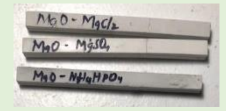


Images by Muhil

- Calcium
- Aluminium, Iron-Used as additive, not strong by itself
- Titanium-Used as additive in top layers, for photocatalytic properties
- Manganese-Researched as additive
- Zirconium, Copper and Strontium are used in dental cement
- Potassium-Its oxide is too reactive
- Sodium-Corrosive to concrete
- Tin-Chlorides, Sulfates and Phosphates are hazardous
- Zinc-Its chloride is hazardous; its phosphate is used for dental cements and is expensive.
- Magnesium is the best candidate. Its oxide can come from non-carbonate ores.

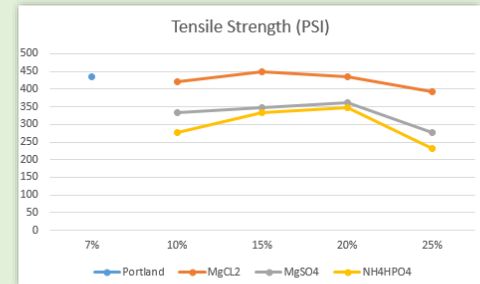
Step 1 – Magnesium Chloride/Sulfate/Phosphate

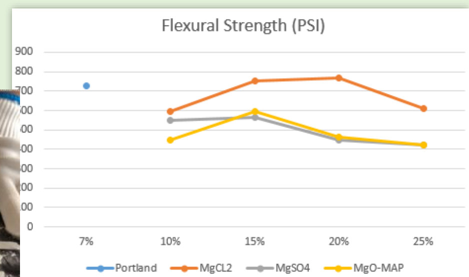
Found which of Magnesium Oxide – Chloride/Sulfate/Phosphate cements is the best.

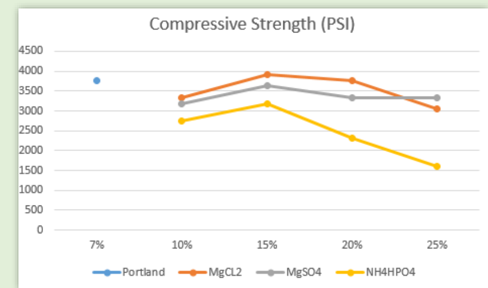


Samples by Muhil

- Magnesium Oxide – Magnesium Chloride cement is the best performer of the three
- The performance is comparable or better than that of regular Portland Cement
- Composition for next step will be 17.5% Magnesium Chloride







Compression Text, Photo by Muhil

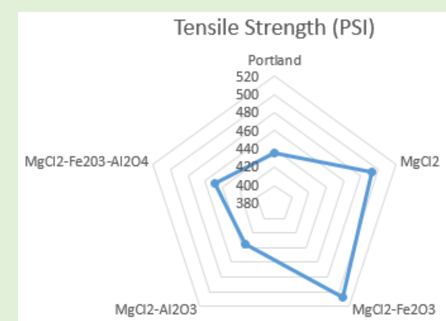
Graphs by Muhil

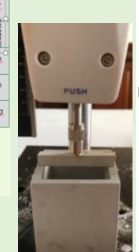
Step 2-Additives

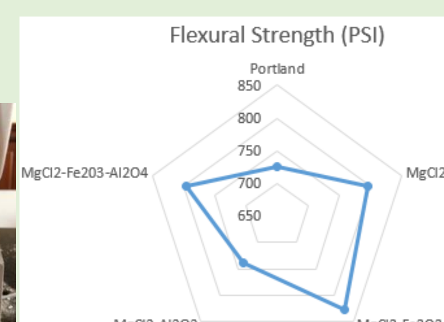
Found if addition of additives to Magnesium Oxide-Chloride- Ferric Oxide cement will increase strength and water resistance.

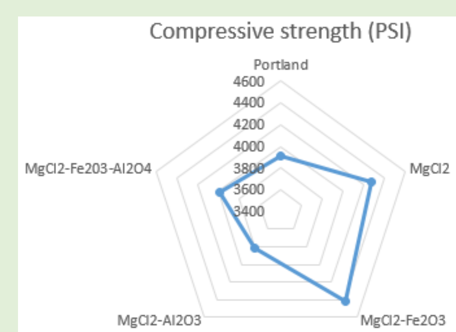
Samples by Muhi

- Ferric Oxide improved strength
- Magnesium Oxide-Magnesium Chloride with Ferric Oxide did better than Portland Cement and Magnesium Oxide – Magnesium Chloride by itself
- Compression Strength improved the most









Flexural Text, Photo by Muhil

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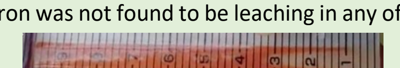
Step 3

Concrete samples were water tested. Iron was not found to be leaching in any of the samples. Chloride was found leaching in the water.



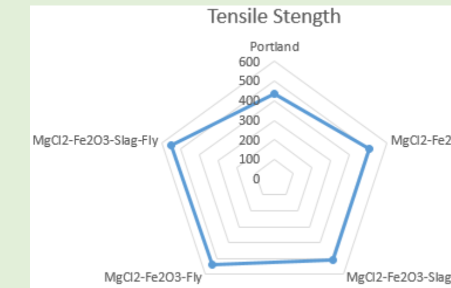
Chloride Ion Text, Photo by Muhil

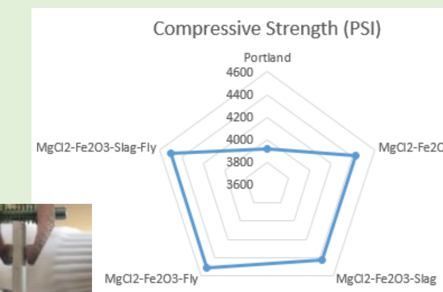
Step 4-Binders

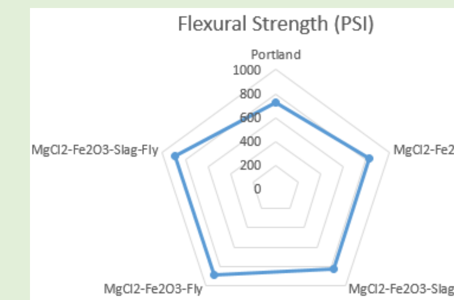
Found if addition of binders to Magnesium Oxide-Chloride-Ferric Oxide cement will increase strength and water resistance.

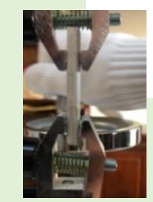
Samples by Muhil

- Addition of Fly Ash increased strength
- Addition of Slag decreased Chloride leaching
- Addition of both to Magnesium Oxide-Chloride-Ferric Oxide cement produced the best combination









Tensile Text, Photo by Muhil

Graphs by Muhil

Chloride Ion Text, Photo by Muhil

Final Results

Final samples displayed significant strength when compared with regular concrete. Best composition was 50% Magnesium Oxide, 25% Silicon Dioxide, 17.5% Magnesium Chloride, 2.5% Ferric Oxide, 2.5 % Slag and 2.5 % Fly Ash

1. Tensile strength was around 540 PSI
2. Flexural strength was round 850 PSI
3. Compressive strength was around 4500 PSI

Final samples Photo by Muhil

Conclusion

This project demonstrated that alternatives to regular cement can be ecologically friendly. Magnesium Oxide can be produced without carbonate ores – Magnesium Oxide can come directly from Periclase or by heating Brucite (releases water). Even if it was obtained by heating Magnesium Carbonate, it would have to be heated only to half the temperature as Limestone. So, more research is needed in Magnesium based cements – they certainly deserve a much bigger part in our future!

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