Analyzing More Sustainable Alternatives Than Using Ordinary Portland Cement in Commercial Construction

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The purpose of this paper is to look at more sustainable alternative options for concrete use for California Commercial Contractors. This paper will analyze the more sustainable options for concrete and come to conclusions on how effective the alternative options are for protecting the environment, encouraging sustainability, maintaining cost effectiveness, and maintaining efficiency in building. This paper provides data on the negative impact concrete use has had on the environment and potential ways to alleviate this. This paper will also analyze how cost-effective the alternative options are to see if the alternative options are realistic and affordable to use in place of Ordinary Portland Cement. Advantages and disadvantages of potentially switching to a more sustainable option for concrete building will be discussed and analyzed. This paper will provide data on the negative impact that concrete use has had on the environment through CO_2 emissions and the termination of our resources. This is mainly from Portland Cement, which is made from chalk and clay. Through research, this paper will draw conclusions regarding whether switching to a more sustainable option for California Commercial Contractors is worth it for the contractors, given the convenience, sustainability, effectiveness, and cost.

Keywords: Concrete, Sustainability, Environment, Ferrock, Geopolymer, Cement.

Introduction

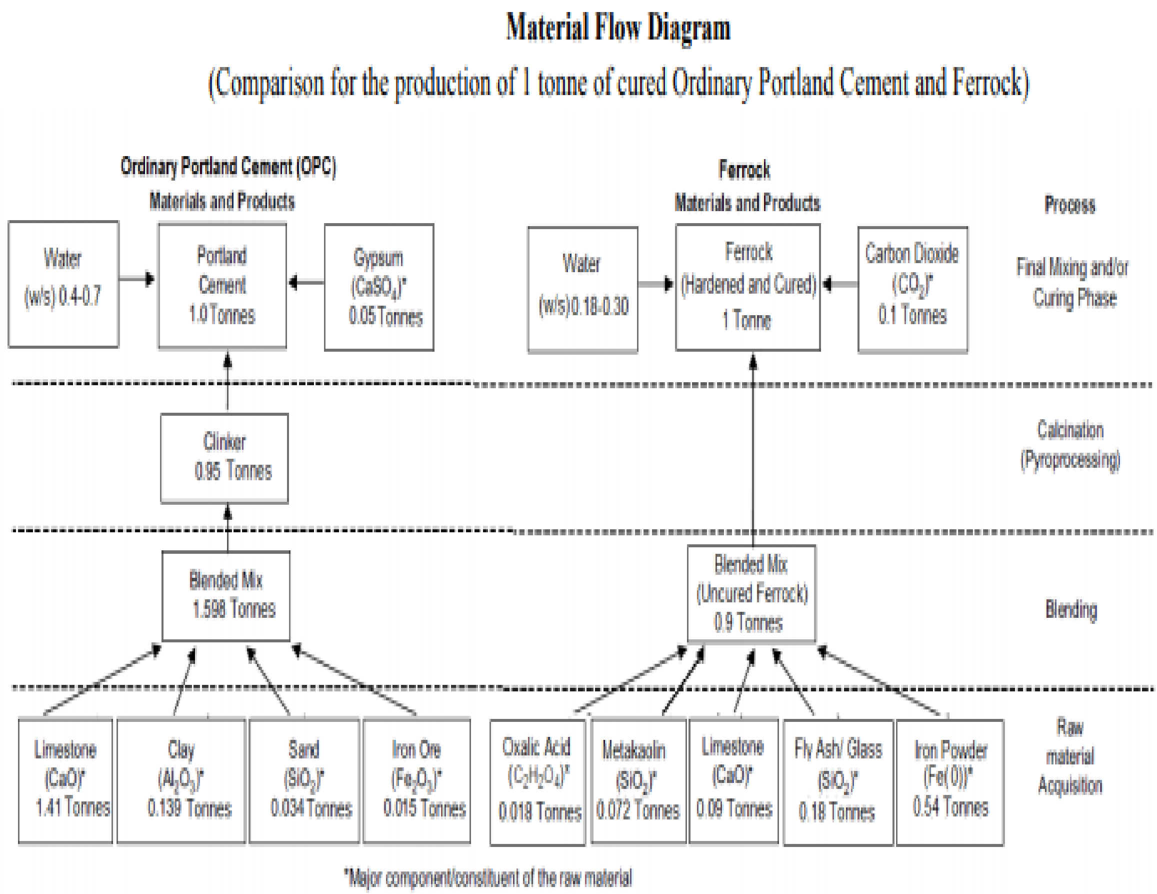
Background Information

After water, concrete is the most widely used substance on Earth (Watts 2019). Annually around 10 billion metric tons of concrete, mostly Ordinary Portland Cement, are produced worldwide with over 500 million tons in the United States alone (Assi 2018). Production is expected to reach two billion metric tons of concrete in the United States by 2050, which is four times higher than in 1990. All this Ordinary Portland Cement production is greatly harmful for the environment and is responsible for 7% of worldwide CO_2 emissions. Cement production is the third ranking producer of man-made CO_2 after transportation and energy generation (Kenai 2015). As population increases, building increases, and the supply of quality limestone used to produce cement decreases. It is possible that some regions will run out of quality limestone and there will be no more Ordinary Portland Cement. This would cause a huge damage to the concrete industry, which will directly affect all the jobs and money it produces. Ordinary Portland Cement would also greatly rise in price when its accessibility becomes more difficult. This would have a great negative affect on the construction industry as a whole unless contractors find a worthy alternative. Due to this and the elevation of CO_2 emissions, scientists have developed alternative and more sustainable concrete and cement options.

Literature Review

Ferrock Concrete

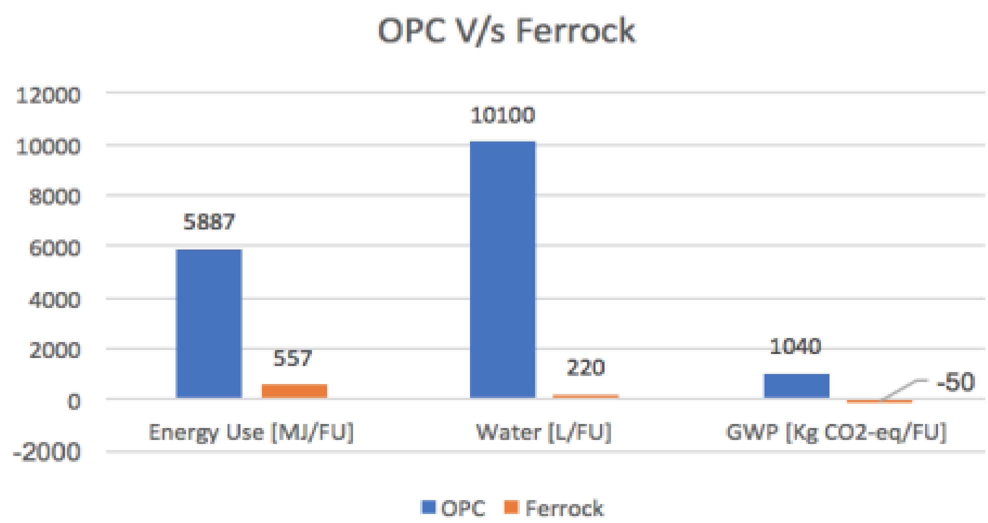
David Stone developed a new form of concrete known as Ferrock. Around 95% of it is made from recycled materials and iron carbonate (HRL Tech 2014). It is created from waste steel dust that would normally be discarded from industrial processes and silica from ground-up glass. The main ingredient is metallic iron powder, which is a byproduct of shot blasting, a finishing technique for steel manufacturing. The ingredients are combined as a dry mix with a source of silica, such as fly ash or recycled glass. Oxalic acid is also added to facilitate the chemical process and then blended to create a uniform mixture. The iron within the steel dust reacts with CO_2 and ruse to form iron carbonate. It is then fused into the matrix of Ferrock rock, and, after it is dried, it cannot melt back into liquid but retains hard rock qualities like concrete. Ferrock also uses clay and limestone as part of its composition, like Ordinary Portland Cement does, but Ferrock uses a much smaller ratio; about 8-10 % of what Ordinary Portland Cement uses (Bello 2011).



(Bello 2011)

“In addition, the iron-based binder requires a fractional amount of time to cure compared to OPC; 4 days of carbonation compared to 7 the 28 days of hydration that is required for cement to cure. The curing process for Ferrock also has the theoretical potential to be further expedited based on the purity of the compressed carbon dioxide.” (Bello 2011) Ferrock is actually five times stronger than Ordinary Portland Cement. “From the performance perspective, compressive and flexural strength tests show the pure paste (without aggregate) to be stronger than comparable samples of OPC. In the case of compressive strength, Ferrock shows typical strengths in the range of 5,000 to 7,500 psi, and even as high as 10,000 psi. These values are above the 28- day cured OPC standard values for commercial use (4786 psi for OPC-33 MPa, 6236 psi for OPC-43 MPa and 7687 psi for OPC-53

MPa).”(Bello 2011) Testing samples of Ferrock paste averaged over 1,200 psi, compared to 275 psi for similar 28-day cured OPC samples, and can be even higher with the addition of glass fibers Additional characteristics are defined by a comparison with the pore structure of 28-day cured OPC pastes, showing that the overall pore volume was lower in iron-carbonated binders, but the critical pore sizes were larger. “This explains that the value of permeability of Ferrock after 4 days of carbonation (k = 2.5 x 10-16 m2) is significantly higher than 28-day cured cement paste (k = 6.17 x 10-20 m2” (Bello 2011). It can withstand more compression before breaking and is far more flexible, meaning it could potentially resist earth movements caused by seismic activity or industrial processes. Ferrock is resistant to rust, oxidation, UV radiation, rotting and corrosion. Therefore, Ferrock is the superior material for marine applications like seawalls, piers and structural pilings. Ferrock is not affected by sewage water like hydrogen sulfide and sulfuric acid which would corrode cement pipes. It is also less brittle compared to concrete so it has a superior pipe to pipe connection and there is less damage while aligning and installing sections. (Bello 2011) Ferrock concrete is also far better for the environment than Ordinary Portland cement, instead of emitting large amounts of CO_2 as it dries, Ferrock actually absorbs and binds it. This results in a carbon negative process that actually helps trap greenhouse gases (Geiger 2017). Ferrock also uses significantly less energy, water, and GWP as proven from the table below.



(Bello 2011).

The production of Ferrock uses far less of precious environmental resources to accomplish the same job as Ordinary Portland Cement. This can be greatly appealing to those who are looking to lower their carbon footprint through using more sustainable materials.

While it is pretty clear that Ferrock can perform well in small projects, it is still unclear if Ferrrock could work well for large projects because it is unproven how well it can be scaled in manufacturing (Bonnefiin 2019). It is currently unclear if Ferrock would be practical for large scale industrial use like highways. Currently Ferrock is much cheaper than concrete as its sourced from waste materials and is carbon negative as it absorbs more carbon dioxide than it creates when hardening (Build Aboard 2016). But if Ferrock becomes popular and steel dust suddenly goes from being a waste to a highly wanted material its price could increase significantly and the cost could lower the potential application of Ferrock. The cost benefit analysis of Ferrock was analyzed in a study for four different scenarios.

	Scenario 1: Cast in place (use of CO2 bottles)	**Scenario 2: Pre-cast manufacturing (free CO2)**	**Scenario 3: Glass powder / Cast in place (No use of fly ash/ use of CO2 bottles)**	**Scenario 4: Glass powder / Pre-cast (No use of fly ash/ free CO2)**
Cost	$138.6/tonne [FA] + $1.49/tonne [LM] + $11.88/tonne to $23.76/tonne [MK] + $8.91/tonne to $14.85/tonne [OA] + $135.7/tonne [CO2] ____________ **$296.58/tonne to $314.4/tonne**	$138.6/tonne [FA] +$1.49/tonne [LM] + $11.88/tonne to $23.76/tonne [MK] + $8.91/tonne to $14.85/tonne [OA] + $135.7/tonne ____________ **$160.88/tonne to $178.7/tonne**	$138.6/tonne [FA] +$1.49/tonne [LM] +$11.88/tonne to $23.76/tonne [MK] +$8.91/tonne to $14.85/tonne [OA] +$135.7/tonne [CO2] ____________ **$157.98/tonne to $175.8/tonne**	$1.49/tonne [LM] +$11.88/tonne to $23.76/tonne [MK] + $8.91/tonne to $14.85/tonne [OA] + $135.7/tonne ____________ **$22.28/tonne to $40.1/tonne**
Benefit	$112.2/tonne [H2] +$24.3/tonne [IP] +$195.23/tonne [Ferrock] ____________ **$331.73/tonne**	$112.2/tonne [H2] +$24.3/tonne [IP] +$195.23/tonne [Ferrock] ____________ **$331.73/tonne**	$112.2/tonne [H2] +$24.3/tonne [IP] +$195.23/tonne [Ferrock] ____________ **$331.73/tonne**	$112.2/tonne [H2] + $24.3/tonne [IP] + $195.23/tonne [Ferrock] ____________ **$331.73/tonne**
Net Margin	**$17.33/tonne** **to** **$35.15/tonne**	**$153.03/tonne** **to** **$170.85/tonne**	**$155.93/tonne** **to** **$173.75/tonne**	**$291.63/tonne** **to** **$309.45/tonne**

(Bello 2011)

These results show Ferrock has strong economic potential. It should be noted that the reduction of the curing phase to 4 days would impact the set time of the construction schedule which would reduce the critical path of construction which should reduce building times and costs. Ferrock has the potential to be a very desirable product for the construction industry.

Geopolymer Concrete

Geopolymers are another quality alternative to Ordinary Portland Cement**.** Geopolymers are based on fly ash a fine waste collected from the emissions liberated by coal burning power stations. This is activated by an alkaline activator that has potential to lower the significant carbon footprint of Ordinary Portland Cement. Geopolymer is an inorganic materials that is rich in silicon and aluminum; once it reacts with alkaline activators it becomes cementitious. Alkaline activators that are used for Geopolymers are usually a combination of hydroxyl or potassium hydroxide and a glassy silicate consisting of sodium silicate or potassium silicate with NaOH and sodium silicate being the most common due to cost and availability. A study by Gale looked at the emission of manufacturing both fly ash and Ordinary Portland Cement using calculations based on the collective contributions of "C[O.sub.2], C[H.sub.4], N[O.sub.2], and synthetic gases evolved during each activity, taking into account the energy content of the fuel, the global warming gas types produced, and the respective gas global warming potential (GWP), when the fuel is fully combusted" "Fly ash is a waste by-product arising from coal-burning power stations and therefore some studies have considered the raw material to contribute zero C[O.sub.2]-e [14]. However energy expenditure occurs during fly ash capture, milling and grinding, drying, and transport [29] and an emission factor of 0.027 kg C[O.sub.2]-e/kg for fly ash has been calculated. Compared with OPC and the alkali activators, fly ash has a significantly lower emission factor" (Gale). The emission factor for Ordinary Portland Cement production in the study was "0.82 kg C[O.sub.2]-e/kg [27]" (Gale). This shows Ordinary Portland Cement produces significantly more harmful emissions than Geopolymer Concrete. The study also looked at the different emission factors from coarse and fine aggregates. "has been used for estimating the emission factors of 0.0408 kg C[O.sub.2]-e/kg for coarse aggregate and 0.0139 kg C[O.sub.2]-e/kg for fine aggregate. Despite the inclusion of the activities of quarrying and crushing, transport of raw materials to the concrete manufacturing premises, the emission factor for the aggregates is very low when compared with OPC and the alkali activators" (Gale). They found that the emission factor for aggregates is also significantly better for the environment than using Ordinary Portland Cement.

While observing each of the testing activities from sourcing raw materials to the manufacture and construction of concrete. Ordinary Portland Cement was by far the most significant contributor to emissions contributing 76.4% of CO_2 for OPC concrete. However, the alkali activators expend a significant amount of energy during manufacturing and the contribution of the Geopolymer is 201kg CO_2 as compared with OPC 269kg CO_2. The total emissions from the OPC and geopolymer concrete comparison mixes used in this report were estimated as 354 kg CO_2 and 320 kg CO_2 respectively, showing 9% a difference.

While this is strong data to show the environmental benefit of using Geopolymer Concrete it was not as strong as predicted. The key factors that led to the higher than expected emissions for Geopolymer Concrete included the inclusion of mining, treatment, and transport of raw materials for manufacture of alkali activators for Geopolymers. Also, the expenditure of significant energy during manufacture of alkali activators, and the need for elevated temperature curing of Geopolymer Concrete to achieve reasonable strength may have led to not as strong benefits as they originally predicted.

There are some disadvantages when using fly ash concrete that may draw contractors away from using it. One large drawback is that it has questionable or inefficient freeze/thaw performance. It also has a slower strength gain, an increased need for air entraining admixtures, and an increase of salt scaling produced by the higher proportions of fly ash (Rodriguez 2019). For some contractors these disadvantages may not be worth the sustainable and environmental benefits.

As it is pretty clear there is an environmental benefit from using geopolymers. The cost of Geopolymer Concrete also is potentially more affordable. A study from the International Journal of Civil Engineering research performed a cost analysis for Geopolymer Concrete compared to Ordinary Portland Cement. They used different levels of grades to see if there was a clear difference on what was more affordable

Grade of concrete	Cost of production of $1m^3$ of OPC	Cost of production of $1m^3$ of GPC	Savings in Cost (Rs)	Savings in %
M30	5780	5883.5	-103.5	-1.7 %
M50	6618	5864	754	11%

(Thaarrin 2016)

Based on the data and calculations the cost of production for Ordinary Portland Cement is higher for higher grades while Geopolymer Concrete can be more expensive for lower grades. These results only suggest that Geopolymer Concrete is more effective if you are using a higher grade of Concrete. This shows the Geopolymer Concrete may not be the best cost effective alternative to Ordinary Portland Cement if you are using a lower grade of concrete.

Timbercrete

Timbercrete is a blend of sawmill waste, cement, sand binders, and a non toxic deflocculating additive which is cured using the renewable resources of sun and wind into a unique building block. It is then converted into brocks, blocks, panels, and pavers that are used not only in residential, industrial, and commercial building projects but also landscaping design. It can be used in a vast amount of different sizes, shapes, colors, and textures. Timbercrete is around 2.5 times lighter than concrete or clay and has a semi-flexible quality that improves its application (Build Abord 2016). It has an improved insulation and thermal mass as compared to Ordinary Portland Cement so it will store energy more efficiently and release it more slowly reducing heating and air conditioning costs and the environmental knock on effects.

The fire rating of Timbercrete is also much better than concrete and it has been tested to ensure it is completely safe, non-toxic, and is suitable for those sensitive to allergens. Timbercrete is also far less porous than most concrete and won't wash away or erode when exposed to the elements like mud bricks. Timbercrete also offers significant environmental benefits as it uses significantly less energy than Ordinary Portland Cement, it can also actually store carbon gas and offsets a large amount carbon gas emissions. (Timbercrete 2017). This is because it is a carbon trap. This means it traps carbon rather than harmfully emitting it into the atmosphere.

As it is known Timbercrete certainly has its environmental benefits but it’s use is limited to specific projects. Timbercrete can be used to build fences, retaining walls, garages, and BBQs but not much else. While Timbercrete can also reduce laying costs and will almost always save money as compared to using Ordinary Portland Cement; there hasn't been any detailed studies on just how sustainable and cost effective Timbercrete is as compared to ordinary concrete in the long term, so it wouldn't be realistic to say that it is currently likely that contractors will begin to use Timbercrete frequently as a substitute currently.

Conclusion

Although there are other options for Ordinary Portland Cement substitutes, the three types discussed thoroughly are the best options that can be used in the most scenarios. Some of the other options include Straw Bales, Grasscrete, Hempcrete, Bamboo, recycled plastic, wood, and mycelium. The other options either do not have many studies done on them that would prove their benefits or they only have benefits for a specific type of concrete building and would not function as an alternative for Ordinary Portland Cement in most scenarios. While Timbercrete is a great potential alternative in some scenarios, like retaining walls, fences, and garages, its use is limited to these specific tasks. Also, although there is a clear benefit of the low environmental impact, energy use, and fire rating of Timbercrete, the lack of detailed long-term studies on Timbercrete eliminates the chance for Timbercrete to currently become an acceptable long term alternative for Ordinary Portland Cement. Geopolymer concrete in some cases can potentially be a great alternative to Ordinary Portland Cement, with a 9% decrease in overall emissions in comparison to Ordinary Portland cement. It is clear Geopolymer concrete is at least a little better for the environment in many different cases. Geopolymer concrete also can be cheaper than Ordinary Portland Cement in many scenarios, but studies suggest it can be more expensive when using lower grades. Since Geopolymer concrete can be more expensive, this could be a big drawback for some contractors. Another large drawback is that studies show it has inefficient freeze/thaw performance. It also has a slower strength gain, an increased need for air entraining admixtures, and an increase of salt scaling produced by the higher proportions of fly ash. These drawbacks make it questionable to believe that Geopolymer concrete is the best alternative for Ordinary Portland Cement in the vast variety of scenarios. Ferrock Concrete seems to be the best alternative with the most research to back up its benefits and minimal research to show drawbacks. Ferrock Concrete has a lower curing time, it is five times stronger than Ordinary Portland Cement, it uses 8-10% of the amount of clay and limestone that Ordinary Portland Cement uses, it binds CO_2 to protect the environment, and it is currently much cheaper than Ordinary Portland Cement. The only concern for Ferrock Concrete is that, if it becomes a mainstream long-term alternative for Ordinary Portland Cement, it could become much more expensive when it is no longer a waste material. With all of its benefits and limited drawbacks, as supported by evidence, Ferrock Concrete clearly has the strongest potential to become the best alternative for Ordinary Portland Cement. Ferrock Concrete is ideal for contractors who are looking after the environment, looking to save money, or even if looking for a substitute for when our resources of limestone become minimal.

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