Geopolymers as a sustainable alternative for Ordinary Portland Cement

Statement: Ordinary Portland Cement should be replaced by geopolymers for achieving a sustainable cement industry.

The cement industry as a major emitter of greenhouse gasses
Worldwide, building and infrastructure projects require huge amounts of concrete, which makes it the most widely used construction material and even the second most used commodity by mankind after water (Deventer, Provis, Duxson, & Brice, 2010; Habert, d’ Espinose de Lacaillerie, & Roussel, 2011). Traditionally, concrete is produced by using Ordinary Portland Cement (OPC) as the binder. However, the manufacture of OPC contributes approximately 5-7% to global anthropogenic CO₂ emissions (Turner & Collins, 2013). This carbon footprint is predominantly caused by the formation and release of CO₂ during calcination of limestone, and by the energy demanding manufacturing process which includes heating raw materials at temperatures higher than 1400 °C. Emissions from cement are set to grow significantly as the Middle East, India, China, and other countries in Asia are rapidly developing infrastructure (Deventer et al., 2010).

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As an attempt to reduce greenhouse gas emissions, OPC can be partly substituted by supplementary cementitious materials, such as fly ash and slags. These blended cements are capable of reducing concrete CO₂ emissions by 13-22% in typical concrete mixes (Flower & Sanjayan, 2007), although this estimates can vary depending on factors such as amount of OPC replacement, energy sources, and transportation distances. Another approach is the production of novel binder types which no longer consist OPC. Geopolymeric cements are emerging as a sustainable alternative to OPC as they show comparable mechanical properties and can have a significantly lower carbon footprint (Nath & Kumar, 2013). This is because no intensive heating is required and several wastes or industrial by-products can be utilized for its production. Geopolymers are inorganic polymeric materials that were invented in the 1970s by Joseph Davidovits. Geopolymerisation involves a chemical reaction between amorphous aluminosilicate raw materials and alkali silicate-hydroxide solutions yielding amorphous to semi-crystalline three-dimensional polymeric structures which consist Si-O-Si and Si-O-Al bonds (Geopolymer Institute, 2014; Mellado et al., 2014). Alkaline activators used for geopolymers, are usually a combination of a hydroxyl and a glassy silicate, with sodium hydroxide and sodium silicate being the most common due to cost and availability (Turner & Collins, 2013).

As a result of discussions around the life cycle analysis of geopolymers and different mix designs and binder types, literature provides results varying from 80 to 30% estimated CO₂ savings comparing geopolymers to OPC (Provis et al., 2014). However, the outcome of a recent study shows only a saving of 9% on the CO₂ footprint of geopolymer cement compared to OPC (Mellado et al., 2014). It was concluded that synthesis of commercial sodium silicate solution has the highest contribution to CO₂ emissions in geopolymeric mortars, and a replacement by rice hull ash-derived sodium silicate solution...
can reduce CO₂ emission by 50%. CO₂ emission estimates should always be interpreted critically. Proximity, availability and composition of raw materials; energy/fuel types; concrete mixture compositions, and manufacturing processes for the alkali activators, are factors that all should be taken into account. Nevertheless, geopolymers have the advantage over OPC that no CO₂ is released during the chemical reaction and no high temperatures are required during the manufacturing process, which results in a potential 80% reduction in the emission of greenhouse gasses compared to OPC.

Producing geopolymers on a larger scale
Flyash from coal fired power plants and metallurgic slags are the most widely used materials for producing geopolymers. These are both large waste streams from major industries and therefore, they are ideal candidates for the production of green cement on a larger scale. Some companies are already commercially supplying geopolymers. The Australian firm Zeobond for example, produces a geopolymer concrete product, called E-crete, with a 60% reduction in the overall carbon footprint (McCaskill, 2011). Zeobond has focused on developing a product that can take on concrete in its core markets, which are footpaths, slabs and precast concrete panels. Progress has been made locally, with Vicroads, the state road and traffic authority in the state of Victoria, approving E-Crete for their projects. The major challenge is the cost of the necessary infrastructure. E-Crete production can be integrated into existing concrete manufacturing plants, but modifications are required. This means that the adoption of E-Crete is best done in conjunction with the building of new plants, so Zeobond is looking to markets where demand for concrete is still growing rapidly, like China and India (McCaskill, 2011).

E-crete is a good example of a low-carbon cement being marketed and used in the real world and not simply being a subject of endless academic research. The downside possibly exists in the long-term availability of the waste products. Currently there are extensive reserves of fly ash and slags for the production of such concretes. If geopolymer concrete become widespread, what should be the ambition, the demand will grow and despite of the extensive reserves of slag and fly ash, supplies of raw materials could pose restrictions. That’s why we should also focus on all kinds of materials which are locally available. In fact it can be said that any kind of silica or alumina source that easily dissolves in alkaline solution, can be potentially used for making geopolymers (Nordic Road & Transport Research, 2014).

For example former landfills from the previous century can provide such a material. After filtering out basic materials like metals and plastics, plasma gasification can be used for converting the waste into a clean natural gas. This gas can be fed to a gas engine or gas turbine for efficient power generation. During plasma gasification, the ash is converted into a fully stabilized environmentally sustainable product called Plasmarok, which is ideal for producing geopolymers (Draulans & Van Baarle, 2013). New technologies, like plasma gasification of waste, are crucial for increasing the interest in geopolymers as a sustainable alternative for OPC. It’s estimated that there are around 500 000 of these landfills around Europe, which results in a huge amount of potential raw material for making geopolymers.

Beside waste products there are also natural resources which have the necessary properties for being used in sustainable cement. The eruption of the Icelandic volcano Eyjafjallajökull in 2010 inspired a team of researchers at the Innovation Center Iceland (ICS) to start with the development of a
geopolymer using the volcanic ash as a source material. After they explored how the volcanic ash could be activated, other waste materials from Iceland, such as fly ash and slag, were included into the project. But they also investigated the addition of geothermal silica from geothermal power plants, and even the addition of fossilized remains of aquatic single celled algae. This resulted in a substantial knowledge database of how a number of Icelandic waste materials can be used for producing geopolymers (Nordic Road & Transport Research, 2014). For geopolymers to become widespread, it is important that both awareness and knowledge about local raw materials are present. The researchers from ICS set a great example by composing a knowledge database of how a number of certain waste materials can be used for producing geopolymers.

The importance of sharing this expertise can be underscored through the case of an Argentine woman who had the plan of producing bricks from the volcanic ash which covered her hometown Villa La Angostura in 2011. After being surrounded for weeks by the grey sediment spewed by the volcano, Maria Irma Mansilla decided to make it in something useful. She heard that many years ago, the residents of the village made bricks from the volcanic ash of a previous eruption. She started doing the same and hoped to increase the production of these bricks. Her goal was very noble; first she wanted to help building houses for the older people, then for single mothers, and after that for herself (“Argentine makes bricks of ashes from Chilean volcano,” 2011). The fact that she wanted to use the volcanic ash for building up the village is admirable but her plan unfortunately wasn’t successful because the formula she developed required more cement than she could afford (“Town Digs Out of Volcano’s Destruction, Stronger But Dustier,” 2013). Her recipes still contained cement as a binder, the volcanic material itself was only used as an aggregate, so she wasn’t producing a geopolymer. In this case the locally available materials are used but the knowledge on how to use it properly was not available. If the expertise on the geopolymerisation of the volcanic ash would be available in this region, no cement would be needed and the huge amount of volcanic ash could be a potentially cheap sustainable building material for the local population.

Drivers for introducing the use of geopolymers on a larger scale
Geopolymeric cements are not new but market issues, lack of environmental awareness, inconsistent ingredients, and limited knowledge of cement chemistry restricted alkali cement to a niche market (Spencer, 2012). Considering nowadays the push for green standards is becoming more serious, the time for more widespread application of alternatives may be right. But huge hurdles are faced: The trustworthy reputation of cement, established industry and economic interests. The technology may be the simplest barrier to overcome. But the future looks hopeful as the European Cement Association recognises the problem and developed a roadmap which shows a very profound approach towards greenhouse gas emissions caused by the cement industry and presents a vision for the sector whereby the cement carbon footprint by 2050 could be reduced by 32 to 80% compared with 1990 levels (Cembureau, 2013). Hopefully this is sincere and the evolution of ecology doesn’t become something regulated by the industries themselves, used more as a marketing tool than a goal on its own. Furthermore, Governments in Asia and elsewhere are kick-starting green building industries, opening doors for alkali-activated and other green cements. China’s newest cement standards, for instance, require a 15 percent reduction in energy use. India’s green-building standard takes a life-cycle approach and emphasizes recycling and pollution reduction (Spencer, 2012).
the EU’s Emissions Trading System (ETS) could also be a motivation for lower emission of greenhouse gases and the implementation of more sustainable technologies. The ETS sets a limit on the amount of certain greenhouse gases that can be emitted by each industry. This limit is reduced over time in order to lower total emissions. Within this system, companies receive a certain amount of emission allowances. These allowances can be traded between companies, which financially motivates lower emission of greenhouse gases. Companies who don’t have enough allowances at the end of the year have to pay heavy fines. But one big problem is that most industries are caring profits more instead of CO₂ emission. Industries which cannot achieve the emission limit set by the EU, could possibly transfer production to other countries which have laxer constraints on greenhouse gas emissions. This is called carbon leakage and could even lead to an increase in their total emissions (European Commission, 2015). The EU doesn’t want to risk that major industries such as the cement industry transfer their activities abroad. As a result the cement industry is getting most of their emission allowances for free over 2015-2019 to help meet obligations under the ETS and compete in global markets (European Commission, 2014). It looks like a worldwide approach is needed in order to address this problem.

Conclusion
There’s a high need for alternative materials and technologies in order to reduce the carbon footprint of the cement industry. Geopolymers can fill out this vacancy since they have a high potential for drastic emission reductions at reasonable cost (Spencer, 2012). They can be produced from a variety of materials like waste streams from large industries and even waste from landfills. It will be hard to change mentality and policy towards an established product as Ordinary Portland Cement and implement geopolymer technology on a larger scale. But with growing demand for more sustainable building materials and perhaps with some help from carbon taxes in the future, I believe geopolymers can become widely used as a sustainable building material. But in order to contribute to a low carbon economy, concrete technologies and applications have to go beyond emission reductions from production alone. How and when concrete is used can also have a profound effect on global emissions since intelligently conceived modern concrete buildings are more energy efficient and around 18% of global energy is consumed by conventional buildings during their life (Cembureau, 2013).

References


