Geopolymers: The future cement replacement?

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Various strategies have been proposed for reducing the CO_2 emissions of cement manufacture. The Intergovernmental Panel on Climate Change (IPCC) stated that "Materials substitution, for example the addition of wastes (blast furnace slag, fly ash) and geopolymers to clinker" could be used to reduce global CO_2 emissions. Most current research on this area has focused on and geopolymers based on fly ash and GGBS with a view to produce materials with the lowest possible CO_2 emissions. Completed studies have not normally included the constraint of the availability of waste materials and geologic mineral precursors and the effect this can have on outcomes.

1 Introduction

In 2015, the United Nations Climate Change conference was held in Paris. The text of the Paris Agreement needs to be signed and put into law by at least 55 countries by April 2017 to be legally binding. This is the most recent major international agreement on climate change and demonstrates the increasing importance of CO_2 emissions, even in times of economic uncertainty.

It has been recognized by the Intergovernmental Panel on Climate Change (IPCC) that cement manufacture plays a major role in global CO_2 emissions and that ""Materials substitution, for example the addition of wastes (blast furnace slag, fly ash) and geopolymers to clinker" could be used to reduce global CO2 emissions from cement manufacture (Solomon et al, 2007).

2 Options for low CO_2 binders

There have been a number of papers which have demonstrated the effect of reducing the clinker content in Portland cement (PC) based binders and data such as that in Figure 1 has been used to demonstrate the potential reductions in GWP by replacing clinker with mainly ground granulated blastfurnace slag (GGBS) and fly ash (FA) from coal-fired power stations. These analyses have not, however, considered the availability of materials.

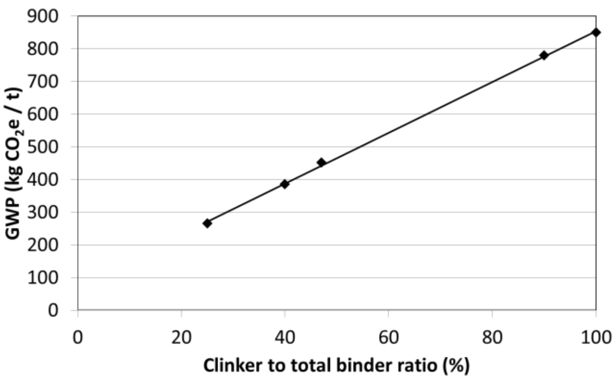

Figure 1. Effect of clinker substitution on binder GWP (data from Feiz et al, 2015)

Likewise, there has been a lot of research into potential CO_2 reductions from using geopolymer binders (also called alkali activated binders) as a PC based binder replacement, as summarized in Figure 2.

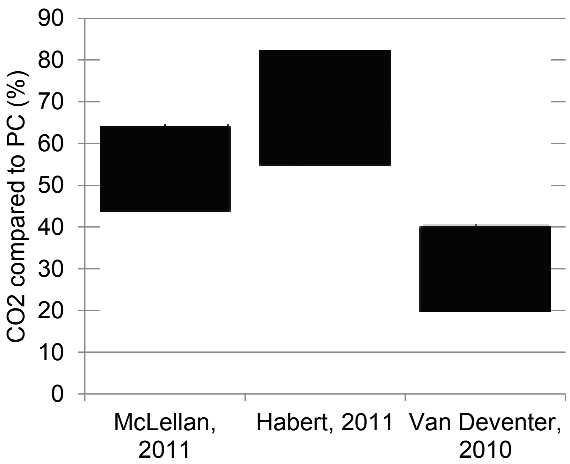

Figure 2.CO_2 from FA/GGBS geopolymer binders (data from Heath et al, 2013)

As shown in Figures 1 and 2, the IPCC promotion of high FA/GGBS contents in PC based binders and geopolymers appears reasonable as reductions of up to 80% of CO_2 appear achievable, but the global impact needs to be considered.

3 Material availability

For the full impact to be achieved, it is necessary to have sufficient materials for high levels of PC substitution or geopolymer use, and as shown in Figure 3, that is not feasible as globally only approximately 18% of binder needs can be met by FA and GGBS. There are additional materials available in historic stockpiles, but these are not normally cost-effective to extract and quality may be variable.

In many European countries, including the UK, there is now a shortage of both materials and FA and GGBS are now imported in order to fulfil mainly PC based binder needs. This is because of the move to reduce global CO_2 from electricity production which has led to a reduction in coal fired power generation which produces far more CO_2 per unit energy production than any other major generation type (Hertwich et al, 2015).

There are exceptions to this reduction in coal fired power and a number of developing economies, and in particular India, are predicted to have a substantial increase in coal fired power generation over the next 25 years (IEA, 2015). This will lead to large increases in global CO_2, but this is mainly because the CO_2 per capita in India is one of the lowest in the world, and even by 2040 after the large increases, India will still have CO_2 per capita 40% lower than the global average (IEA, 2015).

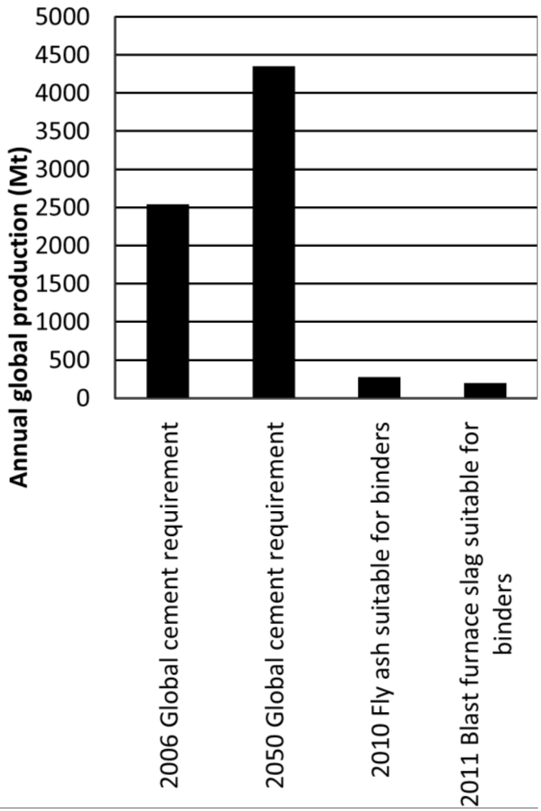

Figure 3. Material needs and availability (from Heath et al, 2014)

Predictions for power consumption trends in the UK (DECC, 2011) and India (IEA, 2015) are summarized in Figure 4. It should be noted when reading the graph that between 2011 and 2015, CO_2 per capita was 7.1 tonnes per year for the UK and 1.7 tonnes per year for India, both of which are well below the USA value of 17.0 tonnes per year (World Bank, 2016). By 2040, CO_2 per capita in the UK and India are predicted to be similar.

With the UK coal fired energy production reducing, it is understandable that there are concerns of a shortage of FA, but in India there is likely to be increased FA available. It is important that a strategic view on how to use this FA is taken so the optimal technical and environmental outcome is achieved.

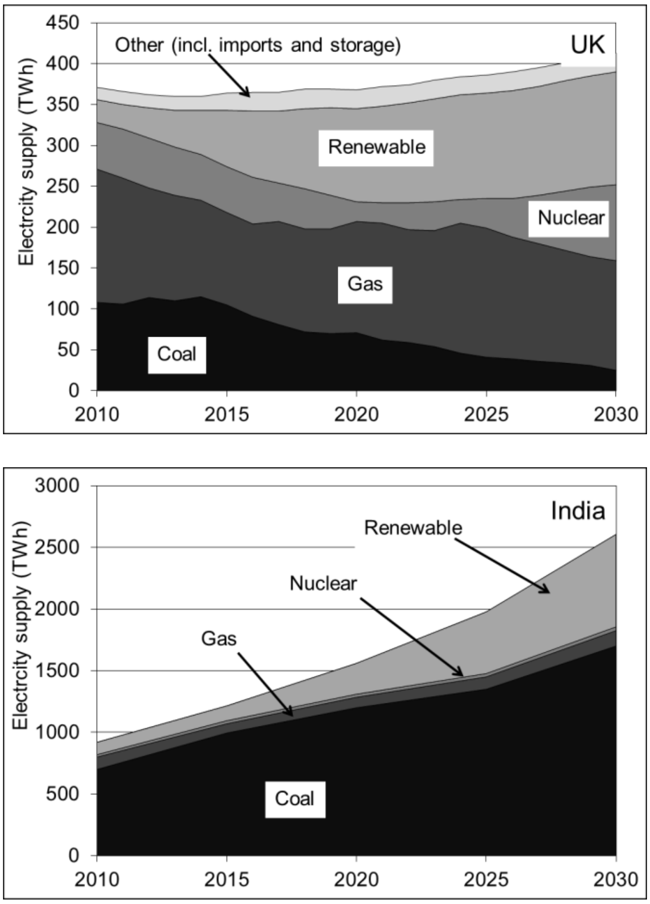

Figure 4. Electricity generation by mode for UK (top) and India (bottom) (DECC, 2011; IEA, 2015)

4 Technical aspects

While the global data indicates it is unlikely that geopolymers will overtake PC based binders because of material shortages, geopolymer concretes can have some technical advantages over PC based concretes, including improved fire, chloride and acid resistance (Davidovits, 2011).

There are however, some technical disadvantages and areas which need considerable research. One of the major technical disadvantages is that geopolymers using FA as the only precursor do not generally harden and gain strength at ambient temperatures. This is normally overcome by using a GGBS and FA blend as the precursor, but this means both materials have to be available.

The RILEM Technical Committee 224-AAM has identified carbonation, fatigue, creep, shrinkage and cracking as areas requiring detailed scientific attention to provide accurate prediction of geopolymer performance in service.

In addition, if geopolymers are to take a major market share, the recyclability of geopolymer concrete as an aggregate in PC based mixes, and the recyclability of PC based concretes as an aggregate in geopolymer concretes need investigation. This is an area where considerable research is needed and some initial research has indicated there are some technical differences recycling geopolymer and PC based concretes (Chaliasou, 2016).

5 Conclusions

This paper has shown that it is possible to reduce CO_2 emissions of PC manufacture by using either high replacement percentages of FA and GGBS or FA/GGBS based geopolymers. Up to 80% reduction in CO_2 is possible for individual cases, but there are currently insufficient global FA and GGBS resources to achieve this on a large scale.

While a number of European countries, including the UK, are predicted to have declining FA production because of decarbonisation of their energy supply, this is not the case in countries like India where there are predicted to be large increases in coal fired power, and resulting increases in FA production. Some of this valuable resource may be sold to countries with a deficit in FA, and a managed scheme for FA use in India should be investigated to ensure the optimal environmental and economic is achieved.

In addition to research into optimal use patterns, it is important that researchers in India focus on technical aspects of geopolymer performance under local conditions to ensure buildings and infrastructure are low impact and resilient into the future.

6 References

Chaliasou, N.A., Heath, A. and Paine, K., 2016. Investigation of the Recycling of Geopolymer Cement Wastes as Fine Aggregates in Mortar Mixes. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 10(4), pp.450-456.

Davidovits J., 2011, *Geopolymer Chemistry and Applications*, 3rd edn. Institut Géopolymére, Saint-Quentin, France.

DECC (Department for Energy and Climate Change). 2011 *Updated Energy and Emissions Projections*, DECC, London, UK.

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A. and Marshall, R., 2015. Improving the CO 2 performance of cement, part I: utilizing life-cycle assessment and key performance indicators to assess development within the cement industry. *Journal of Cleaner Production*, *98*, pp.272-281.

Habert G, d'Espinose De Lacaillerie JB, Roussel N., 2011. An environmental evaluation of geopolymer based concrete production: reviewing current research trends. *Journal of Cleaner Production*, 19, (11): 1229–1238.

Heath, A., Paine, K., Goodhew, S., Ramage, M. and Lawrence, M., 2013. The potential for using geopolymer concrete in the UK. *Proceedings of the Institution of Civil Engineers: Construction Materials*, *166*(4), pp.195-203.

Heath, A., Paine, K. and McManus, M., 2014. Minimising the global warming potential of clay based geopolymers. *Journal of Cleaner Production*, *78*, pp.75-83.

Hertwich, E.G., Gibon, T., Bouman, E.A., Arvesen, A., Suh, S., Heath, G.A., Bergesen, J.D., Ramirez, A., Vega, M.I. and Shi, L., 2015. Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies. *Proceedings of the National Academy of Sciences*, *112*(20), pp.6277-6282.

IEA, 2015. *India Energy Outlook:* World Energy Outlook Special Report, International Energy Agency, Paris.

McLellan BC, Williams RP, Lay J, van Riessen A, Corder GD, 2011. Costs and carbon emissions for geopolymer pastes in comparison to ordinary Portland cement. *Journal of Cleaner Production*, 19, (9–10): 1080–1090.

Provis, J.L. and J. Van Deventer, eds. 2014 *Alkali Activated Materials*. RILEM State-of-the-Art Reports. Vol. RILEM TC 224-AAM. Springer.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., 2007. *Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*, 2007.

van Deventer JSJ, Provis JL, Duxson P, Brice DG, 2010. Chemical Research and climate change as drivers in the commercial adoption of alkali activated materials. *Waste and Biomass Valorization*, 1, (1): 145–155.

World Bank, 2016. *CO_2 emissions*. http://data.worldbank.org/indicator/EN.ATM.CO2E.PC, accessed 10/5/2016.