Geopolymer (green) concrete technology: State of the art, challenges/gaps and way forward

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INTRODUCTION

The greenhouse gases released by various anthropogenic activities have necessitated research on the recycling of industrial waste into green geopolymer concrete or monoliths[1]. The industrial waste, sometimes called the supplementary cementitious material (SCM), includes secondary resources such as fly ash, steel slags, rice husk ash, mine tailings, and silica fume, to name but a few[2]. The biggest advantage of using these materials is the low CO_2 emissions associated with their production and the relatively low energy demands for the synthesis process which dovetails into sustainable development goals for many nations[3]. The use of industrial waste as secondary resources will also help preserve and conserve natural resources. However, these advantages have not translated into mainstream/commercial use of the named precursors. Therefore, this paper investigates the current state of the art in geopolymer concrete technology. The paper also examines the current challenges, and lastly, the paper proposes a way forward to overcome these challenges.

METHOD

A systematic review of the published papers where SCMs were used for the synthesis of geopolymers was done. The key words/phrases typed for the review included geopolymer concrete, supplementary cementitious materials, geopolymer durability and geopolymer challenges. A summary of the properties of some of these geopolymers is also outlined.

GREEN CONCRETE TECHNOLOGY STATE OF THE ART

There has been a steady increase in the amount of research on green concrete in the past five years. A survey of the Elsevier and Springer websites shows a 199% and 439% increase in the number of published geopolymer papers, respectively (Figure 1). This, therefore, shows that the research into geopolymer concrete is progressing. Figure 2 shows some of the precursors that have been used to synthesise geopolymer concrete together with their corresponding maximum strengths. It is important to note that the list is not exhaustive but shows that good quality geopolymers can be obtained from these industrial wastes.

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[1] Davidovits, J. (1991). Geopolymer cements to minimize carbon-dioxide greenhouse warming, in: Moukwa, M., Sarkar, S.L., Grutzeck, M.W. (Eds), Cement Based Materials: Present, Future and Environmental Aspects, Am. Ceram. Soc., Cera. Trans. 37 (1999) 165–182.
[2] Mehta, A., Siddique, R. (2016). An overview of geopolymers derived from industrial by-products. Construction and Building Materials, 127, 183–198.
[3] Yang, K.H., Song, J.K., Song, K.I. (2013). Assessment of CO2 reduction of alkali-activated concrete, J. Cleaner Prod. 39, 265–272.

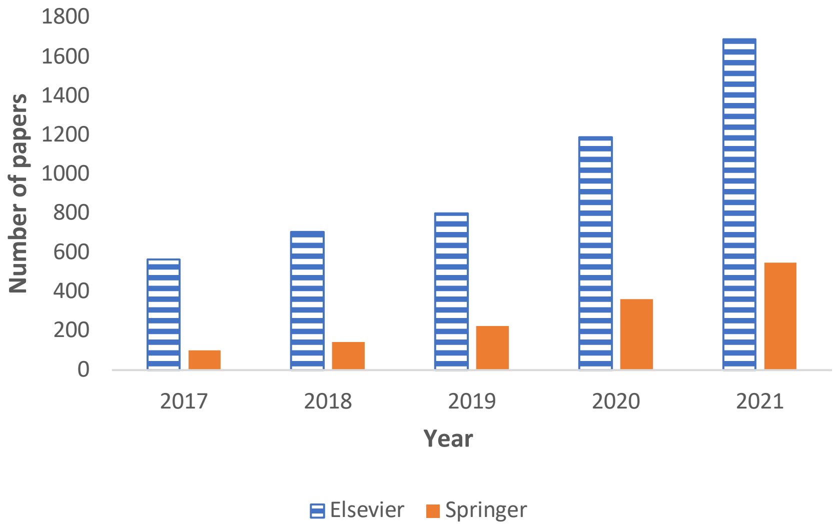

Figure 1. Geopolymer concrete publications in the last five years.

Most of these wastes are found in many countries, thus presenting boundless opportunities for their utilisation as secondary resource materials.

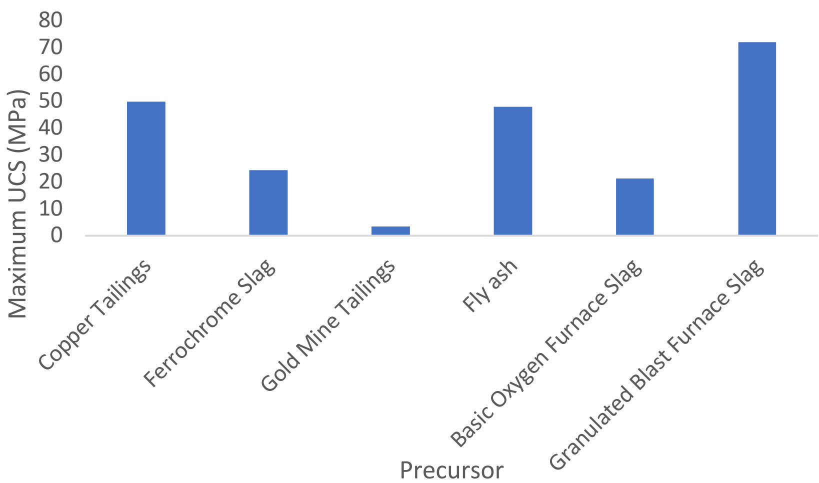

Figure 2. Maximum strength of some geopolymers.[4][5][6][7][8]

[4] Ahmari, S., Zhang, L. (2013). Utilization of cement kiln dust (CKD) to enhance mine tailings-based geopolymer bricks. Constr. Build. Mater. 40, 1002–1011.
[5] Falayi, T. (2020). *A comparison between fly ash- and basic oxygen furnace slag-modified gold mine tailings geopolymer.* International Journal of Energy and Environmental Engineering, 11, 207–217.
[6] Falayi, T., Ntuli, F., Okonta, F.N. (2018). *Synthesis of a paste backfill geopolymer using pure acidic gold mine tailings*. Journal of Solid Waste Technology and Management, 44, 311-320.
[7] Sithole, N.T., Mashifana T. (2020). Geosynthesis of building and construction materials through alkaline activation of granulated blast furnace slag Construction and Building Materials, 264, 120712.
[8] Adak, D., Sarkar, M., Mandal, S. (2014). Effect of nano-silica on strength and durability of fly ash based geopolymer mortar. Constr. Build. Mater. 70, 453–459.

CHALLENGES

There are various challenges in the mainstream use of geopolymer concrete. These challenges include the use of high temperature curing and high use of alkaline activators[9], the varying quality of same precursors found in different parts the world and efflorescence[10]. Most of the published papers focus on laboratory mix design without adapting the designs for field work, leading to low buy-in by the construction industry. The lack of internationally-agreed standards for the industrial waste precursors is another challenge, as this stops the standardisation of the geopolymer synthesis. The synthesis routes for most alkaline activators have been shown to pollute the environment, making it difficult to justify large-scale use of geopolymer concrete.

GAPS

The major gaps in green concrete include lack of adequate knowledge of reaction mechanism and lack of long-term durability studies (greater than 20 years).

Way forward

Various ways have been postulated[11] to overcome some of these challenges. These include collaborative research between different professionals in the construction industry. Most academic research is done in silos; hence repetition is very high, therefore, national and regional collaborative research is required. There is a need to have activation methods which reduce curing temperatures. Academic research needs to move out of the laboratory to field research. The publish or perish culture does not support long-term research into geopolymer concrete. There is therefore a need for a paradigm shift by the institutions to support long-term less research output activities.

CONCLUSION

Industrial wastes provide opportunities for recycling as secondary resources to satisfy sustainability goals. There is, therefore, a need to change the current research approach for the geopolymer concrete products to go mainstream.

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[9] Ahmari, S., Zhang, L., Zhang, J (2012). Effects of activator type/concentration and curing temperature on alkali-activated binder based on copper mine tailings. Mater. Sci. 12, 6497–6499.
[10] Provis, J.L., van Deventer, J.S.J. (2014). Alkali-Activated Materials: State-of-the Art Report, RILEM TC 224-AAM, Springer/RILEM, Dordrecht, 2014
[11] Liew, K.M., Sojobi, A.O., Zhang, L.W. (2017). Green concrete: Prospects and challenges. Construction and Building Materials, 156, pp. 1063-1095

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I am currently a lecturer in Chemical Engineering with the Namibia University of Science and Technology. My research interests are in solid waste valorisation and solidification with particular emphasis on circular economy together with remedial treatment of wastewater. I am currently a fellow of the African Science Leadership Program. I have authored and co-authored 22 peer reviewed research articles and 15 peer reviewed conference proceedings. I have experience in curriculum review and industrial-university linkages baseline studies together with needs assessment studies. I am also a trained mentor in innovation with a particular emphasis on human centered design, agile project management and systems design approach. I have co supervised over 4 postgraduate students and over 45 final year chemical engineering research projects. I have 10 years industrial experience in pharmaceutical, refinery and ferrochrome industries.