



Review

An overview of geopolymers derived from industrial by-products



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HIGHLIGHTS

- Utilization of various industrial waste products in development of geopolymers.
- Properties of geopolymers containing industrial wastes.
- Limitations of geopolymers in field applications.

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ABSTRACT

Large amount of industrial wastes are being released from various industries like power generation industry, iron making industry, steel making industry, mining industry, etc. These wastes like fly ash, bottom ash, blast furnace slag, metakaolin, etc poses various difficulties in their disposal. To overcome these waste management issues, the best solution is to utilize these waste products for some other applications. On the other hand cement industry have been found to be highly energy intensive industry acting as a major source for carbon dioxide emission leading to some serious environmental hazards like global warming, however, due to the need of high infrastructure the use of cement is unavoidable. Therefore, the approach can be to find the best alternative of the conventional Ordinary Portland Cement concrete which can provide better or comparable strength and durability properties and is economical and easy to prepare. The intense amount of work on geopolymeric binders derived from these industrial by-products have proved its utility having similar strength and durability properties that of conventional concrete. This alkali source provider, in the presence of alkaline medium forms geopolymerization products, that have comparable or even better characteristics than Calcium-Silicate-Hydrate products of conventional concrete.

This paper presents a concise review of various studies that have indicated the utilization of various industrial waste products in the synthesis of geopolymers. It has been observed from the studies that various industrial by-products such as fly ash, bottom ash, metakaolin, volcanic ash, etc. can be used effectively as source material for geopolymerization. Also despite of comparable properties to cement concrete the limitations that are resisting the use of geopolymers in actual industrial applications are also discussed.

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1. Introduction

The greenhouse gases like carbon dioxide released from various industries have prompted the use of materials like fly ash, silica fume, steel slag, palm oil, fuel ash etc commonly known as Supplementary Cementitious Materials (SCMs) in concrete productions. It has been observed that in producing around 1 kg of Portland cement, 1 kg [1] of carbon dioxide is released and if we study the emerging trend, it can be estimated that cement production can be increased to 100% from the current level by the year 2020. This clearly reflects the impact of global warming in near future [2]. It is well known that carbon dioxide is the major source of green house effect [3], it becomes very essential to find alternate cementitious materials that can very well satisfy the need for construction materials with least contribution to global warming and helping in making a sustainable environment. Due to very low carbon dioxide emission, geopolymers are gaining interest worldwide in comparison to Portland cement [4]. The mechanism for geopolymers is a polymerization process that involves a chemical reaction of alumina-silicate materials in the presence of alkaline medium which results to the formation of three-dimensional polymeric chain [5]. For geopolymers, activation is required for the polymeric reaction which can be attained with alkaline compounds as NaOH based, KOH based or mixture of Na₂O and SiO₂ based. The behaviour of heat cured geopolymers for structural elements like beams, columns, bonding, etc. are found to be similar or even superior to that of members made of OPC. Conventional OPC concrete is alkaline in nature, due to which it is susceptible to acid attack. Geopolymers on the other hand have proved to be a promising alternate [6] especially in some aggressive situations [7] which makes it even more suitable for the development of acid resistant concrete. They have numerous advantages as binders, because they can provide mechanical strength up to 100 MPa [8], better chemical resistance to sulphates [9] and harmful acids [10], low creep and shrinkage, high early strength, etc. [11] and resistance to high elevated temperatures [12]. Low calcium or high calcium fly ash has been extensively used in the synthesis of geopolymers and most of the researches so far have been more confined to fly ash only but other SCM's such as bottom ash, blast furnace slag, iron making slag, cement kiln dust, silica fume, industrial & other wastes, rice husk ash, metakaolin, etc may also have potentials to be used as replacement or addition to fly ash in making geopolymers. This paper presents a review of utilization of these SCM's and their effect on strength and durability properties and the challenges which are resisting the use of geopolymers in actual industrial applications.

2. Method

Geopolymers are being used across the globe with wide range of applications as an alternative to normal conventional concrete. Most works have been carried out on fly ash based geopolymers

whereas very few works have been reported on the potential of other SCM's like bottom ash, granulated blast furnace slags, cement kiln dust, fuel ash, volcanic ash etc as raw materials for geopolymers. Here a review is prepared for the works that are published so far, where these SCM's other than fly ash have been used. The effect of these SCM's on properties of geopolymers like compressive strength, tensile strength, porosity, RCPT, etc are studied and based on that, their future scope is suggested.

3. Potential of industrial waste products (IWP) as Supplementary Cementing Materials (SCM's)

There is a three step mechanism for geopolymers starting from the dissolution of silica and alumina from the source materials like fly ash or other SCM's followed by coagulation and gelation of the dissolved materials which then further polymerizes to form 3-D networks of silica aluminates structures [13]. The materials rich in silica and alumina can be used as source materials for geopolymers. So to check the potential of these industrial waste products, a detailed knowledge of their chemical components must be there. In various research works where geopolymers are synthesized using these waste products, a summary of them have been discussed here. Table 1 summarizes the results of XRF studies that have been explained in various publications [14–23] on various industrial by-products that have been used for the synthesis of geopolymers. The materials like volcanic ash, metakaolin, red mud, granulated blast furnace slag, granulated corex slag, blast furnace slag, palm oil fuel ash are found to have fair amount of silica and alumina content which suggests that these SCM's can be used as source material for geopolymers. Also Fig. 1 shows XRD analysis of various raw materials that suggests the phases present in the materials. For volcanic ash and metakaolin [16], Anorthoclase, D as diopside, H as hematite, M as maghemite, N as napheline, Q as quartz, I as illite, G as gibbsite, B as bassanite, A as anhydrite. When XRD analysis of geopolymer samples containing these materials were carried out, it was observed that except napheline, all the crystalline phases were also present after the geopolymerization. Also mineral phases Al₂O₃ was found to be completely dissolved during the reaction which enhanced the properties of resultant geopolymers. For red mud [15] H refers to as hematite & C as calcite, few sharp peaks of calcite & hematite was observed suggesting the dominance of crystalline phases rather than amorphous phases. These crystalline phases generally do not get involved in the geopolymerization rather they remain present as inactive fillers [21]. For ultrafine palm oil fuel ash & ground slag [22] A refer to as alite, L as lamite, B as belite, Br as bregidite, An as anhydrite, O as olivine, D as diopside, P as portlandite, Q as quartz, S as spinel, C as calcite, Cr as cristobalite, K as potassium aluminium phosphate, both the materials were found to have both crystalline as well as amorphous phases. Amorphous phases are found to be absent after geopolymerization for both the materials which means their participation in the reaction enhances the

Table 1
XRF results of industrial by-products used for geopolymers [14–23].

Element as Oxide	Volcanic Ash	Metakaolin	Red Mud	Granulated Blast Furnace Slag (GBFS)	Granulated Corex Slag (GCS)	Blast Furnace Slag (BFS)	Pulverized Fuel Ash (PFA)	Palm Oil Fuel Ash (POFA)	Cement Kiln Dust (CKD)
SiO ₂	41.36	48.31	89.34	32.01	32.51	33.8	46.7	53.5	11
Al ₂ O ₃	14.51	40.48	0.45	17.35	18.36	11.5	35.9	1.9	3.9
Fe ₂ O ₃	12.88	2.62	0.4	1.49	1.49	0.6	5	1.1	2.0
MgO	6.45	0.36	0.49	11.43	11.08	9	0.8	4.1	3.6
CaO	7.88	0.04	0.76	33.06	33.31	38.3	3.9	8.3	42
K ₂ O	0.90	1.30	4.98	0.83	0.68	0.9	0.5	6.5	0.6
Na ₂ O	2.22	0.15	–	1.24	1.19	0.5	0.6	1.3	–
LOI	9.31	2.43	–	1.39	0.49	–	1.0	18	–

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