Geopolymer as a Green Concrete Alternative to Portland Cement Concrete: Article review

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Abstract : Concrete is the second most product in the world, this leads to Portland cement being the largest product on a global scale. The production of Portland cement process causes the emission of carbon dioxide into the atmosphere, contributing increased pollution and exacerbating the problem of global warming. In order to contribute the reducing of greenhouse gases emission to atmosphere and to encourage the use of environmentally friendly alternatives, geopolymer-cement has been traded as an alternative to Portland cement. Geopolymer-cement is produced from industrial residues rich in silicon and aluminium. Geopolymer-cement preserving the environment in two ways, first reducing the contribution to greenhouse gas emissions and secondly benefiting from industrial waste and preserving landfills. In this paper, the fresh properties, mechanical properties and performance of geopolymer concrete were reviewed from published research by some authors. Reviewing these properties of geopolymer as an alternative to Portland cement concrete. The bottom line of this paper is that geopolymer are similar in properties or even better in some of them than Portland cement concrete, and that geopolymer represents a promising possibility and an excellent choice in the future.

Keywords: Geopolymer, Global warming, Geopolymerization, Portland cement.

الخلاصة: الخرسانة هي ثاني أكبر منتج في العالم، وهذا يؤدي إلى أن يكون أسمنت بورتلاند أكبر منتج على نطاق عالمي. يتسبب إنتاج عملية إسمنت بورتلاند في انبعاث ثاني أكسيد الكربون في الغلاف الجوي، مما يساهم في زيادة التلوث وتفاقم مشكلة الاحترار العالمي. وللمساهمة في خفض انبعاثات غازات الدفيئة في الغلاف الجوي وتشجيع استخدام بدائل صديقة للبيئة، جرى الاتجار بالأسمنت البوليمري الجغرافي كبديل لأسمنت بورتلاند. يتم إنتاج أسمنت البوليمر الجغرافي من المخلفات الصناعية الغنية بالسيليكون والألومنيوم. الأسمنت الجيوبوليمري الذي يحافظ على البيئة بطريقتين، ويقلل أولاً من المساهمة في انبعاثات غازات الدفيئة ويفيد ثانياً من النفايات الصناعية ويحافظ على مدافن النفايات. في هذه الورقة، تمت مراجعة الخصائص الجديدة والخصائص الميكانيكية وأداء خرسانة البوليمر الجغرافي من الأبحاث المنشورة من قبل بعض المؤلفين. مراجعة خصائص البوليمر الجغرافي كبديل لخرسانة أسمنت بورتلاند. خلاصة القول في هذه الورقة هي أن البوليمر الجغرافي متشابه في الخصائص أو حتى أفضل في بعضها من خرسانة أسمنت بورتلاند، وأن البوليمر الجغرافي يمثل إمكانية واعدة وخيارًا ممتازًا في المستقبل.

1. Introduction

Global warming become universal problem today and Portland cement which is the second biggest product wanted today response of carbon dioxide emission in the atmosphere [1]. To produce one ton of Portland cement there are 0.87 ton of CO2 which represent about 7% of total emitted greenhouse gas in the atmosphere [2]. So, to find cure for global warming there is a need to replace our demand for Portland cement with alternative meets the requirements [3]. On the other, many industrial wastes produce by product form burden on environment by consumption landfill, natural resource, and contributed and in environmental pollution. One of promising alternative is geopolymer which is inorganic polymer, this alternative requires to be helpful in energy conservation and reducing environment pollution, also mange waste issues . Portland cement known as a binder when water add to it, but alkali-activated play the binder component in geopolymer when it mixed with solid silica-alumina recourse which may found in industrial waste as by-product like fly ash, silica fume, ground granulated blast furnace slag, palm oil fuel ash, etc.[4].

The process of geopolymerization depend on dissolving and reorganizing, condensing, and polymerizing aluminate and silicate components from oligomers to large forms of polymers, and when the end of grope meeting together, water will be formed as a free water [5].

2. Materials:

To product geopolymer it will need aluminosilicate resources and activated alkali binder, and there are different types of these as illustrated in (figure 4).

3. Factors affecting mix properties:

3.1. Influence of mix design

Ling, 2019 [9], they investigated the influence of mix method of fly ash based geopolymer on compressive strength, they concluded that SiO2/Na2O ratio arise the compressive strength increased. mole module (Module), concentration of solute in alkaline solution (Concentration), liquid-to-fly ash mass ratio (L/F), and curing temperature on the geopolymerization process, set time, and compressive strength. As activated alkali molarity increased, the set time was accelerated but the total heat generated from geopolymerization and the compressive strength of the geopolymer were reduced, while the total heat of geopolymerization and strength of these mixes were increased [10].

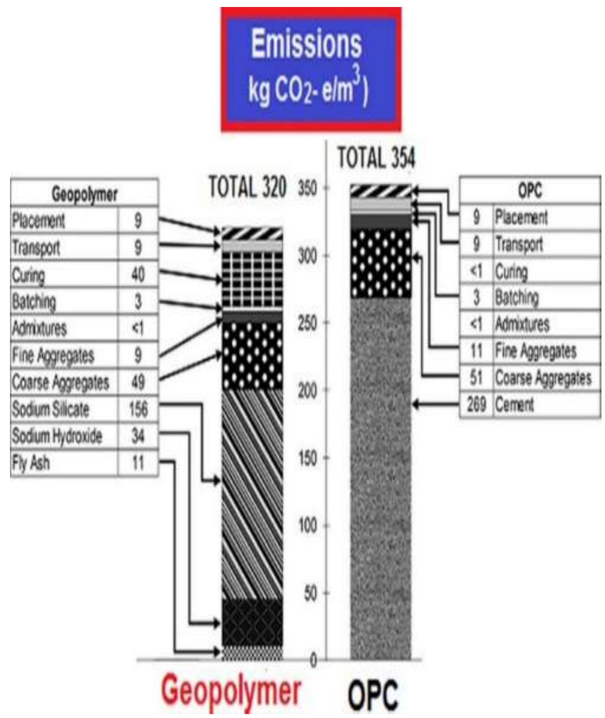


Fig. 1. the emission of carbon dioxide for ordinary Portland concrete and geopolymer concrete [6].

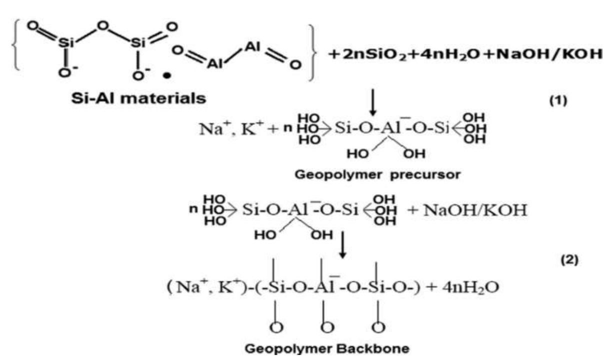


Fig. 2. Schematic representation of formation of geopolymer materials [7]

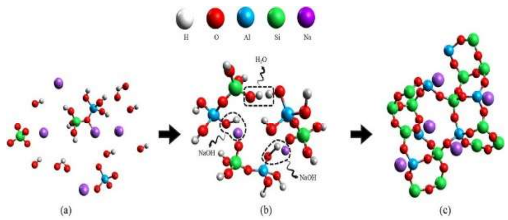


Fig.3. geopolymer production process: (a) aluminosilicate reorganizing, (b) condensing oligomers, and (c) polymerizing [5].

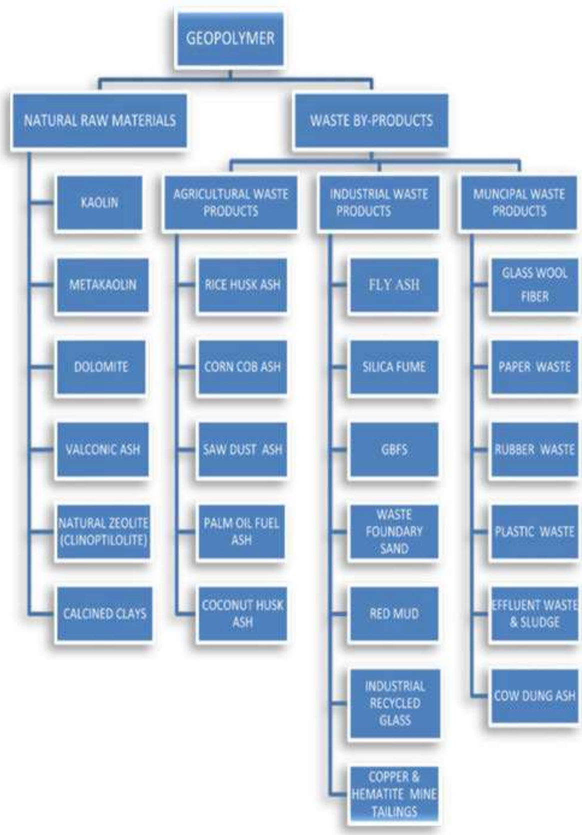
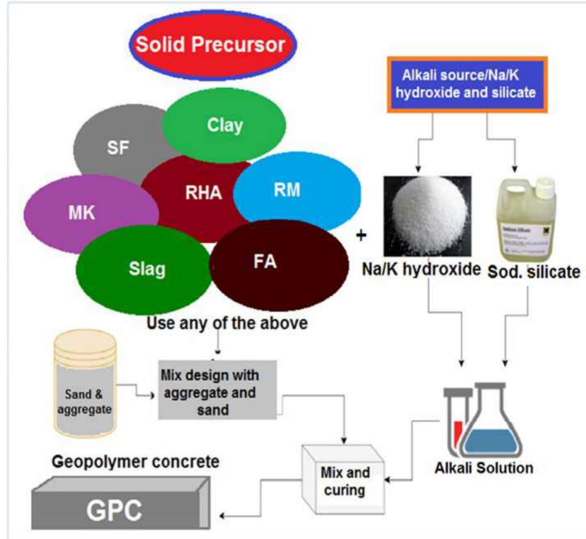


Fig. 4. Popular brand of foundation resources used in geopolymer composites [8].

increased the total heat of geopolymerisation, and improved the strength of the geopolymers. Concentrations of 20–25%, and L/F 0.40, and elevated curing (e.g., at 50 C) is preferred [9].



Fie. 5. production geopolymer process [11].

3.2. Influence of curing:

Gholampour et. al.[12], they investigated slag/ fly ash based Geopolymer concretes in Two different proportion the first 80% fly ash/20% ground granulated blast furnace slag (GGBS) and the second 50% FA/50% GGBS where Two dissimilar curing temperature are used, the ambient temperature at 23℃ and oven cured at 70℃. they study the effects of the curing temperature on compressive strength of the geopolymer. They conclude that 50/50 proportion mix show slightly improve stress and strain than 80/20 proportion mixes, and the oven-cured shows a slightly higher than ambient-cured for strength and a slightly lower for strain for the geopolymer. Also, *Zhao et. al.* [13], showed that specimen for good compressive strength should cured with 50℃ curing temperature.

4. Influence of some admixture and other addition:

4.1. Influence of superplasticizer:

Alrefaei et al. [14], examined the influence of three samples of different kind of high range water reduce agent, Polycarboxylate, Naphthalene and, Melamine on the compressive strength and the ability of flow for fly ash-slag based geopolymer activated by Ca $(OH)_2/Na_2SO_4$ fine particles blend., and they found an increased in compressive strength and significantly improved in flow by using high range water reduce agent, by reducing the porosity and improved the compressive strength. Also, it found Na_2SO_4 activator exhibited significantly lower compressive strength compared to Na_2SiO_3 activator.

4.2. Influence of nano and micro silica fume:

Adak et al. [15], study the effect of nano-silica and micro-silica on the workability and mechanical properties of fly ash based geopolymer, containing variable proportions of nano and micro silica (up to 15%). The additives improve the compressive strength, splitting tensile strength, workability, and water absorption up to 5% and improve the durability of geopolymer . Nano silica addition up to 6% of fly ash will be affected in reducing sitting time[16], and the rate of reaction of the geopolymer constituted will enhances with presence of the nano silica.

4.3. Influence of Limestone:

Bayiha study the influence of limestone dust in metakaolin based geopolymer mortar cured at ambient temperature. Using alkaline activator were mixed (1:1 ratio) of sodium silicate and sodium hydroxide solution at different molarities (5, 8 and 10 M). they investigated the initial setting time, linear shrinkage, water absorption, compressive strength. Limestone played as setting retarder in mortar. As well as increasing the activator molarity the setting time will be accelerated. Also, they show that shrinkage will be increased in addition to increased limestone amount. For limestone addition up to 45%, water absorption, decrease by increasing limestone amount, with enhancement of compressive strength [17].

5. Fresh properties of geopolymers:

As pointed earlier, properties of geopolymer will depended on the nature of the resources. Authors illustrated to these differences, following paragraphs will show some of the effect of these resource materials. Slag based geopolymer displays low workability for geopolymer concrete , and the flowability will decrease with increasing the amount of slag [18]. The matrix will be high viscously due to hydration process of silicate in mixes [19]. Also, due to geopolymerisation process which will accelerate the chemical process and the setting time . Metakaolin clay will request more water to produce good flowability for the matrix due to high surface area [20]. Increasing metakaolin content in mixture will increasing the water amount, for constant water ratio the workability will decrease , and for high reactivity the geopolymerisation processes result in acceleration process and educing sitting time [21]. Silica fume noticeable as highly fine particle with high surface area which require high water proportion to produce good workability [22], and when it added to fly ash to product geopolymer concrete or geopolymer mortar showed great loss in slump, as well as increasing in silica fume content . The high reactive and high fineness of silica fume makes it able to accelerate the process of the reaction and decreasing sitting time [23].

6. Mechanical properties:

Ground Granulated Blast Furnace Slag based geopolymer showed good mechanical properties for geopolymer concrete like strength which depend on the amount of slag [19]. It had been found that with increasing the content of slag the compressive strength will be increased in geopolymer concrete and with geopolymer mortar compressive strength will increased with higher proportion . Due to increased silicate to aluminium ratio in the matrix which had affected in Ca-Si-Al hydration and improving mechanical properties [24].

As well as slag, research found that metakaolin add to fly ash based geopolymer concrete as a partial replacement had affected the mechanical properties of geopolymer mixture and improve the compressive strength depending on the metakaolin content in mixture, the compressive strength will increase with increasing the amount of metakaolin, due to accelerating the geopolymer hydration process [21]. Metakaolin as a micro unit in the mixture, which will allow it to act as fine filler constitute and occupy the empty pores and result in densify the matrix [25].

As reported by authors small addition of SF less than 1% to fly ash with low calcium based geopolymer concrete will increase the compressive strength about 80% at early age due to accelerated geopolymer hydration . Increasing amount of nano-silica above 2.5% in the geopolymer matrix is reported to drop the compressive strength was appointed to inadequate moistening and scattering of silica elements [23], and was suggested that silica ratio not above 2% to avoid unreacted nano-silica which will increased the microcracks in the matrix and lowering compressive strength due to a rising demand on water in mixture [26].

7. Durability properties:

Slag based geopolymer produce durable geopolymer due to reducing size of capillary pores and refine it, also, improve matrix density . Authors reported increasing slag content result in reducing absorbed water content compared with geopolymer without Ground Granulated Blast Furnace Slag . When slag react chemically will forms C-A-S hydrated gel which will be bonded with water and occupy pores volume comparing with fly ash based geopolymer which will procedure N-A-S hydrated gel with less able chemical bonded with water resulting more pores matrix [27]. Fly ash based geopolymer with addition of slag produce durable matrix to elevated temperature, firing, and sulphate attack [28].

Metakaolin with fine particle property would be helpful in packing and densify the geopolymer matrix . The humidity of the matrix will be reduced as the temperature a raise, water will be lost by evaporation from the surface of the spacemen and generating differences in pressure stress on empty void, this well be allowed development of microcracks [24].

Some research concludes in their study that silica fume helpful with transform amorphous phases to crystal phase for the matrix combinations, furthermore silica fume played significant role in increasing matrix density . Authors suggest that suitable dosage of silica fume will improve geopolymer in micro scale, reduced pore size and enhanced durability [29].

7.1. Resistance to acid attack:

S. Afridi et. al., examined the resistant to acid attack for Poly (Vinyl Alcohol) copolymer with polyacrylic acid was used as the superabsorbent polymer (SAP) based geopolymer. Also, they investigate the resistance to sulphate, and chloride attack. They used samples contain 0, 1, and 2% SAP content by weight of were prepared. Where the models cured at 80℃. The samples dunked in the compound liquids of hydrochloric acid sodium sulphate, calcium chloride with 5%(HCl), 5% (Na2SO4), and 5% (CaCl2) respectively for 180 days. There assessed of performance for geopolymer was centred on the alteration of weight and compressive strength for the models. They conclude that geopolymer had significant resistance to chemical attack [30].

7.2. Resistance to freeze-thaw cycles:

Y. Aygörmez et al., investigated the effect of freezing-thawing of 56 and 300 cycles, an improve for compressive strength was find out after 56 cycles but a reduce was noticed after 300 cycles [31]. S. Pilehvar et al., investigated the effect of frost conditions on the physical and mechanical properties of geopolymer concrete (GPC). Geopolymer concrete provided an excellent resistance against freeze-thaw cycles with minor reduction of the compressive strength [32]. M. Zhao et al., they confirmed that cycle of freezing and thawing for class F fly ash based geopolymer specimens show good durability [13].

7.3. Resistance to high elevated temperature:

Y. Aygörmez et al., studied the effects of exposure to high-temperature on compressive and flexural strengths, for metakaolin based geopolymer produced by silica fume addition as replacement of metakaolin and colemanite waste with and without polypropylene fibres, up to 20% at 300, 600, 900℃. the models preserved in stable condition. And Polypropylene improved flexural strength in elevated temperatures [31]. S.K. Shill et al., studies durability of fly ash based geopolymer mortar against both chemical fluids and elevated temperature, they tested compressive strength of 3 and 28 old day. The samples had been suffered with loses in compressive strength, and the saturated geopolymer with hydrocarbon fluids decompose to soap and salt after 60 cycles of high temperature [33].

X. Jiang et al., investigated resistance of geopolymer concrete to fire condition more than 1200℃ temperature and comparing with ordinary Portland cement concrete. they conclude that conventional concrete showed more lose in compressive strength than geopolymer concrete [34]. Nazari et al., they examined the effect of cooling fly ash based geopolymer concrete to water and air after exposed to high temperature started from 400℃ and ending to 1000℃, they conclude that geopolymer concrete showed excellent mechanical performance [35]. Y. Aygörmez et al., pointed that specimen still show stable condition when they exposed to elevated temperature at 900 C, and fibres addition help in rising flexural strength for the specimen at elevated temperature [31]. F. Fan et al., examined fly ash based geopolymer heated to 500 C and they conclude that the proportion of water to fly ash and regimen of curing had significance role in determining mechanical and thermal properties for geopolymer [36].

H.Y. Zhang et al., they studied the influence on strength bond of geopolymer concrete reinforcement exposed to 100, 300, 500, and 700 C degree of temperature, and they result that the bonding force between geopolymer concrete and the reinforcement bar showed good bond strength until the temperature rich 300 C, after that strength will had reduction [37]. T. Kovárˇík et al., they remarked that metakaolin based geopolymer concrete exposed to elevated temperature reach to 1000 C had durable mechanical strength when the aggregate to metakaolin ratio is (2.5) [38]. A.Z. Mohd Ali et al., experimented fly ash based geopolymer concrete by exposed to fire at tow hour range shows slightly weight loss due to evaporation the free water of the samples, and the thermal compatibility of geopolymer matrix and aggregate improve the resistant of spalling [39]. R.K. Preethi, B.V. Venkatarama Reddy, they showed that high compressive strength will be improved by using fly ash and ground furnace blast of slag as supply of alumina and silica based geopolymer concrete, and they improved that efflorescence caused by sodium salt unreacted moving to the surface do not influence on compressive strength [40]. W.G. Valencia Saavedra, R. Mejía de Gutiérrez, they pointed that ground furnace blast of slag/fly ash based geopolymer concrete will showed higher performance than normal concrete produced by ordinary Portland cement when exhibited to 1100 C [41].

8. Conclusion:

Geopolymer as a technology process represents a good solution to manage the waste of industrials produced by-product. The physical and chemical properties of the geopolymer resources determined the characters of geopolymer. Activators like alkali and curing regimen play significance role in geopolymer properties. Based on published research, it can be drawn the following assessed:

1. A wide range produced as industrial, agricultural waste as by-product may come as a source of silicate, aluminate for Geopolymer production.

2. Water content significant effect the mechanical properties.

3. Curing time and degree of heat curing related directly with compressive strength, so it directly related with engineering properties.

4. Geopolymer showed good resistance to aggressive environmental attack.

5. Using fineness rescores materials will be improving the mechanical properties and produce high compressive strength so as enhance the microstructure of the matrix. Also, fineness particles usefully in reducing permeability and accelerating the polymerization reaction which will improve the early strength.

6. Alkali activators concentration and its molarities significantly impact on fresh properties and setting time of the mixture.

7. Geopolymer have better resistance for sulphate attack, acid attack.

8. Geopolymer exhibits more durable performance in firing and had lower reduced in compressive strength rate from Portland cement concrete.

9. Geopolymer shows lower shrinkage issue from Portland cement concrete.

10. Curing for geopolymer need 50 to 90 C for 24 hr.,

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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