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Properties of One-Part Versus Two-Part Geopolymers Composites – A Review

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ABSTRACT
Cement is one of the basic materials that used in the concrete industry, as it used in many engineering applications. The cement industry is one of the main phenomena that causing the global warming process, as it has a high carbon footprint. Cement contributes about 8 % of CO_2 emissions global. The discovery of geopolymer concrete is a step forward for the development of alternative materials for cement. Consequently, the development of one-part geopolymer concrete has better features than the conventional two-part geopolymer. Some useful information about materials of geopolymer was introduced in this review. The review included the types of activators, the preparation methods of geopolymer, fresh properties, mechanical properties and the durability of geopolymer were discussed. Finally, the environmental impact and costs of geopolymer concrete was summarized. There is no need to use conventional geopolymer with viscous and corrosive solutions, as the one-part geopolymer concrete has better mechanical properties and it is cured at ambient temperatures. However, one-part alkali-activated materials could be best suited for in situ casting while their two-part counterparts might find applications in precast work.

Keywords*: Geopolymer, One-part geopolymer, Two-part geopolymer, Mechanical properties, Durability, Cost, Environmental impact*

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I. Introduction

Nowadays, it is necessary to find environmentally friendly construction materials as alternative to ordinary Portland cement (OPC) in order to limit CO_2 emission. The manufacturing of cement is one of the phenomena of global warming and melting of ice in different regions, because approximately 6% of CO_2 emissions are caused by the cement industry [1]. Moreover, to produce 1 ton of OPC 1 ton of CO_2 is released [2]. The global cement production rate reached 4.1 billion metric tons for the year 2018 [3]. The production of cement in the year 2018 around the world is shown in Fig. 1. Consequently, the researchers worked hard to find alternative materials for cement to reduce the emission of CO_2.

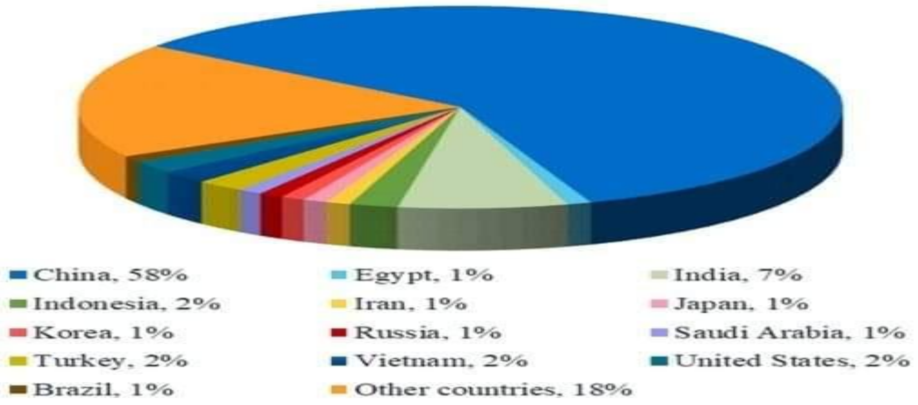


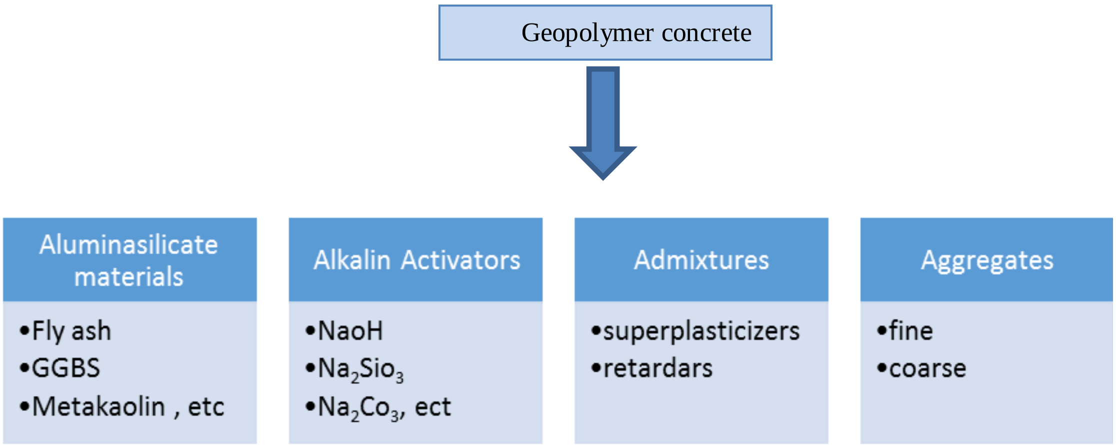
Fig. 1. Production of cement in the year (2018) around the world (USGS, 2019).

Geopolymer is one of the best innovation in replacing the (OPC). When using an appropriate mixture of geopolymers, reduction up to 80% in CO_2 emissions and 60% in energy consumption compared to cement [4]. Therefore, geopolymer has become widely known and occupied a great position among researchers [5], [6], [7]. Davidovits (1979), was the first author to address the term of geopolymer [8]. The traditional geopolymers reported in previous researches are two-part mixtures which components contains both liquid phase (activator) and solid phase (aluminosilicate materials). Geopolymers have many advantages, namely: more environmentally friendly, high level of workability, higher compressive strength [9], [10], [11], more resistance to acids and sulfate [12], [13], high resistance to temperature ([14], [15], lower drying shrinkage and creep ([9], [16], [17]. On the other hand, geopolymerization is a complex process [14]. Moreover, there are still some shortcomings associated with geopolymer concrete such as alkaline solutions make the handling and applications of geopolymer difficult because this solutions are corrosive, viscous, difficult to move from one place to another and difficult to store in large quantities ([5], [18], [19]. The soluble silicate, which is added to geopolymer is not completely consumed during the geopolymerization process, and this one of the reasons for increasing the permeability and decreasing the durability of conventional geopolymer. Therefore, the need to evolve geopolymer mixes.

The discovery of a one-part geopolymer "just add water" is a step forward in the field of manufacturing geopolymer mixtures. One-part geopolymer called geopolymer cement because it is simply added water only in the application of its use. One- part geopolymer consist of solid alkali activator and solid aluminosilicate. Before usage, the solid alkali activator and solid aluminosilicate are mixed together uniformly and then adding water when the usage is needed similar to Portland cement [20]. Thus, lead to that the usage of alkaline solution in the conventional geopolymer is not necessary. Initially, some researchers found defects in one-part geopolymer such as low compressive strength [21] and low mechanical strength [22]. Therefore, there are many efforts from researchers to develop one-part geopolymers. Through the efforts of the researchers, the geopolymer has achieved a compressive strength up to 57 MPa at ambient temperature, this make one-part geopolymer gain comparison with two-part geopolymer [23].

II. Materials of geopolymer

Geopolymer is consist of alkali activator materials and aluminosilicate materials (solid wastes) as source materials [24], [25], [26], [27]. The constituents of geopolymer concrete and some of their examples that are used can be seen from Fig. 2 [28], [29]. Additionally, aluminosilicate materials can be divided into three mainly categorize industrial wastes (by-product), agricultural wastes, and municipal wastes. Fig. 3 shows the solid wastes that used in geopolymers concrete in detail [30].



Aluminasilicate materials	Alkalin Activators	Admixtures	Aggregates
•Fly ash	•NaoH	•superplasticizers	•fine
•GGBS	•Na_2Sio_3	•retardars	•coarse
•Metakaolin , etc	•Na_2Co_3, ect		

Fig.2. Constituents of geopolymer concrete [28],[29].

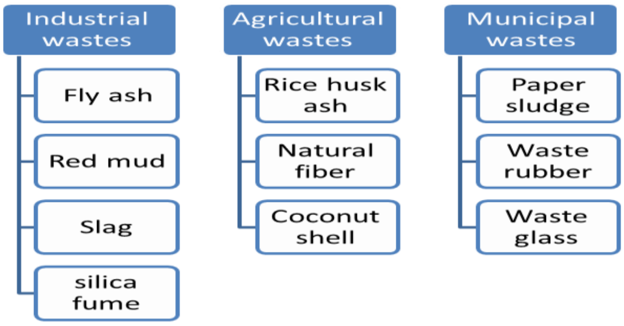


Fig. 3. Solid wastes that used in geopolymers concrete [30].

2.1. Alumino-silicate materials

Raw materials for the binder are a material with high alumina and silica. There are many types of aluminosilicate materials such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin and silica fume. Fly ash class (F) and GGBS are more used because of their availability and desired properties [31].

2.1.1. Fly ash

Fly ash is aluminosilicates by-product that is generated in thermal power plants. There are two classes of fly ash class (c), having greater than 20% of CaO and class (F), having lower than 7% of CaO. The main difference between these classes is the amount of calcium, silica, alumina and iron content in the ash. The shape of the fly ash particle is spherical glassy, with a specific surface area of 2500–5000 g/cm^2 and a density of 2.2–2.8 g/cm^3 [29]. The use of low calcium fly ash (class f) gives a longer setting time and better workability [31], [32], lower shrinkage and carbonation [33], [32], higher chloride resistance [33] and better fire resistance [31], compared to high calcium fly ash (class c). Fly ash was activated by different alkaline solution like sodium hydroxide, potassium hydroxide and potassium silicate. The results showed that the workability becomes better with potassium hydroxide or potassium silicate in fly ash geopolymer [34].

2.1.2. Ground granulated blast furnace slag (GGBS)

GGBS is a cementitious material whose main use is in concrete and is a by-product from the blast-furnace used to make iron. It added to the mix to achieve hardening at ambient temperature curing. It mainly contains CaO, silica, alumina, and small amounts of magnesia and has a ‘‘bulk density from 1000-1300 kg/m^3 and fineness 350 m^2/kg. The use of it gives increasing in sulfate and weather resistance [35], [36].

2.2. Alkaline activators

The alkaline activators, important material to product geopolymers. Sodium hydroxide, sodium silicate and sodium carbonates are generally used as alkaline activators [37]. There are two types of the activators, solid and liquid. Liquid activators usually used in two-part geopolymer; however solid activators usually used in one-part geopolymer. By using solid activators, the cost of materials and environmental footprint become lower and transportation becomes easier [38]. Chemical mechanism that followed in two cases whether solid or liquid to dissolve Si, Al and Ca is the same [39].

2.3. Coarse aggregates and fine aggregates

Aggregates occupy almost 70% of concrete volume, where the mass proportion of coarse aggregate and fine aggregate usually used is 65% and 35% respectively. There are tests should be done on aggregates such as: sieve analysis, impact test, etc [40], [41].

2.4. Admixtures

Admixtures are the material used to change rheological properties of fresh concrete [42]. Superplasticizers are used to enhance the slum value and the workability of concrete. Retarders are the materials used for increasing the setting time of concrete [28], [29].

III. Comparison of one-part and two-part geopolymer

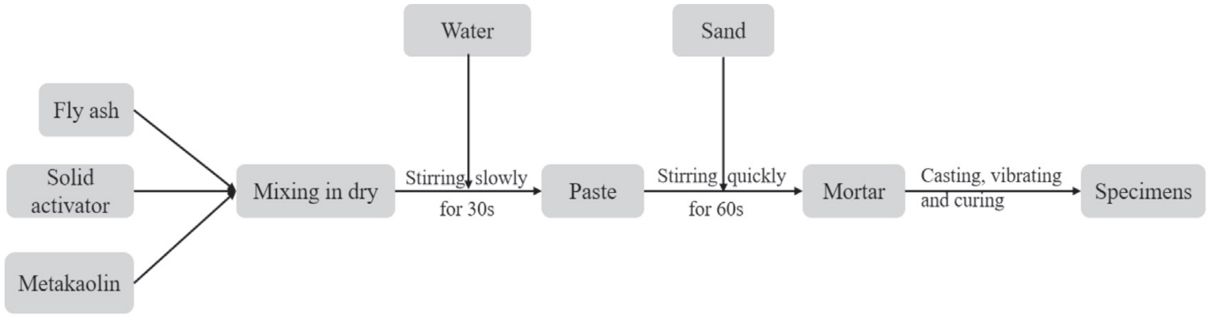
There are many efforts of researchers to make comparison between one-part geopolymer and two- part geopolymer by doing a lot of experiences to study the different properties of them. One-part geopolymer is similar to two-part geopolymer in their materials but there are a few differences between them in the activator materials and the preparation method [43].

3.1. Activator materials

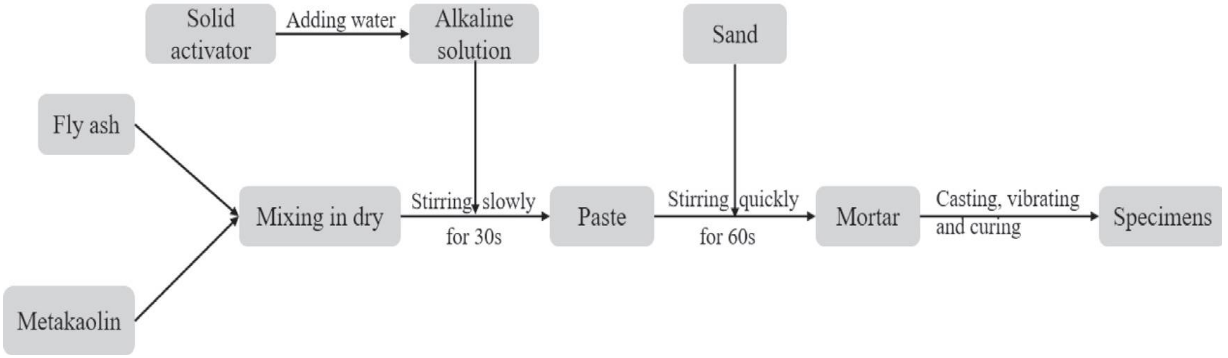
In one-part geopolymers, the activator materials are solid. However, in two-part geopolymers, the activator materials are solutions. Sodium meta silicate is the main type of activator that used as solid activator [37]. It was found that by [44] that CaO powder generates higher heats of hydration than $Ca(OH)_2$. Moreover, $Ca(OH)_2$ used instead of NaOH, because solid NaOH is corrosive and hygroscopic [45], [46]. In addition to, [47] used $Ca(OH)_2$ with Na_2CO_3 and make comparison between them and NaOH , the results showed that one part geopolymer that activated by $Ca(OH)_2$ and Na_2CO_3 has compressive strength 60% higher than that activated by NaOH.

3.2. Preparation method

During the preparation of one-part geopolymer, the solid activators and precursors were mixed with water at the same time when the usage in the site. However, during the preparation of two-part geopolymer, the activator solution was prepared and cooled at ambient temperature before mixing with the precursors. The preparation methods of one-part geopolymers and two-part geopolymers shown in Fig. 4 [43].



A- One-part geopolymer

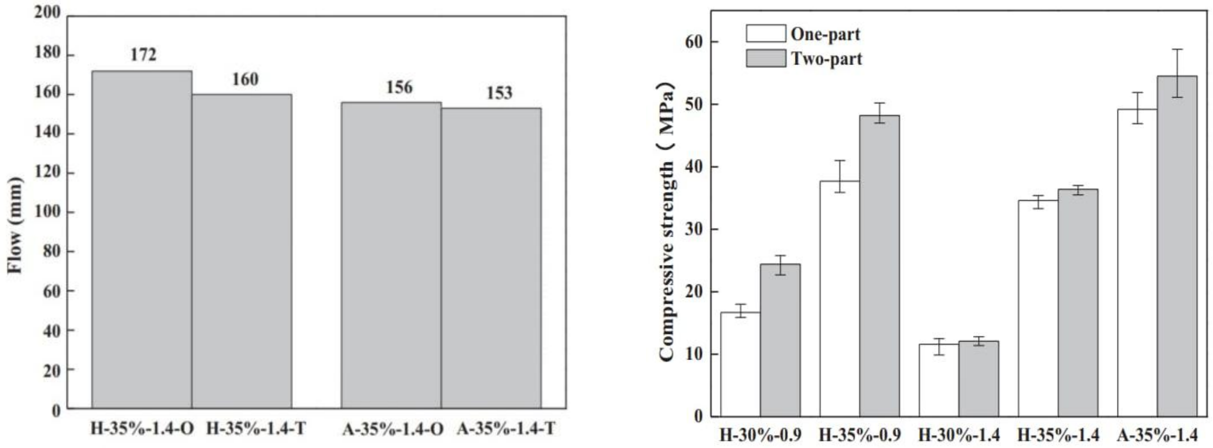


B- Two-part geopolymer

Fig. 4. Preparation methods of geopolymers concrete [43].

It is obvious that the properties of geopolymers depend on many factors such as; concentration of the activator and curing conditions. The study of [48] showed that the flexure and the compressive strength of one-part and two-part geopolymers increase by increasing the concentration of the activators and the workability decreases. Moreover, it was reported that geopolymers have been cured at high temperature or high pressure give compressive strength higher than that have been cured at ambient conditions [49], [50]. Additionally, (Nematollahi et al., 2015) [51] showed that the compressive strength and workability of the one-part geopolymer that consists of fly ash and slag and activated by three different of sodium silicate decreased by 31% and 35% respectively, as compared to that the corresponding two-part geopolymer.

Moreover, (Wang et al., 2017) [52] studied the mechanical properties and reaction process of slag with sodium silicate in two cases (solid and liquid). The results showed that, the two reaction processes were similar, however the mechanical performance of one-part geopolymer was better than that the two-part geopolymer. Consequently, (Zhang et al., 2021) [43] reported that, the workability of one-part geopolymer is better than that the two-part geopolymer at the same conditions (constant activator concentration 35% and the same activator modulus 1.4). Fig. 5-a shows the comparison of the fluidity of one-part and two-part geopolymer, and they reported that the compressive strength of one-part geopolymer was lower than the corresponding strength of their two-part geopolymer, and this is shown in Fig. 5-b. The comparison of one-part geopolymer and two-part geopolymer was summarized in Table 1.



a-comparison on the fluidity of one-part and two-part geopolymer

b- comparison between one-part and two-part geopolymer at 7-day curing age

Note; T: two-part geopolymer, H: hydrous sodium silicate (Na_2SiO_3), O: one-part geopolymer and A: anhydrous sodium silicate (Na_2SiO_3).

Fig. 5. Comparison between one-part and two-part geopolymer in fluidity and compressive strength (Zhang et al., 2021)[43].

Table (1): Simple illustrative comparison of one-part and two-part geopolymer

Parameters	One -part geopolymer	Two-part geopolymer
Constituent materials	1-ALumina silicate sources such as: (Fly ash, slag, kaolin, and slaked lime…,ect). 2-Solid alkali activator such as: NaOH powder, Na2Sio3 powder, and Na2CO3 powder or mix of them. [53], [54], [55].	1-Alumina silicate sources such as: (Fly ash, slag, kaolin, and slaked lime…,ect). 2- Alkali activator solutions such as : NaOH, Na2Sio3, and Na2CO3 or mix of them. [56], [54], [57].
Mixing method	-All materials are mixed together at the same time (binder and filler). -mixture design depends on; water to cement ratio (w/c). [10].	-The binders are made in another place before mixing. -Mixture design depends on; 1-The ratio of the solid materials to the liquid materials. 2-The ratio of pozzolanic materials to alkali activator solution. [10].
Setting time	-setting time decreased by increasing activator content [58]. -initial setting time was between 25-45 min, and final setting time was between 55-125 min (Bashar et al., 2019); however, initial setting time was between 23-150 min and final setting time was between 69-230 min [39].	-The difference between initial and final setting time decreases with increasing slag content [42]. It was reported the initial setting time decreased to 290 min by using 10% of slag in binder, and by using 20% and 30% of slag, it reduced to 94 min and 41 min respectively [59].
Compressive strength	-It was 45 MPa by activating fly ash or slag by sodium metasilicate at air curing [60]. -It was 39 MPa and 36 MPa by activating fly ash and GGBFS by sodium metasilicate at air and heat curing respectively [61]. - It was 66 MPa by activating GGBFS by using sodium metasilicate at ambient curing [20]. - It was 44.9 MPa and 48 MPa by activating fly ash and GGBFS by sodium metasilicate, sodium carbonate and potassium hydroxide at heat curing and air curing respectively [65].	- It was 37 MPa by activating fly ash by sodium silicate and sodium hydroxide at air curing [62]. - It was 42.5 MPa by activating GGBFS by sodium silicate and sodium hydroxide at air curing [63]. - It was 45 MPa by activating fly ash by sodium hydroxide at heat curing [64].
Split tensile strength	-It was 3.5 MPa, 3.1 MPa and 4.75 MPa at water, air and solar 23°C curing respectively [61].	-It was 3.1 MPa at steam curing [66]. -It was 3.3 MPa at water curing [67].
Flexural strength	-It was 6 MPa at ambient curing [20]. -It was 5 at water curing, 8.3 MPa at plastic curing and 4.2 MPa at air curing [68]. -It 3.4 MPa at air curing [69].	- flexure strength increase by increasing the molarity of alkaline solution [70], [34]. -It was from 2.24 MPa to 6.41 MPa [71]. - It was from 4.9 MPa to 6.2 MPa [72]. -It was 6.86 MPa [73].

		- It was from 5 MPa to 12 MPa [74].
Acid and sulfate resistance	It has better resistance to acid and sulfate [10].	It has better resistance to acid and sulfate [10], [75],[76].
Fire Resistance	It has a good fire resistance. [10].	It has a good fire resistance. [10]. [77], [78], [79].

IV. Properties of one-part and two-part geopolymer

4.1. Properties of conventional geopolymer (two-part)

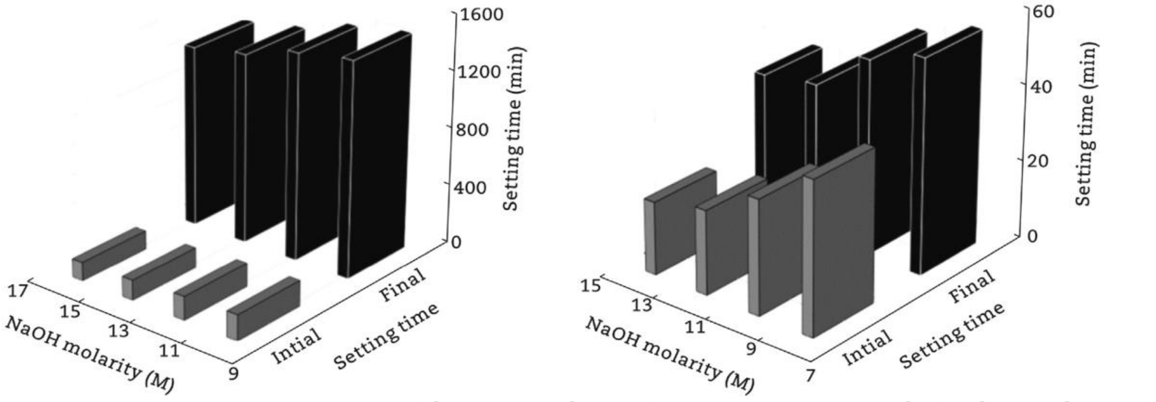
Geopolymer concrete is considered one of the innovation and sustainable materials compared to cement because of it is many advantages. It is obvious that the properties of concrete depend on several factors that are reviewed in this part. In addition to the curing conditions and durability of geopolymer concrete will be discussed below.

4.1.1. Workability

The particle size of raw materials and types of alkali activator and its amount are among the most important factors affecting on the workability. For example; anhydrous sodium meta-silicate has better fluidity than other activators [80]. The study of (Mehta and siddique, 2016)[66] showed that the use of Na_2SiO_3 as an alkali activator without NaOH, reduces the slump of geopolymer concrete. Another study showed that the increasing of rate of SiO_2 / Na_2O in Na_2SiO_3 solution, increases the slump of geopolymer concrete [81]. In other studies, with increasing of the concenteraion of NaOH, the workability of geopolymer concrete that prepared from different sources of fly ash was improved [82], [83]. According to the particle size of raw materials, the reduction of particle size of fly ash improves the workability, but the irregular shape of slag particles gives poor workability [84], [85].

4.1.2. Setting time

The high slag content accelerate the intial and final setting time [86], [87]. However, the study of (Elyamany et al., 2018) [88] showed the use of slag and fly ash reduce the setting time of geopolymer concrete. Reaserchers found that the type of alkali activator affecting on the setting time. The use of NaOH alone without Na_2SiO_3 causes a delay in the setting time [89] and make the geopolymer set very slowely [19]. Moreover, the reaserchers found from their studies that the setting time of geopolymers consist of fly ash was effectively extended with the decrease in the molar concentration of NaOH [90], [91]. However, the increasing the molarity of NaOH causes increasing in final setting time in geopolymer mortar [88], this is shown from Fig. 6. Additionally, the using of Na_2SiO_3 solution increases the setting time , and the use of Na_2SiO_3 and NaOH together makes setting time shorter [92].



a- (Elyamany et al., 2018) b- (Zailani et al., 2020)

Figure 6: Setting time of FA-based geopolymers vs. NaOH molarity.

4.1.3. Comperessive strength

Compressive strength of geopolymer concrete depends on raw materials, type of activator and curing conditions, and this is summerized in Table 2, SS means, Na_2SiO_3 and SH means NaOH. Moreover, it was reported that the strength of geopolymer which activated by Na_2SiO_3 was improved at room temprature [93], [86]. The study of (Zhang et al., 2020) [94] showed that the compressive strength can reach 80.7 MPa by using potassium silicate and potassium hydroxide. Besides, some researchers used fiber to improve the mechanical properties of geopolymer [95], [96], [97], the compressive strength that achieved after 28 days was 47.60 MPa and tensile strength was 2.8 MPa [98].

Table 2: Compressive strength of geopolymer concrete

Compressive Strength (MPa) (28 days)	Curing time & Temperature	Slump (mm)	Activator	Aluminosilicate precursor
64.0 (7 days)	70 ° C for 1 day	100	SS SH+	FA [99]
36.0	25 ° C	-	SH	GGBS [100]
64.4	23 ° C	240	+SS SH	GGBS [101]
52.3	75 ° C for 1 day	130	+SS SH	GGBS+FA [102]

The study of (Huang et al., 2018) [103] showed that the compressive strength reached 56,4 MPa and of about (36-58 MPa) (Ghazy, 2020) with ambient temperature, while when geopolymer mortar activated by Na_2SiO_3 and NaOH at ambient temprature. Moreover, it was reported that geopolymer consist of fly ash and activated by Na_2SiO_3 and NaOH has a 7-day compressive strength of 67.4 MPa at room temprature. However, after high temprature curing for 28-day, the compressive strength was only 52.75 MPa [104], [86]. Fig. 7 showed the variation of compressive strength at room temperature.

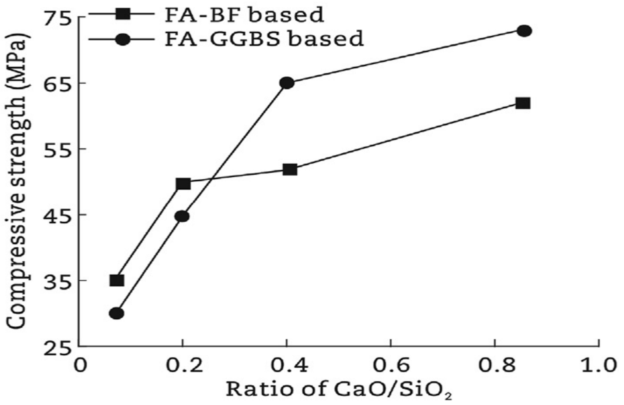


Fig. 7: The variation of compressive strength at room temperature, BF (bazalt fiber), [105].

4.1.4. Durability of geopolymer concrete (two-part)

Durability is defined as the ability of concrete to withstand the conditions for which it is designed without deterioration for a long period of years. The following factors control the durability of geopolymer concrete.

4.1.4.1. Resistance to acid attack

There are many studies on the effect of acid attack on geopolymer concrete [106], [107], [108], [76]. In the resistance of acid attack, the degradation of the geopolymer depends on two factors: the concentration of the acidic solution and the exposure time. There was a study by (Thokchom et al., 2009) [109] on resistance of fly ash based Geopolymer mortars in sulphuric acid. The duration of the immersion was 18 weeks in 10% sulphuric acid solution, it was reported that there is very low weight loss (0.41% to 1.23%) and the higher weight loss happened on samples having higher percentage of Na_2O The samples almost lost alkalinity. The loss of compressive strength was 28% when Na_2O at 8% and 52% when Na2O at 5%. And this lead to the geopolymer mortars has better durability and excellent mechanical properties under sulphuric acid environment. From previous study by (Zang et al., 2020) [110], it was reported that geopolymer has better resistance to acid attack as compared to (OPC) and this showed by exposing these mixes to 5% H_2SO_4 [111] and 2% H_2SO_4 [24].

4.1.4.2. Resistance to chloride attack

From the previous studies, they found that the geopolymer has a high resistance to the attack of chlorides, as a test was conducted on a sample of the geopolymer composed of fly and exposed to severe environmental conditions using chloride for a period of 90 days. It was noted that the surface of the test sample did not have any damage or significant loss in compressive strength, which leads to the use of geopolymer in the sea water area is much better than cement [112]. Bellum et al. (2020) [113] reported that the geopolymer concrete has a good resistance to chloride attack. Albitar et al. (2017) [114] investigated the durability of geopolymer concrete in various corrosive environments. Specimens were exposed to 3% of sulphuric acid and 5% solutions of sodium chloride, sodium sulphate, and magnesium sulphate, respectively. Besides, they were subjected to alternate wetting, cooling, heating and drying cycles. The results showed that geopolymer concrete has a good resistance to all of the corrosive solutions and environments. Tennakoon et al. (2017) [75] reported that geopolymer concrete that contains of fly ash and slag has lower diffusion of chloride as compared to (OPC).

4.1.4.3. Resistance to sulfate attack

To assess the resistance of geopolymer concrete to sulfate attack, the dynamic elasticity modulus is one of the most important criteria. There are two main factors to get the best sulfate attack: slowing down the corrosion of sulfate due to much denser microstructure and more stable polymerization. Geopolymer concrete's resistance to sulfate attack is excellent [75]. Even after exposure of these specimens for up to 90 days to sodium sulfate solution, there is no damage to the surface. The compressive strength loss was between 7 % to 38 % when exposed to sodium sulfate [112].

4.1.4.4. Resistance to heat

From previous study by (Satpute et al., 2012) [115] it was reported that the activation of geopolymer concrete curing temperature and its duration are very important. The temperature and curing time improves the compressive strength, although the increase in strength may not be significant for curing at more than 600°C. (Bakharev, 2005) [13] reported that the study of thermal stability of properties firing to around 800°C-1200°C of materials prepared by using fly ash class f and using potassium and sodium as activators, when compared to sodium and potassium silicate, potassium silicate as activator was better in compressive strength on heating and retro gradation was started at 1000°C. Aygormez et al. (2020) [116] reported that geopolymers have a good resistance to temperature by curing the specimens of geopolymers mixes at room temperature for almost year. Geopolymer that consists of fly ash, aggregates and OPC was subjected to a temperature of 95°C showed a good resistance against varying temperature [117]. Saavedra et al., (2017) [118] studied the effect of elevated temperature on geopolymer concrete that composed of fly ash and the results showed that GPC has a good resistance to temperature.

4.2. Properties of one-part geopolymer concrete

In recent years, one-part geopolymer has been discussed by many researchers [119], [120], [121], [122]. Therefore, the fresh properties, harden properties, heat cured and ambient cured of one-part geopolymers are discussed below. In addition to environmental impact and costs of one-part geopolymers are summarized.

4.2.1. Workability

Nematollahi et al. (2015) [51] reported that in one-part geopolymer, workability decreases with increasing the amount of sodium silicate activator in fly ash and slag and workability according to relative slump values of one-part geopolymer was approximately 35% lower in comparison to similar two-part geopolymer. It was reported that fly ash and blast furnace slag have been given a good workability during mixing and vibration [123]. It was reported that the fluidity of the mixture that consists of constant solid activator (anhydrous Na_2SiO_3 or hydrous Na_2SiO_3) concentration of 35% decreased by 27% when the activator modulus decreased from 1.4 to 0.9. This lead to that when the modulus of activator decreases, the workability decreases [43].

4.2.2. Setting time

The initial setting time is measured from the beginning of adding water to the dry mixture until the penetration of the sample surface to the bottom of the plate with the needle to a depth of 3mm-5mm, while the final setting time is measured from the beginning of adding water to the dry mixture until the inability of the needle to affect the surface of the samples. It was reported that the setting time increased when, solid sodium hydroxide was kept instant, solid calcium carbonate was decreased, and the amount of blast furnace slag was increased [119]. Initial setting times of one-part geopolymers have varied between 23-150 min and final setting times have varied between 69-230 min [119], [39]. In one-part geopolymer which contains of fly ash it was reported that the initial setting time of one-part geopolymers was 25-45min and the final setting time was 55-125 min [58].

4.2.3. Water absorption

It was reported that, in comparison of slag-rich alkali activated systems with fly ash-based alkali activated systems, the water absorption was lower [124]. The water absorption values of one-part alkali-activated blast furnace slag was 7–16%, and these values decreased as curing time increased [119], and water absorption decreased with increase in blast furnace slag content [23].

4.2.4. Compressive strength

From the previous study by (Kolousek et al., 2007) [21] one-part geopolymer was prepared by kaolinite and powdered hydroxides achieved compressive strength lower than 1 MPa with 7-days. Moreover, many researchers prepared one-part geopolymer by using anhydrous sodium metesilicate powder in a fly ash+slag or fly ash+slag+lime system at ambient temperature, the compressive strength over 37 MPa [51]. In addition, some researchers employed sodium hydroxide and sodium silicate in fly ash or GGBS at ambient temperature, strength of GGBS only could achieve about 50 MPa with 28-day [7]. The reported 28-day strength of one-part geopolymer prepared by Ground furnace slag and Ultra-fine fly ash (FASB) that activated by different three types of sodium metasilicate under standard curing ranges from about 35 MPa to 75 MPa [125].

The simultaneous use of Na_2CO_3 and Na_2SiO_3-anhydrous in one-part geopolymer and the influence of Na_2CO_3 on the microstructure of Na_2SiO_3-anhydrous activated slag and FASB composites have been studied by (Ma et al., 2019)[122]. The 60-day strength of single GGBS-based geopolymer activated by half Na_2SiO_3-anhydrous and Na_2CO_3 can reach over 70 MPa. This means that the using of Na_2CO_3 makes the one-part geopolymer cleaner, even though there is a little difference in the cost of per MPa for a cubic meter of specimens. And this indicates that one-part geopolymer activated by both Na_2SiO_3-anhydrous and Na_2CO_3 has less potential environmental impact without sacrificing the performance and economic benefit. The 57 MPa compressive strength was achieved by using anhydrous metasilicate as alkine activator and using lithium slag (LS) and (BFS) as alumino-silicate precursors [23]. In thermal treatment, one-part geopolymers that activated by 33 % Na_2CO_3 are higher than that activated by 25 % NaOH with the same ratio of Na_2O, and the largest 210-day compressive strength 55.8 Mpa. This lead to that Na_2CO_3 is more better than NaOH for use in one-part geopolymers [126]. Activated Metakaolin and fly ash by anhydrous Na_2SiO_3 or a combination of anhydrous Na_2SiO_3 and NaOH to compare one-part geopolymers with two-part geopolymers [43]. The results showed that the use of anhydrous Na_2SiO_3 is more effective than the combination of anhydrous Na_2SiO_3 and NaOH on the properties of one-part geopolymers and the compressive strength reached 49.2 MPa after 7-day at ambient temperature.

In one-part geopolymer the heat curing depends on precursors and mix design and it have been cured at elevated (40-80°C) and at ambient (25°C). The curing occurs at saturated condition such as temperature and relative humidity. The heat generated by dissolution the solid activator has a positive effect on the curing [127]. From a previous study of one-part geopolymer with 28-day of curing, a compressive strength at 20 °C was < 5 MPa and at 80 °C was 38.5 MPa [128]. Some authors reported that regardless of the type of activator used in the geopolymer mixture and geopolymer source materials, the 28-days compressive strength can be obtained in an ambient curing similar to the compressive strength in a heat curing [129]. This lead to the possibility of using the solid activators in practice without the heat curing.

4.2.5. Tensile strength

It was reported that the tensile strength decreases with increasing the solid activator anhydrous sodium metasilicate [58]. From the previous studies on one-part geopolymer that activated by blast furnace slag; they reported that tensile strength, flexural strength, modulus of elasticity which all decreased as the portion of light weight aggregate to sand was increased [130].

V. Environmental impact and costs of one-part geopolymers

There are some factors control the cost and environmental impact of geopolymers such as; the contents and types of activators and curing methods [121],[125].

5.1. Environmental impact

There are environmental impact factors that increase the global warming of geopolymers such as heat curing and transportation of raw materials. Geopolymers have a modest positive or negative impact compared to the impact of OPC concrete [131]. From the previous studies, the environmental impact is 24% for one-part geopolymer and 60% for two-part geopolymer of the environmental impact of (OPC) [132], [133]. Portland cement has CO_2-emission 0.83, so geopolymer much cleaner than it [134]. With the updated data, the CO_2-e per kg of the dry component (i.e. without the water) was calculated, the difference between sodium hydroxide and sodium silicate was only around 10 % [6]. Therefore, one-part geopolymer more environmental friendly than two-part geopolymer [121]. The embodied CO_2 index (ECI) which can be expressed as the following equation (1); [135], [136], [121].

$$\mathbf{ECI= (CO_{2\text{-}e_T}) / FC_{28}} \quad \mathbf{(1)}$$

Where;

- ECI (kg/ MPa.m^3) is the embodied $CO_{2\text{-}e}$ index.
- $CO_{2\text{-}eT}$ (kg/m^3) is total $CO_{2\text{-}e}$ emission of 1m^3 of cementitious materials.
- FC_{28} (MPa) is compressive strength measured at 28 days in laboratory.

5.2. Costs

The cost of materials that used in engineering applications is an important factor. The cost of solid activators is very higher than that OPC, but the cost of Fly ash and GGBS are lower than OPC. There is integrated cost index which can be expressed as the following equation (2); [121], [125].

$$\mathbf{PM=CT / FC_{28}} \qquad \mathbf{(2)}$$

Where;
- PM ($\$/m^3$.MPa) is price per MPa for a cubic meter of cementitious materials.
- CT ($\$/m^3$) is actual cost for a cubic meter of materials.
- FC_{28} (MPa) is compressive strength measured at 28 days in laboratory.

Economic allocation of one-part geopolymer was compared by (Habert et al., 2016) [6] they reported that it would be possible to achieve an 80% reduction in costs compared with OPC. The most cost-efficient one-part geopolymer thermal insulation material would cost €67/m^3 [133].

VI. Conclusions

The following summarizes and highlights the points discussed in this review:

(1) The production of Portland cement is one of the main causes of global warming, as it emits large amount of carbon dioxide, so the discovery of geopolymer was a step forward, as well as alkaline activated materials that lead to the least impact of cement on global warming.

(2) One-part geopolymer more environmental friendly than two-part geopolymer. Through as no need the viscous corrosive solution that used in the manufacture of traditional two-part geopolymer. With researchers continue to strive to develop geopolymer mixtures, so the discovery of one-part geopolymer had a great impact because it is mixed with water when the usage such as cement. As the one-part geopolymer concrete has better promising properties and it can be cured at ambient temperatures.

(3) Fly ash class F and ground granulated blast furnace slag are the major aluminosilicate sources because of their availability and desired properties, whereas synthetic solid: sodium metasilicate, sodium hydroxide, sodium carbonate and sodium silicate are the major solid activators used to produce the geopolymer mixtures in most literatures. However, these synthetic chemicals, especially synthetic sodium silicate, do not represent a commercially or ecologically optimized solution when used as the sole activators.

(4) The cost of solid activators is very higher than that Portland cement, whilst the cost of fly ash and ground granulated blast furnace slag are lower. Consequently, there have been innovative attempts to replace sodium hydroxide with red mud, sodium carbonate, or calcium oxide, for instance, and sodium silicate with silica fume, rice husk ash, or maize cob ash.

(5) The published information on the shrinkage of one-part geopolymers and the effect of retardants on the setting time of one-part geopolymers are scarce. The study of the PH conditions of the alkali activation materials is needed to prevent the steel corrosion. Also, more studies about early strength of one-part geopolymer are needed.

(6) However, more documentation and testing is still required in order to demonstrate the suitability and long-term durability of these binders. In addition, fundamental understanding on the reaction kinetics is lacking.

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