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A REVIEW OF MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE

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ABSTRACT

A safe disposal of huge amounts of industrial waste from different industries (wood industry, power generation industry, iron and steel industry, mining industry, rice grinding industry and other industries) is a major challenge in addition to the environmental and health damage caused by these wastes. The best way to get rid of this waste is to dispose of the waste. In recent years, the use of geopolymers has been used. The use of geopolymers in solving solid waste management problems of alumosilicate solid waste from various industries is also characterized by solving the ecological degradation problem regarding to utilize of OPC as a main bond in a construction manufacture. The outcome of modern studies indicate that geopolymer cement manufactured utilizing different by-product showed identical mechanical or physical properties and strength comparized with OPC concrete.

The present paper dealt with the brief review of previous studies on use of the industrial by-product as major bonding material within geological concrete manufacturing. The influence of key factors such as particle size distribution, strong environmental exposure to mechanical strength, use of chemical activator, physical properties, microstructure, post-processing system, and durability properties of geological concrete were also addressed. In addition, the current procedures for physical design, manufacturing and post-industrial processing have been thoroughly reviewed to determine the restrictions of present geopolymer technique in order to hinder their widespread application in the construction process. This review study also analyzed the microbiological structure of the geopolymer samples and the comparison of the geological polymers with the other bonding materials.

Keywords: Waste Management; Recycling; Sustainability; Geopolymer concrete; Microstructure; Fresh properties; Mechanical properties.

Contents

1. Introduction

Long-standing Ordinary Portland Cement (OPC) is a traditional documented material widely used in the manufacture of concrete. However, the uses of OPC in basic building materials have been widely doubted over the past decades due to the different ecological effects of clinker production [1, 2]. Within reality, clinker plants produce Portland cement worldwide at a rate of 1.5 billion tons of carbon dioxide per year, which recorded 5% of total carbon dioxide emissions and if this way continues unwanted will raise this value to about 6% per year [3-5]. Apart from OPC, sand and gravel are also key constituents in a manufacture of concrete, whose created from excavate processes that are both energy heavy and generate a high grade of environmentally harmful junk. The lack of normal resources for building materials within numerous developing cities have also lead to the transportation of building materials over long distances, thereby increasing the cost of building materials. All above problems are versus a sustainable situation and immediate remedial action should become taken to assure sustainability in this area [1].

Environmental problems resulting from the above issues have led to a variety of research conducted in an effort to reduce carbon dioxide emissions. The use of supplementary cement materials as a partial substitute for cements [6-10] has been initiated and then use for a new cement, ie, geopolymer [11-14]. Geopolymers are substitutional cement materials assembled by joining rich alumina and silica source materials such as fly ash, ground granulated blast furnace slags with sodium hydroxide, potassium hydroxide, and sodium silicate, where the disband Al_2O_3 and SiO_2 are subjected to geocrystallization to form a tridimensional amorphous alumosilicate network of similar strength or more than concrete. In general, the geopolymer technique can be divided to three major phases: (1) solution of oxide metals of source materials (generally alumina and silica) at severe alkaline conditions. (2) Transport/direction of soluble oxide metal followed via coagulation / gel; (3) polycondensation into shape a three-dimensional grid of silium-aluminate structure [15]. Based on the kinds of chemical bond produced, three kinds of frames derived from the three-dimensional aluminosilicate grid: poly (sialate-siloxo), poly (sialate-disiloxo), and poly (sialate) [16].

Geopolymer has been supported to replace OPC through the provision of processing by-products produced in diverse industries that have appropriate for utilize as origin materials and all industrial by-products cause problems in finding a perfect solution through safe disposal. For example, powdered fuel ash (fly ash), an industrial by-production of the burning coal plant industry, accounts for 75%-80% from world annual ash production [17]. The geopolymers have mechanical characteristics and strength higher than concrete made of traditional Portland cement [18-20]. Further by-products of iron ore too important utilize in the produce

geopolymer concrete with a high-strength [21, 22]. The utilize of fly ash from palm oil, waste materials derived from the burning of empty , oil palm husks, and industry of generate electricity as a geopolymer have proliferated in recent years. The fly ash from palm oil is widely used as a compound installer in some oil-opulent states such as Thailand and Malaysia because the increase in quantity that has made disposal in the landfill feasible [4, 11, and 23]. There are some non-industrial products such as rice straw dust (RHA), red mud (RM), copper and hematite mine mines etc. [14, 24, 25, 26] used in the manufacture of geopolymer concrete.

The current problem is to limit the use of OPC in construction, as well as the disposal of industrial byproducts from different industries. Geopolymer concrete has the potential to replace normal Portland cement, which is documented in construction. Thus, the objective of this paper is to review the present trend in geopolymer concrete, with emphasis on the physical and mechanical properties. Moreover, the microstructure of geopolymer is also reviewed.

2. Factors affecting on geopolymer properties

2.1. Effect of chemical steroids and treatment system on the properties of geopolymer

2.1.1. Mechanical properties

A chemically activated or alkali-activated solution plays a pivotal turn in the initiation process of the geopolymerization. Mostly, the alkali medium is very needful to raise the exterior hydrolysis of the aluminosilicate molecules sitting in the raw material whilst chemical activator concentricity has an impact on the mechanical property of the geopolymers [27, 28]. Moreover, the decay of Si and the species through a geopolymer synthesis largely depends on the concentricity of sodium hydroxide, where the amount of Al and Si Leaching mostly govern NaOH concentricity [29]. Gorhan and Kurklu [30] studied the effect of NaOH solution on the compressive strength during seven days of ASTM class-F FA geopolymer mortar exposed to various NaOH concentricity levels. Three concentricity levels of sodium hydroxide (3, 6 and 9 molarities (M)) were utilized during the laboratory action with the persistence of certain ratios such as sand/ash ratio and sodium silicate/sodium hydroxide. Based on the compressive strength results, the optimum concentration of sodium hydroxide is 6 M that produce the highest seven-day compressive strength of 22 MPa. The above concentration (6 M) provided a perfect alkaline climate for the proper solubility of the molecules and on a same time did not disrupt the reproduction process. When the molarity of sodium hydroxide is very soft at 3 M, it's not enough to stimulate a potent chemical reaction however the excessive high concentricity of NaOH (9 M) performed in early coagulation of silica whose in both states culminated in a low power.

While many studies have shown that compressive strength increases with the increased concentricity of chemical solution NaOH [30, 25, 31, 32], some study displays a complete variation in the development of compressive force. A study by He et al. [14], whose focus on red mud/ground rice ash, showed that the high concentricity of sodium hydroxide performed in a reduction in the strength of the geopolymer pressure. The potentially causes of the contrasting trend can explained by: (1) high viscosity of the NaOH solution because the high concentricity of Al and Si ions, (2) the plus OH concentricity in early geopolymeric precipitation, (3) Due to the deficient degradation of Al and Si types, in the degradation of mechanical property of geopolymer.

Somna et al. [31] investigated the effect of changing the NaOH concentration from 4.5-16.5 M on the compressive strength of Ground FA (GFA) at ambient temperature. The results showed that when sodium hydroxide concentration increased from 4.5-9.5 M, an important increment in compressive strength of the adhesive samples was observed. However, the change of NaOH concentration from 9.5-14 M increments the compressive strength of an adhesive sample but at a much lower rate. The increment in compressive strength together increased sodium hydroxide concentration is mainly due to increased alumina and silica membrane. The compressive strength for the reinforced GFA is beginning to decrease at NaOH concentricity of 16.5 M. The reduction in compressive strength due to surplus hydroxide ions while precipitated aluminosilicate gel deposition at a quite early age, performing in a less potent forming of geopolymers.

Ahmari and Zhang [33] built environmentally friendly geological bricks using copper mine residues and NaOH as chemical activators. Sodium hydroxide concentric ranged from 10-15 M to demonstrate the impact of sodium hydroxide concentricity on non-confined compressive strength of treated geopolymer brick. The results showed that unconfined compressive strength (UCS) of 15 M sodium hydroxide samples were higher than their counterparts 10 M sodium hydroxide for all mixtures because of the high NaOH /Mine Tailings (MT) ratio, resulting in greater Na/Si and Na/Al. Its turn produces more stable gelatin than the geopolymer that binds non-interacting particle and contributes direct to UCS of the geopolymer brick.

Komljenovic et al. [34], studied the effect of five different types of alkaline steroids, $Ca(OH)_2$, NaOH, NaOH + Na_2CO_3, KOH, and Na_2SiO_3 at different concentricity levels for the manufacture of mortar of the geopolymer. The results showed that the highest alkali activator (highest compressive strength) were Na_2SiO_3 superior to Ca$(OH)_2$, NaOH NaOH + Na_2CO_3 and KOH. Compressive strength is generally increased with the increased concentration of the activator. The results showed that the optimum value of Na_2SiO_3 is 1.5.

Nguyen et al. [35] studied the mechanical properties of geobolymeric concrete prepared with sea sand, such as fine aggregates and corrosion of the steel bar embedded in the concrete subjected to accelerated corrosion tests. Test data revealed that for geopolymer sand-based concrete, compressive strength reaches high values at alkaline/fly ash ranging from 0.35 to 0.45. The geopolymer concrete showed high compression strength with a low aggregate to fly ash ratio. Also, a slight difference was observed between the mechanical properties of geopolymeric concrete using sea sands and river sands. The steel bar corrosion measurements indicated that the steel in the geological concrete with the sea sands was exposed to corrosion such as regular concrete. However, the potential of steel rod in geopolymer concrete was greater than Portland cement concrete.

Sukmak et al. [36] conducted the impact of Na_2SiO_3/NaOH and the alkaline fluid / FA (L/FA) were studied on the compressive strength of FA-clay bricks. (Na_2SiO_3/NaOH) was 0.4, 0.7, 1.0, 1.5 and 2.3 however the L/FA ratio utilized was 0.4, 0.5, 0.6 and 0.7 via the dry mud mass. Clay-FA geopolymer brick was then left 24 hours at room temperature before exposure to the treated furnace at 75 ° C for 48 hours. Compressive resistance tests were conducted during days 7, 14, 28, 60 and 90 days of treatment. The result display that the L/FA ratio minimal than 0.3 and maximal than 0.8 were not appropriate for the manufacture of gypsum brick. While the optimal values for Na_2SiO_3 / NaOH and L / FA ratios are 0.7 and 0.6, respectively.

Law et al. [37] conducted the optimal MS through F-based geopolymers concretes is 1.0, wherever the incremental in mixed silica (MS) does not result in any considerable rise within compressive strength. Yusuf et al. [38] conducted a strength of malleable slag on alkaline soil / alkaline activated ground blast furnace slag ultra-fine palm oil fuel ash (AAGU) with mixed silica (MS) ranging of 0.915-1.635 was not significant, as with MS=0.915 the compressive force was 69130 KPa, however, MS = 1.635 resulted in compressive strength around 65000 KPa.

Guo et al. [39] studied the effect of alkali activator content within a compressive strength of the class FA-based geopolymers. A mixture of sodium silicate and sodium hydroxide were utilized as an alkaline activator into class FA. Alkali activation factor ranged from 1.0-2.0 while an alkali activator contents was based up a large percentage of Na_2O to class FA and extend between 5%-15%. The outcomes showed that both silica alkali plants and alkali-activated content were equally important for an expansion of class FA geopolymers strength.

The empirical work showed the impact of the treatment temperature of compressive strength of the copper oxide mine tailings (MT) gyromolymer (UCS) layers. The optimum processing temperature produced by the top layers of UCS was found to be 90 °C. Any higher temperature will result in a sharp reduction in the UCS of a geopolymers brick. The researchers explained that rising temperature shall lead to the early forming of excessive geological gels that shall inhibit dissolution of silica and non-reacting alumina [39]. Furthermore, Ridtirud et al. [40] found that a high temperature of treatment to 60 °C leads to the fast growth of strength during the early periods of treatment, ie, 7-28 days. After 28 days of treatment, the growth of the force was considered minimal for a higher treatment temperature. Primary treatment at high temperature accelerates a response of the geopolymers and thus improves the strength of resulting geopolymer.

Chindaprasirt et al. [41] proposed a method to reduce the time period for heat treating of high-calcium phosphate geopolymers. The outcomes showed that by display the sample to microwave warming for 5 minutes and the

traditional 6-hour oven treatment 60 °C, the compressive strength gained was higher when compare to other sample treated 60 °C for 24 hours without-Microwave Processing.

2.1.2. Durability properties

Ridtirud et al. [40] conducted the impact of sodium silicate/NaOH (SS / SH) concentration on a contraction of ASTM class-C FA geopolymers mortar. The study showed that FA shrinkage geopolymer mortar increases with increased sodium hydroxide concentricity due to lower strength of identical mortar sample. They too studied the impact of treated temperature on properties of ASTM shrinkage class FA geopolymers FA mortar shells.

Aydin and Baradan [42] investigated the impact of vapor therapy and autoclave treatment on shrinkage rates during drying of alkaline activated slag. The standard OPC mortar were manufactured and utilized for comparison to all other hot mortar shells. In addition, a range of OPC and alkali activated slag mortars shells (AAS) were processed in the case of standard water were utilized for comparison purpose. At the heat treating, the samples were wealth to cool to a temperature of the room and sample length changes were periodically measured up to 6-months. Results of the study were: (1) the value of deflation during the drying of mortar AAS was higher compared to PC mortars in all treatment condition, (2) deflation values were reduced during the drying of AAS and PC compared at heat treatment, (3) Autoclave treatment was institute to be extra active in decrease the drying contraction of AAS and PC bombs than vapor treatment.

The acid and sulfate resistance of high-calcium gypsum glycolium stick has been significantly improved utilizing a microwave-assisted heat treatment mode to treat adhesive samples. It is believed that microwave radiation enhances the melting rate of Si and Al types of FA molecules by fast and uniform warming of alkaline water sol using microwave energy, resulting in the formation of a multiple gel, thus the matrix is stronger, denser and durable if created compare to traditional heat treatment of the furnace [41].

2.1.3. Physical and rheological properties of geopolymer

The rheological characteristics and the physical properties of the geopolymer that are affected by their nature and geopolymerization complexity, which was mostly governed by the chemical stimulant as well as the treatment system used [43-46], were determined.

Sathonsaowaphak et al. [33] conducted the flowing test on caller Ground Bottom Ash for different sodium silicate/NaOH, alkali/liquid ash, and NaOH concentrations. The applicable zone of alkali / gray ash ratios was contracted to become between 0.429-0.709. High alkali / ash ratios to geopolymer mixtures are extra applicable faith to reduced particles intervention and increased particle stretch. Moreover, a practical zone of NaOH and sodium silicate / NaOH concentration ranges between 7.5-12.5 M and 0.67-1.5, respectively. The growth in the ratio of sodium hydroxide/sodium silicate and sodium hydroxide concentricity conformed in minus practical mortar mixtures due to high sodium silicate viscosity and NaOH. Also it is recommended that a value of sodium silicate in the mortar mixtures remains as soft as a potential in economic reason, however at the same period not affecting both operability and strengths of the geopolymer mortars.

The greater amount of flowering was spotted in geological paste sample of palm oil feed (POFA) containing minimize solids to lower liquid and lower sodium salts/sodium hydroxide ratio [47]. The greater sodium ions in low sodium silicate/sodium hydroxide ratios and the ratio of solid/liquid have a higher tendency for alkali appearance on the surface of the sample due to the presence of weak sodium ions in the geological structure of the geological generation.

2.1.4. Microstructure matrix

Komljenovic et al. [34] analyzed x-ray images from various sources of polyethylene-activated epitaph epitope utilizing sodium silicate with MS different concentricity. All epithelial epithelium was treated for one day near 20 ° C, pursure by 6 days near 55 °C. The value of MS utilized was 0.5 and 1.5 however the concentricity of sodium silicate was 8%-10%. The MS of sodium silicate has been modified via adding NaOH. The morphological zeolite

stages of faujasite were lead on geopolymers samples with MS soft of 0.5 however vaished in MS 1.5 samples, in any case of sodium silicate concentricity as presented in Figure 1. The study showed that the reduction or absence of a crystalline produce has contributed to increase the force of pressure of the geopolymer.
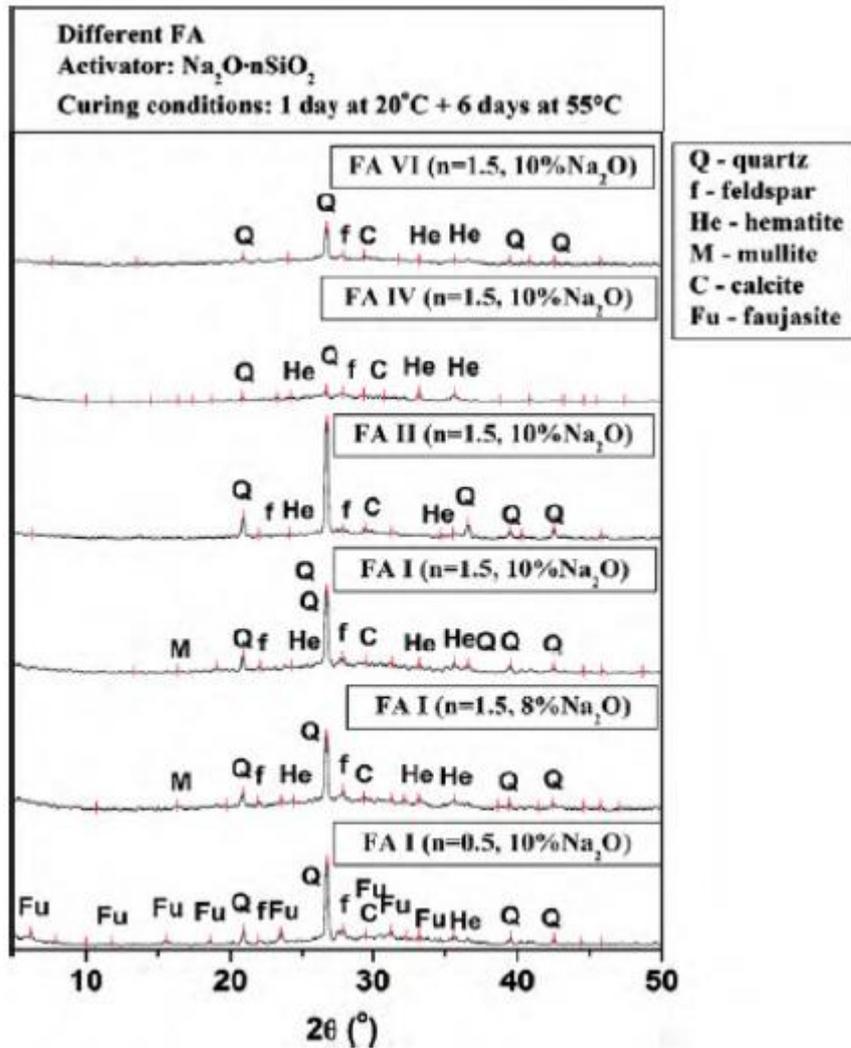

Fig. 1. X-ray diffractogram of different FA activated by sodium silicate with various concentricity and modulus (n) [34].

The effect of temperature and primary heat treatment stages on the morphology of gypsum brick FA (FA) was studied by Sukmak et al. [36]. A microcracks were plainly configured in samples at a raise temperature such as 85 °C even in a comparatively low treatment period of 24 hours (Figure 2). Similar developments were observed in the micro-cracks of the samples treated at a small temperature (75 °C), however treatment periods were much tall (72 hours) and were illustrated in Figure 3. Both minor cracks were highly correlated with the significant loss of material. The pore and moisture fluids of the geopolymers matrix that caused undue shrinkage through drying and loss about a structural wire of a geological matrix of clay-clay [48, 49].
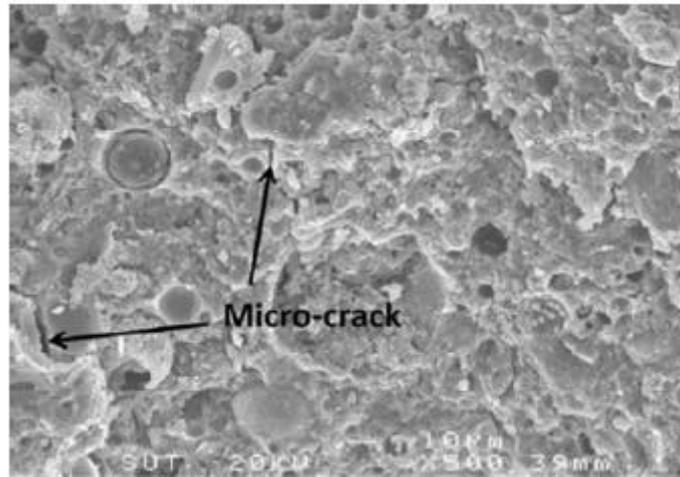
Fig. 2. SEM photograph of 28 days clay-FA geopolymers brick treated near 85 °C through 24 h [36].
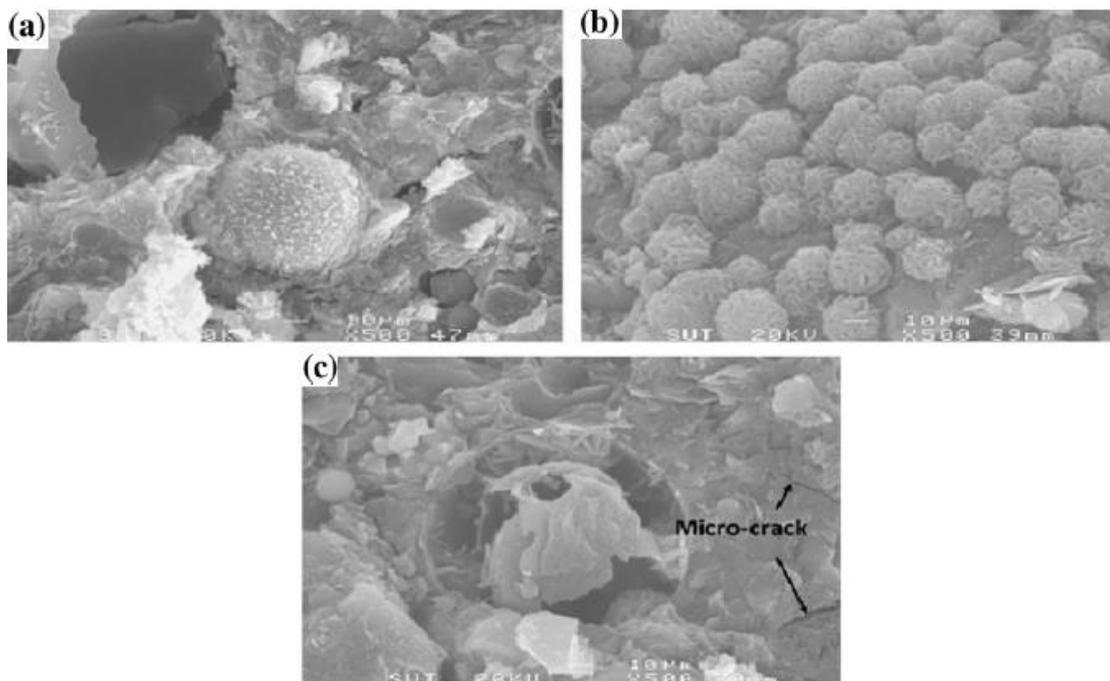

Fig. 3. SEM photograph of 28 days clay-FA geopolymers brick treat in 75 °C within (a) 1 day, (b) 2-day, and (c) 3-days [36].

Guo et al. [39] they performed micrographs analysis (Fig. 4) of pure C FA class (CFA) and also CFA optimum geopolymer (CFAG). CFAG was optimized on MS and Na2O / CFA content of alkali activator of 1.5% and 10% respectively. CFA morphology (Figure 4a) showed a series of spherical glass particles with different sizes, similar to those of the F FA class. When geo-crystallization, partial deviation of CFA particle we seen plainty in Fig. 4b and the bores of broken CFA particle appear become filled with large quantities of fine particle for reaction product as presented in Fig. 4c. EDXA also confirmed that the main gelological gel generation found in CFAG is Na-poly (sialate-disiloxo-), ie Nan- (Si-O-Al-O-Si-O- Si). The geo-gels was also present to co-exist with the CSH gel and some non-interacting CFA spheres (Figure 4d).
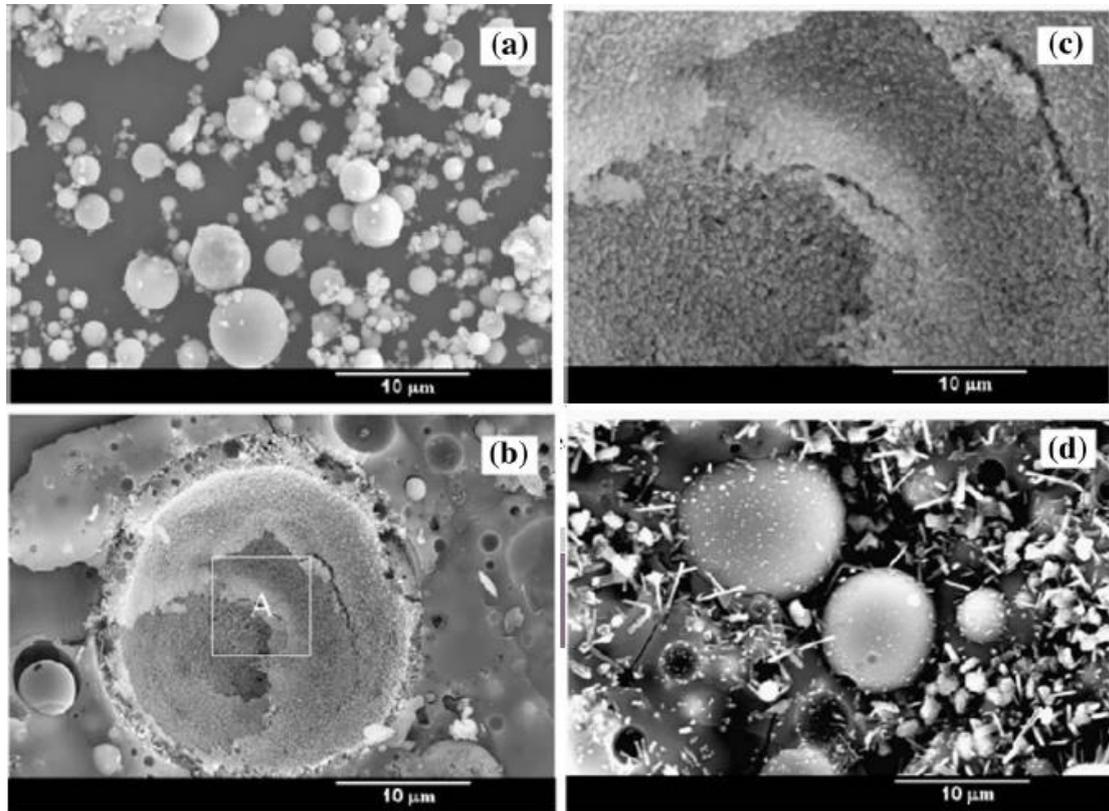
Fig. 4. SEM images of: a) pure CFA powder, b) the reactive CFA sphere, c) the reactive area ''A'' of the CFA sphere in SEM image b), and d) CFAG treat in 75 °C within 8 h followed by treat in 23 °C within 28 day [39].

2.2. Impact of particle distribution of additives and binder phase on geopolymer properties

The nature and accuracy of geopolymer materials play a crucial role in the development of strength, endurance characteristics and microscopic structure of resulting accumulated geopolymer matrices. The impact of particle distribution at the binding period on compressive strengths, physical properties and microscopic structure of the resulting geopolymer was studied [50]. In general, the binding phases with particle distribution has greater interaction and then produce a geopolymer paste with a denser microscopic structure, higher compressive strength and clear physical properties [51]. The impact of particle distribution for a documented step and additions to a mechanical, durability, physical and microscopic properties of the geomolymers derived of processing byproduct will be illustrated below.

2.2.1. Mechanical properties

Coal ash production represents 20% of bottom ash (BA). To date, most BA is being orignized of you an oil compound due to applied and processing constraints as compare to FA. Morever, because their similarity in alumina and silica content with exclution of excessively high amount of carbon due to imperfect combustion and great particulate matter, many investigator has begun to incorporate them into the production of the geopolymer [50, 52, and 53].

Sata et al. [50] studied the impact of the particles size of the bottom ash (BA) on compressive strengths of BA geopolymers. Triple various qualities of BA as included in mortar samples: BA (15.7, 24.5, and 32.2 µm). The compressive strengths was tested at different time periods of 7, 28, 90, 180, and 360 days. The outcomes show the particle size (15.7 µm) give higher compressive strength for all treatment periods. Superplasticizers ability to integrate into the geological system in command to decrease its water content however maintains the required

operability, which helps to use high-strength geological polymers [54-56]. Puertas et al. [57] conducted that the addendum of vinyl copolymer and polycarbonate polymers based on polymers to geopolymer paste did not result in significant changes in compressive strength nor the possibility of using the resulting geological polymers.

Nath and Kumar [58] studied the effect of two different types of iron slag, GCS and GBFS, on the FA (FA) geopolymers in a domain of 0-50% by mass. Before being used as mixture components, GCS and GBFS was milled for two hours to investigate a desired accuracy of d50 = 18.49 µm and 18.53 µm, respectively. A compressive resistance of the geopolymer was exmained on 7th and 28th day of treatment. The most important results based on the results of compressive strength were the raise in compressive strengths with the refuse content of both geological polymers, GBFS-FA and GCS-FA.

Organic soluble organic polymer was added to enhance mechanical property of the geopolymer by modifying a microstructure and dividing the pore sizes of a produced geopolymer matrixs. Zhang et al. [59] they have enhanced the mechanical property of the slag-based globulin (MK) / ground kiln (GBFS) by combining 1-15% by weight of polymer resin. The results of the study showed that by adding only 1% resin in terms of weight ratio improved mechanical performance by 41% for compound geopolymer composites. The effect of high temperature on MK / GBFS-based geochemical compounds was also studied in a separate study [60]. The results of the study showed that when exposed to high temperatures ranging from 450 to 850 degrees Celsius, mechanical performance is significantly reduced due to drying of the geopolymer matrix.

2.2.2. Microstructure matrix

The flue gas desulfurization gypsum have establish its road into the manufacturing procedure of geoplolymer. That wasted gypsum that created from the coal-burning manufacture have a potential to promote the procedure of geoplymerization [61, 62]. Boonserm et al. [63] a characteristic microstructure of FA: FA (FA) was studied with a various ratio of BA/FA with a various level of substitution also by FGDG. The ratio of sodium silicate / sodium hydroxide and liquid / ash ratios was constant at 1.0 and 0.6 respectively in all geopolymers paste. Mixed pasta was placed in a 40 °C electrical furnace for 48 hours and analyzes using a SEM after 28 days. Figure 5 shows a geopolymerization product of mixed BA/FA, also obtained very dense geolymer matrices with 100 and 70% mixtures of FA as in Fig. 5. The matrix was less heavy and low homogeneous at lower content than FA as presented in Figure 5.
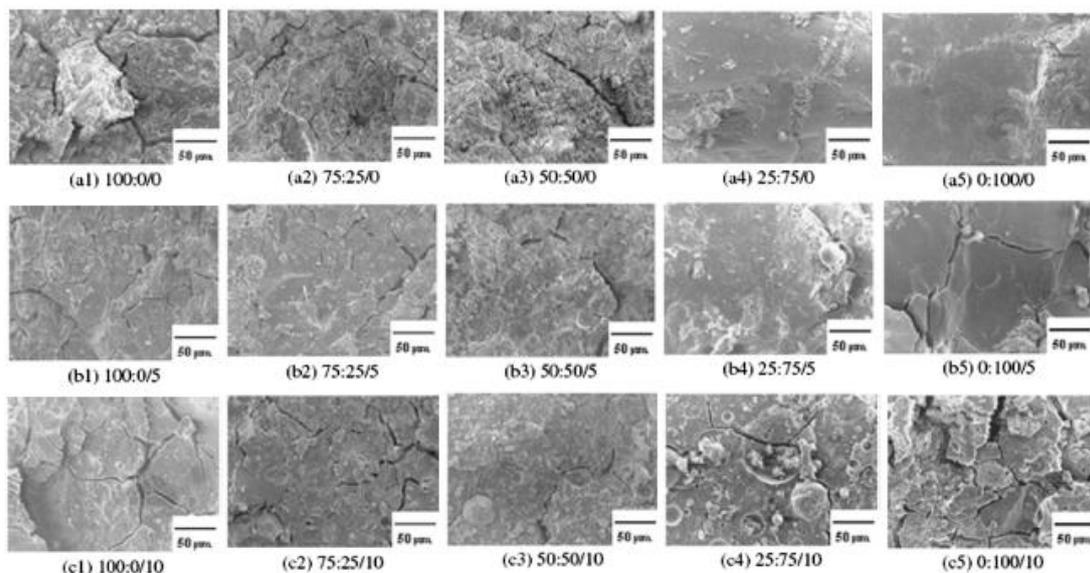

Fig. 5. SEM photo of fractured BA and FA geopolymers [63].

2.2.3. Physical and rheological properties of geopolymer

Nematollahi and Sanjayan [64] conducted the impact of adding commercial superplasticizer to a relative stagnation of the F-geopolymer dictionaries. Melamine (M), Naphthalene, and PC-based SPs was utlized on 1% of the FA mass during the emperical work. Two types of chemical steroids was utlized in the work, ie, a concentricity of 8 m of NaOH and a multivariate compound consisting of Na_2SiO_3 and 8 M NaOH with Na_2SiO_3 / NaOH = 2.5. A relative decline of modern geopolymer agglomerates was recorded use the microclimate test mode according to ASTM C1437. In geopolymers paste activated with 8 m Sodium hydroxide, SP represent the optimal effective water mixing reactor. By adding 1% N-based SP increase the relative drop of fresh geopolymers cores via 136% a relative to case without SP. For the multi-stimulant geopolymers epithelium, computer-based SP is the best effective water mixtures at 46% increase in relative decrease, given by N-based SP at 8% increase however M-based SP showed relative decreases in relative precipitation 3%. Nematollahi and Sanjayan [64] conducted the impact of adding commercial superplasticizer to a relative stagnation of the F-geopolymer dictionaries. Melamine (M), Naphthalene, and PC-based SPs was utlized on 1% of the FA mass during the emperical work. Two types of chemical steroids was utlized in the work, ie, a concentricity of 8 m of NaOH and a multivariate compound consisting of Na2SiO3 and 8 M NaOH with Na_2SiO_3 / NaOH = 2.5. A relative decline of modern geopolymer agglomerates was recorded use the microclimate test mode according to ASTM C1437. In geopolymers paste activated with 8 m Sodium hydroxide, SP represent the optimal effective water mixing reactor. By adding 1% N-based SP increase the relative drop of fresh geopolymers cores via 136% a relative to case without SP. For the multi-stimulant geopolymers epithelium, computer-based SP is the best effective water mixtures at 46% increase in relative decrease, given by N-based SP at 8% increase however M-based SP showed relative decreases in relative precipitation 3%.

2.3. Impact of forming pressure and water content on geopolymers properties

The forming pressure and water content affect direct on porous matrix geopolymer In general, high water content leads to increased total porosity of the geopolymer matrix [65]. Morever, the increase in forming pressure will decrease the total porosity of a geopolymer matrixs. As a result, the use of compression modulation method of the manufacture of the geopolymer allows for a significant reduction in water requirements compared with vibration modulation methods [66]. The effect of water content and pressure formation on the characteristics of the geopolymer will be addressed.

2.3.1. Mechanical properties

During the process of alkali activation the geopolymer interaction depends firstly on the chemical reaction between the silicate and aluminate in a very alkaline climate. The entite water in the geopolymic acts only as the transfer waist between dissolved silicates and aluminum ions. Besides, it is not directly involved in geopolitical interaction [67].

Zhao et al. [65] investigated an impact of forming pressure on strength in bricks made of low silicon residues was studied. The alkali-based alkali cement-based cement and FA was mixed within the mixture in order to product low density silicon higher strength brick. Where the water content in the mixture was 7.5%, the ratio of waste to the mass of the cement material is about 85:15, and the steam pressure 1.0 MPa. The outcomes present that the pressure strength of brick increases with increasing pressure forming. The optimal forming pressure between 18 and 20 MPa should also be considered to produce brick with sufficient mechanical strengths with minimum energy use.

2.3.2. Water absorption

The water absorbed process is of so high importance in the manufacture of the geopolymer brick because it refers to the degree of reaction and permeability of the geopolymer brick. Freidin et al. [68] conducted that the water absorbed of mins than 10% of the geopolymer-based brick of FA is reported to add hydrophobic additives. All absorbed water values for MT-bathe sed geopolymers was well less the maximum absorbed water of a various type of brick according to ASTM standards are: (C34-03, C126-99, C62-10, C902-07 and C216-07a).

2.4. Impact of environmental exposure on geopolymers properties

The previous Studies have shown that geopolymer binding materials has superior strength to acid attacks and sulfate during exposure to the marine environment [69-72]. Studies have shown that the resistance of sulfur, acid and chloride to geochemical connections is done using different analytical methods and methods, such you through immersion in a sulfate solution and pre-acid solutions followed via next force measurement and mass loss [70]. The effect of climate exposure on the property of geopolymer will be studied in term of their effect on physical properties, mechanical property and microstructure change.

2.4.1. Physical properties of geopolymer

Previous studies have shown that the PFA-POFA based mixed fuel ash geopolymers concrete (BFAGC) has superior durability of exposure to the sulfur environment for longer periods of time compared to OPC, as shown in Fig. 6. When exposed to the sulphate environment for a longer period of time, to 20% compared with a 4% reduction in the BFAGC mass. The reason for this was found to be the small calcium contents of BFAGC, which makes it more resistant to sulfate attack [71].

Fig. 6. Visual appearance of BFAGC and OPC concrete after 18 months [71].

Reddy et al. [73] investigated the corrosion of composite polyethylene when exposed to the marine environment through the use of a laboratory electrochemical method. The geopolymer reinforced concrete columns and reinforced concrete pillars were manufactured with a 13 mm Ripper, centrally supported with 150 * 150 * 525 mm dimensions and tested for abrasion resistance using the above method after 28 days of treatment. The outcomes present that geopolymerial had a superior residual to relatively salt attack compared to reinforced concrete. The strength of the geopolymer concrete was also checked. There was no loss of mass for the barriers at the end of the accelerated corrosion test. A loss of 71.2% was recorded after the completion of the OPC test.

2.4.2. Mechanical properties

Rattanasak et al. [74] conducted the influence of magnesium sulfate ($MgSO_4$) and sulfuric acid (H_2SO_4) on compressive strengths of the existing RHA. RHA ware replaces by Al $(OH)_3$ at 2.5%, 5% and 10% by weight. 10 m NaOH and Na_2-SiO_3 was utilized as a chemical stimulant and mass ratio of Na_2SiO_3 / NaOH was stabilized at 1.5. The mass ratio of sand to powder is 2: 1 in all samples. When poured into 50 mm cube molds, fresh hydrodioxide was wrapped with an anti-adhesion membrane to prevent moisture loss and was subject to a treatment furnace on115 °C within 48 hours. And cooling to space temperature, all samples were immersed in 5% by weight of $MgSO_4$ and 3% of H_2SO_4 during 90 days, next the loss of compressive strengths was determined for the sample. For non-exposed samples, the compressive strengths increase with increased Al (OH)3 value with the highest compressive strengths at 20000 KPa. This because the reduction of Si / Al as an outcome of Al $(OH)_3$. After the immersed period, samples subject to 5% by weight of $MgSO_4$ drive showed a higher rate of loss of strengths compare to samples was immersed in 3% H_2SO_4. For, high silica, the reaction of Mg $(OH)_2$ with the silica gel and the form of magnesium hydroxide water which does not have binding capacity led to sharp reduction in strengths. The outcome showed was a mixed relationship between mechanical properties, durability, and

microstructure of RHA-based gyolomers [74]. Ahmari and Zhang [72] they recorded the strength of the geopolymer residues from copper mine tailings (MT) after immersion in pH4 and pH 7 for 4 months. The temperature and concentration of treated sodium hydroxide was adjusted from 90 M and 15 M during the experimental study.

2.4.3. Microstructure analysis of geopolymer

Bascarevic et al. [75] studied the impact of sodium sulphate solution (50 g/l) on changes in a mineral phase of geophysical polymers based on 365 days. The XRD of the geopolymer sample presented that no new phases was constructed even after 365 days of exposure, indicating that geophysical polymers have high resistance to sulfur.

Bhutta et al. [71] they studied the effect of changing the metal phase of the Gyolomery concrete from mixed ash (PFA-POFA) before and after immersion in Na2SO4 for 6 months. As shown in Figure 7, after 18 months of exposure to 5% Na_2SO_4, a slight change was observed in the semi-crystalline alumino-crystalline gel (N-A-S-H) present before immersion. On the other hand, a significant change occurred in the OPC sample that was used as a control sample after 18 months of 5% Na_2SO_4 exposure.

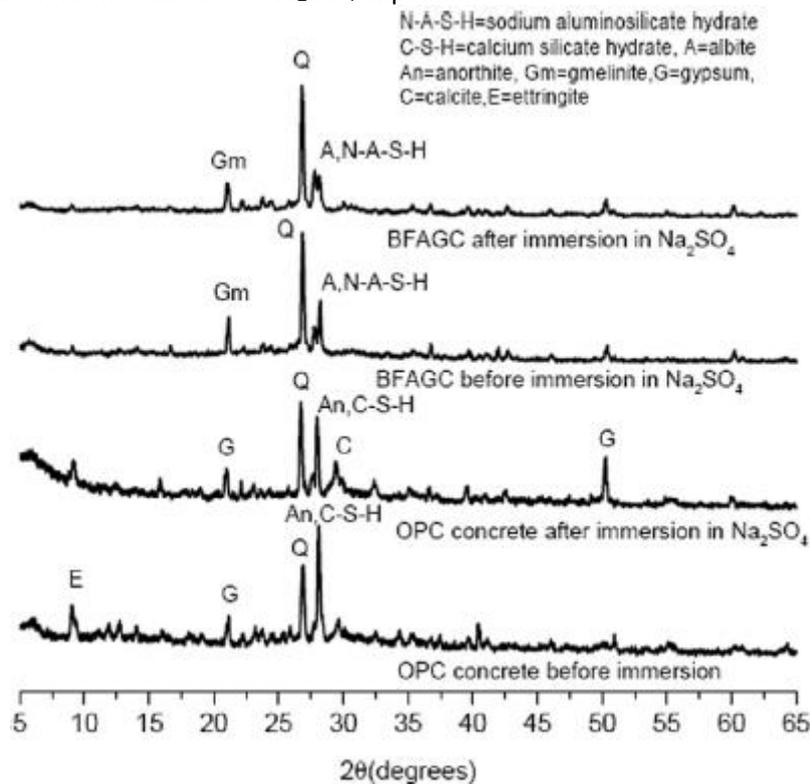Fig. 7. XRD of OPC concrete and BFAGC in 5% Na_2SO_4 for 18 months [71].

3. Microstructure of geopolymers

3.1. Fly ash-based geopolymer.

Several researchers have studied the performance of volatile gyromolymer cement from fly ash with the alkaline variables: additional bonding material, molar, alkali activating ratio, treatment temperature and treatment time [76-78]. Pavithra et al. [77] they studied the performance of gyromolymer based ash ash and suggested a method for obtaining the best design for the mix. Authors suggested using the maximum size of the total control of water content. The effect of the different contents of the solutions was compared to the binder on the microbiological structure of the geopolymer structure as shown in Figure 8. The results showed that with the increase of the AAS / Binder ratio, the precipitation decreases continuously. It is understood that with the increase in this ratios, the strengths of concrete is reduced because increased mass of water in geopolymers mixture. With appropriate

alkaline doping / binder ratio of 0.4-0.5, non-reactivated FA particle were found to be minimal as presented in Fig. 8 (a, b). Also, the number of spaces is uneven as presented in Figure 8 (c-e).
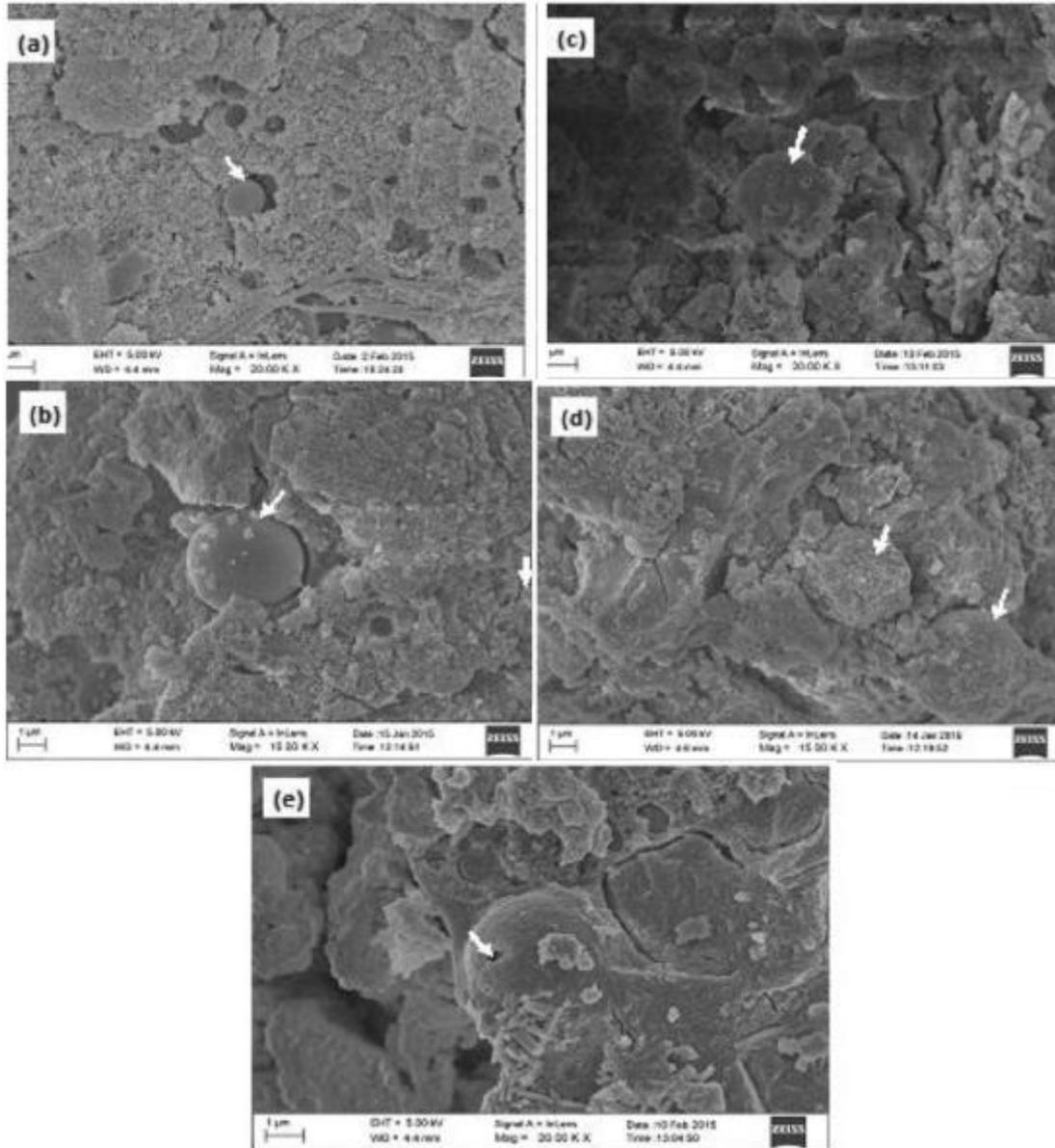

Fig. 8. Microstructure of fly ash-based geopolymers [77].

Okoye et al. [79] they studied the microscopic structure of the geopolymer made of fly ash and silica fumes. The geological concrete sample of fly ash has a fracture surface in contrast with previous studies in this area as shown in Figure 9.
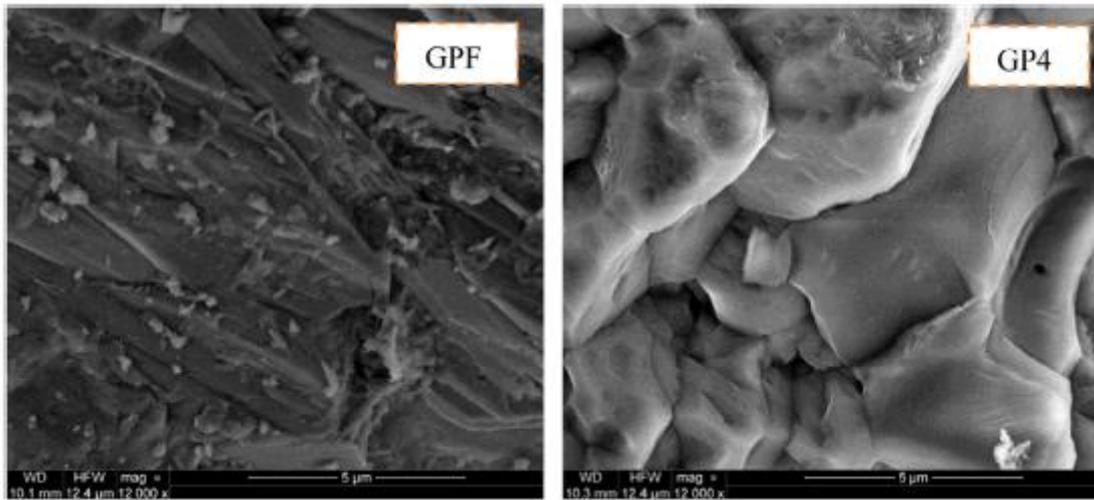
Fig. 9. SEM image of GP4 and GPF [79].

Figure 10 illustrates the logical transition zone between the assembly matrix and the geopolymers. According to Embong et al. [80], promoting the breakdown of fly ash particle and the multiple intensification of the alumosilicate compound provides a link between matrix and aggregates. Since the composition of the alumosilicate fills the ITZ, the pressure strengths of samples has been greatly enhanced. A fiber straw is suspected in the geopolymer matrix able to reduce the melting of fly ash particle. Non-reactive fly ash particle was accurse in a matrix where the fiber straw covered a surface, as presented in Figure 10 (c).
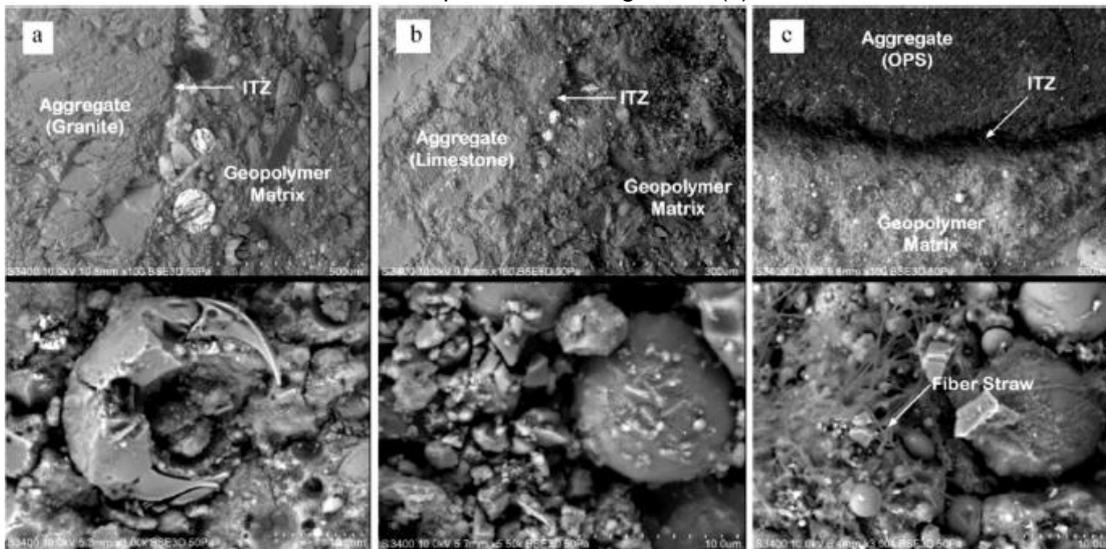

Fig. 10. SEM photo of geopolymers made from a) granite, b) limestone, and c) oil palm shell [80].

Figure 11 shows partial analysis of the geopolymer structure. Non-reactive FA residue was observed as presented in Figure 11 (a). Figure 11 (f) presented small elements of the sodium were observed at non-reacting metals cover non-reactive FA particle (2016). Figure 11 (b, c, and f) present the evidence of the geopolymers production. Because, of a small calcium content in a Gaston-FA. A small amount of calcium as shown in Figure 11 (d).
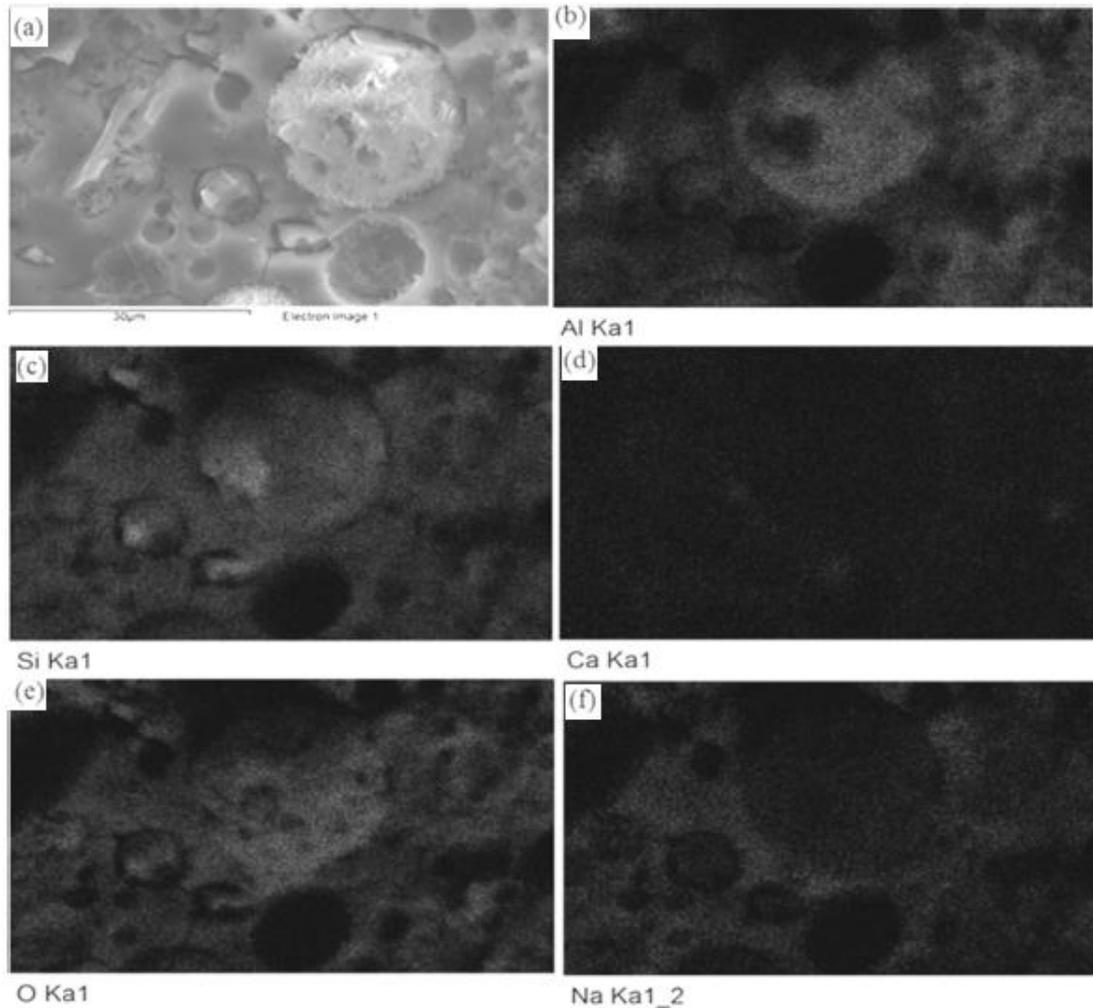
Fig. 11. geopolymer microstructure made from a) Gaston fly ash; b) aluminium; c) silicon; d) calcium; e) oxygen; and f) sodium [81].

3.2. Palm oil fuel ash-based geopolymer.

Kabir et al. [82] conducted a behavior of oil palm shell (OPS) and palm oil clinker (POC) as a coarse aggregate with a triangular bond of ground granulated blast furnace slag, metakaolin, and palm oil - existing geopolitical concrete. POC is effective in improving strength because of the bonding ability of the POC to the porous of the POC. Figure 12 shows a compact and dense matrix.
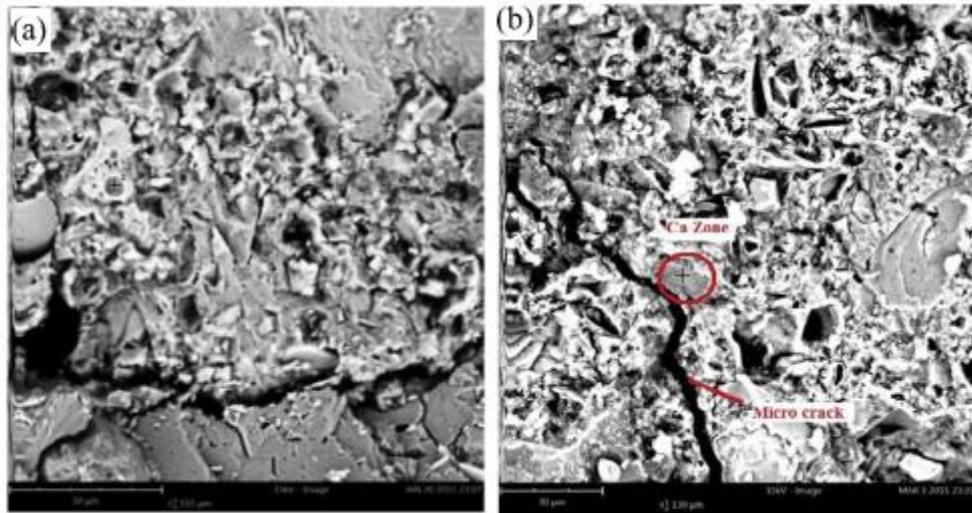
Fig. 12. Microstructure of geopolymer with (a) POC and (b) OPS [83]

3.3. Metakaolin-based geopolymer.

Tchakouté & Rüscher [84] studied the microstructure of the methacellase-based geopolymer in the alkaline acid-based (GPS4) system (GPWP). Figure 13 illustrates the morphology of geopolymers cement on120, 250, and 5,000 magnification. The air bubbles and large pores were observed in GPWP samples while the numbers of small clusters were observed on GPS4-surface. During a process of disintegration and condensation, the air bubble trapped in a geo-cement over an attributed to the large capillary pores. The low strengths of alkaline-based geopolymers cement compared with phosphate-based geopolymers cement was recorded due to the presence of large pores observed in GPWP samples.
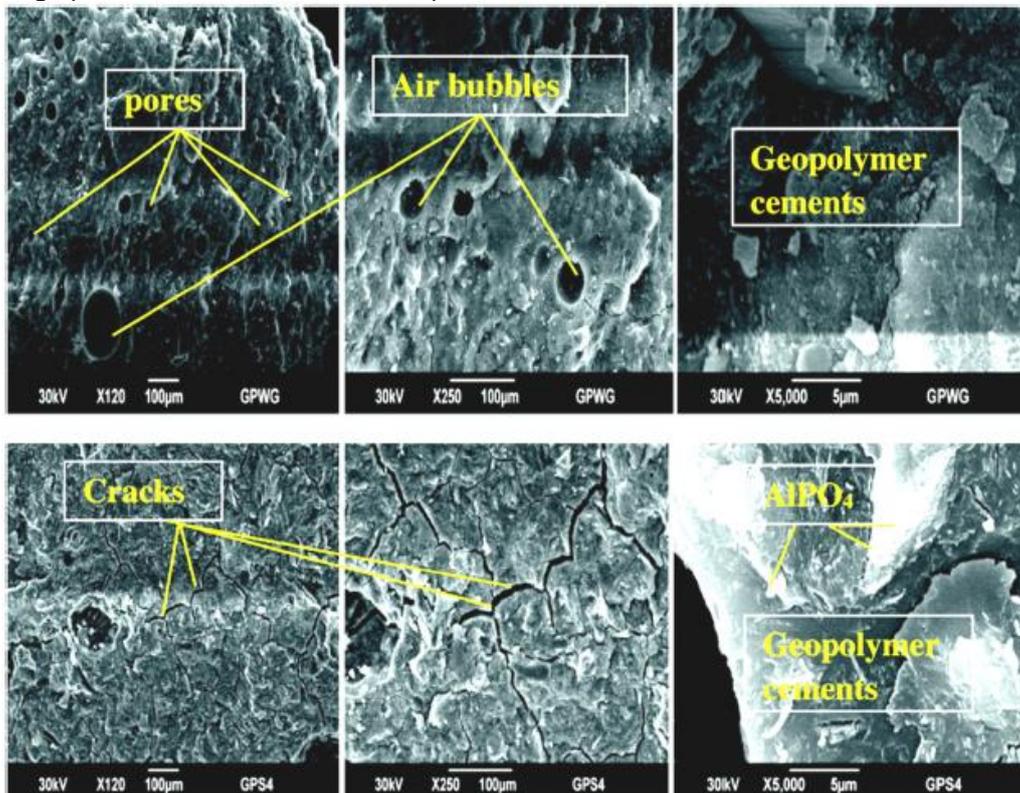

Fig. 13. Microstructure of metakaolin-based geopolymers in GPS4 and GPWG [84]

3.4. Ground granulated blast furnace slag-based geopolymers.

Sharmin et al. [85] they studied the effect of using a large amount of GGBS with catheter ash and ashes (RHA). As shown in Figure 14, it was observed that the use of mixtures with higher-volume of GGBS to replaced RHA enhanced the pressure strengths.
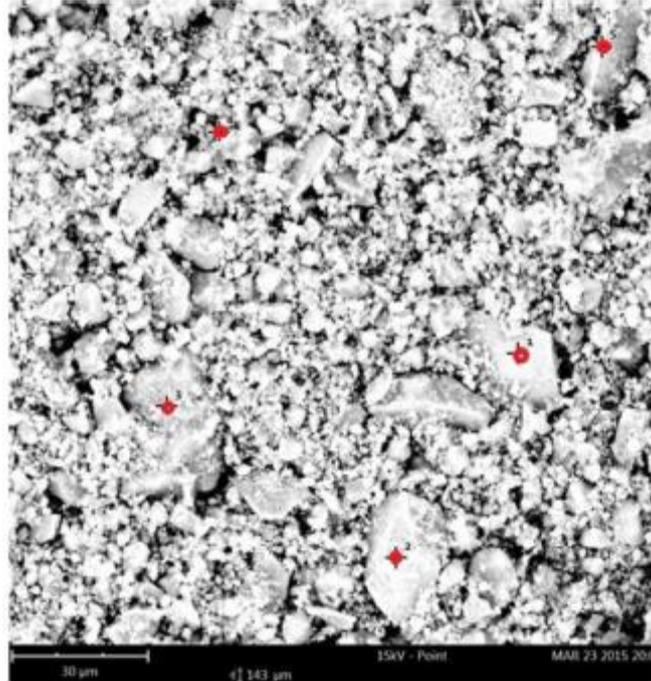

Fig. 14. Microstructure of RHA-MK-GGBS [85].

3.5. Waste clay brick powder-based geopolymers.

Tuyan et al. [86] conducted a microbial structure of the mud bricks (WCBP). Figure 15 shows SEM images for sample. Figure 15 (a) shows the presence of non-interacting WCBP particle (A) with blanks (B) in geopolymers with 10%. Na_2O and SiO_2 / Na_2O ratios from zero. The comparison between Fig. 15 (a, c) showed an increase in SiO_2 / Na_2O to 1.6. A denser structures is presented in Fig. 15 (b) due to high Na_2O content in the geopolymer mix. Figure 15 (d) also shows that the slight improvement in microstructure only occurs when the SiO_2 / Na_2O ratio is increased to 2.2. Figure 15 (e, f) shows the impacts of low water content on the geopolymer bond, which reduces specimens porosity.
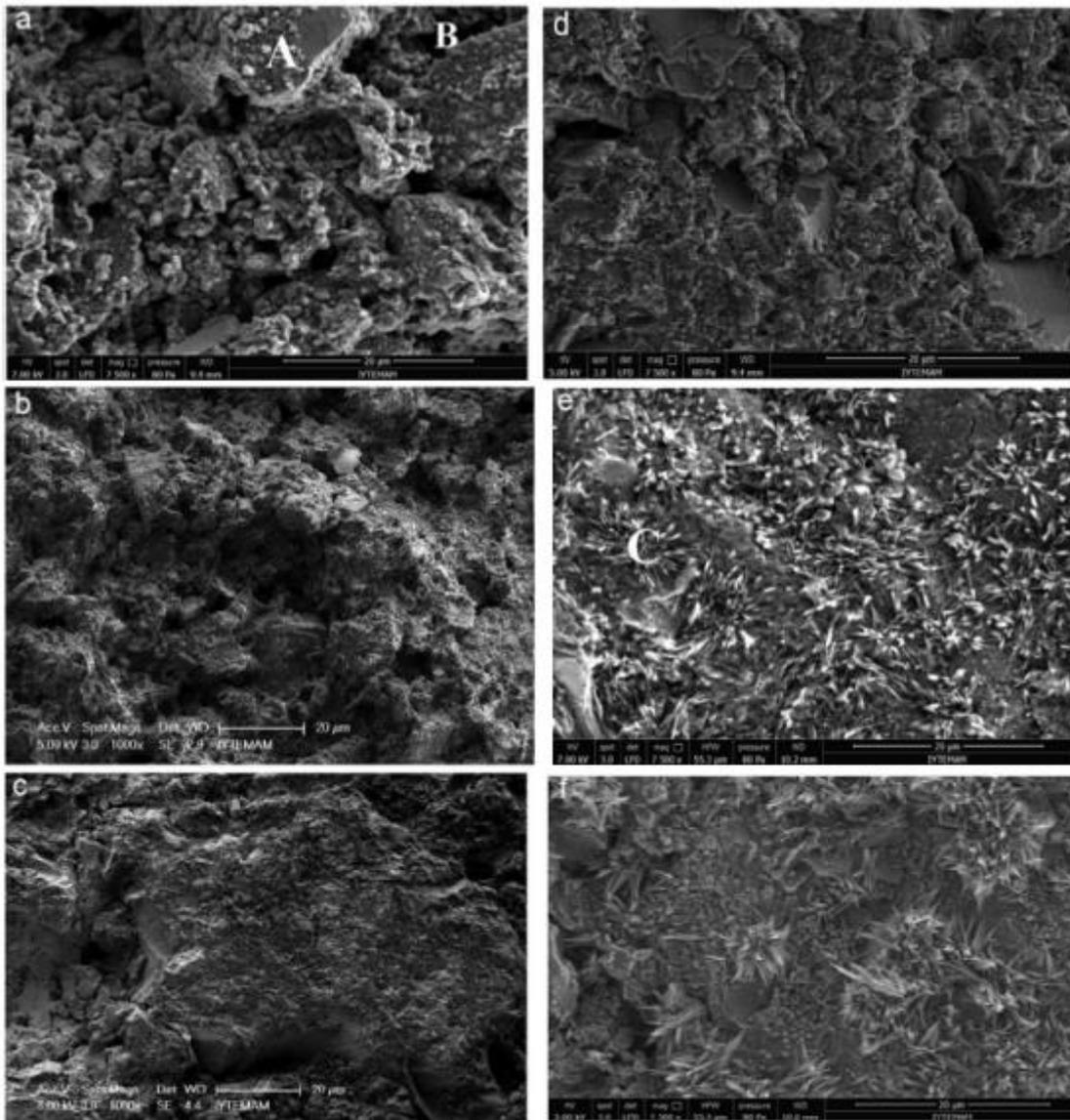
Fig. 15. Microstructure of clay brick with a) $Na_2O=10\%$, $SiO_2/Na_2O= 0$, (b) $Na_2O= 4\%$, $SiO_2/Na_2O= 1.6$, (c) $Na_2O= 10\%$, $SiO_2/Na_2O= 1.6$, (d) $Na_2O= 10\%$, $SiO_2/Na_2O= 2.2$, (e) $Na_2O= 10\%$, $SiO_2/Na_2O= 1.6$, and (f) $Na_2O= 10\%$, $SiO_2/Na_2O= 1.6$ [86].

4. Conclusions

The present paper addressed the fundamental factors that significantly affect the geopolymer characteristics derived from different industrial byproducts. Several challenges and issues facing geopolymers technology and step to overcome these challenges have also been discussed.

The current review study provides a detailed explanation of several factors that affect the property of the geopolymers. A large number of different studies have been presented to covering the different aspects of the applied geomolecules such as geophyllamine and GGBFS. Also, detailed study such as those related to the deduction and model of kinetic of interaction under different processing and manufacturing condition for the emerging layer of geopolymer such as RHA, POFA, and blended geochemistry was required. In addition, the contrasting results of the combined energy and carbon footprint of the geomolymers should be addressed compared to traditional Portland cement. Thus, the development of new technology for the manufacture of geological materials aimed at reducing the cost of production, the combined capacity of energy and the carbon footprint is necessary to ensure the sustainability and future implementation of ground polymer technology as useful building and manufacturing materials.

The optimal use of geopolymers in actual industrial applications brings many benefits towards the construction industry and solves many of the problems of waste management in the industry. Research in geopolymer, particularly in the use of processing waste, have been intensified and is surely a pace forward in a full application of geopolymer in the construction manufacture.

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