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## A REVIEW ON GEOPOLYMER AS A NEW GREEN COATING MATERIAL

**RINGKASAN:** Kerja-kerja penyelidikan melibatkan kaedah melindungi logam dan infrastruktur dari kemerosotan menggunakan lapisan konvensional telah lama dijalankan. Ia disebabkan penggunaan lapisan konvensional membawa kepada pelbagai kesan buruk termasuk pelepasan sebatian organik beruap yang membawa kepada kesan rumah hijau, penipisan lapisan ozon dan isu berkaitan kesihatan termasuk asma, bronchitis dan radang-radang kulit dan kanser paru-paru. Penyelidikan melibatkan alternatif hijau dan mampan untuk menggantikan lapisan konvensional mula mendapat perhatian apabila peraturan baru berkaitan dengan keselamatan kesihatan dan alam sekitar mula diperkenalkan. Oleh itu, salutan konvensional perlu digantikan dengan lapisan alternatif yang lebih selamat berasaskan air dan inorganik Geopolimer mempunyai ciri-ciri dan aplikasi yang menarik berpotensi sebagai bahan salutan baru. Kertas ini membincangkan sejarah, sifat, aplikasi dan batasan geopolimer sebagai bahan salutan baru.

**ABSTRACT:** For many years, researchers have been working on the sustainable ways to protect metals and infrastructures from deterioration, but recently new regulations related to the health safety and environment has driven the attention of the research community to introduce green alternatives to conventional coatings. Serious implementation of the conventional coatings include the release of VOCs lead to a greenhouse effect, ozone layer depletion and health related issue including asthma, bronchitis and sometimes skin and lung cancer. To reduce such impacts, conventional coatings are replaced by water-based alternatives and inorganic coatings. In the past few decades, geopolymers have been materialized as a potentially new material with interesting properties and applications. A review on geopolymers about the history, properties, applications and limitations of geopolymer is discussed. Some preliminary results are provided.

Keywords: Coatings, corrosion resistance, geopolymer

## INTRODUCTION

In order to maintain the durability of a pipeline system coatings are applied on metal surface. There are several types of coatings that are available in the market such as organic, metallic, zinc and ceramic, in which, different coatings will be chosen for different application. Coatings form a barrier to protect metal surface from harsh external environmental conditions, that is significant to offer a protection from a serious problem such as corrosion attack (Ahmad, 2006) and (Fedrizzi and Bonora, 1997).

Surprisingly, coatings itself can attribute serious corrosion issues, that occurred when it was subjected under certain failure. Consequently, it will bring into major operation issues together with big economic losses. There are various forms of coatings failure, most of which are marked coatings detachment. The coatings detachment involves a gradual formation of defects followed by the penetration of corrosive species which promotes progressive adhesion loss and subsequent attack of the underlying base metal (Leidheiser, n.d.), (Armstrong *et al.*, 1992) and (Armstrong and Lindholm, 1986).

Not just with the issue of detachment, a scientist also needs to figure out a greener alternative to conventional coatings as to protect metals and infrastructures from deterioration. It is acknowledged that most of conventional coatings such as polyurethane, acrylic, polyethylene and etc. is an organic coatings, that emit carbon dioxide, CO<sub>2</sub> into atmosphere. This process indirectly increase the greenhouse effects. Serious emission of CO<sub>2</sub> may cause health related issues such as asthma, bronchitis and sometimes skin and lung cancer (Armstrong *et al.*, 1991).

To serve the specific purposes for which coatings are applied, the technology of protective organic/inorganic coatings has expanded tremendously in the last decades. Hence, in the past few decades, a new alternative to conventional coatings by inorganic coatings is proposed. Geopolymeric precursors likes metakaolin, fly ash, and blast-furnace slag have been materialized as a potentially new inorganic material with interesting properties such as high compressive strength, good thermal stability, high flexural strength and good fire resistance (Kolezynski *et al.*, 2018; Fan *et al.*, 2018).

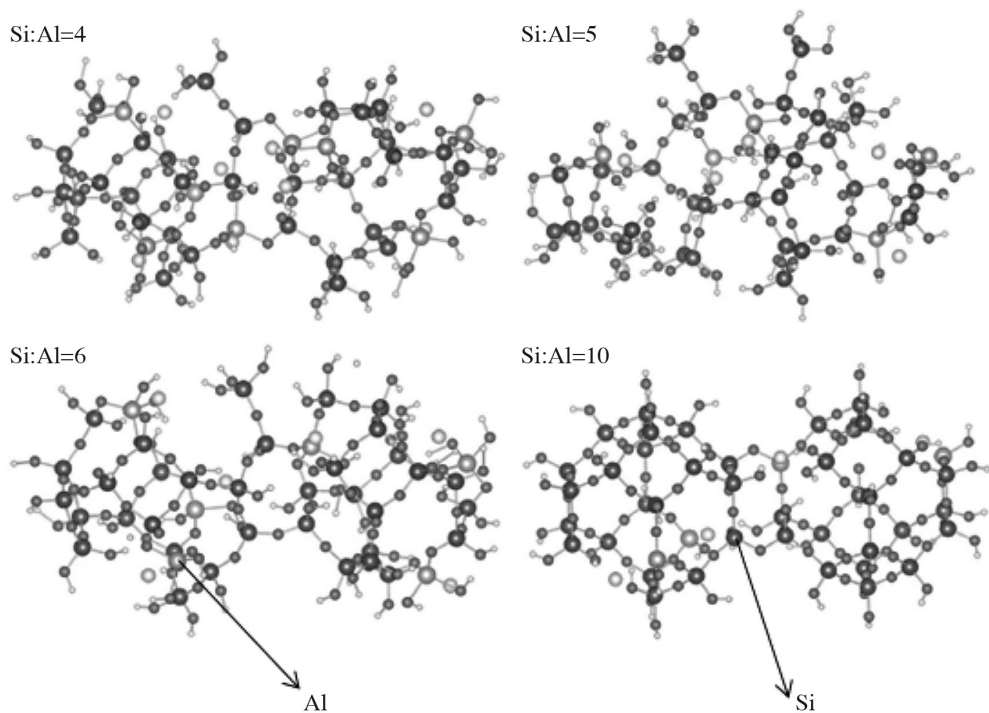
In this review, detailed description of history, properties, applications and limitations of geopolymer discussed and some preliminary results are provided.

## A REVIEW

### History of Geopolymer

Geopolymers are synthetic green polymeric materials prepared by the chemical interaction of raw aluminosilicates obtained from power plants such as coal fly ash, mineral clays (metakaolin), and/or the slag form metallurgy, with an aqueous

alkaline and/or alkaline silicate solution as reaction process accelerators and inducing development of solid, insoluble binding material (Provis and Bernal, 2014; Provis 2013) Chemically geopolymers are tetrahedrally cross linked aluminosilicates with  $\text{Si}^{+4}$  and  $\text{Al}^{+3}$  units and the structure is charge stabilized by alkali cation (Palomo *et al.*, 2014). The chemistry of geopolymers depends on the Si and Al content of the starting materials and type of activator used (Prudon, 1940). Geopolymer chemistry is synonymous to zeolite with the exceptions that geopolymers are amorphous and the unreacted starting material is also intact with geopolymer gel. Several structural models of selected clusters with various Si:Al ratio is shown in Fig. 1.



**Figure 1.** Structural models of geopolymer clusters with various Si:Al ratio (Kolezynski *et al.*, 2018).

The history of alkali activation technology dates back to 1908, when Kuhl *et al.* patented their first formulation called “slag cement” by mixing the blast furnace slag (BFS) with alkaline components (Kuhli, 1908). In 1930-1950, first lab scale researches on cement prepared from steel slag and alkalis were published by Prudon *et al.* in Belgium (Prudon, 1940). Later, the technology was implemented in Russia to develop building material by alkali activation of low calcium aluminosilicate precursors. These materials known as “soil cement” and “soil silicates” (Glukhovskii *et al.*, 1967). Beside all the previous work, Davidovits in 1970s was first to introduce the term “geopolymer” for alkali activated metakaolin. The products were commercialized as fire resistant, inorganic materials. He used the term ‘geopolymer’ to highlight some of the resemblances of the geopolymers with organic thermoset resins (Davidovits, 1982).

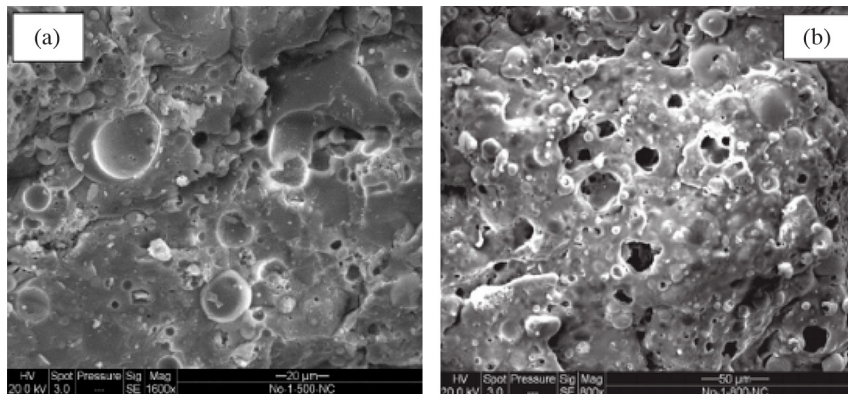
The product has gained interest of the research community as a direction towards the future building material and in 1980-1990, in North America, a hybrid concrete called "Pyrament" having high early strength was commercialized (Davidovits, 2008). High early strength concrete is one of the types in high performance concrete. A high early strength concrete means that the compressive strength of the concrete at the first 24 hours after site-pouring could achieve structural concrete quality (compressive strength > 21 MPa).

Geopolymers based on fly ash were first reported by Wastiels et al. in 1990s and patented a binder prepared from alkali activation of blast furnace slag (BFS) and fly ash (Wastiels *et al.*, 1994). After more than a century, the main reason behind the high appreciation of geopolymer technology is owing to its potential for the decrease in CO<sub>2</sub> discharge and thermal stability. As the industrial waste products are most commonly used as precursors in the geopolymerization process, considerable greenhouse gases reduction have been offered by these binders compared to Ordinary Portland Cement (OPC). Moreover, a sustainable solution of the waste ash disposal and reutilization, along with cutback of the ample consumption of mineral carbonates (calcium carbonates) in the OPC industry is also presented by geopolymers. Approximately, 0.8 ton of CO<sub>2</sub> is emitted per ton of OPC, as a result of combustion of fuel and the gases released the de-carbonation of calcite, contributing to 5-7 % of the global CO<sub>2</sub> release (Provis, 2013).

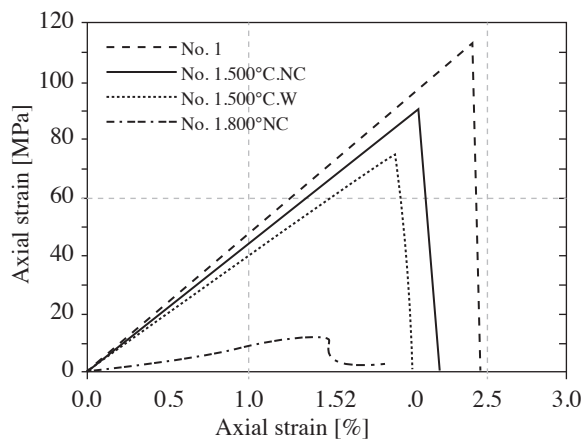
### Properties of Geopolymer

Geopolymers have displayed better physical, chemical and mechanical properties. Some of these properties include nano porosity, thermal stability, fire resistance, corrosion mitigation, low shrinkage, high compression strength, early setting, exchangeable metal cations and ability to coat infrastructure and metal surfaces. Mechanical properties of the geopolymers; mostly described by compression and flexural strength have been found comparable to OPC based mortars and concretes (Provis, 2013). The mechanical properties of geopolymers are dependent upon the activator, raw material, SiO<sub>2</sub>: Al<sub>2</sub>O<sub>3</sub>, Na: Al, and water: solid ratio, curing time and temperature, and setting time.

The tested results show that the geopolymer cured at appropriate conditions can reach a compressive strength of more than 100 MPa after 500 °C heating (Fan *et al.*, 2018). The effect of temperature on the strength could be explained by the microstructure images as shown in Fig. 2. The pores, cracks, voids, unreacted fly ash balls and semi-spherical concavities were observed on sample at 500 °C heating (Fig. 2(a)). Surprisingly, by increase the heating temperature up to 800 °C the sample becomes loose, porous and honeycomb-shaped patterns. This kind of morphology resulted in much lower compressive strength, as shown in Fig.3 (Fan *et al.*, 2018). The figure shows a value of compressive strength for a mixture of samples at water: ash ratio of 0.2, of which is designated as No.1 and heated at 500 °C and 800 °C. The NC refers to natural cooling down method while W refers to water cooling down method.



**Figure 2.** The microstructure of the sample with water: ash ratio of 0.2 at (a) 500°C and (b) 800°C heating (Fan et al., 2018)



**Figure 3.** Compressive strength of samples at water: ash ratio of 0.2 at different heating temperature (Fan et al., 2018)

Fernandez-Jimenez et al. reported geopolymer mortars from alkali activation of fly ash and investigated the effect of Si: Al ratio on the mechanical properties of geopolymer. A compressive strength as high as 70-80 MPa was achieved, and the studies revealed that maximum strength was attained with the Si: Al molar ratio less than 2 (Palomo et al., 2014).

The presence of MgO and CaO in blast furnace slag resulted in the fast setting and considerable increase in compressive strength up to 50 % - 80 % was observed in sodium silicate activated geopolymer, whereas in the alkali activation there was no considerable change. Besides, alumina content in slags resulted in the lowering of compression strength during the first three weeks of curing due to slower chemical reaction, a relatively less significant change in compression strength was observed at four weeks and above (Haha, et al., 2011). In fly ash geopolymer, the higher calcium content in fly ash is responsible for a considerable decrease in compression strength

due to the formation of porous structure. While, in metakaolin geopolymer, the compressive strength are influenced by the extent of dehydroxylation, calcination's temperature and time along with the particle size of metakaolin. Maximum compression strength was produced by the systems having Si: Al ratio in the range of 1.9-2.5 and Na: Al ratio of 1.0-1.3. Higher Na: Al ratio is undesirable, as the carbonation of unused alkali result in decrease of compression strength after 28 days (Provis and Bernal, 2014).

Other important properties of geopolymers include thermal stability and resistance of fire, at temperature of flame approximately 1100–1200 °C. The alumino silicate bonds in geopolymers are thermally stable and the material itself does not catch fire due to the absence of any organic component (Temuujin *et al.*, 2009). The effect of thermal treatment on the compression strength and physical appearance of geopolymer, according to Euro code EN1991-2 was studied. A more severe spalling was recorded on the OPC concrete, whereas the geopolymers does not show such phenomenon, indicating that the geopolymers are able to withstand the high temperature. Similarly, L.K. Yong *et al.* recorded a compression strength of 62 MPa for the geopolymer exposed to 800 °C, whereas the OPC samples were broken even at 400 °C (Sanjayan, 2010). Sun *et al.* studied the thermal behavior of geopolymer synthesized from waste ceramics by heating up the sample up to 1000 °C. The result showed the compression strength was even higher than the unheated geopolymer (Sanjayan, 2010), (Sun *et al.*, 2013). The latest study conducted by Temuujin *et al.* found that a compression strength of more than 120 MPa is recorded for fly ash based, fired at 1000 °C. In another study, they investigated the thermal properties of metakaolin based geopolymer when it was heating up to 50-1000 °C. It was noted that, only 5.95 – 6.40 % of mass loss was observed, showing a tremendous thermal stability. The mass loss was correlated to the dehydration of surface and silanol bonded waters (Temuujin *et al.*, 2011).

Geopolymers have presented cation exchange ability when the powdered inorganic polymers were stirred in aqueous solution of secondary cation e.g. ammonium. A study by O'Connor *et al.* reported that a simple ion exchange method for the replacement of Na<sup>+</sup> cations with other cations using immersion method. A 100 % cation exchange was found for K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Ag<sup>+</sup> and Pb<sup>2+</sup>, whereas the cation exchange efficiency was reduced for divalent cations e.g. Mg<sup>2+</sup> and Cd<sup>2+</sup> (O'Connor *et al.*, 2010). The cation exchange property of geopolymers presented a simple route for the utilization of geopolymers as ion exchange resins and catalysts. Due to these tremendous properties, geopolymer have got a number of applications and some of these are discussed below.

### **Application of Geopolymers as Coating Materials**

There are several types of coatings that have been used as surface protection materials such as acrylic, polyurethane and epoxy (Rodrigues *et al.*, 2000), (Medeiros and Helene, 2009), (Alomayri and Low, 2013). These organic coatings usually cover

the material surface by physical absorption. For a good coating application, the coating materials need to be coated on the substrate by both physical and chemical adsorption bonding which will improve the material protection (Balaguru, 1957). In order to improve the adhesion of coating materials to substrate, the use of an inorganic coating has been proposed to substitute an organic coating. It is well known that geopolymer which is an inorganic polymer or alkali activated binders has gained worldwide interests and its high anticorrosion makes it a novel coatings material (Temuujin *et al.*, 2010). The coating formulation of geopolymer utilizes by-products that would otherwise be disposed of in landfills at a growing cost and liability. Use of the by-product creates the opportunity for carbon offset credits to further enhance profitability (Duxson *et al.*, 2007).

As an inorganic polymer based on synthetic aluminosilicate materials, geopolymer has a potential in fire resistant and protective coatings for different surfaces including metal due to their superior mechanical, chemical and thermal resistance properties (Temuujin *et al.*, 2010). Recently geopolymer and their derivatives have been used in coating application owing to their unique structural attributes.

Metakaolin (MK) and granulated blast furnace slag (GBFS) based geopolymer have been used as protective coating materials (anti-corrosion coating) for concrete structure which was exposed to marine environment. They found that the geopolymer synthesized with 90 % MK and 10 % GBFS gives porosity of 22.3 % and 94 % open pores of < 20 nm that gives low permeability of water and good as anticorrosion material. In contrast, the well prepared OPC pastes had a porosity of 29.5 % and 73.7 % open pores of < 50 nm ( Provis and van Deventer, 2007). The porosity and pore size distribution are crucial to the anticorrosion of geopolymer because they are the dominating factors to the permeability of the hardened matrix. Less and smaller pores make the penetration of the erosive medium into the geopolymer difficult, thus reducing the destruction of structures. From the analysis it shows that metakaolin-based geopolymer can be used as anti-corrosion coating for concrete structure ( Zhang *et al.*, 2010).

Besides anti-corrosion, geopolymer coating had been researched for other coating applications such as construction industry coating (Ahmed, 2014), fire resistant coating (Temuujin *et al.*, 2009), and protective marine coating (Zhang and Yao, 2010). A recent review has also appeared on the use of fly ash-based geopolymer in coating application. Irfan Khan *et al.* (2014) mentioned that the adhesion strength of coal fly ash-based geopolymer coatings was more than 3.5 MPa.

In Al Bakri Abdullah *et al.* (2013) work, fly ash based geopolymer was exposed from 600 °C to 1500 °C flame and gives compressive strength of 40 MPa. Metakaolin and palm oil fuel ash also gives maximum compressive strength at 7 days curing which is 68.86 MPa (Ismail *et al.*, 2013). These research show that geopolymer based material can withstand fire at high temperature thus allowing it to be made as coating materials purpose by altering its chemical composition in the reaction system. Temuujin *et al.*

have also reported the use of fly ash for fire resistant coatings on metal substrate. The adhesive strength of greater than 3.5 MPa have been achieved on mild steel surfaces for compositions with Si:Al of 3.5 (Temuujin *et al.*, 2010). Similar result was observed by using metakaolin based geopolymer. The coating exhibited excellent adhesion to steel substrates achieving greater than 3.5 MPa tensile stress. Geopolymer type coatings prepared by using an industrially available sodium silicate solution ( $\text{SiO}_2$ :  $\text{Na}_2\text{O} = 3.1$ ) showed up only 3 % thermal expansion after heating to 800 °C and the coating maintained high structural integrity with steel substrates when subjected to a heat treatment (Temuujin *et al.*, 2011).

Metakaolin and fly ash based geopolymer combination also have been proven to exhibit the same level or higher bending and compressive strength as that of OPC paste both at ambient temperature and after high temperature exposure. After exposure to 800 °C, the ratio of compressive strength of geopolymer paste is 22 % compared to compressive strength of OPC paste which is completely lost (untraceable) (Zhang *et al.*, 2014). Generally, all the studies have shown that geopolymer based material can be used as coatings material.

### Limitations of Geopolymers as a Coating Materials

Although these geopolymer based are very good in terms of increasing the strength and toughness, the disadvantages of these geopolymer are still there, where geopolymer are very brittle that may lead to catastrophic failure service (Shaikh, 2013). This is due to the porosity and structure itself which contains amorphous geopolymeric gel, residual unreacted raw material particles and varied pores (Zhang *et al.*, 2009). Geopolymer without any filler will result in low permeability and low fire and chemical resistance. Geopolymer itself cannot stand alone due to the brittle nature of geopolymer (Shaikh, 2013).

Fly ash-based geopolymer that is used as fire resistant coatings appears to have severe damage and shrinkage while curing at high temperature. For thermal resistant coatings, the thermal expansion should match the substrate to maintain structural integrity during heating and cooling. When heated, metal expands while generally geopolymer shrink creating a thermal mismatch that could lead to cracking of the coatings and loss of adhesion. It also reported that, the porosity of the geopolymer was increased when heated at high temperature which leads to the cracking of geopolymer paste (Temuujin *et al.*, 2010).

Table 1 summarizes the geopolymer application with its limitations from previous studies. Clearly, most of geopolymers coatings have similar problems such as brittle, large shrinkage and crack when cured at certain temperature that leads to a reduce in strength. The major factor in strength weakness, cracking and brittleness of geopolymer is the presence of porosity. Earlier qualitative work showed that geopolymer strengths are very much dependent on the porosity (Perera *et al.*, 2006). Therefore, in order to address this problem, fiber reinforced geopolymer composites are introduced.



**Table 1.** General properties of additive manufacturing strategy.

| References                        | Activator and raw material                                      | Curing condition                                      | Findings  | Application     |
|-----------------------------------|---|---|---|-----------------|
| (Irfan Khan <i>et al.</i> , 2015) | Sodium hydroxide, fly ash                                       | Curing time of 3 days; curing temperature of 60°C     | <ul style="list-style-type: none"> <li>• Highest adhesion obtained at 3.8 MPa;</li> <li>• Mesoporous surface with pore sizes of 50 - 100 nm</li> </ul>  | steel coating   |
| (Al Bakri <i>et al.</i> , 2013)   | Sodium hydroxide, sodium silicate, fly ash                      | Curing time of 24 hours; curing temperature of 70°C   | <ul style="list-style-type: none"> <li>• Curing at high temperature cause the sample examined severe damage due to shrinkage formed</li> </ul>  | ceramic coating |
| (Temuujin <i>et al.</i> , 2010)   | Sodium hydroxide, sodium silicate, fly ash                      | Curing time of 24 hours; curing temperature of 70 °C  | <ul style="list-style-type: none"> <li>• Highest adhesion strength obtained at 3.9 MPa</li> <li>• geopolymer coating a bit soft to be mold</li> <li>• exhibit shrinkage with temperature increase</li> <li>• the sample is brittle</li> </ul> | steel coating   |
| (Zhang <i>et al.</i> , 2010)      | Sodium hydroxide, metakaolin, and granulated blast furnace slag | Curing time of 24 hours; curing temperature of 60 °C; | <ul style="list-style-type: none"> <li>• Highest compressive strength obtained at 74.6 MPa</li> <li>• large shrinkage at early age of geopolymer fabrication</li> <li>• micro cracks on surface of geopolymer</li> </ul>                      | marine concrete |
| (Temuujin <i>et al.</i> , 2009)   | Sodium hydroxide, sodium silicate, metakaolin                   | Curing time of 24 hours; curing temperature of 70 °C  | <ul style="list-style-type: none"> <li>• highest adhesion strength obtained at 3.5 MPa</li> <li>• high porosity after expansion</li> <li>• the sample is brittle</li> </ul>   | metal substrate |

## Fiber Reinforcement

Fiber reinforcement is mostly used in the last decade to improve brittle product into tough and ductile product and also increase durability through bridging the cracks. The most common fiber reinforcement used in geopolymer composites for concrete structure are carbon, basalt and glass fibers. Other inorganic fibers such as silicon carbide, alumina, mullite or boron can be utilized. Maximum flexural strengths of >500 MPa have been reported by several authors for unidirectional carbon fiber-reinforced geopolymer composite and desirable non-brittle fracture was observed when short carbon fibers were used (Alomayri and Low, 2013).

There are also some reports mentioning that short polyvinyl alcohol (PVA) fiber was used to reinforce fly ash/metakaolin-based geopolymer composites for concrete and showed a good flexural strength and reasonable toughness. The short PVA fiber could be applied to modify the brittle properties of fly ash-based geopolymer. All fiber exhibited improvement in flexural strength of geopolymer composites. Most notable carbon and PVA Fiber Reinforced Geopolymer Composites (FRGC) exhibited about 50 % and 62 % increase in the flexural strength, respectively along with significant improvement in post-crack ductility (Shaikh, 2013).

It has also been reported that five kinds of water-soluble organic polymers, such as sodium polyacrylate (PAANa), polyacrylic acid (PAA), polyacrylamide (PAm), polyethylene glycol (PEG), and PVA were employed to prepare organic polymer reinforced uncalcined-kaolinite geopolymer. It was found that the incorporation of PAA and PAANa could obviously improve the compressive strength (Irfan Khan et al., 2015). Yet, the limitation in FRGC is still existed up to current knowledge. Table 2 summarizes the findings from previous studies on the fiber reinforced geopolymer composites (FRGC).

**Table 2.** Fiber reinforcement geopolymer composites

| References                      | Geopolymer system  | Findings  |
|---------------------------------|--|---|
| (Bernal <i>et al.</i> , 2010)   | <ul style="list-style-type: none"> <li>• Steel fiber reinforced slag based FRGC</li> <li>• Amount of steel fiber: 40 kg/m<sup>3</sup> to 120 kg/m<sup>3</sup></li> </ul>   | <ul style="list-style-type: none"> <li>• 25 % reduction of compressive strength at 7 and 28 days of curing period for FRGC containing 40 kg/m<sup>3</sup> of steel fiber</li> <li>• 23% reduction of compressive strength at 7 and 28 days of curing period for unreinforced FRGC</li> <li>• The compressive strength is not affected by increasing the steel volume from 40 kg/m<sup>3</sup> to 120 kg/m<sup>3</sup></li> <li>• The increase in flexural strength at all ages is observed</li> <li>• An increase in flexural strength with increase in curing time of all fiber content</li> <li>• They observed as high as 70 % increase in flexural strength of the FRGC at 28 days of curing period</li> </ul>  |
| (Puertas <i>et al.</i> , 2003)  | <ul style="list-style-type: none"> <li>• Slag, fly ash, slag/fly ash combination</li> <li>• Polypropylene (PP) fiber with 0.5 % and 1.0 % was used</li> </ul>  | <ul style="list-style-type: none"> <li>• The addition of 0.5 % and 1.0 % of fiber did not much affect the compressive strength at 2 and 28 days of curing period.</li> <li>• In fly ash based geopolymer composite the compressive strength is increased for 2 days curing period due to increase of PP fiber contents. But, an opposite trend is observed at 28 days of curing period in the same composite</li> </ul>   |
| (Zhang <i>et al.</i> , 2009)    | <ul style="list-style-type: none"> <li>• Combination of fly ash and calcined kaolin with a ratio of 1:2</li> </ul>   | <ul style="list-style-type: none"> <li>• In the case of combined slag/fly ash based FRGC, slight increase in compressive strength is noticed by increasing the PP fibers from 0.5 % to 1.0 % at both curing period.</li> <li>• The increase in compressive strength by about 68% and 20% at 1 and 3 days curing period, respectively is observed in FRGC containing 0.5% PP fiber (by weight.). However, beyond this fiber content the rate of increase of compressive strength decreased at both ages curing period.</li> <li>• Significant improvement in the flexural strength of PP fiber FRGC at 1 and 3 days curing period are observed</li> <li>• The flexural strength is doubled due to the addition of 0.75% PP fiber at both ages curing period</li> </ul> |
| (Natali <i>et al.</i> , 2011)   | <ul style="list-style-type: none"> <li>• Metakaolin/ slag based FRGC</li> <li>• Types of fiber: carbon, E-glass, polyvinyl alcohol (PVA) and polyvinyl chloride (PVC)</li> </ul>   | <ul style="list-style-type: none"> <li>• All fibers exhibited improvement in flexural strength of FRGC</li> <li>• Most notable carbon and PVA fiber reinforced FRGC exhibited about 50% and 62% increase in the flexural strength, respectively, along with a significant improvement in post-crack ductility</li> </ul>  |
| (Yunsheng <i>et al.</i> , 2009) | <ul style="list-style-type: none"> <li>• Extruded PVA fiber FRGC made from a sodium silicate/sodium hydroxide activated metakaolin and fly ash/metakaolin blend</li> <li>• The PVA fibers with 14 μm in diameter, 6 mm in length are used at 0%, 1%, and 2% by volume</li> </ul> | <ul style="list-style-type: none"> <li>• The metakaolin based FRGC exhibited substantial increases in midpoint deflection and distributed micro-crack in due to increase in fiber content</li> <li>• The ultimate flexural strength is not improved due to the addition of PVA fibers in the metakaolin in base FRGC</li> <li>• Increasing the quantity of fly ash in metakaolin/fly ash blended FRGC decreases the flexural strength except the composite containing 10% fly ash, where the flexural strength is increased by about 30% than that containing no fly ash (i.e. 100% metakaolin)</li> </ul>  |

Polypropylene has become a solution to any application due to its properties that are low density, high melting points, long-term durability and most important they are resistant to stress, cracking and chemical corrosion. It is also resistant to humidity, warm, acid rain, ultraviolet ray and other adverse environmental conditions, which could damage the metal.

In another study on polypropylene fiber, it was reported that the flexural strength of the fiber reinforced geopolymer concrete (FRGC) was doubled by addition of 0.75 % polypropylene fiber (Zhang *et al.*, 2009). Compressive strength of fly ash and metakaolin based FRGC was increased by about 68 % due to addition of 0.5 % polypropylene fiber (Shaikh, 2013). The presence of polypropylene fiber had caused reducing the amount of shrinkage and expansion of concrete that can significantly affect the lifespan of the structure. Concrete compressive strength also has reported an increase that is proportionate with the increase in volume ratios of propylene fibers, the highest strength values were seen in the volume ratios of 1.5 kgm<sup>-3</sup> and 2 kgm<sup>-3</sup>. The fibers used lead to the prevention of the crack propagation by creates bridging effect between the pores (Kakooei *et al.*, 2012).

It was reported that application of nylon and polypropylene fibers improves the plain concrete properties including splitting tensile strength, first-crack strength and impact resistance (Song *et al.*, 2005). Alhozaimy *et al.* observed that an additional amount of 0.1 % polypropylene fibers in the plain concrete had 44 % increase in flexural toughness of the concrete. Some researchers also reported evidence of small but favorable effects of fiber addition on toughness (Alhozaimy *et al.*, 1996). Bagherzadeh *et al.* reported that compressive strength increased by about 25 % at 0.5 % volume fraction of polypropylene fibers in the concrete mixture design (Bagherzadeh *et al.*, 2012).

## CONCLUSION

A rich alumino silicate material such as fly ash is one of the cheapest and easily accessible raw material that can be used to form geopolymers. With promising mechanical and chemical properties, the geopolymers have the potential to be applied in various applications including coating material. Further research by incorporating fiber reinforcement agent into geopolymers system seems to give an enhancement to the geopolymers properties.

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