

Potential Application of Kaolin Without Calcine as Greener Concrete: A Review

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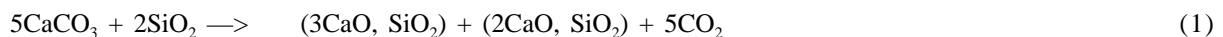
Abstract: Kaolin is a white raw material that has an essential constituent which makes it ideal for industrial applications such as green concrete. Based on a historical review, it appears that green polymeric composites created by using kaolin itself are very limited. Research works carried out in developing other alkali-activated binders, such as fly ash and metakaolin, shows that this new binder based on kaolin is likely to have enormous potential to become an alternative to ordinary Portland cement (OPC) concrete. This paper summarizes current knowledge about alkali-activated binders through a review of previously published work and outlines the potential of kaolin to produce an environmentally friendly, energy-saving, clean technology to conserve the natural environment and resources. These binders are still in the early stages of development; hence, they need further research to become technically and economically viable construction materials. Much work on alkali-activated binders has already been conducted, but much work on kaolin for greener concrete remains to be done. It is hoped that future research in this field will drive a new era of greener materials in the construction industry.

Key words: Geopolymer; Green Concrete; Kaolin; Calcined Kaolin; Alkali-activated Binder.

INTRODUCTION

Concrete is the most widely used construction material in the world. Traditionally, ordinary Portland cement (OPC) has been used as the binding agent for concrete. Since it has now become a priority to control the trend of global warming by reducing carbon dioxide emissions, it is appropriate to search for alternative low-emission binding agents for concrete (Sarker, 2009). The only exception is the so-called 'blended cement' (Voglis, 2005) which uses traditional and up-to-date mineral additives; blended cement is considered to be state-of-the-art technology for cement production because it uses supplementary materials such as blast furnace slag, fly ash, natural pozzolan, silica fume, burnt shale, and limestone powder (Ozer, 2004) where the CO₂ emissions are slightly suppressed by a maximum of 10% to 15%. No current technology exists to reduce carbon dioxide emissions of Portland cement (PC) any further.

PC results from the calcination of limestone at very high temperatures of approximately 1450-1500°C, and silico-aluminous material according to the reaction:



means that the manufacture of 1 metric ton of cement generates 1 metric ton of CO₂ greenhouse gas (McLeod, 2005). Unless something drastic and different is done, the world's atmosphere will continue to be damaged by the production of PC, which is a far worse source of atmospheric pollution than production from the oil or any other industry. 5 to 8 percent of all human-generated atmospheric CO₂ worldwide comes from the concrete industry. Production of PC is currently topping 2.6 billion metric tons per year worldwide and growing at 5 percent annually (Allouche, 2009). Geopolymers have been shown to offer an environmentally friendly, technically competitive alternative to OPC. These materials can provide comparable performance to traditional cementitious binders in a range of applications, but with the added advantage of significantly reduced greenhouse emissions. Depending on the raw material selection and processing conditions, geopolymers can exhibit a wide variety of properties and characteristics, including high compressive strength, low shrinkage, fast or slow setting, acid resistance, fire resistance and low thermal conductivity (Duxson, 2007).

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So far, research work carried out in developing alkali-activated binders has shown that they are likely to have enormous potential to become an alternative to OPC concrete. These binders are still in the early stages of development; thus, further research work is needed to develop them into technically and economically viable construction materials. Many researchers have focused on metakaolin obtained by calcined kaolin at elevated temperature due to the presence of highly reactive elements in metakaolin and the ease of creating high strength, among several other useful properties.

Mohsen and Mostafa (2010) investigated the possibility of using low kaolinitic clays in production of geopolymer bricks. The results showed that two of the studied clays have characteristics adequate for geopolymer brick manufacture by activation with NaOH solution. All studied clays were suitable for geopolymer brick manufacture if activated with a sodium silicate solution. Low kaolinitic clays thermally treated at 700°C for 2 hours prior to use, even though without calcine, a raw-material kaolin with low reactive phase just like low kaolinitic clays, might be possible for the manufacture of concrete with specific strength.

In this paper, the most relevant knowledge about alkali-activated binders involving kaolin as a raw material in the production of green concrete will be reviewed. The term “green” refers to environmentally friendly, energy-saving, clean technology that conserves the natural environment and resources. The production of 1 metric ton of geopolymeric cement generates 0.180 metric tons of CO₂ from combustion carbon-fuel, compared with 1 tonne of CO₂ for PC, i.e., six times less (Davidovits, 2008). Furthermore, using kaolin instead of metakaolin can eliminate the step of calcinations, which involves elevated temperatures.

2. Historical Background of Geopolymer:

The history of developments in alkali-activated binders contains major contributions starting from the 1940s. Table 1 summarizes the historical background marking important inventions in the field of alkali-activated cement binders (Roy, 1999; Li, 2010). In 1957, Victor Glukhovsky, a scientist working in the Ukraine at the KICE (Kiev Institute of Civil Engineering in the USSR), investigated the problem of alkali-activated slag binders and in the 1960s and 1970s made a major contribution by identifying calcium silicate hydrates, and calcium and sodium alumino-silicate hydrates (zeolites) as solidification products. Glukhovsky called the concretes produced with this technology "soil silicate concretes" (1959) and the binders "soil cements" (1967).

Table 1: Bibliographic history of some important inventions about alkali activated binders (Roy, 1999; Li, 2010).

| Year | Author | Significance |
|------|-------------------------------|---|
| 1939 | Feret | Slags used for cement. |
| 1940 | Purdon | Alkali-slag combinations. |
| 1959 | Glukhovsky | Theoretical basis and development of alkaline cements. |
| 1965 | Glukhovsky | First called “alkaline cements”. |
| 1979 | Davidovits | “Geopolymer” term. |
| 1979 | Malinowski | Ancient aqueducts characterized. |
| 1983 | Forss | F-cement (slag-alkali-superplasticizer). |
| 1984 | Langton and Roy | Ancient building materials characterized. |
| 1985 | Davidovits and Sawyer | Patent of “Pyrament” cement. |
| 1986 | Krivenko | DSc thesis, R ₂ O-RO-SiO ₂ -H ₂ O. |
| 1986 | Malolepsy and Petri | Activation of synthetic melilite slags. |
| 1986 | Malek et al. | Slag cement-low level radioactive wastes forms. |
| 1987 | Davidovits | Ancient and modern concretes compared. |
| 1989 | Deja and Malolepsy | Resistance to chlorides shown. |
| 1989 | Kaushal et al. | Adiabatic cured nuclear wastes forms from alkaline mixtures. |
| 1989 | Roy and Langton | Ancient concretes analogs. |
| 1989 | Majundar et al. | C ₁₂ A ₇ -slag activation. |
| 1989 | Talling and Brandstetr | Alkali-activated slag. |
| 1990 | Wu et al. | Activation of slag cement. |
| 1991 | Roy et al. | Rapid setting alkali-activated cements. |
| 1992 | Roy and Silsbee | Alkali-activated cements: an overview. |
| 1992 | Palomo and Glasser | CBC with metakaolin. |
| 1993 | Roy and Malek | Slag cement. |
| 1994 | Glukhovsky | Ancient, modern and future concretes. |
| 1994 | Krivenko | Alkaline cements. |
| 1995 | Wang and Scivener | Slag and alkali-activated microstructure. |
| 1996 | Shi | Strength, pore structure and permeability of alkali-activated slag. |
| 1997 | Fernández-Jiménez and Puertas | Kinetic studies of alkali-activated slag cements. |
| 1998 | Katz | Microstructure of alkali-activated fly ash. |
| 1999 | Davidovits | Chemistry of geopolymeric systems, technology. |

Table 1: Continue.

| | | |
|-----------|--|---|
| 1999 | Roy | Opportunities and challenges of alkali-activated cements. |
| 1999 | Palomo | Alkali-activated fly ash — a cement for the future. |
| 2000 | Gong and Yang | Alkali-activated red mud–slag cement. |
| 2000 | Puertas | Alkali-activated fly ash/slag cement. |
| 2001-2002 | Bakharev | Alkali-activated slag concrete. |
| 2003 | Palomo and Palacios | Immobilization of hazardous wastes. |
| 2004 | Grutzeck | Zeolite formation. |
| 2006 | Sun | Sialite technology. |
| 2007 | Duxson | Geopolymer technology: the current state of the art. |
| 2008 | Hajimohammadi, Provis and Deventer | One-part geopolymer. |
| 2009 | Provis and Deventer | Geopolymers: structure, processing, properties and industrial applications. |
| 2010 | M.R. Wang, D.C. Jia, P.G. He, Y. Zhou | Influence of calcination temperature of kaolin on geopolymer. |
| 2010 | Daniel L.Y. Kong, Jay G. Sanjayan | Effect of elevated temperatures on geopolymer. |
| 2010 | C. Villa, E.T. Pecina, R. Torres, L. Gómez | Geopolymer synthesis using alkaline activation of natural zeolite. |
| 2011 | Somma et al. | NaOH activated ground fly ash geopolymer. |
| 2011 | Elimbi et al. | Calcination temperature effect of kaolinitic clays. |

In 1972, the ceramicist team of Latapie and Davidovits confirmed that water-resistant ceramic tiles could be fabricated at temperatures lower than 450°C, i.e., without firing. One component of clay, kaolinite, reacted with caustic soda at 150°C. In fact, the industrial application of this kaolinite reaction with alkali began in the ceramics industry with Niels Olsen (1934) and was later rediscovered in 1964 by Berg et al. (1970), a Russian team (Davidovits, 2008).

Investigation into the field of alkali activation increased exponentially after the research results of French author Davidovits, which described developed and patented binders obtained from the alkali activation of metakaolin. Davidovits, the inventor and developer of geopolymerization, coined the term “geopolymer” in 1978 to classify the newly discovered geosynthesis that produces the inorganic polymeric materials now used in a number of industrial applications (Kong, 2008).

Geopolymers are presently developed and applied in nine main classes of materials: waterglass-based geopolymer, kaolinite / hydrosodalite-based geopolymer, metakaolin MK-750-based geopolymer, calcium-based geopolymer, rock-based geopolymer, silica-based geopolymer, fly ash-based geopolymer, phosphate-based geopolymer, and organic-mineral geopolymer, as summarized by Davidovits (Davidovits, 2008). According to Davidovits (Davidovits, 2008), geopolymers are polymers transformed, polymerized and hardened at low temperature, but they are also inorganic, hard, and stable at high temperature, as well as non-flammable.

Based on the historical review, investigation into green polymeric composites by using kaolin itself is very limited; researchers have mainly focused on metakaolin and fly ash as their starting materials because of their high reactivity, which contributes to optimum performance, rather than on the less reactive kaolin. Therefore, in this paper, we will focus on kaolin which does not need to be calcined at high temperature and might contribute to the greener, less energy-consuming production of green concrete.

3. Prime Materials:

Kaolin is a naturally occurring material composed primarily of fine-grained minerals; it is the most abundant mineral found in the earth. Kaolin essentially is composed of silica, alumina, and water in variable combinations; clay mineral kaolinite frequently predominates. It has the potential to become the major replacement of OPC materials because of its unique properties and chemistry for producing environmentally friendly composites. Kaolinite is formed by rock weathering. It is white, greyish-white, or slightly colored. Kaolinite is formed mainly by decomposition of feldspars (potassium feldspars), granite, and aluminum silicates. The process of kaolin formation is called kaolinization. Kaolin is a soft, lightweight, often chalk-like sedimentary rock that has an earthy odor. In addition to kaolinite, kaolin usually contains quartz and mica and, less frequently, feldspar, illite, montmorillonite, ilmenite, anastase, haematite, bauxite, zircon, rutile, kyanite, silliminate, graphite, attapulgitite, and halloysite. The morphology of the kaolin crystals is plate-like (Varga, 2007). Kaolin is a clay mineral that traditionally has been used in the manufacture of porcelain. “Kaolinite” is the mineralogical term that applies to kaolin clays. Kaolin is also used in other clay bodies, such as some stoneware bodies, and in glazes. It is highly refractory and stiff, has a stable chemical structure, and contains good physical properties for ceramics production.

The term “kaolin” is derived from the Chinese term “Kauling”, meaning high ridge, the name for a hill near Jauchau Fu, China, where this material was mined for ceramics centuries ago. The main constituent, kaolinite, is a hydrous aluminum silicate of the approximate composition $2\text{H}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$. Structurally, it

is a layered silicate mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedral or, in other words, two-layer crystal silicon oxygen tetrahedral layers joined to alumina octahedral layers exist alternately and have the theoretical formula $(OH)_8Si_4Al_4O_{10}$ and the theoretical composition of 46.54% SiO_2 , 39.5% Al_2O_3 , 13.96% H_2O (Prasad, 1991). Table 2 shows one of the general chemical compositions of the raw materials kaolin obtain by X-ray fluorescence (XRF) (Qhatani Mohsen, 2010) note that SiO_2 and Al_2O_3 are the major constituents.

Table 2: General chemical compositions of kaolin (Qhatani Mohsen, 2010).

| Element | SiO_2 | TiO_2 | Al_2O_3 | Fe_2O_3 | MgO | CaO | Na_2O | K_2O | P_2O_5 | SO_3 | LOI |
|---------|---------|---------|-----------|-----------|------|------|---------|--------|----------|--------|-------|
| Kaolin | 48.28 | 0.06 | 35.69 | 0.97 | 0.07 | 0.05 | 0.28 | 1.42 | 0.12 | 0.11 | 12.75 |

Kaolin has many industrial applications and new ones are still being discovered. It is used in paper, paint, rubber, plastics and ceramics industries, among others (Abdel-Khalek, 1999). It is chemically inert over a relatively wide pH range, is non-abrasive, and has low conductivity of heat and electricity. Some uses of kaolin, such as in paper coating or fillers for paints and plastics, require very rigid specifications, including particle size, color and brightness, and viscosity; other uses require no specifications (e.g., in concrete where the chemical composition is most important) (Prasad, 1991).

Davidovits (2008) used kaolinite and metakaolin as sources of alumino-silicate oxides to synthesize and produce geopolymers. Other researchers have also focused on the manufacture of geopolymeric products and their industrial applications by using either kaolinite or metakaolinite as the main reactant (Xu, 2002; Komnitsas, 2007).

Geopolymers derived from metakaolin may require too much water due to porosity increases and therefore may become too soft for construction applications. However, according to Duxson *et al.* (2007) metakaolin is important in the production of geopolymers for applications as adhesives, coatings, and hydroceramics. Xu and Van Deventer (Komnitsas, 2007) conducted extensive research and concluded that if only kaolinite is used without the presence of other alumino-silicates, a weak structure is formed.

Kaolinite is the main structure forming species in the overall geopolymerization process. Xu and Van Deventer (Komnitsas, 2007) proposed that the addition of kaolinite is necessary because the rate of Al dissolution from the raw materials is not sufficient to produce a gel of the desired composition and, due to the low reactivity of kaolinite, it requires additional time for interactions among the source materials to form. Xu and Van Deventer also said that the nature and behavior of the starting materials and the actual concentrations in solution affect the formation and setting of the geopolymerization product (Xu, 2002; Komnitsas, 2007). However, if a large amount kaolinite is added, the added kaolinite may not take part in the synthesis reaction summarized by Van Jaarsveld *et al.* (2002). Kaolin-type clays undergo a series of phase transformations upon thermal treatment in air at atmospheric pressure. Metakaolin (MK) is a pozzolanic material. It is obtained by calcination of kaolinitic clay at a temperature between 500°C and 800°C. The “meta” prefix in the term is used to denote change. In the case of metakaolin, the change that is taking place is dehydroxylation, brought on by the application of heat over a defined period of time (Siddique, 2008).

At just above 100°C, clay minerals lose most of their adsorbed water. The temperature at which kaolinite loses water by dehydroxylation is in the range of 500°C to 800°C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylation, kaolinite retains two dimensional orders in the crystal structure and the product is termed “metakaolin”. The key in producing metakaolin for use as a supplementary cementing material, or pozzolan, is to achieve as close to complete dehydroxylation without over-heating as possible. Successful processing of kaolinite results in a disordered, amorphous state, which is highly pozzolanic. Thermal exposure beyond a defined point will result in sintering and the formation of mullite, which is dead, burned, and not reactive (Siddique, 2008). In other words, kaolinite, to be optimally altered to a metakaolin state, requires thoroughly roasting, but should never be burned.

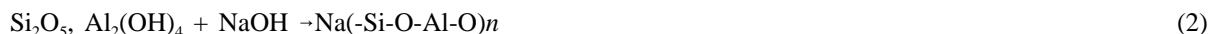
4. Reaction Mechanism of Kaolinite:

Geopolymer is synthesized by the polycondensation of silico-aluminate structures. Highly alkaline solutes such as NaOH and KOH are incorporated with source materials rich in SiO_2 and Al_2O_3 (Songpiriyakij, 2010). The geopolymer binders show good bonding properties and utilize a material such as fly ash or metakaolin as the source of silicon and aluminium for reaction by an alkali.

In a fly ash-based geopolymer binder, fly ash is reacted with an alkaline solution to create an alumino-silicate binder. Geopolymer binders are used together with aggregates to produce geopolymer concrete. There is no Portland cement involved in this cementing material. To demonstrate how the nature of selected raw

materials can affect the progress and development of chemical reactions, other alumino-silicate precursors, in particular synthetic alumino-silicate powders and natural minerals, have also been the subject of some investigations (Duxson, 2007).

The basic mechanism of kaolinite was illustrated by Davidovits (2008). Alumino-silicate kaolinite reacts with NaOH and polycondenses into hydrated sodalite or hydro-sodalite as illustrated in equation (2).



A geopolymer can take one of three basic forms - polysialate, polysialate-siloxo or polysialate-disiloxo - as seen in Figure 1.

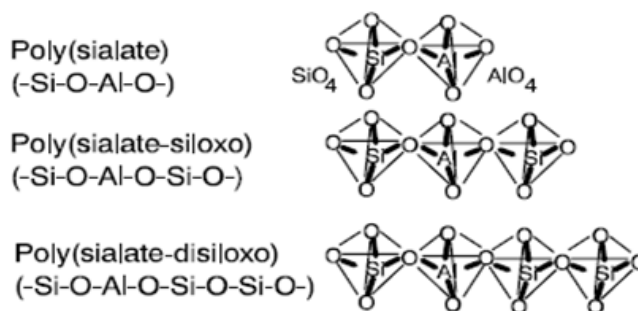


Fig 1: Different system based on the number of siloxo Si-O units (Davidovits, 2008).

Initially, formation of tetravalent Al occurred in the side group sialate $\text{O}_3\text{-Si-O-Al}(\text{OH})_3\text{Na}^+$. Second, alkaline dissolution starts with the attachment of the base OH^- to the silicon atom, thus extending its valence sphere to the penta-covalent state. Third, the cleavage of the siloxane oxygen through transfer of the electron from Si to O forms intermediate silanol Si-OH on one hand and basic siloxo Si-O^- on the other. Next is the formation of silanol Si-OH groups and isolation of the ortho-sialate molecule, the primary unit in geopolymerization, followed by reaction of the basic siloxo Si-O^- with the sodium cation Na^+ and formation of the Si-ONa terminal bond. Then, Si-ONa and aluminum hydroxyl OH-Al condensed with production of NaOH and the cyclo-disialate structure are created. Here, the alkali NaOH is liberated and allowed to react again. Finally, the polycondensation process occurs in the hydrosodalite network, as shown in Figure 2 (Davidovits, 2008).

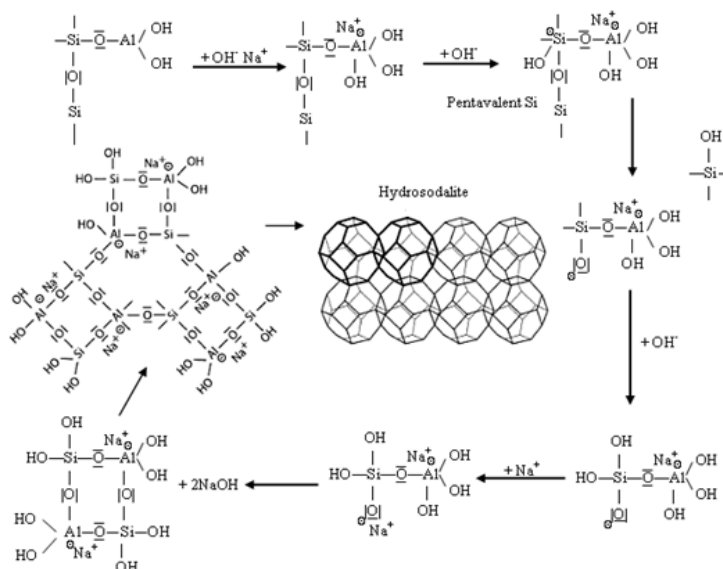


Fig 2: Chemical mechanism of kaolinite with NaOH (Davidovits, 2008).

Synthesis of geopolymer consists of three basic steps. The first is the dissolution of alumino-silicate in a strong alkali solution; this is followed by reorientation of free ion clusters, and the last step is

polycondensation. However, each step includes many pathways. The dissolution step, for example, includes eight pathways based on thermodynamics. Different pathways can create different ion clusters that directly determine the final properties of the geopolymer. Thus, it is important to understand the actual pathways for producing geopolymer to gain insight into the mechanism of geopolymerization. However, to date no such studies have been performed. This is because the forming rate of geopolymer is extremely rapid; as a result, these three steps take place almost at the same time, which makes the kinetics of these three steps inter-dependent. Thus, it is impossible to separate these steps in experimental studies (Li, 2004).

Geopolymerization is an exothermic process and it has been assumed that the synthesis is carried out through oligomers (dimer, trimer) that provide the actual unit structures of the three-dimensional macromolecular edifice. At the moment, only the sodium-poly(sialate), (Na)-PS, the potassium poly(sialate), (K)-PS, the (sodium, potassium)-poly(sialate-siloxo), (Na, K)- PSS, and the potassium-poly(sialate-siloxo), (K)-PSS, are used in geopolymeric processes (Davidvoits, 1988).

Similarly, some research describes the basic steps of geopolymerization as involving dissolution of solid aluminosilicate oxides in an MOH solution (M: alkali metal), diffusion or transportation of dissolved Al and Si complexes from the particle surface to the inter-particle space, formation of a gel phase resulting from the polymerization between added silicate solution and Al and Si complexes, and, finally, hardening of the gel phase (Komnitsas, 2007). The following reaction scheme was proposed by Xu and Van Deventer for the polycondensation taking place during geopolymerization of minerals (Xu, 2000):



↓



↓



In reactions (3) and (4), the amount of Al-Si material used depends on the particle size, the extent of dissolution of Al-Si materials, and the concentration of the alkaline solution. The formation of $[\text{M}_z(\text{AlO}_2)_x(\text{SiO}_2)_y \cdot n\text{MOH} \cdot m\text{H}_2\text{O}]$ gel essentially relies on the extent of dissolution of aluminosilicate materials, while geopolymers with an amorphous structure are formed during reaction (3). The time required for the aluminosilicate solution to form a continuous gel depends on raw material processing conditions (Komnitsas, 2007).

Under alkaline conditions, aluminosilicates are transformed into extremely reactive materials and it is generally believed that the dissolution process is initiated by the presence of hydroxyl ions. Higher amounts of hydroxyl ions facilitate the dissociation of different silicate and aluminate species, thus promoting further polymerization (Komnitsas, 2007).

5. Factors Affecting to the Formation of Geopolymer:

Panagiotopoulou *et al.* (2007) studied the dissolution of different aluminosilicate industrial minerals and by-products and reported that the extent of dissolution is higher when NaOH rather than KOH is used. This is attributed to the smaller size of Na^+ which can better stabilize the silicate monomers and dimers present in the solution, thus enhancing the minerals' dissolution rate. The size of the cation also affects the eventual crystal morphology. Na^+ , having a smaller size than K^+ , displays pair formation with smaller silicate oligomers (such as monomers). The larger size of K^+ favors the formation of larger silicate oligomers with which $\text{Al}(\text{OH})_4^-$ prefers to bind. Therefore, in KOH solutions, more geopolymer precursors exist, resulting in better setting and stronger compressive strength than geopolymers synthesized in NaOH solutions (Phair, 2001).

Wang *et al.* (2005) have proven experimentally that the compressive strength, as well as the apparent density, and the content of the amorphous phase of metakaolinite-based geopolymers increase with an increase of NaOH concentration (within the range 4-12 mol/L). This can be attributed to the enhanced dissolution of the metakaolinite particulates and hence the accelerated condensation of the monomer in the presence of the higher NaOH concentration. Granizo *et al.* supported the idea that the alkali activation of metakaolin using solutions containing sodium silicate and NaOH results in the production of materials exhibiting higher mechanical strength compared to activation with only NaOH. Moreover, the flexural strength increases when the activator volume decreases or the concentration of Na increases.

The effect of curing temperature on the development of the hard structure of metakaolin-based geopolymer was studied by Rovnanik (2010). This study aimed to analyze the effect of curing temperature (10, 20, 40, 60, and 80°C) and time on the compressive and flexural strengths, pore distribution and microstructure of alkali-

activated metakaolin material. The results showed that the treatment of a fresh mixture at elevated temperatures accelerates strength development, but the 28-days mechanical properties deteriorated in comparison with results obtained for mixtures that were treated at an ambient or slightly decreased temperature.

Alonso and Palomo (2001) found that the rate of polymer formation is influenced by parameters such as curing temperature, alkali concentration, and initial solid content, among others. When the activator concentration increases, a delay in polymer formation is produced, whereas temperature accelerates its formation. The solids ratio (metakaolin/Ca(OH)₂) does not influence the rate of aluminosilicate formation, but larger product precipitation is produced when the solids ratio increases. The effects of high-temperature heat treatment on the mechanical properties of unidirectional carbon fiber-reinforced geopolymer composites studied by Peigang *et al.* (Sun, 2004) include that mechanical properties and fracture behavior are correlated with their microstructure evolution including the fiber/matrix interface change.

According to Xu and Van Deventer (2002), during geopolymerization of natural minerals, when an aggregate such as granular sand is added to the geopolymer mixture, compressive strength increases. Zuhua *et al.* (2009) examined the role of water in the synthesis of calcined kaolin-based geopolymer. Water plays an important role in the whole process of geopolymer synthesis and their results indicated that non-evaporable water was necessary to keep the strength stable.

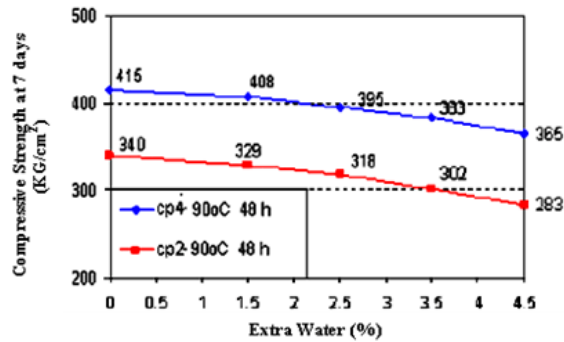


Fig. 3: Effect of extra water on compressive strength (Pacheco-Torgal, 2008).

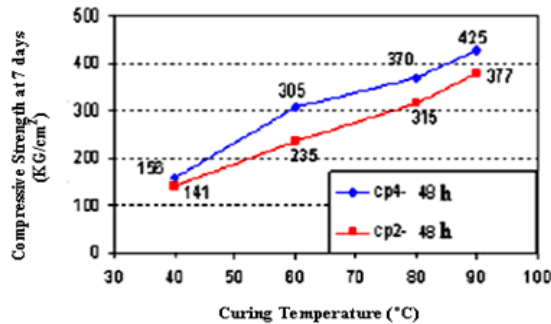


Fig. 4: Effect of curing temperature on compressive strength (Pacheco-Torgal, 2008).

Van Jaarsveld, Van Deventer, and Lukey (2002) studied the effect of composition and temperature on the properties of fly ash- and kaolinite-based geopolymers; the results showed that initial curing at higher temperatures does not increase compressive strength substantially above that achieved by curing at room temperature. Curing at higher temperatures for more than a couple of hours does seem to positively affect the development of compressive strength, however. Curing at 70°C seems to substantially improve compressive strength compared to curing at 30°C for the same period of time. It is of interest to note that curing for longer periods of time at elevated temperature appears to weaken the structure, suggesting that small amounts of structural water must be retained to reduce cracking and maintain structural integrity. It seems that prolonged curing at elevated temperatures breaks down the gelular structure of the geopolymer synthesis mixture, resulting in dehydration and excessive shrinkage, as the gel contracts without transforming to a more semi-crystalline form.

Compressive strength measurements are used as a tool to assess the success of geopolymerization. This is due to the low cost and simplicity of compressive strength testing, as well as the fact that strength

development is a primary measure of the utility of materials used in different applications of the construction industry (Xu, 2002). Figure 3 shows that as the extra water increases, the compressive strength decreases, whereas Figure 4 and Figure 5 show that as the curing time or curing temperature increases, the compressive strength increases (Pacheco-Torgal, 2008). Therefore, compressive strength depends on curing time and curing temperature, and water will give affect the strength of the final product. Some authors believe that the optimum mixing order for alkali-activated binders leads to the best results; initially the solids are mixed, then the activator is prepared and put to rest for 24 hours, and finally the activator is mixed with the raw materials. Another researcher reported that the best mixture is achieved by mixing raw materials and sodium/potassium hydroxide for 10 minutes, and then adding the sodium silicate and mixing for 5 minutes, placing the mixtures in molds, and vibrating them for 5 more minutes. Therefore, it is important to confirm whether the mixing order remains the same for other prime materials and also how it is influenced by the type of alkaline activator (Pacheco-Torgal, 2008).

Many parameters, such as the water content, the fly ash/kaolinite ratio, and the type of metal silicate used, have a substantial effect on the final properties of the geopolymer. In particular, the current work have shown that the thermal history of the source materials, such as kaolinite, as well as the curing regime for the geopolymer are important factors that must be taken into consideration when designing a kaolin-based geopolymer product for a specific application (Van Jaarsveld, 2002).

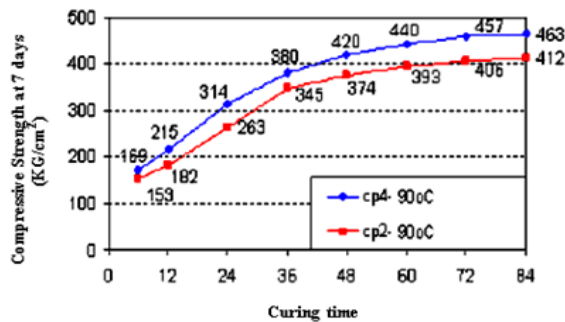


Fig. 5: Effect of curing time on compressive strength (Pacheco-Torgal, 2008).

6. Conclusion:

Development of alkali-activated kaolin-based concrete seems to present a greener alternative to OPC. This paper has reviewed the historical background of alkali-activated binders, introduces kaolin as a prime material, described the reaction mechanism of kaolinite, and identified factors that affect the formation of this geopolymer. Inorganic polymer concretes have emerged as novel engineering materials with the potential to form a substantial element of an environmentally sustainable construction and building products industry. However, the development of this material is still in its infancy, and a number of advancements are still needed.

Although extensive research has already been carried out, the development of kaolin as a new binder in concrete has not yet been explored. Much work on alkali-activated binders has been done, yet a significant amount of work on kaolin for the production of greener concrete remains to be done. It is hoped that future research in this field will drive a new era of greener materials in the construction industry.

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