Review On Geopolymer Concerte With Different Additives

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Abstract— *The development of new binders, as an alternative to Portland cement (PC), by alkaline activation, is a current researcher's interest. Geopolymer binder is obtained by a manufacturing process less energy-intensive than Portland cement and involves less greenhouse gases emission and also reducing initial cost of the project. A supplementary material belongs to prospective materials in the field of civil engineering. Researchers have employed Various molecular ratio, temperature and duration, Fibers addition, Superplastizers, Setting time, alkaline activators and alternate binders to modify some properties of Geopolymer system. This paper presents a comprehensive overview of the previous works carried out on using different additives by varying various properties.*

***Keywords*— Geopolymer, Alkaline activator, molecular ratio, temperature and duration, Fibers, Setting time, Superplastiziers**

I. INTRODUCTION

The use of alkali materials and aluminosilicates to form a cement is broadly referred to as 'Geopolymer' technology, coined by French researcher Davidovits, but is also known as alkali-activated cement and inorganic polymer concrete in various parts of the world. Geopolymer technology provides comparable performance to traditional cementitious binders, but with the added advantage of significantly reduced Greenhouse emissions, increased fire and chemical resistance and waste utilization. The use of Geopolymer in modern industrial applications is a recent development, becoming increasingly popular due to its intrinsic environmental and technical benefits.

The concrete industry produces approximately 12 tonnes of concrete worldwide in a year. The production of cement is increasing about 3% every year. The manufacture of 1 tonne cement requires about 2 tonnes of raw materials like shale and limestone and releases 0.87 tonne of CO2, about3 kg of Nitrogen Oxide, an air contaminant that contributes to ground level smog and 0.4 kg of PM10 (particulate matter of size 10 µm), an air borne particulate matter that is harmful when inhaled. The global release of CO2 from all sources is estimated at 23 billion tonnes a year and, according to IEA (International Energy Authority), the Portland cement production accounts for about 6 to 7% of total CO2 emissions. The production of cement also consumes huge amounts of energy, the third largest use of energy after aluminum and steel industries.In the light of these problems, many researchers have been trying to seek new processes, technologies and materials in order to provide the construction industry an alternate for concrete.

Geopolymers are a type of inorganic polymer that can be formed at room temperature by using industrial waste or by-products as source materials to form a solid binder that looks like and performs a similar function to OPC. Geopolymer binder can be used in applications to fully or partially replace OPC with environmental and technical benefits, including an 80 - 90% reduction in CO2 emissions and improved resistance to fire and aggressive chemicals.

Geopolymer cement is made from aluminium and silicon, instead of calcium and silicon. The sources of aluminium in nature are not present as carbonates and therefore, when made active for use as cement, do not release vast quantities of CO2. The most readily available raw materials containing aluminium and silicon are fly ash and slag .The main process difference between OPC and Geopolymer cement is that OPC relies on a high-energy manufacturing process that imparts high potential energy to the material via calcination. This means the activated material will react readily with a low energy material such as water. On the other hand, Geopolymer cement uses very low energy materials, like fly ashes, slags and other industrial wastes and a small amount of high chemical energy materials (alkali hydroxides) to bring about reaction only at the surfaces of particles to act as glue.

This approach allows the use of measured amounts of chemicals to tailor the product to specification, rather than using an amount of very high-energy material required for OPC, regardless of whether the material is used to build strength (such as the inside of particles). This approach results in a very large energy saving in the production of Geopolymer cement.

The properties of Geopolymer cement, when used to make concrete, have been repeatedly and independently shown to be equivalent to other cements in terms of the structural qualities of the resulting concrete.

This presents a review of recent research on low calcium fly ash-based geopolymer paste with different additives included. These approaches will be used to predict the utilization of various supplementary materials in geopolymer mortar.

II. MOLECULAR RATIO

Raul Arellano-Aguilaretetet al., (2014) Analyzed the chemical composition on Strength development with varying the molar ratio.Compressive strength increases with S/A and N/A and decreases with H/N (Optimum level S/A=3-3.3 and N/A =0.85-1.0.The increment in the percentages of POFA increased the silica/alumina (SiO2/Al2O3) ratio and that resulted in reduction of the early compressive strength of the geopolymer and delayed the geopolymerization process. The addition of POFA produces the lower density compared to fly ash. In contrast to the FA based mortars, the POFA based mortar achieved only about 40% and 62% of the 112-day strength after 3 and 28 days, respectively. NavidRanjbar et al.(2014) showed increasing amounts of SiO2/Al2O3 ratioenhance elastic behavior deformation rather than the brittle crushing noted for the specimens of FA based specimens.Partial replacement of Rice husk and bark ash (RHBA) was used as a rich SiO2 source to fly ash in making geopolymer. Compressive strength increased as the SiO2/Al2O3 ratio increased. The compressive strength at 3 days was 10.9 MPa at an SiO2/Al2O3 ratio of 4.03(100% FA). The strength increased rapidly when some RHBA was added because this enriched with Si in the matrix, which allowed stronger Si–O–Si bonds to form. The strength actually dropped when the ratio exceeded 15.9. Smith Songpiriyakij et al.(2010) indicated that the decrease in Na2O/SiO2 and Na2O/Al2O3 (or less Na2O) resulted in increases in compressive strength of the geopolymer. High Na2O content was found to promote an amorphous–crystalline transformation in the system. The optimum Si/Al ratio for maximum compressive strength of this FA–RHBA geopolymer was eight (SiO2/Al2O3 = 15.9). A geopolymer with the relatively high compressive strength of 73 MPacould be obtained.N. Marjanovic et al.(2014) concluded that, optimal characteristics of alkali-activated binder were related to the following chemical composition of the binding gel: Ca/Si=0.34–0.50, Al/Si=0.15–0.24, Mg/Si=0.07–0.16 and Na/Si=0.21–0.37.In order to study solids-to-liquid and alkaline activator ratios on kaolin-based geopolymers, C.Y. Heah et al.(2012) revealed that the Compressive strength was highest at S/L and Na2SiO3/NaOH ratios of 1.00 and 0.32, respectively. In term of molar ratios, optimum was achieved at Al2O3/Na2O of 1.09 and SiO2/Na2O molar ratios of 3.58.Jian He et al.(2013)Changed the ratio of RHA / RM so that Si/Al ratios varied from1.68 to 3.35 .Where the compressive strength (f), Young's modulus (E), and failure strain (f) increases to 20.5MPa upto 2.8 and above this ratio decreases. Two types of fly ash activated using Na2O/SiO2 molar ratio ranging from 0.12 to 0.20.For Geopolymer Workability and polymerization reaction increased with increase of the Na2O/SiO2 molar ratio. Increasing the proportion of sodium silicate solution in the formulations generally encourages geopolymer gel formation. Maria Chiara Bignozzi et al.(2014)indicated that the Water absorption and mechanical strength (both flexural and compressive) decrease with the increase in Na2O/SiO2.Use of higher amounts of Na-silicate resulted in compressive strengths for the geopolymer 200–300% higher than those samples made with the lowest amounts of Na-silicate.K.Pimraksa et al.(2011) told that however, the geopolymer materials with high Na2O/Al2O3 (>1.5) were not stable in water submersion. With regards to the types of alkali, geopolymer pastes activated with 10 M NaOH possessed higher compressive strength than that with 10 M KOH. Curing temperature and duration also affected the properties of the geopolymers. The optimum curing temperature and time were 75 ◦C and 5 days. The starting Na2O/Al2O3 ratios of mixtures also affected the properties of the geopolymer pastes. At starting SiO2/Al2O3 ratio of 13.0, the increase in starting Na2O/Al2O3 ratios from 1.0 to 3.0 increased the compressive strength from 11 to 60 kg/cm2 but the samples. According to Patrick N. Lemougna.et.al (2011) the optimum compressive strength in this material (about 55 MPa) was obtained for samples with Na2O/SiO2 = 0.30, but higher Na2O concentrations were found to be detrimental to the mechanical properties. The geopolymer products were found to be relatively stable to heat, retaining about 60% of their initial compressive strength and shrinking only slowly up to 900oC. The Compressive strengths of the heated materials and their thermal behavior suggest their suitability as low-grade refractories as well as in potential building applications. P. De Silva et.al(2007) indicated with the increasing SiO2/Al2O3 molar ratios up to 3.4–3.8, For this, the Al2O3/Na2O ratio was in the range of 0.8–1.0 is largely responsible for the high-strength gains observed at later stages. A corresponding increase in Al (low SiO2/Al2O3) leads to products of low strengths, accompanied by microstructures with increased Na–Al–Si grains rather than amorphous Na– Al–Si-containing geopolymers.

III. TEMPERATURE AND DURATION

The temperature and duration of heat curing plays a major role for the strength development of fly ash based geopolymer mortar. For the fly ash based specimens cured for 20 hours, the reaction was completed at 7 days and reach maximum strength(19.40Mpa). Regardless of curing duration, all the specimens cured at 100°C, have reached their maximum strength(21.90Mpa) which can be observed by almost constant strength at the age of 3 days and beyond. AndiArham Adam et al.(2014) concluded that the highest compressive strength was obtained at the temperature and duration of curing of 120°C and 20 hours(33 MPa) at 7 days. Mo Bing-hui.et.al(2014)indicated that elevating curing temperature will accelerate the dissolution, polymerization, precipitation processes of the geopolymerization reaction. The compressive strength of samples cured for1 day at 20 °C is 12.09 MPa and increased to 61.95 MPa after 7 days. The optimum curing temperature of geopolymer is about 60 °C at which the geopolymer samples present the best mechanical properties with the compressive strength of 97.95MPa after cured for 7 days. The samples cured at 80 °C and 100 °C showed faster increase in compressive strength (43.90 MPa and 52.43 MPa after curing for 2 h, respectively), than the samples cured at lower temperatures.AndriKusbiantoro et al.(2012)) revealed that increasing the curing temperature to 65 oC has significantly improved the MIRHA based geopolymer concrete compressive strength. 3% inclusion of MIRHA in fly ash based geopolymer system has the compressive strength up to 14.17% higher than non-MIRHA based specimen, while 7% inclusion has the strength increment up to 19.41% higher. Gokhan Gorhan et al.(2014) concluded that the optimal thermal curing temperature and the optimal NaOH concentration were 85 oC and 6 M. The increase in the curing times reduced the apparent porosity in the samples cured at 85 oC. These values ranged from 25.3% to 29.8%. Development of room temperature hardening slag / fly ash based geopolymer cements for Geopolymer Concretes for the implementation of all kind of geologicalmaterials. The European Research Project GEOASH (2004-2007) explained conventional (User-hostile system) and geopolymer methods (User-friendly) of room curing. Room temperature hardened slag / fly ash-based geopolymer cements have better properties: higher strength, safer long-term durability and lower leachates. Ali Nazari et al.(2011) discussed various things like, Curing temperature has a significant effect on the compressive strength development because it affects specimens setting and hardening. The optimum curing condition for the all mixtures is at 80 ◦C. The concentration of alkali activator has a main effect on the strength of geopolymeric specimens. The highest strength was achieved using a 12 M NaOH solution. This may be due to production of more compacted specimens In all mixtures, the specimens with the SiO2/Al2O3 ratio equal to 2.99 had the highest strength. On the other hand the highest strength was achieved equals 58.9 MPa for the mixture of fine fly ash to fine rice husk bark ash of 70:30.JitingXie et al.(2013)investigated the compressive strength values for the 24-h heat treated samples were higher than those which were heat treated for only 4 h. Both the 4-h and the 24-h heat treated samples behaved according to the trend that the lower the value of W/G, the higher the compressive strength obtained. In ambient curing condition the vacuum aided desiccation process would cause relatively low internal water atmosphere and it seems that this condition has resulted in higher strength gain. This is possibly because the lower moisture content could lead to a higher extent of the polycondensation reactions, and thus more produced geopolymers. Djwantoro Hardjito et.al(2008)revealed that as the concentration of alkaline activator increases, the compressive strength of Geopolymer mortar also increases. Specimens cured at temperature of 65oC for 1 day showed the highest 28 days compressive strength. From the test results, it can be concluded that the higher the curing temperature, the higher the rate of geopolymerization process of geopolymer mortar, which eventually accelerates the hardening of Geopolymer mortar.D B Raijiwalaet.al(2012) seen that the geopolymer concrete cured at 800C gives the best results. The values are much higher than OPC. Also, it can be seen that 1 day strength of GPC is much more than OPC on all the experiments performed because of curing at higher temperatures. Later on the strength increases at room temperature possibly because of polymerization process but the actual reason is not known. Also, at temperatures higher than 800C, the strength of all tests is not found to increase. Hence, 800C can be thought of as an optimum temperature for curing the geopolymer samples. Raul Arellano-Aguilaretet et al., (2014) showed that, After 28 days, the CS of mortars cured at 20 oC increased noticeably reaching between 53 and 57 MPa, while that the values of CS of samples exposed at 75 oC were of 48–51 MPa. This indicates that although the curing at high temperature accelerates the reactions during the first day, the polymerization processes does not show a significant progress at later ages of curing and the CS remains with small variations. Smith Songpiriyakij et al.(2010) revealed that the compressive strength at 3 days of fly ash and ice Husk bark ash paste with room temperature curing was 24.3 MPa. After demolding at age of 2 days, the same mixture was cured at 60 0C for 24 h. The compressive strength of this paste reached 49.2 MPa within 3 days, comparable with the 28-day strength of paste cured at room temperature. PavelRovnanik et al.(2010) showed that 1-day compressive strength of geopolymer mortar cured for 1 h at 40 0C was only 13 MPa, the strength increased almost three times to 37 MPa, when such curing was prolonged to 4 h. The specimens that were cured for two or more hours at high temperature reached their final strengths in 3 days with the values about 50 MPa.C.Villa.et al.,(2010) reveals the relationship between the compressive strength and the temperature. Material synthesized at a curing temperature of 40oC exhibited the highest compressive Strength. At ambient temperature curing increased activator ratio upto 1.5 resulting in higher CS at 90 days than neat cement. At 40oC at an activator ratio with 1.5-10 increases CS and at the ratio of R10, CS increases by 11%.And for low activator ratio 0.4 is enough to produce high CS at temperature between 60 and 80^{o}C.

IV. ALKALINE ACTIVATOR

Gum Sung Ryu.et al.,(2013),D. Hardjito(2005) developed fly ash based geopolymer and shows that the compressivestrength is increased with a higher molar concentrationof NaOH.Mix of sodium silicate and NaOH(mix ratio 1:1and SiO2/Na2O = 8) used as an alkaline activator further increases the pH and activates the reaction, this showed Compressive strength around 47 MPa. MoslihAmerSalih et al.(2014) showed that there was a direct proportion between the compressive strength and SS/SH ratio. The compressive strength was increased by increasing the sodium silicate to sodium hydroxide ratio. As can be seen, the maximum strength was achieved at SS/SH ratio of 2.5 for both groups. However, at SS/SH ratio of 3.0 there was a slight decrease in compressive strength which may be attributed to the high amount of activating solution hindering the geopolymerization process. With solid to liquid ratio of 1.00, incorporation of POFA resulted in the strength of 24.48 MPa and 23.83 MPa for sodium silicate to sodium hydroxide ratios of 2.5 and 3.0, respectively, while solid to liquid ratio of 1.32 led to strength of 32.84 and 31.72 MPa at the same sodium silicate to sodium hydroxide ratio at 28 days. F. Pacheco-Torgal.et al.,(2012) show that the workability decreases with the concentration of sodium hydroxide and increases with the amount of calcium hydroxide and super plasticizer. The use of a super plasticizer content of 3% combined with a calcium hydroxide content of 10%, allows increasing a mortar flow of less than 50% to over 90%.The results show that the use of a super plasticizer content up to 3% does not lead to mechanical strength reductions, with the exception of the mixture with a calcium hydroxide content of 10% and a sodium hydroxide concentration of 12 M. BehzadNematollahi et al.(2014) used solid activators could also results in some economical saving compared to the commonly used NaOH and Na2SiO3 solutions. The GD Grade sodium silicate powder is the most effective type of solid activator in the case of using a combination of low calcium (Class F) fly ash and hydrated lime as the geopolymer source materials. The feasibility of developing a one-part geopolymer mix containing 100% fly ash as the source material and a combination of NaOH and GD Grade Na2SiO3 powders as the solid activator with compressive strength over 29 MPa instead of the commonly used NaOH and D Grade Na2SiO3 solutions. P. Chindaprasirt et al.(2014) concluded that increasing compressive strength of geopolymer concrete between 28 days and 3 years tended to be high with the increase of NaOH concentration and the highest increase was in geopolymer concrete with sodium hydroxide concentration of 18 molar. For instance, geopolymer concrete with Na(OH) concentration of 8, 10, 12, 14, 16 and 18 molar had percentage compressive strength at 3 years as compared to 28 days of 107.3%, 112.8%, 117.7%, 125.2%, 125.2% and 126.1%, respectively. At the same time Chloride Penetration and Steel Corrosion reduced with increasing NaOH concentration. Keun-Hyeok Yang et al.(2012)examined with 7.5% Ca(OH)2 was used for the main activator and either 1% Na2SiO3 or 2% Na2CO3 was added for an auxiliary activator. The same water-to-binder (W/B) ratio, Ca(OH)2 and Na2SiO3- activated GGBS mortars developed a higher 28-day compressive strength than Ca(OH)2 and Na2CO3-activated GGBS mortars by an average of 130% and 120% for air-dried curing and water curing, respectively. M. FadhilNuruddinet.al(2011) observed that an increase in compressive strength from 8M to 12M but decreased from 12M to 14M for all days of testing. For all days of testing, 12M NaOH solutions showed the highest compressive strength of 47.83, 48.52, 49.44 and 51.52MPa respectively.C.Y. Heah et al.(2012) showed at higher Na2SiO3/NaOH ratio than 0.32, it was believed that the high amount of waterglass liquid may inhibit the geopolymerization process.

V. STRENGTH PROPERTIES

Zuhua Zhang.et al., (2014) replaced fly ash in Metakaolin and found that10% replacement of metakaoin increases the compressive strength by 15%.A partial replacement of Metakaolin(less than 30%) reduces the rate of reaction but the reaction continues for an extended duration and able to provide comparable 28 day compressive strength. Maximum rate of heat evolution consistently decreases from 28.4mW/g to 17.7 mW/g due to the replacement of fly ash upto 40%.PavelRovnanik et al.(2010) showed that metakaolin based mortar cured at an ambient temperature reached the compressive strength 62 MPa and flexural strength 11.6 MPa at the age of 28 days. Both, compressive and flexural, strengths of geopolymer mortar cured at 60 or 80 oC, respectively, reached their final values just 24 h after mixing and three times exceeded the values observed for samples cured at an ambient temperature. PradipNath showed that when GGBFS was incorporated in the mixture with unaltered alkaline activator (40%) and SS/SH ratio of 2.5, the strength increased significantly from the early age of 3 days. In other words, the 28-day compressive strength increased about 10 MPa for every 10% increment of the slag content. Hence setting time increased by approximately 33% for every 5% increase of alkaline liquid in the pastes. Final setting time also increased with the increase of activator liquid content. When SS/SH ratio is increased from 1.5 to 2.5, the amount of soluble silica is increased in the mixture. As the amount of soluble silica is increased, the polymerization processes is accelerated to some extent. Hence reduced setting time was observed in the mixtures having higher quantity of sodium silicate or higher SS/SH ratio. Azizul Islam et al.(2014) showed that Compressive strength of mortar with 70% of GGBS produced the highest strength while further increase in the GGBS content reduces the compressive strength. The ground POFA with high fineness is a reactive pozzolanic material and can be used to produce high-strength concrete. The suggested level of POFA content as cement replacement in normal concrete was 20% to produce high-strength concrete. S.Detphan and P.Chindaprasirt (2009) concluded that the optimum burning temperature of RHA for making FA-RHA geopolymer is 690ºC.FA and the ground RHA with 1%-5% retained on No.325 sieve are suitable source materials for making geopolymer, and the obtained compressive strengths are between 12.5-56.0 MPa and are dependent on the ratio of FA/RHA, the RHA fineness, and the ratio of sodium silicate to NaOH. Relatively high strength FA-RHA geopolymer mortars are obtained using a sodium silicate/NaOH mass ratio of 4.0, delay time before subjecting the samples to heat for 1 h, and heat curing at 60ºC for 48 h.H.TchakouteKouamo.et.al(2012)varied alumina-oxide up to 40% by weight. The compressive strength of geopolymer obtained from 100% MK (44.8 MPa) is higher than the CS of geopolymer obtained from 100% Vol (36.1 MPa).The compressive strength of Metakaolin-based geopolymer increased with increase of alumina content up to 20%(52.9 Mpa) and the moderate reduction of compressive strength was observed when the amount of alumina increase up to 40%.For the volcanic ash based geopolymer the compressive strength increases with alumina addition up to 40% alumina(47.8 Mpa). H.TchakouteKouamo.et.al(2013) introduced Alkali fusion process to enhance the reactivity of the volcanic ash. Various amount of Metakaolin up to 60% was used to consume the excess alkali needed for the fusion. The amount of reactive phase in natural volcanic ash is equal to 29%.By Alkali fusion method amount of reactive phase is increased as 76%..J.N.Y.Djobo.et.al(2014)reveals that geopolymer pastes with Volcanic Scoria reached a reasonably high 28-days compressive strength of 68.8 MPa. During the dissolution process the particle of Metakaolin will react first and more than those of volcanic scoria, so the degree of geopolymerization and the amount geopolymer gel in the matrix rise. Volcanic scoria is relatively low reactivity so various amount of Metakaolin upto 25%added in order to compensate the deficiency of Al2O3and to increase the amount of amorphous phase in the volcanic scoria. Thus the unreacted particle of volcanic scoria will act as coarse aggregate in the matrix and increase the compressive strength. D.Adak(2014) concluded that Geopolymer mortar with the addition of 6% nano silica shows appreciable improvement in compressive, flexural and tensile strength at 28 days under ambient temperature curing. It iswell accepted that the strength of geopolymer mortars without nano silica and cured at 60 oC for 48 h were more than conventional control cement mortar of (cement and sand ratio-1:3) at all ages. Utilization of nano materials like nano-SiO2 and nano-Al2O3 on the properties of high calcium fly ash geopolymer paste is effective for strength development. At 90 days, the compressive strengths of pastes containing 2% nano-SiO2 and nano-Al2O3increased to 51.8 and 56.4 MPa, respectively compared with 39.4 MPa of the control paste. At 90 days, the flexural strengths of pastes containing 2% nano-SiO2 and nano-Al2O3 were 5.98 and 5.92 MPa compared with 4.31 MPa of the control paste.Above 2% addition, started to adversely affect the strength of geopolymer. Tanakorn Phoo-ngernkham.et.al (2013), revealed that the additional of 3% nano-SiO2 and nano-Al2O3 resulted in an excessive amount of nano-particles and less dense structures were formed. Kang Gao et al.(2013) showed that a metakaolin-based geopolymer sample with a solid-to-liquid ratio of 1.03 containing 1% nano-SiO2 exhibited higher strength, higher density, and lower porosity than other samples. And also the optimal amount of nano-SiO2 addition was 1% at a solid-to-liquid ratio within the range of 0.97–1.10. The reduction in compressive strength while adding more than 1.0% of nano-SiO2 may be due to the fact that the quantity of nano-SiO2 presented in the mix is higher than the amount required to combine with the gels during the process of polymerization thus leading to excess silica leaching out and causing a deficiency in strength. Mehmet Burhan Karakoc et al.(2014) utilized Ferrochrome in the production of geopolymer. The shortest initial and final setting time of paste 60 and 120 min were obtained at samples having 0.7 silica modulus and 4% Na2O. The highest 28-day compressive strength of the geopolymer paste samples were obtained at 7% Na2O and 0.70 silica modulus. At the same time, highest 28-day compressive strength of the geopolymer mortar sample was obtained at 0.30 w/b ratio and at curing laboratory conditions. ParthaSarathi Deb et al.(2014) showed that 28-day compressive strength reached up to 51 MPa in geopolymer concrete containing 20% slag and 80% fly ash in the binder and 40% activator liquid with SS / SH ratio of 1.5 when cured at 20oC.Zengqing Sun et al.(2013) synthesized geopolymer pastes from waste ceramic exhibited a maximum 28-day compressive strength of 71.1 MPa and favorable anti-thermal properties by showing a higher compressive strength of 75.6 MPa after heat treatment of 1000 oC. SravanthiPuligilla et al.(2013) observed an increase in the rate of hardening with the addition of slag. Calcium dissolving from slag is important for both early and late age properties. Slow reaction rate and low strength development has been confirmed when fly ash with low calcium content is activated with low concentration alkali activator and cured without any heat treatment. A slow dissolution of calcium from slag effectively increases compressive strength as rapid geopolymerization continues for a longer duration. Shiqin Yan et al.(2012) evaluated that addition of up to 10 wt% paper sludge in geopolymer mortar mixes at a fixed liquid/solid ratio of 0.2 reduced flow from 112% to 75%.The average 91-day compressive strengths of mortar samples incorporating 2.5 wt% and 10 wt% paper sludge loadings retained 92% and 52% of the reference mortar strength, well within range of predicted masonry product usage. NavidRanjbar et al.(2014) concluded that the shape, particle size and surface area of POFA and FA particles affect the hardened mechanical properties of geopolymer mortar. The POFA particles with higher BET and crumpled shape increased the water demand to produce a workable geopolymer, while spherical FA particles enable workable mix with reduced amounts of water. Consequently, the increase in the evaporable water in POFA based geopolymer resulted in slightly more porous material. The low specific gravity of the POFA along with its inherent raw material density and shape are capable of trapping air, resulting in a porous geopolymer mortar with about 6% less density compared to FA based mortar. N. Marjanovic et al.(2014) High concentration of the activator (10%Na2O) contributed to better strength of mortars with predominant content of FA in the blend, while it adversely affected the strength of mortars with predominant content of Blast Furnace Slag in the blend. The blend FA–BFS 25–75,activated with WG of modulus 1.0% and 10% of Na2O emerged with remarkably high mortar compressive strength (80.09N/mm2).

VI. MECHANICAL ACTIVATION

Influence of mechanical activation and curing process of raw kaolin on the final compressive strength. Mechanical activation was performed by dry ball-milling of raw kaolin at 250 rpm for 1 h. The curing temperatures were 40 , 70 and 100^{o}C for 24 h, 48 h or 72 h.Ayi D. Hounsi et al.(2013)showed that without mechanical activation, the optimal curing condition was 24 h at 70 ^{o}C and the compressive strength was 15 MPa after 28 days of ageing. Under mechanical activation, improvement of the compressive strength was obtained with a curing time of 72 h at 70^{o}C (to reach 35% increase) or with a curing temperature of 100^{o}C (for 76% improvement).N. Marjanovic et al.(2014)observed that mechanical activation of FA for 15 min resulted in drastic increase of geopolymer compressive strength (in all cases >1000%). High strength values were associated with improved FA reactivity obtained mainly by the reduction in particle size and reduced water/binder ratio. N. Bouzon et al.(2014) synthesized fluid catalytic cracking catalyst (FCC) as mineral admixture and Alkaline activators can be prepared by reflux mixtures of ground or original RHA with NaOH. Refluxing times between 30 and 240 min yielded good performance mortars. All mortars with alkaline activator containing RHA show compressive strength (cured at 65 oC for1day) in the range of 31–41MPa, which is similar to control mortar prepared using an equivalent mixture of NaOH and waterlass.

VII. FIBERS ADDITION

Author	Fiber Type	Effects	Optimum Usage
T.Alomayri et. al.(2014)	different layers of woven cotton fabric are fabricated using layup technique.	improves the mechanical properties of geopolymer composites such as flexural strength, flexural modulus, impact strength and fracture toughness	8.3 wt% woven cotton fabric to the geopolymer composite
A. Natali et al.(2011)	Carbon HT E-Glass PVA PVC (7±1 mm length)	-good adhesion properties -Flexural strength increased -able to control micro-cracks propagation -PVC and carbon fibers exhibited the best energy absorption capacity	1% wt. of reinforcing fibers able to increases flexural strength from 30% - 70%.Polymer fibers show better behavior than Glass fibers
Hai-yan Zhang et al.(2014)	chopped carbon fibers (length 6 mm, diameter 7 μm and density 1.76-1.80 g/cm3)	-effective crack control -enhances bending strength under 20-500 ^oC temperature range -influence compressive strength of geopolymers in 20-700 ^oC temperature range	2% chopped carbon fibers
T.Alomayri et al.(2014)	different layers of woven cotton fabric are fabricated using layup technique.	cottonfibres are hydrophilic in nature and hencehave a poor resistance to water absorption. reduces the flexural strength, flexural modulus, impact strength, hardness and fracture toughness	magnitude of maximum water uptake and diffusion coefficient is increased with an increase in fibre content
T.Alomayri et al.(2014)	different layers of woven cotton fabric are fabricated using layup technique (30 cm × 7.5)	addition of OPC with fly ash improving the fibre-matrix adhesion, increasing both the flexural strength and impact strength	Optimum amount of OPC 5%. Beyond this caused a reduction in the fracture toughness due to the reduction in energy dissipation processes such as interfacial debonding, fibre pull-out and crack-bridging
Hai Yan Zhang et al.(2015)	-Short carbon fibers (length 6 mm,diameter 7 μm and density 1.76-1.80 g/cm^3) -basalt fibers(length 6 mm,diameter13 μm and density 2.65-3.00 g/cm^3) -styrene-acrylate emulsion(solid content 48±2 wt%, PH value is 7.5-9 and viscosity coefficient is 800-1000 mp.s)	- short carbon fibers provides better crack control than that of short basalt fibers - styrene-acrylate emulsion is not a good additive because of lower strength development and poor crack control	when the amount of short fibers is increased to 2%, bond strength gets significantly reduced due to decreased fluidity of geopolymers

VIII. SETTING TIME

The rate of setting accelerated significantly by the addition of OPC in the mixture. PradipNath et.al(2014) showed that , the mixtures having 10% slag, 40% alkaline activator and SS/SH ratio 1.5–2.5 with no extra water can be considered as the optimum mixture for reasonable compressive strength in ambient curing condition with a setting time comparable to that of OPC concrete. PradipNath et.al(2014) Showed that Mixture having 5% OPC in the binder achieved initial setting time of 309 minutes, which decreased to 110, 66 and 40 minutes for inclusion of 8%, 10% and 12% OPC in mixtures respectively. The results establish that OPC as a controlled small part of the binary blended binder is effective to accelerate setting time of fly ash based geopolymer concrete in ambient condition. P. Nath et.al was designed with only fly ash as a binder required more than 24 hours before showing any sign of setting. Setting time of geopolymer pastes improved significantly when slag was incorporated in the mix as a binder. Both initial and final setting time decreased with the increase of slag content. Mix having 10% slag of total binder achieved initial setting time of 290 minutes, which decreased to 94 and 41 minutes for inclusion of 20% and 30% slag respectively. The difference between initial and final setting time also reduced with the increase of slag content in the paste. It indicates that the higher the slag content in the paste the quicker is the rate of setting. The results establish that slag as a part of fly ash binder is effective to accelerate setting time of geopolymer concrete in ambient condition. Ganapati Naidu. P(2012) told that mixing of G.G.B.S was tested up to 28.57%, beyond that immediate setting was observed. While mixing without G.G.B.S the setting time was 6 hours but at the same time setting time decreased gradually with the addition of G.G.B.S from 10% to 28.57% of the binder. N.K. Leeet.al(2013) used replacement ratio of the slag for the fly ash by weight and the ratio of water glass to NaOH solution were 20% and 0.5 by weight, respectively. The setting times of the 4 M specimens were an initial time of 55 min and a final time of 160 min, while those of the 6 M specimens were an initial time of 50 min and a final time of 114 min. Those of the 8 M specimens were faster than any of the other specimens (their initial and final times were 10 min and 50 min, respectively).At the same time he showed the higher replacement ratio of the slag for the fly ash led to that a faster setting time, as an increase in the CaO content, which is the main chemical component of slag, accelerated the hydration reaction of the mixture. Phosphoric acid had a positive effect on retarding the setting of the alkali-activated fly ash/slag paste. N.K. Lee et.al(2013)was added phosphoric acid (H_3PO_4)to the mixture up to 2.0% of the total binder (fly ash + slag) amount by weight, the initial time increased slightly and the final time decreased. In contrast, when the ratio of phosphoric acid to binder was 2.25% by weight, the initial and the final setting times increased to 53 min and 90 min, respectively. Mehmet BurhanKarakocet.al(2014)concluded that the Setting time of samples having 0.7 silica modulus increases as Na_2O content increases. The shortest final setting time were obtained at samples having 0.7 silica modulus and 4% Na_2O. The final setting time of geopolymer paste samples were found to be shorter than the normal Portland cements except samples with 0.5 silica modulus and 4% Na_2O. K. Srinivasan and A. Sivakumar (2012) increased replacement of bentonite with flyash there was no substantial reduction in setting time and a similar trend was also observed in the case of increased replacement of bentonite with lime. However, the setting time was faster in the case of bentonite replaced with lime up to 30% compared to bentonite with flyash. N. Marjanovic et al.(2014) told that the setting time(initial and final)of alkali-activated FA–BFS blends dominantly depended on the activator concentration. All investigated paste samples activated at higher activator concentration (10%Na_2O) showed significantly longer setting time comparing to the pastes activated at lower activator concentration (7%Na_2O), independently of the activator modulus and the blend composition. P. De Silva et.al(2007) indicated that the amount of Al available for geopolymer reaction during synthesis appears to have a dominant effect in controlling setting time; accordingly, increasing the SiO_2/Al_2O_3 ratio leads to longer setting times.

IX. SUPERPLASTIZIERS

Super plasticizers affected the workability of the fly ash geopolymer differently. BehzadNematollahi and jay Sanjayan(2013) used the NaOH + Na_2SiO_3 used as the activator the modified Polycarboxylate based SPs(latest generation) was the most efficient type which increased the relative slump of the paste upto 45% with reference to the paste without using any SP. The increase in relative slump was 45,41,39% for the paste with using modified Polycarboxylate based SPs and at the same time 6,8% with using naphthalene based SPs and decrease in slump was 3% for the paste using melamine based powder.Chandan Kumar et.al(2014) added the naphthalene sulphonate-based super plasticizer, up to approximately 2% of fly ash by mass, improves the workability of the fresh fly ash-based geopolymer concrete; however, there is a nominal decrease in the compressive strength of hardened concrete when super plasticizer is used .And also slump value of the fresh fly-ash-based geopolymer concrete increases with the addition of naphthalene sulphonate-based super plasticizer, up to approximately 2% of fly ash by mass.M. FadhilNuruddinet.al(2011) used different superplasticizer dosages upto 7% of the binder. It can be seen that that Mix with SP dosage of 7% shows highest compressive strength as compared to the other mixes that have SP dosage. Heshowed that the maximum performance at 7% SP dosage for all ages. Also the maximum compressiveStrength achieved at 28 days of age, which is, 53.80MPa.He concluded that the required workability achieved with the Super plasticizer dosages only above 5%.Aminul Islam Laskar and RajanBhattacharjee (2012) observed that at 4M concentration, the effect of addition of superplasticizer/plasticizer is negligible. Mixes containing NaOH solutions with molar strength above 4 M show decrease in slump whereas there is increase in workability for all mixes with chemical admixtures at molar strength less than 4 M. It may also be observed that the performance of lignin based plasticizer is still better compared to 3rd generation superplasticizer at all molar strengths of NaOH solution except 1.5 M.

X. CONCLUSION

General conclusions of this literature review can be summarized as following:

- Compressive strength increases with S/A and N/A and decreases with H/N (Optimum level S/A=3-3.3 and N/A =0.85-1.0).
- Optimal characteristics of alkali-activated binder related to the following chemical composition of the binding gel: Ca/Si=0.34–0.50, Al/Si=0.15–0.24, Mg/Si=0.07–0.16 and Na/Si=0.21–0.37.
- In term of molar ratios, optimum was achieved at Al2O3/Na2O of 1.09 and SiO2/Na2O molar ratios of 3.58.
- Increase in Al (low SiO2/Al2O3) leads to products of low strengths, accompanied by microstructures with increased Na–Al–Si grains rather than amorphous Na– Al–Si-containing geopolymers.
- Highest compressive strength was obtained at the temperature and duration of curing of 120°C and 20 hours (33 MPa) at 7 days.
- At the temperatures higher than 800C, the strength of all tests is not found to increase. Hence, 800C can be thought of as an optimum temperature for curing the geopolymer samples.
- Fly ash based geopolymer and shows that the compressive strength is increased with a higher molar concentration of NaOH. Mix of sodium silicate and NaOH(mix ratio 1:1and SiO2/Na2O = 8).
- Higher Na2SiO3/NaOH ratio than 0.32, it was believed that the high amount of waterglass liquid may inhibit the geopolymerization process.
- Alkali fusion process used to enhance the reactivity of the volcanic ash. Various amount of Metakaolin up to 60% was used to consume the excess alkali needed for the fusion. The amount of reactive phase in natural volcanic ash is equal to 29%.
- Addition of 6% nano silica shows appreciable improvement in compressive, flexural and tensile strength at 28 days under ambient temperature curing.
- Mixtures having 10% slag, 40% alkaline activator and SS/SH ratio 1.5–2.5 with no extra water can be considered as the optimum mixture for reasonable compressive strength in ambient curing condition with a setting time comparable to that of OPC concrete.
- Modified Polycarboxylate based SPs(latest generation) was the most efficient type which increased the relative slump of the paste upto 45% with reference to the paste without using any SP.

This paper has presented about the geopolymer concrete with various researches based on strength properties and other criteria related to improve the Strength of geopolymer concrete. This will be useful for developing eco-friendly concrete in all the aspects.

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