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A Review of Lightweight Geopolymer Concrete Based on Slag

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Abstract: The studies on Lightweight Geopolymer concrete (LGC) are leading-edge in the development of sustainable and eco-friendly concrete. Attempts were being made to develop LGC by various methods of production. This paper reviews about previously published research work on lightweight geopolymer concrete and the observations to the material binders - an alternate to the Ordinary Portland Cement (OPC) by the utilization of industrial by-products, alkaline activator solution, foaming agents, chemical expansive agents, lightweight aggregate, production methods, and their physical and mechanical properties. The main focus is to investigate pore size formation, density, compressive strength and curing conditions. From the review it is found that the stabilization of foam and the control of efflorescence are the two challenging problems faced by the industry for the mass production of lightweight geopolymer foam concrete. Furthermore, topics for future work in this field were suggested.
Keywords: Foam Concrete, Geopolymer, Industrial by-products, Mechanical Properties

I. INTRODUCTION

The modern world is unimaginable without concrete; it is widely used on all continents, in the construction of underground and marine structures, transport infrastructure, as well as skyscrapers and concrete roads. The global researcher and representatives of the cement and concrete industry to seek solutions for the reduction of greenhouse gas emissions. It includes elaboration of new materials as alternatives for ordinary Portland cement (OPC)-based concretes or considerable rearrangements related to OPC production technology and current environmental trends complain us not only to try but also to do everything possible to reduce the amount of CO_2 emissions and to be responsible today for the environment we will live soon. It is well-known that the production of ordinary Portland cement (OPC)-based concretes needs a considerable number of resources and ingredients that are acquired through resource mining, as well as exhaustive processing, which, in turn, causes immense quantities of greenhouse gas (essentially CO_2 and NO_X) emissions into the atmosphere. Every tonne of Portland cement produced means an extra tonne of CO_2 and other greenhouse gases because of the calcination process and combustion of fossil fuels[1]. If 20 years ago emissions from making cement for buildings, roads and other infrastructure accounted for 1.4 billion tons of carbon dioxide (CO_2), now it is found that by 2021 this figure had more than doubled, rising to 2.9 billion tonnes and accounting for more than 7% of all global emissions[2] .The production of geopolymers instead of OPC-based concretes allows to reduce the CO_2 emissions by 40% - 80% [3], geopolymers have been called a potential alternative to traditional concrete for decades. . Geopolymer uses waste material (furnace slag, red mud, fly ash etc.), whereas OPC uses natural resources. Additionally, in the making of OPC, the hydration role of water is significant, but in the geopolymerization process water plays a minor role, thus reducing water consumption. When it comes to mechanical properties, geopolymer has high compressive strength, low permeability and good thermal properties. Compared to conventional organic polymers, glass, ceramics, cement or concrete [4]geopolymers have attractive properties as being non-combustible, non-flammable and fire/heat resistant, geopolymer concrete is the family of the alkali-activated cement is growing, the alkaline cement is classified based on a phase composition of the hydration products: R-A-S-H (R = Na+ or K+) in the aluminosilicate based systems and R*C-A-S-H in the alkali-activated slag or alkaline Portland cement.[5] Alkaline activators used for geopolymers are usually a combination of a hydroxyl, usually sodium hydroxide (NaOH) or potassium hydroxide (KOH), and a glassy silicate, consisting of sodium silicate or potassium silicate, with NaOH and sodium silicate being the most common due to cost and availability. Comparing the mixes with Na_2SiO_3/NaOH ratios of 1.5, 2.5, and 3.5, it was found that increasing the NaOH ratio from 6 to 14 molarity reduced the water/binder ratio by 18 %, 14 %, and 10 %, respectively, increasing the compressive strength of 38 %, 33 %, and 31 %. This alteration in the water/binder ratio and the compressive strength in the Na_2SiO_3/NaOH ratio of one is more substantial than the changes in the other ratio. The rise in the Na_2SiO_3/NaOH ratio has caused a reduction in the water/binder ratio, which helps to improve the performance of compressive strength's upward tendency.

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For instance, when the ratio of Na_2SiO3 to NaOH is raised from 1.5 to 3.5, the ratio of water/binder decreases by 7 % and 9 %, respectively, and compressive strength increases by 7 % and 14 %, respectively, compared with a Na_2SiO_3/NaOH ratio of one[6]. but despite their advantages, there are several reasons why they are still not widely used. Geopolymers can be considered to be challenging to create, because the manufacturing process includes a corrosive chemical substance that can harm humans, such as sodium hydroxide; there is no standard mix design, and the properties differ significantly depending on the used raw materials (even the chemical composition of fly ash produced by the same manufacturer in different years is quite diverse); a special curing method is needed, which require more skilled labors and practice. Also, there are technical problems, such as high thermally induced shrinkage in fly ash based geopolymer and efflorescence, which can reduce the durability of geopolymer due to reduced compressive and tensile strength and aesthetic issues.[7] Undoubtedly, the above-mentioned aspects limit the application and use of geopolymer concrete instead of OPC-based concrete. However, considering the vast amount of research that has been carried out on geopolymers, it is worth using the existing knowledge when looking for new application possibilities for geopolymers. One of the promising areas of their application is the production of foamed materials with low thermal conductivity and high fire resistance properties, low cost, and green synthesis protocol, enabling their use in various high-added-value applications. Thereby, this review paper summarizes the recent progress in the field of foamed geopolymers, focusing on the different foaming methods, and material base, as well as the compressive strength, porosity and thermal conductivity of the foamed geopolymer concrete[8].

A. *Light Weight Geopolymer Concrete*

Lightweight concrete can be prepared either by injecting air or by omitting the finer sizes of the aggregate or by replacing them with hollow, cellular, or porous aggregate. The density of lightweight concrete usually ranges from 300 to 1800 kg/m3. whereas the density of normal concrete is approximately 2400 kg/m3. Lightweight concrete has been categorized into three groups, (1) no-fines concrete; (2) lightweight aggregate concrete; and (3) aerated/foamed concrete.[9] No-fines concrete contains a small amount of aggregate, if any. The coarse aggregate should be a single-size material, with nominal maximum sizes of 10 mm and 20 mm being the most common. The use of blended aggregates (10 and 7 mm; and 20 mm and 14 mm) showed satisfactory performance. However, since this type of concrete is characterized by uniformly distributed voids, it is not suitable for reinforced or pre-stressed concrete used in construction. Lightweight aggregate concrete consists of lightweight aggregate (expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure) which can be used as a replacement for normal aggregates such as crushed stone or sand. Foamed concrete is produced by using either cement paste or mortar in which large volumes of air are entrapped by using a foaming agent. Such foamed concrete has high flow ability, low weight, and minimal consumption of aggregates, controlled low strength, and excellent thermal-insulation properties.[10]

There is different material used to make light weight geopolymer concrete

- Light weight aggregate geopolymer concrete
- Pervious aggregate geopolymer concrete
- Geopolymer foam concrete
- Waste tyre rubber mix light weight geopolymer concrete
- Waste glass mix light weight geopolymer concrete

Lightweight aggregates such as diatomite, pumice, vermiculite, and perlite are typically used in conventional concrete. Bottom ash, crushed clay brick (RCB), and waste tire rubber are recycled aggregates and can also be used as lightweight aggregates in lightweight geopolymer concrete. Bottom ash is another by-product of coal-fired thermal power plants, similar to fly ash[11]. It is produced during the melting of coal ash, resulting in coarse-sized and irregularly shaped particles. Bottom ash contains pores and cavities and consists of only a small amount of less glassy phase and semi spherical particles. With a chemical composition similar to that of fly ash, very fine ground bottom ash can be used as a supplementary material in concrete and can also be utilized as a source material for geopolymer binder producing. It can be used as an aggregate for lightweight concrete making, owing to its low density and high porosity. The slump of lightweight geopolymer concrete with an aggregate from bottom ash is lower than in normal geopolymer concretes, owing to its rough surface texture, high porosity, and irregular shape of its particles compared with crushed limestone[12]. The high friction of its particles decreases the fresh concrete workability. In addition, the amount of paste for lubrication between aggregates is reduced owing to the rough surface and high absorption of porosity of bottom ash. The use of bottom ash as a lightweight aggregate in geopolymer concrete decreases the latter’s surface abrasion resistance, splitting tensile strength and compressive strength. This occurs owing to the high Los Angeles abrasion loss, low density and high porosity of bottom ash particles.

In general, RCB have a specific gravity of 2.2–2.5, water absorption of approximately 5%–30%, and a dry density of 1500–1800kg/m3. This material is lighter than normal limestone aggregate; hence, it can be used to make lightweight concrete. A study comparing the properties of geopolymer concrete Construction and Demolition Waste Recycling aggregate with those of the aggregate from volcanic pumice was reported. The lightweight geopolymer concretes containing RCB and pumice aggregate exhibited lower mechanical properties compared with those of geopolymer concrete with crushed limestone (natural aggregate), which was as expected[13]. However, they had better thermal insulation and higher residual strength after exposure to temperatures of 400–800°C. Currently, lightweight concrete blocks are becoming very popular in the construction industry. These blocks have a lighter weight compared to standard concrete blocks and are increasingly used in the construction industry to reduce the dead load[14].Geopolymer foams have important technical advantages. They can be prepared by using different foaming agents with different microstructure [15]. Geopolymer foams are used in environmental remediation, renewable energy production, and as multifunctional and energy-saving building materials. Geopolymer foams have shown promising thermal insulation performance. The most common synthesis route to produce geopolymer foams is by the incorporation of a foaming agent e.g., hydrogen peroxide, fine metallic powders into the geopolymer slurry[16]. usually known as the chemical foaming technique. This strategy takes advantage of in-situ reactions of the foaming agent in the alkaline medium, inherent in the alkali activation of aluminosilicate precursors.

This process generates gas bubbles which are then trapped inside the slurry during setting, leading to the production of voids in the hardened body. Another strategy to create very porous materials without using foaming agents is by direct addition of gas bubbles, which can be achieved by using pre-made foams (e.g., prepared by passing air through a diluted surfactant), or foam concentrates which are then vigorously mixed with the slurry to produce a large volume of voids in the specimens. An alternative approach to produce geopolymer foams is by using sacrificial fillers (e.g., polymers)[17]. In this technique, the porosity is generated by the extraction/removal of the fillers. When polymers are employed, thermal and/or chemical treatments are required to remove this filler and create the porous bodies. However, the extraction of polymeric fillers is not only challenging, but raises environmental and economic concerns due to required amounts of chemical reagents, and gas emission arising from the polymer decomposition. Geopolymer foam concrete have good thermal insulation, sound insulation and light weight[18]. The geopolymer foam concrete (GFC) is produced by introducing pores into the geopolymer slurry or mortar, also known as foam/ foamed, aerated, cellular, or porous geopolymer.

As compared to the Portland foam concrete, the higher strength of geopolymer facilitates the lower density and better thermal insulation performance at an equivalent compressive strength. Meanwhile, the lower level chemically bound water and more discontinuous gel structures in the geopolymer materials further enhance the thermal insulation of matrix. In addition, the other advantages of geopolymer materials (i.e., corrosion resistance and higher durability can be retained in GFC[19].

B. Foamed Geopolymer

Foamed geopolymer concrete has applications in various fields, which is evident from the interest of researchers in areas such as materials, structures, and environmental engineering. The need for alternative, sustainable materials with a low carbon footprint undeniably also exists in the field of insulating materials, where, taking into account the advantages of geopolymers, the idea of using foamed geopolymers seems perspective and justified. These materials may be obtained by chemical or mechanical foaming or by forming syntactic foams. According to the chemical foaming method, a foaming agent is mixed with the other ingredients to generate air voids.

It is possible to produce the foamed geopolymer concrete at ambient hygro-thermal conditions using the chemical foaming method, thus obtaining a lower energy footprint than with other methods, which, in turn, explains the popularity of this technique. The syntactic foam method means that the geopolymer foam is fabricated by embedding hollow spheres into a binding matrix. Microspheres are the main constituents for syntactic foams, and they provide low density, high specific strength and low moisture absorption.

When it comes to the mechanical foaming technique, it is necessary to distinguish between two different types: mixed foaming and pre-foaming. In the first case, foam is generated during the mixing process after adding a surfactant, while in the second - a pre-made foam is mixed with the geopolymer concrete. This method usually involves applying such gases as N_2, AR, and O_2 and the main disadvantage of the mechanical foaming method is that tuning the homogeneity and pore size distribution is very challenging. It should be mentioned that publications about the production of foamed geopolymer concrete using mechanical foaming are mostly found in the period from 2011 to 2015. Nowadays, chemical foaming and forming of syntactic foams are widely used.

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II. MATERIAL AND METHODS

A. Material Binders

The most frequently used binder material is Portland cement i.e. OPC, rapid hardening cement, high alumina cement, calcium-sulfoaluminate cement, etc., which are known as primary cementitious materials. As cement production causing major environmental problems, an alternative material was evolved as secondary cementitious materials (SCM).

SCM's rich in aluminum and silicon can be used as raw materials or geopolymer source materials (GSM) for geopolymerisation with the presence of alkaline solution and these materials are as follows a) Flyash b) Ground granulated blast furnace slag c) Metakaolin d) Kaolinitic Clays e) Rice husk ash f) Red mud g) Silica fumes The mixture of two or more material combinations of the above stated can be used. It can be mix of fly ash and slag, fly ash and metakaolin, slag and metakaolin, etc. Alaa M Rashad10 stated that to obtain some reactivity of fly ash it has to be alkali-activated. The parameters responsible for reactivity are amorphous phase content, calcium, and silica content. They have asserted that calcium and iron content does not influence the compressive strength. Calcium content in the fly ash plays a very important role in the development of strength. Jiandong Wu et al,12 stated that metakaolin powder is composed of plate-like particles. These morphological features made to absorb more liquid to wet the surface. The author concludes that metakaolin blends have good workability and hardening properties. Rovnanik et al,13 show that to attain early gain of compressive and flexural strength, Higher temperature curing has to be done. On the contrary, this had an adverse effect on larger pore size and decrease in 28-day strength when compared to that of ambient curing condition. This is mainly due to attaining an early stage hardening process. Sanjay Kumar et al,14 showed that slag is a high reactive material with good durability and mechanical properties. Authors have shown the mechanism involved in the reaction of slag with alkali activation is due to the formation of C-S-H (CalciumSilicate-Hydrate) gel. Rana Shabbar et al.15 had utilized silica fumes as a replacement material with that of cement. This had shown an increase in strength up to 10% replacement.

Alkali activation of secondary cementitious materials that are composed of silica and alumina content are getting increased attention as an alternate binder to Portland cement. The materials which are alkali-activated has shown better durability and mechanical properties. The alkaline liquids are made out of soluble alkalis such as sodium and potassium. The most commonly used alkaline liquid is made with the combination of Sodium Hydroxide and Sodium Silicates or Potassium Hydroxide and Potassium silicates16. Depending upon prime materials, alkali activation can be established into two mechanisms. From Puteras et al.17 the first mechanism is the presence of Si + Ca in blast furnace slag, by the addition of alkaline solution, C-S-H gel is formed as the main product. the second mechanism rich in Si + Al with low Ca, by alkali activation, a three-dimensional structure A-S-H (Alumino-SilicateHydrates) gel is formed as the main product. Peng Fei Ren et al.,11 noticed leaching on the surface of fly ash particles. Their prediction is that it may be due to the presence of alkali ion Na^+ or K^+. This leaching and efflorescencecan be overcome by increasing porosity and a decrease in solid content. Lightweight geopolymer concrete can be obtained by replacing natural coarse or fine aggregates with lightweight aggregates or with the addition of foaming agents, chemical expansive agents, or by aeration method in geopolymer concrete. The keynote to have all these alternate materials is to reduce the self-weight of the structure and for the easy haulage and handling process in the construction. As mentioned in the previous section the common lightweight aggregate used in geopolymer concrete are natural aggregates like pumice, tuff, scoria, diatomite, volcanic cinders, etc., Artificial aggregates such as expanded clay, shale, slate perlite etc. Also foaming method is one of the most recently researched topic in geopolymer concrete which is produced by introducing large voids (gas or air bubbles) into the concrete or motor by using plant or synthetic-based foaming agents like Sodium lauryl sulfate, Sulfanol, etc. The chemical expansive agents like Al powder or H_2O_2 gas are used.

B. Methods To Produce Lightweight Geopolymer Concrete

Base work required for the development of geopolymer concrete is shown (Fig. 1) The first step is to investigate the geopolymer source materials that are to be used. The materials that are rich in alumina and silica content with the presence of chemical solution which can react and get into geopolymerisation has to be identified. The next step is the preparation of the alkaline solution. Many authors have adopted the following procedure. The Sodium Hydroxide (NaOH) solution is diluted in the water with the desired molar concentration. The dissolution of NaOH being an exothermic reaction, it is prepared preferably 24 hrs before the casting such that the solution cools down from high temperature to room temperature. Once the temperature of the solution is cooled down to room temperature it is mixed with the Sodium Silicate solution. Thus alkali activator solution is prepared with the required concentration20,21. The raw materials and the solution were mixed according to their ratios. To make the mix as lightweight foaming or aeration by the chemical agent or lightweight aggregates were used. All the trial mixes were done with different ratios and quantities of material to attain the target density, setting time, and the desired strength for the purpose of its development. Finally, from the results of trial mixes, appropriate ratios and quantities of materials were determined.

There are numerous ways to produce lightweight geopolymer concrete. From the (Fig. 2)9 , according to the porous nature, it is divided into two types: i) Aerated Concrete ii) Micro-pores. In the formation of the micro-pore structure, highly diluted lime mortar is used. When the setting process starts, the air is allowed to go in to form micro-pores that are uniformly distributed within the matrix. Non autoclaved curing is preferred under constant ambient conditions. Aeration of concrete can be done in two ways i) Autoclaved aerated concrete is done by using chemical expansive agents by including air into the mortar. ii)Foamed concrete is prepared by diluting foaming agent with water. This can be performed by two methods. In the mixed foam method, the foaming agent is directly added to the mixer such that bubbles are formed with the high rotation. This method is quite easy and convenient to use for larger quantities but due to the high rotation speed of the mixer bubbles can be damaged that reduces the included air in the mortar. In the pre-foam method, the foam is generated by the compressed air foaming equipment. The foam with bubbles was created and is mixed up with the base mix (cement + water or cement + water + sand). The delay in the mixing of foam with the base mix makes the foam into liquid and losses the stability of the foam. The pre-foaming can be wet or dry. In dry foam, bubbles will be of 1 mm size and stable for uniform mixing and pumping. the wet foam creates bubbles of 2 - 5 mm in size. These bubbles were unstable for uniform mixing and pumping compared to that of dry foam. Foaming agents that are commonly used are synthetic agents and plant-based agents. All these mixes can be cured by air dry or autoclaved under controlled conditions or nonautoclaved curing. Trial and error processes are used to determine the water content, density, setting time, and quantity of the material proportions for the mix. Mixing and production of lightweight geopolymer can be done in two ways is shown (Fig. 3) a) dry mixing method b) wet mixing method. In dry mixing method, all the raw materials were mixed dry for 1-2 min and then alkaline solution along with foaming or chemical agent was added and mixed for about 5 min or depending upon the desired density required6 . In the wet mixing method, raw materials were mixed for about 2 min, followed by the addition of alkaline solution. Thus, geopolymer paste is produced. To this geopolymer paste, either pre-foaming or chemical agent is added and then mixed to achieve the required consistency of the mix to produce lightweight geopolymer concrete.

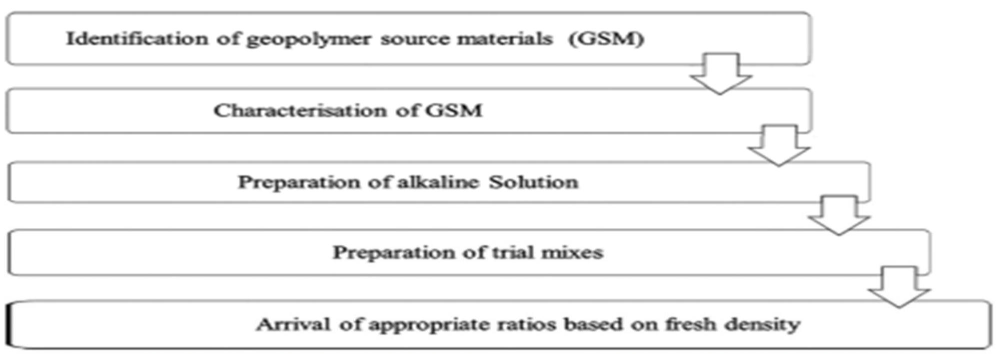

Fig. 1 — Schematic diagram of preparation of geopolymer base mix.

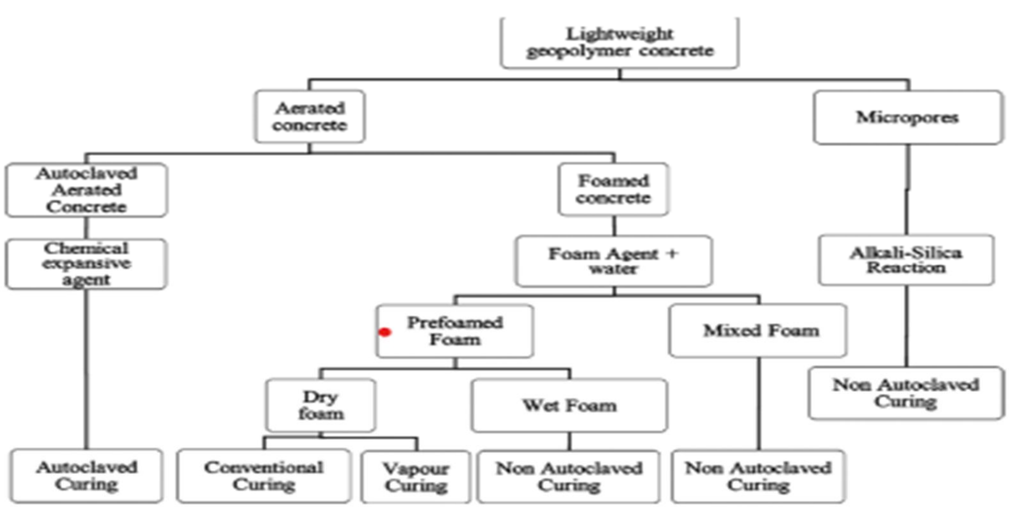

Fig. 2 — Methods to produce lightweight geopolymer concrete.

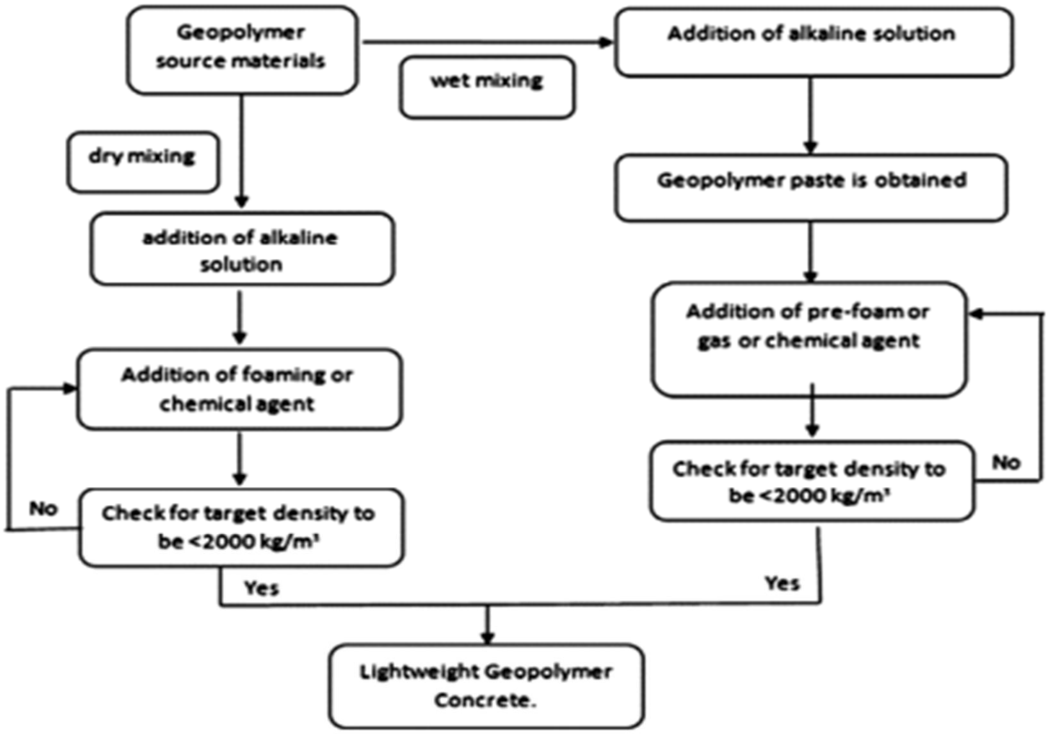

Fig. 3 — Preparation of Lightweight Geopolymer concrete.

III. RESULT AND DISCUSSION

A. Foaming Additives

Chemical foaming Technique

Kranzlein et.al, (2018)22 aimed to use the metal powder as foaming agents. Aluminum powder was added to the slurry in an amount of 0.005, 0.1, and 0.2% by wt of the solid raw materials. Zinc powder was added in 1.0% by wt of the solid raw materials. The powder was added to the Geopolymer slurry and stirred for another 3-4 min before the mixture was molded into the desired forms and then they are covered with foil and set for 28 days. They have concluded that using Zinc powder more porosity is achieved. Bell and Kriven (2009)23 proved that Al powder is a fast-reacting foaming agent. Metal powders, like Zn or Al powders, react in sodium hydroxide solution into their oxidized state, releasing hydrogen in the process. For the same molar amount of Zn powder reacts 50% less hydrogen-free compared with Al-powder. Therefore, Zn-powder reacts slowly and less vigorously than Al-powder. Hajimohammadi et, al. (2017)24 used Al-powder as a foaming agent. As soon as sodium hydroxide solution is mixed with a sample containing aluminium - powder it starts reacting and creates hydrogen gas bubbles in the mixture. They have concluded that Alpowder reduces the effect of carbonation. The early gain of strength is slow in the geopolymer matrix due to the addition of Al-powder but gains strength at a later age. Keertana B et, al. (2011)19 adapted a mix of sand and fly ash ratios at 3:7. The chemical foaming technique with metal powder alumina and foaming agent H_2O_2 is used. After 15 min of casting, there is a substantial increase in volume and microstructure of the specimen. The excess volume is cut-off to make it stable and consistent for further testing. Density obtained is in the range of 1074-1141 kg/m3 with a strength of 5.98-6.78 MPa. Anggarini et. al, (2019)21 studied on a foaming agent to produce lightweight geopolymer concrete with solid to liquid ratio as 2.3. They considered the ratio of Al powder weight percentage to fly ash weight as 0.01% to 0.15% wt and added directly to the geopolymer paste can be tracked back to non-autoclaved aerated curing instead of mixing the Al powder without undergoing any autoclave process. With the increase in Al powder compressive strength and density are decreased. Katiukas et. al, (2019)27 prepared the sample with Tungsten Mining Waste (TMW) and Waste Glass (WG) to produce Foamed Alkaline Activated Material (FAAM). It has been stated that the principle behind the chemical foaming method is the reaction between Sodium Hydroxide and Aluminum to produce H_2 gas. Thus, the expansion occurs based on the following chemical reaction. $2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2$.

Yong Cui and Dongmin Wang (2019)28 performed a synthesis protocol of foamed geopolymer. The concrete is obtained by mixing fly ash, alkali activator, and foam stabilizer (calcium stearate). 30% by wt of H2O2 is used as a foam blowing agent to form a porous structure. The total porosity is increased with an increase in water to the solid ratio from 0.38 to 0.50, but this has weakened the compressive strength from 0.75MPa to 0.45MPa. Aguilar et, al. (2010)29 reported geopolymer foam concrete based on metakaolin binders, aluminum powder as gas releasing agent, and blast furnace slag sand as aggregate. Wet mix is adopted, and Al powder is added at the end of mixing. Replacing metakaolin with 25% fly ash has some positive influence on strength while using slag particles as aggregate seems negative in this respect. In SEM analysis,metakaolin particles that arerich in Al and Si showed less reactivity and unreacted remarkably on day 1. The progressive reaction of metakaolin with a solid-state mechanism is observed in microstructure analysis. Jiandong Wu et. al, (2018)12 produced ultralightweight foamed geopolymer concrete (UFG) by using the materials Flyash, metakaolin, alkaline activator, calcium stearate as a foam stabilizer, and H2O2 as an air-entraining agent. It has been stated that the addition of calcium stearate with 0.3% wt of mix influences the stability of bubbles and improves air void structure. As the amount of H2O2 content with 3.2 wt% and 6.8 wt% of the mix, there is a 69.5% decrease in strength with the increase in H2O2 content. The reasons explained is as the amount of gas released during the reaction, large pore sizes, and low degree of homogeneity is F in the sample mix. Ailar Hajji mohammadi et. al, (2018)30 performed a chemical foaming technique with an H2O2 solution with 20% concentration, 0.328% wt of Sodium Dodecyl Sulphate (SDS) solution, and 0.45% wt of Xanthan Gum (XG). XG has been used as the thickening agent and has remarkably influenced the viscosity of foam solution. Due to the addition of XG, it shows narrow pore size distribution with a higher strength of stabilized foam by the reduction in water content.

B. Admixtures

Waleed Abbas et. Al40, admixture DARACEM19CFMQ was used which is high range water reducing admixture. The type of superplasticizer is liquid-based sulfonated naphthalene. Rupert J Meyers et al.(2014)43 upon exploration used only calcium-free alumino-silicates materials. Permanent cement composed of 80% Portland cement and 20% geopolymer materials. It was known that pyrament can gain early strength rapidly, it was activated by potassium carbonate having citric acid as a retarder. Ahmed et. al, (1991)44 have replaced blast furnace slag with silica fumes. and alkali activator as a binder is used. It is observed that there is an increase in mechanical properties of the specimen, but strength reduces by higher replacements of materials. Hardjito et al. (2004)42 to improve the workability of fresh concrete, a commercially available naphthalene-based high range water reducing admixture was used. The addition of 2% of fly ash by mass improves the workability of fresh concrete. This admixture is mixed with the alkaline solution and then added to the aggregate and fly ash that is mixed in a dry pan. Hilal and Mahamood (2018)34 experimented and showed that a ratio of Sodium Silicates/ Sodium Hydroxide in foamed geopolymer concrete should not be less than 1.75 to avoid a negative reaction between sodium silicate and foaming agent. Hajimohammadi et al. (2018) had used xanthum gum as a thickening agent. It showed a remarkable influence on viscosity and also reduced the coalesce of bubbles. This stabilizer has a positive effect on pore structure and size distribution.

C. Curing Conditions

From the Table 2, the curing conditions involved in lightweight geopolymer concrete were ambient curing (200 C -250 C), sealed curing, oven curing at elevated temperatures (300 C - 1500 C). Abdulkareem et al. (2014)5 The mix with fly ash had shown no visible swelling or spalling and minimum deterioration is observed as exposed to elevated temperatures. The thermal expansion is obtained by the dilatometry analysis, a sharp thermal shrinkage has been observed by elevated temperature from 700 C to 1000 C. Abbas, Khalil, and Nasser (2018)40 For the given molar concentration of alkali activator and excess of curing temperature increase the compressive strength. Al Bakri Abdullah et al. (2012)25 Elevating to higher temperature porosity and water absorption decreases thereby obtaining a denser matrix with greater strength is produced. Şahin et al. (2018)18 The compressive strength of ambient cured samples are much less than that of sealed and oven curing. This is due to leaching of alkaline solution at the early stages, this leads to a decrease in pH, hindering hydration, and less strength gain. Rovnaník (2010)13 The mechanical properties were investigated on the basis of pore distribution analysis. This has been evaluated by means of mercury intrusion porosimetry analysis that was conducted on paste samples using Micromeritics pore size 9300 porosimeter. from the analysis, ambient curing has shown better mechanical properties. For curing at 10°C, the setting has been delayed by 4 days. Instead, it has not shown any adverse effect on strength development in later stages. Ambient curing has shown better mechanical properties which is a contradictory result to other authors25,40. Kumar and Mehrotra (2010)14 Geopolymerisation is dominated by the combined interaction of fly ash and Granulated Blast Furnace Slag (GBFS) at 60°C curing temperature than that of lower curing conditions. GBFS is highly reactive and the improvement in mechanical properties is seen by 25% or more addition.

Y Cui & D Wang. (2019)28 Water is the most effectively involved material in the reaction. The highest humidity levels were maintained in the steam curing which promoted in strength development. In the dry curing, the reaction involved loss of moisture content, and more porosity is seen. This weakens the structure by non-uniform pore formation. Kastiukas et al. (2019)27 Due to the accelerated ion diffusion rate between the liquid and solid material, the strength increases with an increase in curing temperature and thereby producing a denser colloidal structure. The lightweight geopolymers that are undergoing ambient curing conditions have a major problem of leaching and efflorescence. The leaching is mainly due to the higher soluble alkaline contain. The white crystal part is seen on the surface of the mould is known as efflorescence as shown in . This is more predominant in materials that are not rich in alumina and silica. This increases with the increase in curing time. The reduction is efflorescence can be seen by increasing total porosity and pore size structure. This can be done by chemical or foaming method 2,18.

IV. CONCLUSION

The reviewed information shows prompt enhancement in the evolution of lightweight geopolymer foam concrete and their current status. The production of geopolymer foam concrete makes a revolution in the concrete industry in developing environmentally friendly and sustainable material. So far investigations concluded that geopolymer is a potent alternate binder material without compromising in mechanical properties. The development of lightweight geopolymer concrete preclude some considerations regarding durability aspects, such materials are usually used for nonstructural purposes. Geopolymers containing high alkaline content that can react chemically with a foaming or chemical agent to get porous nature. The nature and effects of reactions with different materials are the scopes for further study. Trial and error methods were adapted by considering various parameters and ratios such as liquid to binder ratio, foaming agent to water ratio, etc. Most of the research studies aimed at autoclaved curing conditions that are maintained to undergo an effective polymerization process and to improve physical and mechanical properties. A considerable increase in strength parameters was noticed with increase in the concentration of an alkaline solution, but it is extremely difficult in the mixing and handling process - the chemicals may be harmful to humans. Though geopolymer foam concrete is in use at some parts of the world for a non-structural purpose, more efforts are to be made for larger production under ambient curing conditions. The reactivity of pure mineral samples is not the same as that of waste raw materials or industrial by-products. So the major problems that are faced in the manufacturing of such products undergo climate exposure conditions, leaching, efflorescence, thermal cracks, shrinkage parameters, etc., Further factors are to be considered in the stabilisation of foam and homogeneity in pore structure formation. To address the significant issues research studies and investigations for standard methods and ratios are to be developed for the design mix of lightweight geopolymer concrete.

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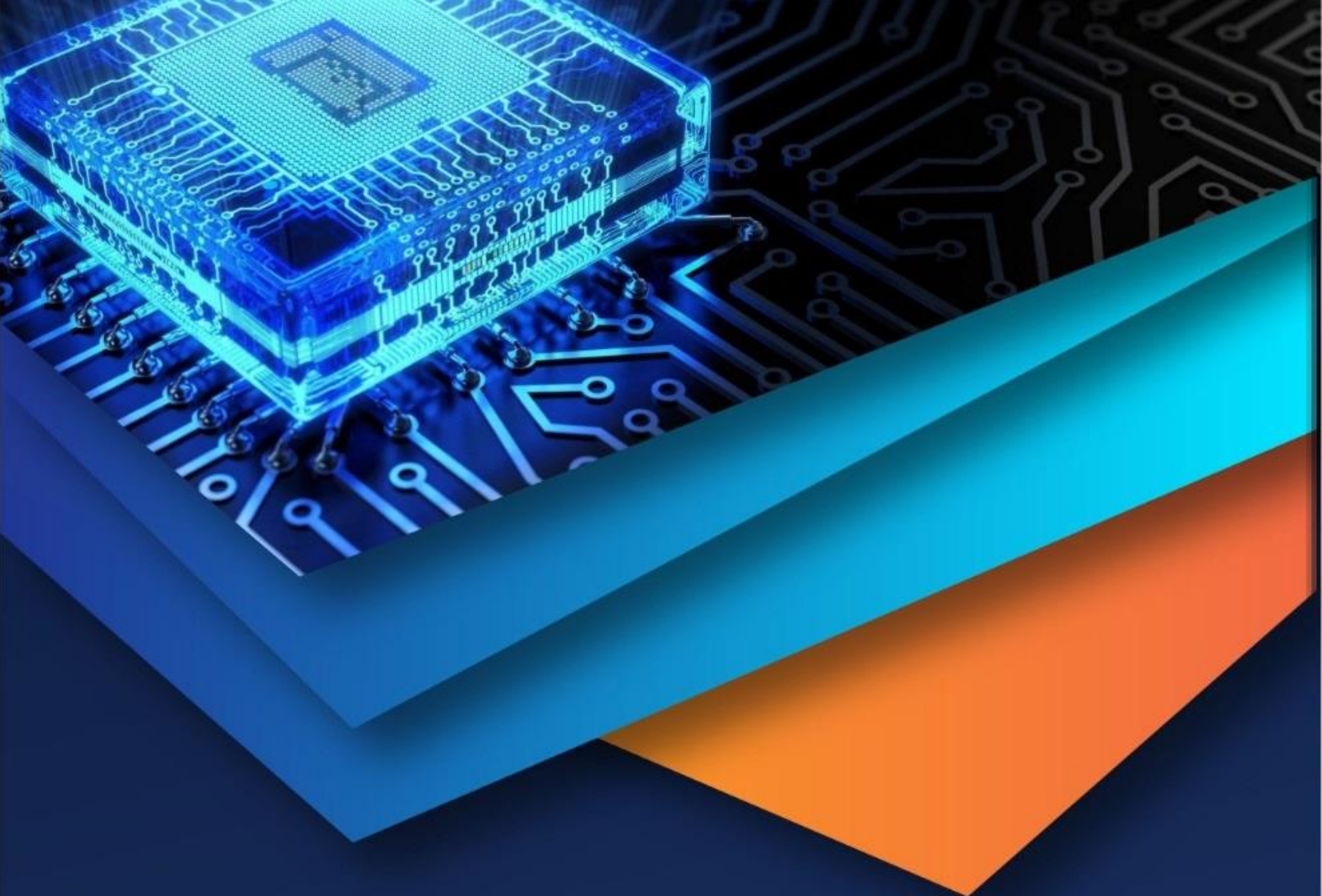

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