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Review Article

Studies on Lightweight Geopolymer Concrete

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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

1 Introduction

Concrete is the world's most reliable construction material. Next to water, concrete is the most used material in which prime constituent is cement.The cement industry is one of the major primary producers of carbon dioxide, a potent greenhouse gas. Production of cement is increasing globally by about 5% per year, and this will be responsible for 12% of total CO_2 emission by 2020[1]**.** The key focus in global housing and concrete industry led to the development of sustainable building materials to reduce environmental effects by both manufacturing and operational phases[2]. To address the aforesaid issue, efforts have been made to find an eco-friendly building material. The above resulted in the development of lightweight geopolymer concrete.

The term Geopolymer was introduced in the early 1970s by Joseph Davidovits. The three-dimensional silico-aluminate materials developed from amorphous to semi-crystalline form, called in French as "géopolymères" which means mineral polymers that are resulting from Geosynthesis[3]. Geopolymers are the inorganic molecules composed of tetrahedral silicate and aluminates units linked in a 3-dimensional structure by a covalent bond. The raw materials that are rich in calcium-silico-aluminates and magnesium-silicates are subjected to alkalisation; under the action of alkali they depolymerize into a small molecule called calcium-disilicate hydrate (CSH). The resulting reaction has free alkali cations K^+ or Na^+ out the structure making it unstable. To convert alkali activation to geopolymer, networking element i.e. materials like

MK-750 has to be added which interacts with the free alkali cations thereby resulting in a stable three-dimensional structure[5]. The raw materials used for geopolymer concrete are secondary cementitious materials such as Flyash, Ground Granulated Blast Furnace Slag, calcined clay, etc., The binders and activator solution under dissolution and polycondensation will transform into hardened material. The geopolymerization technology is an ideal and novel eco-friendly process for producing alternate materials to ordinary Portland cement (OPC). These geopolymer exhibits higher mechanical and durability properties and also reduces CO_2 emission by 80-90%[5]. These were reported to be more sustainable than that of cement.

Lightweight concrete as a building material reduces the dead load of a structure. The density of concrete ranges from about 300 kg/m^3 to 1800 kg/m^3 which is

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lighter than conventional concrete[2]. It also enhances seismic resistance capacity and better thermal insulation with lower density.

Lightweight concrete can be produced in three-different ways[7]

a) Lightweight aggregate concrete
b) Cellular, aerated, foamed or gas concrete
c) No Fines concrete.

Lightweight aggregate concrete is produced from lightweight aggregate such as natural aggregates like pumice, tuff, scoria, diatomite, volcanic cinders or artificial aggregates such as expanded clay, shale, slate perlite materials were fired in a rotary kiln to produce a porous structure[8]. Foamed concrete is produced by introducing large voids (gas or air bubbles) into the concrete or motor by using synthetic based foaming agents like Sodium lauryl sulfate, Sulfanol, Al powder, or H_2O_2 gas. In no-fines concrete, fine aggregate is not used. Only coarse aggregate is used in concrete as a result large voids are left reducing the density of concrete. It has been noted that Romans were the creators of lightweight concrete, by using low weight volcanic rocks[9]. The first cement-based foam concrete was patented by Aylsworth and Dyer in 1914 later by Bayer and Erikkson in 1923. It is prepared by the pre-foaming method or mixed foaming method. In the Pre-foaming method, a suitable foaming agent is used to form a foaming paste. This foaming agent is mixed with mortar to form foam concrete. In the mixed foaming method, the foaming agent is mixed with the slurry using a stable mixer to form foam concrete. This can be done either by dry or wet methods[2]. The main advantages in the production of lightweight concrete to that of conventional concrete is reduction in the weight, fire resistance, better mechanical properties, easy handling, and pumping. Further research in this area led to the innovation of lightweight geopolymer concrete. Developing a deeper and more comprehensive understanding of characteristics, material chemistry, microstructure and control of engineering properties need to be explored for broadening the uptake of this technology. This review paper asses the various production methods to achieve lightweight geopolymer concrete with special emphasis on geopolymer foam concrete and material binders, their physical and mechanical properties attained by the various compositions of additive materials, effects of various curing methods, and their improved performance.

2 Material and Methods

2.1 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 Rashad[10] 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 (Calcium-Silicate-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 silicates[16]. 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-Silicate-Hydrates) 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.

2.2 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 concentration[20,21].

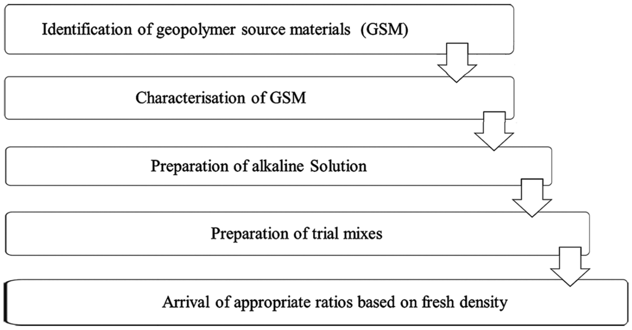

Fig. 1 — Schematic diagram of preparation of geopolymer base mix.

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

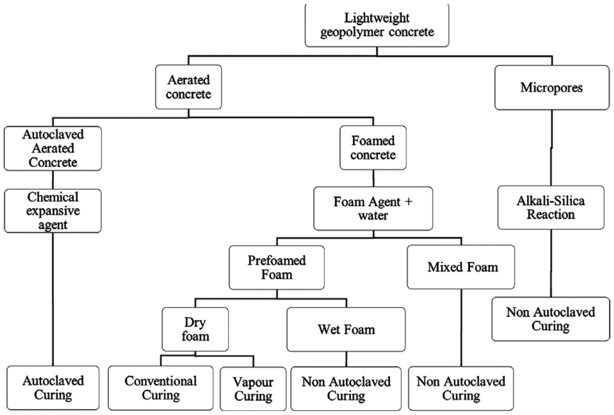

Fig. 2 — Methods to produce lightweight geopolymer concrete.

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 non-autoclaved 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 required[6]. 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.

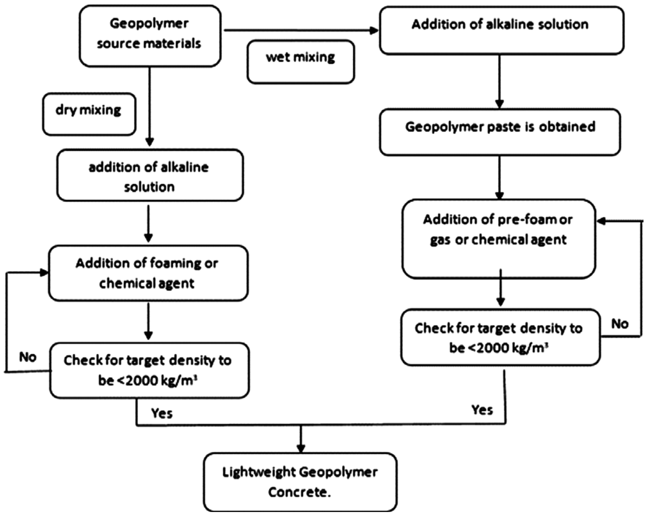

Fig. 3 — Preparation of Lightweight Geopolymer concrete.

3 Result and Discussion

3.1 Foaming additives

3.1.1 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 Al-powder 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 (Fig. 4). 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/m^3 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 H_2O_2 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 ultra-lightweight foamed geopolymer concrete (UFG) by using the materials Flyash, metakaolin, alkaline activator, calcium stearate as a foam stabilizer, and H_2O_2 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 H_2O_2 content with 3.2 wt% and 6.8 wt% of the mix, there is a 69.5% decrease in strength with the increase in H_2O_2 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 H_2O_2 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.

3.1.2 Mechanical foaming Technique

Abdullah et. al, (2012)[25] performed the pre-foaming technique, foaming is produced by diluting foaming agent by water in the ratio of 1:20 by volume. The ratio of geopolymer paste to foam ratio of 1:2 (by vol). It has been observed that micro-cracks had appeared for ambient curing conditions. Under heat curing, a complete reaction took place between fly ash particles and alkaline activators thereby forming an alumino-silicate gel. Siong Kang Lim et.al, (2017)[31] studied the hardened density of Lightweight Foamed Concrete (LFC) with river sand, quarry dust, a synthetic stable foaming agent was used with specific gravity 1.03 and density 45 g/l. There has been no significant difference in the strength with respect to change in water to solid ratio. Quarry dust replacement has shown stable air bubbles without any coalesce, contributing to the strength of concrete. Gunawan and Setiono (2014)[32] produced lightweight concrete using galvalum fibers, foaming agents as a concentrated solution of surfactants. As distinct side,fibres are resistant to corrosion and have good durability properties. Aeration of concrete is done by creating a lot of air bubbles in the concrete. With the addition of galvalum both strength and density were increased. Deepthi et.al,[26]produced geopolymer foam mixes using fly ash, GGBS, NaOH (3.4M), sodium silicates and pre-foaming method by using KV-Lite foaming agent (1:30 by vol)which produced stable foams. They have concluded that up to 8% of foam to geopolymer paste would show better properties.

Puput Risdanareni et. al, (2017)[33] investigated on effect of foam dosage of 0%, 0.3%, 0.6% and 0.9% by weight of binder. To produce lightweight geopolymer concrete (LGPC) with a foaming agent by foam generator, NaOH (10M), Sodium Silicates, pumice, and silica sand as aggregate is used with fly ash(75%) and metakaolin(25%). They have stated that an increase in the dosage of foam shows improvement in workability and porosity but reduces the mechanical and physical properties of geopolymer concrete. Finally, to satisfy the properties of LGPC, 0.3% of foam dosage is recommended as it has shown better properties. Hilal and Mahamood (2018)[34] aimed to produce structural lightweight concrete with zero cement called pre-foamed geopolymer concrete by mixing fly ash with alkaline liquid (8M), the aggregate of size 2.36 mm, and adding pre-formed foam to the slurry. From the Fig. 5, (a-c) these were suggested by Sahin et al.,[18] by using gas releasing agent H_2O_2. The presence of H_2O_2 shows less consistent as the bubbles are damaged by merging and thereby reducing the density. Surfactant foaming agent (EUCO- foaming agent) with specific gravity 1.01 was used for aerating geopolymer concrete and the ratio of a foaming agent to water is taken as 1:30 to produce a density of 1500 kg/m^3. They have claimed that mixing type can influence the density parameters. Panesar (2013)[35] suggested an in-mixing method, three types of foaming agents were used. One is protein-based foam CF200, the other two were CF500 and CF700 synthetic foaming agents supplied by Uniform company.

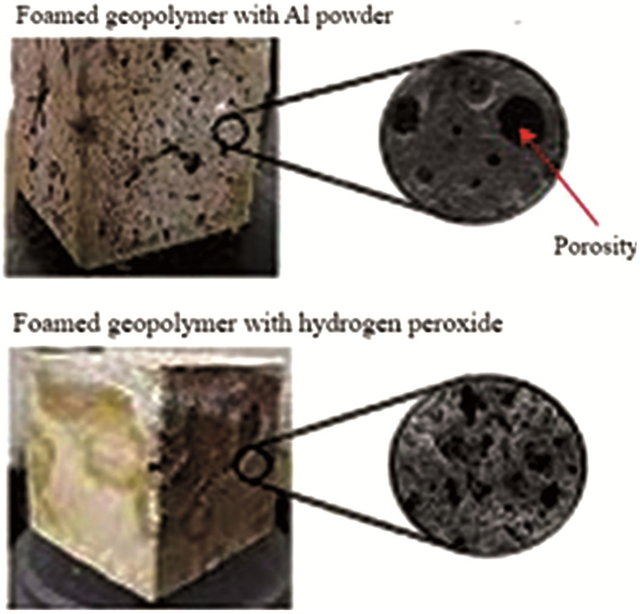

Fig. 4 — Comparison of porous structure of foamed geopolymer with aluminum powder and hydrogen peroxide.[26]

The foaming agent is added to the mixer to create bubbles that are enclosed by air and thereby increases the stability of foam with its high rotating speed. The method is standardized but it produces a big volume of damaged bubbles that consist of included air. In the preformed foam method, compressed air equipment is required to create bubbles and later on added to the motor to create cell structure. Outcomes are the compressive strength of 9, 10, and 5 MPa with foaming agents CF200 CF700, and CF500. Therefore, synthetic foaming agents produced better strength to that of protein-based foaming agents and also less sensitive to change in air content. Anggarini et. al, (2019)[21] used the pre-foaming method to produce lightweight geopolymer concrete with a synthetic foaming agent. The ratio of geopolymer paste to foaming agent volume of 1:0.50, 1:0.67, 1:0.75, 1:1.00, 1:1.33, 1:1.50, 1:2.00 are considered. With the increase of foaming agent, porosity increases with an increase in pore formation, but the strength decreases due to the non-uniform formation of pores. Thus, this weakens the weakening of the formation of polymer cluster linkage and producing cracks of destruction. Katiukas et. al, (2019)[27] performed a mechanical pre-foaming method with an anionic surfactant of 4% by weight of TMW-WG-FAAM obtained density and strength as 770 kg/m^3 and 2.68 MPa respectively. Piotrowski and Piotr Prochoń (2018)[36] produced granulated blast furnace slag based geopolymer foam concrete. The pre-foaming method with Meex AG foaming agent and Idrobase foam nebulizer is used to produce foam. The key consideration is w/s (water to slag) ratio being 0.29 shows the lowest density of 1500 kg/m^3 with a

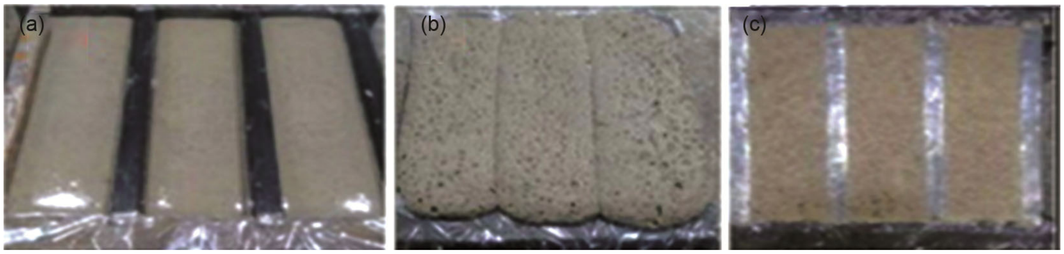

Fig. 5 — Preparation of sample with H_2O_2 a) Sample immediately after casting, b) 15min after casting, and c) Surface cut of sample after 2 h.[18]

relatively high compressive strength of 20 MPa. With the further increase in w/s ratio beyond 0.33 porous structure cannot be seen and also decrease in compressive strength is noticed. Kargin et. al, (2017)[37] experimented on fly ash geopolymer foam concrete. In order to produce foam, the air-entraining method is followed by an H_2O_2 5 - 20% ratio of the component in the mixture to fly ash mass. The average density obtained is in the range of 600 - 380 kg/m^3 and strength as 3.5-1.4 MPa. Dependent parameters, the weight ratio of a foaming agent to fly ash is taken to state the values of compressive strength, and density of concrete. The Table 1 illustrate the filler materials and foaming methods adapted to produce Lightweight Geopolymer concrete and resulting pore size, density and compressive strength.

3.2 Geopolymer Synthesis

The mechanism involved in the synthesis of geopolymerisation is the reaction between the materials that are rich in alumina and silica with that of an alkaline activator solution. This alkaline activation plays a crucial role as a binder material. The chemical reaction thus forms aluminosilicate hydrate gel. This mechanism is based on the mix design, materials used and various parameters considered. Nailia et. al, (2019)[38] studied alkali activation of fly ash with high concentration of alkali activator. According to him, alkaline activation plays a crucial role in the polymerisation reaction and also reported that an activator with a 12 M concentration leads to better results than an 18 M concentration. Ambily et.al, (2014)[39] compared the effects of usage of Sodium hydroxide and potassium hydroxide in Alkali Alumino-Silicates. Alkali activation solution to binder ratio is taken as 0.38 for every mix. They have observed that the gain of strength is maximum with the use of potassium hydroxide as a binder for GGBS (76%), Silica Fumes (24%), and steel fibres (1% to 2%) than with the Sodium Hydroxide.

Table 1 — Filler materials and foaming methods adapted to produce Lightweight Geopolymer concrete and resulting pore size, density and compressive strength.

Material filler	Foaming Method	Foam or chemical percent	Pore Size	Conc. of Alkaline Sol	alkaline/ binder	Density (kg/m^3)	Compressive strength (MP)	References
100% Fly ash	M-P with F:W::1:20	0.5	4µm -37µm	12 M	0.5	1650 - 1657	18.1 - 18.2	17
100% Fly ash	M-P with SFA	1: 0.5 to 1:2.00	50µm	7 M	0.43	1990 - 573	15.40 - 0.2	18
100% Fly ash	C-F by Al	0.01% to 0.15%	50 µm	7 M	0.43	1830 - 1031	42.00 - 4.60	18
100% Granulated Slag	C-F by H	0.25% to 0.5%	50µm - 500 µm	8 M	0.40 - 0.5	~ 500 - 1225	25 – 75	19
Zeolite tuff	C-F by Al	0.05% to 0.25%	278.48µm - 444.31 µm	10 M	0.6	1600 -1400	5.1 - 1.00	20
Zeolite tuff	C-F by H	0.5% to 4%	38.90µm - 402.70µm	10 M	0.4	1700 - 1390	5.7 - 0.98	20
TMW and MWG as 3:2 ratio	M-P by anionic surfactant	2%, '4%' and 6%	-	10 M	0.22	770	2.68	21
TMW and MWG as 3:2 ratio	C-F by Al	3%, '6%' and 9%	-	10 M	0.22	640	3.8	21
100% Fly ash	C-F by Al	1% by wt. of fly ash	10µm - 20 µm	12 M	0.43	1750	30	22
100% Fly ash	C-F by H	30% by wt.	50µm -360µm	-	0.38 to 0.50 @ 0.3	240 - 170	0.75 - 0.45	23
75% Metakaolin, 25% Fly ash,	C-F by Al	0.5% - 1.7%	100µm	-	-	900 600	4.1 2.3	24
100% Metakaolin	C-F by Al	0.5% - 1.7%	100µm	-	-	1200 900 600	14.3 6.4 1.3	24
50% Fly ash, 50% Slag	M-P by ..surfactants	1 : 060	28µm - 200 µm	3 M	0.38	670	1.75	25
50% Fly ash, 50% Slag	C-F by H	0.01%	1mm - 5 mm	3 M	0.38	710	1.52	25

M-P: Mechanical mixing of pre-foaming method; F: W - Foaming agent: Water; C-F by Al - Chemical foaming method by Alumina; C-F by H - Chemical foaming by H_2O_2; TMW - Tungsten Mining Waste; MWG - Municipal Water Glass.

Lynch et. al, (2018)[45] made the first attempt to produce a foamed geopolymer by alkaline activation of Ecuadorian Natural Zeolite. Molarity of NaOH is taken as 10M, Sodium Silicates, and $Ca(OH)_2$ with 3% wt of zeolite were used to prepare Zeolite based foamed geopolymer. SiO2/Na2O ratio is taken as 3. The density of zeolite-based geopolymer foam concrete with H2O2 is more when compared with fly ash-based geopolymer foam concrete, whereas the densities obtained by zeolite and fly ash-based geopolymer with Al powder as foaming agent showed the same results. It has been observed that due to the release of gases in the inner part of geopolymer foam concrete affected surface roughness. Waleed Abbas et. al, (2018)[40] considered the mixing parameters regarding alkaline activation ratio are NaOH: Na_2SiO_3 as 1: 2.5, Water to fly ash ratio is in between 0.25 to 0.61, Alkali activation solution to fly ash ratio as 0.35 to 0.70. The molarity of Sodium Hydroxide is taken as 10 - 16 M. With is an increase in molarity, compressive strength also increased. Finally obtained 7- day compressive strength for 16M concentration of NaOH as 32.8 MPa, whereas for 12M and 14M concentration the strengths were 27.3 MPa and 30.2 MPa respectively.

Abdullah et. al. (2012)[25] have taken trial and error parameter ratios as Geopolymer paste/foam as 1:2 (by volume) with Molarity of Sodium Hydroxide as 12M. fly ash /activator: 2:1; Sodium Silicates / Sodium Hydroxide: 2.5:1. The density and compressive strength obtained are 1667 kg/m^3 and 18.2 MPa. Torgal (2012)[41] suggested the molar ratios for high strength and durability. for the alkaline activator: SiO_2/Na_2O = 1.85; for the metakaolin: SiO_2/Al_2O_3 (3.5–4.5), Na_2O/SiO_2 (0.2–0.48), Na_2O/Al_2O_3 (0.8–1.6); between the activator and the metakaolin: H_2O/Na_2O (10–25). These ratios were recommended and can be used only for the prime materials as Davidovits used a high purity material named Kandoxi obtained from the calcination of kaolin at 75^{0}C for 6 hrs and cannot be applied for nonprime materials like fly ash, blast furnace slag, etc., as their chemical composition may vary. Bell and Kriven (2009)[23] made geopolymer synthesis by mixing all dry materials and then adding alkaline activation solutions in the required amount. The ratios considered are SiO_2/Al_2O_3 = 4.0 & Na/Al = 0.4 - 0.8. The activation solution is prepared using 39T and NaOH pellets are also dissolved into it. The porosity of the structure is observed maximum based on Na/Al ratio of 0.6 and Al powder of 0.2% as foaming agent.

Puertas et. al, (2010)[17] claims that compressive strength is influenced by the 10M concentration of Sodium Hydroxide. The study on a paste of fly ash and slag also reported that strength increases with increases in slag content for high reactivity of blast furnace slag. Ikmal et. al, (2020)[42] investigated on salient parameters of geopolymer concrete. Higher concentration, 8M to 16M (in terms of the molar) of sodium hydroxide solution, and the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass results in a higher compressive strength of geopolymer concrete. The compressive strength of the concrete decreases as the ratio of water-to-geopolymer solids by mass increases. Hilal and Mohmood (2019)[34] had noticed that NaOH is responsible for the white deposit on the surface of the sample as shown in Fig. 6 (a-d). This is due to the excess sodium reaction with atmospheric carbonation to form Na2CO3 and leads to reducing in strength. This can be overcome by adopting SS/SH>=1.75. By decreasing the amount of SH leaching can be reduced.

3.3Admixtures

Waleed Abbas et. Al[40], admixture DARACEM19CFMQ was used which is high range water reducing admixture. The type of super-plasticizer 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

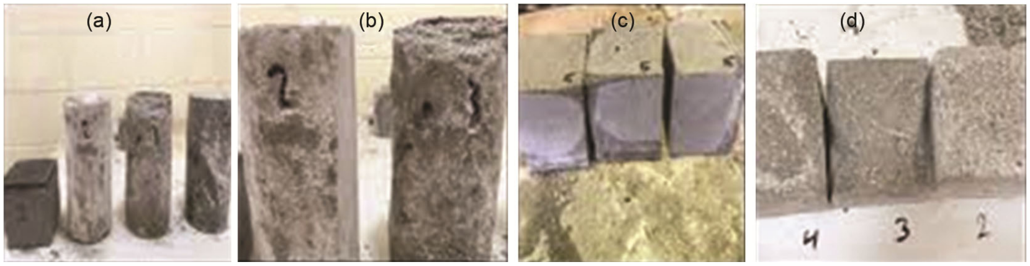

Fig. 6 — The formation of Sodium Carbonate (a) in cylinders, (b) leaching on the surface of cylinders, (c) in cubes, and (d) leaching on the surface of the cubes.

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.

3.4 Curing Conditions

From the Table 2, the curing conditions involved in lightweight geopolymer concrete were ambient curing (20^0C -25^0C), sealed curing, oven curing at elevated temperatures (30^0C - 150^0C). 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 70^0C to 100^0C. 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

Table 2 — Curing conditions adapted for various filler materials in preparation of lightweight Geopolymer concrete.

Materials	Curing Type	Compressive strength (MPa)	Description of curing type	Reference
Fly ash, Artificial lightweight aggregate using bentonite clay.	60^oC @ 48h 80^oC @ 48h 90^oC @ 48h	27.3 29.2 32.8	Prolonged curing with increase in temperature shows increases in the strength.	28
Fly ash, river sand Lightweight expanded clay aggregate	400°C 600°C 800°C	13 26.7 39	With the elevated curing temperature, the mix showed no visible swelling or spalling and minimum deterioration is observed.	5
Fly ash	room temp 60°C	18.1 18.2	Curing at higher temperature showed denser matrix and improved strength with that of curing at room temperature.	17
Granulated Slag, H_2O_2	SC - 28d AC - 28 d 80°C OC- 48h	18 2.5 21.7	Prolonged oven curing from 12h to 48h at 80°C showed increase in strength that SC until tested. Under AC, leaching of alkaline solution is observed, that lead to lower strength.	19
Metakaolin, Quartz sand	10°C 20°C – AC 40°C @ 4h OC 60°C @ 4h OC 80°C @ 4h OC	62 61.9 61.8 49 51	Curing at relatively low temperature led to delay in setting time. Early strength development is seen with Increased temperatures in OC. AC has slow reactivity and better mechanical properties.	13
Fly ash, GBFS (0 - 50%)	27°C - 48h + 60°C- 24h	45	Extended curing at 27°C for 48h continued with 60°C for another 24h. Increase in slag from 0% -50%, strength increases from 30 MPa - 45 MPa.	14
100% Fly ash	a) 95°C,2h + 150°C,6h- DC b) 95°,2h + 95°C,6h- ST c) 95°C, 8h- CCM	a) 30 b) 76 c) 102	Elevated temperature under dry curing has least strength to that of ST and CCM. This is due to retained moisture and reactivity of fly ash.	29
TMW, WG, Al powder	40°C to 100°C @ 24h- HC + 80°C @ 12h.	3.2 - 5.5	Initial curing temperature of 40°C is maintained and prolonged to 100°C for 24h. Before testing the sample HC of 80°C for 12h and then placed in dry chamber for 30min.	21

SC: sealed curing; AC: ambient curing; OC: oven curing; DC: dry curing; ST: steamed curing; CCM: curing in covered moulds.

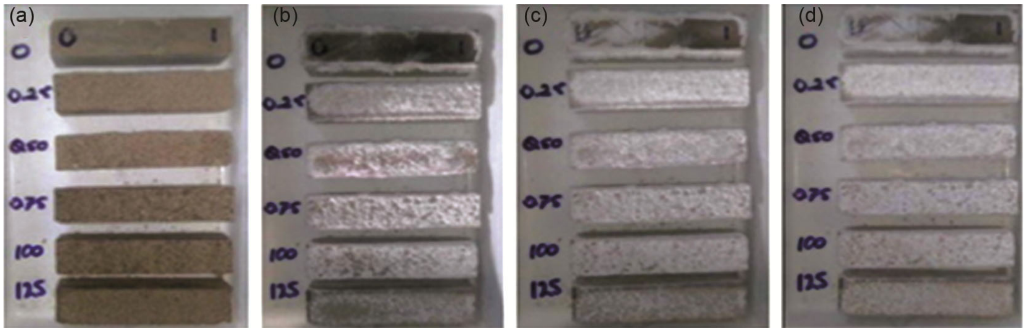

Fig. 7 — The visible effect of efflorescence a) after demoulding, b) after 2 days, c) after 9 days, and d) after 25 days.[18]

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 authors[25,40]. 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 Fig. 7 (a-d). 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].

4 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 non-structural 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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