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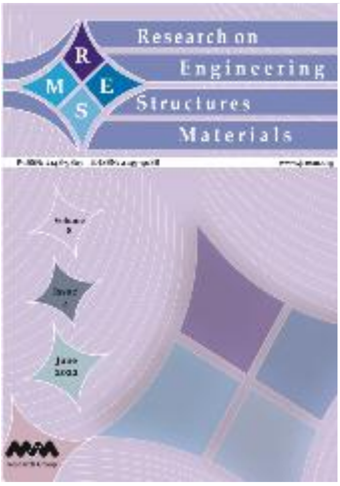

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Online Publication Date: 10 Mar 2022

URL: http://www.jresm.org/archive/resm2022.386ma1401.html

DOI: http://dx.doi.org/10.17515/resm2022.386ma1401

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article

Sheeja TV, Jebadurai SVS, Tensing D. Additive manufacturing techniques in construction. *Res. Eng. Struct. Mater.*, 2022; 8(3): 535-551.

Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org
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Review Article

Additive manufacturing techniques in construction

T. V. Sheeja[a], S. V. S. Jebadurai[*b], D. Tensing[c]

Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamilnadu, India

Article Info

Article history:

Received 14 Jan 2022
Revised 01 Mar 2022
Accepted 08 Mar 2002

Keywords:

Additive Manufacturing; 3D printing; Rheological properties; Extrudability; Buildability; Geopolymer

Abstract

In recent years, additive manufacturing (AM) technology has been one of the emerging innovations in the construction industry and has significant advantages over traditional casting methods. Current scenario mainly faces some challenges upon the material composition of printable materials. Earlier studies reveal a significant lack of experimental data and validated models on additive manufacturing materials. Researches should focus on developing materials with good rheological characteristics to guarantee acceptable fresh and hardened properties. This review paper provides insight into the properties of various printable mixtures and gives proper direction to developing a systematic procedure for mixture design by assessing their extrudability, buildability, robustness and workability retention along with their hardened properties.

1. Introduction

3D printing is a computerized method of making layer-by-layer formation of products. This is opposed to making a product by gradually extracting materials, reducing an enormous mass to a smaller one of required dimension and form, thereby giving the technology the term “additive manufacturing.” Unlike other sectors, construction of buildings, highways and almost every other construction has been an additive development technology. [1]. According to [2], future construction will be a hybrid of conventional methods and additive manufacturing technologies. This will produce large scale printed structures without the use of temporary supports. Geometrical complexity, multifunctionality and structural effects can be enabled within the printed objects through additive manufacturing technology.

As progress to conventional subtractive manufacturing, 3D objects are constructed by successively depositing materials in layers. Additive manufacturing techniques' benefits compared to traditional building processes: 1) Reduction in labor requirements and construction cost. It provides a safer environment in the construction site. 2) Providing versatility in geometry and design that would allow a more advanced method for structural and aesthetic purposes. 3) Minimize the overall project cost and time through a formwork free construction technique provided through extrusion-based additive manufacturing.

Geopolymer is a green construction material since its main ingredients collected from various industrial wastes and its usage in additive manufacturing may contribute to a more sustainable environment [3]. Alkaline activation of alumino silicate minerals produces geopolymers that are eco-friendly. Due to their mechanical performance and strong

*Corresponding author: vincent@karunya.edu
[a] orcid.org/0000-0002-9820-8103; [b] orcid.org/0000-0002-9820-8103; [c] orcid.org/0000-0001-7806-001X
DOI: http://dx.doi.org/10.17515/resm2022.386ma1401

durability features, these materials can assist alleviate the CO2 emission and be an efficient alternative for the construction industry, [4]. At the time of mixture proportioning of geopolymers, for a particular type of binder composition important design parameters to be considered are activator to binder ratio, molar ratio of activators and molarity of alkaline solution [5]. There is significant effect upon the nature of binders with the molar ratio of corresponding alkaline solution [6]. [7] Study reveals that there is significant effect upon the fresh and hardened properties of geopolymer mix due to the design parameters like liquid to binder ratio, mass ratio of alkaline solution and curing temperature. Geopolymerization process involves the activities like mixing up of precursors, generation of primary gel and the end production of silicate network structure [8]. Another research work concludes that [9] the addition of micro fibres like poly propylene fibres impart compressive strength to the geopolymer concrete. Durability aspects of geopolymer concrete exhibit better performance than portaland cement-based materials [10].

The development of additive manufacturing technology is very fast with its wide application in various industries. As far as the construction industry is concerned, suitable printable material is critical to successful printing. This review work covers the review of chemical and physical properties of various alkaline activated cementitious materials and its corresponding fresh as well as hardened properties for usage as an extrudable 3d printable mixture through various sections that are important in technology for additive manufacturing.

2. Additive Manufacturing Techniques

The 3D printing methods commonly adopted in the construction industry can be divided into two basic categories: Extrusion Based 3D Printing (Fused Deposition Modelling) where the printable material paste is extruded through a nozzle pushed by a robot-like device to realize the layer-by-layer final product. The system includes an extruder and a printing surface, S [11]. There are two different types of systems that are used within this technology. Frame- based system and ii) Robotic arm-based system, four – axis gantry and six-axis robot printers, [12] and [13]. Another method used in AM technology is binder jetting, which uses nozzles to spray binder in the form of liquid on top of a powder bed gluing together. Until a thin layer of powder is applied, the nozzle moves according to the planned course. Finally, the stacking of layers creates a 3D object.

3. Materials for Additive Manufacturing Technology

In Additive Manufacturing technology the development of printable material is a major concern. Main challenges in the selection of proper material by considering the rheological properties for the successful extrusion, buildability, material shear strength and open time ultimately the final product being able to provide the specified safety as well as serviceability aspects through additive manufacturing technology [14]. Cost and availability of the material and properties of the printing system may also considerable while choosing the material. Preparing a compatible material for large scale 3D printer is a tedious task [15]. Major properties of novel printing mortar are flowability and buildability, achieving these two parameters simultaneously, is a difficult task for researchers, more over it is important to identify the time for which each layer has to be attain its own yield stress [16]. 3D printed structures possess both isotropic and anisotropic properties. When oriented in different directions the printed specimen exhibits variation in bond strength between layers related with the corresponding time interval required for the construction of consecutive layers, whereas in case of casted specimen which have even distribution of material properties in all directions. Characteristics like viscosity of material, printing time gap between layers and contact area between consecutive layers have strong impact on mechanical properties of the printed materials [17]. [18] Pointed out about the necessity of large-scale additive manufacturing technology in construction industry through an automated extrusion- based process. International developments in standards for non-Portland cement, specifically on alkali activated binders, are being monitored by RILEM Technical Committee 224-AAM. This committee considered the performance-based standards rather than chemistry for the acceptance of a particular binder. It is difficult to find out performance- based standards since there is not any specific procedure for conducting experiments and validating the results for a wide range of binder system [19].

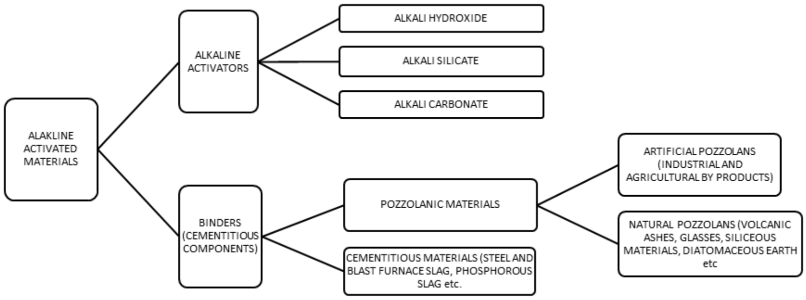

Figure 1. Process of Alkaline activated materials

The total Portland cement demand in the world is expected to rise 4.5% yearly, The production of around one ton of Ordinary Portland Cement in the atmosphere release almost one ton of CO2. [20] and [21] used geopolymer material to minimize greenhouse gas emissions. [20] pointed out that the fundamental explanation for reducing CO2 in geopolymer systems is the minimal amount of refined natural minerals and industrial waste to make the binding materials. Compared with Ordinary Portland Cement, the greenhouse gas emission reduced to approximately 44 to 64 % with the usage of geopolymer materials, [22]. Based on the growth and use trend, the existing limestone reserves available are projected to last only another 35-40 years. Replacement with geopolymer material in concrete construction will reduce cement consumption in concrete and provide durable and sustainable construction. Various studies have been carried out on traditional concrete mixes and propose modifications to obtain better quality concrete having both mechanical and durability requirements with advancements in technology and research. Using by-products such as fly ash (FA) and blast furnace slag (BFS) as alternative binders does not harm the climate based on the researchers' results,[23] Construction industry is in search of an alternative binding material, fly ash like geopolymer increases the performance of concrete mixes by providing better microstructure [24]. As per researchers it is important to provide fillers in concrete that enhances pozzolanic properties as well as hydration reaction[25]. Creation of geopolymers by using fly ash with alkaline activation as a construction material thus leads to sustainable and durable production by preventing the issues of fly ash disposal [26]. In recent years, alkali-activated cements have been of considerable significance for their possible use as building materials that could replace ordinary Portland cement. Performance of alkali activated materials as an alternative binder for Portland cement can reduce CO2 emission by more than 80% [27]. Several studies reveal that alkali activated cements have exceptional mechanical properties with low density. Geopolymer foamed concrete had better thermal insulation qualities than standard Portland cement foam concrete at the same density and strength,[28]and [29]. Figure 1 represents the Alkaline activated materials and its components.

3.1. Binders

Alkaline Activator Materials provides faster and large-scale production for a sustainable environment by reducing the amount of waste material deposited during construction [30]. For the preparation of alkali activated cementitious mortar, mainly used raw materials, exclusively alumino silicate materials, are kaolinite, feldspar, industrial bi products like fly ash, slag, mining waste etc. Reactivity towards alkaline solution depends on their chemical composition, shape, size, fineness and glassy as well as amorphous phases of solids. Raw materials used should possess highly reactive glassy contents and capable of releasing aluminium using less amount of water/binder ratio [31].

Ground granulated blast furnace slag composition includes lime and calcium magnesium aluminosilicate [32]. Addition of slag enhances the polymerization process and impart compressive strength to the product [33].

Metakaolin is an anhydrous alumino silicate material, during the dihydroxylation process, its losses structural water and the product is in amorphous nature, which is highly reactive in presence of alkaline solution [34]. Inclusion of metakaolin demands higher binder/liquid ratio with increased surface area reduces the workability of the mix. Metakaolin is more reactive than fly ash at the time of polymerization [35].

3.2 Activators

The researcher [36] used the term 'geopolymer' in 1970's to describe a class of materials which were produced by the activation of alumino silicate powder through an alkaline solution. Some of the common binders used for making geopolymer concrete are flyash, metakaoline and blast furnace slag. Among these flyash and metakaoline are rich in aluminium and silica whereas calcium and silica are high in blast furnace slag [37]. In order to activate these type of aluminosilicate binders an alkaline medium is required, commonly used alkaline activators are alkaline hydroxide, alkaline silicates or blends of the two. The anions and cations have important role in the process of alkaline activation consequently in the characteristics of the final products Normally used anions are hydroxides, silicates, carbonates and to a lesser extent the sulfates [38]. Chemical reaction involved during activation process:

$$(SiO2\text{-}Al2O2)_n + H2O + OH^- \rightarrow Si\,(OH)4 + Al\,(OH)^4$$

$$Si\,(OH)4 + Al\,(OH)^4 \rightarrow (\text{-Si-O-Al-O-})_n + H2O$$

Under the polymerization of aliumino silicate in presence of highly reactive alkaline medium produces water as its one of the bi products, hence it is used for improving the workability of the mixture [39]. Molarity of sodium hydroxide related with the reaction rate and strength of the final product.

$$NaOH(S) + H2O(l) \rightarrow Na^+ + OH^- + H2O + Heat$$

Soluble silicate influences the workability, strength development and reduces the setting time for the mixture [40]. Addition of alkaline activators instead of water with binders will reduce the yield stress and increase the bond strength of mortar. [41] in their study reveals the printability of extrudable mortar using fly-ash, concurrent with the time dependent yield stress. Metakaolin or fly-ash based alkaline activated cements produces sodium aluminosilicate hydrate gel with different Si/Al ratio whereas slag-based cements create calcium silicate hydrate gel with a low Ca/Si ratio [42].

3.3 Admixtures

Addition of admixtures impart high strength and produces high strength, durable concrete by reducing water cement ratio, [43]. Nano sized admixtures enhance the yield stress speed up the process of thixotropic shape retention property, [44]. In order to enhance the properties of alkaline activated materials ambient temperature conditions admixtures are proposed to be used, [45]. [46] in their study used nano silica as an admixture which increases the strength and durability of concrete due to its pore filling capacity. Due to its high fineness with specific surface area demands more water shows poor workability, [47]. Alccofine, an ultra-fine, amorphous material is added as an admixture in the study, [48] which is rich in calcium oxide hence produce more cementitious gel thus reduces the permeability and increase the durability of concrete. Alccofine increases the flowability and workability of mortar due to its water reducing capacity, [49]. Lignosulphate admixtures enhances workability of all type of activators while it retards the strength development, [50]. Research studies about viscosity modifying agents upon extrudable additive manufacturing technology [51], reveals that the extrusion pressure as well as buildability of printed filament increases with time moreover addition of VMA enhances yield stress and flow consistency.

4. Mix Design and Materials Composition of Alkaline Activated Geopolymer Materials

The mixture design adopted for additive manufacturing technology should have some specifications. These specifications depend on the printer equipment, the type of construction, and the conditions of the construction site. The attributes to be considered are pumpability, extrudability and buildability when designing the mixture design of concrete for a printer. [52]. They also emphasized the effect of admixtures and their interaction on rheological and mechanical properties [53]. In order to formulate an alkaline activated binder, it is necessary to determine the amount of reactive phase of precursors. Mainly used precursors in alkali activated cements are metakaolin, fly ash (class-f, class-c), silica fume and ground granulated blast furnace slag. Binders like metakaolin and class-F fly ash are rarely pure and having non-active crystalline phase in a basic environment with low solubility whereas slags are having fairly similar chemical composition and equivalent fineness, [54].

Activators are necessary for the polymeric reaction of aluminosilicate binders. Mainly used activators are alkali hydroxides, alkali silicates, alkali carbonates and alkali sulphates. Formulation of alkali activated materials depends upon the variety of precursors and suitable activators moreover the role of water depending on this precursor/activator couple

Buildability of the extrudable cement mortar with varying printer parameters are in direct relationship towards the force of attraction between the inter particle, particle size and its arrangement within the material, [55]. [56] in their studies found out that the increase in molarity of NaOH will make a viscous alkaline solution and produce better cohesive mixture with increased inter particle repulsion, hence it possible for the production of an extrudable mixture. [57], discovered in their study that yield stress values of a mortar related with the square of d50. [58], have conducted a study by replacing certain % of fly ash with fine lime stone as filler material to increase the inter particle contact and hence support the overburden pressure for the suitable printability of mortar [59] analyzed the rheological properties of mortar containing fly ash and ground granulated blast furnace slag, concludes that up to 50% addition of slag not at all improving any rheological properties of fresh mortar in the time range of 0 to 25 minutes. Further addition of slag shows increments in yield stress accompanied by a decrease in consistency.

[60] concludes in their study about the effect of ground granulated blast furnace slag mixed with fly ash, that addition of slag maintains inverse relation with workability due to the angular shape of the slag and accelerated reaction rate of calcium when compared to fly ash and it enhances the setting of mortar. Different researchers developed different geopolymer mixes for 3D printing. A few of the designed combinations and the properties considered for designing are summarized in Table 1.

Table 1. Design strategies in research for printable Geopolymer concrete mix

Sl No	Title with Author	Materials used			Activators	Primary Findings	Conclusion
		Binders	Aggregates	Admixtures			
1	The study of the structure rebuilding and yield stress of 3D printing geopolymer pastes [61]	Blast Furnace Slag, Steel Slag	Sand	defoamer, super-plasticizer, and re dispersible latex	NaOH & Na_2SiO_3	Addition of NaOH speed up the process of geo polymerization and rebuilding capacity.	Increment in Si/Na ratio causes a decrement in yield stress development hence in the structural rebuilding also.
2	Additive manufacturing of geopolymer for sustainable built environment [30]	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Thixotropic Filler	KOH & K_2SiO_3	Plotted torque- speed graph using rheometer, and hence measured the thixotropy of mix.	Decrease of thixotropy over time indicates the open time for the material. Below this minimum value of thixotropy, material is not suitable for large scale printing
3	Experimental study on mix proportion and fresh properties of fly ash based geopolymer for 3D concrete printing[62]	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Micro glass fiber & Attapulgite clay	K_2SiO_3 & NaOH	Find out the favorable yield stress value for smooth extrusion.	Novel 3D printable geo polymer mortar was developed for printing non- structural polymer mortar was developed for printing non-structural building components.
4	Optimization of mixture properties for 3D printing of geopolymer concrete [63]	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	-	Sodium meta silicate powder	Increase in activator dosage speed up the reaction rate, yield stress and lower the setting time. Samples with lower % of activator shows higher strength.	Material properties like rheology, open time, compressive strength and printing parameters like pumping pressure, printing speed were studied to achieve a successful geopolymer mixture for 3D printing.
5	3D Printing of geopolymer Concrete [64]	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Actigel	NaOH & Na_2SiO_3	-	Addition of higher % of GGBFS shows a linear increment in compressive strength and exponential decrement in setting time. Introduction of actigel enhances the rheological properties of the mixture.
6	Fresh and hardened	Class-F-Fly ash,	River Sand	Actigel,	KOH & K_2SiO_3	-	To ensure better pumpability,

	properties of 3D printable cementitious materials for building and construction [65]	GGBFS and Silica Fume		Bentonite Sodium lingo sulfonate			thixotropic value should be more than 10000Nmm rpm.
7	Effect of 3D printing on mechanical properties of fly ash-based inorganic geopolymer [66]	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Thixotropic additives	K_2SiO_3 & H_2O	-	In order to provide colloidal interaction in geopolymer (like OPC), thixotropic c additives are helpful to improve printing performances without disturbing the geopolymer mechanism
8	Method of optimization for ambient temperature cured sustainable geopolymers for 3D printing construction applications [67]	FA and Slag	Sand	Anhydrous borax (retarder), sodium carboxy methyl cellulose (VMA)	Combination on of sodium silicate and potassium silicate & Sodium hydroxide & potassium hydroxide	Initial and final setting time significantly reduced, from 295 minutes to 45 minutes (25%)	Formation of additional geopolymeric gel along with C-S-H may be the reason for Accelerated setting.
9	Rheology and Mechanical Properties of Fly Ash-Based Geopolymer Mortars with Ground Granulated Blast Furnace Slag Addition [59]	FA and Slag	Siliceous sand	-	Sodium silicate solution, sodium hydroxide pellets and water	content of GGBFS in the range up to 50 wt.% did not significantly alter the rheology of geopolymer mortars within the time rage from 0 to 25 min the increase in GGBFS content was accompanied by a decrease in consistency	Tests of mechanical properties show a clear increase in strength together with an increase in the amount of GGBFS
10	Mix design and fresh properties for high-performance printing concrete [68]	Cement, Fly ash & Silica fume	Sand	Retarder, formed by amino-tris, citric acid and formaldehyde and accelerator, formed by	Water	Optimum mix corresponds to the binder content of 40% with 1 to 2 % of super plasticizer dosage.	Shear strength controlled by the usage of super plasticizer. By adding micro scale polypropylene fibers to the mix at the rate of 1.2kg/m^3, compressive strength reached more than 100 MPa.

				sulphuric, aluminium salt and diethanolamine.			
11	Mechanical properties of layered geopolymer structures applicable in concrete 3D printing [69]	Fly ash	Sand	Steel and poly Propylene fibres	NaOH & Na_2SiO_3	Addition of 1% of steel fiber reduces the workability by 4% and increases the flexural strength by 20%.	Addition of steel fiber causes bond separation issues and polypropylene fibres decreases the workability.
12	Design 3D printing cementitious materials via Fuller Thompson theory and Marson-Percy model [70]	OPC, Flyash & silica fume	Silica sand	Super plasticizer	Water	Printing with continuous sand gradation mix able to print more layers without any significant deterioration, indicates strong interfacial bond.	Mixes with continuous sand gradation possess higher yield stress and lower viscosity in comparison with uniform sand gradation
13	Fresh properties of a novel 3D printing concrete ink[15]	OPC, Fly ash and Silica fume	Sand	Nano clay, Poly carboxylate e-based high range water reducer	Water	-	Effect of small replacement of cement in concrete by fly ash and silica fume enhances the thixotropic behavior of concrete leads to improved buildability.
14	Process Development of Fly Ash-Based Geopolymer Mortars in View of the Mechanical Characteristics [7]	Fly ash (two types)	sand	-	Sodium silicate solution, sodium hydroxide pellets and water		The highest compressive strength was 60.1 MPa for the geopolymer manufactured with an Liquid/Solid of 0.2 and $Na_2SiO_3/NaOH$ ratio of 2. The best thermal curing temperature for obtaining optimal strength characteristics was 100 ◦C .
15	Effect of molarity of sodium hydroxide and molar ratio of alkaline activator solution on the strength development of geopolymer concrete [6]	Fly ash (two types)	sand	-	Sodium silicate solution, sodium hydroxide pellets and water		16M NaOH yields high compressive strength when SiO_2/Na_2O in Na_2SiO_3 solution is around 2.00 to 2.40 and $Na_2SiO_3/NaOH$=2.5.

5. Properties of Printable Geopolymer Concrete

5.1 Fresh Properties

Printing parameters such as flowability of the extrudable material, printing speed, printing time gap between the consecutive layers etc. have remarkable influence on the final printed object, [71]. To develop proper mix design for printable material extrudability, buildability and workability retention are the essential parameters. The material should possess high yield stress for buildability (high yield stress allows deposition of top layers without causing much deformation of bottom layer) and at the same time, the printable material should below viscous in nature to enable extrudability.

5.1.1 Extrudability

From the analysis of various studies among additive manufacturing extrusion technology, it is revealed that the mixes that are designed for 3D printing need to be extruded through a nozzle to attain the required shape. Extrusion is graded by [72] as full-width printing and filament printing based on layering technique, depending on the rheological properties of the material and geometric configurations of the extruder. Extrusion is so important for further performance; monitoring for real-time efficiency is suggested by [73] by a vision-based technique. 2D images are analyzed in this system, and the reliability of the system was checked by providing various materials.

[62] analyzed the extrudability of geopolymer mortar. Clogging is seen in the study. It will impart the higher yield stress developed due to friction generated between fine aggregates and the importance of further rheological study in geopolymer concrete. The high static yield stress can negatively affect the extrudability, and high pressure is needed to initiate the flow, but not always as cautioned in the study. The fly ash and ground granulated blast furnace slag (GGBS) quantity are varied in geopolymer to vary the thixotropy open time (TOT) for selecting an extrudable mix with the property of shape retention. Study reveals that further modelling is needed to understand extrusion fundamentals with different types of materials and structures.

The extrudability of printable geopolymer pastes are studied by [61] Extrudability is connected to its transition from the mixing system to the printing system. The study concludes that it is safer to decrease the Si/Na ratio of alkali activator to increase the potential of structure reconstruction.

[65] analyzed the properties of printable geopolymers and cementitious materials through his work. In this study to improve the workability and extrudability of mixes, bentonite clay is used as a rheological modifier, and alkaline solutions are used to activate the binders. Results conclude that the geopolymer mix has a higher viscosity in plastic stage than mixtures with cement.

5.1.2 Buildability

3D printable concrete buildability is defined as extruded layers' ability to maintain the printed shape and carry the weight of following layers without failure. The rheological behavior of concrete governs a large part of its buildability property, [53]. The bottom layer is subject to the most challenging load during the time of printing. To ensure the stability of construction until the open time the key factors for maintaining layer-by-layer load are yield stress and structure reconstruction [74].

Different publications on the rheology of geopolymer, [75] mentioned that geopolymer does not have colloidal contact like cement-based materials. Due to the use of the potassium silicate reagent's extremely vicious existence, the hydrodynamic effect will be there in the geopolymer material, therefore, in the analysis, [19] added some nano-clay (attapulgite), compatible with the geopolymer material, to enhance this thixotropic property. It is noted that the internal structural built-up value increased with the addition of clay to mix, causing no problems such as clogging, discontinuity, etc. [61] observed that the interlayer force has a vital role in the buildability of paste in printing process of geopolymer material. Study reveals that the inclusion of alkali activator significantly influenced the rebuilding potential of the paste. This will accelerate the polymerization thus the coagulation of the mixture improves and acquires a greater degree of structure recovery.

5.1.3 Open Time

Another important fresh property of concrete for 3D printing is open-time. There is an optimum time for the printed layer to get initial strength to hold subsequent layers but still wet so the layers can fuse together before final setting, [63]. The open-time is connected to the concrete's initial setting time. A sufficient open time is required to support subsequent layers [68]

[63], developed geopolymer mix with fly ash, slag silica fume and Sodium meta-silicate powder were used as the activator, research work it can be seen that higher wt.% of the activator results in considerably lower setting time because of a faster reaction, higher pH and a higher rate of dissolution of particles. Also, a higher w/s ratio causes prolonged setting time by lowering the pH and dissolution rate and reaction rate. Brief setting time (open-time), although giving the sign of getting strength quickly to support the subsequent layers, can result in less adhesion (fusion) between layers and most importantly the mixture can lose workability for printing very quickly.

In the research work, rather than adding an accelerator/retarder, [19] added various percent of fly ash with GGBS to get difference in open time, and noticed over time by adjusting the ability to structural built up for the chosen mix having extrudability and shape retention capacity. Other researchers have found that an improvement in GGBS typically reduces the setting time, [76] As per [19] observed a similar pattern of increasing the percentage of slag, increasing structural built up over time, which reversely affects the extrusion process.

5.1.4 Rheology

Rheology of the concrete mix (deformation of the flow of material) affects the material's extrudability and buildability. Study of [77] concludes that the rheological behavior of the mortar mix is affected by the relationship between shear stress and shear rate, termed as flow curve, can be analyzed with rheometers, Factors such as granular contacts (tribology), delivery and placement, which decides the pumpability and buildability are affected by the material and equipment parameters, [53]. By measuring the rheological properties of a mixture at various time intervals and comparing it with the open time test, the plastic viscosity and shear stress will provide data on the maximum time values needed for good extrudability.

Unlike Portland cement, the rheological behavior of the alkali-activated materials (geopolymer) is less well known. This is due to the complexity of the chemical environment and reactions taking place and the different physical properties of the main precursors. For example, an alkali silicate-activated slag has a too complicated solution environment with high ionic strength and alkalinity, which is a very challenging environment in understanding rheological behavior, [63] Rheology modifiers such as common superplasticizers (that improves workability without increasing w/s) in Portland-cement based materials not so good in geopolymer materials, [78]. In the research paper, [61] found that geopolymerization requires an alkali activation. The increase of Na ion can speed up the process of dissolution of aluminosilicate source, [79]. [62] noted that GGBS did not give a significant rheological change, affecting the material's time-dependent structural built-up capacity by reducing paste setting time. Therefore, who should carefully regulate the composition of the mixture, thus maintaining a reasonable final strength level but the addition of silica fume in the fresh stage has been useful in regulating the rheological parameters of the mixture. Silica fumes particles having high surface area, which allowed the blend to be smoothly extruded through the deposited filaments and hence shape retention capacity.

[65] concludes through the study that no special relationship exists among the rheological parameters of printable material. For better pumpability for the printable material, thixotropy

value should be more than 10000Nmm rpm. In geopolymer mortar design, [65] applied Acti-gel, since it has the property to provide a mixture with shape stability. It can minimize shear stress through a nozzle during the extruding process and increase the extruded mixture's buildability. By measuring the rheological properties of a mix with different time intervals, particularly the plastic viscosity, it can provide information on the maximum time values needed for good extrudability.

5.2 Hardened Properties

The mechanical properties such as compressive strength, flexural strength, and tensile bond strength must be adequate for a printed structure, in addition to the fresh properties of the geopolymer mixtures for good printing.[63] analyzed that samples with a lower percentage of the activator showed higher strength than the models with higher % of the activator. Lower alkalinity drive formation of a particular geopolymer gel which increases the mechanical performance. Also, higher w/s results typically in lower strength of geopolymers. The samples with higher % of the activator, instead of having faster reaction initiated by lower initial setting time and faster changes in workability (higher rate of increased yield stress vs time), showed lower compressive strength. [80], mentioned in their studies that compressive strength is in direct relation with the molarity of sodium hydroxide when the mortar is prepared with fly ash and slag. [65] concludes that printing parameters such as nozzle orifice shape, printed object complexity etc. influence printed specimens' mechanical properties. Through the research work, [19] reported that the printed sample shows greater compressive strength when load is applied normal to the specimen whereas in flexural test, results are less when loading in the same direction. Results imply that the force of attraction between the layer is less compared with the force along the layers. Another major parameter is the tensile bond strength which is directly influenced by the open time.

6. Conclusion

Geopolymer is a new environmentally friendly cementitious material, and its development has the potential to reduce carbon dioxide emissions caused by the growth of the cement industry. The current analysis analyzed important advancements in geopolymer technology in the construction industry, as well as recent discoveries and future research directions. This topic has piqued the interest of numerous academics over the last decade as a potentially efficient alternative to typical Portland cement-based binders in terms of both technological qualities and environmental sustainability. The increasing number of research publications by years reveals that additive manufacturing technology is a part of industry 4.0. In terms of technological innovation and applicability, significant progress was accomplished as well. One of the most noteworthy achievements achieved is the ability to change geopolymer mixes for sophisticated Additive Manufacturing techniques, which opens up new design flexibility for engineer optimization in the construction industry. In this context, more research is needed to better understand how 3D printing technology might be used to produce effective geopolymer-based applications in the building–architectural disciplines. This state of art paper gives a systematic review of Additive manufacturing techniques and the development of printable material. The effect of several parameters, the type of binders, alkaline activators, admixtures and the binder activator mix ratio on workability, flowability, extrudability, shape retention ability and the mechanical properties of printable alkaline activator mortar. In order to be used in 3D printing of alkali-activated and geopolymer materials, significant rheological development is necessary. Also investigate additive manufacturing technology and critical issues in developing AAM printable materials. For an Additive Manufacturing printed concrete structure with adequate structural and serviceable performance, proper control must be there at the time of material selection, relevant parameters in the mixture design and printing process. For the acceptance of additive manufacturing technology as a construction technology standardization and specification for materials and methods and proper structural design procedures are required.

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