Mixture Compositions of Alkaline Activated Cementitious Materials for the 3D printing process

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Abstract— The construction industry has recently seen the emergence of additive manufacturing (AM) technology, which has a number of advantages over conventional casting techniques. The biggest difficulties in the current situation are related to the make-up of printable materials. The experimental data and verified models on additive manufacturing materials are significantly lacking, according to earlier studies. To provide appropriate fresh and hardened properties, research should concentrate on creating materials with good rheological properties. By evaluating the extrudability, buildability, robustness, and workability retention of various printable mixtures as well as their hardened qualities, this review study offers insight into the properties of different printable mixtures and provides the correct direction for building a systematic approach for mixture design.

Keywords—Additive Manufacturing, Extrudability, Buildability

Introduction

A computerized technique for building products layer by layer is 3D printing. This is in contrast to creating a product through the progressive extraction of materials, which reduces a large mass to a smaller one of the required dimension and form, earning the process the name "additive manufacturing." Construction of buildings, highways, and nearly all other types of construction, in contrast to other industries, has been an additive development technique. qualities of hardness.

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 are collected from various industrial wastes and its usage in additive manufacturing may contribute to a more sustainable environment . Alkaline activation of alumino silicate minerals produces geopolymers that are eco-friendly. Due to their mechanical performance and strong durability features, these materials can assist alleviate the CO_2 emission and be an efficient alternative for the construction industry. 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. There is significant effect upon the nature of binders with the molar ratio of corresponding alkaline solution . 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. Another research work concludes that 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.

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. MIXTURE COMPOSITION OF ALKALINE-ACTIVATED CEMENTITIOUS 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 pump ability, extrudability, and buildability when designing the mixture design of concrete for a printer. . They also emphasized the effect of admixtures and their interaction on rheological and mechanical properties . 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 have non-active crystalline phase in a basic environment with low solubility whereas slags are having fairly similar chemical composition and equivalent fineness.

Activators are necessary for the polymeric reaction of aluminosilicate binders. Mainly used activators are alkali hydroxides, alkali silicates, alkali carbonates and alkali sulfates. The 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, in their studies found out that the increase in molarity of NaOH will make a viscous alkaline solution and produce a better cohesive mixture with increased inter-particle repulsion, hence it possible for the production of an extrudable mixture. Researchers discovered in their study that yield stress values of a mortar related with the square of d50. 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 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.

concludes in their study about the effect of ground granulated blast furnace slag mixed with fly ash, that the 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	Blast Furnace Slag, Steel Slag	Sand	defoamer, super-plasticizer, and re-dispersible latex	NaOH & Na_2SiO_3	The addition of NaOH speeds up the process of geo-polymerization and rebuilding capacity.	An increment in Si/Na ratio causes a decrement in yield stress development hence in the structural rebuilding also.
2	Additive manufacturing of geopolymer for a sustainable built environment	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Thixotropic Filler	KOH & K_2SiO_3	Plotted torque-speed graph using a rheometer,and hence measured the thixotropy of mix.	The decrease of thixotropy over time indicates the open time for the material
3	Experimental study on mix proportion and fresh properties of fly ash-based geopolymer for 3D concrete printing	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	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	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.

						shows higher strength.	
5	3D Printing of geopolymer Concrete	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 properties of 3D printable cementitious materials for building and construction	Class-F-Fly ash, GGBFS and Silica Fume	River Sand	Actigel, Bentonite Sodium lingo sulfonate	KOH & K_2SiO_3	-	To ensure better pumpability, thixotropic value should be more than 10000Nmm rpm.
7	Effect of 3D printing on mechanical properties of fly ash-based inorganic geopolymer	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	FA and Slag	Sand	Anhydrous borax (retarder), sodium carboxy methyl cellulose (VMA)	Combinat ion on of sodium silicate and potassiu m silicate & Sodium hydroxid e & potassiu m hydroxid e	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	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	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	Cement, Fly ash & Silica fume	Sand	Retarder, formed by amino-tris, citric acid and formaldehyde and accelerator, formed by sulphuric,aluminium salt and diethanolamine.	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.
11	Mechanical properties of layered geopolymer structures applicable in concrete 3D printing [69]	Fly ash	Sand	Steel and poly Propylene fibres	NaOH & Na2SiO3	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	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	Mixes with continuous sand gradation possess higher yield stress and lower viscosity in comparison with uniform sand gradation

						interfacial bond.	
13	Fresh properties of a novel 3D printing concrete ink	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.

CONCLUSION:

The development of Geopolymer, a novel ecologically friendly cementitious material, has the potential to lower carbon dioxide emissions brought on by the expansion of the cement industry. The current review examined significant developments in geopolymer technology for the building sector, as well as recent findings and potential future research avenues. Over the past 10 years, this subject has attracted the attention of many academics as a potentially effective substitute for traditional Portland cement-based binders in terms of both technological capabilities and environmental sustainability. According to the growing body of research papers published over the years, industry 4.0 includes additive manufacturing technologies. Significant advancements were made in terms of technological innovation and applicability as well.

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