



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 3, March 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**

9940 572 462

6381 907 438

ijirset@gmail.com

www.ijirset.com

# A Critical Review on the Development of Geo-Polymer Concrete to be used in 3-D Printing Construction Technique

Akshansh Kumar Khare<sup>1</sup>, Kavita Gidwani<sup>2</sup>, Rushikesh D Kamble<sup>3</sup>

M. Tech Green Technology, Energy Centre, MANIT, Bhopal, Madhya Pradesh, India<sup>1</sup>

Assistant Professor, Energy Centre, MANIT, Bhopal, Madhya Pradesh, India<sup>2</sup>

M. Tech Renewable Energy, Energy Centre, MANIT, Bhopal, Madhya Pradesh, India<sup>3</sup>

**ABSTRACT:** Concrete usage around the world is second only after water. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of CO<sub>2</sub> released during the manufacture of OPC due to calcinations of lime stone and combustion of fossil fuel is in order of about one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. In the present context, Geo-polymer cement is the most eligible alternative of OPC because of its advantageous properties over OPC. Geo-polymer is a novel binding material produced by polymeric reaction of alkaline liquid with silicon and aluminium rich materials like fly ash, rice husk, blast-furnace slag, silica fumes etc. It has been found that higher compressive strength is easily achievable in a short period to time in GPC as compared to OPC and has an excellent resistance to acid and sulphate attack when compared to OPC. It can be said that production of geo-polymer concrete has a relative higher strength excellent volume stability and better durability. The development of technologies like 3-d printing (additive manufacturing) on a large volume in the era of industrial revolution 4.0 enables the digitalization in the construction industry. This paper critically reviews the development of Geo-polymer for the 3-D printing process and the impact of using 3-D printing in the construction industry.

**KEYWORDS:** Geo-polymer, Additive Manufacturing, 3-D printing, Construction Industry, Carbon foot-print.

## I. INTRODUCTION

### A. 3-D printing in Construction

3-D Printing is successfully applied in wide range of industries such as aerospace and automotive manufacturing. 3D printing can be divided to three techniques; contour crafting (CC), extrusion and powder printing (Figure 1.1). Structural application of contour crafting was developed by Dr. Behrokh Khoshnevis. [1] However, its application in concrete construction is still in its early stages. Some of the reasons are unsuitability of available automated fabrication technologies for large scale products, limitations in the materials that could be used by an automated system and the economic unattractiveness of expensive automated equipment's. On the other hand, construction industry is facing serious problems [21] such as:

- Accidents rate at construction sites is high;
- Labour efficiency is alarmingly low;
- Work quality is low;
- And controlled construction site is difficult and insufficient and skilled workforce is diminishing.

Worldwide researchers are trying to study and improve 3D printing on concrete, because it is one of the most widely used man-made construction materials on the planet. This technique extrudes the premixed materials through a nozzle to build structural elements layer upon layer based on a computer design without the need of a formwork and produces a laminated structure. It has become more popular in the building industry due to its flexibility in architectural and construction design. [22] In 2004, Professor Behrokh Khoshnevis of the University of South Carolina attempted the

first 3D printed wall. Since then, this innovation has exploded and it's now possible to build a house in just 20 hours! The professor developed an FDM 3D printer, [23] mounted on a robotic arm, that extrudes concrete layers instead of plastic to create a 3D model. This Contour Crafting (Figure 1.4) demonstrated all the qualities needed to use additive manufacturing on construction sites: reduction in costs and waste, faster construction speed, reduction of accidents, complex architectural shapes, and more. His discovery marked the beginning of 3D printing in construction. Some of the known examples of 3D printed projects were executed are the five-story apartment 3D printed by WinSun [2] and the Big Delta [3] project of a castle printed in situ [3] (Figure 2.2 and Figure 2.3). These projects have demonstrated a great potential and feasibility large-scale 3D printing of building components. For this growing innovative technique in the construction field, it is required to develop high performance building materials that are compatible with the 3D printers. Also, there are different types of small-scale 3D printers for laboratory tests and small-scale construction designs. For successful 3D printing, high-quality final properties have to be targeted, further considering that the material needs to successfully go through a 'liquid' stage (fresh material flowing towards and in the print head) and a 'solidification' process (transition to a rigid material supporting self-weight and subsequently added layers). Construction giants are quickly realising the potential of 3D technologies and their impact on the future of construction. The concrete 3D printing market is expected to reach \$56.4m in 2021, and with good reason. More and more companies are starting up in the sector to create new, innovative projects. Some are more futuristic, some are very real in the present, such as Apis Cor's [4] 3D printed house in 24 hours. 3D concrete printing is developing rapidly and relies on different technologies and materials, offering many benefits to its users. The tech is still in its infancy however and is bound by current limitations.

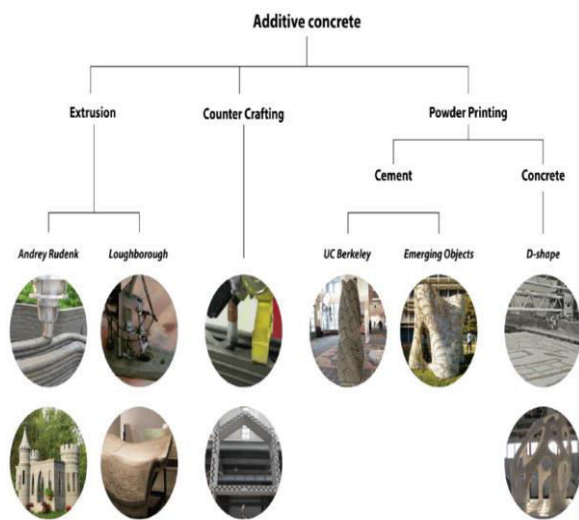


Fig 2.1 Digital Manufactured additive concrete



Fig 2.2 WinSun China build world's first tallest 3D printed apartment building



Fig 2.3 BigDelta project of a 3D printed castle



Fig 2.4 Behrokh's Contour crafting animated demonstration



### B. Geo-Polymer as a Material

The term Geo-polymer was first introduced by Davidovits in 1979 to describe a family of mineral binders that gave a chemical composition similar to zeolites but with an amorphous microstructure. [5] Geo-polymers do not form calcium-silicate hydrates (CSHs) like the OPC to gain its strength but utilize the poly-condensation of silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ) to attain its structural strength. The known binders should be rich in Aluminium (Al), Silicon (Si), such as fly ash (FA) and meta-kaolin (MK). A third known binder is the blast furnace slag (BFS), which is rich in calcium (Ca) and silicon (Si). FA and BFS are known as supplementary cementitious materials (SCM) and are the most common applied cementitious components for concrete. [6] Binders rich in Aluminium and Silicon can only be activated using alkaline solutions. According to Deventer and Provis in 2009 the alkaline activation first started when Purdon demonstrated in 1940 the synthesis of construction materials by alkaline activation of BFS that contains a high amount of calcium. [7] However, Shi et al. (2011) gave this credit to the achievements of the German cement chemist and engineer Kuhl in 1930. [5] [7] In the year 1908 one of Kuhl patent was recognized as the first one that applied alkali activation of alumina-silicate binders in order to obtain an alternative binder material instead of OPC (ordinary Portland cement). Except the work of Glukhovskiy on alkaline cement, not much attention was paid to the field of alkali activation in the last few decades (Table 1.1). According to the research of Davidovits, geopolymers generates around 0.184 tons of  $\text{CO}_2$  per ton of binder. Duxson et al. (2007) stated that the production of disodium oxide ( $\text{Na}_2\text{O}$ ) generates high amount of  $\text{CO}_2$ , whereas the alkaline activated materials generates lower amount of  $\text{CO}_2$  than the production OPC. Based on the work of Duxson and van Deventer in 2009 alkaline activated materials shows 80% reduction in  $\text{CO}_2$  emission compared to OPC [24]

### C. Expected properties of Geo-polymer concrete to be used in 3-D printing technique

In a first stage, the material needs to be fluid, in order to be easily pumped towards the printing unit, and in order to properly compact and fully fill the print volume during the time the concrete is still supported by the print head. However, as soon as the print head is no longer supporting the material, the concrete should be stiff enough. Significant yield stress is needed, in combination with adequate thixotropic [25] behaviour. Well-chosen additions (e.g. clay powders) and admixtures can help to achieve the desired level of thixotropic behaviour, without impairing the high fluidity of fresh concrete while in motion [8]. As soon as the printed concrete is in its final position, the yield stress temporarily provides enough stiffness to ensure shape stability of an individual layer, while the thixotropy should ensure the shape stability of collective layers following in the process of additive manufacturing. However, with increasing number of printed layers, further and speedier increase in stiffness and strength is needed to ensure the shape and buckling stability of the growing structural element. Therefore, the hydration process [26] should proceed soon enough in order to provide a load-bearing internal skeleton of solid hydration products [9,10]. The printed volume should not be prone to shrinkage cracking (plastic shrinkage is of a particular relevance here, since there is no formwork to protect the freshly placed concrete against desiccation). The final result should reach required mechanical properties (including bond to previous layers) and durability performance. The entire 3D printing process should be technically sound and cost-effective, and should be in line with modern environmental considerations. It is note worthy that the rate of printing defines the economic potentials and should be harmoniously controlled, balancing both early strength and ability to avoid cold-joints

## II. RELATED WORK

### A. Experimental work on the development of Geo-polymer

Paul et al. (2017) examined in his work the fresh and hardened properties of 3D printed cementitious materials for building constructions. [19] Three mixture designs were examined on rheological properties, two mixtures contain cement as its binder and one mixture was a geo-polymer mortar mixture, Table-1. The later (Mixture 1) contains fly ash and slag as its binders. To improve the workability and extrudability of Mix 1, Acti-gel as a rheological modifier and bentonite clay were used. Two alkaline solutions, Potassium Silicate ( $\text{K}_2\text{SiO}_3$ ) and Potassium Hydroxide (KOH) were used to activate the binders. The workability of the mortars was examined by means of rheology test (Figure-5 and Figure-6). The plastic viscosity and shear stress were examined by applying the Bingham model for non-Newtonian fluids. The plastic viscosity of mixture 1, shown in Table 6.2, was around 186 Pa.s. Mixture 1 has a higher plastic viscosity than the cement-based mixtures 2 and 3.



Table-1 materials composition for 3D printed concrete [19]

Mix	Materials compositions (kg/m <sup>3</sup> )
Mix 1	Slag: 39, fly ash: 645, silica fume: 78, sand: 1168, actigel: 8, bentonite: 8, water: 47, K <sub>2</sub> SiO <sub>3</sub> : 250, KOH: 23
Mix 2	Cement: 290, fly-ash: 278, silica fume: 145, sand: 1211, water: 285, sodium lignosulfonate: 7
Mix 3	Cement: 289, fly-ash: 277, silica fume: 145, sand: 1209, water: 284, sodium lignosulfonate: 9, glass fiber: 13.5 (density: 2.7, tensile strength: 1.5 N/m <sup>2</sup> , young's modulus: 74 GN/m <sup>2</sup> , failure strain: 2%)

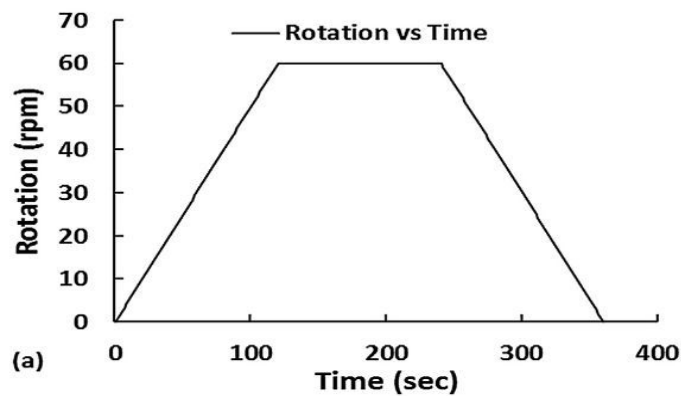


Fig-5 Applied rotation with time for rheology test

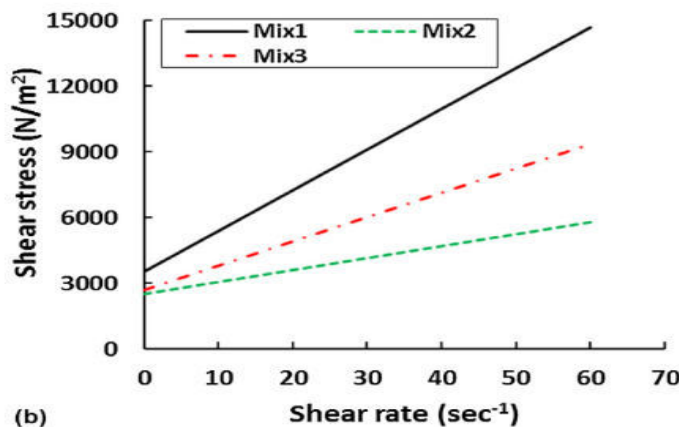


Figure-6 Calculated shears stress and shear rate of the three mortars using the Bingham model

Table-2 Rheological properties of the three mortar mixtures

Mix	Viscomat value				Using calibration coefficients [22]		
	Static yield torque (N mm)	Dynamic yield torque (N mm)	Slope of the curve (N mm/min)	Thixotropy (N mm rpm)	Static yield stress (N/m <sup>2</sup> )	Dynamic yield stress (N/m <sup>2</sup> )	Plastic viscosity (N s/m <sup>2</sup> )
Mix1	1370	358	6.3	11 273	13 522	3534	186
Mix 2	1401	367	4.8	13 756	13 828	3622	144
Mix 3	1763	303	3.8	17 947	17 401	2991	113

### III. METHODOLOGY

Ma et al. (2018) work focused on different testing procedures of cementitious materials containing copper tailings for extrusion-based 3D printing. [20] In the fresh state, the mortar mixtures with different copper tailings are measured on open time, buildability and extrudability. The open time stands for the time interval of the mixture to have good workability/extrudability and printability without disruption of the printed filaments. The extrudability of the fresh mixture is evaluated by the continuity and stability of the filament from a printing nozzle of 8\* 8 mm<sup>2</sup>. There should be no liquid drainage and no blockage of the nozzle during the extrusion process of the fresh mixture.

The results in Figure-7 and Figure-8 show that the structural stability of the printed structures was decreased significantly with the increase of tailing dosage, especially the 30% and 40% of tailing. One of those mixtures was examined on open time test, see Figure-9 and Figure-10. In this test, the width of the filaments was measured every 5 minutes' time interval. The data show that the optimal width of the filaments is obtained after (25- 80) minutes of mixing time and the optimal buildability was between (30-80) minutes. The mixture showed disruption of the filament after 90 minutes of mixing time.

### IV. EXPERIMENTAL RESULTS

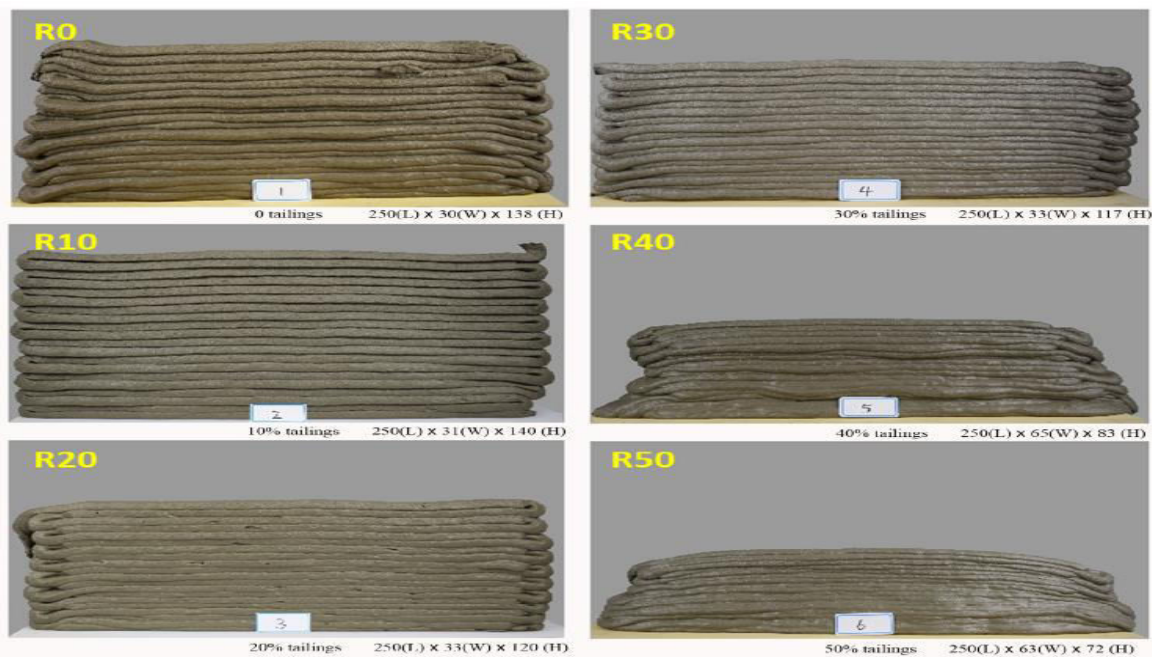


Figure-7 Image of structure built-up with 20 layers of filament in a single process [20]

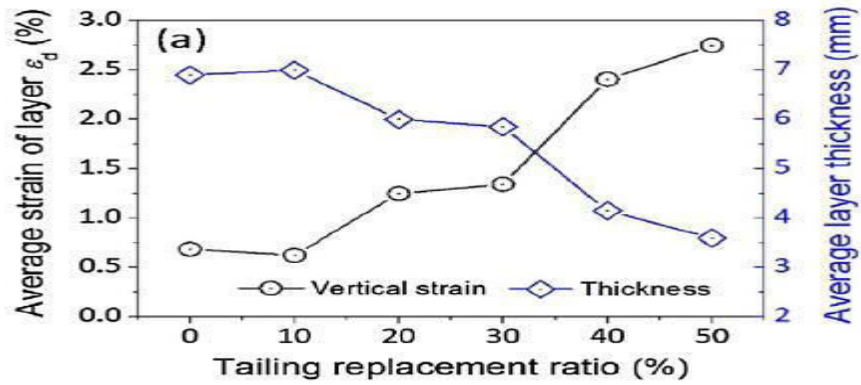


Figure -8 Average vertical strain ( $\epsilon_d$ ) and average layer thickness of the mixtures with different ratios of copper tailing [20]

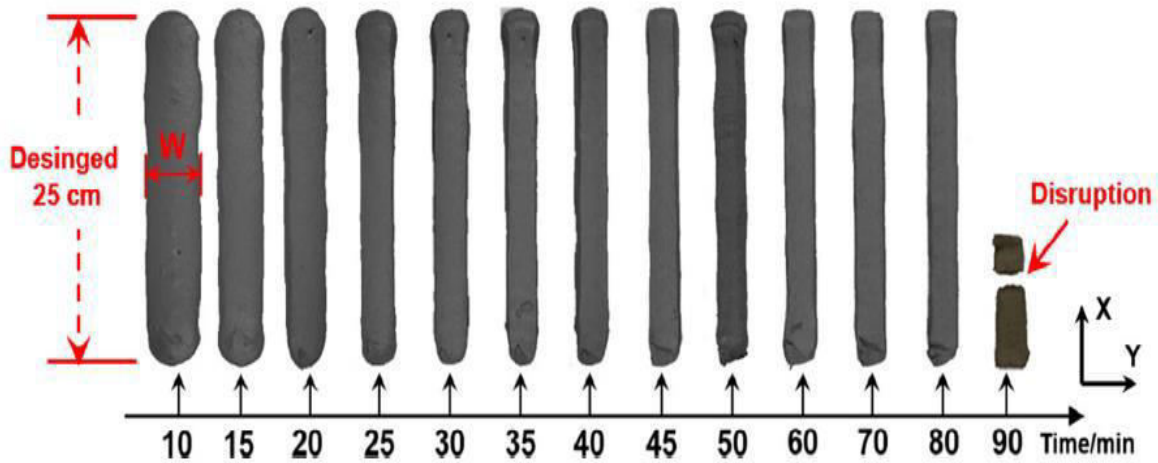


Figure-9 open time of R40 mixture [20]

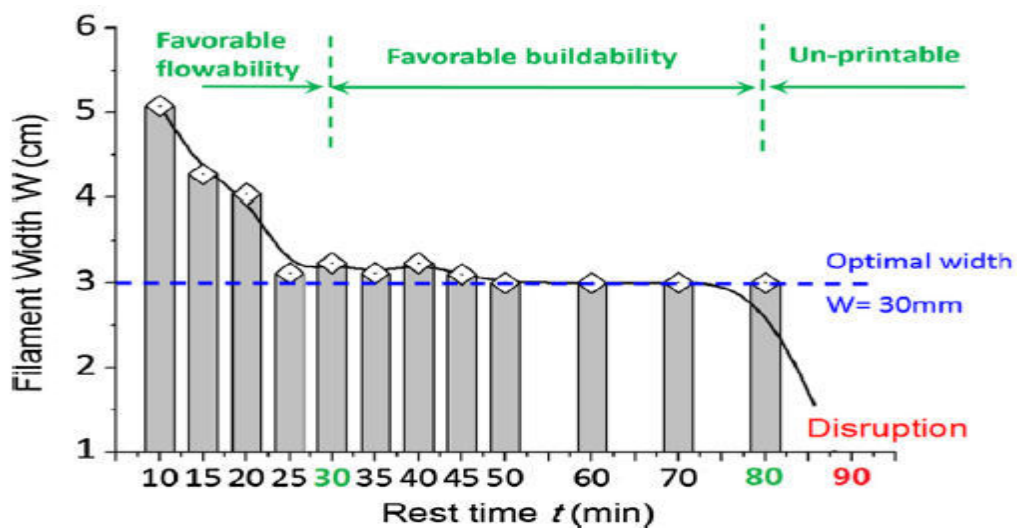


Figure- 10 Open time of R40 mixture [20]

## V. IMPACT OF 3-D PRINTING TECHNIQUE FOR CONSTRUCTION

Advantage- Advantage -The construction sector is responsible for high environmental impacts worldwide, such as 40% energy consumption, 40% solid waste generation, 38% GHG emissions and 12% water depletion [ 20]. Society's increasing concern about sustainability is inducing the emergence of innovative construction processes to overcome the high environmental impacts caused by traditional construction. In particular, additive manufacturing processes have been associated with a cost-effective fabrication that lowers energy use, resource demands and CO<sub>2</sub> emissions over the product life cycle. With the help of this technology, we can do constructions in extreme conditions like hilly areas, underwater constructions naturally destroyed areas etc. The time of construction for a normal house can be reduced to 48 hours only. This technology can be more economical than the conventional one because it eliminates various steps in the construction process. This technology gives the freedom to architecture to design more aesthetic structures that can be built only with 3-D printing (contour crafting). [30]

Disadvantage - The size of the 3D printer is directly related to the scale and size of the printed structural design. Another limitation is the fact that multiple items cannot be simultaneously produced with one 3D printer and for the time being, the costs of buying and setting up a 3D printer is very high. Furthermore, large scale adoption of 3D printing will result in significant job loss. Nonetheless, new technologies almost always end up generating newer jobs.

## VI. CONCLUSION

3-D printing technology for the construction field is growing at a perceptible rate. There are several showcases of 3D printed concrete structures are available worldwide, many challenges remain at the technical and processing level. The range of printable construction materials is very limited at this moment. Currently available high-performance and very durable cement-based materials cannot be directly processed in a printing technique, because of inadequate rheological and stiffening properties. This holds true also for concrete according to the existing design and construction codes. In future, active rheology control (ARC), active stiffening control (ASC) and other novel approaches will provide solutions of extending the material palette for 3D printing applications. Based on the experimental development of geo-polymer discussed in this paper, combination of both types of experimental procedures are quite recommended to be adopted in the testing procedure of the development work, such as testing the rheological properties (plastic viscosity and shear stress) and the open time test of a mixture design. By testing the rheological properties of a mixture, especially the plastic viscosity, with different time intervals and comparing it to the open time test, can give information about the values of the maximum time required for good extrudability. Technology of 3D printing is still young and presents lot of limitations, but there are high expectations and hopes for the future of 3D printed buildings and building components. Versatile applications of 3D printers and the development of new filament materials that could possibly ensure different properties to provide transference, thermal insulation, or strength are under development.

## REFERENCES

- [1] Ma G., Li Z., Wang Li. (2018), 'Printable properties of cementitious material containing copper tailings for extrusion-based 3D printing', *Construction and Building Materials*, vol. 162, pp.613–627.
- [2] Winsun - WinSun China builds world's first 3D printed villa and tallest 3D printed apartment building, Information found from: <http://www.3ders.org/articles/20150118-winsun-builds-world-first-3d-printed-villa-and-tallest-3d-printed-building-in-china.html> (2015).
- [3] WASP, the first adobe building. Information found from: [http://www.wasproject.it/w/en/3d-printers/projects/\(2016\)](http://www.wasproject.it/w/en/3d-printers/projects/(2016)).
- [4] <http://www.apiscoir.com>
- [5] Nedeljkovic M., Arbi K., Zuo Y., Ye G. (2016), 'Microstructural and mineralogical analysis of alkali activated fly-ash- slag pastes', 3rd International Conferences on Microstructure Related Durability of Cementitious Composites: Nanjing, China, RILEM publications S.A.R.L, pp.1-10.
- [6] Nedeljkovi M., Lukovic M., van Breugel K., Hordijk D., Ye G. (2018), 'Development and application of an environmentally friendly ductile alkali-activated composite', *Journal of Cleaner Production*, vol.180, p.524-538.
- [7] Shi C., Fernandez-Jimenez A., Palomo A. (2011), 'New cements for the 21st century: the pursuit of an alternative to Portland cement', *Cement and Concrete Research*, vol.41, pp. 750-763.
- [8] N. Roussel, Rheology challenges in digital fabrication with concrete, *Cem. Concr. Res.* (2018) (this special issue).
- [9] L. Reiter, S. Mantellato, T. Wangler, R.J. Flatt, N. Roussel, *Early Age Structural Build-up*, (2018) (this special issue).





- [10] D. Marchon, S. Mantellato, H. Bessaies, S. Kawashima, Hydration and rheology control of concrete for digital fabrication, *Cem. Concr. Res.* (2018), <https://doi.org/10.1016/j.cemconres.2018.05.014> (this special issue).
- [11] Information found from: [https://en.wikipedia.org/wiki/Coke\\_\(fuel\)#/media/File:Koks\\_Brennstoff.jpg](https://en.wikipedia.org/wiki/Coke_(fuel)#/media/File:Koks_Brennstoff.jpg)
- [12] Tata steel, raw materials. Picture found from: <https://www.tatasteeleurope.com/en/services/specialist/tata-steel-consulting/raw-materials>
- [13] Indiamart, Picture found from: <https://www.indiamart.com/paras-metallurgical/foundry-flux-raw-material.html>
- [14] Provis J.L, van Deventer J.S.J. (2009), 'Geopolymers: Structures, Processing, Properties and Applications, Ed. Woodhead Publishing, 1st edition, University of Melbourne, Australia.
- [15] Garcia-Lodeira I., Palomo A., Fernandez-Jimenez A., '2-An overview of the chemistry of alkali-activated cement-based binders', *Handbook of Alkali-Activated cements, Mortars and Concretes*, pp.19-47.
- [16] Palomo A., Grutzeck M.W., Blanco M.T. (1999), 'Alkali-activated fly ashes—a cement for the future', *Cement and Concrete Research*, vol.29, pp.1323–1329.
- [17] Duxon P., Fernández-Jiménez A., Provis J.L., Lukey G.C., Palomo A., van Deventer J.S.J. (2007), 'Geo-polymer technology: the current state of the art', *Journal of Material Science*, vol. 42, pp. 2917–2933.
- [18] Khale D., Chaudhary R. (2007), 'Mechanism of geo-polymerization and factors influencing its development: a review', *Journal of Material Science*, vol. 42, pp.729–746.
- [19] Paul S.C., Tay Y.W.D., Panda B., Tan M.J. (2017), 'Fresh and hardened properties of 3D printable cementitious materials for building and construction', *Archives of civil and mechanical engineering*, vol.18, pp.311-319.
- [20] Ma G., Li Z., Wanga Li. (2018), 'Printable properties of cementitious material containing copper tailings for extrusion-based 3D printing', *Construction and Building Materials*, vol. 162, pp.613–627.
- [21] <https://www.constructconnect.com/blog/4-major-challenges-facing-the-construction-industry>
- [22] [https://www.designingbuildings.co.uk/wiki/3D\\_printing\\_in\\_construction#:~:text=In%20the%20construction%20industry%2C%203D,to%20print%20entire%20buildings.&text=Construction%203D%20printing%20may%20allow, costs%20and%20producing%20less%20waste.](https://www.designingbuildings.co.uk/wiki/3D_printing_in_construction#:~:text=In%20the%20construction%20industry%2C%203D,to%20print%20entire%20buildings.&text=Construction%203D%20printing%20may%20allow, costs%20and%20producing%20less%20waste.)
- [23] Fabrication of extended-release patient-tailored prednisolone tablets via fused deposition modelling (FDM) 3D printing Author links open overlay panel Justyna Skowryaab Katarzyna Pietrzakac Mohamed A.Alhnana
- [24] <https://www.aboutcivil.org/environmental-impact-opc>
- [25] <https://www.sciencedirect.com/book/9780081006931/science-and-technology-of-concrete-admixtures>
- [26] <https://www.engr.psu.edu/ce/courses/ce584/concrete/library/construction/curing/Hydration.htm>
- [27] <https://www.thermofisher.com/blog/mining/the-cement-manufacturing-process/#:~:text=Cement%20manufacturing%20is%20a%20complex,C%20in%20a%20cement%20kiln.>
- [28] Pozzolanas and Pozzolanic Materials Michael John McCarthy, Thomas Daniel Dyer, n Lea's Chemistry of Cement and Concrete (Fifth Edition), 2019 17,066 Reads with [29] Overview of different type of fly ash and their use as a building and construction material. January 2011 Conference: international Conference of Structural Engineering, Construction and Management, At Kandy, Sri Lanka.
- [30] <https://www.sculpteo.com/en/3d-learning-hub/applications-of-3d-printing/construction-and-architecture/#:~:text=The%20main%20advantage%20of%20using,amount%20of%20material%20they%20need.>
- [31] <https://www.twi-global.com/technical-knowledge/faqs/what-is-3d-printing/pros-and-cons>



**Impact Factor:  
7.512**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  [ijirset@gmail.com](mailto:ijirset@gmail.com)



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details