Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 3 (2023)

Design and Development of 3 Axis 3D Printing of Sustainable Concrete Structures and Characterization of Affordable Housing Solutions

[1]Atul Ramdas Kolhe , [2]Pravin Gorde, [3]Shubham Eknath Chandgude, [4]Jivan Khachane, [5]Vishal Swami, [6]Prashant Sunagar

[1]Associate Professor, Civil Engineering Department, Dr D Y Patil Institute of Engineering Management and Research Akurdi Pune, Affiliated by SPPU
[2]Associate Professor, Civil Engineering Department, Dr D Y Patil Institute of Engineering Management and Research Akurdi Pune, Affiliated by SPPU
[3]Assistant Professor, Civil Engineering Department, Dr D Y Patil Institute of Engineering Management and Research Akurdi Pune, Affiliated by SPPU
[4]General Manager, Airborne Industries Llp, Pune
[5]Assistant Professor, Dr.D.Y.Patil Institute of Engineering Management and Reserch Akurdi pune, Affiliated by SPPU
[6]Assistant Professor, Department of Civil Engineering, Ramaiah Institute of Technology, Mathikere, Bangalore-560054

Abstract: The construction sector is one of the top industries worldwide with about 13% of global industrial expenses but has a very low productivity of only about 1% of annual growth in productivity. The low productivity in the construction industry results in high costs of production. 3D printing of concrete is an evolving technology which utilizes digital and material technology to allow free-form construction without the use of formwork. 3D printing of concrete can significantly reduce the construction time and cost. The aim of this study is to determine the optimum mix for printable concrete with pumpability, extrudability, buildability and shape retention characteristics and print it using a 3D printer capable of extruding concrete in 3 different axes.

1. Introduction

Concrete is one of the most important materials in the construction industry [1]. Concrete offers formability, heat resistance and durability at low production costs. Concrete looks simple, but it has many hidden problems. A construction site is where concrete is transported, pumped, compacted, and hardened using traditional methods [2] [5]. It has been observed that a formwork accounts for about 30 - 40% of the total cost of construction and the cost of the formwork will be increased if the building design is more complex [3] [4]. Also, this formwork would be discarded after using it for several times, this adds to the production and management of the waste produced from the construction sites [5] [7].

The construction industry can account for about 13% of industrial expenses globally [10] [12]. But it has a very low productivity of only about 1% of annual growth in productivity. Construction sector has a habit of low productivity and underdeveloped in technological capabilities, while other industries have mechanized their manufacturing processes [13] [14]. The low productivity in the construction industry results in high costs of production.

Concrete 3D printing is a new technology that uses digital and material technologies to create freeform shapes without the use of formwork [16] [18]. However, in a conventional method of construction, concrete [15] [16] is poured into the Mold. Concrete 3D printing technology, also known as additive [17] [18] manufacturing technology, is a technology that creates structures by adding materials successively layer by layer.

1.1 3D Printing in Construction Industry

3D printing is a layered manufacturing process that applies materials layer by layer [20]. To facilitate easy extrusion of material through the nozzle, the material nozzle must be flowable so that the nozzle is not chocked. When the layer is extruded from the die, it must be strong enough to withstand its self-weight and the deformation due to the weight of the layer printed above it.

From a rheological point of view, the materials used for 3D printing should act like low viscosity liquid inside pumps and nozzles. It must be strong enough to withstand the deformation and harden after it is being printed. Silica fume is a nanomaterial added to concrete to gain strength.

Characteristics of 3D printable concrete

1. Pumpability
2. Extrudability
3. Buildability
4. Strength

    1. **Pumpability** - It is known as the ability of concrete to flow through pressurized pipes while retaining the original characteristics of concrete. Thus, when concrete is pumped, if spaces or voids between aggregates are not filled with mortar, or if the mortar is too thin and runny, pump pressures cause segregation, forcing water through the mix.
    2. **Extrudability** - Extrusion is the process of forcing a concrete paste through a nozzle to a high shear force, resulting in the liquid behaviour of the concrete. Higher flow-ability, up to certain limit, results in easier extrude-ability and vice versa.
    3. **Buildability** - Buildability is the ability of a deposited material bulk to maintain its dimensions under increasing load. This is an inherent prerequisite for formwork free digital concrete construction.
    4. **Strength** - The strength of concrete its ability to resist compressive loads to which it is subjected. Stiff concretes are stronger, more watertight, and more resistant to weathering compared to flowable concrete.

2. Literature Review

Yiwei Weng et al. (2021): They worked on a system in which concrete and bonding agent are applied simultaneously through a nozzle. The results showed that, if the time between printing the layers is 40 minutes, the bond strength of specimen with a small amount of cement paste as the bonding agent is 2.67 times more than the bond strength of specimen without bonding agent. **Manu Santhanam et al. (2020)**: Researchers have focused their study on the development of extrusion-based 3D printing technology for concrete. This paper describes the development of 3D printable concrete based on Portland cement. Based on the test results, it was concluded that a yield stress in the range of 1.5 to 2.5 kPa is required to achieve extrudability and buildability. If the yield point is below the range, the mixture becomes flowable and is not buildable. Mixtures with yield strengths beyond this range are stiff and not extrudable. **Karthick Manikandan et al. (2020):** In this article, fresh cementitious mixtures with different amounts of silica fume and superplasticizer were considered based on the rheological properties of 3D printable concrete. The print area was 20 cm x 20 cm x 20 cm. Of all mixtures, the optimal mix composition was cement-97.5%, silica fume-2.5% and superplasticizer-1.5%. The optimum mix slowly recuperates the yield strength and does not affect the underlying layer during printing.

Yu Zhang et al. (2019): This study deals with the rheological and hardened properties of high thixotropic 3D printable concrete. Five mixtures with sand/cement ratios of 0.6 to 1.5 were tested to obtain the optimum mixture suitable for 3D printing.

The hardened properties such as anisotropy (compression and bending), elastic modulus, and drying shrinkage were investigated. The test results show that as the S/C ratio increases, the viscosity and yield strength increase, but the thixotropy decreases. The compressive strength and flexural strength in the z-axis loading direction were higher than those of the y-axis and x-axis. Flexural strength was reduced when concrete was stiff due to voids between layers and poor adhesion between layers of printed concrete. **A.V. Rahul et al. (2019):** They worked on a concrete mix design that was based on the yield strength and could be printed on a 3D printer. The moldability, extrudability and strength of the mixture were found. It was found that mixtures with a yield stress in the range of 1.5 to 2.5 kPa were workable. Mixture with Portland cement and fly ash lacked stability and robustness and printable only for 15 min. The addition of Nano clay, SF and VMA increases the robustness, buildability, and yield stress of the mixture. 3D printable concrete that contained SF, NC and

VMA were printable for 30, 30 and 45 minutes, respectively. **Yu Zhang et al. (2018):** Their research focused on the development of 3D printable concrete inks that has good fluidity during movement. Cement paste is altered by adding nano clay (NC) and silica fume (SF). The results showed that the thixotropy, green strength of concrete and the buildability of concrete increased with the addition of nano clay and silica fume. **Geert De Schutter et al. (2018):** In this research journal, 3D printing of concrete is studied from a technical, economic, and environmental point of view. The range of building materials for 3D printing is very limited. 3D printed concrete structures reduce labour, material, and machinery costs; reduce material waste and lower construction costs compared to conventional construction methods.

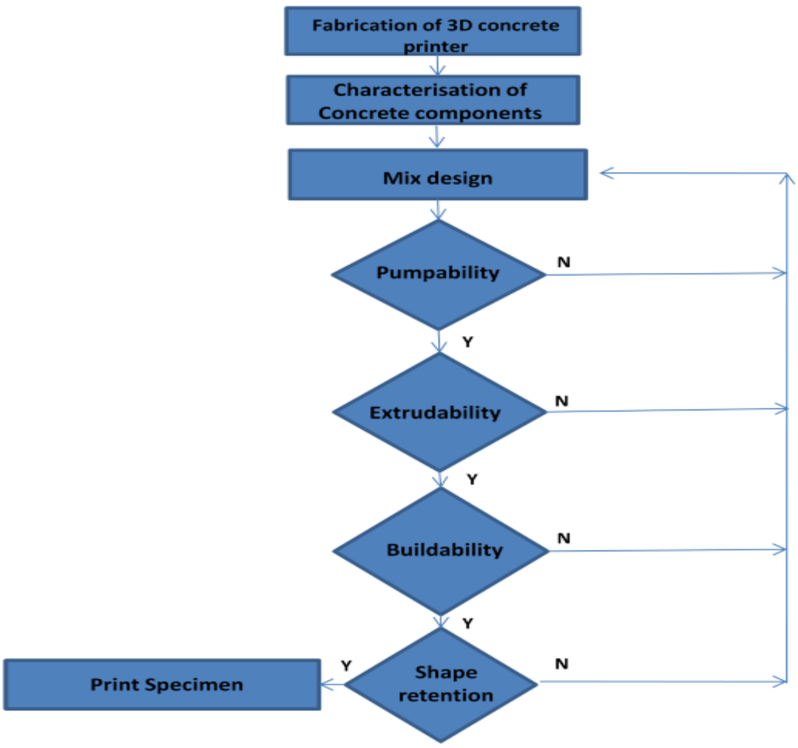
3. Objectives

1. Fabrication of a 3D printer which is capable of extruding concrete in 3 different axes through a nozzle effectively.
2. To develop an optimal concrete mix design suitable for 3D printable concrete using silica fume and nano clay.
3. To build a prototype of a typical vertical wall panel using 3D concrete printer.
4. To achieve a concrete mix which can provide maximal buildability upon pouring of concrete and to maximize the flowability of the concrete mix to ensure the nozzle doesn't get choked.

4. Methodology

The key objective of this study is to arrive at an optimum mix design for 3D printable concrete which has pumpability, extrudability, buildability and shape retention by use of nano materials (silica fume) [21].

Various materials required for preparing 3D printable concrete are characterised and their physical properties are determined [22]. Cement, Silica Fume, Superplasticizer, fine aggregates, and Water are the ingredients required. Basic tests are performed on cement and fine aggregates to assess their quality [22]. Cement is tested for its specific gravity and fineness. Fine aggregates are tested for their specific gravity and fineness modulus [24]. Incorporating Silica fume into the mix helps in immediate shape retention after the concrete is printed and gaining of strength [25].



Flow Chart 1- Methodology

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 3 (2023)

The workability of the 3D printable concrete is checked using mini flow table test. The optimum mix should be flowable enough so that the nozzle doesn't get chocked. Mini flow table test is conducted for mixes with varying superplasticizer dosage. The optimum dosage of the superplasticizer for a workable concrete can be obtained [23].

Buildability and extrudability are the main characteristics of 3D printable concrete [27]. This can be tested using a laboratory vane shear apparatus. Vane shear test is done on the workable mixes to determine their yield strength. Yield strength of concrete gives an idea about the buildability and extrudability of the mix [28]. If the mix is too flowable with low yield strength, it is not buildable; and if the mix is very stiff, it is difficult to be extruded.

The prototype model of a 3D printer is fabricated using aluminium box section which can move and print in 3different axes. The obtained optimum mix is printed and tested for buildability, extrudability and shape retention.

4.1 Workability test on Printable Concrete

The 3D printable concrete should be flowable enough so that the nozzle doesn't get chocked. If the mix is too flowable with very high flow%, the buildability is affected. And if the mix is stiff, extruding the 3D printable concrete from the nozzle is difficult. Hence an optimum mix design it to be attained which has good workability, buildability and extrudability. The mini flow table test gives an idea about the workability of the mortar mix. The optimum mix is obtained by conducting mini flow table for mixes with varying superplasticizer dosage hence determining the optimum dosage of the superplasticizer.

Mini flow table apparatus

Filling the mould with mortar

Spread of mortar after flow test

Measuring the spread of the mortar

Table 1: Average Spread for different superplasticizer dosages

Sl No.	Superplasticizer Dosage (%)	Average Spread (cm)		
		Trial 1	Trial 2	Average
1	0.50%	11	10.6	10.8
2	0.75%	13.43	13.58	13.505
3	1.00%	15.5	15.3	15.4
4	1.25%	17.86	18.5	18.18
5	1.50%	21.3	20.7	21
6	1.75%	20.1	20.6	20.35
7	2.00%	19.4	20.2	19.8

Table 2: Flow value for different superplasticizer dosages

Sl No.	Superplasticizer Dosage (%)	Average Spread, D (cm)	Flow (%)
1	0.50%	10.8	8
2	0.75%	13.505	35.05
3	1.00%	15.4	54
4	1.25%	18.18	81.8
5	1.50%	21	110
6	1.75%	20.35	103.5
7	2.00%	19.8	98

From the results for a superplasticizer dosage of 1.5%, the flow value obtained is about 110%. For a 3D printable concrete, the flow value should be in the range of 110-115%. The combination of 97.5% cement, 2.5% silica fume and 1.5% superplasticizer with water/cement ratio of 0.3 is workable.

Yield Strength of Printable concrete

Mix proportion = 97.5% Cement + 2.5% Silica Fume with varying percentage of Superplasticizer (1.25%, 1.5%, 1.75%, 2%)

Table 3: Maximum torque applied.

Sl No.	Superplasticizer Dosage (%)	Difference in Degrees (^{0})			Torgue (kg-cm)
		Trial 1	Trial 2	Average	
1	1.25	5	5.5	5.25	0.116667
2	1.5	4.5	4	4.25	0.094444
3	1.75	2.5	3	2.75	0.061111
4	2	2	2	2	0.044444

Table 4: Yield stress for various mixes

Sl No.	Superplasticizer Dosage (%)	Torgue (kg-cm)	Yield Stress (kg/cm2)	Yield Stress (kPa)
1	1.25	0.116667	0.0287	2.8124
2	**1.5**	**0.094444**	**0.0232**	**2.2767**
3	1.75	0.061111	0.0150	1.4732
4	2	0.044444	0.0109	1.0714

From the results it is incurred that for superplasticizer dosage 1.5%, the yield stress obtained is about 2.27kPa. For the mortar to have buildability and strength, the yield stress should be between 1.5-2.5kPa. When the yield stress is less than this range, the mix becomes flowable and is not buildable. Mixes with yield stress greater than this range, the mix is stiff and not extrudable. Therefore, the mix with 97.5%cement + 2.5% silica fume + 1.5% superplasticizer and 0.3 water cement ratio is optimum.

4.2 Fabrication of 3D Printer

3D printing using cement on a large scale offers a revolutionary alternative to traditional moulding techniques. Instead of relying on manual placement and moulds, this method uses a computer-aided manufacturing process to place or solidify specific amounts of material layer by layer with precision. This approach can be broadly categorized into three main phases: data configuration, concrete mixture formulation, and the actual component printing.

Designing an efficient machine that can serve as a 3D printer tailored for the concrete mixture is fundamental to ensuring the project's success. The design process isn't straightforward; it demands careful consideration of numerous factors. For one, the printer must meet certain criteria, ensuring it's capable of handling the unique challenges presented by concrete printing. Furthermore, the selection of materials used in the printer's construction is vital. These materials should adhere to specific standards to ensure both the machine's longevity and the quality of its output. In essence, each step of the process, from the initial data preparation to the final printing, is instrumental in achieving the desired results, and careful planning is paramount.

4.3 Materials and Specifications

Aluminium hollow section 1.5-inch thickness (1m cut down for vertical support of the frame, 1.2m cut down for horizontal support of the frame).
L-Shape angles 1.5-inch thickness for joining horizontal and vertical supports.
1-inch screws for locking joints.
Threaded rods 4start 2mm pitch 8mm diameter with length of 1metre.
Brass T-nuts for y-axis lifting.
Nema-17 stepper motors for movement along the planes.
Limit switches to act as boundaries for printable area.
Couplers to connect threaded rods and motors.
Arduino Mega to act as a controller unit.
25amps 12V SMPS for the constant power supply.
RAMPS 1.4 for act as the motor driver.
GT2 belt with 2mm pitch
2mm pitch pulleys and linear rails for movement along the plain.
6200 circular bearings for planar movement support.

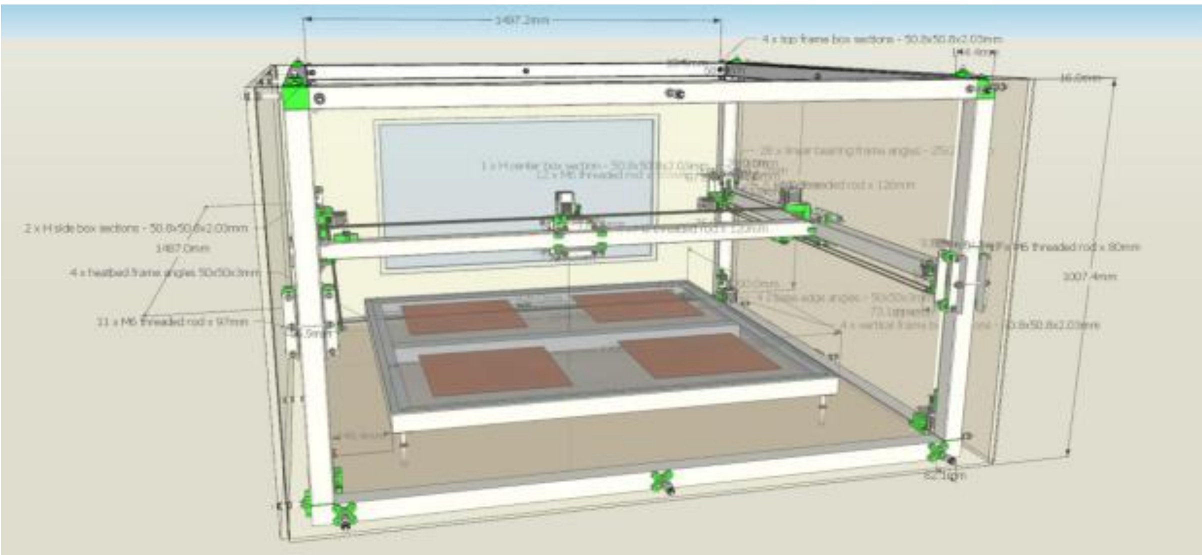


Fig 1: Front Profile Sketch-Up Model

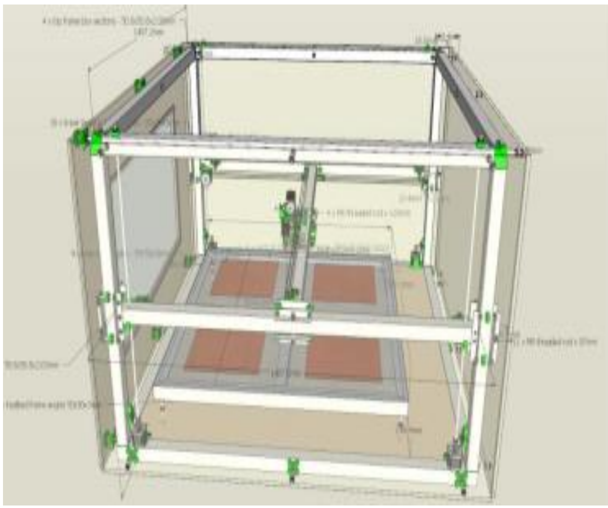


Fig 2: Side Profile Sketch-Up Model

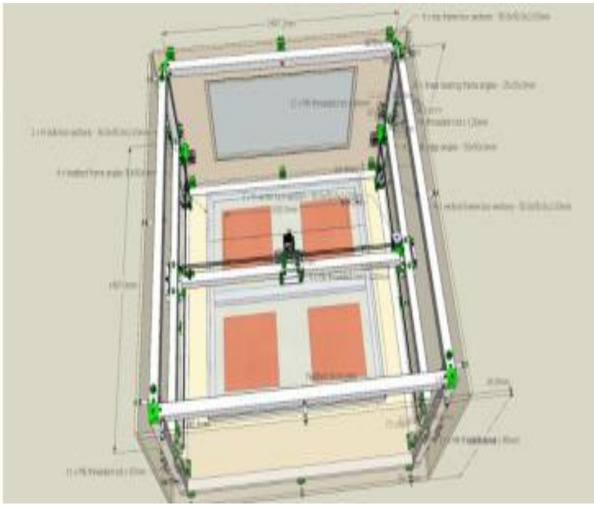


Fig 3: Top Profile Sketch-Up Model

Fig 4: Front view of the model

4.4 Printing of a wall panel

1. The raw materials i.e., cement, silica fume, superplasticizer and fine aggregates are weighed according to the optimum mix obtained (97.5% cement + 2.5% silica fume +
2. 1.5% superplasticizer with w/c ratio of 0.3). The materials are mixed to obtain a homogenous mixture.
3. The 3D printable concrete is then pumped into the nozzle.
4. A rotating auger is fitted into the nozzle to prevent setting of the mixture in the nozzle.
5. The concrete is extruded from the nozzle and then printed layer by layer according to the dimensions of the component to be printed.

Therefore, the mix with 97.5%cement + 2.5% silica fume + 1.5% superplasticizer and 0.3 water cement ratio is optimum.

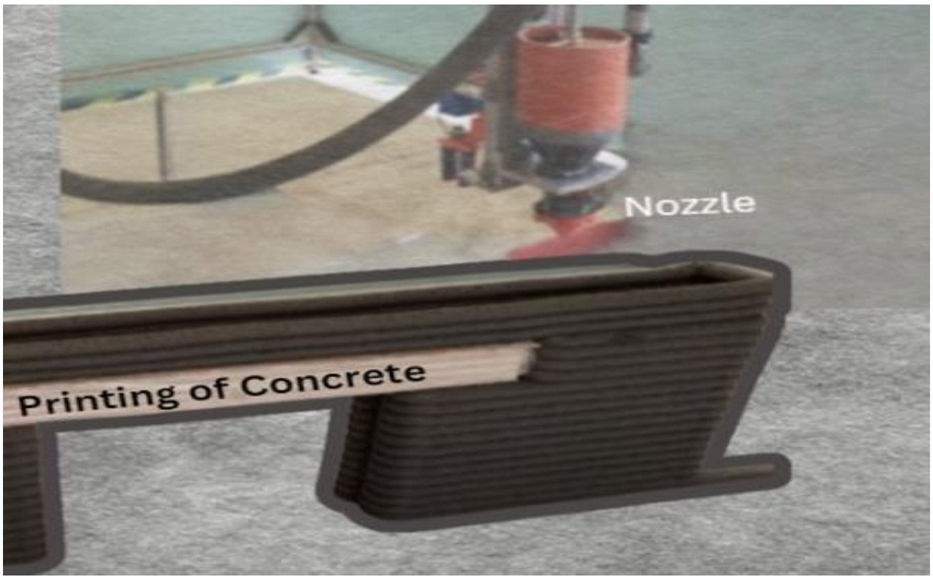


Fig 5: 3D Printed wall up to lintel.

`

5. Conclusions

1. The specific gravity and fineness of cement is obtained as 3.15 and 4% respectively. The specific gravity and fineness modulus of the fine aggregates used are found to be about 2.65 and 3.06 respectively. The values obtained are within the standard range.
2. 2. Mini flow table test is conducted on mixes with varying superplasticizer dosages. The flow value obtained for 1.5% superplasticizer dosage is about 110%. For the 3D printable concrete to be workable and to have fluidity, the flow value should be between 100 – 115%. The obtained flow value for 1.5% superplasticizer dosage is well within the desired range.
3. 3. Vane shear test is conducted on workable mixes of mortar to determine their yield strength. The yield strength of the mix with 1.5% superplasticizer dosage is obtained as 2.27kPa. For buildability and extrudability of the 3D printable concrete from the nozzle without getting chocked, the yield strength should be in the range of 1.5 – 2.5 kPa. The obtained value of yield strength for 1.5% superplasticizer dosage is well within the desired range.
4. Hence the optimum mix design of 3D printable concrete is 97.5% cement + 2.5% silica fume + 1.5% superplasticizer. A ratio cement: fine aggregate of 1:1.5 and water: cement ratio of 0.3 may be considered desirable with 2.5% of silica fume and 1.5% superplasticizer of the cement content for 3D printing.
5. 3D printing of structures is a promising technology which can provide cost effective construction of houses. It reduces the labour cost and the cost of formwork. The rate of construction in 3D printing technology is fast, hence construction time is saved.

6. 3D printing technology can be used in construction of large number of houses within a short period of time. It can be used in PMAY (Pradhan Mantri Awas Yojana – housing for all mission by the Indian government) where 2 crore houses are to be built by year 2022. 3D printing technology can also be utilized in construction of affordable houses for the people who have lost their homes due to natural calamities.

References

[1] Bos, F., Wolfs, R., Ahmed, Z., &Salet, T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing. Virtual And Physical Prototyping, 11(3), 209-225. doi: 10.1080/17452759.2016.1209867

[2] Cementitious materials for construction scale 3D printing :Laboratory testing of fresh printing mixture, Ali Kazemian,XiaoYuan,EvanCochran,Behrokh KhoshneivsA18. Large- scale 3D printing of ultra-high-performance concrete – a new processing route for architects and builders. C. Gosselin, R. Duballet, Ph. Roux, N. Gaudillière, J. Dirrenberger, Ph. Morel

[3] Zhang, Y., Zhang, Y., She, W., Yang, L., Liu, G. and Yang, Y., 2019. Rheological and harden properties of the high-thixotropy 3D printing concrete. Construction and Building Materials, 201, pp.278-285. Contour Crafting Inventor Dr. Khoshnevis: Widespread 3D Printed Homes in 5 Years, High-Rises in 10 Years - 3DPrint.com | The Voice of 3D Printing.

[4] Tay, Y., Panda, B., Paul, S., Noor Mohamed, N., Tan, M. and Leong, K., 2017. 3D printing trends in the building and construction industry: a review. Virtual and Physical Prototyping, 12(3), pp. 261-276. Frearson A. DUS Architects builds 3D-printed micro home in Amsterdam [Internet]. Dezeen. 2019 [cited 5 November 2019]. Available from: https://www.dezeen.com/2016/08/30/dus-architects-3d-printed-micro-home-amsterdam- cabin-bathtub

[5] G. Heirman ,Modelling and Quantification of the effect of mineral Additions on the Rheology of Fresh Powder Tupe Self-compacting Concrete,2011.

[6] Kumar, R., Gous, M. Z., Surakasi, R., Raghuram, K. S., Sunagar, P., Kumar, N. S. (2022). Investigation of Curing Mechanism and Mechanical Properties of Polypropylene/Aliphatic Epoxy Composites. Advances in Polymer Technology, 2022.

[7] Raman, V. V., Kumar, P. S., Sunagar, P., Bommanna, K., Vezhavendhan, R., Bhattacharya, S. (2022). Investigation on Mechanical Properties of Bamboo and Coconut Fiber with Epoxy Hybrid Polymer Composite. Advances in Polymer Technology, 2022.

[8] Sunagar, P., Hemavathy, S., Nagashree, B., Jayakumar, M., & Sumalatha, J. (2021). Experimental Investigation On Properties Of Concrete Using Lime Sludge As Partial Replacement. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 14949-14962.

[9] Santosh, D., & Sunagar, P. (2021). Utilization Of Paper Industry Residue For Producing Supplementary Cementation Material In Concrete-Based On Experimental Investigation. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 14963-14973.

[10] Vinod, B. R., Kumari, T. G., Santhosh, D., & Nayak, P. S. S. G. (2021). Improvement of Loose Red soft soils using Aluminium foil encased stone columns. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 5134-5145.

[11] Sunagar, P., Vinod, B. R., Nayak, S. G., Mahesh Kumar, C. L., Shwetha, K. G., Sumalatha, J., & Shreedhar, K. R. (2021). Investigation of Waste Paper Cellulosic Fibers Utilization into Cement Based Building Materials. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3076-3087.

[12] Vinod, B. R., Sumalatha, J., Jyothilakshmi, R., Sunagar, P., CL, M. K., & Shwetha, K. G. (2021). Enhancing the Index and Engineering Properties of Urban Fills by Stabilizing with Cement, Lime and Bagasse Ash. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3101-3113.

[13] Sunagar, P., Sumalatha, J., Mahesh Kumar, C. L., Shwetha, K. G., Sanjith, J., & Kiran, B. M. (2021). Strength and Durability Behaviour of Fly Ash Based Geopolymer Concrete in Structural Applications. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3088-3100.

[14] Sunagar, P., Kumari, T. G., Jyothilakshmi, R., Mahesh Kumar, C. L., Shwetha, K. G., Sumalatha, J., & Naveen, G. M. (2021). Sustainable Medium Strength Geopolymer with Fly Ash and GGBS as Source Materials. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3114-3124.

[15] Nayak, S. G., Mahesh Kumar, C. L., Sunagar, P., Shwetha, K. G., Sanjith, J., Sumalatha, J., & Kiran, B. M. (2021). Use of Fly Ash and GGBS wıth Alkalıne Solution based Geopolymer. NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, 3125-3134.

[16] Studies on Influence of Feldspar Activator on Slag Based Geo Polymer Concrete, Nagashree B, Prashant Sunagar, Raje Gowda, International Journal of Civil Engineering and Technology (IJCIET), Volume 11, Issue 6, June 2020, pp. 53-61, Article ID: IJCIET_11_06_007 ISSN Print: 0976-6308 and ISSN Online: 0976-6316

[17] V Sai Neeraja, Vinayak Mishra, C. Pramukh Ganapathy, Prashant Sunagar, D. Pavan Kumar, Lukesh Parida, Investigating the reliability of nano-concrete at different content of anano-filler, Materials Today: Proceedings,2022, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2022.08.184.(https://www.sciencedirect.com/science/article/pii/S2214785322053512)

[18] Investigating Conventional Concrete using Rice Husk Ash (RHA) as a Substitute for Finer Aggregate Suganya Natarajan1, Syed Hamim Jeelani2, Prashant Sunagar3, Sushilkumar Magade4, Sahil Sanjeev Salvi5 and Sumanta Bhattacharya Published by IOP Publishing Ltd. Journal of Physics: Conference Series, Volume 2272, International Conference on Design, Manufacturing and Materials Engineering - ICDMME 2021 10/03/2022 - 11/03/2022 Coimbatore, India

[19] Dharek, M. S., Vengala, J., Sunagar, P., Sreekeshava, K. S., Kilabanur, P., & Thejaswi, P. (2022). Biocomposites and Their Applications in Civil Engineering—An Overview. Smart Technologies for Energy, Environment and Sustainable Development, Vol 1, 151-165.

[20] Dharek, M. S., Sunagar, P., Sreekeshava, K. S., Nagashree, B., Thejaswi, P., Kilabanur, P., ... & Satish Chandra, C. (2021). Experimental investigations on strength performance of the brick produced by blending demolished waste with pozzolanic materials. In Advances in Sustainable Construction Materials (pp. 573-583). Springer, Singapore.

[21] Nair, Avinash, S. D. Aditya, R. N. Adarsh, M. Nandan, Manish S. Dharek, B. M. Sreedhara, Sunagar C. Prashant, and K. S. Sreekeshava. "Additive Manufacturing of Concrete: Challenges and opportunities." In IOP Conference Series: Materials Science and Engineering, vol. 814, no. 1, p. 012022. IOP Publishing, 2020.

[22] Dharek, M. S., Sunagar, P., Harish, K., Sreekeshava, K. S., & Naveen, S. U. (2020). Performance of Self-flowing Concrete Incorporated with Alumina Silicates Subjected to Elevated Temperature. In Advances in Structural Engineering (pp. 111-120). Springer, Singapore.

[23] Dharek, Manish S., Prashant Sunagar, K. V. Bhanu Tej, and S. U. Naveen. "Fresh and hardened properties of self-consolidating concrete incorporating alumina silicates." In Sustainable Construction and Building Materials, pp. 697-706. Springer, Singapore, 2019.

[24] Progressive Collapse Analysis of T shape RCC Building, Prashant Sunagar1, Shivaraj G Nayak2, T G Geethakumari1,by IOP Conference Series: Earth and Environmental Science, Volume 1125, 2nd International Conference on Sustainable Infrastructure with Smart Technology for Energy and Environmental Management (SIC-SISTEEM 2022) 24/03/2022 - 26/03/2022

[25] Jolin M., Chapdelaine F., Burns D., Gagnon F., BaupréD.(2006) Pumping concrete; a fundamental and practical approach, presentation Shotcrete for underground support X, Sept.12-16 (2006) 9 p.

[26] Jolin, Marc & Burns, Dennis & Bissonnette, Benoît & Gagnon, Frédéric & Bolduc, Louis- Samuel. (2009). UNDERSTANDING THE PUMPABILITY OF CONCRETE.

[27] Kawashima, S., Chaouche, M., Corr, D., & Shah, S. (2013). Rate of thixotropic rebuilding of cement pastes modified with highly purified attapulgite clays. Cement And Concrete Research, 53, 112-118. doi: 10.1016/j.cemconres.2013.05.019

[28] Le, T., Austin, S., Lim, S., Buswell, R., Law, R., Gibb, A., & Thorpe, T. (2012). Hardened properties of high-performance printing concrete. Cement And Concrete Research, 42(3), 558-566. doi: 10.1016/j.cemconres.2011.12.003