3D CONCRETE PRINTING…" An automation in construction industry for affordable and sustainable houses''

Prof. Hansraj Dikkar[1], Prof. Ravindra Patil[1], Apeksha Gaikar[2], Veena Aher[2], Pooja Kakad[2], Shweta Borade[2]

[1]Assistant Professor, Sandip Institute of Engineering and Management, Sandip Foundation, Nashik
[2]Student of Bachelor of Engineering, Department of Civil Engineering, Sandip Institute of Engineering and Management, Nashik, Maharashtra, India-422213

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Abstract - *The aim of this project is to assess the feasibility of using fresh concrete as a material for additive manufacturing, specifically in 3D concrete printing. 3D concrete printing is an innovative construction method that offers several advantages in terms of construction time, cost optimization, design flexibility, error reduction, and environmental considerations. The quality of the final printed structure depends significantly on the properties of the fresh concrete, which should possess adequate workability to be extruded through an extruder head (printability) and maintain its shape once deposited without collapsing under subsequent loads (buildability). Due to the unavailability of a 3D concrete printer, physical printing was not possible. However, using readily available plumbing materials, a nozzle was constructed, and beams were printed to simulate the process. In this project, seven different concrete mixes were designed, varying the water-cement ratio and the percentage of superplasticizer. The workability of the fresh concrete used in additive manufacturing was evaluated through slump cone tests. Furthermore, tests were conducted to assess the compressive strength and flexural strength of the hardened concrete. Additionally, this research provides an overview of 3D printing and demonstrates the process of modelling a 3D building using AutoCAD software. The building design was converted from .DWG to. stl format for compatibility with 3D printing. To showcase the 3D printing process, a 1BHK plan was designed and 3D printed using FDM technology.*

***Key Words:* *3D concrete printing*, concrete, Additive manufacturing, 3DCP, construction, Affordable houses, automation in construction.**

1. INTRODUCTION

The manufacturing method known as "Additive Manufacturing" or 3D printing is characterized by the addition of material in successive patterns to create the desired shape, in contrast to traditional manufacturing techniques that involve removing material from a preformed block (known as "Subtractive Manufacturing"). In 3D printing, specialized software slices the 3D model into thin layers, typically 0.01mm thick or even thinner. The printer then traces each layer onto the build plate, and once a layer is completed, the next layer is added on top of the previous one, gradually building the final object.

Unlike subtractive manufacturing methods such as milling and cutting, which generate a significant amount of waste as the excess material is typically discarded as scrap, 3D printing significantly reduces waste. This is because in 3D printing, material is only placed in the specific locations where it is needed to form the object, leaving the rest of the space as empty or support material, minimizing unnecessary waste.

By utilizing additive manufacturing techniques, 3D printing offers several advantages, including reduced material waste, more efficient material usage, and the ability to create complex geometries and intricate designs that may be difficult or impractical to achieve through traditional manufacturing methods.

According to a July 2021 report by Grand View Research, the Global 3D construction market is projected to experience remarkable growth of 91% between 2021 and 2028. This growth indicates the increasing recognition of 3D printing as a potential solution to the challenges faced by the architecture, engineering, and construction industries.

One of the significant advantages of 3D printing in construction is its potential to provide affordable housing and shelters in disaster-stricken regions where traditional construction methods may be limited due to a lack of available human resources. Additionally, the technology has the potential for future research in establishing colonies on the moon and other extraterrestrial settlements.

Lower construction costs and time are among the main benefits of 3D printing in construction. The ability to accurately calculate the required volume of construction material reduces waste and enhances cost efficiency. Moreover, the rapid construction speed associated with 3D printing is a significant advantage, contributing to the growing popularity of 3D printed buildings.

Overall, the anticipated growth of the global 3D construction market highlights the potential of 3D printing to address various challenges in the architecture, engineering, and construction sectors, offering benefits such as cost reduction, time efficiency, and the ability to create structures with less waste.

The main objective of this work is to identify the optimal concrete mixture using easily available materials for 3D printing and evaluate the fresh and hardened properties of the designed mix. The assessment includes evaluating the printability and buildability of various concrete mixtures, and determining the best mix proportions for printing structures.

Experimental results are presented in this study, focusing on the mix design and tests conducted to assess the properties of both fresh and hardened concrete. These results provide valuable insights into the performance and suitability of the designed concrete mix for 3D printing applications.

One of the drawbacks of traditional manufacturing processes is the significant waste generated in the construction industry worldwide, leading to financial losses. Moreover, these waste materials contribute to environmental degradation. In contrast, additive manufacturing processes, such as 3D printing, produce minimal waste throughout the construction process. Additionally, 3D printing allows for the creation of more complex shapes compared to other manufacturing methods. Many machines, buildings, and other constructions achieved through 3D printing are accomplished at lower costs compared to alternative options. The continuous advancements in the field of 3D printing are expected to further reduce prices.

The ability of 3D printers to achieve complex shapes is one of their most intriguing features. This capability promotes innovation, flexibility, and the ability to make adjustments in designs, ultimately making the construction process more cost-effective. With 3D printing, what is seen in the drawings can be replicated as a physical object, bringing designs to life.

Overall, this research aims to optimize the concrete mixture for 3D printing, evaluate its properties, highlight the benefits of additive manufacturing in terms of waste reduction and cost efficiency, and emphasize the ability of 3D printers to create intricate and complex shapes in construction and design.

2. MATERIAL IN DETAIL

1. Cement
2. Coarse Aggregate
3. Fine Aggregate
4. Superplasticizer
5. Sand
6. Water

These materials, when properly proportioned and mixed, contribute to the workability, strength, and durability of the concrete used in 3D printing and other construction applications. The specific proportions and characteristics of these materials can vary depending on the desired properties of the final concrete mixture.

1. Cement:

Using Ordinary Portland cement 53 grade for your research project is a common practice in construction. This type of cement is known for its high compressive strength and is suitable for a wide range of applications. Testing the cement as per the Indian Standard Specification (BIS-1489 part 1:1991) ensures that it meets the required quality standards and specifications set by the Bureau of Indian Standards (BIS).

Table 1: Physical Properties of ordinary Portland cement

Physical Properties		BIS-1489:1991	Test Result
Setting time (mm)	Initial	30 Mini	92
	Final	600 Max	248
Specific gravity		_	3.15

2. COURSE AGGREGATE:

Using fractions ranging from 10 mm to 4.75 mm as coarse aggregate is a common practice in concrete mixtures. These fractions provide structural stability and contribute to the overall strength of the concrete.

In this research project, crushed Basalt rock is being used as the source for coarse aggregates. Basalt is a commonly used rock material in construction due to its high strength and durability. It conforms to IS: 383, which is the Indian Standard Specification for coarse aggregates.

To ensure the quality of the coarse aggregates, it is important to maintain the flakiness index and elongation index below 15%. The flakiness index measures the percentage of aggregate particles with a thickness less than a specified ratio to their average size. The elongation index measures the percentage of aggregate particles with a length greater than a specified ratio to their average size. By keeping both these indexes below 15%, you are ensuring that the coarse aggregates have a more cubical shape and are less prone to elongation, which can affect the workability and performance of the concrete.

By using crushed Basalt rock within the specified size range and maintaining the flakiness and elongation indexes below 15%, you are ensuring the quality and suitability of the coarse aggregates for our research on 3D printing with concrete.

3. Fine Aggregate

In this research project, the fractions ranging from 4.75 mm to 150 microns are classified as fine aggregate. Fine aggregates are essential components of concrete that help to fill the spaces between the coarse aggregates and provide workability and cohesiveness to the mixture.

For our project, both river sand and artificial sand are being used as fine aggregates. The selection of fine aggregates from different sources allows for comparative analysis and evaluation of their performance in the concrete mix. It is important to ensure that both types of sand conform to the requirements specified in IS: 383, which is the Indian Standard Specification for fine aggregates.

Conforming to the requirements of IS: 383 means that the river sand and artificial sand used as fine aggregates have undergone screening processes to eliminate any deleterious materials and oversized particles. Screening helps to remove impurities, such as organic matter, clay, silt, and other contaminants, ensuring that the fine aggregates meet the necessary quality standards.

By using both river sand and artificial sand as fine aggregates and adhering to the requirements of IS: 383, you can ensure that the fine aggregates contribute to the workability, strength, and overall performance of the concrete in your research on 3D printing with concrete.

4. Superplasticizer:

Zentrament F BV -SNF based high early strength super plasticizer.

Product properties:

- High early strength super plasticizer
- Chloride free
- Highly pumpable concrete requiring minimum compaction
- Reducing the bleeding and segregation in concrete

Table 2: Technical Data for Zentrament FBV

Characteristic	Unit	Value	Comments
Density	kg/liter	1.07	+-0.02
Mixing ratio	%by wt. of cement	0.8%to1.6% 1.5%to3.0%	For flow concrete For high early strength

5. Water

Water used for mixing and curing of concrete cube shall be clean and free from oil, acids, alkalis, salt and organic material or other substances. Portable water shall be used for mixing of concrete. Suspended solid matter in the water shall not exceed more than 200mg/l. The pH value of the water shall not be less than 6.

6. Sand

Manufactured sand is free of silt and clay particles, and has denser particle packing than natural sand. It also offers high flexural strength, better abrasion resistance, higher unit weight and lower permeability. It is superior and cost-effective alternative to natural sand, crushed stones and lightweight fine aggregate, for use in the manufacture of advanced building material derivatives such as concrete, mortars, roof tiles, tile adhesives etc.

3. EXPERIMENTAL METHODOLOGY

(1) Collection of material

(2) Developing a mix design

(3) Conducting tests for fresh concrete properties

(4) Conducting tests for hardened concrete properties

(5) Discussion of result

(6) Identify best result

By following this methodology, the research aims to identify the best concrete mixture using easily available materials for additive manufacturing and evaluate its fresh and hardened properties. The results will provide insights into the printability, buildability, and overall suitability of the designed mix for 3D printing applications.

Table 3: Mix Design Ratios for 7 Trial Mixes

Mix design	Batch	1	2	3	4	5	6	7
	W/C	0.3	0.3	0.28	0.28	0.25	0.25	0.25
	Chemical %	2	3.25	2.75	3	2.5	2.75	3

The water-cement ratio was fixed between 0.3 and 0.35. Then, five trials were conducted by adding a superplasticizer. In one trial, the water-cement ratio was decreased to 0.28 with the addition of 3% of superplasticizer.

4. EXPERIMENTAL RESULT

4.1 FRESH CONCRETE PROPERTY

1. Workability

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. Slump test carried out using a frustum of cone, having a base diameter of 80mm, top diameter of 70mm and a height of 500mm, a base plate, measuring tape and a trowel. The procedure consists of firstly the inside portion of the cone made wet and is placed in an inverted manner at the center of base plate Then the concrete is filled inside using a trowel with no compaction to concrete. When the concrete is filled the cone is vertically lifted. When the flow stops, diameter at two perpendicular directions is taken and the mean is calculated. All the tests were conducted on all the mixes before casting of specimens and the result of slump test.

Fig 1: flowability test (Concrete Pouring)

2. Flowability

The flowability test was conducted for each mix and the results were obtained. A proper mix was ascertained firstly through this experiment. The first mix M1 was obtained a flow of 0cm and the mix was not so hard so that they can't be used for 3D printing concrete. Further mixes were prepared by reducing water cement ratio. And increasing the % of Superplasticizer Mix M2 and M3 were too watery and it was flowable. Then mix M4 was prepared and conducted flowability test. The mix obtained was of proper consistency. And slump cone test was performed and the result was obtained as 225mm. Then the flowability obtained was 7.2 and the consistency was proper without any bleeding.

Fig 2: flowability test (Concrete Pouring)

3. Concrete Extruder

The next stage involves mixing of concrete or cementitious materials for the printing. To check the printability and stability in layer by layer formation of the developed mix, a concrete extruder was designed. Since we were not having 3 D printer but to show the flowability, printability we use the available CAN Which consist hopper and nozzle to as shown in fig. The extrudability of the mix was carried out using the concrete extruder. The machine allowed the smooth flow of mix through auger and then through the nozzle. As the distance between nozzle and printing surface was proper there was no break in the flow of the mix. There was proper layer by layer adhesion and no bleeding occurred showing the mix was of proper ratio.

Fig 3: Concrete Extruder

4.2 HARDENED CONCRETE PROPERTIES

1 Compressive Strength Test

The test was carried out as per IS: 516-1959. Compressive strength tests were performed on cube samples using compression testing machine. Three samples per batch were tested with the average strength values reported in table 3.

Fig 4. Compressive strength test

Table 4: Compression Test Result

MIX	COMPRESSIVE STRENGTH (N/mm2) (7DAYS)	COMPRESSIVE STRENGTH (N/mm2) (28DAYS)
M1	51.40	60.47
M2	36.69	50.20
M3	49	55.7
M4	30	50

5. RESULTS AND DISCUSSION

(i)For Batch 1: The results obtained by the compressive strength test at the age of 7 days are good as per the acceptable result at the age of 7 days curing is 51.40N/mm2 required for M55 grade of concrete and obtained results are more than that.

(ii) The results obtained by the compressive strength test at the age of 28 days are good as per the acceptable result at the age of 28 days curing is 60.47 N/mm2 required for M55 grade of concrete and obtained results are more than that.

(iii)The workability was determined by slump cone test, the slump value for mix design of batch 1 we got was 225, which is more than a required slump.

(iv) the concrete was flowable and the concrete was also easily extruded from the concrete extruder.

(v)As concrete is a material design for compressive strength, it gives satisfactory results after replacing glass aggregate to coarse aggregate and it doesn't show the suitability of material.

FLEXURAL STRENGTH TEST:

Flexural strength tests were performed on flexural testing machine having 100KN capacity using beam specimen. Three samples per batch were tested with the average strength values reported in table 6.2. The flexural strength of the specimen shall be expressed as the modulus of rupture fb, which, if 'a' equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm, shall be calculated to the nearest 0.5 kg/sq. cm as follows

fb=pl/bd2

Fig 5. Flexural testing Machine

Table 4: Flexural Strength Test Result

Sr. N	Beam	Weight	C/S Area	28 Days Peak Load	Avg
1	B1	12.64	50000	6 N/mm2	9.466 N/mm
2	B2	12.10	50000	8 N/mm2	
3	B3	13.26	50000	14.4N/mm2	

Discussion of Result

(i) The results obtained by the flexural strength test at the age of 7 days are good as per the acceptable range of result required for M55 grade of concrete and obtained results are more than that.

(ii)As concrete is a material design for compressive strength, it also gives good results in flexural strength and it shows that the suitability of material.

6 CONCLUSION

The study was conducted to discover a proper mix for 3D printing concrete. No specific mix was mentioned in any of the referred articles. By trial and error method, a mix was fixed by assessing the fresh properties. Through trial and error method, Total Seven trials were conducted. The first two trials were carried out with 10 mm aggregate, sand, and cement to determine the water-cement ratio. Thus, the water cement ratio was fixed between 0.3 and 0.35. Then five trials were conducted by adding a superplasticizer. By decreasing the water-cement ratio to 0.28 with the addition of 3% of superplasticizer. The assessment of fresh properties by conducting a flowability test was conducted. Through compressive strength test, it was observed that the mix M6 whose 7-day compressive strength was 60 N/mm2.

The results which proven the quality of the designed mix can be summarized as follows:

1. The compressive strength test result was limited to 7 Days and 28 days.

2. Best w/c ratio was found to be 0.37.

3. The experimental investigations proved that the Best mix was M7 in terms of Bleeding, Shrinkage, segregation, and strength.

4. Water cement Ratio plays a very vital role in concrete mic design for the 3D Concrete Printing. The water-cement ratios between 0.25-0.44.

5. 3D concrete has some feasible features such as flowability. These characteristics vary from traditional concrete. Therefore, the development of 3D concrete should be performed with greater care by taking these characteristics into account.

6. The initial cost of concrete printing technology is high due to the high cost of 3D printer machines. 3D concrete printing provides many potential cost-effectiveness advantages for construction processes compared to conventional construction methods, considering the different cost elements (labor, equipment, materials, design, and planning costs).

7. It is necessary to use the minimum amount of water with superplasticizers for better concrete adhesion. Furthermore, we can also that adding materials such as fly ash, silica fume and slag could benefit the mixture if 5 to 30 percent of the total binder volume were added. And the cement will be used in less amount.

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