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3d Printinng Concrete :Mix Dessign

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Abstract— **The demand to technologize the construction process for civil infrastructure has been persistently set in motion by the repeated number of injurious site accidents, huge time and material wastages in the contemporaneous labour intensive point of view.**
Additive manufacturing methods for building construction have been popularised and used in a large scale in the recent years.The primary purpose and aim of this work is to recognize the best concrete mixture with easily available materials for 3D printing and to appraise fresh and hardened properties of the designed mix.The printability and build ability of all the recognized concrete mixture was assessed and the best mix proportions were advanced for printing constructs.

I. INTRODUCTION

3D printing, with its ability to transform drawings into objects, has attracted the attention of researchers around the world in the past few decades. It is a technology which converts a 3D digital drawings into three-dimensional shapes with the requirements of users using a 3D printer.

Formerly used in industrial design and manufacturing, 3D printing technology is expanding into other fields such as medicine, food, and manufacturing. The idea has also attracted towards heed of architects and engineers, the probabilities of it's use seem boundless. Building structures using 3D printing has become a reality, often launched by media. Yet the technology is in its budding stage and its applications are limited to certain regions due to technical weakness. Especially, in the construction sector, further studies are essential to discover precise mechanical, satisfactory printing materials, and dispensing system with those materials.

Also, technical limitations such as increasing production costs of non-structural buildings and tedious construction methods are major obstacles in the construction industry. When using 3D printing technology in manufacturing, it is possible to fit a simple manufacturing and production system without having to go through the entire manufacturing process. It will lead to a new paradigm of manufacturing that allows users to build based on their own instructions using simple manufacturing and production systems. Also, construction time and cost can be greatly reduced without unnecessary construction steps.

A laboratory-scale concrete extruder for printing concrete structures was developed in this project with the use of a mechanical system to control the movement of the material dispenser. A materials study was also conducted to find the ideal mix for the system. The experiments focused on finding the efficient mix ratio of cementitious materials used in the production of physical materials through layer by layer formation using a concrete extruder

A. Significaannce of studyy

II. MATERIALS

A. Cement

Portland Pozzolana Cement (PPC) conforming to IS 12269-1987 was used in the study. Laboratory tests were conducted to determine the various properties like fineness, specific gravity, standard consistency, initial and final setting time.

B. Fine aggregate

M-Sand passing through 300µ IS sieve and retained on 600µ IS sieve was used in the study. Specific gravity, fineness modulus, uniformity co-efficient and moisture content of the fine aggregate were tested as **per** IS 2386 (Part III)-1963.

C. Superplaticizer

CERAPLAST 300 is a high-grade superplasticizer based on naphthalene, highly recommended for increased workability and early and ultimate strengths of concrete .It also reduces the w/c ratio, optimize the cement content, improved durability etc. The recommended dosage is 0.3% to 1.5% ceraplast 300by weight of cement.

D. PVA Fiber

PVA(Polyvinyl Alcohol) fibers are monofilament fibers that disperse throughout the concrete matrix, creating a multi-directional fiber network, providing shrinkage control, abrasion resistance, protection from thermal expansion and contraction, concrete prior to the curing processes and increase their toughness.

III. EXPERIMENTAL METHODOLOGY

A. Methodology

- Collection of materials.
- Developing a mix design.
- Conducting tests for identifying fresh concrete properties.
- Conducting tests for hardened concrete.
- Analysis of result
- Identifying and Suggesting the best mix.

IV. MIX DESIGN

Trial mixes

Table 1: Mix design ratios of the first two trials.

Trials	Cement (g)	Water (ml)	Sand (g)	W/C ratio
1	1000	350	400	0.35
2	500	220	200	0.44

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Firstly, two trial mixes having a water cement ratio 0.35 and 0.44 by using Cement,Water and Sand as ingredients.But the mix having 0.35 w/c ratio was very dry and had less workability.The second mix having w/c ratio 0.44 is found to be very loose.Inorder to attain a proper mix and to reduce the w/c ratio superplasticizer is introduced for further trials.

Table 2: Mix design ratios of the tested mortar

Mix	Cement (g)	Water (ml)	Sand(g)	W/C ratio	S.P(ml)
M1	500	200	200	0.4	6
M2	500	200	200	0.4	2
M3	500	200	200	0.4	1.5
M4	500	190	200	0.38	1.5
M5	500	185	250	0.37	1.5

For attaining a proper mix, superplastisizer (ceraplast 300) was introduced.For the mix M1,M2,M3 by keeping w/c ratio as 0.4 the percentage amount of superplastisizer is varied by 1.2%,0.4%,0.3% respectively.The minimum percentage of superplastisizer is to be added is 0.3% so w/c ratio was reduced to 0.38(M4).The mix M4 was comparitively good but bleeding occurred.Then w/c ratio was reduced to 0.37 and the amount of sand was increased by 50g expecting a proper mix(M5).This was found to be the best mix.

Table.3:Mix design ratios on adding PVA fiber

Mix	Cement (g)	Water (ml)	Sand (g)	W/C ratio	S.P(ml)	PVA fiber(g)
M6	500	185	250	0.37	1.5	0.25
M7	500	185	250	0.37	1.5	0.5
M8	500	185	250	0.37	1.5	0.75

The PVA fibres were added in varying percentage of 0.05, 0.1,0.15 of that of cement for the mixes M6,M7 and M8 respectively. The maximum compressive strength was obtained in M7(0.1% PVA fibre)

V. RESULTS

A. FRESH PROPERTY TEST RESULTS

Flowability test .

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 centre of base plate Then the concrete is filled inside using a trowel with no compaction to concrete. When the concrete is fully filled the cone is vertically lifted up. 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 is given in Table 4.

Table 4: Flowability test results

Mix	Flowability(cm)
M1	15
M2	12
M3	10
M4	7.5
M5	7.2

The flowability test was conducted for each mix and the results were obtained as shown in the table 5.1. A proper mix was ascertained firstly through this experiment. The first mix M1 was obtained a flow of 15cm and the mix was too watery. Further mixes were prepared by reducing water cement ratio. Mix M2 and M3 were also aqueous so that they can't be used for 3D printing concrete. Then mix M4 was prepared and conducted flowability test. The mix obtained was of proper consistency but there was bleeding in the mix. So the water cement ratio was reduced and the sand was increased by 50 gm. Then the flowability obtained was 7.2 and the consistency was proper without any bleeding.

B. HARDENED PROPERTY TEST RESULT

Compressive strength test result

The desirable properties of hardened concrete are related to the compressive strength. Compression strength test is the important and most common test conducted. Compressive strength of concrete is a measure of its ability to resist static load. As per IS: 516-1959, the compression test can be carried out on cube of size 100mm x 100mm x 100mm using compressive testing machine having capacity of 600 KN and a uniform rate of loading of 14 N/mm2 per minute is given until failure occurs. The ultimate load divided by the area gives the cube compressive strength. The compressive strength test results are shown in table 5

Table 5 compressive strength test results

Mix	Compressive strength(N/mm2)
M4	130
M5	140
M6	130
M7	160
M8	140

The hardened properties where assessed with the help of compressive strength test. The mixes till M3 was unable to cast cubes and conduct compressive strength test. The strength for M4 was found to be 130 N/mm2. A compressive strength of 140 N/mm2 was attained for M5 which was the best mix in the assessment of fresh properties. Further trials were conducted by adding PVA fiber in order to increase the compressive as well as to reduce the shrinkage crack. Thus by adding varying amount of PVA fibers, M7 was found to be the best mix with a Compressive strength of 160N/mm2. This mix was used for assessing extrudability and was fixed as the best mix of all the trials

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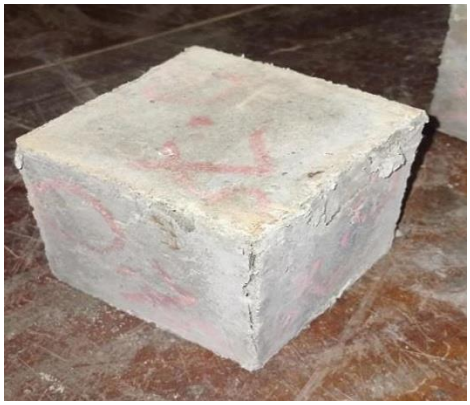

Fig 2: M8 after compressive strength test

VI. 3D PRINTING

CONCRETE EXTRUDER

The next stage involves mixing of concrete or cementitious materials for the printing. In order to check the printability and stability in layer by layer formation of the developed mix, a concrete extruder was designed.

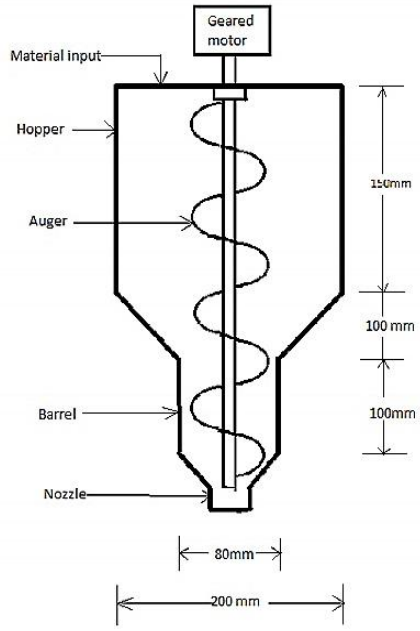

Fig:3 Concrete extruder dimensions

SPECIFICATIONS OF THE MACHINE

This machine consist of a hopper having 20cm dia where the concrete mix is placed. It has a barrel having 8cm dia and a changeable nozzle having diameters 20mm,25mm,30mm respectively.An auger is placed centrally.The auger rotation is provided by a DC stepper gear motor. The motor revolves at 60 rpm.When the materials are placed, the printing is processed using hopper-motor-nozzle system.

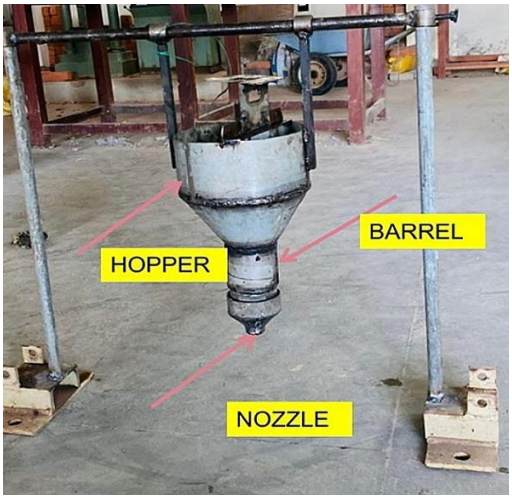

Fig 4: Fully assembled concrete extruder

Fig 5: Parts of the concrete extruder

EXTRUDABILITY OF THE MACHINE

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.

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Fig 6: Layer formation using concrete extruder

VII. CONCLUSION

The study was conducted in order 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 ten trials were conducted. The first two trials were carried out with sand and cement in order to determine the water cement ratio. Thus the water cement ratio was fixed between 0.35 and 0.44. Then five trials were conducted by adding superplasticizer. After those trials a water cement ratio of 0.37 was fixed with addition of 0.3% of superplasticizer. This was fixed through the assessment of fresh properties by conducting flowability test. Then three more trials were carried out by adding varying amount of PVA fiber in order to reduce shrinkage cracks. Through compressive strength test it was observed that the mix M7 whose 7day compressive strength was 160 N/mm2. The results which proven the quality of the designed mix can be summarized as follows:

- The compressive strength test result was limited to 7 Days.
- Best w/c ratio was found to be 0.37.
- To reduce shrinkage cracks PVA fiber was found to be effective. More than 0.1% reduces compressive strength.
- The optimal dosage of PVA fiber was found to be 0.1%.
- The open time for the mix was found as 15 minutes.
- The compressive strength of the best mix was determined as 160N/mm2.
- The experimental investigations proved that the Best mix was M7 in terms of Bleeding, Shrinkage, segregation and strength.
- Mix M7 can be taken for further studies for 14,28,56&90 days and for Durability studies.

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