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3D printing-A Review of Materials, Applications, and Challenges

Sachin J. Pandhare[1], Dr. (Mrs) Geetha K. Jayaraj[2]
[1]*PG.Student, Department of Civil Engineering, Shivajirao S. Jondhle College of Engineeering and Technology, Asangaon, Dist Thane, Maharashtra, India*
[2]*Principal, Shivajirao S. Jondhle College of Engineering &Technology, Asangaon, Dist Thane, Maharashtra, India*

Abstract: ***Now a days 3-Dimensional Printing (3DP) technology is used world widely and it can actually print each and every thing with the desired computer program. In Construction engineering the challenges are like availability of skilled man power, time constraint, cost effectiveness and complicated shapes etc. But with the help of an automated machine, the 3D printing technology, has huge potential to have faster and more accurate construction of complex and more laborious works. This technology can build three-dimensional (3D) objects by connecting layers of materials and can be applied to convert waste and by-products into new materials. The 3DP in concrete construction is increasing thanks to its freedom in geometry, rapidness, formwork-less printing, low waste generation, eco-friendliness, cost-saving nature and safety. This paper attempts to review the digital printing technology introduced in the construction industry and the also highlights the impact on concrete technology. It also discusses about the materials used in 3DP, mix design, various applications and challenges in the construction industry.***
Keywords: 3D printing, Concrete, 3DCP, Mix design.

I. INTRODUCTION

Concrete 3D printing is an emerging technique for the development of buildings and infrastructure. The application of 3D concrete printing technology in construction is taken into account a replacement period for the industry thanks to its potential to disrupt conventional construction practices. This technology completely saves the formwork costs, reduces the labour cost by 50–80%, and decreases the wastage of construction materials, at the site by 30–60%. Additionally, thanks to a rise in productivity at the development site and a discount within the construction time, it's the potential to further reduce construction costs. However, the use of concrete 3D printing for routine constructions is uncommon due to the technical challenges (Atta Ur Rehman and Jung-Hoon Kim, 2021).

Since the invention of the primary 3D printer in 1983, the event of this technology has been improved fast paced. Printers started to be part of everyday life over the years and are currently present in many industries, such as pharmaceutical, medical, automotive, and aerospace (Marcelo Tramontin Souza.et.al,2020). In the year 1987, 3D printing technology was introduced as rapid prototyping . Printing concrete in construction makes construction easier, cost efficient. Printing concrete are often made in several shapes without reinforcements. Aggregates used in printing concrete is very much less in size than in normal conventional concrete(A.R.Krishnaraja , K.V.Guru, 2021).

A. 3D Concrete Manufacturing Process

Concrete used in 3D printing is go through the different stages like pumping, extrusion, and layer-by-layer deposition. These all stages required special characteristics from a concrete mix to conform with the all needs of the printing process.

1) *Mix Design:* Mix design is very important step Considering the challenge in fresh property such as pumpability, extrudability, and buildability. Hardened paste, mortar, and concrete material properties and how they influence the geometry of the created object.(R.A. Buswella et al (2018)
2) *Mixing:* This step is very important as it directly affect fresh and harden properties of final product.Mixing time is totally depend upon the requirement of final workability of concrete .(A. Perrot,et,al,2021).
3) *Material Delivery:* In this stage actual material delivered through the attached mechanical assembly.Material delivery involved two stages i)Pumping and ii) Extrusion. Pumping is depend upon the rawmaterial,mixing,distance from mixing to actual placing.It required very precision to calculate required pump pressure.Extrusion of concrete is material passing through needle at printing area.In extrusion the combination of pump pressure and needle with shape of layer needed to achive final geometries.(A. Perrot,et,al,2021).

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4) *Concrete Deposition:* It deals with the deposition of layer without disturbing the targeted gemetary of the designed structure.This process included Extrusion needle shape,flocculation of material,material Spreading pressure etc.Considering importance of it accordingly all deposition stages deigned. (A. Perrot,et,al,2021).
5) *Material Drying and Curing:* Concrete deposited without formwork can have fast heat of hydration process which takes place high water evaporation.but this waterloss seen into only some locallised area.which directly affecting much on mechanical properties.to cater shrinkage effect successive layer to be placed over within estimated time interval.If the temperature maintained 20-25deg.c. and humidity keep in place then water evaporation can be controlled. (A. Perrot,et,al,2021).

B. Different Methods of 3D Printing

Different methods of 3D printing is adopted to reduce the defects and make it compatible to different material and shapes. Below mentioned methods explained briefly

1) *Fused Deposition Modelling (FDM):* FDM is also one of the low cost 3D printing techniques which is based upon the additive manufacturing concept. In this technique two material is used one is to build part and another one is to disposable support structure. The fillement material filled to head heated to semi liquid state then the head extrudes material with the precision in ultra thin layers. This system runs in X,Y and Z direction, Support structure automatically generated for over hanging structure and later removed them by breaking and object separated.(Tuan D. Ngo,et,al,2018)
2) *Powder Bed Fusion:* Powder bed fusion is used with fine powder fused together with a laser beam or a binder. The laser used to melt powder, excess powder is removed with vaccume. In this method . porosity of parts by binder deposition is generally higher compared to laser sintering or melting. The advantages of it is the powder bed is used as the support system. Disadvantage of this method is it is very slow and costly method. Alsopowder is fused with binder high porocity found.(Tuan D. Ngo,et,al,2018)
3) *Inkjet Printing and Contour Crafting:* This method is used to craft complex structure like scaffolds or engineering objects. Injecting printing is done with ceramic material. There are two types of ceramic inkjet is wax-based inks and liquid suspensions. This method is very efficient and fast. Main disadvantage of this method is less adhesion in interlayer and maintaining workability. this technology is also called as contour crafting. (Tuan D. Ngo,et,al,2018)
4) *Stereolithography (SLA):* This is very old technology used since 1986.UV light is used to ensure chain reaction. Stereolithography system is consist of tank of liquid photo polymer there is a perforated platform which moves in all direction according to printing process. It also has high power ultra violet laser. SLA System also consist of computer interface. Interface controls UV laser and moving platform movement. This menthod is used for additive manufacturing of complex nanocomposites.(Tuan D. Ngo,et,al,2018)
5) *Direct Energy Deposition:* This method is used for manufacturing super alloys. also this method is known as laser engineered net shaping (LENS), laser solid forming (LSF), directed light fabrication (DLF), direct metal deposition (DMD). The difference between both method (DED and SLM) is that no powder bed is used in DED and the feedstock is melted before deposition in a layer-by-layer fashion similar to FDM but with an extremely higher amount of energy for melting metals. This technique is commonly used with titanium, Inconel, stainless steel, aluminium and the related alloys for aerospace applications.(Tuan D. Ngo,et,al,2018)
6) *Laminated Object Manufacturing:* This method is based on layer-by-layer cutting and lamination of sheets or rolls of materials. method is particularly useful for thermal bonding of ceramics and metallic materials. This method is used in various industries such as , paper and metal-filled tapes, polymer composites and ceramics. This method has inferior surface quality. To get final product post processing required also it has lower dimension accuracy. Considering lower dimensional accuracy this method is not very popular.(Tuan D. Ngo,et,al,2018)

II. APPLICATIONS OF 3D PRINTING IN VARIOUS AREAS

3D Printing technology also used in Automobile, Aerospace, fashion, Furniture and Medical industry. With the less cost and time saving. Applications in various industry are as Follows.

1) *Aerospace Industry:* In aerospace industry, 3D printing technology has potential to make lightweight parts, improved and complex geometries, which can reduce energy requirement and resources. Also by using the 3D printing technology, it can lead to fuel savings because it can reduce the material used to produce aerospace's parts. (N.Shahrubudin,et,al,2019) For example The NASA Aeronautics Research Institute is trying to develop an AM non-metallic gas turbine engine Lightweight and high-temperature resistant composite materials are being explored.(Tuan D. Ngo,et,al,2018).

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2) *Automotive Industry:* 3D printing technology have rapidly changed our industry to design, develop and manufacture new things. In the automotive industry Local Motor had printed the first 3D-printed electric car in 2014. It is not only cars and automobile Local Motors also extended the wide range application of 3D printing technology by manufacturer a 3D-printed bus called OLLI. OLLI is the a driverless, electric, recyclable and very smartly 3D printed bus.(N. Shahrubudin,et,al,2019)
3) *Food Industry:* 3D printing technology open the doors not only for aerospace industry, but also for food industry. In world has a growing demand for the development of customized food for specialized dietary needs, such as athletes, children, pregnant woman, patient and so on which requires a different amount of nutrients by reducing the amount of unwanted ingredients and enhancing the presence of healthy ingredients. (N. Shahrubudin,et,al,2019)
4) *Healthcare and Medical Industry:* 3D printing technology can used to print 3D skin, drug and pharmaceutical research, bone and cartilage, replacement tissues, organ, printing for cancer research and lastly models for visualization, education, and communication.3D printing technology also can be used to print out similar organ failure caused by critical problems such as disease, accidents, and birth defects. (N. Shahrubudin,et,al,2019)
5) *Architecture, Building, and Construction Industry:* In the construction industry, 3D printing technology can be used to print entire building or can create construction components. Building Information Modelling is a showing digital representation of actual actual work, can share an information and knowledge about 3D building. The examples of 3D printed building are Apis Cor Printed House in Russia and Canal House in Amsterdam. (N. Shahrubudin,et,al,2019)
6) *Fabric and Fashion Industry:* When 3D printing technology enters the retail industry, 3D printed shoes, jewellery, consumer goods and clothing are emergence into the market. For Example big companies like Nike, New Balance and Adidas are striving to development the mass production of 3D printed shoes. Nowadays, 3D printed shoes are produced for athlete's shoes, custom-made shoes and sneakers. Moreover, the application of 3D printing technology not limited to the fashion industry, but also can print leather goods and accessories.(N. Shahrubudin,et,al,2019)
7) *Electric and Electronic Industry:* In todays time various 3D printing technologies have already been used broadly for structural electronic devices like active electronic materials, electrode and devices with mass customization and accepting design through embedding the conductors into 3D printed devices. The production process for the 3D electrode by utilizing the Fused Deposition Modelling of 3D printing technique provides low-cost and a time efficient approach to mass producing electrode materials.(N. Shahrubudin,et,al,2019).

III. MATERIALS FOR PRINTABLE CONCRETE

As the printing process requires a continuous, high degree of control the material during printing, high performance building materials are preferred. Also, as no supporting shuttering is used for 3DPC, traditional concrete cannot be directly used. For ensuring little or no deformation in the bedding layers, either low to zero slump concrete is required.(Suvash Chandra Paul,et.al,2018).

1) *Supplement Cementitious Materials:* The cement to aggregate ratio of 3DPC at present is much higher than that of normal concrete to achieve the required printability, which may lead to an increased cost. SCMs like fly ash, silica fume, limestone filler, and blast furnace slag, are used to partially replace cement (Shaodan Hou,et.al,2020). If 50% of Portland cement is replaced by SCMs in concrete by mass, the emissions of CO2 would be reduced by 1 billion ton every year(C.D. Tomkins,2009).
2) *Cement:* The mineral composition of Portland cement clinker is mainly composed of C3S, C2S, C3Aand C4AF. Appropriate level of gypsum is added to clinker for grinding cement. The hydration rate and water demand of reaction of each mineral composition are different. It can be expected that the rheological properties of cement paste may be affected by mineral composition of cement. (Dengwu Jiao.et.al,2017).
3) *Flyash:* Fly ash has a lower specific gravity than cement. The replacement of cement with the same mass of fly ash increases the volume of paste, Fly ash particles are mostly spherical, including solid spheres (density=2300–2600 kg/m3) and cenospheres (0.2–1.1% of the total fly ash weight, density<1400 kg/m3) (Brouwers and Van Eijk, 2002)
4) *Ground Blast Furnace slag (GBFS):* GBFS, finely granular and almost fully nanocrystalline, is a by-product of the iron manufacturing industry. Its glass content is predominated by water quenching rate (Dengwu Jiao.et.al,2017). GBFS has hydraulic activity, but slower than that of Portland cement. The specific gravity of slag is approximately 2.90, and its bulk density varies in the range of 1200 ~ 1300 kg/m3. The specific surface area of GBFS measured by Blaine method are 375 ~ 425 m2/kg, 450 ~ 550 m2/kg, and 350 ~ 450 m2/kg(Dengwu Jiao.et.al,2017).

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5) *Silica Fume:* Silica fume is the by-product of electric arc furnace produced silica metal and silica alloys.The specific surface area of silica fume is 20000 ~ 28000 m2/kg, which is 80 ~ 100 times and 50 ~ 70 times higher than that of cement and fly ash, respectively. The particles are round, and tend to be agglomerated. Therefore, superfine silica fume particles can fill the voids between other particles, improves the gradation, increases the packing density of cementitious. materials and even has lubrication effect.(Dengwu Jiao.et.al,2017).
6) *Metakaolin (MK):* It is a pozzolanic material. It is obtained by the calcination of kaolinitic clay at a temperature ranging between 500 °C and 800 °C. The raw material input in the manufacture of metakaolin (Al2Si2O7) is kaolin(Rafat Siddique and Juvas Klaus,2009). Metakaolin on reaction with Ca(OH)2, producesCSH gel at ambient temperature and reacts with CH to produce alumina containing phases, including C4AH13, C2ASH8, and C3AH6 (Changling et al., 1995; Zhang and Malhotra, 1995). Metakaolin had 99.9% particles b16 μm with a mean particle size of about 3 μm(Ambroise,et al., 1994).
7) *Lime Stone Powder:* Limestone powder is a kind of high quality and cheap mineral admixture. Its main component is calcium carbonate, CaCO3. Limestone particles is irregular and rough(Dengwu Jiao.et.al,2017).
8) *Aggregates:* Aggregates, which occupy a 60–70% volume of concrete, play an important role in the performance of concrete. Compared with the cement paste, the yield stress and plastic viscosity are increased with the addition of aggregates, especially for aggregate with large gain size. Besides, the mechanical properties and shrinkage are related to the volume of aggregates (Shaodan Hou,et.al,2020).
9) *Admixture:* Different admixtures are necessary to improve the properties of 3DPC during different printing processes. Superplasticizer is almost applied in every mixture of 3DPC for the its capacity to successful extrusion. The addition of superplasticizer can reduce the yield stress and plastic viscosity of concrete due to the dispersion effect of the binder particles. It should be noted that the applied dosage of superplasticizer should be between the critical and saturation dosage (Shaodan Hou,et.al,2020).
10) *Viscosity modified agent (VMA):* VMA was frequently used in 3DPC to enhance the viscosity and cohesion and then improve the shape stability after extrusion. The addition of VMA could increase the yield stress, viscosity and thixotropy with a shear-thinning behaviours of cementitious materials (Shaodan Hou,et.al,2020).
11) *Fibers:* Considering the brittle failure modes of 3DPC, which are caused by the low ratio of tensile to compressive strength, reinforcement addition to the 3DPC is a good way to improve its structural property. However, embedding the reinforcement into the 3DPC continuously is difficult because of the layer-by-layer printing construction mode. Under this circumstance, the application of fibers attracted more attention. (Shaodan Hou,et.al,2020).The addition of fiber had an evident impact on the flexural and tensile strength.

IV. PRINTABLE CONCRETE MIX DESIGN

The concrete mix must be designed to meet certain vital criteria that have a direct relationship with the methodology of printing the concrete. Thus, it is critical to ensure a complementary connection between the designs of the mix and printing machine. In order to design the optimal mix, certain target goals were set for the mix. Table 1presents these goals.

Table 1: Mix Goals

Maximize compressive strength		Maximize workability
Maximize flowability in the system	YET	Maximize buildability upon pouring
Maximize speed of concrete setting		Maintain appropriate setting rate so as to ensure bonding with the subsequent layer

(Ref: Zeina Malaeb et.al,2015).

As it is seen from the table above, some of the goals seem to conflict with each other and thus the challenge is continuing an perfect balance of all. The five most important aspects of the mix that are studied are extrudability, flowability, buildability, compressive strength, and open time. Extrudability and flowability are related to the 3Dconcrete extrusion, flow, and workability, as the aim is to reach a continuous easy-flowing paste from the source to the printing nozzle. Buildability means to the ability of the concrete layer to hold the layers above it without collapsing. The concrete must fulfill desired compressive strength. Finally, open time studies the change of concrete flowability with time (Zeina Malaeb.et.al,2015).

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Biranchi Panda,et.al,(2017). had developed mix design to find mechanical performance of 3D printed fiber reinforced sustainable construction material. in this paper, an experimental investigation was carried out by reinforcing short glass fiber (GF) of different lengths (3mm, 6mm and 8 mm) and percentages (0.25%-1%) in a custom-made sustainable construction material developed for 3D printing application. The selection of material design and fiber dimensions are purely based on our preliminary investigations to develop printable material for 3D printing application. As an innovative digital construction technology, in this paper, we have explored the directional properties of 3D printed geopolymer with different fiber lengths and content. It is clear from the experimental results that addition of fiber hardly improves the compressive strength but the impact is well visible in terms of flexural and tensile strength for fiber content up to 1%.

Biranchi Panda,et.al,(2018). The main goal of this study was to investigate the rheology and the strength of geopolymer mixtures made with three key materials namely, flyash, silica fume, and GGBFS. The mixtures were formulated with varying amounts of flyash, silica fume, and GGBS.whereas GGBS and SF contents varied between 0-10% (by mass) of the overall binder content.Overall 10 trial conducted with variation in GGBS and SF contents. one mix showed a low yield stress value of 330 Pa. However, the mixes with SF and FA showed higher yield stress values. It could also be the result of the accelerated hardening of the mix after 20 minutes of mixing. The kinetics of the reaction were studied in the 3 mixes. The addition of SF in one mix led to a higher cumulative heat evolution.The addition of SF was also effective in controlling the yield and viscosity of the blends.

Guowei Ma.et,al.(2020) In this study, smart PZT patches were used to evaluate the mechanical properties of both 3D printed and mould-cast samples in the fresh and hardened levels during curing and post-curing. It is evident that the extent of the increase between three and seven days is greater than the increase over the following period. For the three cementitious samples, the average compressive strength was 34.8 MPa, 32.1 MPa, and 29.2 MPa. Comparing the compressed strengths of the printed samples FY and FZ to those of mould-cast ones, they show reductions in compressive strengths of 7.7% and 16.1%, respectively, whereas the 3D printed sample possesses the lowest compressive resistance.

Jun Ho Jo1.et,al (2018). In this research paper Author worked on to develop motion control used in mechanical machining devices with computerized numerical control CNC) programs. All experiment conducted in Seoul, Republic of Korea. To check the execution work with respect to CNC total length of Nozzle screw kept 300mm,Pitch 48mm, Diameter 50mm,Angle blade is 19° also it is designed for pitch to diameter ration is 0.96.To test material properties W/C ratio tested 0.30-0.32 flow measured 190 to 200mm.to get better rheology then again 0.4% sand added to mix sand maximum size was 0.7mm.it is found that this mix works properly but cracks were observed to eliminate crack PVA (Poly vinyl alcohol) fibres used.0.1%PVA given no clogging better and smooth flow through nozzle. With W/C ratio 0.30-0.32 Compressive strength tested and result found 60.4 and 62Mpa.

M. Papachristoforou.et,al (2018). In this research paper author researched on topic printing quality and dimension of printed layers, measurement of workability of fresh concrete, printability and final harden properties like compressive strength, ultrasonic pulse velocity and density. The all study and experiment conducted in Thessaloniki, Greece For experiment material taken are as follows 50% limsestone + 50% river sand maximum size of limestone and river sand considered is 1mm, Binder cement Type II 52.5 used at quantity 500 and 830Kg/m3.Flyash is 5%Ladle Furnace steel Slag (LFS) replaced 20 wt.%, Silica Fume (SF) replaced 10 wt.% of cement. Cement paste quality checked with Le Chatelier apparatus (EN 196-3:2005) Compressive strength measured in 40X40X40mm cube size at 28th days. Curing done in humid chamber., Expansion of concrete measured at flow table observed values lower is 18cm and upper limit is 24cm, Yield stress measured 200 -6000Pa, Vicat value measured 0.5 -30mmThere was two mixes 1)500kg/m3 2) 830 Kg/m3.in 1st mix upper limit of expansion observed 24cm and power consumption 630 watt. Replacement of LFS and FA decreased compressive strength by 30% and density by 10%. compared to mixtures with 100% cement as binder.

Marcin Hoffmann.et,al (2020). In this research paper author studied the construction with 3DCP with the lintel which is different material inserted in between layered construction.as per author mixes which has shear strength in between 03-0.9 Kpa are having best extrudability and buildability here author used W/C ratio is 0.23,70% CEM I 52.5R Portland cement,20%Flyash,10%Silica Fumes & density 2168Kg/m3.With above mix 113.7Mpa strength achieved in 28days.Lintel deflection calculation done considering maximum deflection. Ultimate strain is considered 0.04.it is observed that considering higher shrinkage cracks observed on the surface. pumping operations to be monitored in such a way that printing speed to be set considering the dimension of printing structure.

Manu Santhanam,et,al,(2020). In this research paper author have developed extrusion-based printing 3D concrete printing technology In IIT Madras. Two different grades of quartz sand, both having a maximum size less than 2 mm, and quartz powder having a maximum size less than 100 microns were used as fine aggregates. water cement ratio of 0.32% was used. Yield stress of this particular mix is found 1.6Kpa.

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This reference mix found to have low robustness. To improve robustness mixes additives like silica fume (10 % of binder content), nanoclay (0.1, 0.2, and 0.3 % of binder content) and methylcellulose-based viscosity modifying agents (0.1 % of binder content) were also developed.after doing different trials it was concluded that yield stress in the range of 1.5 to 2.5 kPa is needed to achieve both extrudability and buildability.

Ming Xia,et.al(2019). Here author observed influence of incorporation of fly ash on the properties of powder-based 3D printable geopolymer was investigated in this study. 7-day compressive strength found up to 24.9 MPa was achieved for the post-processed specimens printed with 50 wt% slag/50 wt% fly ash powder. more than 50 wt% fly ash) either did not have enough green strength to resist the de-powdering process. The lower compressive strength of the green samples with higher fly ash content is contributed to the low reactivity of fly ash at ambient temperature. This is because the higher amount of fly ash reduced the average particle size of the geopolymer powder, thereby increased the time needed for the binder droplet to completely penetrate into the powder bed.

Suvash Chandra Paul,et.al(2018). In this research paper author have done research about Rheological behaviour of 3D printable materials author had developed Mix details are as follows Mix 1 Slag: 39 Kg/m3, fly ash: 645 Kg/m3, silica fume: 78 Kg/m3, sand: 1168 Kg/m3, actigel:8 Kg/m3, bentonite: 8 Kg/m3, water: 47 Kg/m3.Mix2 Cement: 290 Kg/m3, fly-ash: 278 Kg/m3, silica fume: 145 Kg/m3, sand: 1211 Kg/m3, water: 285 Kg/m3, sodium lignosulfonate: 7 Kg/m3. Mix 3 Cement: 289 Kg/m3, fly-ash: 277 Kg/m3, silica fume: 145 Kg/m3, sand: 1209 Kg/m3, water: 284 Kg/m3, sodium lignosulfonate: 9 Kg/m3, glass fiber: 13.5 Kg/m3 (density: 2.7, tensile strength: 1.5 N/m2, young's modulus: 74 GN/m2, failure strain: 2%). The inclusion of fibers in Mix 3 leads to a higher static yield torque compared to other mixes Also Mix 1 reported here has lower ultimate strength at 28days is 36 MPa than other mixes.

Venkatesh Naidu Nerella,et.al(2019). Author had created Two printable mixes Combination C1 had Portland concrete (PC) because the sole cover, while Mixture C2 was made from a fastener containing 55 wt% PC, 30 wt% fly debris (FA) and 15 wt% miniature silica (added as 30 wt% of miniature silica suspension, MSS). Also, the glue volume of C1 was diminished to alleviate plastic shrinkage and warm anxieties, the 2 of which are partly higher for things , of upper concrete substance combinations. The secondary cementitious materials utilized in the case of Mixture C2 serve to some extent as ‘‘rheology modifiers” and ‘‘shrinkage reducers”. The below table explains trial outcome.

Trial no	PCE Content	Flow measured at 90min	Flexural strength	Compressive strength at 1day	Compressive strength at 28day
C1	0.75%	110-120MM	9.9&14.1	41.9, 35.9& 42.3Mpa	62.6, 60.9& 70.0Mpa
C2	2%	100-110	23.1	28.3, 28.2& 34.0 Mpa	98.9, 98.9& 96.3Mpa.

Yu Zhang,et.al,(2018). Developed concrete ink with addition of nano clay (NC) and silica fume (SF) concrete ink that has good fluidity during movement and satisfying standing behaviour at static state. Compared to the control mix, when the NC and SF were added into composites concrete with RA (CCR) than with SF addition alone (CS). In addition, a little increase was found for the fresh concrete with retard agent (CCR).The rate of heat of hydration for 3D printing concrete specimens with RA addition was lower, and the rate of hydration heat for specimens without additive was the lowest. The 2 h accumulative hydration heat of specimens with 2% NC replacement was lower than those of specimens with 2% SF, 2% NC and 1% RA, and the double-doped 2% SF + 2% NC. SF had the stronger hydration reaction than NC, but the change rate of the structure re-build of NC was better in the paste at static state.

A. Application in Construction

As in the application in 3D printing the step by step process involved in the onsite printing of a full-scale building can be described in two steps, namely, onsite printing of formwork layers using the printing mortar and addition of reinforcement using another automatic device. The offsite manufactured components of a building can be assembled on the site (Ayesha Siddika,et,al). As described by Duballet et al, horizontally printed layers on the floor can be moved in a vertical position to create a flat wall.Duballet et al.also described a printed beam with an additional reinforcing assembly. Adopting similar technique the company BAM Infra printed concrete bridge components, where the hollow units were printed in horizontal plan and finally assembled in structures. Although the method of printing varies High cost of printing with different manufacturers, the principles of final assembly of structures are similar(Ayesha Siddika,et,al).

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B. Challenges Involved in 3DPC Structures.

1) *Low Bond Strength Between Successive Layers:* The porosity trapped between successive printed layers possesses a challenge, resulting in inferior interfacial bond quality and decreased mechanical performance. Le et al. found a variation in tensile bond strength between successive layers of printing with different time gaps.
2) *Isotropy:* Printed concrete elements demonstrate inhomogenity behaviour under loading conditions. It is observed that the lowest strength is found when the loading direction is lateral to the printing direction. Therefore, the anisotropic behaviour of printed concrete varies with different printed layers, loading directions, and printing processes(Ayesha Siddika,et,al).
3) *Complications in Formwork Less Printing:* Large areas are open in air during 3DP because of the formwork-less construction system, which leads to the risk of cracking due to excessive drying shrinkage. The non-uniform shrinkage of two successive layers reduces tensile bond strength. (Ayesha Siddika,et,al).
4) *High Cost of Printing:* 3DP technology requires special and expensive machinery operation, which consumes more energy and cost than the conventional method. to operate machineries, skilled and experts are needed, which consequently charges more (Ayesha Siddika,et,al).
5) *Lack of Standards:* Specifications and standards remain lacking because 3DP technology, especially in concrete construction, is relatively new. The selection of the shape and size of printed elements still depends on the available printer's properties and the material properties (Ayesha Siddika,et,al).

C. Properties of Concrete in 3d Printing.

Fresh Properties: Due to the difference between conventional construction methods and the novel concrete printing process, it is important to consider the fresh properties of 3D-printed cementitious materials in accordance with the innovative printing technique (Zhanzhao Li.et.al, 2020).

1) *Flowability:* flowability ensures smooth transportation of the materials from the mixer to the printing nozzle. From the point of view of mix design, additives (e.g., chemical and mineral admixtures and reinforcing fibers) are the main factors affecting the flowability of fresh-state cementitious materials
2) *Extrudability:* Extrudability can be defined as the capacity of fresh paste to pass through the printing nozzle as a continuous and intact filament. The yield stress of materials to evaluate their extrudability using a rheometer. High static yield stress results in inadequate extrudability and blocking problems(Panda, B,et,al,2018).
3) *Buildability:* Buildability refers to the printed material's resistance to deformation under load.Without formwork, fresh materials must have sufficient buildability to be stiff enough after extrusion to sustain its self-weight, weight from the upper layers. (Ma,et,al,2017).
4) *Open Time:* Open time is identified as the time elapsed between the initial contact of dry mix and water and the time when the material is printable (flowable in the pumping system and extrudable in the printing nozzle). It is related to the change of the flowability with time(Malaeb, Z,et,al,2015 and Le,et,al,2012).
5) *Hard Properties:* To characterize the hardened properties of the printing mixtures merely by mold-cast samples. The effects of the novel manufacturing process on printed products can be better understood when compared to traditional construction methods(Zhanzhao Li.et.al, 2020).
6) *Density:* There are several factors that influence density, including pump pressure, printing speed, and printing path design(Le,et,al,2012).As per Le,et,al,2012.The well-printed specimens exhibited lower void content (1.0%) and higher density (2350 kg/m3) than mold-cast ones (3.8% and 2250 kg/m3).(Le,et,al,2012 and Panda, B,et,al,2017).
7) *Compressive Strength:* Compressive strength is very important factor considering life of structure. Apart from cube specimens, cylinder and prism specimens were also utilized to evaluate the compressive strength of printed materials(Nerella, V.N,et,al,2016). In some research , cast specimens show higher compressive strength than printed specimens; conversely, other investigations(Nerella, V.N,et,al,2016).
8) *Flexural Strength:* As compressive strength, flexural strength of printed components is also determined by loading(Zhanzhao Li,et,al,2020). In general, the maximum tensile stress takes place along with the extruded filament (i.e., longitudinal direction) at the central bottom area of the prism specimen, which governs the flexural strength.one of the experiment evaluated the effect of fiber and showed that an increasing weight percentage of glass fiber from 0.25% to 1% in the fly ash-based geopolymer mortar enhances the flexural strength of printed samples, irrespective of fiber lengths (3 mm, 6 mm, and 8 mm) (Panda,et,al,2017).

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9) *Tensile Bond Strength:* Measurements of bond strength between an old concrete substrate and new-cast concrete have been developed in terms of tension, shear, and torsion.Tension tests are mainly applied to evaluate the bond strength of printed structures. Similar to compressive and flexural strength, bond strength of the printed structures is also controlled by the printing time gap between extruded layers, which is mostly a function of the structure size. (Panda, B,et,al,2018).
10) *Shrinkage and Cracking:* Since high temperature leads to a high water evaporation rate, good curing with high humidity, as well as reasonable temperature, is ideal for better hardened performance of the printed materials. The curvature of the printing path also applies tensile stress to the freshly printed material. A smaller radius of curvature induces higher tensile stress, and therefore, the designed radii of curvature in the printing path should be over a critical value (Bos.F,et,al,2016).

D. 3D Printing Technology Impact on Construction Industry.

1) *Construction Time:* Construction time In construction, generally the longer the duration between the start of a project and the finished structure, the greater the financial cost of the project. Additive manufacturing offers several opportunities for this construction time to be shortened. Firstly, there is reduced setup time for manufacturing components with these new technique(Leal R,et,al,2017).
2) *Environmental Impact:* Construction uses vast resources; in the US it has been estimated to consume 36% of the total energy, 30% of raw materials and 12% of the potable water (Klotz L,et,al,2007). Globally, construction contributes to 30% of greenhouse gas emissions (Labonnote N,et,al,2016).Traditional construction techniques use standardised components - for example metallic structural cross-sections or reinforcing bar, for beams, columns, floors and walls that have unique dimensions. The components must therefore be cut down to size, ultimately producing waste and increasing the economic and environmental costs(Lim S, Buswell RA,et,al,2012).
3) *Reduced Labour Cost:* Additive manufacturing building processes are typically highly automated, reducing labour costs and reducing the risk of human error during the manufacturing process (Petrovic V,et,al,2011). The increase in automation will involve a step change from conventional, more manual, construction, with automated processes currently limited to sprayed concrete, precast concrete and milling operations(Lim S, Buswell RA,et,al,2012).
4) *Novel Forms:* Architects started using AM for small-scale building models as a way to present a concept of their design to a customer. Large-scale Additive manufacturing of end-user and building materials is allowing architects to produce more complex interior and exterior geometries that would be difficult and costly to produce using conventional construction processes(B. Khoshnevis,2004). AM allows architects to rethink their design and their forms, giving them more freedom without affecting complexity and productivity during construction(N. Labonnote,et,al,2016).
5) *Tolerance Matching/Correcting:* AM for tolerance matching. The construction industry is often faced with the challenge of having elements or modules on the construction site that do not have precise dimensions or sufficient tolerance for assembling them, requiring on-site modifications, complicating the assembly process, and delaying construction(V. Kalasapudi, P,et,al,2015). Matching issues with prefabricated components are due to the inability to maintain tight tolerances, introducing errors that propagate during construction that could risk the integrity of the structure(Y. Shahtaheri,et,al,2017).

V. CONCLUSIONS

After reviewing all research paper conclusions are as follows.

A. The improvement in the mechanical properties of printing concrete mixtures must be analyzed based on composition, printing technology, and loading conditions. In most cases, the mechanical properties of printable mixtures with sufficient compositions are reliable and comparable to those of moldcasted.(Ayesha Siddika,et,al,2019).
B. In comparison, the study by PWC (2014) found that some years ago, 25% of manufacturing companies were involved in prototyping using 3D-printing.(Nils O.E. Olsson,et,al,2019).
C. The rheological properties of fresh concrete are of higher significance, than in the case of conventional concrete construction, due to the specific process characteristics involved. Generally, the mixes used for 3D printing feature a higher binder content and lower water-binder ratio, which result in high shrinkage, including autogenous shrinkage of fresh concrete(Marcin Hoffmann et al 2020).
D. It is seen that workable mix maximum time of 30 minutes was obtained without using any retarder additives. the limestone mixtures required higher amount of water and super plasticizer in order to achieve the same level of workability with the other mixtures leading to lower values of compressive strength(M. Papachristoforou et al2018).

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E. 3d Printing concrete will introduce some changes in the stakeholders as well as in the cost structure. At this point in time, it is too ambitious to quantitatively present the cost structure, considering the different cost elements (labour, machinery, material, design and planning costs), 3d Printing concrete presents many potential opportunities to increase cost-effectiveness of construction processes in comparison to conventional construction methods(Geert De Schutter,et,al,2017).

VI. FUTURE DIRECTIONS

A. In future, additional research on different scanning patterns can be done to reduce the anisotropic nature of concrete printing process. (Biranchi Panda,et.al,2017).

B. More research is needed to be able to develop appropriate strategies for mitigating the formation of weak interlayer joints by adjusting material composition and process parameters as well as by using some chemical additive such as internal or external curing and application of a low-viscosity mineral-based primer before deposition of the subsequent layer. (Venkatesh Naidu Nerella,et.al 2019).

C. How to improve the coordination of the fresh material with the additive processes, and how to optimize the printing setting still needs further research and solution. (Guowei Ma.et,al.2020).

D. Further study on the relationship between screw speed and feed rate would be required to avoid defects such as discontinuity and clogging. (Jun Ho Jo1 et al 2018).

E. Further research concerning mix properties and 3D printing strategies will result in the development of design and construction procedures, which will ensure the required level of printed construction structural safety(Marcin Hoffmann et al 2020).

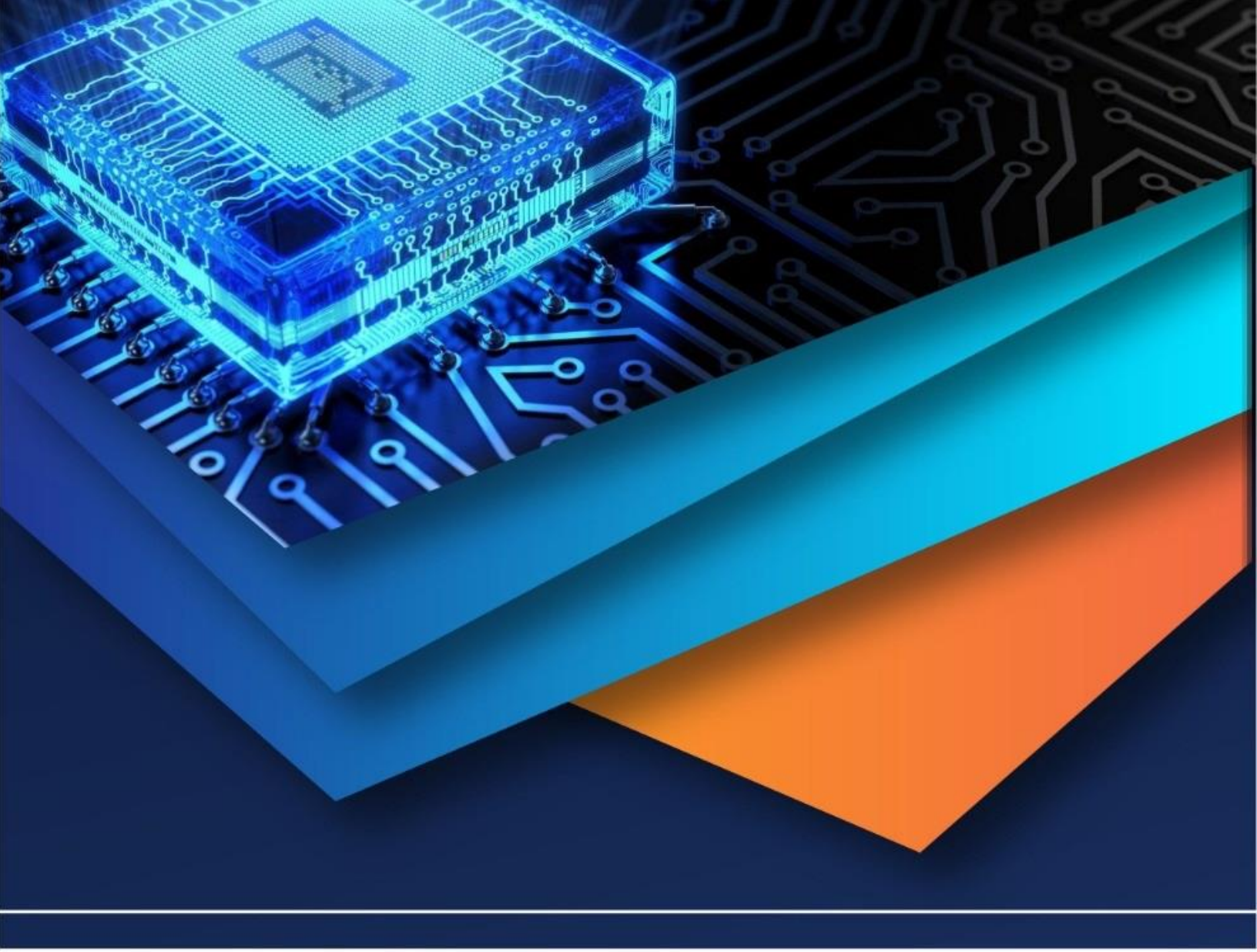
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