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Research and Application of Certain Materials 3d Printed Concrete Grade

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ABSTRACT: 3D printing technology is a modern technology that allows the production of products with complex structures directly from 3D models with computer support. The application potential of this technology in the construction sector is considered to be huge with the aim of improving traditional construction technology, using "green" materials in concrete production, reducing human resource needs, reduce waste and aim for sustainable development. However, the materials used to mix concrete have a great influence on the printing process. The paper approaches the study of the application of several qualitatively oriented 3 D printed concrete-mixing materials, for evaluation purposes affects materials to some features of 3D printed concrete: (1) Effects of fly ash come extrusion ability of printed concrete; (2) Effect of crushed sand on ability to maintain the shape of printed concrete layer; (3) Effect of PP fiber on uniformity and shrinkage reduction of printed concrete.
KEYWORDS:3D printing technology; Fly ash; Grind sand; PP yarn;

I. INTRODUCTION

1.1. Brief introduction to 3D concrete printing technology

3D printing is a form of technology known as additive/layered manufacturing (Additive Manufacturing). Applying processes create objects layer by layer. The American Society for Materials and Testing has come up with a clear concept for additive manufacturing technology: "Additive manufacturing technology is a process that uses materials to make 3D models, usually stacking layers of materials on top of each other, and this process is in contrast to the cutting process often used to make. fabricate ".To start 3D printing, one needs a 3D object design on CAD software, a familiar software that supports computer design. The model of the object is either designed directly on this software or incorporated into the software through the use of a laser scanning device. Once the design is completed, we need to create an STL document (Standard Tessellation Language) a form of document familiar with additive manufacturing technology. Making tesselate in the standard Tesselation language is to divide an object into smaller polygons, to simulate the external and internal structure of the object. This is a very important part of additive manufacturing.

It can be said that, with just over a decade of prosperity, 3D printer construction technology has conquered investors and researchers around the world with achievements that far exceed traditional construction techniques.

Figure 1: Buildings built using 3D printing technology in the world.

3D printing technology has been creating a revolution for the construction industry. Compared to traditional construction methods, construction using 3D printing technology uses completely printed materials different. Therefore, research on printing materials for this technology is a starting problem that plays an important and decisive role in the success of 3D printing technology. At present, however, national standards for this field are very limited, but are based mainly on published results of successful empirical research.

Currently, there are many other methods of building a project using a 3D printer that have been and are being developed. The potential and advantages of 3D printer construction technology are becoming increasingly feasible and convincing. Three types of 3D printing technology are mainly applied in the field of construction barns: border printing, full printing and block printing.

Accompanying these printing technologies are printing devices that are often designed in robot or frame form.

Figure 2: Printing technologies: border printing, full printing, block printing (from left to right).

Choosing printing equipment suitable to the scale of printing products needs to be considered because the cost of printing equipment ranges from 600 million VND to 3.5 billion VND corresponding to the size of the printed product (length x width x high) from 0.7x0.6x0.6m to 9.0x1.8x1.5m.

Figure 3: Some commercial 3D concrete printers.

1.2.Introduction to the trend of using 3Rs environmental protection materials (recycled materials, reused materials, minimizing material usage)

The trend in the use of 3 R environmental protection materials, with a focus on recycled, reused materials and reduced use of materials, is experiencing growth as the construction industry seeks more sustainable measures to minimize its environmental impact.

Recycled materials: The use of recycled materials in construction involves the reuse of waste materials such as crushed concrete, glass, plastic and steel as aggregate or filler in concrete mixtures. By reducing the demand for raw materials, construction projects can significantly reduce carbon emissions and contribute to resource conservation.

Reuse: Reuse requires leveraging and reusing existing building components or materials for new construction projects. This practice not only reduces the need for new materials but also conserves existing energy and resources. The reuse of materials such as wooden beams, bricks and metal fixtures can help extend their lifespan and reduce construction waste.

Reduce material use: Reduce material use involves optimizing the design and construction process to minimize the amount of material needed for a project. This can be achieved through effective design methods, such as the use of lightweight structures, modular construction systems, and advanced construction techniques such as 3D printing.

The integration of 3 R principles in construction is consistent with sustainable development objectives and environmental regulations, driving the sector towards more environmentally friendly practices. By adopting recycled materials, promoting reuse and reducing material use, construction projects can achieve significant benefits in terms of resource conservation, waste reduction and sustainability.

II. MATERIAL “GREEN” IN 3D PRINTED CONCRETE GRADE

2.1. Fly ash

Fly ash is an active mineral powder, capable of acting with cement hydrochemical products at normal conditions, or at high temperature conditions (moist heat machining ≤ 100^0C, thermal machining in autoclave). Fly ash in general exhibits only puzulanic activity, as assessed by the calcium lozenge of 1 gram of finely ground fly ash. Generally the degree of calcium lozenging in mg/g of fly ash depends on the fineness and nature of the material and on the temperature and reaction time. The higher the fly ash content (CaO +MgO), the greater the decrease in calcium lozenges, and at the same time the greater the fineness, the higher the temperature, and the longer the duration, the higher the calcium lozenges

Figure 4: Fly ash; Thermoelectric

Thermoelectric fly ash fired from anthracite and coal grades usually has a total content (CaO + MgO)≤10 – 15%, alkali index Mk<0.1; activity index Ma 0.2-0.8. Therefore, they can be classified as acidic or superacidic, they have strong puzulanic activity expressed in large levels of calcium retention.

Thermoelectric fly ash is usually low-alkali, mainly containing minerals of groups 2 and 3 in the mineral composition, these minerals are mostly in the glass phase so they have high puzulanic activity. The glass phase content in fly ash is usually lower than in slag, the unburnt coal composition is high, so the activity of fly ash is often worse than that of slag. Fly ash activity also depends on fineness, temperature,...so, the aforementioned comparisons are given at the same fineness and temperature conditions. At the same time, it must be noted that the activity of fly ash is different when they originate from different solid fuels, even if they originate from the same fuel source, there are very clear differences. Such differences are due to fluctuations in many parameters of fuel properties (fineness, initial mineral composition...) fire mode and ash discharge, among other reasons.

To evaluate fly ash quality, people often use the following indicators:

According to total content (CaO + MgO). Fly ash with low alkali content (CaO + MgO) = 10-20%, high content (CaO + MgO) <10% is called acidic or superacidic material. The fly ash of the majority of thermal power stations is of the acid type. Particularly for ash, there is also a way to classify into 2 groups: High alkalinity when the content (CaO + MgO) is ≥20%, low alkalinity when the content (CaO + MgO) is <20%.

Thermoelectric ash and slag are by-products of thermal power plants using solid fuels, coal. Depending on the combustion technology, the amount of ash and slag discharged at thermal power plants varies.

2.2. Grind sand

Artificial sand, also known as crushed sand, is sand that is crushed from stone naturally, mining waste rock or waste concrete after the demolition of the old structure... This material is being used by many countries around the world to replace natural sand materials. Not only that, artificial sand is popular because of its many outstanding properties. Sand has more rounded and even grains. Modules are easier to control and adjust to suit the coordination requirements of concrete.

Figure 5: Grinding sand

Concrete types such as cement concrete, asphalt concrete, high-grade concrete, roller compacted cement...Any natural stone with good strength and stability can be used to make artificial sand. Materials for making artificial sand such as: limestone, granite, sandstone, pebbles, hill pebbles, river pebbles, dust eyelashes, sieve eyelashes,...

The advantage of artificial sand is that the controlled size easily meets the classification required by each project. With properties that do not contain organic compounds and soluble compounds that affect the properties of cement. It is thus possible to maintain the required strength of the concrete.

– Artificial sand does not contain impurities such as clay or dust, so it will not affect the connection between cement and aggregate. This helps increase quality amount and durability of concrete.

– The surface of artificial sand is very smooth and consistent so it is very suitable for construction projects. They help to fill the gaps between the coarse aggregates. By reducing pore separation or capillary phenomena which will provide greater strength to the concrete.

– Artificial sand helps concrete withstand conditions in harsh environments. And reduce rebar corrosion by reducing moisture permeability and freezing effects.

– Using artificial sand mixed with concrete will use less water. Therefore, the concrete mixing process is also shortened. This will increase the productivity of construction activities at the construction site.

2.3. PP yarn

Polypropylene (PP) fibers are often used in concrete mixtures because of their ability to improve the toughness and durability of materials. When it comes to 3D concrete printing technology, incorporating PP fibers can offer a number of advantages:

Enhance structural performance: PP fiber helps reinforce concrete foundations, enhance tensile strength and reduce the risk of cracking. In 3 D concrete printing, where complex geometries are created layer by layer, the additional reinforcement provided by PP fibers can improve the overall structural performance of the printed elements.

Improved printability: The presence of PP fibers can enhance the rheological properties of concrete mixtures, making it more suitable for extrusion-based 3D printing processes. The fibers can help control the flow of the material, reduce deflection or slump during printing, and improve the stability of the printing layers.

Anti-cracking: PP fiber acts as an anti-cracking agent in concrete, limiting the spread of cracks and enhancing the durability of printed structures. This is especially beneficial in 3D printed components that can withstand varying loads or environmental conditions throughout their useful life.

Reduce shrinkage: By minimizing the effects of dry shrinkage in concrete, PP fibers can help minimize internal stresses and strains in 3D printed parts. This can lead to improved dimensional stability and overall quality of the printed structure.

Overall, the use of PP fibers in 3D concrete printing technology can contribute to the creation of high-quality, elastic structures with improved mechanical properties and longevity. By carefully optimizing fiber content and distribution in concrete mixtures, designers and engineers can leverage the benefits of PP fibers to create sustainable and durable 3D printing works.

Figure 6: PP yarn

III. COMPONENT PRINTING PROCESS

3.1. Print sequence

The process starts with a 3 D model of the printed pattern designed from specialized software such as SolidWork, Sketchup, etc.. Next, Simplify3D meshing and cutting software is used to create cross-sectional layers of the model, which are exported to G code format files and transferred to a 3D printer. The 3 D printer is operated using Mach3 software to print sample objects by printing each layer.

3.2. Design of printed concrete distribution level 3D

Design methods that coordinate printing materials need to meet printability requirements that are closely related to the printer and corresponding printing process; Therefore, 3D printing mortar is different from conventional printing mortar. During that level design process, extrusion and buildability must be considered first to ensure a successful printing process. The raw material of cement and sand must first be identified to ensure the extrudability requirement is appropriate to the nozzle size of the 3 D printer. Additives, fly ash, silica fume and fibers can be added to meet the requirements of buildability, setting time, strength, shrinkage.

Some gravel design methods for self-compacting concrete can be used for 3D printed mortar because these two types of concrete gravels have high requirements for rheological properties. As the development of 3 D printing mortars is in its early stages, studies of the mixed design approach for 3 D printers still have many limitations. Therefore, the design of printed mortar mix needs to be given more attention to achieve high efficiency in the near future. Based on the published research results, the authors propose three approaches to coordinate design for printed materials: approach from the point of view of stress; approach according to adhesive spread and approach according to scaling factor.

According to the stress point of view approach, indicates a printable material with a yield stress in the range of 1.5 ÷ 2.5 kPa namely a static yield stress higher than 4880 Pa and a dynamic yield stress lower than 220 Pa. This approach to design results in high compatibility with the printability of the material. However, this is a complex academic design method, the practical application is a bit cumbersome and requires precision.

Following the adhesive spread approach, simple formulations that determine the aggregate to adhesive ratio are simply introduced. According to the coefficient approach, the distribution level is designed through the coefficient of relationship between the material components of the distribution level. This coefficient is given based on the designer's experience and subjective perspective to find optimal coefficients between the material problem and the printing equipment. Through many repeated and repeated printing experiments, these coefficients are adjusted and so

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as to ensure that the use of this level to print the sample ensures the required conditions. On the basis of that inheritance, the authors have come up with a design process for mixing with the upper and lower binder sand/binder ratios such as 2.4 and 0.4, respectively.

IV. RESEARCH ON THE INFLUENCE OF MATERIALS ON SOME FEATURES OF 3D PRINTED CONCRETE

4.1. Effects of fly ash come extrusion ability of printed concrete

Fly ash is a byproduct of coal combustion in power plants and is often used as an additional binder material in concrete mixtures. When it comes to the extrudability of printed concrete, the introduction of fly ash can be effects:

Improved workability: Fly ash is known to improve the workability of concrete mixtures by acting as a filler material and reducing water demand. This can lead to a more cohesive and flowable concrete mix, which can enhance the extrudability of the material during 3 D printing. The improved workability provided by fly ash can help maintain the desired shape and consistency of the printed layers, resulting in a smoother and more uniform structure.

Reduce stratification: Fly ash can help reduce the risk of stratification in concrete mixtures, where heavier aggregates settle to the bottom and lighter materials float to the top. By promoting a more uniform particle distribution, fly ash can contribute to a more stable and consistent extrusion process in 3 D printing. This can help prevent layer separation and ensure the structural integrity of the printed elements.

Setting time: A potential challenge with the use of fly ash in concrete mixes is that the set time can be prolonged. Fly ash is a pozzolanic material that reacts slowly with calcium hydroxide in the presence of moisture, resulting in delayed hydration. This prolonged setting time can affect the extrusion speed and overall printing efficiency, as the concrete mixture may take longer to solidify and support subsequent layers.

Strength development: Although fly ash can improve the workability and durability of concrete, it can also affect the strength development in the early stages of the material. This slower strengthening may affect the extrudability of printed concrete, since the structural integrity and stability of the layers depend on the early bond formation between them.

Figure 7: The print is slightly cracked

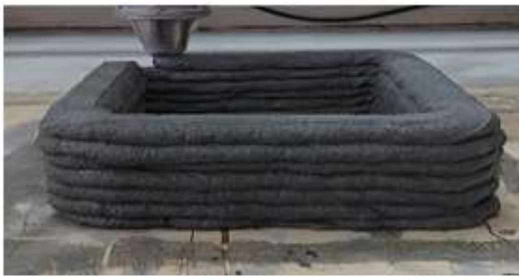

Figure 8: Uncracked print

4.2. Effect of crushed sand on ability to maintain the shape of printed concrete layer

The use of crushed sand in 3D printed concrete mixtures can significantly impact the ability of printed layers to maintain shape. Here are some key points to consider about the impact of crushed sand on maintaining the shape of 3D printed concrete:

Particle size distribution: The particle size distribution of crushed sand plays an important role in the ability to work and maintain the shape of the concrete mixture. Crushed sand with a well graded particle size distribution can improve density uniformly of the material, enhancing the cohesion and stability of the printed layers. The balanced distribution of fine and coarse particles in sand can help fill in gaps and improve intergranular bonding, leading to better shape retention during printing.

Surface texture: The surface texture of crushed sand particles can affect the strength of interlayer bonding in 3D printed concrete. Coarse and angular particles provide better interlocking and adhesion than fine and rounded particles. The surface roughness of crushed sand can enhance mechanical bonding between adjacent layers, promote shape stability, and reduce the risk of delamination or deformation during printing.

Porosity and porosity: The presence of excessive porosity or porosity in crushed sand can weaken the structure of printed concrete layers and compromise their ability to retain shape. Properly compressed and sorted crushed sand will help reduce porosity and porosity in the mixture, enhancing the density and strength of the printed layers. Lower porosity levels contribute to improved interlayer bonding and better shape stability in 3 D printed concrete elements.

Optimize composite design: To maximize the shape retention of 3D printed concrete layers, it is necessary to carefully optimize the composite design incorporating crushed sand. Balancing the properties of crushed sand with other materials such as cement, aggregates, and additives is critical to achieving the desired workability, strength, and shape-maintaining properties in printed structures.

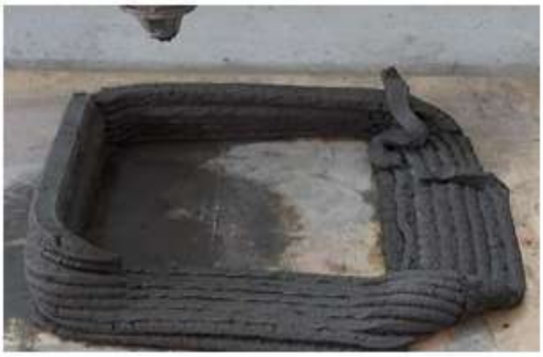

Figure 9: Pour pattern due to geometric deviation between layer 1 and layer 2

4.3. Effect of PP fiber on uniformity and shrinkage reduction of printed concrete

Polypropylene (PP) fibers can have a significant impact on the uniformity and shrinkage reduction of printed concrete in 3D printing technology. Below are the effects of PP fiber in the following aspects:

Uniformity: PP fiber helps improve the uniformity and consistency of the concrete mixture during printing. When added to the concrete mixture, the fibers are dispersed throughout the material, creating a more uniform distribution. This uniformity is important to ensure consistent layer deposition and structural integrity in 3D printed concrete elements. The presence of PP fibers can help prevent segregation and deposition of aggregates, creating a more uniform and stable printing structure.

Shrinkage reduction: One of the main benefits of using PP fiber in printed concrete is its ability to reduce shrinkage. Shrinkage occurs in concrete as it processes and loses moisture, leading to the formation of cracks and deformation. PP fiber acts as an internal reinforcement that limits the stress caused by shrinkage in the concrete matrix.

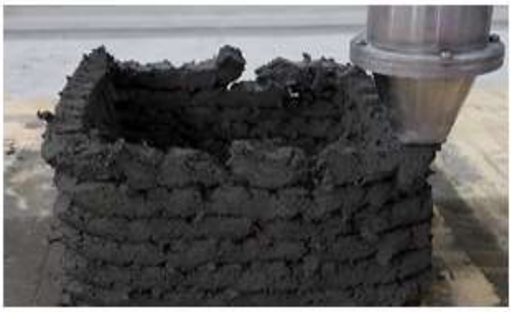

Figure 10: Print has no continuity

CONCLUSIONS

On the basis of the research content presented in the article, some conclusions are reached as follows:

(1) The effect of fly ash on the extrudability of printed concrete is multifaceted and depends on various factors such as composite design, curing conditions and printing parameters.
(2) The selection and use of crushed sand in 3 D printed concrete mixtures can significantly impact the ability of printed layers to maintain their shape.
(3) PP fibers in printed concrete mixtures can enhance material uniformity, leading to more stable printing results and improved performance print.

REFERENCES

[1]. Aremu, A. O., J. P. J. Brennan-Craddock, A. Panesar, I. A. Ashcroft, R. J. M. Hague, R. D. Wildman, and C. Tuck. 2017. “A Voxel-Based Method of Constructing and Skinning Conformal and Functionally Graded Lattice Structures Suitable for Additive Manufacturing.” Additive Manufacturing

[2]. Bendsoe, M. P., and O. Sigmund. 2004. Topology Optimization: Theory, Methods, and Applications

[3]. Carneau, P., R. Mesnil, N. Ducoulombier, N. Roussel, and O. Baverel. 2020. Characterisation of the Layer Pressing Strategy for Concrete 3D Printing.” Second RILEM International Conference on Concrete and Digital Fabrication, 185–195.

[4]. Chen, Y., S. Chaves Figueiredo, Ç Yalçınkaya, O. Çopuroğlu, F. Veer, and E. Schlangen. 2019. “The Effect of Viscosity-Modifying Admixture on the Extrudability of Limestone and Calcined Clay-Based Cementitious Material for Extrusion-Based 3D Concrete Printing.”

[5]. Craveiro, F., S. Nazarian, H. Bartolo, P. J. Bartolo, and J. Pinto Duarte. 2020. "An Automated System for 3D Printing Functionally Graded Concrete-Based Materials." Additive Manufacturing 33: 101146.
[6]. Delgado Camacho, D., P. Clayton, W. O'Brien, R. Ferron, M. Juenger, S. Salamone, and C. Seepersad. 2017. Applications of Additive Manufacturing in the Construction Industry – A Prospective Review." Proceedings of the 34rd International Symposium on Automation and Robotics in Construction, 246–253
[7]. Esfahani, M. H., F. Hejazi, R. Vaghei, M. Jaafar, and K. Karimzade. 2017. "Simplified Damage Plasticity Model for Concrete." Structural Engineering International 27: 68–78
[8]. Huang, Y., Z. Yang, W. Ren, G. Liu, and C. Zhang. 2015. "3D Meso-Scale Fracture Modelling and Validation of Concrete Based on In-Situ X-Ray Computed Tomography Images Using Damage Plasticity Model." International Journal of Solids and Structures 67–68: 340–352.
[9]. Kieback, B., A. Neubrand, and H. Riedel. 2003. "Processing Techniques for Functionally Graded Materials." Materials Science and Engineering: A 362 (1): 81–106
[10]. Martens, P., M. Mathot, F. Bos, and J. Coenders. 2018. "Optimising 3D Printed Concrete Structures Using Topology Optimisation." High Tech Concrete: Where Technology and Engineering Meet, edited by D. Hordijk and M. Luković, 301–309.
[11]. Nguyen-Van, V., N. K. Choudhry, B. Panda, H. Nguyen-Xuan, and P. Tran. 2022. "Performance of Concrete Beam Reinforced with 3D Printed Bioinspired Primitive Scaffold Subjected to Three-Point Bending." Automation in Construction 134: 104060.