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Nano Silica Particles as A Structural Build Up Agent for 3D Printing Cement Paste with Additional Accelerators

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Abstract. 3D printing also commonly known Additive manufacturing (AM) is the layering of materials by a computer to build 3D shapes of desired materials. It's very handy for prototyping and working with geometrically complicated materials. It was founded and developed in the 1980s, but it was a costly and demanding procedure at the time, with few uses. It became quiet relevant and inexpensive in the 2000 and a variety of applications which includes product development, component manufacturing, and tool manufacturing, plastic, aerospace engineering metalworking, Foot wear, dental and medical applications, and electronics. Even the household uses of 3D printers were happening. The construction sector also started using 3D technology and the systems used were called 3D printers for construction Computer-aided design, or CAD design, or the usage of a 3D scanner are both used to build a 3D model.

Introduction

The 3D printing printer reads and takes the design and lays down consecutive layers of a printing medium, which can be a liquid or a sheet material, which are eventually united to make the finished result. Although the whole procedure is slow, it can be utilized to make any shape. Based on the technique we select we can make multiple components continuously and we can use more than on material and color. Accuracy of the process can be increased by various methods like using Removes material from an enormous printed item using a high-resolution subtractive method. Use of dissolved materials that support overhanging features during fabrication is effective in some process. 3D printing can be used to make building components or to make the whole building. It gained popularity in the construction field since it’s already experienced in the computer aided design and manufacturing. The building information modelling or BIM can make use of 3D printing in to a new level.

By the use of 3D printing we can achieve faster and accurate construction of components by lowering man power and waste generated and thus decreasing the overall expense. It can also decrease the risk factor in harsh and dangerous places which is not ideal for human forces. Recent researches towards automated construction have paved the way to the advancement of many strategies and ideas in additive manufacturing. The various techniques now available are contour crafting, D shape and concrete printing. These are considered very nature friendly and effective which makes the construction faster . The use of Nano silica in the development of cement-based matrices for use in 3D printing is found to better the cement's rheological qualities and thus increase the efficiency of the 3D printing process. Further studies have to be done to see the whether there is any change in cement rheological characteristics with the addition of chemical accelerator with Nano silica particle which is added to the cement.

Objectives

To see if combining a chemical accelerator with Nano silica particles in a cement-based matrix formulation for 3D printing provides access to the Nano particle's full potential.

Literature

3D printing is a computer based production of 3 dimensional shapes and sizes.3D printing is considered as the next big thing in construction and has a huge scope for research. Recent discovery and advancement of artificial intelligence has paved Techniques like contour shaping, D-shape, and concrete printing have paved the path for additive manufacturing to advance. These methods are quite effective. can attain eco-friendly cheaper and reliable ways of construction. Different researches considered many set of parameters. This chapter gives salient features of experimental investigations.

Underwater 3D printing of cement based mortar –Ibrahim mazhoud 30th July 2019

The development and advancement of renewable marine energies is needed to face the global warming situations going continuously with the development of automated and digital based construction methods such as 3D printing. Advancement in this area could lead to the change in offshore construction methods. Through studies researchers have reported, the stability and strength of the structure through printing can be seen as a competition between the rarity of cement-based material structural build-up and the rate of increase of load acting on the entire structure.

Extrusion-based 3D printing with micro wire reinforced geopolymer composite January 2019

To enhance and increase cementitious materials' toughness and post-crack moment capacity for extrusion-based 3D printing, additive manufacturing is used in the methodology process. The material used is a fly ash based geopolymer. This research proposes a method for improving cementitious material toughness and post-crack moment capacity.

Nano silica particles as structural fillers in Portland cement pastes for 3D printing January of the next year Oscar A. Mendoza

This paper gives a 3D printing-based comparative investigation of the influence of nano silica particles on the characteristics of Portland cement. Different solid substitutions of cement by pozzolanic particles were used to make cement pastes. After varying amounts of resting time, their yield stress was measured. The rate of thixotropic accumulation of each paste was calculated using the rheological results. The parameters of a perfect 3D printing process were calculated using these data.

Jian Gong uses cellulose nanocrystals as a support material for 3D printing complexly formed structures using multiple materials. August of this year

To produce very high complicated structures sacrificial support materials is required Traditional petroleum-based support materials cannot be taken as sustainable and it cannot by recycled. In place of them cellulose nanocrystals gel can be used as a 3D printing due to its sustainable and renewable properties. CNC is produced from forestry and natural products which is water based and with the use of this material the entire 3D printing process can be made environmentally safe. This paper sees the potential of CNC material as a 3D printing material and use of it for advance applications

3D printing for building with a polymer-foam and concrete complicated wall August 2019 Yulin Huang

This paper introduces a new additive manufacturing approach for concrete structure construction.. The materials used for this proposed idea consist of a two polymer foam printer walls which is used to contain a 3rd wall. This method uses a mobile polyarticulated robot. The foam used is for internal as well as external insulation to the structure. This paper also talks about the potential of doing 3D printing using clay or other earthly materials.

Methodology

Materials

Portland cement

This study looked at class g cement pastes that met API specification 10A/IS010426-1.is used. Portland cement can be used. It is the most common type of cement used around the world as a basic element in concrete, mortar, stucco, and non-specialty grout. It was created by Joseph Aspdin in the late 1800s in England from several types of hydraulic lime, primarily limestone. It is made by forming clinker from limestone and clay minerals in a kiln, grinding it, and adding a specified percentage of gypsum. The most prevalent type is ordinary Portland cement, or OPC. Cement should be free of impurities, lumps, and other foreign materials.

Nano silica

Although nano silica is not a typical material used in concrete, silica fume, which is hazardous, has been employed in micro silica for decades, and high-performance concrete has been produced. It helps refine the pore structure and enhance characteristics even at a low level of replacement because to its fine particle size, which speeds the hydration process early. Using micro silica in concrete is getting popular even though its high cost due to tis pozzolanic behavior. Due to its finer size micro silica fills the remaining voids and thus decreases porosity. The replacement of Nano silica reduces CO2 emissions.

Accelerator

A cement accelerator is a sort of additive used in concrete and mortar that reduces the time it takes for the concrete to set, allowing it to cure sooner. This is beneficial in the winter since it reduces the possibility of frost damage to concrete. Common type of chemicals used in accelerators are calcium nitrate, calcium chloride, calcium nitrite, and calcium formate.

Viscosity modifying agent

VMAs (viscosity modifying agents) are admixtures that change qualities like viscosity workability and cohesion. It has no effect on the yield point of concrete. Some of the type of concrete which uses VMA are

- self-compacting concrete
- pumped concrete
- under water concrete
- light weight concrete
- semi dry concrete
- porous concrete
- concrete with poorly graded aggregates

Cement pastes were made with a 0.45 water-to-cementitious-materials ratio, 0.60 percent VMA addition by mass of cement, and solid cement replacement with Nano silica for this experiment.

Table 1 Formulation of paste used for study

Particle type	Cement	Nano particle	VMA	accelerator	w/c ratio
Nano silica	99%	1.00%	0.60%	1.00%	0.45%

Using the paste shear test was conducted to find shear stress.

With this experiment we have to find the shearing angle and shearing stress. Using equations we have to find rheological properties like rate of thixotropic build up, maximum layer height, and maximum horizontal velocity.

Fig 1. VMA or viscosity modifying agent

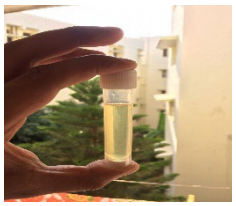

Fig 2. Accelerator

Results

Nano silica is substituted to the cement particles and with the addition of vma and accelerator pastes are made. The quantity of substances added to the cement is specific and are recorded. Shear test and shearing angle have to be found out of this paste at different resting times and the data's should be analyzed.

Table 1 formulations

Particle type	Cement	Nano particle	Viscosity modifying agent	Accelerator	Water cement ratio
Nano silica	99%	1%	0.60%	1%	0.45%

The specific mass and theoretical density of Nano silica particle is noted down.

Table 2 specific mass

Particle	Specific mass(g/cm^3)
Nano silica	2.50

Table 3 theoretical density

Sample	ρ (g/cm^3)
Nano silica	1.885

$$\rho = \frac{\varepsilon mi}{\varepsilon \frac{mi}{pi}} \quad \text{——— 1}$$

Where,

VMA is the mass of the ith component, including water. Mi is the mass of the ith component, including water.

The specific mass of the ith paste component is Pi.

Density is calculated and compared with theoretical density

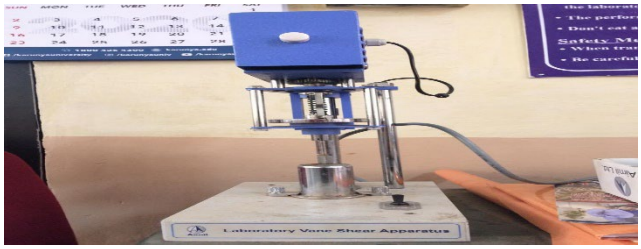

Fig 3 Vane shear apparatus

Vane shear test is done for the paste to find the shear stress and shearing angle with different resting times of the paste after mixture. The resting time is taken from other journal papers which have conducted similar tests. Initial reading and final readings are taken of the pastes with different resting times. Using formulas from the given data torque T and shear stress are calculated.

Obtained data's are recorded in table 4

Vane shear test results for finding shear stress and shearing angle

D=12mm H=24mm

Table 4 vane shear test to find shear stress and shearing angle

Sl no	Resting Time in minutes	Initial reading Ɵ1	Final reading Ɵ2	Ɵ	Torque T	Shear stress
1	0	165	190	25	1.11	0.1943
2	23	172	219	47	2.08	0.3652
3	45	227	276	49	2.177	0.3808
4	68	178	237	56	2.48	0.4352

$$T = \frac{\theta \times k}{180} \quad \text{———— 2}$$

$$s = \frac{T}{\pi\{\left[D^2\frac{H}{2}\right] + \left[\frac{D^3}{6}\right]\}} \quad \text{——— 3}$$

From earlier studies it was found that With just Nano silica, the initial yield stress and rate of thixotropic paste building are increasing.1% of Nano silica was used for such studies as Due to the rheometer's restrictions on the greatest shear stress that could be applied, bigger levels of Nano silica could not be evaluated.

$$\tau_{0,t} = A_{thix} \times t + \tau_{0,fit} \quad \text{——— 4}$$

Where Athix is the linear equation's slope, t is the resting period of zero, and fit is the static yield stress obtained from the fitted equation at t=0.

Using this formula Athix is calculated of pastes with different resting time and is recorded in table 5.

Table 5 rheological properties

SL no	Resting time	A thix
1	23	$7.43x10^3$
2	45	$4.14x10^3$
3	68	$3.542x10^3$

From this data we can calculate h max using formula and check the change is rheological properties

$$h_{max} = \frac{\tau_{0,fit}\sqrt{3}}{\rho g} \quad \text{——— 5}$$

H max=0.0714

$\tau_{0,fit}$=0.1943

ρ=2.50

g=1.885

It has been found that cement paste with resting time 23 minutes is showing better rheological properties as it's A thix and hma values are higher than other resting time values. Athix for cement paste without accelerator at resting time 23 minutes was 6.45x103. The resting time is the time between densification and rheological testing.

Conclusion

Nano silica is found as an effective thickener for paste of cement and is proved in order to increase all the parameters and properties related to a material's structural build-up agent. By the experiment done its been found that using Nano silica with the addition of accelerator rheological properties of cement paste is increasing for one of the resting times.

Scope of future study

Experiments should be done with a higher concentration of NS It was unable to be tested due to the rheometer's limitations on highest shear stress. The type of change in characteristics that will occur on cement paste with increasing concentrations of NS is unknown, but the linear trend is expected to continue.

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