

PROSPECTS OF THE USE OF COMPOSITE SUMI-SHEES ON LIGHT AGGREGATES IN THE CONSTRUCTION 3D PRINT

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Анотація

У роботі досліджено склад і властивості сумішей для адитивного будівництва. Проаналізовано вплив спученого перліту, вермикуліту та армувальних мікрОВОЛОКОН на реологічні властивості свіжого бетону та експлуатаційні характеристики затверділого каменю. Визначено параметри екструдювання та стабільності шарів.

Ключові слова: 3D-друк, спучений перліт, мікрОВОЛОКНО, реологія, екструдювання, енергоефективність.

Abstract

The paper investigates the composition and properties of mixtures for additive construction. The influence of expanded perlite, vermiculite and reinforcing microfibers on the rheology of fresh concrete and the performance characteristics of hardened stone is analyzed. The parameters of extrudability and layer stability are determined.

Keywords: 3D printing, expanded perlite, microfiber, rheology, extrudability, energy efficiency..

Introduction

The modern construction industry is currently at the stage of digital transformation, where additive manufacturing technologies (3D printing) are becoming a key tool for increasing productivity. The implementation of robotic complexes allows for a reduction in construction time by 60–80% and a decrease in total costs by up to 60% due to the complete elimination of formwork, minimization of waste, and a reduction in the share of manual labor. However, the widespread adoption of the technology is hindered by the lack of unified mixture compositions that simultaneously satisfy conflicting requirements: high fluidity for pumping through long pipelines and instant structural strength to support the weight of subsequent layers. The development of composites based on lightweight mineral aggregates is becoming particularly relevant, allowing for the combination of printing speed with high thermal insulation characteristics of building envelopes, meeting modern energy-saving requirements. Furthermore, in modern times, 3D printing is seen as an effective tool for the rapid restoration of housing. The main scientific vector is directed toward the development of lightweight composite materials that will replace heavy materials, providing high thermal resistance for building envelopes without the need for additional facade insulation.

Research results

Concrete for 3D printing is a high-tech cement composition with precisely tuned rheological characteristics, where a key role is played by the balance between extrudability (the ability to be continuously pumped through a nozzle) and buildability (the ability to maintain shape) [6]. The scientific basis of the process is the material's thixotropy: the mixture must have low viscosity under shear stress in the pump and a high static yield stress at rest, which ensures immediate self-support and stability of lower layers to cumulative deformations under the weight of subsequent layers [8]. In addition, to ensure structural integrity and maintain its mechanical properties, the mixture must guarantee high interlayer adhesion and compensate for intense autogenous and plastic shrinkage through dispersed microfiber reinforcement and optimization of the filler granulometric stack [3].

The concretes to be used are special mixtures based on Portland cement (40-45%) with the addition of fine-grained sand (30-35%) and modifiers (20-25%). The hardening speed is 2-3 hours, which is ideal for layer-by-layer printing. Furthermore, such construction is environmentally friendly—using up to 30% recycled materials (slag, ash) reduces CO₂ emissions by 40%. It enables waste-free production due to precise calculation of the required printing volume [7].

It has been established that for successful 3D printing, the mixture must ensure continuous extrusion (Fig. 1) through a nozzle (Fig. 2) with a diameter of 9 to 30 mm. Pumpability refers to the ease and reliability of pumping concrete through the delivery system (from pump to nozzle). Printability or extrudability refers to the material's ability to be extruded through the nozzle in the form of a continuous filament. The filament

should show minimal cross-sectional deformation and an acceptable level of splitting or tearing [6]. Buildability is the ability of extruded concrete layers to withstand the load of layers placed above without noticeable settlement [8]. Printed concrete filaments must have sufficient strength and stiffness to avoid significant deformation after subsequent filaments are applied.

Open time is the duration during which the concrete mixture can be used in the 3D concrete printer. If concrete is extruded after the open time ends, the mixture may be too hard for extrusion. Additionally, open time is related to the hydration rate of the concrete mixture. Sufficient adhesion must exist between subsequent layers without forming "cold joints". Open time affects pumpability and extrusion. On the other hand, open time is significantly influenced by the mixture's viscosity and yield stress.

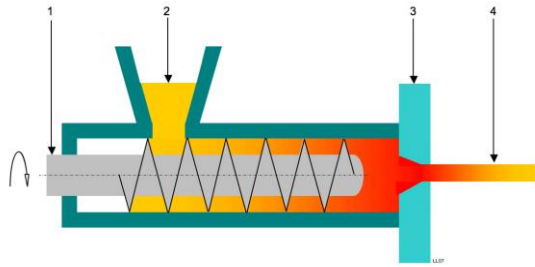


Fig. 1. Extrusion process diagram



Fig. 2. 3D printer nozzle

The use of an optimal water-cement ratio of $W/C = 0.27$, in combination with plasticizers, provides the necessary "open time" (30–60 min) for interlayer adhesion without the formation of "cold joints" [6]. Innovative 3D clay printing (Fig. 3) is a cutting-edge solution that combines environmental friendliness and significant resource savings. This technology allows for a 95% reduction in production costs and the creation of exceptionally strong structures (15–20 MPa), suitable for constructing three-story buildings with a projected lifespan of over 50 years [1].

An additional advantage is the low thermal conductivity of the walls (0.5–0.7 W/(m·K)), which provides up to 30% energy savings. Additive manufacturing also opens unprecedented opportunities for architectural design, allowing for the realization of complex geometric shapes, domes, and arches with high precision and variable wall thickness (15–40 cm) [7].



Fig. 3. House built using clay and 3D printing

Mixtures containing fibers exhibited the best workability characteristics, as the fibers improved the binding properties of the mixture [2]. The mixture containing polypropylene fibers showed the lowest workability in the ASTM flow table test, which remained consistent in subsequent tests, as it extruded a narrower and less dense filament. The optimal mixture was the one containing PVA fibers (Fig. 4), with a sand-to-binder ratio of 3:2 and a water-cement ratio of 0.27. This mixture possessed optimal workability and extrudability characteristics and demonstrated minimal deformation under the load of subsequent layers.



Fig. 4. PVA fibers

They create an internal framework that restrains the expansion of microcracks. Structural optimization using micro-fillers (shell limestone) allowed for a compressive strength of up to 120 MPa and record-breaking durability indicators: frost resistance F400 and water resistance W20, which guarantees the reliability of structures for over 100 years [5].

Conclusions

Additive manufacturing of concrete is a promising technology. It has the potential to revolutionize the concrete construction industry due to its ability to produce architectural and structural components without the limitations of formwork, the opportunity to automate design and construction stages, increase the accuracy of concrete placement, and improve the health and safety of workers, among other benefits [6-7]. The rheological properties of the mixture are the determining factor for the success of 3D printing. The use of chemical additives in combination with porous aggregates allows for the creation of a mixture that is easily extruded but instantly gains structural strength [4].

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