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Influence of structural and technological parameters on the quality of 3D printing of building structures

ABSTRACT

The article provides a review of publications presenting results on the influence of design and operational parameters of 3D printers as well as technological factors, on the quality characteristics of extruded construction mixtures and concretes based on them. Experimental data are presented on the influence of the shape and diameter of the extrusion nozzle of printers, the nozzle movement speed and the feed rate of the construction mixtures on the quality characteristics of the extruded layers and their adhesion. Date on the influence of 3D printing resolution, the accuracy of mechanisms and their kinematics are analyzed. A proposed scoring system for assessing of mixtures extruded from the printer nozzle is presented. A review of studies on the influence of the technological properties of extruded mixtures is presented. The possibility of achieving the required balance between workability, which determines formability and sufficient structural strength of the extruded mixtures is demonstrated. Studies aimed of achieving high interlayer strength of extruded concrete are also consider including the effects size distribution and the time interval between the placement of individual layers. Based on the generalization of data obtained by various researchs the authors present the desired values of the main properties of concrete mixtures and concretes based on them for, 3D printing of building structures. The importance of further research aimed at reducing cement consumption throw the use of various additives, optimization mixture compositions and improving both economic and environmental efficiency of 3D printing of construction structures is substantiated.

Keywords *3D construction printer, extrusion, nozzle, extrusion quality, splitting tensile strength,interlayer strength, rheological properties, designing concrete mixtures, size distribution, mineral additives.*

1. INTRODUCTION

The introduction of 3D printing into the construction industry is a new effective stage in the progress of this industry. The main positive features of this technology are material and energy saving, as well as reduction of labor costs [1–5]. The construction industry accounts for a significant part of global CO_2 emissions and the consumption of more than 50% of natural raw materials annually [1, 6], therefore increasing the scale of application of 3D printing in construction is an urgent economic and environmental problem. Additional advantages of 3D printing are the speed of construction, the possibility of erecting structures with increased architectural expressiveness while simultaneously reducing material waste and labor costs [7–9].

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The plans of the European Union envisage reducing raw material by 2030, the EU should have the capacity to extract 10%, process 40% and recycle 25% of the strategic raw materials it consumes [10]. For Ukraine, this task, taking into account the need for post-war reconstruction, is especially relevant.

Studies show that 3D printing reduces material waste used in the construction of structures by this method by up to 60%, increases construction speed by 50%, and allows the use of environmentally friendly materials [11–13].

In construction, portal and robotic, as well as mobile printer systems are used for 3D printing. Portal systems are characterized by stability and speed and are suitable for the construction of large structures, including residential and commercial buildings; robotic systems are effective due to their flexibility and the ability to create complex architectural structures [14–15]. Mobile printers are mounted on tracked or wheeled platforms, which allows them to move freely around the construction site. Mobile 3D printers provide minimal material consumption and fast printing, but have a limited working area.

The quality of 3D printing is significantly influenced by the design features of printers [16, 17], as well as by the technological parameters of 3D printing.

2. EXPERIMENTAL RESULTS AND THEIR ANALYSIS

Influence of structural parameters of 3D printing. The key parameters of 3D printers used in construction are the shape and diameter of the nozzle, extrusion speed, and layer height and width.

An important feature of 3D printers is the geometry of the printer nozzle [18]. Extrusion nozzles can be classified by shape; they can be circular, elliptical, square, and rectangular. Nozzles have a significant influence on the flow behavior and deformation of printed concrete. It is noted that the reduction in mechanical strength of the extruded material is associated with the circular geometry of the nozzle, as this contributes to the generation of air voids in the printed layer and causes stress concentration. In contrast, rectangular nozzles contribute to a larger contact area between layers, which positively affects the strength of the concrete. At the same time, circular nozzles are most commonly used, as they provide greater flexibility and the ability to print architecturally complex structures.A comparison of circular and rectangular nozzles by key parameters is given in Table 1 [18-21].

Circular nozzles provide more versatile operation, high accuracy, and good repeatability when printing complex geometries. Rectangular nozzles, in turn, are optimal for forming uniform surfaces, increasing productivity, and improving adhesion between passes. The choice between them should be based on the requirements for mechanical properties, productivity, and the level of detail of the product.

Along with the shape, the *nozzle diameter* also has an influence [18]. This is related to the contact area between layers, which depends on the nozzle diameter, as well as the effects of extrusion stress and gravity—factors that lead to reduced porosity and improved mechanical behavior of extruded concrete.

The rheological behavior of printable mixtures and the quality of printed concrete are significantly influenced by *the movement speed of the nozzle* and *the feed rate of the building mixture* [22–27]. At insufficient extrusion speed, discontinuous layers, increased porosity, and reduced interlayer adhesion may occur. A significant influence of printing speed on layer adhesion, as well as on pore formation and size, has been established.

Table 1. Comparison of nozzle shape

№	Parameter	Circular cross-section	Rectangular cross-section
1	Flow stability	High, symmetrical	Depends on orientation, less symmetrical
2	Accuracy of small elements	Better	“Over-extrusion” may occur at corners
3	Area coverage	Moderate, requires more passes	Very efficient
4	Surface smoothness	High at low layer heights	High even at thicker layers
5	Interlayer adhesion	Good (elliptical profile)	Potentially higher (flat profile)
6	Quality of curvilinear contours	Optimal	Segmentation possible with sharp changes in direction
7	Stability during layer-by-layer build-up	Worse due to narrower contact profile between layers	Better

It directly affects the formation of the extruded layer and the accuracy of reproducing the design geometry, which in turn determines the quality of the printed structure or building. In particular, these parameters determine the shape and uniformity of the extrusion layer, geometric accuracy, and interlayer adhesion of the material: when the nozzle movement speed increases without appropriate adjustment of the material feed rate, the probability of uneven extrusion and layer defects increases, which leads to a decrease in surface quality and mechanical characteristics of the structure [19].

Analysis of the literature shows that the ratio between the nozzle movement speed and the material feed speed, as well as the height of the nozzle above the lower layer, significantly determines the cross-sectional shape and uniformity of the layer: a lower ratio ensures more uniform geometry and better structural integrity of the printed element [21].

It has been experimentally shown [16, 21] that an increase in printing speed leads to a decrease in both the mechanical properties of concrete and its durability. Increasing the printing speed to ≤100 mm/s resulted in chloride penetration 20 times greater than at an optimized extrusion speed. It was shown that at a printing speed of 50 mm/s, the extruded concrete exhibited the highest strength values in both compression and bending.

The strength of concrete is significantly affected by the duration of the *interlayer interval* during printing [28-30]. An extended interval substantially reduces the compressive and tensile strength of concrete. The greatest moisture loss and the highest pore volume were recorded within the first 10 minutes of movement.

An important parameter of 3D printing is resolution [16, 21], which determines the minimum size of an element (layer height or line width) and affects the accuracy of geometric shapes, structural strength, and surface quality. It is usually limited by the nozzle diameter. High resolution allows the creation of complex architectural forms but increases printing time. Lower resolution (larger nozzle diameter) leads to a rough surface texture, which often requires additional finishing. Optimal resolution ensures better structural integrity. The higher the resolution, the slower the construction process.

The accuracy of mechanics and kinematics can be assessed by deviations from the required geometric parameters. The mechanical design of the printer (guides, belts, lead screws, frame stiffness) determines the stability of the movement of the printing system, which may cause instability in straightness and printing accuracy according to the programmed path [31-32].

Low stiffness or backlash leads to: vibrations, layer shifting, deformation of geometry.

High kinematic accuracy:ensures repeatability of positioning, improves interlayer adhesion, reduces shape errors.

Based on the conducted observations, a quality scale of the extrusion layer produced using a 3D printer was proposed [32, 33]. This scale is expressed in arbitrary units (points) from 1 to 5 and is described in Table 2.

Table 2. Scale for evaluating the quality of mixture extrusion from the printer nozzle

Quantitative evaluation (points)	Description
1	Extrusion with the formation of significant defects that do not allow forming a structure
2	Extrusion with the formation of minor breaks and bulges on straight and curved printing sections. Does not allow printing structures or buildings
3	Satisfactory extrusion with variable layer geometry (non-uniform thickness and height of the layer), as well as the formation of voids (incomplete filling of the layer cross-section with the mixture). Does not allow printing structures or buildings to full height continuously, as the geometry of deposited layers is disrupted and leads to failure.
4	High-quality extrusion of the mixture on straight sections and the formation of breaks and bulges on curved printing sections. These shortcomings may be acceptable, provided that the structure or building meets strength requirements and appearance criteria.
5	High-quality extrusion of the mixture on both straight and curved printing sections

Influence of technological parameters of 3D printing. For the effective implementation of the printing process, it is necessary, on one hand, to ensure sufficient *plasticity* (workability) of the mixture for its delivery to the extruder nozzle and extrusion, and on the other hand, the mixture must have sufficient strength in the viscoplastic state (*structural strength*) to maintain the shape of the layer directly at the moment of printing and after being loaded by the upper layers [33-36]. Obviously, these characteristics of mixtures for 3D printing differ significantly from the rheological properties of traditional concrete mixtures [38].

In construction practice, the standardized rheological characteristics of concrete mixtures are workability, stiffness, and viscosity, which are regulated according to the requirements of normative documents. However, these parameters only characterize the consistency of the concrete mixture, while none of the indicators account for its ability to hold shape, making them unsuitable for evaluating mixtures suitable for 3D printing. Therefore, there is a problem in justifying a comprehensive indicator for assessing the viscoplastic properties of mixtures for 3D printing and a method for its operational control.

When 3D printing with fine-grained concrete mixtures, to ensure the necessary formability (extrudability) from the printer nozzle, it is necessary to achieve the required consistency. In turn, formability or extrudability can be characterized as the ability of fine-grained concrete mixtures to be extruded from the printer nozzle without cracks or delaminations along the length of the beam during linear and curvilinear formation [35, 36]. In this case, a very important factor is the need to find a balance between sufficient workability for extrusion and high structural strength after formation [39, 40].

Several authors have conducted studies that made it possible to generalize, to some extent, the necessary rheological properties of materials suitable for 3D printing [34, 37]. Overall, the rheological characteristics of concrete mixtures depend on the mixture composition, which is related to the quantitative and qualitative characteristics of the components, in particular the type of Portland cement, the type and amount of mineral additives, the presence of chemical additives (superplasticizers, accelerators, and hardening activators, etc.), the granulometric composition and shape of the filler particles, as well as the water-to-binder ratio [41-47].

In 3D printing technology, one of the determining indicators of the quality of printed structures is *interlayer strength*, as it ensures the uniformity and spatial integrity of the printed element. Unlike traditional concreting, where the material structure is formed simultaneously throughout the volume, in additive manufacturing the structure is created layer by layer, which results in potentially weakened contact zones between adjacent layers. Insufficient adhesion in these zones can lead to anisotropy of mechanical properties, reduced load-bearing capacity, and decreased durability of the products [48-54].

It is advisable to assess interlayer strength using tensile-splitting strength indicators, which quantitatively represent the strength limit at interlayer failure along the contact surface. This approach allows for an objective characterization of the mixture's adhesive capacity, the effectiveness of introducing modifying additives, and the influence of technological printing parameters on the formation of structural bonds in the interlayer zone.

An insufficiently studied problem related to the development of mixtures suitable for 3D printing is the investigation and establishment of the necessary properties of concrete and mortar mixtures that allow the formation of structures or buildings by extrusion under certain 3D printer design parameters. Compared to flowable and cast concrete mixtures used in traditional technology, the absence of formwork to ensure stability of mixture characteristics during printing is the main reason for this problem.

In 3D printing with fine-grained concrete and mortar mixtures, to ensure the necessary formability (extrudability) from the printer nozzle, contradictory requirements for rheological characteristics must be met: high workability and thixotropic thinning during pumping and extrusion, as well as increased plastic strength after deposition in a resting state to create a layer-by-layer structure [36, 48, 55]. Therefore, these mixtures must have relatively low slump flow and high thixotropy to be usable in 3D printing technology [56, 57]. Accordingly, when changing the maximum grain size and particle size distribution, the above rheological characteristics can change significantly, which will be accompanied by a deterioration of properties and their suitability for formation on a 3D printer.

Many studies [36-40, 58, 59] have focused on investigating the printability of cement-based mixtures: their extrudability, open time, and layer-by-layer build-up. The term formability or extrudability can be characterized as the ability of fine-grained concrete or mortar mixtures to be extruded from the printer nozzle without defects along the length of the beam during linear and curvilinear formation [36].

Research [43, 44, 60] has been conducted using aggregates of different fractions. It is noted that the maximum aggregate grain size directly affects the rheological properties of the mixture, the stability of the extrusion process, and the formation of the material structure. As grain size increases, internal friction in the mixture rises, which can complicate its passage through the extruder and cause uneven material flow. This, in turn, negatively affects the geometric accuracy and uniformity of the extruded layer.

Studies show [45] that using aggregates with excessively large maximum grain sizes can lead to defects such as delamination and the formation of localized voids. This factor is especially critical for thin-layer extrusion, where the grain size approaches the layer height or width. Under such conditions, the grains may hinder uniform compaction of the material and cause microcracks. At the same time, reducing the maximum aggregate grain size promotes greater uniformity of the extruded layer structure and improves its surface quality. Fine-grained aggregates provide better particle packing, reducing the risk of segregation. However, excessive reduction in particle size can lead to increased water demand, which in turn increases binder consumption and negatively affects strength and shrinkage deformations of the material.

The grain diameter is directly related to the properties of the concrete mixture, in particular its plasticity and workability. As the grain size changes, the water demand of the mixture must be adjusted to ensure extrudability [40, 41]. In addition, the content of cement paste is important, as it acts as a “lubricant” to reduce friction against the inner surface of the nozzle and balance the flow rate of the mixture through its cross-section, thereby reducing extrusion defects.

In a number of studies [43-45, 60], the necessity of optimizing the maximum aggregate grain size depending on the design requirements of the layer and equipment characteristics is emphasized. An optimal granulometric composition allows achieving a balance between technological ease of extrusion, layer shape stability, and its physical and mechanical properties. However, the influence of the maximum aggregate grain size on the quality of the extruded layer has not been fully investigated, and it does not allow for accounting for increased coarseness when changing aggregates. At the same time, as is known [61], using coarser aggregates allows reducing the water demand of concrete and mortar mixtures.

As the workability of the mixture increases, the conditions for wetting and contact between layers improve; however, at the same time, the tendency of the printed layer to spread and lose shape stability also increases [55].

The time interval between the deposition of successive layers plays a significant role in ensuring the necessary physical and mechanical properties of the printed structure or building [48]. Increasing the interval between layer deposition promotes the development of structural strength in the lower layer but leads to a reduction in the material’s ability to form a strong interlayer bond. Bos et al. [62] showed that interlayer strength directly depends on the waiting time between layer deposition and the printing speed. Thus, these factors act in opposite directions and create a technological compromise between the mixture’s rheological suitability and the structural integrity of the printed construction.

A longer delay, especially when using fast-setting mixtures, can lead to the formation of numerous voids, significantly reducing the structural integrity of the print. These voids are more frequently observed in constructions where the time interval between layers is increased. This is primarily associated with the loss of surface moisture (cold joint), which occurs as the interval increases, leading to reduced interlayer bonding strength [63-65].

Table 3. Technical requirements for building mixtures for 3D printing

No	Requirement	Functional purpose	Indicator
1	Concrete mixtures		
1.1	Water holding capacity,%	Ensuring the homogeneity of the mixture during manufacture and transportation	no less 97
1.2	Delamination,%		no more 10
1.3	Viscosity, Pa s	Ensuring the possibility of transportation through pipes and uniform laying of the mixture	109-1012
1.4	Structural strength, Pa	Ensuring the necessary strength of the mixture, sufficient for laying the next layer	no less 800
1.5	Initial of setting time, min	Ensuring the possibility of laying the next layer	at least 20 after mixing
1.6	Mixture workability, by cone immersion, cm	Ensuring the ability of the mixture to be extruded and have a stable geometry	8-12
1.7	Mixture workability, by Suttard viscometer, mm		150-170
2	Properties of concrete		
2.1	Compressive strength, MPa	Ensuring the strength of structures	no less 20
2.2	Average density, kg/m^3	Ensuring thermal insulation and other physical and mechanical properties	600-2000
2.3	Adhesion, MPa	Ensuring adhesion between the layers of the mixture for strength and uniformity of the structure	no less 2
2.4	Thermal conductivity, W/(m K)	Thermal insulation of building elements	no more 0.7
2.5	Frost resistance, cycles	Ensuring the durability of structures and resistance to seasonal temperature changes	no less 100

The interlayer time interval is determined by both the geometry of the printed object and the printing speed. For small prefabricated elements, the interval may be limited to a few minutes. However, when printing large structures or buildings with a significant surface area, the time interval between layers can reach approximately one hour [60]. In such cases, it may be suggested to divide the geometry of the printed element to avoid excessive delays between layer deposition, but this may jeopardize the structural integrity of the printed object. Pan et al. [66]introduced layer deposition intervals of 15, 30, 45 seconds and 60 minutes, the results of clearly indicated a reduction in interlayer bond strength measured by direct tensile tests. Similar results were obtained by Chen et al. and Tay et al., who used time intervals of 1, 5, 10, and 20 minutes [64, 67].

Analysis of the experience of using 3D concreting in the manufacture of various structures and buildings allows us to formulate the average values of technical requirements for working mixtures (Table 3), which may vary depending on the type of printed structure and type of printing equipment.

Portland cement is usually the main binder used in 3D concrete, comprising approximately 15–45% of the total mixture [68]. The binder content in mixtures for 3D printing is generally higher than in traditional concretes and mortars [69, 70]. Partial replacement of clinker with active mineral additives, in particular ground granulated blast-furnace slag (GGBFS), is appropriate.

It is known that partial replacement of clinker with GGBFS improves workability and reduces heat of hydration, which enhances the pumpability of concrete or mortar mixtures and, accordingly, their extrusion forming using a 3D printer [36, 71]. Previous studies have shown [72] that the use of GGBFS can positively affect the properties of both fresh and hardened concrete, but their influence on 3D concrete remains an active area of research [41]. Considering the unique requirements for a mixture suitable for 3D printing, including the balance between pumpability, shape stability, and strength, understanding the effect of clinker replacement with ground granulated blast-furnace slag on these properties is critically important.

Partial replacement of cement with GGBFS alters the rheological properties of the mixture [73]. When part of the Portland cement is replaced with GGBFS, extruded mixtures may exhibit reduced water demand and plasticity, which negatively affects extrusion and the stability of joints during printing. According to [73], slag content (up to ~20–30%) allows the construction mixture to remain suitable for extrusion and depends on the ratio of GGBFS to other mixture components. This positively affects the strength of interlayer bonds, since GGBS, as an active mineral additive, increases the volume of hydration products during cement hardening [71, 72], which creates the conditions for its positive influence on the interlayer structure of extruded concrete.

The absence of formwork in 3D concrete printing significantly increases the influence of environmental conditions on the quality of the printed structure or building. Fluctuations in ambient or mixture temperature affect the properties of concrete and mortar mixtures as well as hardened concrete or mortar, including shrinkage, crack resistance [74], thixotropy, and layer-by-layer deposition.

Experimental studies show a significant influence of temperature on layer-by-layer formation (structural build-up). In the work [75], it was found that heating the mixing water leads to accelerated formation of the concrete structure, as well as a reduction in the interlayer bonding strength. Increasing the temperature from 20 to 40 °C causes a greater acceleration of structure formation compared to changing the rate from 10 to 20 °C [76]. At the same time, research [77] shows that regardless of temperature (from 10 to 30 °C), no noticeable structural changes are observed during the first 90 minutes of 3D printing. But a significant influence of ambient temperature on structural build-up is noted by the authors for cement pastes [78] and mortars [79]. These discrepancies indicate that the effect of temperature has not yet been fully studied and additional research is needed.

To achieve the necessary extrudability, rapid early strength gain for concretes and mortars, and to ensure the required quality of constructed structures, the composition of the concrete mixture must provide sufficient plasticity, a defined "formability window," satisfactory strength growth kinetics, as well as crack resistance. This necessitates ensuring the correspondence of selected components and the concrete mixture composition to the type of printer, printing speed, and temperature factor. The selected components and concrete mixture composition must provide the necessary adhesive and cohesive properties, as well as a porous structure of the printed concrete, ensuring the durability of the structures [80]. Special importance is given to the choice of Portland cement, which must have a chemical-mineralogical and material composition, as well as fineness, that provide the required plasticity, structural and adhesive strength of concrete mixtures, as well as a set of physical-mechanical properties that meet the design requirements for structures and buildings.

Achieving the necessary properties of Portland cement and mixtures based on it is ensured by various additives: plasticizers, hardening accelerators, viscosity regulators, etc. [71].

Particular importance is given to the introduction of active mineral additives that reduce cement consumption while simultaneously increasing both the economic and environmental efficiency of 3D printing. A number of studies have been conducted on the use of coal fly ash and blast-furnace slags as additives for concretes used in 3D printing [81]. It has been shown [82, 83] that the introduction of these additives, under conditions of mechanical-chemical activation of composite binders, significantly improves the rheological and physical-mechanical properties of the construction mixtures used. Fine-grained materials, including those of anthropogenic origin (fly ash, ground granulated blast-furnace slag, limestone, etc.), are used in 3D printing concrete alongside the purpose of saving cement to increase cohesion, stability, and viscosity [71, 84-86]. Such materials can improve the flocculation of cement grains, providing more contacts and bridges between cement particles [87], which promotes the development of structural strength for the applied layers of the construction [36]. The use of fly ash can ensure better extrudability due to the spherical shape of the grains [88]. The addition of granite aspirated dust reduces the capillary porosity of the contact zone, also serves as additional nucleation centers, and accelerates the initial stage of chemical hardening [89].

The increased demand for fly ash and cementitious granulated slag as active mineral additives, as well as the need to utilize various industrial wastes, determines the relevance of establishing the possibility of using other different wastes as active mineral additives in mortar and concrete mixtures. Among waste utilization issues in Ukraine, the problem of using construction waste, namely stone crushing waste and concrete debris, is currently relevant [90-93]. The latter was generated in large quantities as a result of the destruction of buildings and structures due to military actions. Several studies have established that the fine-grained fraction of concrete debris exhibits pozzolanic activity [90, 91].

Designing concrete mixtures for 3D printing has a number of specific features and requires consideration of both structural and technological parameters. Taking into account the required resolution requires selecting the appropriate aggregate grain composition and, along with the water-cement ratio, ensuring sufficient binder content, which may include cement and finely dispersed mineral additives [94-99]. Alongside mineral additives, the effective incorporation of various types of fiber into concrete mixtures for 3D printing is also employed [100, 101].

With an increase in the printing speed of the mixture, it is necessary to ensure improved rheological and adhesive properties of the mixture, as well as the crack resistance of the concrete [102-104].

When designing concrete mixtures for a 3D printer, unlike conventional concrete, it is necessary to take into account the structural features of the constructed structures, their elements, and the structural parameters of the printer. In addition to workability and compressive strength, it is necessary to include parameters such as viscosity, plastic strength, setting time, early compressive and flexural strength, adhesive strength, and shrinkage. To maintain the required operational properties of extruded construction mixtures, it may also be necessary during mixture design to assign and ensure properties such as thermal conductivity, frost resistance, and other characteristics.

Multifactor prediction of concrete properties and the design of its optimal mixtures is possible using mathematical models obtained through the mathematical design of experiments [105, 106]. Research for this purpose has been conducted and successfully tested in practice for conventional concrete and a number of other concrete types with specific applications [107]. For concretes obtained by 3D printing, sufficient experience in this area is still lacking.

The complex set of special requirements for mixtures used in 3D printing of building structures has led to the search for composite materials that, in addition to cement, include other binders such as gypsum, polymers, as well as fibrous substances for dispersed reinforcement. At the same time, construction mixtures based on Portland cement remain the primary base for 3D printing.

3. CONCLUSION

1. The quality of 3D printed structural elements is determined by the complex interaction of the printer design parameters and the technological characteristics of the printing process.

2. Nozzle geometry significantly affects the structural characteristics of printed elements: round nozzles provide greater flexibility and precision for complex geometries, while rectangular nozzles improve interlayer adhesion and mechanical strength.

3. Printing speed and extrusion speed must be carefully balanced, as excessive speed leads to increased porosity, layer defects and reduced material durability.

4. Interlayer time intervals are a critical factor affecting the strength of the connection: increased

delays lead to moisture loss, the formation of weak interfaces and reduced structural integrity.

5. The rheological properties of the mixtures must simultaneously satisfy the conflicting requirements: sufficient fluidity for extrusion and high ability to structural build-up to maintain layer stability.

6. The size distribution of the aggregates has a decisive influence on the extrusion quality: smaller aggregates improve the homogeneity and surface quality, while larger particles can cause defects and instability in the layer formation.

7. The use of mineral additives, in particular ground granulated blast furnace slag, can increase the stability and interlayer strength, but requires optimization of the mixture composition.

8. Environmental conditions, especially temperature, significantly affect the setting kinetics, rheology and interlayer bonding, which needs to be taken into account in the practical application of the technology.

9. The proposed extrusion quality rating scale (1–5) is a practical tool for assessing and optimizing printing performance.

10. Further research is needed to develop predictive models for the design of mixtures and process parameters to ensure consistent quality and scalability of 3D printing in construction.

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IZVOD

UTICAJ STRUKTURNIH I TEHNOLOŠKIH PARAMETARA NA KVALITET 3D ŠTAMPANJA GRAĐEVINSKIH KONSTRUKCIJA

Članak daje pregled publikacija koje predstavljaju rezultate o uticaju dizajnerskih i operativnih parametara 3D štampača, kao i tehnoloških faktora, na karakteristike kvaliteta ekstrudiranih građevinskih smesa i betona na bazi njih. Prikazani su eksperimentalni podaci o uticaju oblika i prečnika ekstruzione mlaznice štampača, brzine kretanja mlaznice i brzine dovoda građevinskih smesa na karakteristike kvaliteta ekstrudiranih slojeva i njihovu adheziju. Analizirani su podaci o uticaju rezolucije 3D štampanja, tačnosti mehanizama i njihove kinematike.Predstavljen je predloženi sistem bodovanja za procenu smeša ekstrudiranih iz mlaznice štampača.Predstavljen je pregled studija o uticaju tehnoloških svojstava ekstrudiranih smeša.Demonstrirana je mogućnost postizanja potrebne ravnoteže između obradivosti, koja određuje oblikovnost, i dovoljne strukturne čvrstoće ekstrudiranih smeša. Takođe su razmotrene studije usmerene na postizanje visoke međuslojne čvrstoće ekstrudiranog betona, uključujući efekte raspodele veličine i vremenskog intervala između postavljanja pojedinačnih slojeva. Na osnovu generalizacije podataka dobijenih različitim istraživanjima, autori predstavljaju željene vrednosti glavnih svojstava betonskih smeša i betona na njihovoj bazi za 3D štampanje građevinskih konstrukcija. Potvrđen je značaj daljih istraživanja usmerenih na smanjenje potrošnje cementa upotrebom različitih aditiva, optimizaciju sastava smeša i poboljšanje ekonomske i ekološke efikasnosti 3D štampanja građevinskih konstrukcija.

Ključne reči: *3D građevinski štampač, ekstruzija, mlaznica, kvalitet ekstruzije, zatezna čvrstoća cepanje, međuslojna čvrstoća, reološka svojstva, projektovanje betonskih smeša, raspodela veličine, mineralni aditivi.*

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