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Article

Exploring the capabilities of 3D Printer S-6045 for additive manufacturing of street furniture

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Abstract. This paper examines the potential of 3D printing for additive manufacturing of street furniture, specifically a flowerbed measuring 1.63 m in length, 0.3 m in height according to a custom design. The study investigates the production process, material selection, and design considerations for street furniture, as well as the workability of the selected concrete mixture and the strength of the hardened structure. It uses the S-6045 3D printer to produce the flowerbed and tests the concrete mixtures for workability and strength of concrete at the age of 28 days. The study produced a concrete mixture that exhibits the required attributes for use with the S-6045 3D printer. The findings may also have implications for other applications of additive manufacturing in the urban environment.

Keywords: additive manufacturing, street furniture, concrete mixtures, workability, strength.

1. Introduction

Today, additive building technology is becoming more and more popular. The use of 3D printing in construction is due to the expectations of unlimited design of forms and elements, as well as the provision of new aesthetic and their functional characteristics [1]. The development of additive technologies is due to many factors: increasing the level of automation, improving product quality, reducing construction time, reducing the amount of waste in the production process. These factors stimulate interest in additive technologies in construction, and allow the use of 3D - prototyping as an alternative to traditional construction methods [2]. The commercial success of 3D printing lies in the creation of robust design and manufacturing processes, and in the ability of architects and engineers to develop certified construction materials and components [3].

Also additive manufacturing is a rapidly developing technology with a wide range of applications in various fields. One of the areas where it has gained significant interest is street furniture. Street furniture refers to the items that enhance the functionality and aesthetics of public spaces, including parks, sidewalks, and urban plazas. Examples of street furniture include benches, trash cans, bus stops, bike racks, and streetlights [4].

Additive manufacturing has several advantages and disadvantages for street furniture production. While it offers greater design flexibility, faster production times, reduced material waste, and customization options, it may also be expensive, have limited production sizes, require additional finishing steps, have material limitations, and may not be as durable as traditionally manufactured street furniture. Ultimately, the decision to use 3D printing for street furniture production will depend on the specific needs of a project and the balance of advantages and disadvantages for that particular situation [5].

There are several 3D printers available on the market that can be used for additive manufacturing of street furniture, and one of them is 3D printer S-6045 [6]. S-6045 is a professional-grade additive manufacturing system that offers a large build volume, high accuracy, and excellent material compatibility. It is capable of producing high-quality parts with a variety of materials, including thermoplastics, composites, and metals.

The aim of this study is to explore the capabilities of the S-6045 3D printer for additive manufacturing of street furniture, in particular the flowerbed of cutom design. We investigated the production process, material selection, and design considerations for street furniture. Additionally, we evaluated the workability of the selected mixture, as well as the strength of hardened structure.

The results of this study may provide insights into the potential of 3D printing for street furniture production and inform the design and manufacturing practices for this field. The findings may also have implications for other applications of additive manufacturing in the urban environment.

Objectives of the study:

- Investigating the parameters of 3D printer;
- Selecting the concrete mixtures components;
- Testing concrete mixtures for workability and early strength;
- Designing the structure and setting parameters for 3D printing;
- 3D printing, reinforcing and filling voids with heavy concrete.

2. Methods

A 3D printer S-6045 from D. Serikbayev East Kazakhstan technical university was used in this study. The S-6045 is a modern construction printer belonging to the category of professional laboratory equipment. Its characteristics are presented in Table 1 below.

Table 1 – S-6045 characteristics [6]

Parameter	Value
Manufacturer	AMT Group of Companies, Russia, Yaroslavl
Type of drive	Stepper motors with cylindrical gears
Productivity, m^3/h	0.7
Working area, m	3.5×3.1×1.0
Components	Printer, laptop with a set of licensed software, control cabinet, passport, operation manual, non-return transport packaging, high pressure washer, manual mixer, three additional nozzles of different diameters.
Positioning speed, m/mm	12
Positioning accuracy, mm	2
Power consumption, kW	2.4
Size of the printed layer (height, width), mm	5-10, 20-50
Concrete consumption, m^3 per 1 m^2 of wall with 4-layer printing	0.12
Dimensions (length, width, height)	4.0×5.0×3.6
Weight, kg	870
Types of mixtures	Cement mixtures with or without plasticizers and antifreeze additives, gypsum mixtures
Requirements for operating conditions	The equipment must be operated in dry, enclosed heated rooms at operating temperatures from +5 °C to +40 °C and at a humidity of no more than 60 %, non-condensing

Two concrete compositions had to be prepared for the production of the intended structure: for additive printing and for filling the voids. The water according to [7] in the ratio of 0.18 l per 1 kg of dry material (cement and sand), cement according to [8] at a water-cement ratio of 1/3, sand with a fraction of 2.5 mm according to [9], and plasticizers according to [10] were selected for the mixture to additive printing. To fill the voids, the same components were supplemented with coarse aggregate (crushed stone) by [11] in a ratio of 1/3 with cement, in order to obtain heavy concrete.

The composition for additive printing was subjected to tests for workability at a mixture state and for compressive strength at a hardened state.

The workability tests were conducted according to [12]. According to this standard, the workability of a concrete mixture is evaluated by measuring the depth of immersion of a reference cone in the mixture, expressed in millimeters. The cone should immerse freely in the mixture. The second reading is taken 1 minute after the start of immersion of the cone. The immersion depth of the cone, measured with an error of up to 1 mm, is determined as the difference between the first and the second reading. At least three samples of the mixture are tested, the average results of which should not exceed 20 mm.

The compressive strength tests were conducted according to [13] using hydraulic press. Two specimens were taken for the test, extracted from a structure printed in 6 layers and cured for 28 days, with different surface areas (i.e., footprints).

A street flowerbed custom design was selected for printing with the dimensions of 1.63 m in length, 0.3 m in height. It was designed using AutoCAD as a continuous closed-loop polyline, converted to 3D using SheetCam and integrated to the Mach3 software coming with S-6045. The following 3D printing parameters were set in Mach3 preliminarily:

- The average printing speed of 0.5 m^3/h
- The working area was 2 m^2, which is slightly larger than the size of the printed structure;
- The coordinates of a starting point, where each layer closes the printing layer and goes to the next layer;
- The height of one layer is 10 mm and the width of the layer is 35 mm.

The 3D printing of the intended structure was performed in steps to the height of 0.3 m, each containing certain layers, enabling the fresh concrete to gain a certain level of strength, at which it can carry the subsequent layers. During printing it was another task to define an optimal mode of printing for a chosen concrete composition (dependence between the number of simultaneously printed layers, printing speed, layer height and width, as well as a curing time).

After the structure was printed, its inner void was reinforced with a knitted frame made of rebar with a diameter of 8 mm and poured by heavy concrete.

3. Results and Discussion

The results of workability test of the printing mixture is presented in Figure 1 below.

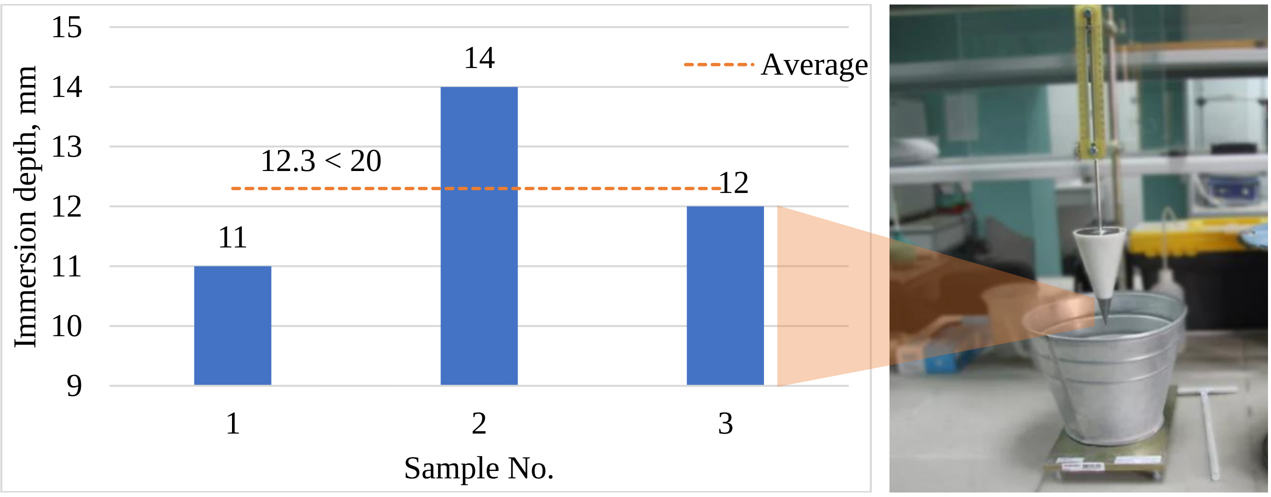

Figure 1 – Workability test results

The figure above shows that the measurement of cone immersion depths amounted 11, 14 and 12 mm for the samples 1, 2 and 3 respectively. Their average value is 12.3 mm, which is less than 20 mm. Consequently, the selected composition meets the requirements for workability specified in [12].

After the workability test, the prepared mixture was filled into the mortar hopper and the 3D printer was put into operation. As planned, 6 layers of the structure were printed, of which after 28 days of curing, 2 samples were extracted for strength testing with surface areas of 54.6 and 46 cm2 respectively. The results of strength test are presented in Figure 2 below.

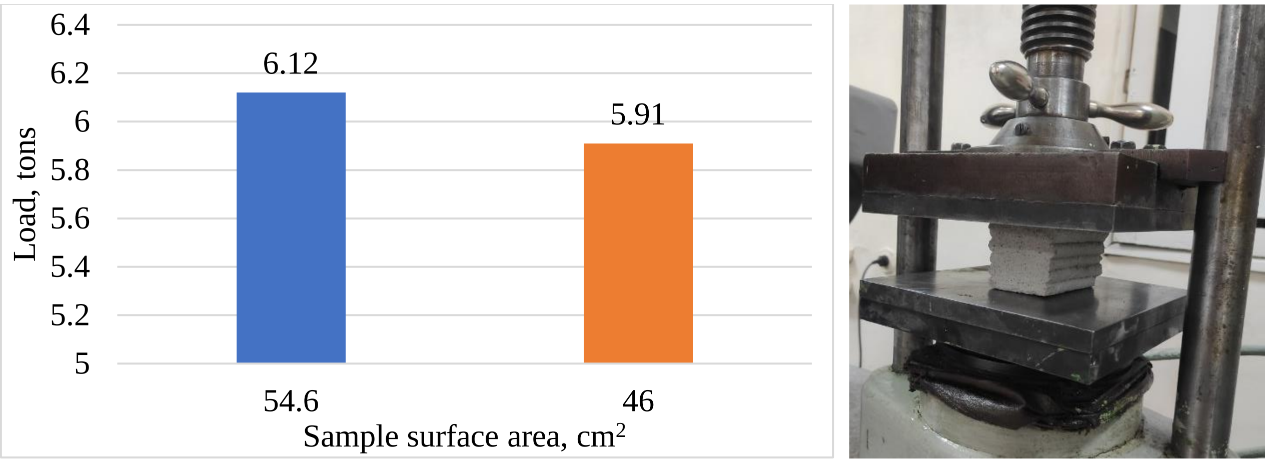

Figure 2 – Compression test results

The compression test showed that the two samples crashed at the loads of 6.12 and 5.91 tons respectively. Taking into account their surface area, it can be assumed that both samples showed the similar compressive strength of around 10 MPa. This value corresponds to the concrete grade of M100 according to [14]. Accordin to this standard, concretes of grade M100 can be used for small repairs or as a permanent formwork for which it is necessary to pour heavier concrete.

After the compression test, the 3D printing of the intended structure started. The first trial of simultaneous printing ended with 14 layers then fall. This led to the number of layers to be decreased to 12 at the second trial. The second trial did not fall, but slightly bended. This could be due to the vibration of printing aggregate while moving, as well as viscosity of concrete mixture, which leads to pulling the printer part when the aggregate moves. Finally, at the third trial it was decided to print 10 layers at a time, and keep the structure cured for some time till it gains certain level of robustness. The printing of the next layers started the next day (Figure 3a), and for the structure with 0.3 m in height it took altogether 3 days for printing, and plus one day of curing (Figure 3b).

a) Day 2 b) Day 4

Figure 3 – 3D printing process

Finally, the inner voids of the ready structure was reinforced and pured with heavy concrete (Figure 4). To make the rebar evenly installed in height of structure, it was hanged using metal wires.

Figure 4 – Reinforcing and pouring the voids with heavy concrete

4. Conclusions

In this study, we successfully printed a street flowerbed using a 3D printer and a custom-made concrete mixture. The workability test showed that the selected mixture meets the requirements for workability, and the compression test indicated that the concrete has a compressive strength of around 10 MPa, corresponding to the concrete grade of M100. The 3D printing process required several trials to find the optimal mode of printing for the chosen concrete composition, and it took 3 days to print the structure and one day for curing. The inner voids of the structure were reinforced with a knitted frame made of rebar and filled with heavy concrete.

The results of this study demonstrate the feasibility of using 3D printing technology for the production of concrete structures, which can be used for small repairs or as a permanent formwork. The technology allows for the creation of complex shapes and designs, which can be customized to meet specific requirements. However, further research is needed to optimize the printing parameters and to improve the strength and durability of the printed structures.

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