ISSN 1815-2066. Nauka innov., 2019, 15(5), 85—90 https://doi.org/10.15407/scin15.05.085

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MANUAL VERSION OF 3D PRINTING

Introduction. *The program of colonization of the Moon and Mars is gradually approaching the practical phase. Researchers are actively discussing various aspects of the presence of people on the surface of the planets.*

Problem Statement. *The number one problem is housing construction: materials and construction technologies. The use of regolith — the lunar or the Martian soil — is supposed to be used as a building material. The construction technology involves the placement of astronauts heating furnace on the lunar surface for sintering bricks, followed by laying them in building structures. The bricks will print on a 3D printer. This idea will require the development and delivery of a 3D printer to the lunar base.*

Purpose. *It is interesting to check the possibilities of simple and cheap options for creating building elements in the conditions of the lunar surface in the absence of a 3D printer and complex heating devices. The purpose of the research is to make a simple product by an additive method, modeling the process of 3D printing without expensive and complicated instruments and devices.*

Materials and Methods. *The manual version of 3D printing using concentrated solar energy from minimally processed local regolith is a simple, economical method of making building components on the surface of the Moon or Mars. The materials used were sand and basalt of terrestrial origin. All necessary operational work for modeling the 3D printing process was done manually. Various devices were used to concentrate the sun's rays on the basis of paraboloid concentrators to create a thermal source of the printer.*

Results. *Simple products from basalt powders and mixtures of basalt with sand were obtained by an additive method without the use of complex expensive equipment. A primitive installation for a 3D process and a heating device from paraboloid concentrators can be easily assembled from structural elements brought from Earth.*

Conclusions. *Manual 3D printing of a minimally processed local regolith using concentrated solar energy is a simple, economical method of making building components on the surface of the Moon or Mars.*

Keywords: 3D printing, solar radiation, concentrator, sintering, regolith, Moon, Mars.

The colonization program of the Moon and the Mars is gradually approaching the practical phase. Researchers are actively discussing various aspects of people's stay on the surface of the planets. The number one problem is the construction of housing: materials and construction technology. The regolith is considered as the building material. Regolith is important for human beings since it has been used since the dawn of civilization to build houses, roads, and other civil engineering works [1—2]. The lunar soil is the fine fraction of the regolith found on the surface of the Moon. Its properties can differ significantly from terrestrial soil due to mechanical destruction of rocks caused by continuous meteoric impact and bombardment by interstellar charged atomic particles over years [3]. According to the mineral composition of the regolith, it is established that the lunar seas are mainly composed of basalts. Basalt is the most common igneous rocks on the surface of the Earth and other planets of the solar system. The composi-

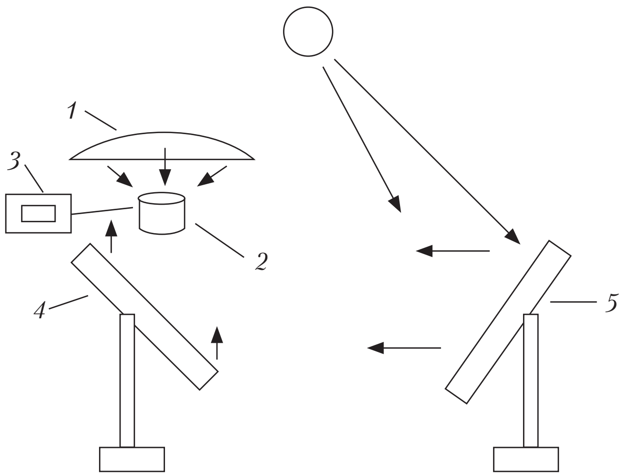

Fig. 1. Device 1 for 3D printing using concentrated solar radiation: *1* — paraboloidal concentrator of solar radiation; *2* — mobile platform; *3* — hand control panel; *4* — mobile heliostat; *5* — stationary heliostat

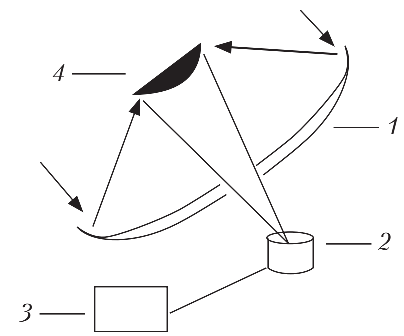

Fig. 2. Device 2 for 3D printing using concentrated solar radiation: *1* — paraboloidal concentrator of solar radiation; *2* — mobile platform; *3* — hand control panel; *4* — secondary mirror

tion of basalt samples delivered from the Moon includes 40—42% SiO_2 [4]. The melting point of basalts reaches of 1370—1520 K, sometimes up to 1720 K [5]. The technology of construction assumes the deployment by astronauts of a solar furnace on the lunar surface for the sintering of bricks with the subsequent laying of them into building structures. Perhaps, they will use blocks with connecting sections. It may be necessary to print a lunar base of lunar dust on a 3D printer. This idea will make it possible to avoid the problems of sending a pile of glue to bonding of bricks, but will require the design and disembarkation of 3D printer for the lunar base [6—8]. All these options involve significant financial costs and technological difficulties. Therefore, it is interesting to check the possibilities of simple and cheap variants of creating building elements in the conditions of the lunar surface in the absence of 3D printer and complex heating devices. Simulation of similar works carried out under terrestrial conditions is described below.

The technology of producing a simple sand product in the African desert using concentrated solar irradiation (CSI) is shown in the video [9], but there were the solar panels, a large Fresnel lens, a computer and 3D printer. Quality building materials from local breeds are created in large solar furnaces in Uzbekistan [10]. Our task is to make a simple product by additive method, under modulating the 3D printing process without expensive and complex devices. Sand and basalt of terrestrial origin were used as materials (Table 1).

The materials were dispersed in an Abiha mortar, whereas the mixes were prepared with simple blenders in the form of cylindrical or hexagonal drums which were horizontally mounted on the shaft. Various devices on the basis of paraboloid concentrators to concentrate solar rays were used to create a thermal source. Three types of devices were used to obtain CSI: two heliostats and a paraboloid concentrator, a paraboloid concentrator and a secondary mirror, paraboloid concentrators and optical fibers.

Fig. 1 shows a schematic diagram of one of the used devices [11]. The device consists of a para-

Table

Materials for Manual 3D Printing

Material	Dispersity
Initial sand (IS)	up to 0.5 mm
Sand dispersed (SD)	up to 0.18 mm
Basalt dispersed (BD-1)	up to 1 mm
Basalt dispersed (BD-2)	up to 0.18 mm
Mixture of IS and BD-1 (% by volume — 50:50)	
Mixture of SD and BD-2 (% by volume — 50:50)	

ISSN 1815-2066. Nauka innov., 2019, 15(5)

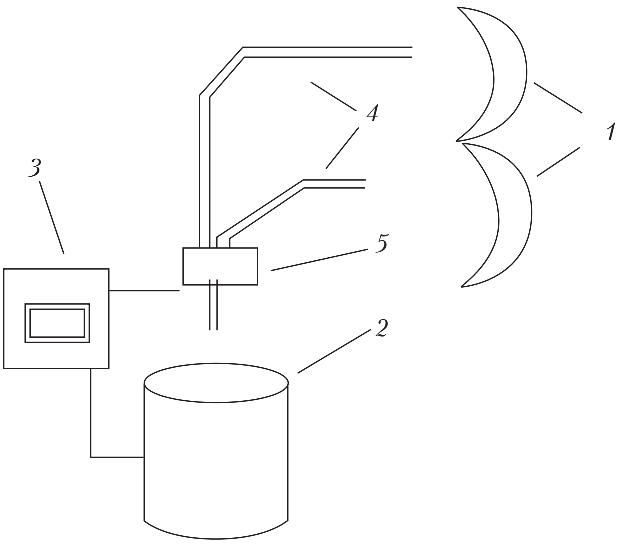

Fig. 3. Device 3 for 3D printing using concentrated solar radiation: *1* — paraboloidal concentrator of solar radiation; *2* — mobile platform; *3* — hand control panel; *4* — fiber-optic wave guides; *5* — cage for second ends of the guides

boloidal concentrator of solar radiation (*1*), a mobile platform (*2*), a hand control panel (*3*), a mobile heliostat (*4*) and a stationary heliostat (*5*). The device operates as follows. With the help of the guidance and tracking mechanism (not shown in the diagram), the mobile heliostat (*4*) was guided to the Sun so that the solar radiation reflected by it was directed to a stationary heliostat (*5*), and then it came into the mirror of a stationary paraboloid concentrator. The solar radiation focused by the concentrator (*1*) was incident on the surface of the powder medium poured on the platform (*2*), which moved in accordance with the actions of the control panel (*3*). The attachment of the platform (*2*) enabled its movement with three degrees of freedom, which is necessary for the selective sintering of the powder material in accordance with the actions of the control panel (*3*).

Fig. 2 shows the schematic diagram of the device [12] of the paraboloidal concentrator (*1*), the mobile platform (*2*), the hand control panel (*3*) and the secondary mirror (4). The paraboloid concentrator 1 and the secondary mirror 6 interacted according to the Cassegrain optical scheme and formed a focus in the technological zone of the movable platform (*2*), which was governed with the panel (*3*).

Fig. 3 shows a schematic diagram of the device [13] of several solar irradiation concentrators (*1*) attached to a mobile frame (not shown in the diagram), a mobile platform (*2*) and a hand control panel (*3*). The device is equipped with fiber-optic wave guides (*4*) that are fixed at the ends of concentrators, while second ends of these light guides are fixed in cage (*5*). The movement of the cage (*5*) was regulated with the control panel (*3*). The solar irradiation concentrated in the total stream was directed to the technological zone of the platform (*2*). Two or more optical fibers are capable to transfer the amount of concentrated solar radiation which sufficient to conduct the sintering process of metallic or ceramic powders.

All necessary operational works for modeling 3D printing process was done manually. Most of the work was done on a device with heliostats. The powder mixture was poured into a ceramic cuvette, which was fixed in a movable cage. The flat surface of the powder was led to the focus zone of the device for beginning process sintering of the

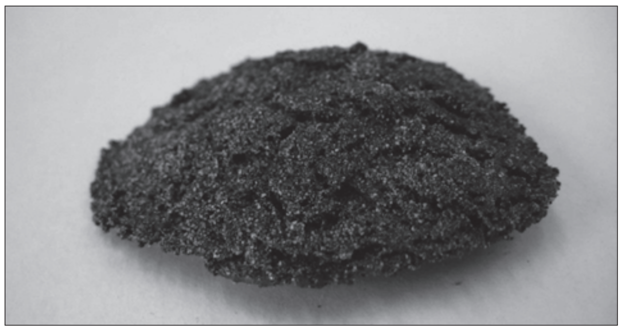

Fig. 4. 3D printing product No. 1

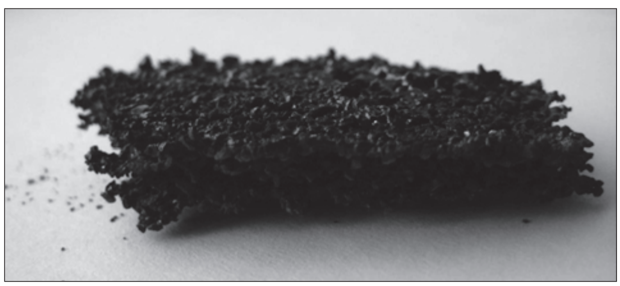

Fig. 5. 3D printing product No. 2

necessary contour. When the sintering of the contour was completed, the level of the mobile platform was lowered, a flat thin layer of powder mixture was poured and the sintering process was repeated. Usually, two operators worked: one manipulated the platform, while the other man provided operations with the working powder mixture. In principle, these two works can be done by one person.

The sintering temperature was of 1370—1570 K. The sintering rate was determined as the volume of sintered product per unit time. In our experiments, the sintering rate was approximately 2 cm^3/min. The sintering rate and the area of the simultaneously sintered surface can be adjusted by changing distance between the platform and the mirror. The powder can be poured continuously or in layers with an equalization. The resolution of the print device was usually about of 2 mm for the last case. For reasons of time and labor saving the compositions 3 and 5 are the most interesting for the preparation of building materials in the conditions of the lunar surface, as the most approximate granulometric composition to powders, which can be easily prepared on the lunar surface. Fig. 4 shows a product in the form of a fungus, sintered with continuously pouring powder mixture 5. Fig. 5 features a product in the form a brick sintered by pouring layers of basalt powder 3.

It is shown the principal possibility to produce products by an additive method without using complex expensive equipment. Manual 3D printing of a minimally processed local regolith with using concentrated solar energy represents a simple economical way of making building components on the surface of the Moon or Mars. A primitive installation for 3D process and a heating device of paraboloid concentrators can easily be assembled from elements of structures brought from Earth. It is also easy to arrange the preparation of the initial building material on the basis of a device such as the Abiha mortar and a mechanical mixer. Thus, it is possible to adjust the construction process on the surface of planets in conditions of limited economic, construction and energy resources.

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Стаття надійшла до редакції / Received 21.03.19
Статтю прорецензовано / Revised 17.05.19
Статтю підписано до друку / Accepted 21.05.19

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РУЧНА ВЕРСІЯ 3D-ДРУКУВАННЯ

Вступ. Програма колонізації Місяця й Марса поступово наближається до практичної фази. Вчені активно обговорюють різні аспекти перебування людей на поверхні цих планет.

Проблематика. Першочерговою проблемою в цьому процесі є будівництво житла, зокрема питання матеріалів та технології будівництва. Як будівельний матеріал передбачено використання реголіту — місячного або марсіанського ґрунту. Технологія будівництва передбачає розміщення космонавтами нагрівальної печі на місячній поверхні для спікання цегли з подальшим укладанням її в будівельні конструкції. Цеглини будуть друкувати на 3D-принтері. Ця ідея потребує розробки та доставки 3D-принтера на місячну базу.

Мета. Перевірка можливості реалізації простих і низьковартісних варіантів створення будівельних елементів в умовах місячної поверхні за відсутності 3D-принтера та складних нагрівальних приладів. Розробка адитивним методом простого виробу, моделюючи процес 3D-друкування без використання високовартісних і складних приладів та пристроїв.

Матеріали й методи. Ручний варіант 3D-друкування з використанням концентрованої сонячної енергії з мінімально обробленого місцевого реголіту є простим економічним способом виготовлення будівельних компонентів на поверхні Місяця або Марса. Як матеріали використано пісок і базальт земного походження. Всі необхідні оперативні роботи для моделювання 3D-процесу друку було виконано вручну. Для створення теплового джерела принтера використано різні пристрої для концентрування сонячних променів на базі параболоїдних концентраторів.

Результати. Виготовлено прості вироби з порошків базальту та сумішей базальту з піском адитивним методом без використання складного високовартісного устаткування. Примітивна установка для 3D-процесу та нагрівальний пристрій з параболоїдних концентраторів можуть бути легко зібрані з елементів конструкцій, транспортованих із Землі.

Висновки. Ручне 3D-друкування мінімально обробленого локального реголіту з використанням концентрованої сонячної енергії є простим економічним способом виготовлення будівельних компонентів на поверхні Місяця або Марса.

Ключові слова: 3D-друкування, сонячне випромінювання, концентратор, спікання, реголіт, Місяць, Марс.

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РУЧНАЯ ВЕРСИЯ 3D-ПЕЧАТИ

Введение. Программа колонизации Луны и Марса постепенно приближается к практической фазе. Ученые активно обсуждают различные аспекты пребывания людей на поверхности этих планет.

Проблематика. Первоочередной проблемой в этом процессе является строительство жилья, в частности, материалы и технологии строительства. В качестве строительного материала предполагается использование реголита — лунного или марсианского грунта. Технология строительства предполагает размещение космонавтами нагревательной печи на лунной поверхности для спекания кирпичей с последующей укладкой их в строительные конструкции. Кирпичи будут печатать на 3D-принтере. Эта идея потребует разработки и доставки 3D-принтера на лунную базу.

Цель. Проверка возможности простых и недорогих вариантов создания строительных элементов в условиях лунной поверхности при отсутствии 3D-принтера и сложных нагревательных приборов. Разработка аддитивным методом простого изделия, моделируя процесс 3D-печати без использования дорогих и сложных приборов и устройств.

Материалы и методы. Ручной вариант 3D-печати с использованием концентрированной солнечной энергии из минимально обработанного местного реголита представляет простой экономичный способ изготовления строительных компонентов на поверхности Луны или Марса. В качестве материалов использовались песок и базальт земного происхождения. Все необходимые оперативные работы для моделирования 3D-процесса печати были выполнены вручную. Для создания теплового источника принтера использованы различные устройства для концентрирования солнечных лучей на базе параболоидных концентраторов.

Результаты. Получены простые изделия из порошков базальта и смесей базальта с песком аддитивным методом без использования сложного дорогостоящего оборудования. Примитивная установка для 3D-процесса и нагревательное устройство из параболоидных концентраторов могут быть легко собраны из элементов конструкций, привезенных с Земли.

Выводы. Ручная 3D-печать минимально обработанного локального реголита с использованием концентрированной солнечной энергии представляет собой простой экономичный способ изготовления строительных компонентов на поверхности Луны или Марса.

Ключевые слова: 3D-печать, солнечное излучение, концентратор, спекание, реголит, Луна, Марс.