BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 69 (73), Numărul 4, 2023
Secţia
CONSTRUCŢII DE MAŞINI
DOI:10.2478/bipcm-2023-0037

COMPARATIVE STUDY BETWEEN CONVENTIONAL AND ROBOTIC METHODS IN 3D PRINTING

BY

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Received: April 10, 2024
Accepted for publication: April 29, 2024

Abstract. The 3D printing is a technology of manufacturing that is now well known. Usually the part is obtain using layer-by-layer deposition and the main inconvenience of this process is that the deposition of material takes place in the plane (2D space) and then it is moved to the next plane by applying a constant increment on the third axis. The accuracy of the product is given by the increment value. The properties of the product, such as strength, also is given by the bond that is made between the layer and the density of the layers. Nowadays, it is proposed a new type of 3D printing using robotic arms. This approach give the possibility to work in 3D space and obtain a 3D defined deposition. It is believed that the properties of the part will be improved together with the mechanical properties of the part. In this article will be presented a comparative study that will indicate the positive and negative aspects of both conventional 3D printing and robotic printing.

Keywords: 3D printing, robot arm, programming, accuracy.

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1. Introduction

The domain of 3D printing has evolved into a highly competitive and demanding field. The new requirements in 3D printing are: dimensional accuracy, surface quality, and mechanical strength. all while aiming to reduce production time and costs. Amidst the advent of new technologies in this arena, the ability to meet elevated prototyping demands, particularly in terms of functionality, has significantly improved. However, achieving absolute control over these factors and attaining the desired level of perfection remains a substantial challenge, both for manufacturers and end users, when it comes to identifying optimal printing conditions that ensure repeatability and reliability.

A pivotal aspect in establishing these optimal conditions lies in the consideration of various influencing factors. These include, but are not limited to, the geometric specifications of the parts, the chemical composition of the filament material, the operational conditions of the printing machinery, post-printing positioning and fixing of the part, elements characteristic of specific 3D printing techniques, the configuration of the extruder assembly, and the printing parameters themselves establish the field and the problem to be tackled.

There are several types of conventional 3D printing technologies developed in the last period, Fig. 1. Among several 3D printing methods currently in use – (Hongyuan *et al*., 2020), such as Stereolithography (SLA), Selective Laser Sintering (SLS), Digital Light Processing (DLP), Multi Jet Fusion (MJF), PolyJet, Direct Metal Laser Sintering (DMLS), and Electron Beam Melting (EBM), FDM was considered the most suitable for creating parts due to its specific advantages.

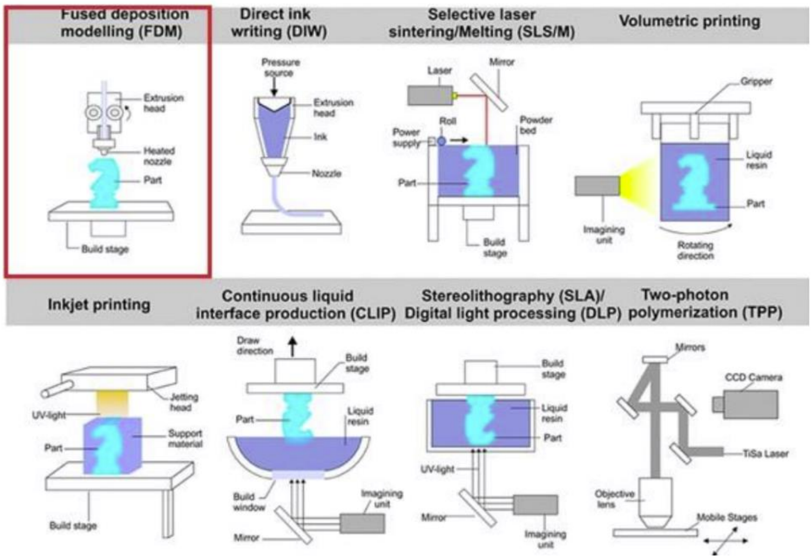

Fig. 1 – Conventional technologies used in additive manufacturing.

Concurrently, the domain of robotics has experienced notable progressions, transitioning from conventional, solitary industrial robots to exceedingly intricate, cooperative systems (Chitariu *et al*., 2020). Collaborative robots, called cobots, have been specifically engineered to operate in conjunction with human labourers, augmenting their skillsets and optimising both efficiency and safety within the workplace. In contrast to previous models, the cobots, have attributes such as adaptability, user-friendly programming interfaces, and the ability to operate with humans safely. These qualities render them highly suitable for a diverse array of tasks, including those within the domain of additive manufacturing. Integrating cobots in the confluence of additive manufacturing and robotics has given rise to a novel concept known as robotic-assisted additive manufacturing (RAAM). Integrating robotics and 3D printing in the form of RAAM results in a collaborative fusion that combines the accuracy and consistency of robotic technology with the adaptability and inventive potential of 3D printing. The integration of this technology holds the potential to facilitate advancements in the manufacturing sector, including the automation of intricate manufacturing procedures, improvement in the quality of printed components (Fig. 2) and broadening the scope of printable materials and geometries. Another important property is that the fibre in 3D printing with robot arm is continuous with respect to conventional 3D printing (Fig. 2). This is possible due as a consequence of the above mention property namely the robot arm have more than 3 degrees of freedom. This lead to an increase of mechanical properties of the printed product. Also the roughness is improved (Fig. 3).

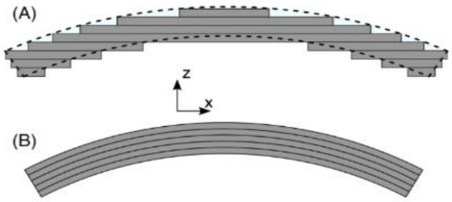

Fig. 2 – Cross section in products obtained by conventional 3D printing (A) and robotic 3D printing (B).

Fig. 3 – Comparison between surfaces obtained by conventional 3D printing.

The execution of RAAM presents several difficulties. The customisation of collaborative robots, also called cobots, such as the UR3e model developed by Universal Robots, for additive manufacturing necessitates resolving several challenges. The factors mentioned above encompass the adaptation of the printing extruder, identification of appropriate materials, creation of sophisticated control software for converting 3D models into robotic commands, and meticulous calibration of the robot arm and extruder. A multidisciplinary approach is required for these areas, necessitating the integration of expertise from several fields, such as mechanical, electrical, automation, and software engineering. The effective incorporation of RAAM technologies requires a deep understanding of robotic dynamics and additive manufacturing processes. This includes expertise in trajectory planning for robotic arms, optimal material extrusion, and balancing speed, precision, and material qualities. The paper (Bhatt Prahar *et al.*, 2019) plays a crucial role in this context, providing a novel perspective on controlling fibre orientation with a robotic manipulator and a multi-nozzle extrusion system. This approach significantly impacts the produced items' mechanical properties and surface finish, directly aligning with our focus on enhancing the quality and precision of 3D-printed components. Further exploring the nuances of RAAM, paper (Safeea *et al.*, 2022) introduces a multitasking framework, spanning system design, integration, and generation of collision-free robot trajectories. Its use of closed-loop inverse kinematics to address challenges in redundant robots and the focus on robot tip orientation innovatively enhances the quality of manufactured surfaces. This methodology, validated through experimentation with a 7-axis redundant robotic manipulator, marks a significant stride in the field. The paper (Jiang *et al.*, 2021) comprehensively reviews multi-DOF AM systems in another critical study. It underscores the evolution from traditional three-axis techniques to more complex multi-DOF configurations, enabling the production of intricately designed components. This review categorizes existing multi-DOF AM systems and offers insights into future research directions, contributing significantly to understanding AM technology evolution and its application in system design and robotic 3D printing. Aligning with our research objectives, the study (Pollák and Kočiško, 2021) delves into integrating additive manufacturing technology with robotics, focusing on the UR5 collaborative robot. This research highlights the simplification of robotic movements and the reduction of structural modifications in printing systems, mirroring our aim to enhance collaborative robots' adaptability in additive manufacturing. The methodologies and insights from (Alexandrescu *et al.*, 2001) not only complement but also deepen our understanding of the complexities in merging these advanced technologies, guiding our advancements in RAAM.

2. Apparatus and Method Used

For the experimental part of this research, the Fused Deposition Modeling (FDM) method was employed. FDM was selected due to its direct compatibility with the range of materials used and its adaptability to our specific robotic arm setup. In our setup, the FDM process involved using a direct drive printing head attached to the final element of the robotic arm, allowing for precise control over the material deposition. This method aligns with the current trends in the field which favor materials that facilitate optimal performance, especially for parts with complex surfaces. The extrusion challenges posed by these materials are effectively addressed by FDM, considering the geometry and dimensional characteristics of the part, thus avoiding the need for post-processing interventions. Achieving superior surface quality in our experiments was contingent on a detailed understanding and application of these optimal printing conditions. The type of 3D printer is Stratasys Fortus 250 mc.

Fig. 4 – 3D printer Stratasys Fortus 250mc.

After the parameterization of the printing process and the exportation of the G-code delineating print head trajectories, attention is directed towards the virtual construction of the workstation, a pivotal stage where the RoboDK software assumes a central role. At this stage, the workstation is virtually assembled within RoboDK, incorporating the importation of a UR3E robot from Universal Robots and integrating a print head from DYZE DESIGN into the simulated environment.

RoboDK software is indispensable in this workflow because it facilitates offline programming and motion simulation across a diverse spectrum of industrial and collaborative robotic platforms. It significantly optimizes the virtual simulation procedure, thereby augmenting efficiency and accessibility throughout the various stages of the project. Furthermore, the software's adaptability in accommodating an array of robotic configurations obviates the necessity for proficiency in diverse, proprietary programming languages and environments.

The project substantially benefits from the streamlined programming processes and the versatility proffered by RoboDK, rendering it an essential instrument in establishing the virtual workstation. To visually manifest this facet, Fig. 5 is presented, showcasing both the virtual model of the robot as conceived in RoboDK and its physical analogue. A salient feature illustrated in this figure is the strategic mounting of the real robot model on the ceiling of a frame composed of aluminum profiles. This portrayal accentuates the precision and authenticity achieved in the virtual simulation and exhibits the meticulous replication of actual operational conditions within the RoboDK environment. Consequently, it exemplifies the software's proficiency in bridging the gap between virtual planning and real-world execution, a quintessential attribute of modern robotic-assisted additive manufacturing.

In the subsequent phase, the G-code program generated by the CURA software was imported into the RoboDK environment. This was essential for aligning the detailed printing parameters with the robotic functionalities.

Within RoboDK, specific printing speeds suitable for the UR3E robot were chosen, ensuring synchronization between robotic movements and printing requirements. Following this, the G-code was generated within ROBODK, involving a detailed visualization and optimization of the printing trajectory as determined by the robotic arm's path. In Fig. 6 it is presented the extruder that it was mounted on the robot arm.

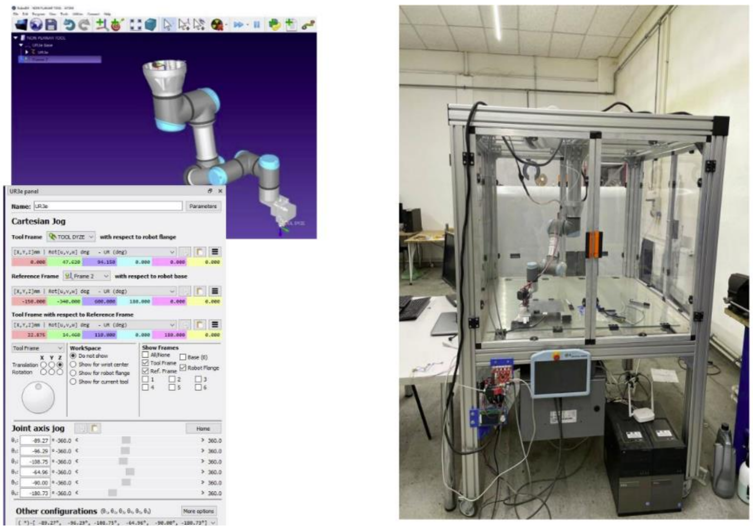

Fig. 5 – Virtual robotic workstation development in RoboDK vs. real workstation.

Fig. 6 – Then extruder used.

The aim of the experiment is to create 3D probes obtained using conventional 3D printing and robotic 3D printing and then to test these probes, obtain the mechanical properties and to compare the results. The model of the probe is presented in Fig. 7.

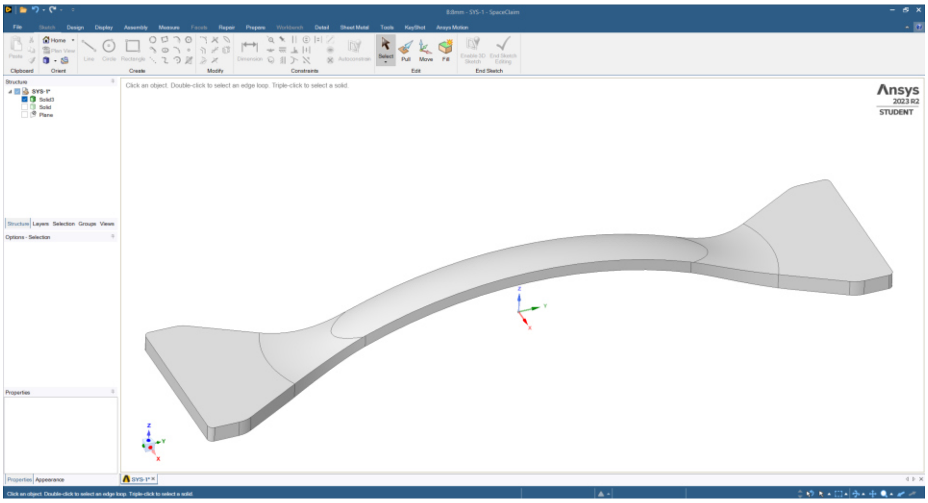

Fig. 7 – The 3D model of the probe.

The probe is modelled using spline type curves. In order to obtain this probe by robot 3D printing one have to follow some steps:

1. Importing the program in Cartesian G-Code format from the SLIC3R program into ROBODK and overlaying the new curves imported from the ROBODK program.

2. Manually adding the print flow for each newly created curve in the ROBODK program for the 7th axis corresponding to the extruder.

3. The union and compilation of the two programs into a single program

4. Export to a storage medium
5. Importing to the UR3E robot from UNIVERSAL ROBOTS
6. Execution and actual realization of the 3D landmark by the robotic arm

The first problems observed during printing were that the robot did not move at the same printing speed synchronized with the flow rate of the extruder. As a result, the texture of the printed surface was visually observed, which had a discontinuity, as can be seen in Fig. 8. Then we tried to increase the flow rate of the extruder head, but even in this situation we did not achieve an acceptable quality of the surface to be printed. From this printing problem I realized that there is a problem due to the geometric shape defined in the CAD program, namely that this curved surface was made of spline curves. Later, an attempt was made to solve this problem by using another CAM software called POWERMILL, where the new kinematics of the robot was introduced into the robot library of the software (UR3E). Within this software, it was desired to generate the trajectory of the tool on a curved surface with constant speed. This was achieved using work strategies common in 5-axis machining. The disadvantage of this approach was that it is not possible to insert the 7th actuation which corresponds to the extruder required for 3D printing. In Fig. 8 it can be observed the first probes obtained by 3D robot printing.

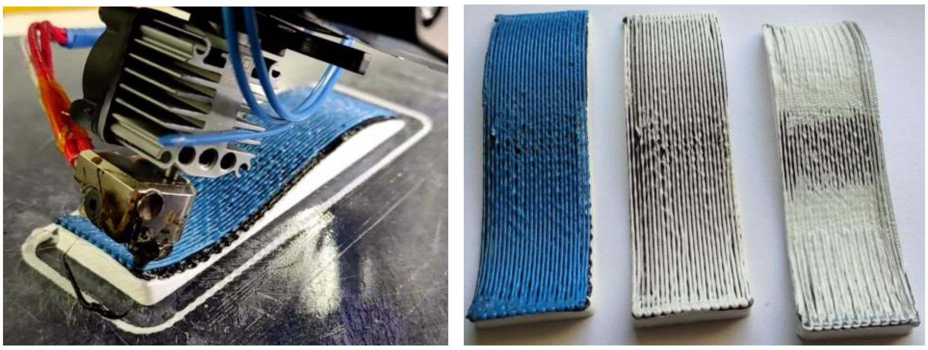

Fig. 8 – The first probes obtained using 3D robot printing.

For tensile testing of the specimens, a Lloyd Instruments LRX Plus testing machine from the "Gheorghe Asachi" Technical University of Iași was used (Fig. 9). The specimen is presented in Fig. 10.

Lloyd Instruments incorporate an extensive range of features and are used to perform complex test applications. The device is microprocessor controlled and uses 32-bit technology for high-precision load measurement and fast data acquisition. The integral interface consists of a side-mounted control console with large positive-acting membrane switches, allowing complex tests to be performed at the push of a button (Fig. 11).

Fig. 9 – Traction test equipment Lloyd Instruments.

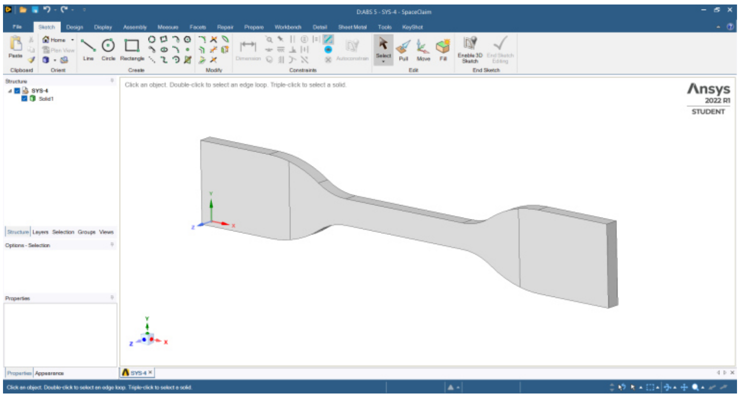

Fig. 10 – Screenshot in SpaceClaim 2022 R1 of the specimen.

Fig. 11 – Traction test carried out on Lloyd Instruments.

The high stiffness frame incorporates a crossbar guide system to prevent lateral loading of the test specimen. The crosshead is driven by two screws and a high-precision servo motor and DC servo system to achieve a wide range of speeds over the entire load range. The machine is capable of running at full load at full speed. A high precision load cell is used for tension, compression and cycling through force measurements. The system is ideal for use in manufacturing, quality control, educational and research environments.

All machines are designed to meet a wide range of applications. This is mainly achieved through the built-in control software and easy-to-configure data acquisition software. NEXYGEN Plus software is compatible with Windows, seamlessly integrates with contemporary Microsoft Office programs using OLE2 technology. Data can be easily exported to programs such as Excel, Access, Outlook and Powerpoint for further manipulation and enhanced presentation. The NEXYGEN Plus software contains a library of pre-programmed test setups for performing fully automated tests in accordance with international standards.

3. Results

In order to establish the characteristics of the material we chose, in this case ABS material, we carried out an experiment on the tensile test equipment and then we validate the finite element analysis with experimental tests results from tensile tests. In the "Engineering Data" column, the material data are entered, such as the elastic limit (Yield), the breaking limit (Ultimate Tensile Strength) and the elastic or tangent modulus (Young's modulus), as shown in Figs. 12 a, b.

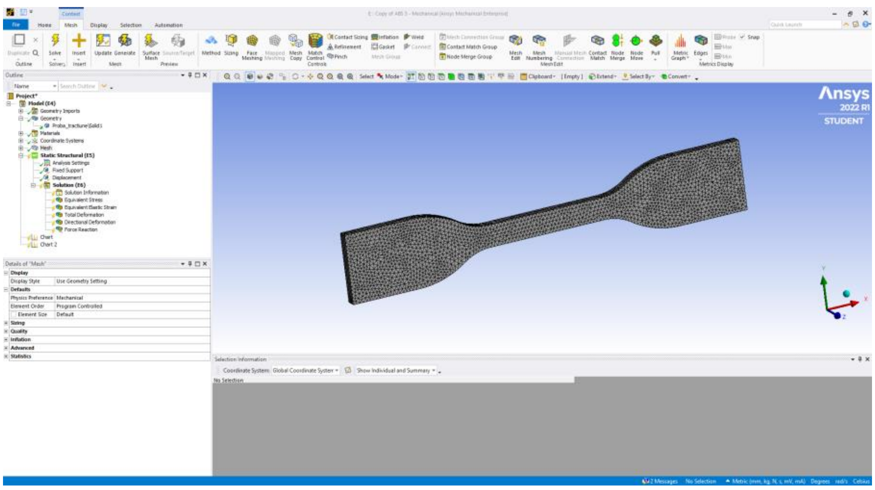

Fig. 12 a – Finite element model of the 5ABS specimen.

The results will be used in the model of the probe shape that it will be obtain both from 3D conventional printing and 3D robotic printing. In Figs. 12 a, b one present the results of the Finite Element Analysis.

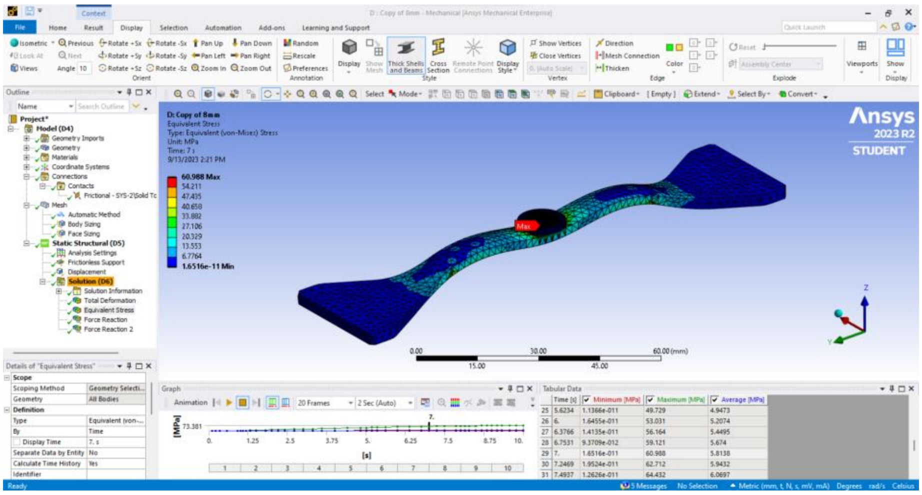

Fig. 12 b – Von Mises equivalent stress for the probe.

In Fig. 13 one present the graphic of the stress variation as a function of displacement. In Fig. 14 one present the variation of stress as a function of deformation for ABS material. There are three colours because we make this test for three specimens in order to validate the experimental data and test.

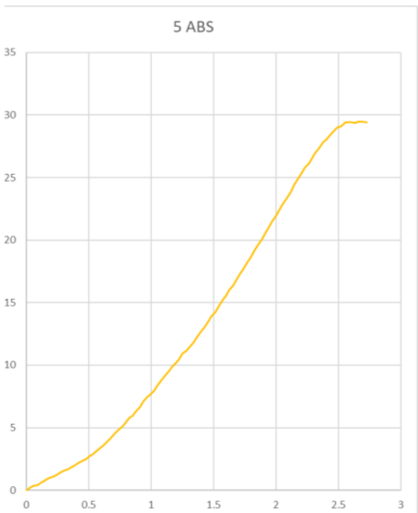

Fig. 13 – Stress variation as displacement as a function of displacement.

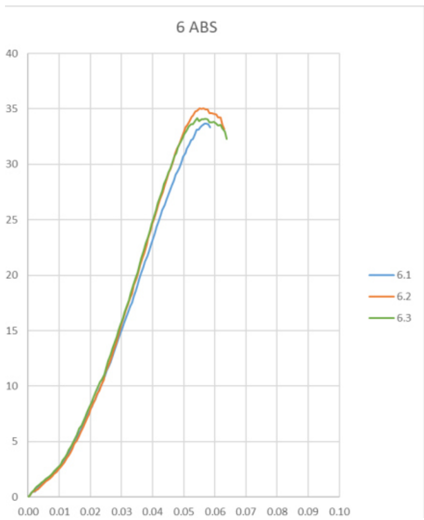

Fig. 14 – Stress variation a function of as a function of deformation.

4. Conclusions

The surface quality of the part is the result of complex phenomena involving the entire 3D printing process, taking into account:

- Material to be printed (shape, working regime)
- The deposition route of the extruded material
- Deposit speed
- The melting temperature of the material,
- Nozzle diameter

The thermal regime of the nozzle is a little studied phenomenon.

The route and direction of deposition is very important in obtaining superior surfaces

Prototyping tends to become an increasingly competitive and demanding process with a very high requirement in terms of dimensional accuracy and the quality of the resulting surface, taking into account a reduction in production times and costs.

The influencing factors that must be taken into account determine the establishment of optimal working condition.

The robot 3D printing is at the beginning and it must be improved. The further steps which must be followed is to improve the interface between the computer and the robot arm for 7 axis. Another step is to set an optimum velocity to the robot arm calibrated with the deposition of material and the melting time.

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STUDIU COMPARATIV ÎNTRE METODELE CONVENȚIONALE ȘI METODELE ROBOTICE UTILIZATE ÎN IMPRIMAREA 3D

(Rezumat)

Imprimarea 3D este o tehnologie de fabricație care este acum binecunoscută. De regulă, piesa se obține prin depunerea strat cu strat, iar principalul inconvenient al acestui proces este că depunerea materialului are loc în plan (spațiu 2D) și apoi este mutată în planul următor prin aplicarea unui increment constant pe a treia axă. Precizia produsului este dată de valoarea de increment. Proprietățile produsului, cum ar fi rezistența, sunt date și de legătura care se realizează între strat și densitatea straturilor. În prezent, se propune un nou tip de imprimare 3D folosind brațe robotizate. Această abordare oferă posibilitatea de a lucra în spațiu 3D și de a obține o depunere definită 3D. Se crede că proprietățile piesei vor fi îmbunătățite împreună cu proprietățile mecanice ale piesei. În acest articol va fi prezentat un studiu comparativ care va indica aspectele pozitive și negative atât ale tipăririi 3D convenționale, cât și ale imprimării robotizate.