Research of 3D anti-Gravity Printing Methods

Zhunan Cao

Houston International Institute, Dalian Maritime University, Dalian, China
nick1cewood@dlmu.edu.cn

Abstract. As the use of 3D printing becomes more popular, the need to print in complex gravity environments or even low gravity environments is emerging. In order to meet these anti-gravity 3D printing needs, many individuals or organizations have proposed different solutions. This paper describes three mature antigravity 3D printing solutions, namely FDM-based Mataerial printers, anchorless selective laser sintering, and magnetic levitation printing. These three technologies are suitable for different environments and can accomplish different purposes. For example, Mataerial is suitable for adding a structure to an existing structure, because this printer does not need to move the workpiece, and the thermoplastic material it uses allows it to print at any angle and under any gravity conditions. For anchorless selective laser sintering, it is more suitable for use under industrial production conditions. Because this technology optimizes most of the support structure, and as an SLS technology, its lower cost and faster production speed are highly competitive. For magnetic levitation printing, it have low operating temperature, flexible printing, and it can ignore the influence of gravity, is very suitable for printing related equipment in complex environments, such as space, to help human space exploration. By comparing these three anti-gravity printing technologies in terms of material selection and printing methods, one can attempt to summarize the advantages and disadvantages of each of the three technologies. Ultimately, this paper hopes to conclude the development prospects and applicable environments of each of the three technologies, and to make speculations and suggestions on their future development directions.

Keywords: 3D Printing; Anti-Gravity; FDM Technology; SLS Technology.

1 Introduction

With the development of related technologies, 3D printing technology and its products have become an indispensable part of people's production and life and play a pivotal role in the field of art, medicine and even engineering. With the expansion of the 3D printing environment, many times the existing printers cannot meet the needs of people on the 3D printing. For example, if someone want to print in a low-gravity environment or in an anti-gravity environment, the existing printing equipment will not be able to meet the demand, and then people need to use anti-gravity 3D printing technology. In fact, anti-gravity 3D printing has been around for a long time. Among

Y. Yue (ed.), *Proceedings of the 2024 International Conference on Mechanics, Electronics Engineering and Automation (ICMEEA 2024)*, Advances in Engineering Research 240,
https://doi.org/10.2991/978-94-6463-518-8_20

the many conceptual designs, the most famous and eye-catching is the magnetic levitation printing technology from Boeing. Boeing uses innovative superconducting and antimagnetic materials to levitate prints at ultra-low temperatures, allowing the printed object to not adhere to any flat surface and to rotate freely [1]. Another relatively well-known design is the "MATAERIAL" antigravity 3D printing technology from the Instituto Superior de Arquitectura de Catalunya (IAAC) in Spain and Joris Laarman Studio in Amsterdam, the Netherlands [2]. This is a 3D printing technology based on rapidly hardening polymers, where the printing device is placed at the end of an industrial robotic arm for high degree of freedom control, and the printed structure is constructed by replacing 2D printed layers with 3D curves through a new extrusion technique [3]. In addition to this, there are many anti-gravity printing techniques based on laser sintering, such as selective laser sintering without anchors from the Additive Manufacturing Research Center (ADAM) at the University of Sheffield, which will not be repeated here.

Among the two FDM-based antigravity 3D printing designs mentioned above, the "MATAERIAL" antigravity 3D printing technology is more mature and easier to realize than the magnetic levitation printing technology and can be put into actual production activities more quickly. The magnetic levitation printing technology has a broader application prospect, the quality of the printed parts is higher, and the environmental requirements are smaller.

2 Literature Review

2.1 "MATAERIAL" Anti-Gravity 3D Printing Technology

The object of this research is the "MATAERIAL" anti-gravity 3D printing technology from the Institut d'Architecture Supérieur de Catalunya (IAAC), Spain, and Joris Laarman Studio, Amsterdam, The Netherlands.

Printing materials. Mataerial uses thermoset polymers rather than the thermoplastic or resin polymers commonly used in 3D printers. The thermoset polymers used by Mataerial have heat curing characteristics and better physical properties than the polyolefin resins or ABS plastics used in traditional FDM 3D printing. In the case of ABS plastic, the melting point of the print filament is about 270°C, and it is the most widely used material for 3D printing functionality testing.ABS prints can be up to 80% as strong as ABS injection molded parts [4]. And Mataerial uses thermoset polymers that are cured by heat and have better physical properties [4]. The thermoset polymers used by Mataerial, on the other hand, behave as a gelatinous liquid substance at room temperature, which transforms into a solid state when heated. This transformation is irreversible and cannot be converted back to the initial prepolymer state even when reheated [5]. However, related research has shown that Mataerial can also be printed using new remoldable thermosets, such as Vitrimer, which is one of the more established secondary processable thermosets.Vitrimers are permanently crosslinked networks that can be reprocessed in response to certain external stimuli [6].

Table 1. Physical and mechanical properties of four polyimide vitrimer materials [7]

Material type	Gel content/%	tensile strength/MPa	Elongation at break /%	Tg °C	energy storage modulus/GPa
PTI-H	95.2	30.9	51.2	67	1.68
PTI-CH	97.3	55.0	27.8	86.0	1.82
PTI-pP	96.7	38.0	55.9	63.8	1.77
PTI-mP	97.1	55.2	36.0	84.0	1.88

From "The effect of diamine structure on the properties of polyimide vitrimer materials" (Table 1), By adjusting the temperature at the nozzle outlet, Mataerial can allow the added material to soften the Vitrimers material in the printed portion twice when it comes into contact with the printed portion, thus enhancing the interlayer strength and improving the surface quality [7]. The Vitrimers materials obtained by different fabrication methods have different physical properties, but all of them are capable of performing the printing jobs mentioned in this paper [8].

Printing methods. Mataerial uses a traditional FDM additive manufacturing approach where the printed object is constructed by extruding the material and curing the stack. Unlike conventional printing, Mataerial uses 3D strip printing instead of 2D layer stacking, which allows for self-supporting by covering the stress lines of the printed body with a complete strip structure as in Figure 1 below, thus enhancing the physical properties of the printed part [9].

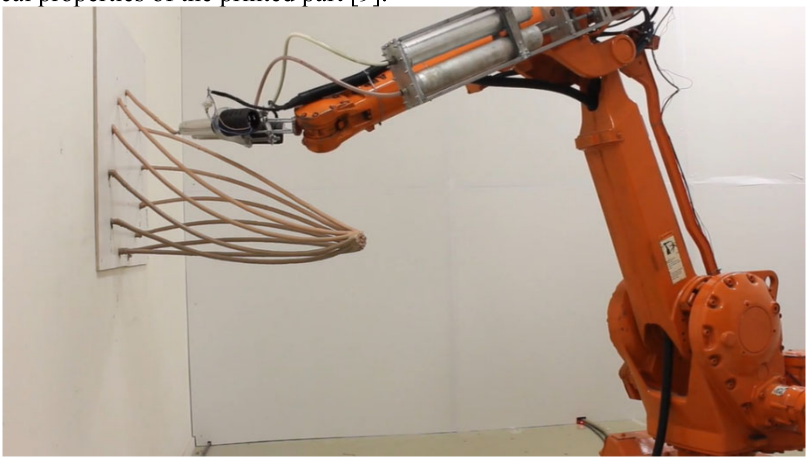

Fig. 1. Mataerial prints antigravity prints using stress line structures [9]

Design advantages. In the opinion of the design's founding team, there are two major advantages to such 3D printing. 3D printing on irregular or non-horizontal surfaces is considered impossible by conventional methods due to the effects of gravity and the environment, but Mataerial can counteract the effects of gravity [9]. As shown in Figure 2 below, Mataerial can print on vertical surfaces [9]. As shown in Figure 2 below, Mataerial can print on vertical indications.

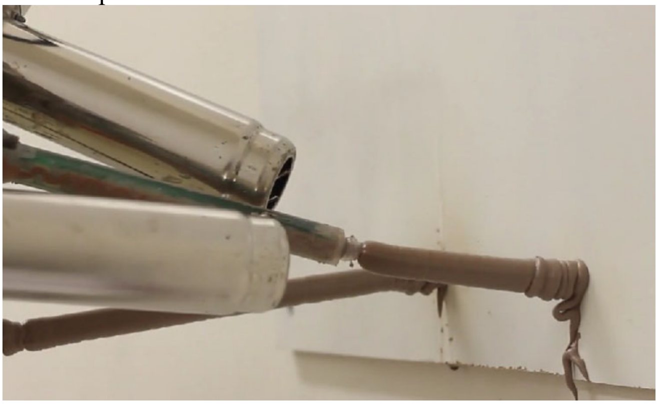

Fig. 2. Mataerial printing on a vertical surface [9]

While traditional 3D printing uses 2D layer stacking, Mataerial uses 3D curve stitching, which creates more natural and realistic objects [4]. As shown in Figure 3 below, the printed structure of Mataerial is smoother than that of traditional FDM, without obvious stratification and ladder-like traces.

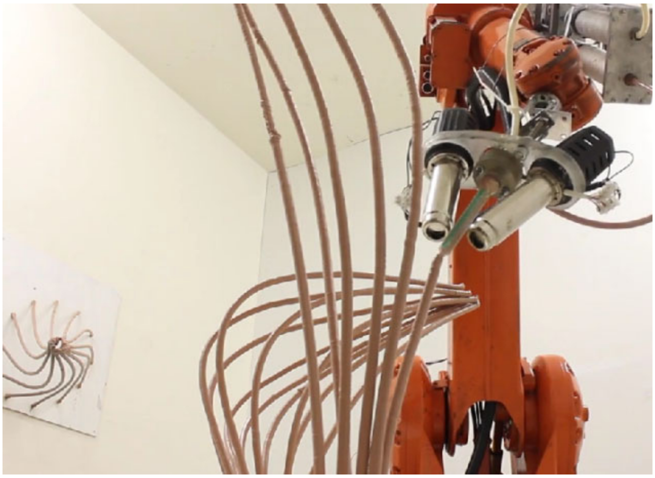

Fig. 3. Mataerial uses curves to construct a print body [9]

A review of the data shows that since Mataerial does not need to be attached to any specified flat surface, printing on walls or even ceilings or other vertical structures is perfectly feasible, and the heat curing material it uses is not subject to the effects of gravity to produce sagging, fulfilling the main requirement for anti-gravity printing, i.e., printing underneath a suspended surface.

Design flaws. The design flaws of the Mataerial are actually quite obvious. First, due to the thermoset polymer, the pre-exported additive reaches a rapid cure state, causing it to not fully integrate with the subsequent additive. This reduces the interlayer structural strength of the printed part and causes the creation of voids and bubbles within the structure. As shown in Figure 4 below, a defective joint-like structure can be clearly seen in the Mataerial's printed structure.

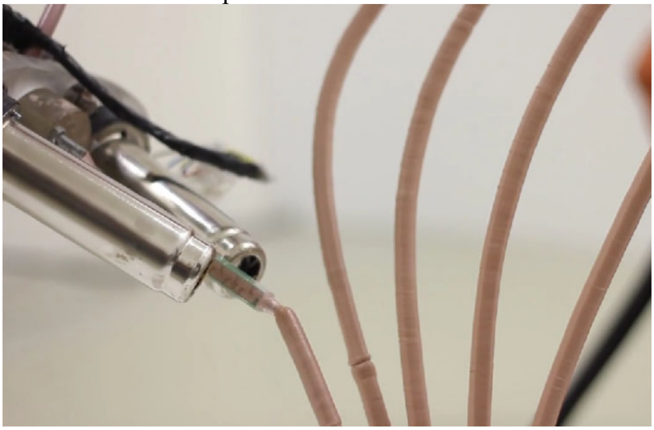

Fig. 4. Defects in Mataerial Printing [9]

Secondly, in order to ensure proper printing under anti-gravity conditions, the 3D printing filament output from Mataerial printers is much thicker compared to conventional printers. Although the curve structure of the printed part will be smoother due to continuous printing, the surface quality and fineness cannot be guaranteed. As shown in Figure 5 below, even the curves themselves do not have a very high surface quality.

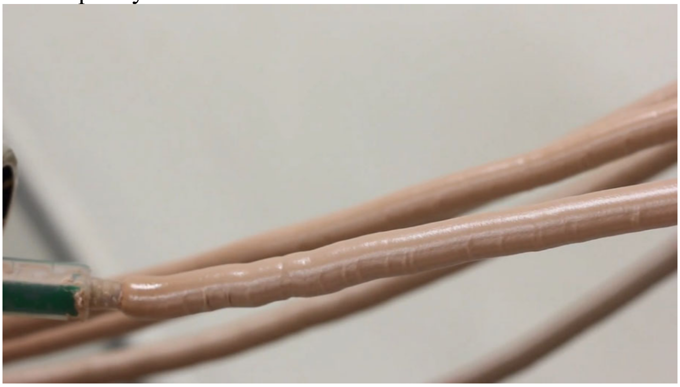

Fig. 5. Surface quality of Mataerial prints [9]

Finally, while Mataerial greatly reduces the effects of gravity and the requirements of the printing surface compared to traditional 3D printing, it still needs to be attached to other surfaces. It does not attach to any component, as Boeing's maglev prints do.

A quick look at the data shows that the Mataerial is currently used to print artistic constructions or structural models made up only of lines. In this way, the design team and users have been able to avoid the shortcomings of the Mataerial when printing face structures or other surface structures.

Future outlook. Mataerial does not currently have the ability to print surface structures, and its print quality is lower than other printers. If the Mataerial's shortcomings in printing surface structures can be improved through improvements in the printing method or structure, the Mataerial could be a promising technology for building temporary structures or repairing surfaces that are difficult to move. For example, the device could be used to build temporary canopies or windbreaks in disaster areas.

2.2 Anchorless Selective Laser Sintering Technology

This paragraph examines a new laser sintering technique developed by Professor Neil and his team at the University of Sheffield's Advanced Additive Manufacturing Research Center (ADAM).

Printing materials. The concept of anchorless selective laser sintering is based on the metallurgical term "low eutectic alloys", which solidify rapidly at a low temperature (low eutectic point). For example, the melting point of aluminum is 660 degrees Celsius and that of silicon is 1,414 degrees Celsius, but the low eutectic temperature of silicon-aluminum alloys is only 577 degrees Celsiu [4]. By accelerating this solidification process, printer can make the metal material fast. This allows us to make the printed part self-supporting during the 3D printing process, which can lead to printing on vertical surfaces and even anti-gravity printing. As can be seen in Figure 6, there is no need to print additional support structures for SLS printing using this technique, and the printed part can be self-supported for extension.

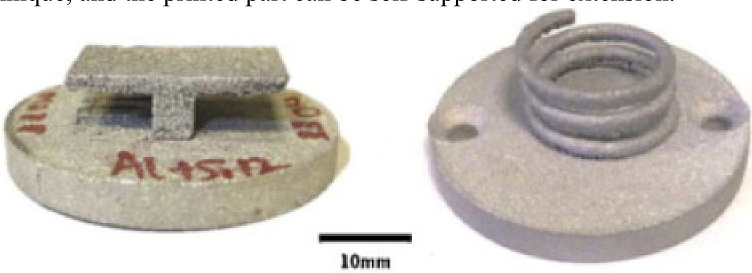

Fig. 6. Anchorless selective laser sintering technique for unsupported printing [10]

The University of Sheffield's Advanced Additive Manufacturing Research Center experiments with a variety of low eutectic alloys for 3D printing. Experiments with low-melting alloys have been quite fruitful so far [11]. The team is also currently exploring the issue of changing the properties of the experimental material, aluminum powder, at a higher temperature, and substantial progress has been made.

Printing methods. Anchorless selective laser sintering is a special type of SLS technology. When printing with SLS technology, the usual method to transfer or reduce excessive pressure on a particular structure is to add an anchor point here (i.e., to set up a support), but the countermeasure of ASLS is to curing the model rapidly at a low temperature to cope with the pressure [5]. In this way, the printing device can print in complex gravity environments in a molding mode similar to the Mataerial printer mentioned above, but using completely different principles and materials.

Design advantages. Anchorless selective laser sintering technology reaches the SLS technology based unsupported printing, which is the most mature anti-gravity 3D printing technology not based on FDM technology that exists today. It has the following advantages: 1. Metal materials can be printed, and the strength of the printed parts is high. 2. SLS-based printing, low printing costs, allowing the printing of more complex structures. 3. Faster printing speeds.

Design flaws. Anchorless selective laser sintering technology has the following drawbacks due to technical and material limitations. Firstly, limited material selection, for high melting point metal monomers and alloys, the print quality will be significantly reduced. Secondly, it has rough surface quality. Finally, it is a kind of high-temperature processing with high environmental requirements. It does not achieve complete gravity-free machining.

Future outlook. Anchorless selective laser sintering is the most promising technology for the industrialization of 3D printing. With anchorless selective laser sintering, printer can eliminate the cumbersome process of removing supports in the 3D printing process. If the problems of low material strength and poor surface quality caused by SLS can be improved, in fact, anchorless selective laser sintering has a great advantage over traditional subtractive manufacturing in the processing of complex workpieces.

2.3 Maglev Printing

This paragraph examines the means of magnetic levitation anti-gravity 3D printing designed by Boeing or using the same design ideas as Boeing.

Printing materials. Boeing's other maglev printing designs similar to the design use materials that can float in a magnetic field [12]. Combining multi-material printing technology with magnetic levitation technology mixes the print material with magnetic particulate material in a certain ratio to realize anti-gravity 3D printing, thus achieving 3D printing without support [4].

Printing methods. What people are describing as maglev printing is actually "spatial levitation printing", which is the use of magnetic levitation-related techniques to levitate printed parts and additive particles in a given space. By using this technique, most of the support structure of the printed part can be reduced, and the additive can be stacked and molded in any direction on any plane. At the same time, as shown in Figure 7 below, the multiple printheads in this design allow multiple surfaces to be printed at the same time.

Fig. 7. Maglev printing mode of operation [13].

Studies have shown that there are many ways to levitate materials. Among the possible methods Boeing mentions in its patent are the following: acoustic levitation, magnetic levitation, quantum levitation, and electrostatic levitation. One of these, magnetic levitation, requires "super-cooling the object and then placing it in a magnetic field to hold it under magnetic control." [5]. But even with such constraints, magnetic levitation is still the easiest levitation condition to achieve.

Design advantages. The advantages of maglev printing are obvious. Compared to the antigravity printing mode mentioned above, magnetic levitation printing firstly does not need to be attached to any flat surface, and secondly the printing direction is not limited [10]. The additive can rotate freely in the levitation space and attach to any surface of the printed part for fabrication. For example, in Figure 8 below, the additive can be stacked and printed along a curved surface.

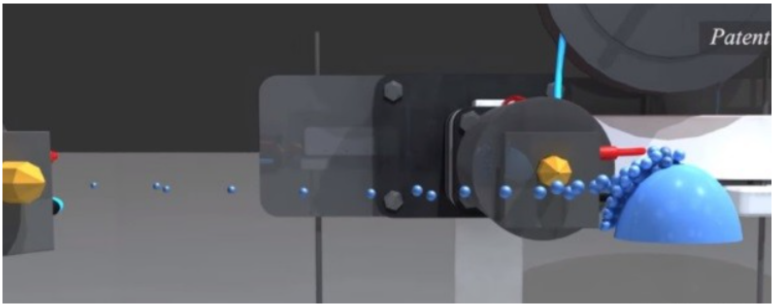

Fig. 8. Stacked printing of additive material along a curved surface [13]

In addition, the technology is a low-temperature additive manufacturing, which is safer to produce at lower temperatures [14]. Studies have shown that compared with high-temperature environments, low-temperature environments are easier to realize under 3D printing conditions, which also helps to improve the structural quality of the printed parts. The development of low-temperature printing should be the main direction for the subsequent development of 3D printing [15].

Design flaws. There is in fact a very obvious problem with magnetic levitation printing. In order to meet the magnetic levitation requirements, the designers added magnetic powder to the additive material using a multi-material printing mode [16]. The effect of this operation on the physical properties and structural strength of the material is debatable [17]. Through the study of sintered structures with structurally similar powders, it is easy to realize that adding powders to the material affects the tensile strength and yield stress of the material. Considering that the 3D printed parts themselves are not very strong and are not suitable for high loading environments, the effect caused by the addition of powder requires further experimentation.

Future outlook. Maglev printing is still only a design model, and even Boeing has not succeeded in designing a maglev printing device with practical value. But first of all, the device is completely free from the effects of gravity and has the ability to 3D print in complex gravity environments such as space stations. Secondly, the device is a cryogenic printing device, more suitable for working in small spaces. In summary if the device is successfully built, it is a promising 3D printing device for working in space. Perhaps it could be used for additive manufacturing in space to produce necessary parts or even for building habitation stations.

3 Conclusion

This article has pointed out some of the current advances in groundbreaking 3D antigravity printing, describing three of the more typical antigravity 3D printing solutions available as examples. The fact that the three printing solutions above use different design ideas makes them have completely different (and sometimes complementary) strengths and weaknesses. In fact, 3D printing solutions designed using different ideas are themselves designed to meet different environmental needs. It is through the development of many different 3D printing solutions that people will be able to satisfy the different needs of the production and living environments.

As of now, antigravity 3D printing is mainly used for repairing the surface of very large workpieces or for additive manufacturing in low-gravity environments. In the first case, people usually need to work with large structures that cannot be easily moved, and a design like the Mataerial is most appropriate. When people need to mass produce a large number of structures, laser sintering can save a lot of time in removing support structures and save material. When people need to additively manufacture in low-gravity environments, such as printing on a space station, using a model similar to maglev printing minimizes the effects of the low-gravity environment while controlling the print temperature to prevent damage to surrounding structures.

References

1. Sohu news, https://www.sohu.com/a/60534822_181700
2. China Computer Correspondence College: Anti-gravity 3D printing technology for vertical surfaces. Digital Community & Smart Home 2(5), 28 (2013).
3. China Academy of Space System Science and Engineering: Vertical surface 3D printing robot is born. Dual-use Technologies and Products 2(9), 35 (2013).
4. Pingwest, https://www.pingwest.com/a/16533#
5. Huang, P.: Take the melting point of an alloy. Chemistry in Middle School 2(9), 17–18 (2003).
6. Hua, L., Qing, X.: Research and progress on yield conditions of powder sintered materials. Journal of Wuhan University of Technology 2(4), 1–5 (2004).
7. Li, J., Ju, B.: Effect of diamine structure on properties of polyimide vitrimer. Engineering Plastics Application 2(5), 1–5 (2020).
8. Baidu Baike: Thermosetting polymer. Available at: https://baike.baidu.com/item/%E7%83%AD%E5%9B%BA%E6%80%A7%E8%81%9A%E5%90%88%E7%89%A9/7600983
9. https://www.designboom.com/technology/mataerial-anti-gravity-3d-printer-by-petr-novikov-sasa-jokic-joris-laarman/
10. Wang, Y., Sheng, J., Wu, H.: Application and research status of 3D printing materials. Journal of Aeronautical Materials, 36(4), 89-98 (2016).
11. Chen, Q., Yang, Y., Yu, Y., Xu, H.: "Reprocessable Thermosets": Synthesis and Characterization of Vitrimer in the Undergraduate Lab Course. Journal of Chemical Education, 98(4), 1429-1435 (2021).
12. Antarctic Bear 3D Printing Network. Available at: http://nanjixiong.com
13. Li, H., Dang, J., Zhang, R.: A new idea of anti-gravity 3D printing technology. Science and Technology Fashion 4, 195-196 (2017).
14. https://www.designboom.com/technology/mataerial-anti-gravity-3d-printer-by-petr-novikov-sasa-jokic-joris-laarman/
15. Cheng, L.: Comparison of thermoplastic materials with thermoset materials and metals. Electromechanical Component 22(4), 36-39 (2002).
16. Yu, D., Fang, A., Zhang, J.: 3D printing materials. Metal World, 5, 6-13 (2014).

17. Su, G., Jiang, H., Ma, Y.: 3D printing material technology and its trends. China Science and Technology Expo 18, 101 (2015).