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## **Current Status of Research on FDM 3D Printing to Reduce Material Wastage during Multi-Material Changeovers**

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# Current Status of Research on FDM 3D Printing to Reduce Material Wastage during Multi-Material Changeovers

Junwen Zheng

*School of Mechanical and Electrical Engineering, The University of Electronic Science and Technology of China  
Zhongshan Institute, Zhongshan, Guangdong, China*

zeiti@ldy.edu.rs

**Abstract.** FDM 3D printing technology is widely used in many fields with the advantages of low cost and easy operation. Still, the single nozzle FDM 3D printer has material waste problems in multi-material changeover, which restricts its sustainable development, this paper focuses on this topic, through the detailed analysis of the single nozzle FDM 3D printing changeover process and waste link, while exploring the improvement of dual nozzle and multi nozzle changeover technology, the study finds that The study *found* that there are many wasteful links such as old material extrusion and mixing of new and old materials in single-head material exchange. At the same time, dual-head and multi-head, although improving efficiency and reducing part of the loss, are faced with the challenges of nozzle coordination, interference and material distribution, etc. The study shows that in the future, it is necessary to optimise the structure of the nozzles, material exchange algorithms, improve the research on the compatibility between the control system and the materials to improve the level of automation and intelligent control, and research and development of environmentally friendly materials and recycling technologies to achieve the environmental protection and recycling of FDM 3D printing. environmental protection and sustainable development of FDM 3D printing.

## INTRODUCTION

Fused Deposition Modeling (FDM) 3D printing technology, as an important branch of the Additive Manufacturing (Additive Manufacturing, AM) field, is rapidly emerging and widely used in the manufacturing industry, FDM technology, with its low cost, simple operation, rich variety of materials, and other significant advantages, for the manufacturing engineering products, agricultural tools, biomedical implants and packaging, etc. [1], Y. Li pointed out that 3D printing is essentially an additive manufacturing technology, and FDM is one of the most technologically mature and widely available, illustrating the possibility of introducing 3D printing into the general shop floor, as well as the process of designing and implementing it, and ultimately, the benefits for the production shop floor [2]. Mohammed Nuwaid Nattukallingal et al. mentioned that FDM 3D printing technology is one of the most common additive manufacturing technologies and is widely used in various fields due to its relatively low cost of printing units and materials [3].

However, despite the significant advantages of FDM technology in terms of material utilisation efficiency, single-nozzle FDM 3D printers still suffer from material wastage during material changeover when printing multiple materials, which restricts their sustainable development to a certain extent. Material wastage during material changeover not only increases the production cost, but also negatively affects the environment, as well as the quality of the print, Mohammed Nuwaid Nattukallingal et al. mentioned that although FDM technology is cost-effective, the technology is unable to convert 100% of the raw material into a complete product and there is a potential plastic waste problem [3].

The core principle of FDM technology is based on digital model files (such as the common STL format), the model is discretised into a series of thin slice layers by slicing software, thermoplastic materials (e.g. PLA, ABS, etc.) are fed into the nozzle part of the printer in the form of filaments, and the heating device inside the nozzle heats the material to a molten state so that it has a good fluidity [2-5], and under the action of the print control system, the

Under the action of the print control system, the nozzle moves back and forth in the XY plane according to the preset path and speed, extruding and depositing the molten material on the printing platform layer by layer, and each layer of material will be bonded tightly with the next layer of material after cooling to finally construct a complete three-dimensional object, this layer-by-layer printing method not only improves the production efficiency, but also significantly reduces the material loss in the production process because the material is deposited on demand, compared to the conventional manufacturing methods without the need to remove large amounts of excess material [2][4][5].

In recent years, researchers have conducted a lot of studies on reducing material waste in the material changing process of FDM 3D printing, and these studies mainly focus on the optimisation of nozzle structure, optimisation of the material changing path, and improvement of the material properties, etc., O.M.F. Marwah et al. have used the response surface methodology to optimise the build parameters of FDM printing in order to take into account the material waste and energy consumption issues, which to some extent involves the optimisation related to the material change process, as the build parameters are closely related to the material change and other aspects [4], these studies not only focus on the optimisation at the technological level, but also explore the strategies to reduce the material wastage in order to reduce the impact on the environment from the sustainability point of view, Mohammed Nuwaid Nattukallungal et al. develop the 3D printer material recycler concept, which aims to recycle the plastic waste produced by FDM machines to address material waste from a sustainability perspective [3].

In this paper, a review and optimisation study is conducted on the material wastage problem in the material changeover process of FDM 3D printing. On the one hand, it analyses the practical effectiveness of existing optimisation methods in solving the material waste problem; on the other hand, it points out that current.

## **SINGLE-HEAD FDM 3D PRINTING WASTE LINK ANALYSIS**

### **Single-Head FDM 3D Printing Changeover Process**

#### *Preparatory Phase*

Before starting the changeover operation, it is crucial to ensure that the printer is in a working condition, the printhead temperature must reach a temperature range that is suitable for the current material melting temperature, which varies from one print material to another, and the new consumables to be replaced must be prepared and of good quality, with no obvious impurities, bubbles, etc. This stage is the basis for a successful changeover, which directly affects the subsequent printing results.

For example, S. K. Selvamani mentioned that different polymer materials such as ABS have unique thermal properties, and the temperature needs to be accurately controlled during the FDM printing process to ensure a good moulding of the material, which is in line with the requirement of the nozzle temperature during the preparation stage of the changeover [6].

#### *Extruding Old Material*

After the printhead temperature reaches the standard, the old material is extruded with the help of the printer control software, the heating element in the printhead heats the old material to the melting state, and the motor-driven feeding mechanism prompts the old material to be extruded from the printhead, during which the old material extrusion needs to be closely observed to ensure that it is smooth and to prevent clogging, and that the old material is easy to carbonise due to overheating when it is left for a long period of time in the printhead to affect the print quality.

As pointed out by Fico D, the flow of recycled PLA decreases due to thermal history, and the extrusion volume needs to be increased by 1-2 times to ensure the print quality, which is consistent with the mechanism of waste triggered by changes in the properties of the old material during changeover [7].

#### *Cut off the Old Material*

When the old material is extruded to a certain length, the new material is about to be accessed, the use of scissors and other tools to cut off the old material at the appropriate location, cut off the location selection is extremely

critical, too close to the nozzle, the old material access to the old material residue is too much, affecting the new material extrusion and printing, away from the nozzle is too far away from the waste of old material.

In the actual FDM printing operation experience as well as related process research, have emphasised the importance of cutting off the old material position for material waste control [8].

#### *Insertion of New Material*

Cut one end of the new material into a bevelled opening of about  $45^\circ$  to increase the contact area with the internal channel of the nozzle for easy insertion, slowly insert the new material along the feeding channel until it reaches the heating area of the nozzle, and the insertion process should avoid bending and jamming of the new material to ensure smooth feeding, and the appropriate angle of the bevelled opening and the correct insertion method will help the new material to enter the nozzle smoothly, and reduce the waste of material caused by improper insertion.

This operation is mentioned in many FDM 3D printing practice guides as well as related technical documents, and is a common method to ensure smooth feeding of new material [8].

#### *Extrusion of New Material*

New material inserted into place, through the control software to perform extrusion operations again, so that the new material in the heated state of the extrusion nozzle, the initial extrusion of the old and new material mixing occurs, is a normal phenomenon, continue to extrude a certain length of the new material until the extrusion of the material is completely new material and the state of stability, no drawing, bubbles and other issues, the new and old material mixing section length by the structure of the nozzle, the old and new material compatibility and other factors.

Shen Lin mentioned that the nozzle structure and the compatibility of the old and new materials and other factors will have an impact on it, for example, when changing from PLA to ABS, the mixing section is longer due to the big difference in chemical properties, which shows that the difference in material properties plays a key role in the extrusion process of 3D printing material replacement [5].

#### *Calibration and Test Printing*

After the material change is completed, in order to ensure the print quality, the printer needs to be calibrated, such as Z-axis height calibration, through the printing of a simple test model, to check the new material printing effect, including line flatness, inter-layer bonding, etc., if the printing effect is not good, you need to adjust the printing parameters, such as temperature, extrusion speed, etc., after the material change of the calibration and test print to ensure the quality, but will also consume a certain amount of material, multiple material changes The amount of accumulated waste should not be underestimated.

Like Leng Jie's study on the relationship between parameter adjustment and print quality in the FDM printing process, calibration and test printing after material change is an important link to ensure print quality, but also consumes materials [9].

### **Analysis of Wasteful Aspects of the Changeover Process**

#### *Waste of Old Material Extrusion*

When extruding old material, in order to ensure the smooth access of new material extrusion, often need to extrude more old material. Especially when the old material stays in the nozzle for a long time and its properties change, more will be extruded to ensure the quality, resulting in waste, and this part of the extra extruded old material directly increases the consumption of materials, which has a negative impact on the cost control and resource utilisation.

### *Wasteful Mixing of New and Old Materials*

At the beginning of the new material extrusion, due to the old material residue in the nozzle, the old and new material will be mixed and extruded, the performance of this mixed material is different from a single material, which usually can not be used for normal printing and discarded, the length of the mixing section is related to the structure of the nozzle, the compatibility of the old and new materials, the nozzle internal channel is long, the old and new materials are poorly compatible, the mixing section is long, and the wasted material is large, for example, from the PLA change to the ABS, the mixing section reaches 10-20cm, which is an insignificant source of waste in the process of changing materials [5][10].

The differences in the chemical and physical properties of different materials determine the changes in their properties after mixing, which have been elaborated in detail in the relevant studies of materials science, and the waste of mixed materials caused by such differences in the FDM changeover process is also more prominent [5], and the differences in the mixing section lengths of the different materials changeover have been verified in the actual printing [10].

### *Calibration and Test Print Waste*

The calibration and test printing after material change will consume certain material although it is to ensure the subsequent quality. The calibration process, such as Z-axis height calibration, needs to print the calibration pattern several times and consumes a certain length of material each time, and the test printing will consume new material even for the small-size test model, and usually 5- 10g of material will be consumed by the calibration and test printing after each material change, and the frequent material change will make this part of the waste increase significantly [9][11].

For example, Leng Jie emphasised the importance of print parameter calibration for print quality, a process that inevitably consumes material [9], and the amount of material wastage accumulated from calibration and test prints under frequent material changeover has been demonstrated in real-world print production [11].

### *Cutting off Old Material Improperly Positioned Waste*

Cutting off the old material position from the nozzle is too far away from the old material will lead to waste, assuming that each time due to the position of the improper waste of 5cm of old material, every day, many times to change the material operation, the cumulative amount of waste can be considerable, accurate control of the cut-off position is essential to reduce the waste of old material, is to optimise the material change process is one of the key links [8][12].

In the actual FDM printing operation experience, cut off the old material position improperly leading to waste occurs, and through theoretical calculations and simulations can also confirm the severity of the cumulative effect [8], the related FDM printing process optimisation research also highlights the importance of controlling the cut-off position [12].

### *Waste of Material Adhesion*

In the process of material change, the inside of the nozzle and the wall of the feeding channel will adhere to the old and new materials, these adherent materials can not be completely extruded and utilised, with the increase in the number of material change, the accumulation of the amount of increase in the waste, viscous materials such as nylon, the phenomenon of adhesion is even more serious, reduce the adhesion of the material to reduce the waste of materials in the process of material change is of great significance.

In the study of the interaction between the material and the pipe surface, the viscosity of the material and surface tension and other factors will affect its adhesion in the pipe wall, which is also applicable to the nozzle and the feeding channel of FDM printing, which provides a theoretical basis for solving the problem of material adhesion waste.

## IMPROVEMENTS IN MATERIAL CHANGEOVER TECHNOLOGY

### Definition and Principle of Dual Nozzle Structure

Dual nozzle structure refers to the printing equipment equipped with two nozzles, which can separately perform different printing tasks. In the 3D printing of FDM process, dual nozzles are used as the core components, and their working principle is based on the extrusion and moulding of materials.

For example, in industrial-grade 3D printing equipment, the dual nozzle conveys filament material to the nozzle through the filament feeding mechanism, extrudes it after heating and melting, and then stacks it layer by layer on the working platform to form a three-dimensional object, the filament feeding mechanism and the switching mechanism are the key components of the dual nozzle, and the traditional filament feeding mechanism exists such as damage to filament material, high driving force requirements, and unstable extrusion, etc., whereas the innovative design of the threaded filament feeding mechanism. The innovative design of the thread feeding mechanism can make the thread and silk material contact uniformly, and achieve the stable extrusion of silk material with less driving force, and at the same time, reduce the requirements for the drive motor. In terms of the switching mechanism, the purely mechanical, drive-free, high-precision switching mechanism scheme reduces the weight and volume of the dual nozzle, and improves the accuracy and efficiency of the switching of the nozzle, which ensures the efficient work of the dual nozzle [13].

### Definition and Principle of Multi-Nozzle Synergistic Structure

Multi-nozzle synergistic structure means that multiple nozzles cooperate with each other in the printing process to jointly complete the printing task of complex structures. Taking biological 3D printing as an example, through the independent control of multiple nozzles, it is able to support simultaneous printing and achieve the sequential deposition of different bio-ink materials, so as to build a heterogeneous tissue structure, and in this structure, the dual-gantry mechanical structure with fourteen degrees of freedom of multiple nozzles is adopted to cooperate with the corresponding control system and the upper computer software, to achieve precise control of each nozzle, in the printing process, each nozzle according to the preset path planning, work together, the different materials will be deposited synchronously, to shorten the printing time, to improve the tissue activity, and to promote the fusion between different materials.

### Advantages

#### *Improve Printing Efficiency*

Multi-nozzle co-printing breaks the limitations of traditional single-head or sequential printing, and multiple nozzles work simultaneously to complete the printing task in a shorter time, for example, in biological 3D printing, the printing efficiency is significantly improved when building complex heterogeneous tissue models by using multi-nozzle co-printing compared to sequential printing [14], and different nozzles carry out different parts of the printing at the same time, which greatly reduces the overall printing time, which meets the needs of rapid manufacturing.

#### *Parallel Printing*

The multi-nozzle synergistic structure realises parallel printing, i.e., multiple nozzles can print on different areas or different materials at the same time, and this parallel operation not only improves the printing speed, but also makes it possible to deposit bio-inks of different cells within the same layer at the same time, which can help to construct more complex and functional tissue structures, e.g., in the construction of a biological tissue model, different nozzles can print different types of cells at the same time, and Promote the interaction between cells and improve the functionality of tissue models [15].

## Multi-Material Printing Flushes Out Material Loss

### *Losses Due to the Operating Principle*

Compared with single-head multicolor printing, dual-head or multi-head structure can optimize the flushing material loss to a certain extent, multiple printheads work in parallel, in some cases, a specific colour of the printheads can be continuously extruded the same colour material, reducing the number of printhead flushing due to the frequent switching of colours.

Single nozzle multicolor printing often uses a single nozzle multi-channel structure, the nozzle body has a number of radial feed ports, through the control of different feed ports material extrusion to achieve multi-color printing, Tang Jingke et al. proposed a single nozzle multi-channel colour 3D printing mechanism, which adopts such a structure [16], but when the colour switching, it is also necessary to flush the internal channels of the nozzle to prevent the colour mixing, due to the structural limitations of a single nozzle, the internal channels of its Cleaning is more difficult, compared with the multi-nozzle system, more flushing material is needed to ensure that the material inside the channel is completely removed to avoid colour crosstalk, and it has been pointed out that the single-head multi-colour printing consumes an average of about 20-30% more flushing material than the multi-nozzle system each time when the colour is switched[17].

### *Print Job Complexity and Wear and Tear Relationship*

Complex multi-colour print jobs, especially those involving patterns or models with frequent colour switches, can significantly increase printhead flushing material loss, for example, in the case of producing artwork prints with rich colours and frequent transitions, the printheads need to switch colours frequently, with each switch accompanied by a flushing operation.

Whether it is dual-head or multi-head multi-colour printing or single-head multi-colour printing, the complexity of the printing task has a significant impact on the loss of printhead flushing material, but dual-head or multi-head multi-colour printing to deal with the complexity of the task, if you can reasonably allocate the work of the printheads, you can relatively reduce the loss of printhead flushing material.

In contrast, single-head multicolor printing in the face of complex tasks, the printhead flushing material loss is more difficult to control, due to the singularity of the single printhead, no matter how often the colour switch, can only rely on the completion of this one printhead, resulting in an increase in the number of printhead flushing, material loss increased accordingly, in the same degree of complexity of the print task, single-head multicolor printing printhead flushing material loss than the multi-jet system is higher than the multi-jet system of about 40% - 60% [18].

### *Impact of Printhead Control and Calibration On Wastage*

Accurate nozzle control and calibration is significant to reduce the loss of flushing material, the nozzle preheating time, switching accuracy and other control parameters affect the flushing effect and material loss, if the nozzle preheating time is inaccurate, the material extrusion is not smooth, and more flushing material is needed to dredge the nozzle, the nozzle switching accuracy is not enough, the inside of the nozzle will retain more of the previous colour material, increase the amount of flushing material, research shows that when the nozzle preheating time Research shows that when the deviation of nozzle warm-up time is more than 5 seconds, the consumption of flushing material for each nozzle switching increases by 10-15 grams, and when the deviation of nozzle switching accuracy is more than 0.1 mm, the consumption of flushing material increases by about 15-20% [19].

### *Differences in the Consumption of Support Materials*

In the 3D printing process, the use of support material is crucial to ensure the stability of the printed structure during the forming process, whether it is a dual- or multi-nozzle multi-colour printing or a single-nozzle multi-colour printing, the consumption of the support material is closely related to the structure of the printed model, and for models with complex overhangs or internal hollowing structures, more support material is needed to ensure the smooth operation of the printing [20].

In dual-head or multi-head multi-colour printing, given the large number of printheads, when printing certain complex structures, the connection and transition between the materials extruded by different printheads may require more support materials to assist, in order to avoid structural deformation due to the accumulation of materials or uneven contraction, as mentioned by Lai Zhouyi, the printed model contains a base, the model itself and the model wrapped around the support layer of the three parts, and most of the Most of the printing raw materials are consumed in the aperture cleaning and the support layer, which reflects that complex structures consume less support material when printing with multiple printheads, and studies have shown that the support material consumption of the multi-nozzle system is about 10-20% higher than that of the single-nozzle system when printing complex structural models [21].

Single-head multicolour printing, due to the relative simplicity of the printhead structure, will require slightly less support material compared to the multi-head system in the printing of some relatively regular models, but overall, the complexity of the printed model has a more critical impact on the consumption of support material, and the higher the level of complexity, the significantly higher the consumption of support material for both single-head and multi-head multicolour printing.

## Technology Progress and Application Expansion

### *Advances in Dual Nozzle Technology*

In the field of biomedical tissue engineering, it is significant to construct scaffolds with complex structures and multiple biologically active components. Dual-jet 3D printing technology can print different biomaterials at the same time, such as extracellular matrix simulation materials and cell-loaded hydrogels, for example, a study has successfully constructed a bone tissue engineering scaffold with the help of a dual-jet 3D printer, where one nozzle prints a collagen matrix and the other prints a bone-forming cell-containing sodium alginate hydrogel, showing good biocompatibility and cell adhesion, compared with a single-material scaffold printed with a single nozzle. For example, a study successfully constructed a bone tissue engineering scaffold with a dual-jet 3D printer, one nozzle printing collagen matrix and the other nozzle printing sodium alginate hydrogel containing osteoblasts, the scaffold showed good biocompatibility and cell adhesion, and the cell proliferation rate of the composite scaffolds printed with dual-jet nozzles was increased by 30% compared with that of the scaffolds printed with single material with single nozzle printing and the cell activity was significantly enhanced after 14 days of cultivation, which indicates that dual-jet nozzle technology can simulate the in vivo microenvironment more effectively to promote the cell growth and tissue regeneration [22].

Dual-head 3D printing can also accurately control the distribution of different drugs or carrier materials, to prepare a unique release characteristics of the drug delivery system, the researchers use dual-head printer, respectively, printing drug-carrying polymers and slow-release materials, made of multilayered structure of the drug microspheres in the in vitro drug release experiments, compared with a single structure of single-head printing of the microsphere, showing a more ideal slow-release effect, dual-head printing of the The microspheres printed with dual nozzles achieved a sustained and stable drug release within 7 days, with a cumulative release rate of 80%, while the microspheres printed with a single nozzle basically ended the drug release after 3 days, with a cumulative release rate of only 60%, which shows that the dual nozzle technology can better regulate the kinetics of drug release and enhance the efficacy of the drug [23].

Dual-nozzle 3D printing technology helps in the accurate manufacturing of continuous fibre-reinforced composites. Taking continuous fibre-reinforced polyamide composites as an example, Wang Lijuan used 3D printing additive manufacturing (ALM) process to manufacture continuous fibre-reinforced polyamide composite parts, and the study showed that after the fibres were surface-treated, the silane coupling agent reacted with the chemical reaction on the surface of the glass fibres, and the 3D-printed glass fibres and the polyamide material are well combined. Along the fibre direction, the tensile stress reaches 550MPa, strain 4.23% when fracture, compression fracture strength 86.82MPa, strain 0.62%; vertical fibre direction, tensile fracture strength 10.56MPa, strain 1.32%, compression fracture strength 13.95MPa, strain 1.22%. Compared with single-head printing, dual-head printing significantly improves the material properties, which has great potential for application in aerospace, automotive and other fields that require high material properties [24].

With the help of dual-nozzle simultaneous printing of materials of different compositions, materials with functional gradient characteristics can be prepared, such as in the preparation of electromagnetic shielding materials, reference can be made to the relevant ideas of Kalaimani et al. By adjusting the printing parameters to achieve the

gradient distribution of the internal composition of the material, the use of selective hot melting (SHM) technology to manufacture functional gradient materials, the specific conditions can be obtained under the material with good performance, compared to single nozzle-printed homogeneous materials, the functional gradient materials printed by dual nozzles are more advantageous in terms of specific properties and can meet the shielding needs in different electromagnetic environments [25].

For bio-gel, silicone rubber and other flexible materials such as the complex shape of the molding difficulties, dual-nozzle 3D printing technology can achieve the integration of the mold and flexible materials molding, a nozzle printing PLA and other engineering plastics as a support and mold, the other nozzle printing silicone rubber, bio-gel and other flexible materials, the test results show that the dual-nozzle printing device for the molding of flexible materials to bring a breakthrough in molding process, can achieve the mold and flexible materials integrated molding, compared with a single nozzle, it saves molding time and cost, through simultaneous printing to improve the fit of the mold and flexible materials and product accuracy, such as printing complex shapes of silicon rubber products. Flexible materials integrated molding, compared with a single nozzle, it saves the time and cost of mold making, through simultaneous printing to enhance the fit of the mold and flexible materials and product accuracy.

#### *Advances in Multi-nozzle Technology*

In the field of electronics manufacturing, the manufacturing of multi-layer flexible electronic devices requires a high degree of process integration and efficiency, the traditional manufacturing methods usually require multiple processes and a variety of equipment combinations, the process is complex and costly, multi-jet 3D printing technology for the integrated manufacturing of multi-layer flexible electronic devices brings the possibility.

In order to manufacture five-layer flexible pressure sensors as an example, the experiment compares the single-nozzle and multi-nozzle printing methods, single-nozzle printing, each layer of material needs to be printed sequentially, due to the long waiting time for nozzle switching, the completion of the five-layer structure of the printing time-consuming, and the use of multi-nozzle systems, such as four-nozzle, each nozzle is responsible for the printing of specific materials, can be carried out at the same time for the different layers of the printing process, which significantly improves the efficiency of the printing process. Li pointed out that through reasonable multilayer circuit layout and optimised process parameters, the use of multi-nozzle 3D printing technology can achieve efficient manufacturing, compared with single-nozzle printing, the multi-nozzle system not only dramatically reduces the printing time, but also effectively improves the resistance stability of the inter-layer connection points through precise nozzle positioning and synchronisation control, which in turn improves the performance and reliability of the sensor [26].

Taking the large industrial parts model as the experimental object, the single nozzle printing speed is 20mm/s, accuracy  $\pm 0.3\text{mm}$ , and it takes 48 hours to complete. The use of four nozzle parallel printing system, the nozzles to 25mm / s speed at the same time, based on the nozzle tangential tracking principle and the principle of equal spacing printing to achieve multiple trajectory parallel printing, printing time has been significantly reduced to 12 hours, an increase of 75% efficiency.

In terms of accuracy, the multi-head parallel system, with the help of 2-axis-4-axis interpolation data conversion algorithm, improves the accuracy to  $\pm 0.1\text{mm}$ , which is 66.7% higher than that of a single printhead. In terms of print quality, the model printed by the multi-nozzle has a smoother surface and a denser internal structure, and the mechanical property test shows that its tensile strength is 20% higher than that of the model printed by a single nozzle [27].

Printing a variety of materials mixed model, multi-nozzle system has obvious advantages, can achieve the precise distribution and mixing of different materials, to print composite electronic devices with different electrical properties, for example, a single nozzle extrusion of different electrical properties of the material in turn, the material is prone to electrical properties of the intersection is unstable, multi-nozzle system can be extruded at the same time as the conductive and insulating materials, precise control of the nozzle extrusion volume and trajectory, to achieve a microscopic uniform mixing and distribution of materials. Material microscopic uniform mixing and distribution.

Small circuit board model printing experiments show that the circuit board printed by a single nozzle, conductive lines and insulating areas at the junction of the resistance fluctuation range of  $\pm 10\ \Omega$ ; multi-nozzle printed circuit boards, the resistance fluctuation range of the junction is controlled within  $\pm 5\ \Omega$ , which effectively improves the stability of the electrical properties of electronic devices [28].

## CHALLENGES AND DEVELOPMENT

### Single-Head 3D Printing Technology

Single nozzle 3D printing in the multi-material change process, because the nozzle can only be extruded one material at a time, in the replacement of materials, the nozzle inside the residue of the previous material can not be completely extruded for printing, thus resulting in waste, in order to ensure the quality of the print, the need to clean the nozzle before replacing the material, which will also consume a certain amount of material, in addition, the single nozzle 3D printing in the multi-material printing, the printing efficiency is low. Because each material change needs to pause the printing process, which extends the overall printing time to a certain extent, and factors such as the stability of the equipment during a long period of time will also affect the print quality, increasing the risk of material waste.

In order to reduce the waste of single printhead multi-material changeover, researchers are working to develop a more optimised printhead structure, for example, by improving the design of the internal flow channel of the printhead, so that the amount of material residue is reduced, and at the same time, also in the research and development of intelligent changeover algorithms, according to the needs of the print model, precise control of the timing of the changeover to reduce the waste of material due to inappropriate changeover, and some research has also attempted to combine the characteristics of the material, the development of the printhead can be compatible with a wide range of materials nozzles to reduce the number of material changes and reduce material waste from the root.

### Dual Nozzle 3D Printing Technology

Although dual-head 3D printing can improve the efficiency of multi-material printing to a certain extent, there are challenges in the coordination between the two nozzles, in the process of changing materials, the material switching time and speed of different nozzles need to be precisely matched, otherwise it is easy to print faults, material buildup and other problems, resulting in material waste, in addition, the compatibility of the two materials in the connection between the nozzles is also a key issue, if the materials can't be In addition, the compatibility of the two materials in the printhead connection is also a key issue, if the materials can not be well integrated, it will affect the overall quality of the printed parts, so that some of the printed results due to quality problems and scrap, resulting in material waste, and the dual-head equipment in the maintenance and calibration of the more complex, improper maintenance and calibration will lead to clogging of the nozzles, uneven material, and other issues, which will increase the waste of materials.

For the dual nozzle coordination problems, researchers have developed an advanced control system, through real-time monitoring of the nozzle status and material flow, precise adjustment of the nozzle's operating parameters, to achieve more accurate material switching, in terms of material compatibility, continue to explore the combination of new materials and the development of interfacial processing technology, in order to improve the strength of the combination between different materials, and at the same time, the development of simpler and more efficient maintenance and calibration methods, to reduce the material waste caused by equipment problems. methods to reduce material waste due to equipment problems.

## CONCLUSION

This paper focuses on the material waste problem of multi-material changeover in FDM 3D printing, and analyses found that there are multiple wasteful links in the single-head printing changeover process, such as old material extrusion, mixing of new and old materials, and calibration test, etc. In terms of improvement technology, although the dual-head and multiple-head structure improves the efficiency and reduces the part of loss, it is also faced with the challenges of nozzle coordination, interference, and material distribution.

These studies are of great significance in promoting the sustainable development of FDM 3D printing technology, which not only reduces costs and environmental pollution, but also improves the print quality and expands the application scope of this technology in multiple fields.

In the future, single-head printing can reduce waste by optimising the printhead structure and material exchange algorithms, while dual-head and multi-head printing need to further improve the control system and material compatibility research. In the long run, improving the degree of automation, developing intelligent software to

achieve precise control, and developing environmentally friendly materials and recycling technologies will enable FDM 3D printing to meet the complexity and diversity of printing needs, while achieving environmental protection and sustainability goals, bringing more profound benefits to the manufacturing industry. This will bring far-reaching changes to the manufacturing industry.

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