Selection of Removable FDM Support Materials

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Abstract. The selection of support materials in Fused Deposition Modeling (FDM) technology directly affects the quality of printed parts and the efficiency of post-processing. This paper systematically reviews the research on the removability of FDM support materials. Firstly, it analyzes the dissolution mechanism of soluble materials (such as PVA and AA copolymers) and their advantages and limitations in precision manufacturing. Secondly, the cost-effectiveness and applicable scenarios of mechanically removed materials (such as PLA) were discussed, and their drawback of easily damaging the main body was highlighted. In addition, the potential and challenges of emerging technologies such as composite materials and sand supports are introduced. The research further compared the performance of different materials and summarized the shortcomings of existing technologies in terms of environmental friendliness, cost, and application scope. Finally, the future development directions were proposed, including optimizing material ratios, developing recyclable support materials, and improving process design, to promote the application of FDM technology in industrial and high-precision fields. This article provides a theoretical basis and practical guidance for the scientific selection of supporting materials.

Keywords: FDM 3D printing technology, support materials, soluble materials, sand support.

1. Introduction

Fused Deposition Modeling (FDM) technology is widely used in the field of 3D printing, and the selection of support materials directly affects the quality of printed parts and the efficiency of post-processing. The role of support materials is to ensure the stability of complex structures, but their removability determines the convenience of post-processing and the surface accuracy of the finished product [1]. In this field, research has primarily focused on soluble materials, predominantly composed of polyvinyl alcohol and acrylic acid, as well as materials based on polylactic acid that can be removed mechanically, and methods to enhance these support materials [2]. For example, how to use blending modification methods to combine the characteristics of two different types of support materials into a new material that takes advantage of both, or to study the use of other special materials, such as sand and wax, as support materials for FDM 3D printing technology. Therefore, the study of the performance of support materials and their removal mechanisms is of great significance for optimizing the printing process and reducing costs.

This article reviews the selection criteria of existing FDM support materials, including soluble materials (such as PVA), mechanically removable materials (such as PLA), as well as emerging composite and sand support materials, and analyzes their removal mechanisms and applicable scenarios. At the same time, it discusses the advantages and disadvantages of different materials in terms of print quality, post-processing efficiency, and environmental friendliness, providing references for practical applications.

2. Dissolvable Supporting Materials

2.1. Typical Materials

Dissolvable supporting materials are one of the most commonly used supporting materials in the current research of FDM printing technology. By using a material that is different from the printing material and can dissolve as the support, and immersing the printed object in an organic compound to dissolve or separate the supporting material from the main body, the purpose of removing the supporting material is achieved [1]. Currently, polyvinyl alcohol (PVA) water-soluble supporting materials and acrylic (AA) copolymer water-soluble supporting materials are the most widely used in FDM technology [2]. In addition, some soluble thermoplastic polymer materials such as Ultem9085 can also remove the supporting material [3].

2.2. Dissolving Reagents and Influencing Factors

The removal ability of soluble materials is affected by temperature, solution concentration and time [4]. Studies have shown that the dissolution rate of PVA increases over time and reaches a maximum [5]. Similarly, acrylic acid also exhibits a similar effect in sodium hydroxide solution. Research indicates that when the solution concentration is increased to 0.4% and the temperature is raised by 50 degrees, or with the assistance of ultrasound or raised to 70 degrees, the polymerization time of AA copolymer will be significantly shortened from 170 minutes to 70 minutes [6]. The Ultem9058 material has the same properties as the above two materials and is also affected by the same characteristics.

2.3. Advantages and Disadvantages of Using Soluble Supporting Materials

The advantage of using soluble supporting materials is that they can automatically peel off without being damaged, affecting the main body of the printing, and increasing the smoothness [4]. However, the time for removing the soluble material is longer, ranging from several tens of minutes to several days, and is more widely applied in medicine and industry [5]. In addition, when removing the soluble supporting materials, an organic solution needs to be configured, which brings the cost problem of the initial configuration and storage, and the challenge of how to handle the subsequent waste liquid. If the waste liquid is not handled properly, it will cause environmental pollution and is not conducive to the environmental protection concept.

3. Using Mechanical Removal-type Support Materials

3.1. Typical Materials

In the current market, the most commonly used support materials for FDM printers are non-dissolvable support materials mainly composed of polylactic acid (PLA). These materials need to be removed from the main body of the material either manually or with the aid of tools. After removing these support materials, processes such as abrasive flow processing are used to improve the surface smoothness and accuracy of the printed main body [7].

3.2. Influencing Factors

The influencing factors of these materials are the contact time between the support material and the main body, the bonding temperature, and the bonding pressure. When the time, bonding temperature, or bonding pressure increases, the bonding strength between the support material and the main body also increases, resulting in the support material being less likely to be removed from the main body [4]. This is achieved through the diffusion process of molecules and is also known as the molecular penetration theory [4]. In this theory, the molecular chains of high-molecular compounds are considered to be flexible, and the interlayer molecules constantly undergo thermal motion, which leads to the disappearance of the interlayer interface and the interlayer molecules being firmly interconnected in an interwoven state as the influence factors such as time, temperature, and pressure increase.

3.3. Advantages and Disadvantages of Using Mechanical Removal-Type Support Materials

Using mechanical removal type support materials is simpler and does not require the configuration of water solvents, and is more cost-effective. Therefore, it is widely used in the market. As a result, most of the support materials used in 3D printers currently available on the market are of this type.

Moreover, compared to soluble support materials, the hardness and brittleness of support materials removed by mechanical means are higher [2]. However, because these materials cannot be automatically removed, the use of such support materials significantly increases the possibility of damaging the main body of the material during the removal of the support materials [6]. Due to the need for manual or assisted peeling, traces will be left on the main body after the removal of these materials, which will greatly affect the accuracy and surface smoothness of the printed main body. When printing some precise and complex parts, these materials are also replaced with other materials due to their effect on the characteristics of the main part [8].

4. Comparison of Two Different Removal Methods for Supporting Materials

By comparison, the process of dissolvable supporting materials is quite complex, but it can form very complex and precise parts and even print assembly components. They need to be immersed in organic solutions for removal, such as alkaline solutions. After removal, the surface of the printed main body is relatively smooth and intact. However, the time required for removing the supporting materials is very long, sometimes even several days. In contrast, the supporting material removed by mechanical means has a simpler operation process, only requiring manual or tool-based peeling. The time spent is also shorter. However, it can only print components with relatively simple formed structures, and it is prone to damaging the surface of the printed main body. The surface of the printed main body is rougher compared to the components with supporting materials removed by dissolvable ones [2].

5. Support Materials Using Other Removal Methods

5.1. Support Materials Using a Composite Removal Method

In addition to the above two types of materials, there are many other types of support materials. For example, support materials using a composite removal method. This method combines soluble support materials with non-soluble support materials through a blending modification design approach. This design method can reduce the bonding strength between the support material and the main body and increase its hardness, and also add certain brittleness to the material to facilitate its peeling. However, in contrast, the material's fluidity also deteriorates, and during printing, problems such as layer collapse and nozzle blockage may occur [2]. Figure 1 is a development design diagram of a composite structure support material.

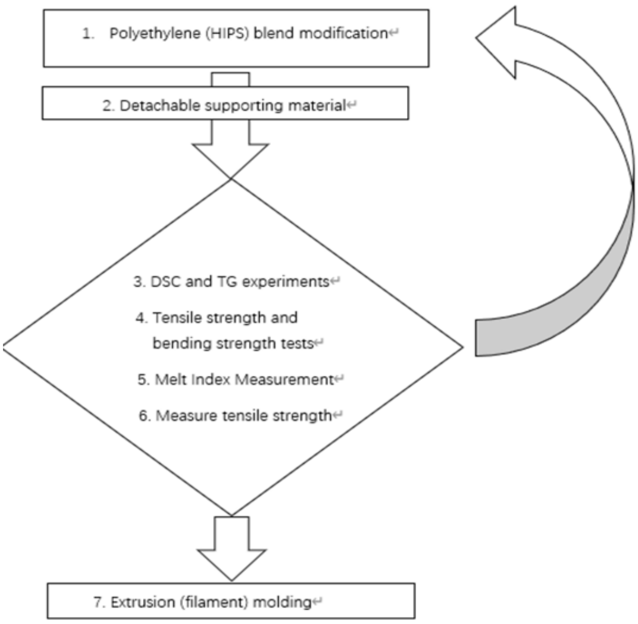

Fig. 1 Design scheme diagram for the peelable support material development plan [2].

5.2. Using Sand as Support Material

Sand can also be used as a support material for FDM 3D printing. Due to its greater discreteness and fluidity, sand is more suitable as a new type of support material for creating complex precision parts [8]. By referring to the powder laying structure of the laser sintering 3D printing method, a cavity model and a sand laying device were manufactured to ensure the control of the sand flow direction. This device was divided into three parts: sand supply, sand scraping, and sand switch. Figure 2 is the cross-sectional structure diagram of sand-supported FDM 3D printing. During the printing process, a wall was established on the outermost layer, and sand was evenly laid in the printed layers and the outer wall using a dual-nozzle mode, achieving the supporting effect. The main body printing and the outer wall printing and sand laying were carried out simultaneously. When the main body printing was completed, the outer wall was printed layer by layer along with the printer to form a closed container structure [9]. However, this method does not currently take into account the situation where sand may stick to the main body during the layer-by-layer printing of the main body, so further research is needed for FDM 3D printers specifically for sand support.

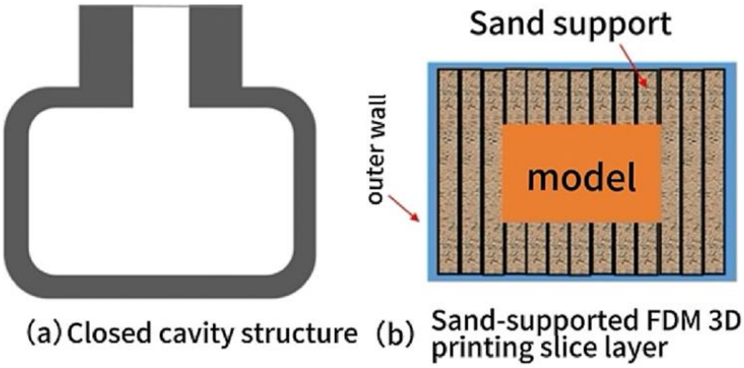

Fig. 2 The FDM 3D printing structure supported by sand [9].

5.3. Using Wax Material as a Supporting Material

Wax material can also be used as a removable FDM printing support material [10]. The low tensile strength and high adhesion of wax material can offer advantages under specific printing conditions. Moreover, the melting point of wax is lower than that of the printing main body material, making it easier to remove without damaging the main part of the print and maintaining a higher smoothness. However, due to the low melting point of the wax material, if the temperature of the main part during printing is too high, the wax material will melt, resulting in a high level of fusion between the main material and the supporting material [10].

6. Challenges and Development

6.1. Facing Challenges

Currently, there are still many challenges in the selection and application of support materials for FDM printing technology. The primary issue is the balance of material properties. Soluble support materials can be removed automatically through solutions and reduce damage to the printing main surface, improving smoothness, but it requires a lot of time. Mechanical removal-type materials with higher strength, such as PLA, are prone to causing damage to the main structure during peeling, which is not conducive to the complete formation of thin-walled or fine components. Therefore, developing a new type of support material that not only has sufficient mechanical performance, is easy to remove, and can achieve controlled adhesion at the interface has become an important research direction in this field.

Furthermore, environmental protection and cost issues cannot be ignored. Dissolvable supporting materials usually require organic solvents (such as alkaline aqueous solutions or specific chemical reagents), and the disposal of their waste liquids may cause environmental pollution problems.

Moreover, the storage, preparation and recycling of solvents increase the usage costs. In contrast, mechanical removal-type materials have lower costs, but the recycling rate of discarded supporting materials is low, which can easily lead to resource waste.

Finally, technological maturity is also a hindrance. Although composite supporting materials (such as the PVA/PLA blend system) can combine the advantages of solubility and mechanical peeling, their fluidity, interlayer bonding strength, and other properties are still unstable. During the printing process, layer separation defects and nozzle blockage may occur. Sand support, wax material support, and other emerging technologies, although showing potential in the formation of complex structures, still need to solve problems such as the adhesion of sand particles to the printing body and the low melting point of wax materials, which can easily fuse with the body.

6.2. Looking Forward to the Future

The development of removable support materials for FDM printing will place greater emphasis on the development of new processes and materials. By precisely regulating the ratio of the blended materials, the optimal configuration of material properties can be achieved, thereby increasing the removal rate of the support materials and the smoothness of the main body surface. On the other hand, new reusable material technologies such as sand support and wax material support, are expected to receive more in-depth research and wider application, promoting the development of the support system towards a green and efficient direction.

The industry will also explore environmentally friendly solutions, including developing biobased degradable materials or recycled materials to reduce the negative impact on the environment [11]. At the same time, developing low-toxicity or water-soluble dissolution systems and optimizing solvent recovery processes will also become important paths for the sustainable development of removable support materials. With the continuous maturation of technology and in-depth interdisciplinary cooperation, removable support materials are expected to achieve breakthroughs in printing quality and efficiency, and play a key role in aerospace, biomedicine, and customized manufacturing, providing solid support for the overall progress of additive manufacturing.

7. Conclusion

Soluble support materials (such as PVA, AA copolymer and some thermoplastic polymers) can be automatically removed through solvent immersion. They perform exceptionally well in protecting the integrity of the printed main body and improving surface quality, especially in fields such as medicine and industry, where precision is required. However, this method has issues such as long processing time, high cost of solvent usage, and environmental pollution. Moreover, the dissolution efficiency is affected by multiple factors such as temperature, concentration and time.

In contrast, mechanical removal-based materials (such as PLA) are widely used in desktop-level printing due to their low cost and simple operation. However, the removal process can easily damage the surface of the components and the bonding strength is significantly affected by process parameters. Therefore, they are mostly used for ordinary models with lower surface requirements. The emerging composite materials attempt to balance the ease of removal and mechanical properties through blending modification, but they face technical bottlenecks such as poor fluidity and unstable processes. While non-traditional methods based on sand support or wax material support have significant potential in the formation of complex structures, they still have problems with particle residue and process compatibility.

Overall, the development of support materials in the future will tend towards multi-functional composites and green sustainability. On one hand, it is necessary to further optimize the material ratio, improve the economic and environmental performance of the soluble materials, and improve the adaptability of mechanical removal materials to fine structures. On the other hand, efforts should be made to promote the innovation of biodegradable, water-soluble or recyclable material systems, and improve the recycling and treatment processes of corresponding solvents to achieve environmental friendliness and resource conservation. As technology gradually matures, support materials are expected to play a more crucial role in high-end manufacturing, bioengineering, and personalized customization, promoting additive manufacturing to develop towards higher quality and wider applications.

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