Application and Development of 3D Printing Technology in Mold Manufacturing

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Abstract. The paper gives an overview of designing and implementing of 3D printing technology in mould production. The idea of several mainstream additive manufacturing techniques, namely Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Melting (SLM), is presented and the properties used in the production of molds are outlined. Moreover, the application examples in medical engineering, construction, automotive manufacturing, and composite materials are examined to explain the potential in using additive manufacturing in the production of molds. The challenges that are present in the research also include; a summary of material performance, surface quality, and production cost. On the whole, the findings suggest that 3D printing has the potential to enhance flexibility of designing the mold, reduce the time in development, and facilitate innovative methods of manufacturing in the mold industry.

Keywords: Additive manufacturing; 3D printing technology; Mold design; Rapid tooling; Industrial applications

1 Introduction

In the recent past, additive manufacturing, which is also referred to as 3D printing, has evolved slowly to transform the way numerous industrial items are manufactured. Researchers and engineers of various fields of expertise have become more and more interested in the technology, including materials processing, medical engineering, and industrial manufacturing [1]. As digital design tools, material development and computing technology have continued to advance, 3D printing is no longer only used in the rapid prototyping process, but is also now being considered in the production of functional parts, industrial molds, and intricate structures. Provided by the concept of Industry 4.0 that advocates intelligent manufacturing, digital integration, and flexible production systems, this development can also be viewed as a consistent one [2-4].

Molds are vital in the contemporary production as the quality of the products, their dimensions, and the efficiency of production usually rely on the functionality of the molds [5, 6]. Nevertheless, customization Mold production traditionally, machining, electrical breakthrough machining etc., are normally characterized by complex processing steps, extended make

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durations, and face a great production expense, particularly amidst intricate interior designs or tailored aspect in the moulds [4, 6]. Additive manufacturing provides the possible solution to these restrictions. The 3D printing process can be used to create complex geometries that are challenging to realize by other methods, enabling the optimization of the structures of molds, quick tool creation, and integrated design. Past research has demonstrated that the use of 3D printing to develop molds may significantly decrease the time or duration needed during the development process, material wastage, and increasing the productivity of production [2, 5]. Moreover, 3D printing has also been extended to other fields of engineering like medical engineering and building. Indicatively, it is able to manufacture custom surgical directions, medical implants and dental molds, concrete parts and prefabricated construction units [5]. Its industrial applicability has also been enhanced beyond by the creation of multi-material composites and high-performance materials [3, 5, 6]. These experiences of cross-industry indicate that 3D printing technology is increasingly becoming more mature and versatile and is a good reference to the diversification of mold manufacturing development. It is in this context that the current research paper focuses on exploring how 3D printing technology can be used and developed in the manufacturing of moulds. Some of the typical additive manufacturing methods are examined and their nature, benefits, and drawbacks in making molds analyzed. The analysis contributes to the improvement of the comprehension of the way in which additive manufacturing may be included into the contemporary processes of mold design and production. Meanwhile, the discussion can be used as valuable reference to engineers and researchers in their attempts to choose the right manufacturing technologies and make the process of mold development more efficient in industrial practice[7-10].

2 Two commercial 3D printing technologies in the molding process

There are a number of 3D printing technologies, which are being used in mold production. All the technologies demonstrate varying traits regarding the accuracy, material performance, cost and efficiency in production. Depending on the functions of molding, material demands, anticipated working life as well as volume of production, one is supposed to select a fitting technique [2, 3]. Technology types that are used commonly are Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Melting (SLM). Metal additive manufacturing is among them and it is significant in production of high-performance molds [11,12].

3 Technology types

3.1 Fused deposition modeling

There is prevalence of FDM due to low cost of equipment and their easy operation [1]. The important aspect is that the process is used to melt thermoplastic filament and build layer upon layer depending on the digital model. Common ones are ABS, PLA, PETG and nylon. FDM is predominately applied in prototype molds, low-load molds and auxiliary tooling in mold manufacturing. These tooled molds assist the engineers in verifying geometry, assembly state and an initial shape forming behavior at the initial stages of design.

Nonetheless, FDM molds are known to have little heat resistance and surface quality. Dimensional stability can also be deformed by thermal deformations and layer lines are generally visible. Moreover, FDM components inherently exhibit anisotropic mechanical characteristics since the bond (or strength of the bond) between the layers printed is usually lower than in each layer. Crashes can spread along the interfaces between the layers when the force of demolding is used in the molding process. Due to this trait, FDM molds are typically restricted to comparatively low-stress instances. Nevertheless, FDM can still be applied to verification of the design and to testing of functionality. Digital models can be remodeled by engineers fast, and reprinted molds can be reprinted to facilitate rapid iteration and can contribute to lowering the cost of development [1, 2].

3.2 Stereolithography (SLA)

SLA is a technique which layers the liquid resin with ultraviolet lights. This technology has more dimensional accuracy and smooth surface finish than FDM [2]. Precision mold inserts, casting mold, and fineness pattern are frequently subjected to SLA [2, 6]. The increased resolution renders SLA appropriate in molds that have demanding dimensional and surface standards.

Relative to FDM, SLA molds normally need to be finished less on the surface and reproduce the details better. Their applications are mostly in silicone molding, vacuum casting and low-pressure injection. But after processing is still a significant procedure in SLA production. To obtain stable mechanical properties and dimensional accuracy, printed parts typically must be cleaned, support structures removed, and secondary UV curing done. Moreover, the resin materials are mechanically weak and heat resistant. Repeated cycles of thermal use can result in degradation of material on a long-term use basis. These limitations do not negate the capability of SLA to be used in small-batch production as well as short-term molding, when dimensional accuracy is more important than longevity.

4 Industrial uses in relation to the manufacture of molds.

The available application of 3D printing in other sectors guarantees interesting reference to molding. Additive manufacturing has been applied in fields like medical engineering, building and construction, car-making, and making of composite materials to assist in precision, large-scale shaping, and functional assembly [7, 12]. Those applications assist in illustrating the way like-minded technical concepts are capable of being transformed to shape design and production.

4.1 Medical engineering applications.

The medical sphere is one of the most common spheres where 3D printing is implemented to print surgical guides, implants, and even personalized medical molds [7, 10]. Such products demand tight geometry, constant dimensions and quality surfaces always. Indicatively, in spine surgery, the molds and papers patient surgical guides are to be very much similar in terms of anatomy to be assured of proper placement and safety of the implant during the operations [10].

This is directly linked to the production of moulds. Medical molds are normally characterized by sophisticated cavities and undercuts, as well as compact manufacturing batches. In this eventuality, traditional machining is normally ineffective. Additive manufacturing enables engineers to manufacture personalised mold inserts directly through medical imaging experiences. Such strategy reduces the time of development and enhances design precision. Strictness of quality demands in medical applications is also useful as reference towards precision mold manufacturing.

4.2 Constructions and civil engineering applications

3D printing in construction and civil engineering is primarily used in the area of concrete elements, formwork systems, and structural elements [8, 9]. These applications are concentrated on the large scale forming, material efficiency and intricate geometry. Additive manufacturing, compared to other conventional construction techniques, enables the creation of parts with optimum internal structures through the manufacturing of components at reduced material wastes.

Even though construction moulds are not as large or as composed in terms of materials as industrial moulds, the technical principles used are also similar. Several construction industries involve intricate shape formwork required. The process of producing the traditional formwork usually takes a lot of cutting and assembling, thus, raising the cost of labor and material. With 3D printing, it is possible to create customized molds and formwork directly based on the digital models and this reduces the time required to prepare and increases geometric accuracy.

The study of 3D printed concrete structures also focuses on efficiency and sustainability of materials [8, 9]. Optimization internal structures minimize the consumption of materials, but the structures are still strong. These concepts are applicable to shape production. Similar design strategies can be used in large bases of molds or supportive frames and auxiliary structures, and again the weight of molds can be decreased without impacting upon either stiffness or service performance.

4.3 Automotive and mechanical engineering applications

Lightweight structures, functional components and multi-material systems are some of the many applications of 3D printing in the automotive industry [12]. Car products can be in need of challenging geometry, high mechanical performance, and consistent quality. To fit these requirements, additive manufacturing enables the optimization of material allocation and structural arrangement to the engineers.

The same application cases apply to the mold manufacturing. A car mold regularly encompasses various functional sectors, including high energy areas, and cooling sectors and wear-resistant surfaces. The conventional manufacturing processes complicate the incorporation of these requirements into one mold shape. There are multi-material and structural optimization techniques applied to automotive components that can be rather helpful in terms of mold design. It is possible to create mold portion inserts that have region-specific properties through additive manufacturing.

Also, the automotive manufacturing simply prioritizes efficiency and cost management. Mold cooling performance has direct implications on the the cycle time and the product quality. The effective use of energy-absorbing and functional structures (made with 3D printing) in automotive engineering demonstrates that additive manufacturing is able to fulfill the challenging mechanical and thermal demands [12]. This favors extended application of 3D printed mold inserts in manufacturing to do with automotive.

4.4 Advanced engineering applications and composite material

There are also recent reports of 3D printing used with filament winding and other approaches to make fiber-reinforced polymer structures [11]. The different components demonstrate consistent mechanical performance and high-strength to-weight performance. Composites continue to find use in aerospace, automobile, as well as high-performance engineering.

In the case of manufacturing of molds, this study would be of great reference. Composite moulds are also beneficial as there is low weight, resistance to corrosion, and thermal stability. Conventional method of mold production of composite is time consuming and has an excessive dependence on manual production processes. Using 3D printing along with composite reinforcement methods, engineers are able to create complex structures of molds with enhanced consistency and fewer time wastage on manufacturing time. This method is particularly appropriate when dealing with molds that are employed in the manufacture of composite parts, where a surface finish and dimensional capability matter.

Based on the cross-industry application cases reviewed above, this paper systematically summarizes the core challenges and future development trends of 3D printing applied to mold manufacturing, as shown below.

Although 3D printing is beneficial in the production of molds, a number of challenges continue to restrict the expanded implementation of the technology in the manufacturing of molds. A significant problem is one associated with material performance. Polymer-based printing materials are unable to endure a great number of conditions of high temperature, high secretive force or prolonged mechanical stress. Despite the fact that metal additive manufacturing offers superior mechanical properties, the extent of materials and durability of the printed parts need to be improved.

There are also issues of surface quality and dimensional accuracy. To create surface printed molds which can be compared to industry standards sometimes further post-processing (which may be machining or polishing) is required. These extra measures add on to the production time and the cost of production. Also, printing flaws, stress left-overs and thermal deformation can also affect the mold reliability and service life particularly when the molds are intended to be employed in high temperature molding.

The other difficulty can be linked to equipment investment and cost of production. Additive manufacturing metal systems remain relatively costly still, which can be one of the factors preventing its use by small and medium-sized organizations. Meanwhile, there are no standard design elements and quality control systems of additively manufactured molds that are evolving. There are no clear guidelines on the design of the mold, process control, and inspection procedures that would be required in the industrial for wider use.

Future studies should aim to enhance printing materials, print manufacturing, and come up with hybrid manufacturing techniques comprising of additive manufacturing and conventional machining. Large-scale printing systems and multi-material printing can also open up more opportunities of this technology. As the cost and technological advancement persist, 3D printing will gain a greater significance in the manufacturing of moulding and facilitate more flexible production and efficient production in the industrial environment in the future.

5 Conclusion

This report was a literature review about the application and development of using 3D printing technology in the production of molds. Some of the mainstream addition manufacturing techniques, such as FDM, SLA and SLM, were proposed and their behavior in mold production was discussed. Based on the discussion, various technologies were found to have unique merits in regard to cost, precision, material performance and structural complexity. In contrast to the conventional approaches to the manufacturing process, 3D printing offers more flexibility of designs and allows creating molds that have more complicated internal architecture, which may reduce the development process and increase the efficiency of the manufacturing process.

Concurrently, there are various obstacles, which nevertheless restrict more extensive implementation of this technology, namely, limitations on material performance, issues with the quality of surfaces and quite high prices of the equipment. These elements imply that more technological advances and optimization of processes are yet to be improved.

As the process control, printing materials and hybrid manufacturing technologies are constantly advancing, 3D printing will become increasingly significant in the manufacturing of molds. Overall, additive manufacturing combined with conventional processes has the potential to enhance the way molds perform and increase the efficiency of the production process and further shape more flexible and intelligent systems of manufacturing in the future.

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