

Exploring Additive Manufacturing Technologies in Engineering: A Comprehensive Study

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Abstract

The objective of this research was to systematically elucidate various pathways in casting, focusing on the utilization of Additive Manufacturing (AM) technology and its transformative impact on investment casting. The purpose of this systematic review is to ascertain whether AM may be a practical solution for investment casting production. Diverse databases, including Google Scholar, Research Gate, Mendeley, and Science Direct, were utilized for comprehensive research. When compared to creative techniques like employing additive manufacturing to create wax patterns for low-volume production, traditional investment casting techniques may prove to be less effective in terms of cost and turnaround time. Addressing this challenge, additive manufacturing has been introduced for pattern creation in investment casting processes. The paper critically examines the specific applications of rapid prototyping within the casting industry. After applying the inclusion criteria this study concluded that using Additive manufacturing in investment casting in place of the unadventurous method is more cost-effective and time-efficient.

Keywords: Additive manufacturing, rapid investment casting, sintering, rapid prototyping, 2d cross-sections

INTRODUCTION

Additive Manufacturing

Additive manufacturing encompasses a range of technologies that efficiently translate virtual solid model data into physical models through a rapid and straightforward process. These technologies fabricate parts by polymerization, fusion, or sintering of materials in predetermined layers, eliminating the need for traditional tools. Initially, the model of the desired product is created in CAD software, wherein Computer-Aided Design data is converted into 2D cross-sections of a specific thickness. These cross-sections are then fed into 3D printers, where they are sequentially added together, layer by layer, to form the physical part. This method ensures the faithful reproduction of the part's geometry in the Additive Manufacturing machine without the need to adjust various parameters such as undercuts and draft angles. The underlying principle drives most AM machines, albeit with variations in techniques for creating layers and bonding them together. These variations encompass aspects like speed, layer thickness, material range, accuracy, and, notably, cost factors [1].

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Rapid Investment Casting

The use of additive manufacturing technology in the investment casting process is known as "rapid investment casting.". This approach facilitates both the design and manufacturing of master patterns in a cost-effective manner. Even for small-scale

production, Additive Manufacturing is economically viable since it minimizes casting time without sacrificing product quality. Numerous studies in the literature highlight cost-effective solutions for investment casting, particularly in fields like orthopedic implants. Additive Manufacturing, with its potential to enhance traditional manufacturing methods, offers benefits such as mass customization without the need for extensive tooling, shorter production times, cost-effectiveness for mass production with intricate designs, and reduced material waste. This advancement in technology not only appeals to designers and artists for precise realization of complex ideas but also streamlines production processes by minimizing reliance on skilled craftsmen and reducing production timelines [2]. Challenges faced by conventional methods, such as limitations in mold making using traditional techniques like machining, are addressed by Additive Manufacturing, which eliminates constraints on minimum wall thickness, sharp corners, and undercuts, thereby reducing fabrication costs. This is particularly advantageous for parts with intricate designs, where traditional tooling complexities are heightened. The primary aim of this study is to assess the capabilities and effectiveness of Rapid Prototyping in facilitating efficient investment casting production. The subsequent sections provide a comprehensive review of additive manufacturing types, applications, advantages, and limitations within the metal casting domain. Additionally, a proposed design flowchart outlines the methodology of this study, supplemented by case studies for empirical evidence. The study culminates in conclusions and key findings summarized in the final section [3].

Investment Casting

Investment casting, also known as lost-wax casting, relies on molding wax patterns and stands as one of the oldest recognized casting techniques, having been utilized in various forms for decades. Its widespread use stems from its capacity to deliver components with precision, versatility, repeatability, and integrity across a range of metals and alloys. The material is first poured into a hollow in a refractory material in this method. But there are several significant drawbacks to classic investment casting techniques, notably when it comes to cost, especially with small casting runs. The high costs associated with investment casting arise from factors such as specialized equipment, expensive refractories and binders, the need for multiple operations to create a mold, significant labor requirements, and the occasional occurrence of minute defects [4].

Technologies for 3D printing come in a variety of forms, each with special benefits and methods.

Fused Filament Fabrication (FFF) or FDM

FFF utilizes heat to melt polymer materials, which are then extruded through a nozzle in a plastic state. The material is deposited layer by layer on the printer bed, following the XYZ coordinates of the machine, to create a three-dimensional object according to the designed model [5].

Multi Jet Printing

During printing, this technique uses piezo printhead technology to deposit materials layer by layer. It offers cost and time reductions for blade production, with higher dimensional accuracy compared to silicone rubber molding, particularly suitable for parts with freeform surfaces like gas turbine blades [6].

Stereolithography (SLA)

SLA utilizes a high-powered laser to harden liquid resin held in a reservoir, creating the desired shape layer by layer through photo polymerization. SLA printers typically consist of four primary sections: a reservoir with liquid photopolymer, a perforated platform immersed in a tank, a high-powered UV laser, and a computer interface managing platform and laser movements [7].

SLA 3D Printing Process

In SLA, the laser solidifies the resin wherever it hits, layer by layer, controlled by mirrors and a computer. Desktop SLA printers often work upside-down, with the laser pointing up to the build platform. After each layer, the platform is raised incrementally, allowing additional resin to flow below.

Untouched resin can be reused. Desktop SLA printers frequently function in an upside-down position, which distinguishes them from larger industrial SLA printers. In these desktop models, the construction platform is elevated above the resin vat, with the laser pointing upward. As the laser hardens the resin to produce the first layer, the build platform is elevated sequentially by a precise, tiny amount, usually only a fraction of a millimeter. This movement permits new liquid resin to flow beneath the previously formed layer, ready to be cured by the laser in the subsequent pass [8].

Post-Processing

Once the printing is complete, excess resin is drained, and the model is removed, washed, and cured in a UV oven for durability. After the excess resin has been drained, the model is gently taken off the construction platform. To protect any fragile structures that could have been formed during the printing process, this step must be done precisely. The model is thoroughly cleaned after it has been safely removed. This usually entails immersing the model in a solvent—like isopropyl alcohol—that efficiently eliminates any resin that may still be present. The washing process is essential for getting rid of any uncured resin, which might be sticky and lower the quality of the model. Following washing, the model is dried and then placed in a UV oven to cure. The curing procedure involves exposing the model to ultraviolet (UV) radiation, which further hardens the resin and improves the object's structural integrity. This phase is critical to producing the desired durability and strength of the finished product. UV curing ensures that all model components are equally cemented, lowering the likelihood of warping or other deformations over time [8]. This final step in the post-processing phase not only enhances the mechanical qualities of the printed object, but also assures that it is suitable for future usage or application.

Alternative Process

Digital Light Processing (DLP): DLP utilizes a digital projector screen to flash each layer's profile across the entire platform. The resolution of a DLP printer is determined by the pixel size, contrasting with SLA, which relies on the laser spot size for resolution. A DLP printer's resolution is mostly governed by the projector's pixel size. A pixel is represented by each of the thousands of small mirrors that make up the digital projector used in DLP printing. The pixels on the resin match particular spots on the print bed when the projector flashes an image of a layer onto it. As the pixel size reduces, the printed model's resolution and complexity rise. In contrast, the size of the laser point used to cure the resin in SLA determines the resolution. Although tracing each layer takes longer with a smaller laser point, the features are more finely detailed [9].

Limitations of Additive Manufacturing Process

Some limitations affect the application and suitability of additive manufacturing for different purposes. The design of components or patterns is limited because to the limited choice of materials, making it material-dependent. The resolution of 3D printing technology usually varies from 50 to 300 microns, which affects the accuracies obtained. Moreover, operating cycle time can be a limiting issue. Operating temperatures for materials such as poly-lactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are normally below 100°C. Temperature restrictions also apply to material processing. Furthermore, the size of the component is restricted to the size of the print bed, leading to related assembly issues, and printing voluminous parts can consume a significant amount of time [10]. Even while 3D printing is frequently advised for prototyping using plastics like ABS or PLA, it might not be the best option for large-scale manufacturing. Furthermore, prior to final treatment procedures, the product's mechanical characteristics are typically anisotropic.

RESEARCH METHODOLOGY

In this systematic review, research papers were chosen based on specific keywords related to the role of Additive Manufacturing (AM) in casting, including variations such as Rapid Investment Casting (RIC), three-dimensional printing, and their applications in various casting fields. The primary aim is to elucidate the impact of Rapid Investment Casting on the casting industry and explore the limitations of conventional investment casting processes. Additionally, the study seeks to identify the benefits of

integrating Additive Manufacturing technology into investment casting. The eligibility criteria for selecting studies encompassed research focusing on Additive Manufacturing, Rapid Investment Casting, evaluations of AM in casting, and articles published in English. The search strategy involved independent searches by four authors across platforms such as Google Scholar, Research Gate, Science Direct, and Mendeley databases, with articles selected up to September 2021 meeting the specified criteria. Subsequently, the chosen research papers were saved in Mendeley for data extraction, ensuring a comprehensive analysis by all authors involved in the study [11].

CONCLUSION

Additive manufacturing, particularly 3D printing of resin patterns, presents a cost-efficient solution for small-batch manufacturing and offers a viable alternative to traditional wax pattern manufacturing. Its advantages include faster production, cost-effectiveness, reduced time consumption, and precise results, suggesting its potential to eventually replace conventional techniques entirely. Resin molds have been demonstrated to produce intricate products with necessary accuracy, although conventional metal-mold technology remains superior for large-scale manufacturing due to longevity and higher output rates. Despite its current limitations, additive manufacturing holds significant promise and could contribute significantly to the transition to a more sustainable industrial system. Successful applications have been witnessed across various fields, including casting. Continued research in this domain may unlock new possibilities, extending the applications of 3D printing into everyday life.

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