Proceedings of CONF-MCEE 2026 Symposium: Geomaterials and Environmental Engineering
DOI: 10.54254/2755-2721/2026.MH30441

Selective Laser Melting Application in Die Casting Industry

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Abstract. This paper reviews the current progress of Selective Laser Melting (SLM) tooling applications within the die casting industry. The primary sources for this review include professional interviews, conference presentations from the China Diecasting & China Nonferrous 2025 exhibition, and relevant academic literature. The main objective is to provide readers with up-to-date information on various commercial applications of SLM tooling. Three notable application cases are the focus: 1) conformal cooling channels (CCC), 2) metal grafting printing, and 3) permeable steel. Various commercial SLM-produced tooling products are examined and their performance is compared against traditionally manufactured counterparts. The economic viability of SLM-produced parts is also discussed, outlining both benefits and limitations to clarify industry cost preferences. Furthermore, industrial policy guidance from the National Development and Reform Commission is considered to assess future opportunities for SLM tooling in die casting. Finally, a summary of consensus and opinions from the business community is presented to aid in understanding the potential future role and development trajectory of SLM technology.

Keywords: Additive Manufacturing, Die Casting, Selective Laser Melting

1. Introduction

Selective Laser Melting (SLM) is an advanced additive manufacturing technology that uses a laser beam to selectively melt and fuse metallic powder particles layer-by-layer, based on a computer-aided design model, to fabricate solid metal parts. During the process, a thin layer of metal powder is spread across a build platform, and the laser scans the cross-section of the part, melting the powder to form a solid layer. Subsequent layers are then added atop previous ones until the complete part is formed [1]. This layer-by-layer approach enables the creation of highly complex geometries that are difficult or impossible to achieve using conventional manufacturing methods like machining or casting. Additionally, SLM is well-suited for rapid prototyping and low-volume production, with minimal material waste due to its additive nature. These characteristics make SLM an attractive option for manufacturers in sectors such as aerospace, automotive, and medical equipment, where it has already seen successful implementation [2].

However, in terms of absolute market share and penetration, SLM remains a niche technology. Specifically, within the die casting industry, reports indicate that the market penetration rate for

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SLM and related additive manufacturing business is less than 6% [2]. The majority of parts and products are still manufactured using conventional methods like machining, casting, and forging. The industry has not yet adopted SLM technology to a level that fully exploits its potential. Several factors contribute to this limited adoption, including high costs, an immature supply chain, material limitations, a lack of standardized industrial procedures, and a shortage of specialized expertise [3]. Despite these significant challenges, it is anticipated that as the die casting industry evolves towards greater digitalization and flexibility, and as market demands shift towards customization and frequent product upgrades, the inherent advantages of SLM tooling will become more pronounced. This trend is likely to attract increased investment in the technology.

2. Application cases of SLM in die casting

This section reviews key applications of SLM tooling within the die casting industry, focusing on three major areas identified as particularly impactful.

2.1. Conformal Cooling Channels via SLM in die castings

Conformal Cooling Channels (CCC) are cooling channels with intricate layouts designed to follow the contours of the mold cavity surface closely. Typically positioned equidistant from the mold surface, these channels offer superior thermal management capabilities compared to traditional straight-drilled cooling channels [4]. Precise temperature control of the mold is critical in die casting, making CCC a significant focus for mold manufacturers. Early pioneering work on CCC was conducted by researchers at MIT in the 1990s [5,6], sponsored by an undisclosed industrial client. Their initial results demonstrated improvements, such as a 15% reduction in cycle time with a 9% decrease in part distortion. Or alternatively, a 37% reduction in part distortion with the same cycle time [5]. Other similar work done by University of Texas, and EOS GmbH demonstrated that SLM or DMLS (Direct Metal Laser Sintering, an EOS GmbH trademarked SLM technology) method could achieve better accuracy and manufacturability of the mold [7].

Today, SLM is widely recognized within the die casting industry as the standard method for manufacturing molds with CCC. Modern commercial applications often report substantially greater benefits, such as 60-70% cycle time improvements and 200-300% reductions in part distortion [8]. For instance, Company Y, a supplier of CCC molds and inserts to the new energy vehicle industry, demonstrated that their SLM-manufactured inserts with CCC can achieve a service life of 15,000 cycles—double that of conventionally tooled inserts with straight-drilled channels—while simultaneously halving the defect rate of the final cast parts. Company Y attributes this performance to their in-house developed stainless steel powder series (referred to as Powder Ys) and specialized post-processing finishing techniques. The mechanical characteristics of a low-carbon variant of Powder Ys are listed in Table 1 below [8].

Table 1. Mechanical characteristics of powder Y (low-carbon)

Item	Tensile Strength	Yield Strength	Fracture Elongation	Hardness	Maximum Moldable Weight
Powder Y	1849MPa	1800MPa	10.3%	52HRC	280kg

In addition to their proprietary powder, Company Y employs Physical Vapor Deposition (PVD) to apply a thin, wear-resistant coating [8]. The PVD coating enhances surface smoothness and wear resistance, thereby increasing the overall performance and reliability of the CCC molds and inserts [9]. It is important to note that SLM-produced parts often exhibit microstructural differences, such

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as higher content of retained and reversed austenite and nanostructures not found in conventional parts, which can initially result in lower yield and tensile strength compared to forged counterparts [10,11]. To address this, manufacturers typically apply heat treatment processes to anneal the parts, reducing residual stress and enabling mechanical properties equivalent to those of conventionally produced tooling [12].

2.2. A SLM technique: Metal Grafting Printing

Metal Grafting Printing, often referred to simply as "grafting," is a term used within the SLM community, drawing an analogy that is easily understood by non-expert clients. Technically, grafting is a subtype of Hybrid Additive & Subtractive Manufacturing (HASM). HASM combines additive manufacturing (AM) and subtractive manufacturing (SM) to leverage the advantages and mitigate the limitations of both processes [13]. To avoid ambiguity, "grafting" in this context specifically refers to a process where a subtractively manufactured base component is subsequently used as a substrate for SLM printing, forming an integral part. The combined part then undergoes post-processing to become a finished product.

The advantages of grafting can be illustrated using the CCC mold example. The inlets and outlets of CCCs are often straight sections, while the internal channels follow the complex mold contour. A mold designer can partition the mold: the base section, containing the straight inlets/outlets, is produced via traditional machining, while the top section, containing the complex cooling channels, is fabricated using SLM. This hybrid approach reduces the volume of material that must be printed by SLM, thereby saving costs and shortening supply chain lead times. From a business perspective, grafting allows SLM manufacturers to outsource the production of the typically bulky base sections to specialized partners, achieving further cost savings [14]. Furthermore, as SLM can process different metal powders, the base and top sections can be made from different materials. The combination of dissimilar metals, coupled with appropriate heat treatment, can result in components with enhanced mechanical properties at the joint interface [15].

2.3. SLM fabrication of permeable steel

Permeable steel, also known as breathable mold steel, is a porous metal material used in die casting and injection molding. It contains a large number of semi- or fully interconnected microscopic pores distributed throughout its volume. These pores allow trapped gases to be vented during the injection or casting process as pressure cumulates, while preventing the infiltration of molten metal into the pores. This unique characteristic helps reduce injection pressure, shorten cycle times, and decrease scrap rates [16].

Traditional methods for producing permeable steel include techniques like foaming agents, powder metallurgy, plasma sintering, and self-propagating high-temperature synthesis. These methods often involve complex, difficult-to-control parameters and cumbersome processes, limiting the consistency and applicability of the final product [17]. Furthermore, key patents for traditional production methods are held by a few established companies, which hinders wider adoption.

Researchers and manufacturers are now turning to SLM to overcome these challenges. Unlike traditional methods, SLM fabricates permeable steel directly in a layer-by-layer manner [17]. This innovative approach offers significant advantages. Firstly, SLM allows precise control over pore size, porosity, and the topology of the interconnected channel network. It can even produce gradient porous structures, enabling a combination of high specific strength, adjustable permeability, and tailored mechanical performance. Secondly, the inherent flexibility of SLM facilitates the creation of

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complex geometric shapes for the permeable components. Thirdly, the permeable steel structure can be directly printed onto a conventional mold base, creating an integrated final product without the need for additional joining processes like welding. Finally, the SLM method can circumvent existing production patents related to traditional techniques. Research, such as that by L. Zhang et al., has explored the relationship between SLM printing parameters, permeability, and the resulting mechanical properties of permeable steel, generally finding a positive correlation between porosity and permeability, and a negative correlation between porosity and compressive/tensile strength [18]. While much research focuses on stainless steel, SLM can also be applied to fabricate permeable structures from other alloys, including iron, tungsten, and various non-ferrous metals.

3. Development, challenges and opportunities

SLM technology has generated substantial interest and growth within the die casting manufacturing community. Over the past decade, the price of SLM printing equipment has decreased significantly—from a range of around 10 million yuan to 1-2 million yuan—primarily due to the entry of Chinese equipment manufacturers [14]. This cost reduction has lowered the capital expenditure barrier, allowing smaller companies to compete in niche markets.

However, SLM still faces challenges in competing with traditional manufacturing methods on a per-unit cost basis for high-volume production. According to industry sources, the current cost per kilogram for a SLM-printed object can be around 400 yuan, excluding post-processing. This cost can be approximately 70% higher than using traditional 5-axis machining, making SLM economically uncompetitive unless factors like significantly reduced delivery times or essential geometric complexity justify the premium [14]. SLM also shares common challenges with other 3D printing technologies, including the high cost versus economies of scale dilemma, the occurrence of unpredictable printing defects, limitations imposed by available material properties, and a lack of standardized post-processing criteria.

In response, the SLM community within the die casting industry is pursuing several solutions. First, adoption of the HASM model can help balance the contradiction between cost and scale. Second, accelerating the implementation of digital twin technology in production lines could enable real-time defect identification and process optimization. Third, establishing robust material recycling schemes would not only be environmentally friendly but also help stabilize the performance of different batches of printing powder, improving consistency and potentially reducing material costs.

Other promising opportunities are emerging. For example, some companies are building comprehensive data libraries that correlate different metal powders with their corresponding printing performance parameters. These companies may offer contract printing services at nearly unprofitable prices to gather extensive operational data. Once established, such databases could be offered as subscription services, providing valuable information to users seeking optimal printing parameters for specific materials and applications [14].

Finally, and most importantly. There are targets set by the National Development and Reform Commission (NDRC), which encompass the establishment of 30 smart manufacturing demonstration factories, the development of more than 100 green factories, and the reduction of foundry waste and emissions [19]. Given that SLM technology directly supports the achievement of these strategic priorities, it is anticipated to benefit from policy incentives, including subsidies and preferential permitting.

4. Conclusion

In summary, the current status of SLM production within the die casting industry indicates that the technology remains more expensive and less mature than conventional manufacturing processes. SLM-produced parts are often semi-finished and typically require additional post-processing. As the primary demand for SLM shifts from rapid prototyping towards mass customization and specialized production, issues related to the consistency and optimization of mechanical parameters remain a key research focus.

Despite these technological and economic hurdles, there is a general consensus that SLM stands to benefit significantly from the ongoing global wave of industrial upgrading, often supported by governmental policy initiatives. The inherent advantages of SLM in creating complex geometries, enabling functional integration, and facilitating customization align well with future manufacturing trends, suggesting a growing role for this technology in the die casting sector.

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