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A Review of Die Casting Methods in Manufacturing Processes

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Abstract. This review explores seven die casting methods: High-Pressure Die Casting (HPDC), Low-Pressure Die Casting (LPDC), Vacuum Die Casting (VDC), Gravity Die Casting (GDC), Squeeze Casting, Semisolid Metal Casting (Thixomolding), and Cold Chamber Die Casting. Each method is evaluated based on its advantages, limitations, and industrial applications. HPDC is widely used for high-volume production but faces challenges like porosity and mold wear. LPDC offers better material density with slower production rates. VDC produces high-quality components with minimal defects but is more costly. GDC is suitable for simple geometries and smaller volumes, while Squeeze Casting delivers high strength and density, ideal for automotive parts. Thixomolding offers precise material flow, producing lightweight, strong components. Cold Chamber Die Casting is effective for high-melting metals but requires careful heat control. The review also discusses advancements in materials, mold designs, and simulation technologies, which enhance the efficiency and sustainability of die casting processes. Despite existing challenges, die casting remains a critical method for high-precision, large-scale manufacturing. Choosing the right method depends on product specifications and industry needs.

Keywords: die casting; manufacturing processes; high-pressure die casting (HPDC)

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1. Introduction

Die casting is a widely utilized manufacturing process in which molten metal is injected into a mold cavity under high pressure to produce complex (1), precise, and high-quality metal components (2). This technique plays a pivotal role in various industries, including automotive, aerospace, electronics, and consumer goods, due to its efficiency in mass production and ability to achieve dimensional accuracy (3).

Over the decades, advancements in die casting methods have driven improvements in product quality, process efficiency, and sustainability (4). Technologies such as high-pressure die casting (HPDC), vacuum die casting, and squeeze casting have enabled the manufacturing of components with enhanced mechanical properties and minimal defects (5). Moreover, the integration of lightweight materials like aluminum and magnesium alloys has further expanded the applicability of die casting in industries where weight reduction is critical (6).

Despite its advantages, the die casting process is not without challenges (7). Issues such as porosity, thermal fatigue of molds, and energy consumption require continuous innovation and optimization (8). Researchers and industry professionals have explored various approaches to address these challenges, including advancements in mold design, process parameter optimization, and the adoption of Industry 4.0 technologies for monitoring and control (9). Die casting methods, especially high-pressure die casting (HPDC), have undergone significant advancements, allowing manufacturers to produce components with high precision and minimal defects (10). Among the various die casting techniques, HPDC is the most employed due to its ability to rapidly produce complex and intricate parts in high volumes (11). However, it is not the only method used in industry, other methods, such as low-pressure die casting (LPDC), vacuum die casting (VDC), and squeeze casting, each offer unique advantages depending on the material, component size, and required

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mechanical properties (12). Each of these methods is tailored to meet the needs of specific industries, such as automotive, aerospace, and electronics, where lightweight, durable, and high-strength components are crucial (13).

Despite the growing diversity in die casting methods, challenges persist. Issues such as porosity, surface defects, and mold wear are commonly encountered in die casting processes, particularly in high-pressure methods (14). Porosity, for instance, can negatively impact the mechanical properties of cast parts, leading to failures in critical applications (15). Advances in mold design, process optimization, and new materials are continuously being explored to address these challenges (16). Furthermore, as industries increasingly focus on sustainability, there is a growing demand for more energy-efficient die casting methods and the use of environmentally friendly materials, which adds another layer of complexity to the manufacturing process (17).

This review aims to explore the different die casting methods available in the manufacturing industry, with a particular focus on their advantages, limitations, and applications (18). By synthesizing the most recent research and industry practices, this paper will provide an overview of how die casting processes have evolved and offer insights into future trends in the field (19). The goal is to highlight areas where ongoing innovation can lead to improvements in efficiency, cost-effectiveness, and environmental sustainability in die casting production (20).

In recent years, advancements in automation, simulation technologies, and material science have significantly influenced the die casting industry (21). The integration of Industry 4.0 technologies, such as real-time monitoring systems, Artificial Intelligence (AI), and machine learning, is opening new avenues for optimizing die casting processes (22). These technologies help in predictive maintenance, quality control, and the optimization of process parameters, ultimately improving both efficiency and product quality (23). Furthermore, advancements in simulation techniques allow for more accurate predictions of fluid dynamics, heat transfer, and mold filling behavior, which can aid in the optimization of die casting designs before physical production begins (24).

The development of new alloys and composite materials is also a key factor in expanding the capabilities of die casting (25). Alloys with superior strength-to-weight ratios, enhanced corrosion resistance, and improved thermal conductivity are enabling manufacturers to meet the increasingly stringent demands of industries like aerospace and electric vehicles (26). For instance, the use of magnesium and aluminum alloys in die casting has led to the creation of lighter components for the automotive industry, supporting efforts to improve fuel efficiency and reduce emissions (27).

Moreover, there is an increasing focus on sustainable manufacturing practices within the die casting industry (28). This includes efforts to reduce energy consumption, minimize material waste, and recycle scrap material generated during the casting process. One approach to achieving these goals is through the optimization of cooling systems, the use of more energy-efficient furnaces, and the exploration of alternative, eco-friendly mold materials. As industries worldwide move toward greener manufacturing processes, die casting methods are also being adapted to align with these sustainability goals (29).

Despite the numerous advancements, the die casting industry continues to face challenges (30). One such challenge is the limitation in producing certain complex shapes with traditional die casting methods, especially when dealing with thinner sections or highly intricate designs. To address this, innovative techniques such as Thixomolding (semi-solid metal casting) are being explored, which allow for improved control over the flow of material and reduction in defects like porosity. Furthermore, ongoing research into mold materials, coatings, and process variations are expected to help overcome some of the existing limitations of current die casting technologies (31).

In this review, we will discuss the various die casting methods, examining their evolution, current trends, and the future of die casting technologies (32). The aim is to provide a comprehensive understanding of these methods' capabilities and limitations, as well as the opportunities they present for the manufacturing industry. Through this analysis, the review seeks to identify key areas where innovation can drive improvements in product quality, process efficiency, and sustainability in die casting manufacturing (33).

2. Methodology

This study is a literature review of previously published research results related to casting engineering methods. Research with this kind of analysis method is focused on drawing conclusions from the methodology or approach used by previous studies. This review literature is the result of research related to casting methods, both traditional and modern. Through a descriptive study of related literature, it is hoped that this article can be developed and become a reference for the future need.

3. Die Casting Processes

In this study, various die casting methods used in the manufacturing industry have been analyzed, focusing on the advantages, disadvantages, and challenges faced by each method (34). The most widely used die casting methods include High-Pressure Die Casting (HPDC), Low-Pressure Die Casting (LPDC), Vacuum Die Casting (VDC), Gravity Die Casting (GDC), Squeeze Casting, Semisolid Metal Casting (Thixomolding), and Cold Chamber Die Casting. Each method offers different characteristics according to the specific application and needs of the industry (35).

3.1 High-Pressure Die Casting (HPDC)

High-Pressure Die Casting (HPDC) is one of the most widely used methods in the manufacturing industry, especially for automotive and electronic components (36). This process uses high pressure to inject molten metal into the mold at high speeds, resulting in components with excellent precision and high production rates (37). The main advantage of HPDC is its ability to produce parts with complex shapes in large quantities. However, the main challenge of HPDC is the potential for porosity and mold wear-related issues, which can affect the quality and durability of the final product. Efforts to reduce porosity and extend mold life continue to be made through innovations in mold design and process (38).

3.2 Low-Pressure Die Casting (LPDC)

Low-Pressure Die Casting (LPDC) uses low pressure to flow molten metal into a mold (39). This method is very effective for producing components with large size and high structural strength, such as automotive engine parts and aircraft components. One of the advantages of LPDC is its ability to reduce porosity, as the metal flows more slowly and trapped gases can escape more easily (40). Despite having advantages in terms of product quality, LPDC is not as fast as HPDC, which limits its use in applications that require mass production (41).

3.3 Vacuum Die Casting (VDC)

Vacuum Die Casting (VDC) is a method that uses vacuum to reduce gases trapped in molten metals (42). By creating a vacuum chamber inside the mold, this process can produce components with very low levels of porosity, excellent surface quality, and high strength (43). VDC is often used in industries that require high-precision components, such as electronics and aerospace. However, the initial cost for vacuum equipment and the complexity of the process are constraints for mass production. The reduction in the cost of vacuum technology in the future may increase the appeal of VDC for high-volume production applications.

3.4 Gravity Die Casting (GDC)

Gravity Die Casting (GDC) uses gravity to flow molten metal into a heated mold. This method is often used for components with simpler geometries and is more suitable for small to medium-sized productions (44). Although this process is not as fast as HPDC or LPDC, GDC produces components of good quality, especially in terms of density and material strength (45). GDC also tends to produce fewer porosity defects and is more economical compared to high-pressure methods. However, limitations in production speed and the ability to create parts with intricate designs reduce its advantages in large applications (46).

3.5 Squeeze Casting

Squeeze Casting is a method that combines pouring molten metal into a high-pressure mold, resulting in components with high mechanical strength and good density (47). The process begins by pouring the molten metal into the mold and then applying high pressure to compact the metal, which allows for a denser material and fewer internal defects. Squeeze casting is often used to produce automotive components that require high strength, such as wheel rims and engine parts. Although it provides excellent results in terms of material quality, the longer cycle time compared to HPDC is one of the drawbacks of this method (48).

3.6 Semisolid Metal Casting (Thixomolding)
Semisolid Metal Casting, or Thixomolding, uses metals that are in a semi-solid state, i.e. between the solid and liquid phases (49). This metal has a fairly high viscosity, which allows for a more controlled flow into the mold, reducing defects such as porosity and improving the quality of the final product. Thixomolding is particularly beneficial for applications that require high density and high geometric accuracy, as well as in industries that want a reduction in component weight, such as automotive. However, the main obstacles of this method are the high initial cost for equipment development and the need for highly precise temperature control (50).

3.7 Cold Chamber Die Casting
Cold Chamber Die Casting is a method in which molten metal is heated in a separate heating chamber, then transferred to an injection chamber to be fed into a mold (51). This method is more suitable for metals with high melting points, such as aluminum and copper. Cold chambers have advantages in terms of material flexibility, but they are slower compared to HPDC methods because they involve more steps in the process. Meanwhile, better heat management can improve the efficiency and quality of the final product. Cold chambers die casting is also often used to produce larger components, such as machined parts that require high precision.

3.8 Trends and Innovations in the Die Casting Industry
One of the key trends in die casting is the use of lighter and stronger materials, such as aluminum, magnesium, and copper (52). The use of this material is particularly important in the automotive and aerospace industries, where weight reduction contributes to fuel efficiency and emission reduction. In addition, the development of molds with more durable materials and environmentally friendly coating technologies is a major focus in reducing the environmental impact of the die casting process. Innovations in process simulation also allow manufacturers to predict metal flow behavior and design molds with greater accuracy, leading to increased efficiency and reduced defects (53).

4. Conclusion
The seven die casting methods discussed in this study—HPDC, LPDC, VDC, GDC, Squeeze Casting, Thixomolding, and Cold Chamber Die Casting—have their own advantages and challenges. HPDC and LPDC excel in high production volumes, while VDC and Squeeze Casting offer better quality, albeit at a higher cost. Gravity Die Casting is suitable for products with simple geometries, while Thixomolding and Cold Chamber Die Casting are more efficient for materials with high melting points. Innovations in materials and simulation technology continue to improve efficiency and quality, while challenges such as porosity and mold wear remain the focus of development. The selection of the right die casting method depends on the specific needs of the product and the industrial application

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