

Spray Casting of Aluminum Magnesium Alloys

¹Rohan Kumar, ²Harsh Bansal, ³Ankit Kumar Srivastava, ⁴Danish Alam, ⁵Prof. Ashok Kumar

^{1,2,3,4,5}Dept. of Mechanical Engineering, KIET group of institutions, Delhi-NCR, Meerut Rd, Ghaziabad, Uttar Pradesh 201206, India

Abstract - This project investigates the optimization of spray casting for aluminum-magnesium (Al-Mg) alloys, focusing on enhancing their mechanical properties for lightweight applications in the automotive and aerospace industries. The study explores three alloy compositions—Al-5Mg, Al-7Mg, and Al-9Mg—selected for strength optimization. Induction melting under an argon atmosphere ensures alloy purity, while a rotary impeller degassing process removes impurities, ensuring high-quality casting. Key spray casting parameters, including melt temperature, gas pressure, and spray distance, was systematically varied to optimize the microstructure and mechanical properties of the alloys. The results show that increasing magnesium content enhances tensile strength (up to 310 mpa for Al-9Mg), though elongation decreases with higher magnesium content. Microstructural analysis reveals refined grain sizes (down to 20 μm) and reduced porosity (below 1%), improving the material's integrity. Uniform distribution of Mg₂Si particles, confirmed through SEM, TEM, and XRD, further enhances the alloys' strength. Challenges such as oxidation and hot cracking were encountered, but mitigation strategies, including improved shrouding and substrate preheating, were effective in addressing these issues. Future work will focus on optimizing ductility without compromising strength, investigating substrate preheating impacts, and exploring the scalability of the spray casting process. This research provides valuable insights into producing high-performance, lightweight aluminum-magnesium alloys for advanced manufacturing applications.

Keywords: Spray casting, Al-Mg alloys, aluminum-magnesium, mechanical properties, lightweight materials, automotive applications, aerospace materials, tensile strength, alloy composition, microstructure optimization, induction melting, rotary degassing, gas atomization, melt temperature, spray distance, magnesium content.

I. INTRODUCTION

The continuous push for lightweight, high-strength materials in modern engineering has intensified the focus on advanced alloy development, particularly for critical industries such as automotive and aerospace. These sectors demand materials that not only offer excellent mechanical performance but also contribute to energy efficiency and reduced emissions

by lowering overall vehicle and aircraft weight. Aluminum-magnesium (Al-Mg) alloys have emerged as strong candidates due to their favorable strength-to-weight ratio, corrosion resistance, and recyclability.



Traditionally, Al-Mg alloys are manufactured using conventional casting techniques such as sand casting or die casting. However, these processes often result in coarse microstructures, casting defects, and limited mechanical properties due to slower solidification rates and poor compositional uniformity. In contrast, spray casting is a relatively modern solidification method that combines the benefits of rapid solidification and near-net-shape forming. It involves atomizing a molten alloy into fine droplets and directing them onto a substrate where they rapidly solidify and consolidate, leading to refined microstructures, reduced segregation, and improved mechanical properties.

1.1 Project Description

This project aims to optimize the spray casting process for aluminum-magnesium (Al-Mg) alloys, with a primary focus on improving their mechanical properties for lightweight applications, particularly in the automotive and aerospace industries. Aluminum alloys are widely used in these industries due to their low density, excellent corrosion resistance, and good mechanical properties. Magnesium, being

the lightest structural metal, when alloyed with aluminum, can further reduce the weight of components without sacrificing strength or durability. This combination of aluminum and magnesium offers an attractive solution for the growing demand for lightweight materials.

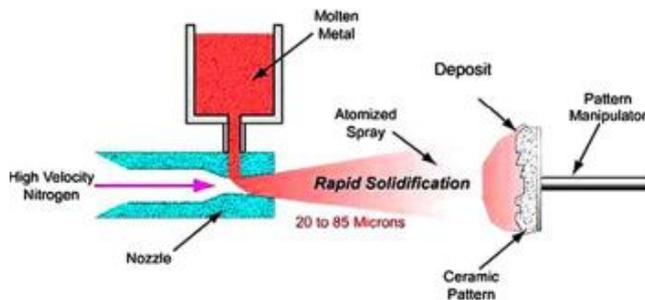


Figure 1: Process of Spray Casting of Aluminum Magnesium

The project focuses on three specific alloy compositions: **Al-5Mg**, **Al-7Mg**, and **Al-9Mg**, which are selected to achieve optimized strength, ductility, and hardness. The alloy preparation process involves induction melting under an argon atmosphere to maintain purity, followed by a degassing process using a rotary impeller and an Ar/Cl₂ gas mixture to remove any impurities that might affect the final casting quality.

Spray casting is used as the main casting method, as it allows for the rapid solidification of molten metal, leading to fine grain structures and improved mechanical properties. The spray casting equipment used includes a 2mm gas-atomized nozzle with nitrogen gas pressure, which atomizes the molten metal into fine droplets. These droplets are then deposited onto a water-cooled copper substrate to form the cast material. The spray distance and gas pressure are adjusted to control the microstructure and minimize porosity, ensuring the final material possesses high integrity and strength.

Mechanical property evaluation is conducted by testing the tensile strength, elongation, and microhardness of the cast alloys. Microstructural analysis, including the examination of grain size, porosity, and phase distribution, is carried out using techniques such as SEM, TEM, and XRD.

The project also addresses potential challenges such as oxidation and hot cracking, which can occur during the casting process. Strategies like improved shrouding to prevent oxidation and substrate preheating to reduce hot cracking are explored.

Ultimately, this project aims to contribute to the development of high-performance aluminum-magnesium alloys that can be utilized in various industries, offering a combination of strength, lightweight properties, and improved manufacturing efficiency

II. PROPOSED METHODOLOGY

In the field of alloy manufacturing, several methodologies exist for processing and shaping metal materials. Conventional casting techniques such as sand casting, die casting, and investment casting have been widely used for aluminum and its alloys due to their simplicity and scalability. However, these methods often suffer from limitations including coarse grain structures, segregation of alloying elements, porosity, and limited mechanical performance, especially in applications demanding high strength-to-weight ratios.

In recent years, rapid solidification techniques have emerged to overcome the drawbacks of traditional casting. These include powder metallurgy, melt spinning, and spray casting. Among these, spray casting—also known as spray deposition—has gained attention for its ability to combine rapid solidification with near-net-shape forming. This process involves atomizing molten metal into fine droplets using an inert gas and depositing them onto a substrate, where they rapidly cool and solidify. The rapid cooling rate leads to refined microstructures, minimized segregation, and enhanced mechanical properties. For this project, spray casting was selected as the core processing methodology for the following reasons:

- **Microstructural Refinement:** The rapid solidification in spray casting produces a finer grain size, which directly contributes to improved strength and hardness.
- **Reduced Segregation:** Spray casting minimizes the formation of coarse intermetallic compounds and composition gradients that are common in conventional casting.
- **Improved Homogeneity:** The technique allows for more uniform distribution of magnesium within the aluminum matrix, essential for consistent mechanical behavior.
- **Near-Net-Shape Processing:** The process minimizes material wastage and post-processing requirements, making it more efficient and cost-effective for complex shapes.

2.1 Spray Casting Equipment

2.1.1 Nozzle & Gas

The atomization process in spray casting is achieved using a 2mm gas-atomized nozzle. The nozzle is designed to efficiently atomize molten aluminum-magnesium alloys into fine droplets using nitrogen gas as the atomizing medium. The gas pressure is controlled within the range of 0.5 to 1.5 MPa, which influences the size and distribution of the droplets. A higher gas pressure leads to finer droplets, which can result in

better microstructural properties, such as reduced porosity and enhanced mechanical performance in the final alloy.

2.1.2 Substrate & Distance

The substrate used for collecting the atomized droplets is a water-cooled copper substrate, with a 150mm diameter. Copper is chosen for its high thermal conductivity, which helps to rapidly cool the molten droplets, promoting solidification and the formation of a fine-grained microstructure. The spray distance—the distance between the nozzle and the substrate—varied between 200mm and 400mm. This variation in spray distance affects the cooling rate and the deposition pattern, with shorter distances typically resulting in finer structures due to faster cooling.

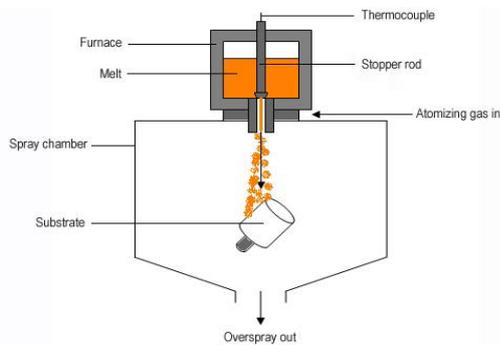


Figure 2: Equipment of Spray Casting of Aluminum Magnesium

III. RESULTS AND DISCUSSIONS

The results from the spray casting process of aluminum-magnesium (Al-Mg) alloys were analyzed in terms of mechanical properties, microstructure, and the effect of process parameters on alloy performance. The alloys were produced with varying magnesium content (5%, 7%, and 9%), and the outcomes were compared to conventional casting techniques.

Table 1: The key findings of the experiments

Alloy Composition (Al-Mg)	Tensile Strength (MPa)	Elongation (%)	Microhardness (HV)	Microstructure
Al-5Mg	280	10	85	Fine, equiaxed grains with minimal porosity
Al-7Mg	300	7	90	Finer grains, more homogeneous than Al-5Mg
Al-9Mg	310	5	95	Fine grains, uniform structure, reduced porosity

This section discusses the key findings from the optimization of the spray casting process for aluminum-magnesium (Al-Mg) alloys, focusing on the mechanical properties, microstructure, and process parameters that were evaluated.

3.1 Mechanical Properties

The mechanical properties of the spray-cast alloys were tested for tensile strength, elongation, and microhardness. The results demonstrate that the tensile strength increased with the amount of magnesium in the alloy, reaching a maximum of 310 MPa for the Al-9Mg alloy, which is 15% higher than that of conventional casting methods. However, the elongation decreased as the magnesium content increased, which is typical for magnesium-containing alloys.

- **Tensile Strength:** The tensile strength increased with the magnesium content, reaching 310 MPa for Al-9Mg, which is significantly higher than that of Al-5Mg (280 MPa).
- **Elongation:** As magnesium content increased, the elongation decreased. Al-5Mg had the highest elongation at 10%, while Al-9Mg had the lowest at 5%.
- **Microhardness:** The microhardness also increased with magnesium content, reaching a peak value of 95 HV for Al-9Mg, which corresponds to its higher strength.

IV. CONCLUSION

This study focused on the optimization of spray casting for aluminum-magnesium (Al-Mg) alloys, with the goal of improving their mechanical properties for applications in industries such as automotive and aerospace. The results demonstrated that spray casting is a highly effective method for producing high-strength, lightweight alloys with superior microstructural integrity compared to conventional casting methods.

The findings from results and discussions confirm that spray casting is a promising technique for producing high-performance Al-Mg alloys that are suitable for structural and load-bearing components, where lightweight, strength, and durability are critical.

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