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ROLE OF MAGNESIUM IN SOLIDIFICATION FEEDING OF HYPOEUTECTIC Al-Si5-Mg ALLOYS

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Abstract

The growing demand for high-performance Al-Si casting alloys stems from their excellent mechanical properties in engineering applications. Hypoeutectic Al-Si-Mg alloys offer superior fluidity, low thermal expansion, and corrosion resistance; however, they face solidification challenges such as shrinkage porosity. This study investigates magnesium's influence on feeding regions in AlSi5Mg alloys. Results show that increasing magnesium content from 0% to 0.6% significantly affects interdendritic and burst feeding regions, potentially impacting shrinkage porosity formation.

Keywords: *AlSi5Mg alloys, Magnesium, Thermal analysis, Feeding effectiveness*

1. INTRODUCTION

The growing demand for AI-Si casting alloys with superior mechanical properties has increased interest in hypoeutectic AI-Si-Mg alloys. These alloys are widely used in many engineering fields due to their excellent fluidity, low thermal expansion, high strength-to-weight ratio, and corrosion resistance [1,2]. Silicon and magnesium are the primary alloying elements defining microstructure and mechanical properties [3]. Silicon enhances fluidity and castability while reducing shrinkage porosity, whereas magnesium improves strength, hardness, and fatigue properties [4–6]. However, these alloys face challenges during solidification, particularly shrinkage porosity caused by volume contraction. Aluminum-silicon hypoeutectic alloys shrink 4–8 % depending on composition [1]. Campbell [2] identified five feeding regions during solidification: liquid feeding (LF), mass feeding (MF), interdendritic feeding (IDF), burst feeding (BF), and solid feeding (SF). Understanding these regions is essential for optimizing casting quality. Multiple factors influence feeding ability, including chemical composition, solidification characteristics, casting design, process parameters, and environmental conditions [2,3,5]. While silicon's effects have been extensively studied [1, 3, 6], limited data exist on the impact of magnesium on feeding regions. This study examines the impact of magnesium content (0–0.6 wt.%) on characteristic solidification temperatures and feeding regions in AlSi5Mg alloys, aiming to determine whether increased magnesium levels contribute to the formation of shrinkage porosity. Thermal analysis was used to achieve these objectives.

2. EXPERIMENTAL

Experiments were maintained under constant conditions, except for alloy composition, by controlling gas/oxide content and ensuring uniform mold filling. All melts were free of trace elements (Sr, Na, Sb, Ti, P, B, Pb, Sn…) affecting solidification temperatures. Pure aluminum (99.7 %), silicon (99.9 %), and magnesium (99.9 %) were melted in a 10 kg electric furnace without additives. Alloy compositions (Table 1) were determined by OES analysis to investigate magnesium's influence on feeding behavior.

Table 1. Chemical compositions of synthetic AlSi5Mg alloys

Alloy	wt.%						
	Si	Mg	Cu	Mn	Cr	Ni	Zn
AlSi5	4.96	0	0.007	0.02	0.001	0.001	0.006
AlSi5Mg0.2	4.86	0.209	0.008	0.003	0.002	0.002	0.007
AlSi5Mg0.4	5.11	0.405	0.007	0.004	0.001	0.002	0.008
AlSi5Mg0.6	4.84	0.590	0.021	0.004	0.002	0.001	0.008

Thermal analysis used 200±10 g samples in conical steel crucibles (60×50 mm) with two calibrated K-type thermocouples positioned at the wall and center, 20 mm from the bottom. Temperature was recorded between 700–400 °C (±0.10 °C accuracy) using a National Instruments system (NI cDAQ-9171) at five data points per second. A constant cooling rate of 10 °C/min was maintained. Experiments were replicated for each alloy composition from Table 1.

3. RESULTS AND DISCUSSION

Porosity is the key defect in aluminum castings, caused by insufficient feeding and hydrogen precipitation. This study quantifies the impact of magnesium on solidification temperatures and feeding regions in AlSi5Mg alloys with varying magnesium concentrations (0–0.6 wt.% Mg). Figure 1 shows cooling curves, ΔT curves, and derivatives for all alloys. Liquidus and solidus temperatures were determined from first derivatives, while dendrite coherency and rigidity temperatures were determined from ΔT minima. Following Huber et al. [7], these define five feeding regions: liquid, mass, interdendritic, burst, and solid feeding.

Figure 1 shows cooling curves (blue-full line), first derivative curves (red-dotted line), and ΔT curves (gray-interrupted line) of Al-Si-Mg alloys. The green points indicate how characteristic solidification temperatures (Liquidus, Dendrite coherency, Rigidity, and Solidus) have been determined using the cooling curve or ΔT curve.

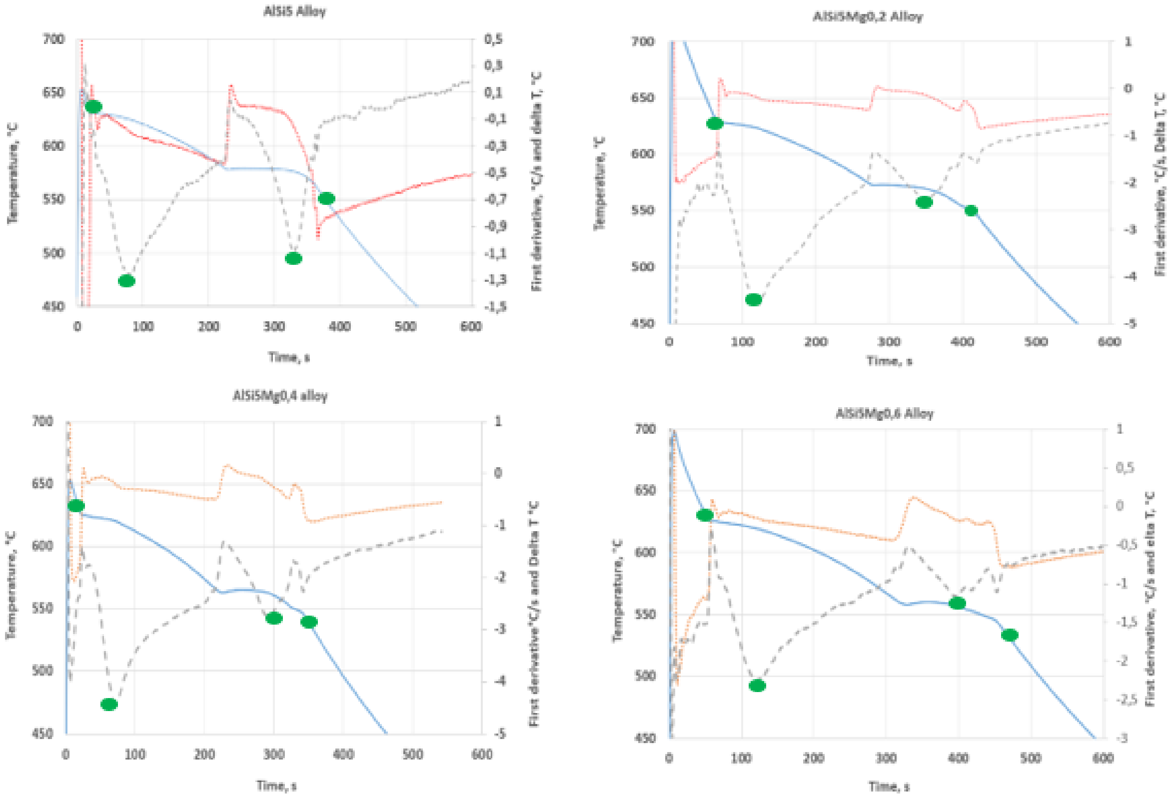

Figure 1. Cooling curves, ΔT curves and derivatives for all alloys

Figure 2 demonstrates that increasing magnesium content significantly lowered rigidity (green-dotted line) and solidus temperatures (light blue-dotted line) while slightly decreasing liquidus (dark blue-dotted line) and dendrite coherency (orange-dotted line) temperatures. Magnesium addition up to 0.6 wt.% reduced liquidus temperature by 5.9 °C, dendrite coherency by 4.9 °C, and rigidity temperature by 20.3 °C. This occurs because higher magnesium concentrations induce finer dendrites and form Mg_xSi_y based precipitates (primarily Mg_2Si), altering solidification behavior [1, 8].

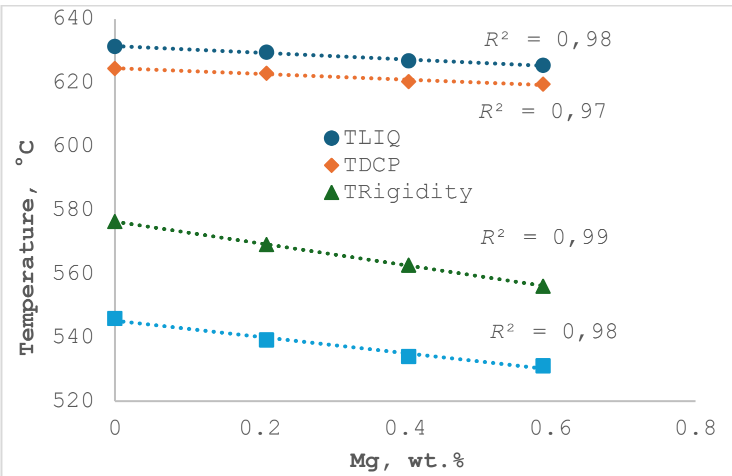

Figure 2. Impact of various contents of magnesium on the characteristic solidification temperatures of AlSi5Mg alloys

As illustrated in Figure 3, the presence of magnesium yields notable effects on both interdendritic and burst feeding regions. With an incremental rise in magnesium content from 0 to 0.6 wt.%, the temperature ratio within the interdendritic constrained feeding areas increases by 10.8 %.

Conversely, the temperature ratios within the burst feeding regions decrease by approximately 9 %. This alteration is visually depicted in Figure 3, where the interdendritic feeding expands while the burst feeding diminishes in duration. These fluctuations in temperature ratios across interdendritic and burst feeding domains could potentially influence the formation of shrinkage porosity in the resultant cast structures.

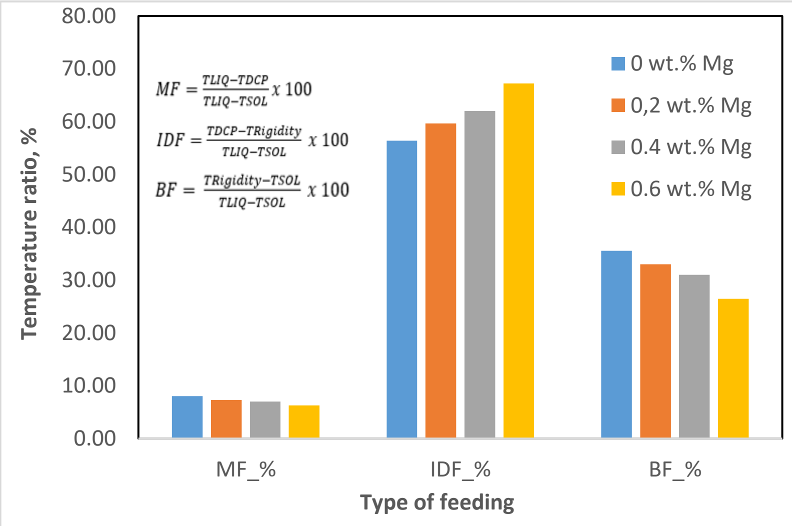

Figure 3. The impact of magnesium on the temperature ratio of different feeding regions

4. CONCLUSION

In this work, the impact of Mg on the different feeding regions of AlSi5Mg alloys is studied using thermal analysis techniques. It was found that magnesium has an effect on mass, interdendritic, and burst feeding regions. It can be assumed that the interdendritic constraint feeding region is more responsible for defect formation in gravity castings. In contrast, the burst feeding controls the formation of defects in high-pressure die castings.

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