The Influence Of Chemical Composition on TiC Particle Distribution in In-Situ Al-Based Cast Composites

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Abstract: To improve fuel efficiency while maintaining the safety and performance of modern vehicles, lightweight Aluminum-based Metal Matrix Composites (AMMCs) are essential. These materials offer significant potential for enhancing vehicle performance due to their high strength-to-weight ratio, which is further improved by the addition of TiC, enhancing their mechanical properties. However, challenges such as the manufacturing process, the pushing-engulfment phenomenon, particle interaction, and particle-matrix reactivity need to be addressed to fully realize their potential. Main goal of this work was to determine the influence of the Al-base alloy's chemical composition on the pushing-engulfment phenomenon of the TiC particles and their interaction. The Al 1000/TiC composite exhibits an inter-dendritic distribution of TiC particles, resulting from the pushing phenomenon at the solid-liquid interface. In contrast, the Al-7Si/TiC composite displays an inter-eutectic arrangement, with TiC particles being engulfed within the eutectic regions and the formation of the Al_3Ti phase, indicating additional reactions within the Al-Si-TiC system. It was found that the TiC particle size increases were observed for Al-7Si compared to Al 1000 alloy.

Keywords: AMMC, casting, in situ, TiC, pushing-engulfment phenomenon, tensile strength

1 Introduction

The requirement to reduce the weight of automobiles has become increasingly important due to growing environmental concerns. To improve fuel efficiency while maintaining the safety and performance of modern vehicles, lightweight AMMC are essential and offer significant potential for increasing vehicle efficiency. Although the application of this group of materials is often discussed, commercial solutions are still rare. One of the main issues is the manufacturing process, pushing-engulfment phenomenon, particle interaction and particle-matrix reactivity. Aluminum matrix composites reinforced with titanium carbide (TiC) particles represent a significant area of research in materials science and foundry technology, driven by the properties of TiC such as high hardness, low density, and good wettability by molten aluminum [1]. The incorporation of TiC strengthens the composite, enabling it to withstand higher loads and stresses, thereby contributing to both fuel efficiency and durability enhancements in automotive applications. It has been demonstrated that TiC particles in aluminum not only function as a strengthening phase but also contribute to grain refinement by being pushed to the grain boundaries, thereby inhibiting grain growth [2]. The main goal of this work was to determine the influence of the Al-base alloy's chemical composition on the pushing-engulfment phenomenon of the TiC particles and their interaction.

2 Experimental procedure

This study focused on two types of MMC matrices: Al 1000 and Al with 7 wt% Si. The raw material used for TiC synthesis consisted of Ti and C powders. These powders were subsequently compacted to obtain a reactive green compact, which was then introduced at 10 wt.% into a furnace during the casting process. The schematic of the materials manufacturing process is shown in Fig. 1.

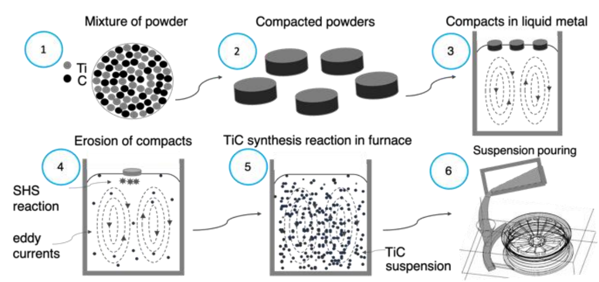

Figure 1. Schema of the in-situ TiC/Al-base composites manufacturing process

Finally, Al 1000/TiC and Al-7%Si/TiC composites were successfully fabricated. Microstructure, structure, chemical composition in the micro area and tensile strength of composites were examined.

3 Result and discussion

Differences in the Al 1000/TiC microstructure and Al-7Si/TiC microstructure is visible in Fig. 2. The Al 1000/TiC composite is characterized by the inter-dendritic distribution of TiC particles forming a coating around each grain. In contrast, the Al-7Si/TiC material exhibits an inter-eutectic arrangement of TiC particles. The inter-dendritic distribution is a consequence of the pushing phenomenon, which results in the accumulation of TiC particles at the solid-liquid interface (SLI) during dendritic grain growth. Only a few TiC particles are incorporated directly within the grains, confirming the criterion that the critical velocity, above which particles are engulfed by the SLI, is inversely proportional to the particle radius. This implies that the SLI will engage larger particles and push away smaller ones for specific particle-matrix system.

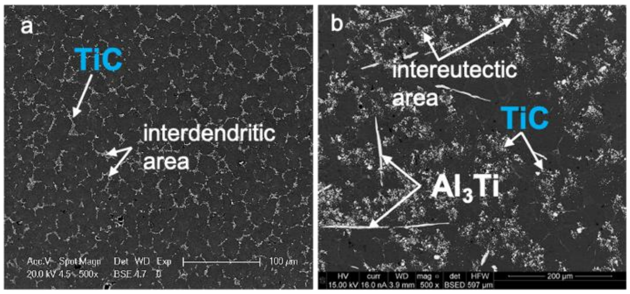

Figure 2. SEM-BSE microstructure of the Al 1000/TiC (a) and Al-7Si/TiC (b)

Another particle distribution observed in the Al-7Si/TiC composite involves the engulfment phenomenon within the eutectic area and the pushing around the (Al) dendrites (Fig. 3). This indicates that the Al-Si-TiC system represents a different mechanism. Additionally, the microstructure of this composite shows the formation of the oblong Al_3Ti phase.

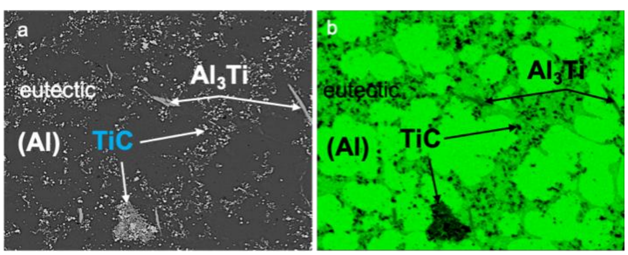

Figure 3. SEM-BSE microstructure of the Al-7Si/TiC composite (a) and corresponding SEM-EDS elements distribution map (b)

This suggests that additional reactions take place in the discussed system, which may form the basis for the Al-Si-Ti-C system's reactivity. This reactivity was reported by Guo and al. [4] during the wettability examination. In addition to different particle distribution in the matrix, the size of TiC particles also changes in both analyzed composites. Therefore, in Al 100/TiC the particle size is much smaller than in Al7Si/TiC. Bearing in mind that the chemical composition is the only variable factor, we can confidently assume a change in the physicochemical properties. Then we can consider a higher probability of coalescence in the Al7Si/TiC composite compared to Al 1000/TiC. The TiC agglomerates are visible on the SEM/EDS Al distribution map (Fig. 2b), highlighting a general tendency observed in the Al-7Si alloy. The formation of these TiC agglomerates indicates the initial stage of the coalescence process.

4 Conclusion

The Al 1000/TiC composite shows an inter-dendritic distribution of TiC particles, attributed to the pushing phenomenon at the solid-liquid interface. In contrast, the Al-7Si/TiC composite exhibits an inter-eutectic arrangement, with TiC particles engulfed within the eutectic area and the formation of the Al_3Ti phase, indicating additional reactions in the Al-Si-TiC system. Furthermore, TiC particles are smaller in Al 1000/TiC than in Al-7Si/TiC, suggesting a higher probability of coalescence in the latter due to differences in physicochemical properties.

Acknowledgments

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