UTM Faculty of Mechanical Engineering UNIVERSITI TEKNOLOGI MALAYSIA THE ENGINEER STORY

e-ISSN: 3009 - 0792 Volume 12, 2024, 9-12

DEVELOPMENT OF ZEBRA-LIKE ALTERNATING LAMELLAR STRUCTURES IN ZINC-ALUMINIUM ALLOYS

Muhammad Afiq Irfan Mohd Shumiri [1,*], Abdillah Sani Mohd Najib [2], Nor Akmal Fadil [2]
[1] Material Research Consultancy Group, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Malaysia.
[2] Department of Materials, Manufacturing and Industry, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia.
[*] Corresponding author: muhammadafiqirfan@graduate.utm.my

ABSTRACT

This study delves into the fabrication of zebra-like alternating lamellar structures within Zn-Al alloy system, with focus on the mechanisms of eutectic and eutectoid phase transformations and their influence on microstructural evolution during solidification. Two alloy compositions, eutectic and hypereutectic Zn-Al, were fabricated to explore the microstructural variations resulting from different alloying element concentrations. The eutectic composition of Zn-5Al (wt%) exhibits diffusion-controlled growth, resulting in well-defined Zn-rich and Al-rich lamellae that enhance properties such as corrosion resistance and electrochemical performance. The alloys were fabricated using melting metallurgy techniques. Optical microscopy was employed to confirm the development of consistent lamellar patterns. These findings provide valuable insights into the dynamics of bimetallic solid-phase transformations that contribute to the development of tailored materials with specific microstructures.

KEYWORD

Zinc-aluminium alloy, lamellar structure, eutectic, eutectoid, solid-phase transformation

INTRODUCTION

Zn-Al alloys are widely recognized for their distinctive microstructural feature and versatile functional properties, making them valuable material for engineering application. Among these, the eutectic composition of Zn-5Al (wt%) is particularly notable for the ability to form highly uniform lamellar microstructures through controlled eutectic solidification. This process occurs at specific temperature, where the liquid alloy undergoes eutectic reaction, resulting in the simultaneous crystallization of alternating Zn-rich and Al-rich phases (Xu et al., 2024). This zebra-like arrangement of lamellae is functionally advantageous which offers superior phase uniformity (Meng et al., 2024).

The alternating lamellar structure improves localized corrosion resistance by distributing the phases uniformly, thereby reducing weak points that are prone to degradation (Wang et al., 2020). Furthermore, the ability to control the spacing, orientation and thickness of lamellae allows for tailoring the material properties to meet specific requirements (Neogi & Janisch, 2022). Understanding kinetic factors that govern the formation of these lamellar structures is critical for advancing materials processing techniques (Jackson & Hunt, 1988). The composition of alloying element significantly influences the microstructure. This study investigates the development of eutectic Zn-Al alloy lamellar structures through controlled solidification, offering valuable insights into solid-phase behaviour.

MATERIAL AND METHODOLOGY

Zn and Al granules were weighed according to the composition and mixed in alumina crucible. The mixture was melted at 750°C in melting furnace. The molten alloy was mechanically stirred using stainless-steel rod to ensure complete homogenization. After that, the molten alloy was cast into preheated plate mold and allowed to cool under ambient conditions to facilitate controlled solidification. Once solidified, the ingot was sectioned into thin sheets using precision cutter.

Several cuts were made perpendicular to the orientation of lamellar structure. The samples were subsequently ground with silicon carbide papers and mechanically polished to achieve mirror-like surface. This preparation ensured good microstructural observation under optical microscope (Nikon, Eclipse LV150). The phase evolution during solidification was analysed using Zn-Al phase diagram to understand the eutectic and eutectoid reaction, which further refines the microstructure into distinct solid solutions. Schematic illustration of the fabrication process is shown in Figure 1.

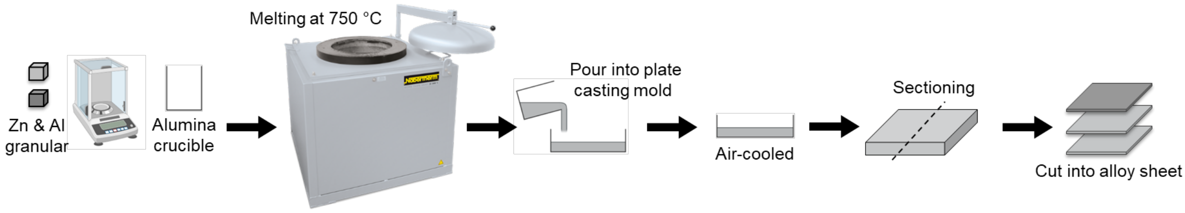

Figure 1: Schematic illustration of the fabrication process of binary Zn-Al alloy.

RESULT AND DISCUSSION

Based on Figure 2, Zn-Al phase diagram provides clear understanding of thermodynamic transitions that govern the development of microstructures. During solidification process, eutectic reaction at 370 °C transformed the molten alloy into two distinct solid phases, ZnAl (γ) and Zn (β), arranged in lamellar pattern. This lamellar structure arises from the coexistence of two solid phases. The lamellae align parallel to the heat flow during solidification, growing in longitudinal direction. Lateral diffusion of Zn and Al towards the solid-liquid interface occurs in equilibrium with the formation of Zn/Al interfacial regions. The close proximity of phases minimizes diffusion distances, making it energetically favourable for Zn (β) and ZnAl (γ) to grow together, resulting in the characteristic alternating lamellar morphology. Upon further cooling to 270 °C, the eutectoid reaction refines the ZnAl (γ) phase into Al (α) and Zn (β). This transformation stabilizes the microstructure at room temperature.

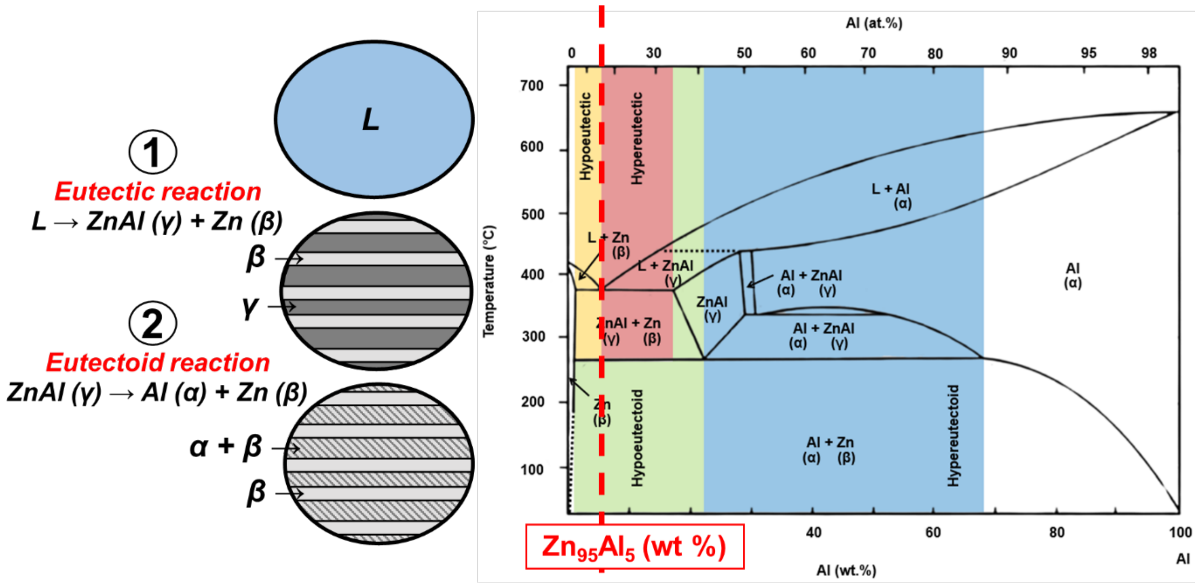

Figure 2: Phase transition of eutectic Zn-Al alloy during solidification process.

Microstructural analysis demonstrated the formation of distinct lamellar structures, comprising alternating Zn-rich and Al-rich phases with periodicity attributed to diffusion-controlled growth during eutectic solidification. As shown in Figure 3, the results highlight the influence of alloy composition on the final microstructure, reflecting the limited miscibility between Zn and Al. Figure 3a-b presents uniform lamellar arrangement characteristic of the eutectic composition, with evenly distributed phases forming consistent zebra-like pattern. In contrast, Figure 3c-d reveals disrupted microstructure, where regions of Al (α) and Zn (β) phases vary in size and distribution. This irregularity arises from the nucleation of primary ZnAl (γ) phase before the eutectic reaction. The presence of this phase interferes with the lamellar formation, leading to the random dispersion of small ZnAl (γ) colonies throughout the matrix. These results show the effect of alloying element composition on the microstructural evolution and solidification dynamics. The formation of primary phases disrupts phase uniformity, emphasizing the necessity of precise control over composition to achieve desired material properties.

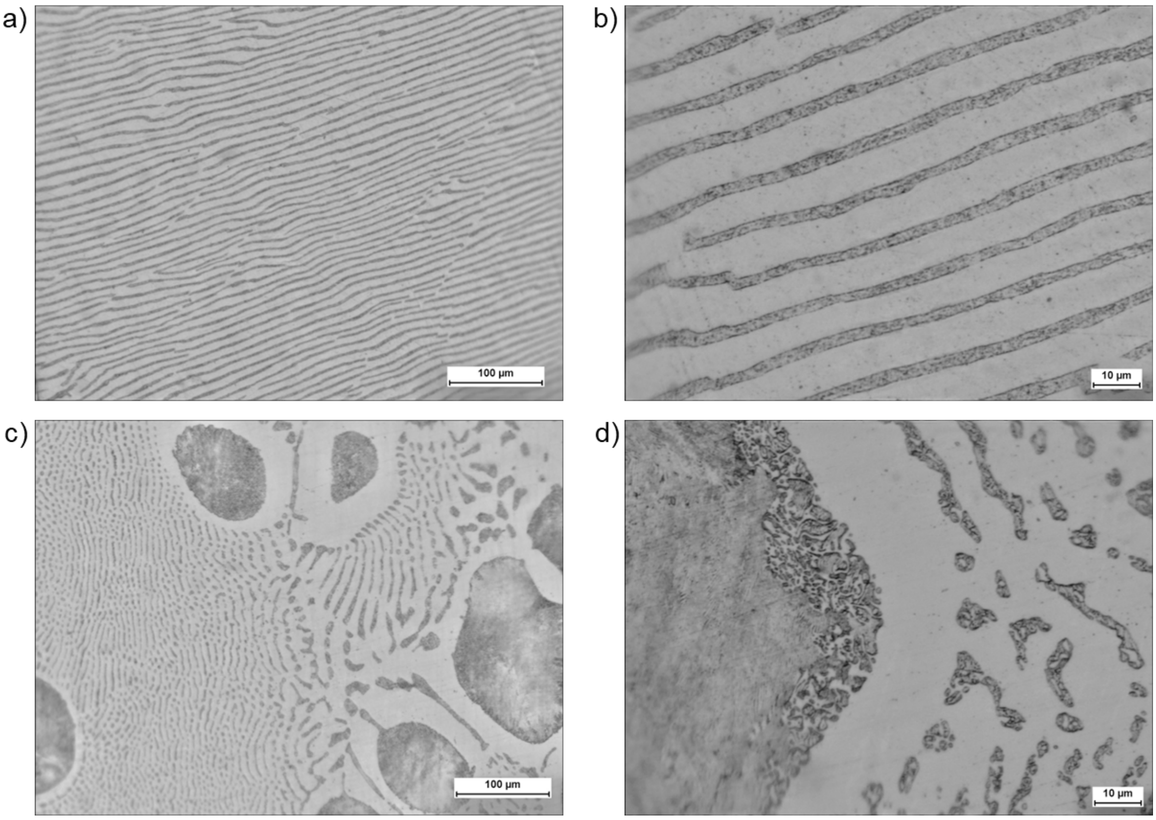

Figure 3: Optical micrographs of Zn-Al alloys at high and low magnifications. a-b) Eutectic Zn-5Al alloy showing uniform zebra-like lamellar structure composed of alternating Zn-rich and Al-rich phases. c-d) Hypereutectic Zn-10Al alloy showing non-uniform microstructures with random distribution of Al (α) and Zn (β) phases.

CONCLUSION

In conclusion, the fabrication of highly uniform lamellar microstructures in Zn-5Al eutectic alloy was successfully achieved. Controlled solidification facilitated the development of alternating Zn-rich and Al-rich lamellae through eutectic and eutectoid phase transformations. This study shows the critical role of phase behaviour and processing conditions in tailoring material properties. Further study into alloying strategies could broaden the applicability of Zn-Al alloys, paving the way for the integration into advanced material engineering.

ACKNOWLEDGEMENT

We thank the Material Research Consultancy Group, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia for the research support towards this publication.

REFERENCE

Jackson, K. A., & Hunt, J. D. (1988). Lamellar and Rod Eutectic Growth. In Dynamics of Curved Fronts (pp. 363-376). https://doi.org/10.1016/b978-0-08-092523-3.50040-x

Meng, H., Ran, Q., Dai, T.-Y., Jia, J.-H., Liu, J., Shi, H., Han, G.-F., Wang, T.-H., Wen, Z., Lang, X.-Y., & Jiang, Q. (2024). Lamellar Nanoporous Metal/Intermetallic Compound Heterostructure Regulating Dendrite-Free Zinc Electrodeposition for Wide-Temperature Aqueous Zinc-Ion Battery. Advanced Materials, 36(26), 2403803. https://doi.org/https://doi.org/10.1002/adma.202403803

Neogi, A., & Janisch, R. (2022). Unravelling the lamellar size-dependent fracture behavior of fully lamellar intermetallic γ-TiAl. Acta Materialia, 227, 117698. https://doi.org/https://doi.org/10.1016/j.actamat.2022.117698

Wang, S. B., Ran, Q., Yao, R. Q., Shi, H., Wen, Z., Zhao, M., Lang, X. Y., & Jiang, Q. (2020). Lamella-nanostructured eutectic zinc-aluminum alloys as reversible and dendrite-free anodes for aqueous rechargeable batteries. Nat Commun, 11(1), 1634. https://doi.org/10.1038/s41467-020-15478-4

Xu, Y., Liu, S., Chang, J., He, Y., Liu, S., Hua, R., Zou, J., Zhao, Q., & Chen, Y. (2024). Formation of lamellar eutectic structure and improved mechanical properties of directional solidified Al0.9CoCrNi2.1 high-entropy alloy. Intermetallics, 173. https://doi.org/10.1016/j.intermet.2024.108430