OR3-6

静電浮遊，電磁浮遊，ガス浮遊における ヘテロ凝固核 TiC 添加 Ti6Al4V の結晶粒微細化

Grain Refinement of Ti6Al4V with Heterogeneous Nucleation Site Particles TiC in Electrostatic Levitation, Electromagnetic Levitation, and Aerodynamic Levitation

花田知優 [1]，青木祐和 [1]，馬渕勇司 [1]，上田雄翔 [1]，門井洸衛 [1]，櫛舎祐太 [1]，米田香苗 [2]，左口凌成 [2]，山田素子 [2]，佐藤尚 [2]，渡辺義見 [2]，原田侑直 [3]，小澤俊平 [3]，中野禅 [4]，小山千尋 [5]，織田裕久 [5]，石川毅彦 [5]，渡邊勇基 [6]，鈴木進補 [1]

Chihiro HANADA[1], Hirokazu AOKI[1], Yuji MABUCHI[1], Yuto UEDA[1], Koei KADOI[1], Yuta KUSHIYA[1], Kanae YONEDA[2], Ryosei SAGUCHI[2], Motoko YAMADA[2], Hisashi SATO[2], Yoshimi WATANABE[2], Yuma HARADA[3], Shumpei OZAWA[3], Shizuka NAKANO[4], Chihiro KOYAMA[5], Hirohisa ODA[5], Takehiko ISHIKAWA[5], Yuki WATANABE[6], and Shinsuke SUZUKI[1]

[1] 早稲田大学，Waseda University,
[2] 名古屋工業大学，Nagoya Institute of Technology,
[3] 千葉工業大学，Chiba Institute of Technology,
[4] 株式会社 Henry Monitor，Henry Monitor Inc.,
[5] 宇宙航空研究開発機構，Japan Aerospace Exploration Agency (JAXA),
[6] 株式会社エイ・イー・エス，Advanced Engineering Services (AES)

1. Introduction

To clarify the grain refinement mechanism in Ti6Al4V alloy with heterogeneous nucleation site particles TiC, a space mission named *Hetero-3D* was carried out using the electrostatic levitation furnace in the International Space Station (ISS-ELF). Meanwhile, melting and solidification experiments with the same samples in electrostatic levitation (ESL), electromagnetic levitation (EML) and aerodynamic levitation (ADL) were necessary as ground-based reference experiments. According to the previous research[1)], ESL, EML, and ADL provide different levitation environments such as the Reynolds numbers of 15, 2.4×10^4 and 923 in droplets, respectively. Thus, the objective of this study was to reveal the solidification behavior of the samples and the grain refinement effects of heterogeneous nucleation site particles in these levitation methods.

2. Experimental Procedures

Ti6Al4V powder with 5 mass% TiC was sintered using the spark plasma sintering method and cut into cubes of approximately 30 mg for ESL, 700 mg for EML, and 20 mg for ADL. The samples for ESL and ADL were solidified into spheres in an arc furnace for stable levitations. The samples were melted using lasers and solidified spontaneously in all levitation methods. The numbers of prior-β grains per 1 mm^2 were counted on grain maps of cross-sections of the samples obtained by SEM-EBSD after the levitation experiments.

3. Results

The numbers of prior-β grains in the cross-sections of the samples for ESL, EML (surface), EML (inside), and ADL were 6, 23, 15, and 272 /mm^2, respectively. In the ADL sample, larger grains (A in **Fig. 1(c)**) are located on the lower side, while extremely fine grains (B in **Fig. 1(c)**) are situated in the middle area.

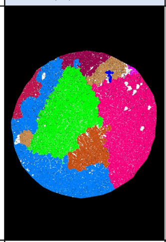
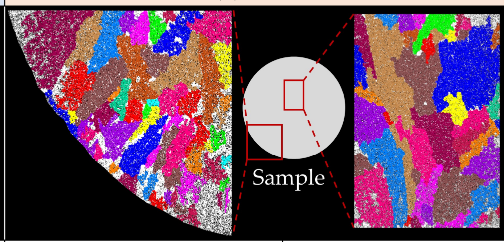
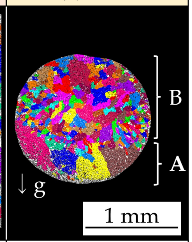
Levitation method	(a) ESL	(b) EML		(c) ADL
Grain map				
Number of grains / mm^2	6	23	15	272

Figure 1. Grain maps of prior-β in the samples in (a) electrostatic levitation (ESL), (b) electromagnetic levitation (EML), and (c) aerodynamic levitation (ADL). Corresponding counts of grains per 1 mm^2 are also provided. The arrow in (c) indicates the direction of gravity. Due to a sample rotation, the gravitational direction could not be identified in ESL and EML.

4. Discussion

In an ADL sample, a large temperature gradient exists in the vertical direction due to gas jet and laser heating[1]. This leads to nucleation starting from the lower side of a sample and subsequent columnar grain growth. However, as columnar grains grow, equiaxed grains also form due to a decrease in the temperature gradient caused by latent heat and solute concentration. It is referred to as columnar equiaxed transition.

In ESL and EML samples, most nucleation occurs near a sample surface, where temperature begins to drop first due to contact with the atmosphere during cooling. As a result, most grains in the ESL sample, as shown in **Fig. 1(a)**, were in contact with the sample surface. In contrast, in a molten sample that experiences significant convection, it is hypothesized that growing crystals do not stay in their nucleation locations but move along the flow. Therefore, a greater number of grains with nearly the same size were formed throughout the EML sample, which was significantly different from the ESL and ADL samples, as shown in **Fig. 1(b)**.

5. Conclusions

In EML, the significant convection in a molten sample with heterogeneous nucleation site particles TiC results in a greater number of prior-β grains with more uniform grain sizes than those in ESL. An ADL sample with temperature gradient solidifies in vertical direction, which generates both columnar and equiaxed grains.

Reference

1) T. Usui, S. Shiratori, K. Tanimoto, S. Ozawa, T. Ishikawa, S. Suzuki, H. Nagano, and K. Shimano: Surrogate models for the magnitude of convection in droplets levitated through EML, ADL, and ESL methods. Int. J. Microgravity Sci. Appl., **40** (2023) 400302, DOI: 10.15011/jasma.40.400302.