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ガス浮遊と地上静電浮遊における TiC 添加 Ti6Al4V の凝固挙動

Solidification behavior of Ti6Al4V with TiC in aerodynamic levitation and electrostatic levitation

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1. Introduction

One of the ways to prevent Ti6Al4V to get large columnar grains during additive manufacturing is adding TiC as heterogeneous nucleation site particles which promote nucleation of equiaxed and fine grain microstructure[1)]. However, its mechanism has not been completely clear yet because of many barriers to observe nucleation in additive manufacturing. To eliminate them, our research group is planning a space mission *Hetero-3D* to conduct experiments in Electrostatic Levitation Furnace on International Space Station (ISS-ELF) which is the most ideal tool to study the nucleation mechanism without external factors. However, ISS-ELF experiments have limited opportunities. Then, Electrostatic Levitation (ESL) is a ground based containerless processing which includes little external factors except for evaporation of samples and has been considered as the closest one to ISS-ELF. On the other hand, aerodynamic levitation is also a kind of containerless processing but has not been used for observation of Ti6Al4V nucleation yet. Our study aimed to reveal the possibility to reproduce the ideal environment like ISS-ELF in aerodynamic levitation by comparing with ESL.

2. Experimental Procedure

The samples were prepared through sintering Ti6Al4V powder with 0.3 vol.% TiC particles by spark plasma sintering (SPS) method and cutting into approximately 30 mg each. They were solidified in a sphere shape in the arc furnace before the experiments. In the aerodynamic levitation furnace, the sample was forced to levitate by Ar gas blowing up from the below and heated from the above by a laser. Temperature of the sample was measured by the radiation thermometer from the above. In the ESL, the charged sample levitated among electrodes due to coulomb force and was heated by three lasers. Temperature of the sample was measured by two radiation thermometers. In both containerless processing experiments, the lasers were turned off immediately after melting the entire samples. The values in the cooling curves obtained with the radiation thermometers were adjusted to fit melting point to 1923.15 K based on the reference[1)]. The cross sections of the samples were tilted at 70° during observation in Electron Backscatter Diffraction (EBSD), then obtained the Inverse Pole Figure (IPF) images on the cross sections were corrected by projection transformation. However, because of the cross sections leveled manually, the scale cannot be applied in the vertical direction. For the sample in the aerodynamic levitation, its vertical cross section in levitating state was observed.

3. Results

Figure 1 shows the cooling curves of the samples with 0.3 vol.% TiC in the aerodynamic levitation and the ESL. The undercooling of the sample in the aerodynamic levitation ΔT_a was 113 K and the undercooling of the sample in the ESL ΔT_e was 267 K. Therefore, the undercooling ΔT_a was smaller than ΔT_e by 154 K.

Figure 2 shows the IPF images on the cross sections of the levitated samples. When a region with the same crystal orientations is defined as one prior-β grain in IPF images, prior-β grain boundaries were observed in the sample in the aerodynamic levitation. However, they were not observed in the sample in the ESL, which suggests the entire cross section of the sample was consisted of one prior-β grain.

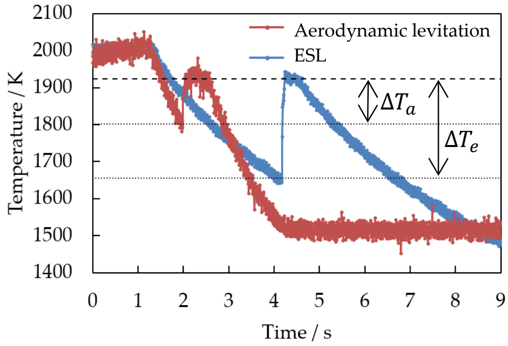
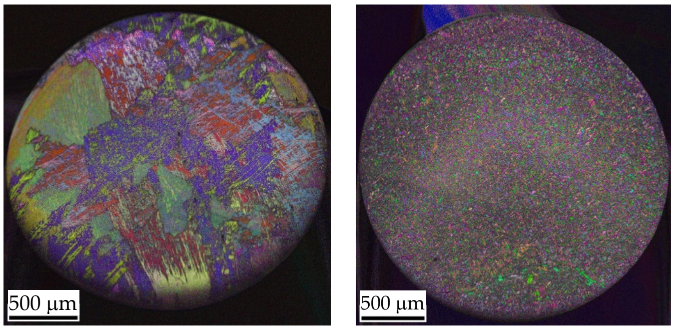


Fig. 1 Cooling curves obtained from the levitation experiments



(a) Aerodynamic levitation (b) ESL

Fig. 2 IPF images on the cross sections of the levitated samples

4. Discussion

The undercooling ΔT_a was smaller than ΔT_e and microstructure in the aerodynamic levitation was finer than that in the ESL. One of the causes of these results can be the differences of solidifying environment in the furnaces. In the ESL, the temperature distribution in the sample can be considered homogeneous because it was heated by three lasers. Therefore, it is considered that the entire sample solidified almost at the same time. On the other hand, the sample in the aerodynamic levitation has a temperature gradient originating from blowing gas and a laser. Therefore, the crystals grew from the bottom, the cooler part of the sample, and latent heat of solidification may have inhibited the undercooling of the top of the sample, where temperature was measured, from being larger. The undercooling of the lower part of the sample, which means genuine undercooling ΔT_a at the start of crystal growth, cannot be measured. However, it is estimated to be smaller than that in the ESL because the microstructure of the sample in the aerodynamic levitation was finer than that in the ESL.

5. Conclusion

The undercooling ΔT_a was smaller than ΔT_e by 154 K and microstructure of the sample in the aerodynamic levitation was finer than that in the ESL. According to these results, it is difficult to reproduce the solidification experiments in microgravity environment by using aerodynamic levitation. Therefore, ISS-ELF experiments are necessary to reveal the solidification behavior of Ti6Al4V with TiC clearly.

References

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