Influencing mechanisms of melt behavior on metal vapor characteristic and columnar grain formation in wire-arc directed energy deposition of titanium alloy

Department of Energy Control of Processing, Joining and Welding Research Institute

Assistant Professor Dongsheng Wu Researchmap https://researchmap.jp/dongshengwu?lang=en

Associate Professor (Lecturer) Hisaya Komen Researchmap https://researchmap.jp/H_Komen?lang=en

Abstract

The tungsten electrode is easily contaminated during wire-arc directed energy deposition (WA-DED), which would destabilize the arc and decrease the deposition quality. The metal vapor characteristics influenced by melt behaviors have great effects on the tungsten electrode contamination. In this study, a spectroscopic system was adopted to measure the arc temperature and metal vapor distributions in WA-DED of titanium alloy. The tungsten electrode contamination mechanism were revealed. The Ti+ ion can be transported to the negative electrode surface by the cataphoresis, dominating the electrode contamination.

Background & Results

WA-DED is one type of additive manufacturing where an electric arc is adopted to melt the solid substrate and wire, and three-dimensional metal components could be fabricated by adding feeding materials layer by layer with higher deposition rate and material utilization and lower cost compared with conventional manufacturing processes. A tungsten inert gas (TIG) arc was widely used as the heat source in WA-DED of titanium alloy. However, the tungsten electrode was easily contaminated during TIG arc processing, which would destabilize the arc and decrease the processing quality.

The equilibrium composition of Ar-Ti mixture calculated by the minimization of Gibbs free energy suggested that when the temperature was higher than 7100 K, the Ti+ ion became dominant. The spectroscopic analysis suggested that the arc temperature in the calculated region was higher than 10000 K, so the ionization of Ti atom to Ti+ ion was expected. The high melt temperature in WA-DED of titanium alloy caused strong Ti evaporation. Ti vapor entered the arc plasma and absorbed its energy, causing a high concentration of Ti+ ion in the whole arc region. The tungsten electrode was negative and the Ti+ ion was positive, therefore compared with Ti atom, the Ti+ ion can be easily transported to the electrode surface by the cataphoresis, causing the electrode contamination.

In the multi-layer WA-DED process, the molten pool temperature and Ti vapor concentration are higher, so more Ti atom ionizes to Ti+ ion, and the overall number density and distribution area of Ti+ ion are higher.

Significance of the research and Future perspective

This research reveals the electrode contamination mechanism, indicating that decreasing the metal vapor content and changing its distribution could suppress the electrode contamination. It can be expected that decreasing the arc current, or increasing the travel speed and wire feeding rate, or using pulsed current mode could decrease the melt temperature and Ti evaporation, as well as electrode contamination.

In order to suppressing the electrode contamination and columnar grain formation, in the future, we will develop an ultra-high frequency pulsed TIG-based WA-DED process to fabricate titanium components.

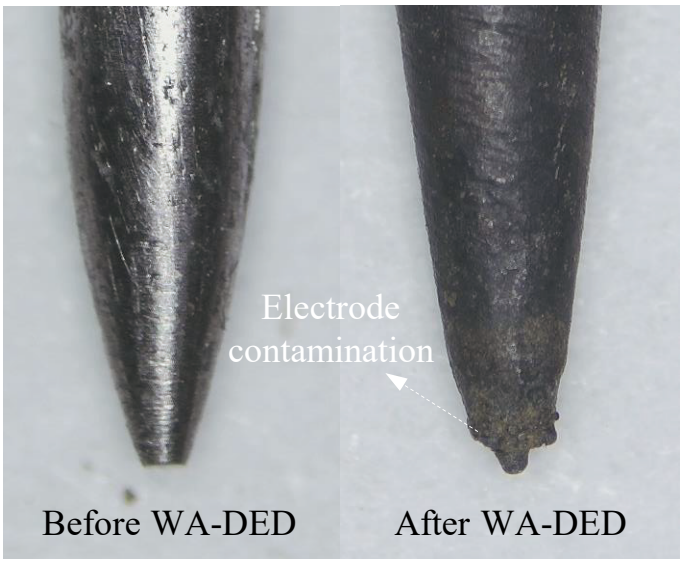

Fig. 1 Electrode morphologies before and after WA-DED

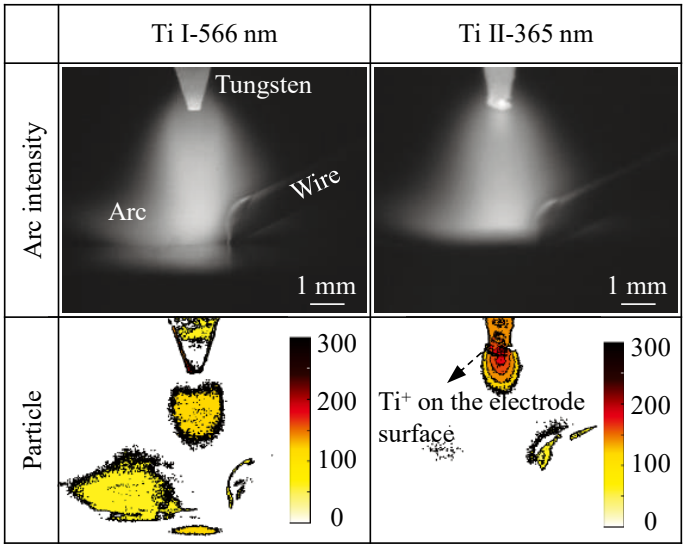

Fig. 2 Arc intensity and particle distribution during WA-DED

Patent

Treatise Xiao, Xiao; Wu, Dongsheng; Komen, Hisaya et al. Influencing mechanisms of melt behavior on metal vapor characteristic and columnar grain formation in wire-arc directed energy deposition of titanium alloy. Additive Manufacturing. 2024, 82, 104029. doi: 10.1016/j.addma.2024.104029
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Keyword wire arc additive manufacturing, titanium alloy, metal vapor, columnar to equiaxed transition