Feasibility Study on the Fabrication of Additive-Manufactured Disposal Canister using a Large-Scale Wire-Arc Additive Manufacturing (WAAM) System

Young-Ho Lee*, Jae-Deuk Kim, Jin-Seop Kim
Korea Atomic Energy Research Institute, 111 Daeduck-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea
Corresponding author: leeyh@kaeri.re.kr

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1. Introduction

Recent advancements in metal additive manufacturing (AM) technology have led to significant progress in producing complex, high-value components for various industries including aerospace, energy, and shipbuilding [1-3]. However, several challenges remain in scaling up metal AM technology, including applicability to large-scale high-value products, relatively slow deposition rates, lack of measurement techniques for automation, and limitations in implementing intelligent manufacturing processes. Wire Arc Additive Manufacturing (WAAM), which adapts traditional wire-based welding techniques for additive manufacturing, has emerged as a promising solution to address some of these challenges. WAAM offers several advantages, including low-cost metal wire feedstock, high energy efficiency, improved productivity compared to powder-based methods, capability to produce large complex components, and economical maintenance costs.

While WAAM technology development is actively progressing in the US and Europe, primarily driven by industry, domestic research is largely confined to universities and research institutes. There is an urgent need to develop WAAM systems suitable for large-scale structure fabrication in domestic industry. To address this, recent efforts have focused on developing WAAM systems for large-scale structures. Key technologies required for this development include: multi-robot systems capable of high-speed deposition, intelligent integrated control systems for real-time monitoring and control of the deposition process, optimized CAM technology for complex large-scale structures and thermal management and quality control techniques for process stabilization and autonomous manufacturing.

Recently, research on developing an additive-manufactured copper shell of disposal canister as one of the alternative manufacturing methods is currently underway due to considerations of economic feasibility and manufacturing capability. However, to fabricate a copper disposal canister using additive manufacturing, it is essential to evaluate the efficiency of large-scale deposition of oxygen-free copper (OFC) material with specially designed system. This study presents preliminary results of process development for directly depositing oxygen-free copper, a challenging material to weld [4], onto the outer surface of a cast iron insert for spent nuclear fuel disposal canisters, focusing on the application of a twin torch (Tandem) system capable of large amount deposition for manufacturing large-scale structures and the characteristics of deposited OFC layers was experimentally evaluated.

2. Methods and Results

2.1 Weldability of Oxygen-free Copper

Copper, known as difficult-to weld material due to its exceptional electrical and thermal conductivity, is a crucial material in various industrial applications, including the disposal canister of spent nuclear fuel. The OFC for outer copper shell is particularly appealing due to its long-term corrosion resistance for maintaining protective layer over extended periods. Traditional welding methods often struggle with these inherent properties of copper, leading to issues such as poor energy absorption, thermal damage, and the formation of defects like porosity and intergranular cracking. Therefore, considering the high thermal conductivity of copper, thermal management of the deposition area is crucial for improving weldability.

Fig. 1. Schematic view of a twin torch (Tandem) system and its application of OFC deposition on cast iron plate

2.2 Twin torch (Tandem) system

For large-scale additive manufacturing, a system with high deposition rates is essential. While conventional WAAM processes typically employ multiple welding robots with single torches, a recently developed twin torch (tandem) system incorporates two wires in a single torch, as shown in Fig. 1.

Fig. 2. OFC 3-layer deposition using a Tandem system

The advantage of this system is the ability to apply different welding processes to each wire during lead and trail welding. Oxygen-free copper requires preheating to enhance weldability. With the twin torch system, it is possible to optimize the welding process between the base material and the welding material using the leading wire, minimizing melting, and then control the deposition with the trailing wire. Based on these advantages, we evaluated the applicability of this tandem system for OFC deposition.

2.3 Copper Multi-layer Deposition by WAAM

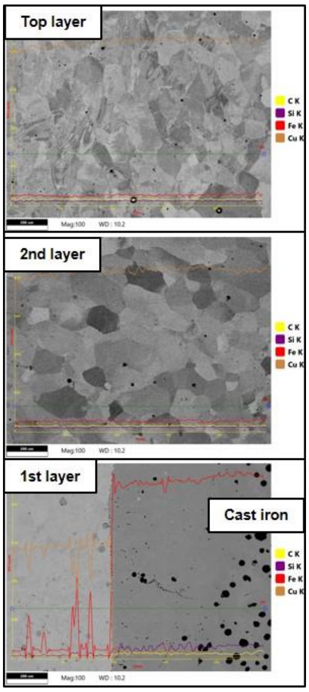

Fig. 3. SEM-EDS results of OFC layers on cast iron substrate

OFC deposition on cast iron plate was performed using a tandem system. A cast iron plate approximately 20 mm thick was used as the substrate for simulating direct deposition on a cast iron insert of disposal canister. The OFC wire with a diameter of 1.2 mm was applied for deposition up to 3 layers. Because exceptional high thermal conductivity of OFC results in very short solidification times after melting. non-uniform weld bead shapes can occur if the temperature range deviates from the optimal conditions. To address this, repeated bead-on-plate (BOP) experiments were conducted to establish the optimal deposition process and 3 layers of OFC were successfully deposited as shown in Fig. 2. The OFC deposited sample was cross-sectioned perpendicular to the build direction for examining defect inspection, the Fe dilution from the cast iron substrate, and grain size and orientation of OFC layers. Fig. 3 shows typical SEM-EDS results and the Fe dilution rapidly decreased in the upper OFC layers, with the composition becoming nearly identical to that of the OFC wire. Additionally, the grain size also meets the design criteria of conventional Copper shell, suggesting that it could be applied to the production of full-scale additive-manufactured disposal canister.

3. Summary

In this study, the twin torch system applied for large-scale deposition facility is expected to be effective for additive-manufactured disposal canister fabrication, with optimization of thermal management for grain size and deposition rate control. Furthermore, it can also be applied to the manufacturing of large complex structures, thereby enabling the production of next-generation nuclear-related components using Ni-, Fe-based and other wires.

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