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Dissimilar metal deposition with a stainless steel and nickel-based alloy using wire and arc-based additive manufacturing

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ABSTRACT

The wire and arc-based additive manufacturing process applies arc welding technology; the wire material is melted by the arc discharge, and is then accumulated successively in this process. The wire and arc-based additive manufacturing process directly and locally adds material to the molten pool. By changing the material locally during the process, more than one kind of material can be used simultaneously in a single manufactured component. In this study, two kinds of dissimilar metal deposition were conducted. A combination used was a stainless steel and Ni-based alloy. Mechanical properties near the interface such as hardness and bond strength were investigated. As a result, it was found that the mechanical properties of the manufactured alloy were comparable to those of a bulk material. In addition, an additive manufacturing system and a torch path planning method for using more than two kinds of material were proposed. By using this method, highly functional shapes whose surfaces and inner structures are made of different material could be made.

1. Introduction

The additive manufacturing (AM) process, which can make complicated shapes from 3D-CAD data, is expected to be used to fabricate not only prototypes but also machine parts and die tools [1,2]. The AM processes using metal can be categorized into two types: powder bed fusion and directed energy deposition (DED). Powder bed fusion is also known as selective laser sintering (SLS) or selective laser melting (SLM) [3], which melt metallic powder, sinter, and accumulated metal. The dimension accuracy and surface roughness of components made by powder bed fusion are relatively better than those of components made by DED. However, the powder bed fusion process is not suitable for the fabrication of large components because the deposition rate of the powder bed fusion type machine is not very high and the build volume is not large. The deposition rate of the powder bed fusion type machine is 0.009–0.2 kg/h [4,5]. The maximum build volume of the commercially supplied machine is 800 mm × 400 mm × 500 mm (x, y, z) [6]. On the other hand, the DED process is suitable for the fabrication of large components. The build efficiency of the DED type machine is more than 1.8 kg/h [5], and there are almost no limitations of the build volume. The build volume only depends on the stroke of the deposition head. The mechanism of the DED process is similar to cladding by welding. In these process, the powder or wire metallic material is provided. The material is melted by the energy of a laser, electron beam or arc discharge. Then the molten metal is deposited as a weld bead. Through the accumulation of weld beads, three-dimensional shapes can be made. The DED process can add material not only to the substrate but also to an existing part, such as to repair a worn part or tool. The DED process can be classified according to the material type and energy source. In most cases, powder and laser-based DED, which uses a powder material and a laser as an energy source, is applied [7]. This is because the powder and laser-based process can produce relatively higher dimensional accuracy.

Compared with the powder and laser-based DED process, wire and arc-based DED, which uses wire material and an arc discharge as an energy source, has some advantages. Wire and arc-based DED has a high deposition rate. Deposition efficiency is a parameter that is used to describe the ratio of actual deposited material to the total used material. The deposition efficiency of powder and laser-based DED is only 14% [8], while wire-based DED has a higher material usage efficiency of up to 100% [9]. The energy efficiency of wire and arc-based DED is also higher than that of powder and laser-based DED. The energy efficiency of wire and arc-based DED can be as high as 90% [9,10], and powder and laser-based DED is 30–50% [8].

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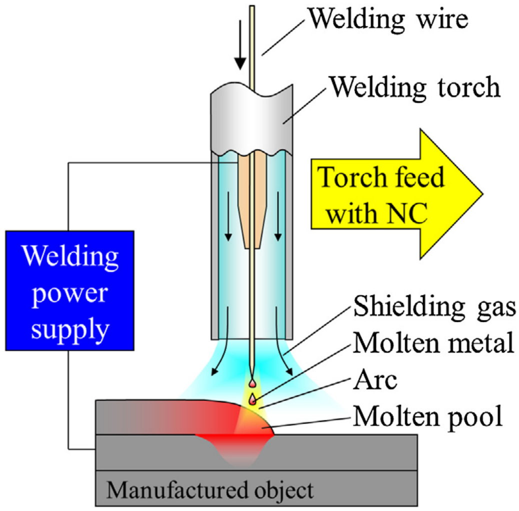

Fig. 1. Process mechanism.

In addition, the cost of the wire material and arc-based DED system is much lower than that of the powder material and laser-based DED system.

The Rolls-Royce research group reported shaped metal deposition (SMD), which applies TIG or MIG welding technology to the making of aerospace components [11]. Martina et al. [5] investigated the microstructure of the titanium alloy made by the plasma wire deposition process. Some research groups mounted a welding system to a milling machine and enabled post processing by milling [12,13]. Xiong et al. [14] developed a system for the monitoring and control of the weld bead shape during the deposition process.

Direct metal lamination using arc discharge is one of the wire and arc-based DED processes. Direct metal lamination was developed by the authors' research group [15–20]. In this process, wire metallic materials are melted and accumulated by MIG/MAG welding technology. Fig. 1 shows the process mechanism. Welding wire is fed to the welding torch tip and works as a positive electrode. The welding wire tip and manufactured object are melted by the arc discharge caused between the wire tip and manufactured object. Molten metal is dropped on the molten pool of the manufactured object. As the welding torch moves along the targeted path, accumulated molten metal is solidified and deposited. MIG/MAG welding technology is widely used, and various materials are commercially supplied. With MIG/MAG welding technology, various metallic materials can be used in this process. It was reported that the tensile strength of a built object made of various materials such as mild steel, stainless steel and Ni-based alloy is comparable to that of the bulk material [18], so metallic products with high strength can be made rapidly. In addition, the built objects can be made as a near net shape. So this process can reduce the quantity of material removed and is especially expected to be useful in fabricating large-sized dies and single machine parts that require high strength.

Compared with powder bed fusion, DED has one more advantage. The DED process has the capability of performing dissimilar metal deposition; that is, more than one kind of material can be used simultaneously [2]. The DED process directly and locally adds material to the molten pool. By changing the material locally during the process, a structure that is made of more than one kind of material can be made [21,22]. On the other hand, it is difficult to change the material locally using powder bed fusion because of the powder-bed-making process.

Dissimilar metal deposition, which uses two kinds of material for the AM process, is similar to the cladding process performed by welding. Cladding by welding, which adds different kinds of material to the surface of the products, is generally used when the products require high heat resistance, corrosion resistance, abrasion resistance and so on. In the cladding process, two kinds of materials are mixed in the molten pool. It is expected that the mechanical properties near the interface between two kinds of materials are different from those of the base metal. Therefore, metallurgical observation near the interface between the weld metal and base metal has been conducted and mechanical properties such as bond strength have been investigated [23–25]. However, little research has been done on the mechanical properties near the interface between two kinds of weld metal [22]. Nor has a way to make a highly functional structure that cannot be made by other conventional processes been proposed.

The objective of the present research is to investigate the mechanical properties near the interface between two kinds of weld metal made by dissimilar metal deposition and to determine the path planning required to make a highly functional structure. In this paper, dissimilar metal deposition using a nickel-based alloy, which is the equivalent of Inconel 600, and stainless steel, which is the equivalent of SUS304L, was conducted. The weld materials used in this study were YS308L and Ni6082. These materials

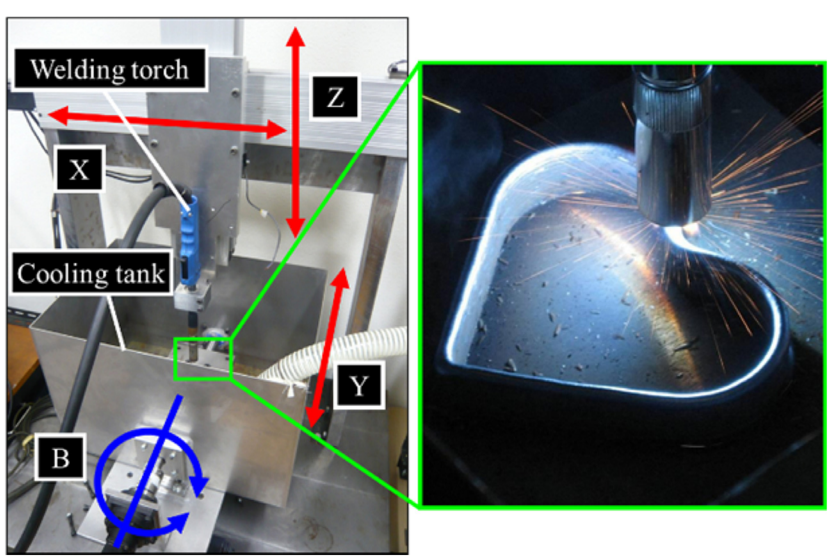

Fig. 2. Wire and arc based AM machine.