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Fabrication of Lattice Structures by Wire and Arc-based Additive Manufacturing

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Abstract
Wire and arc-based additive manufacturing (AM) is one of the additive manufacturing technologies which applies the arc welding. This process is especially expected to be useful in fabricating large-sized die and prototype machine parts. Also, AM process is expected to make complicated shapes which cannot be made by conventional process. Building lattice structures inside a component enables to give light weight and high strength. Strut shapes have to be made to build lattice structures by wire and arc-based AM. In this study, the influence of process parameters on the built object geometry was investigated. As a result, arc discharge time has much influence on the layer height and diameter. Inclination angle had little influence on the dimension accuracy of the built object. Finally lattice structures were successfully built by wire and arc-based AM.

Additive manufacturing, Arc discharge, Arc welding, Wire material, Lattice structures

1. Introduction

The additive manufacturing (AM) process, which can make complicated shapes from 3D-CAD data, is expected to be used for the fabrication of not only prototypes but also machine parts and die tools. Directed Energy Deposition (DED) is one of the metal AM technology. Compared with the powder bed fusion process, which is also metal AM technology, DED process has high build efficiency. Additionally, DED process has almost no limitations of the build volume except the stroke of deposition head. DED process, therefore, is suitable for the fabrication of large components.

AM technology is expected to make complicated shapes which cannot be made by conventional processes such as machining, molding and forging process. For example, lattice structures can be built inside the component. Lattice structures are usually built by powder bed fusion process [1]. On the other hand, it is difficult to make lattice structures by DED process because strut shapes, as shown in Figure 1, have to be built for the making of lattice structures [2]. DED process is generally expected to make thin-walled shapes [3, 4, 5] or solid shapes [6, 7].

Wire and arc-based AM, which uses wire material and an arc discharge as an energy source, can be regarded as one of the DED process. MX3D project successfully made the strut shapes by wire and arc-based AM [8]. Strut shapes could be built by repeating spot welding process. Layer geometry, defined in Figure 1, should be controlled by process parameters such as welding current, voltage, deposition time, and so, to make lattice structure by wire and arc-based AM. However, few research was conducted to reveal the relationship between the layer geometry and the process parameters. Therefore, the objective of this research is to investigate the relationship between the layer geometry and the process parameters. In this study, strut shapes were built by wire and arc-based AM. Then, the layer geometry of the built object was measured. Finally, lattice structures were built.

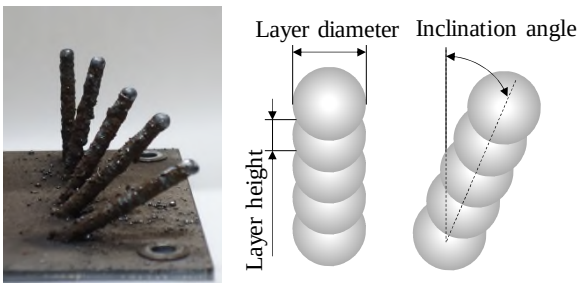

Figure 1. Strut shapes and layer geometry

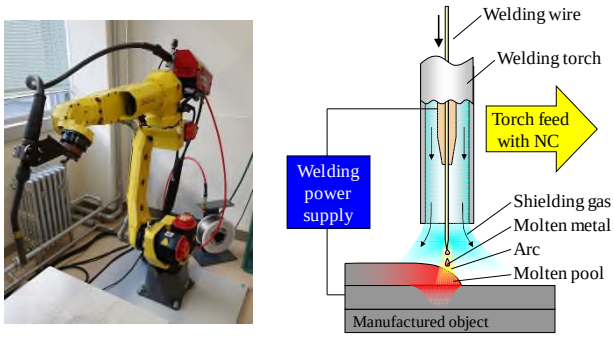

Figure 2. wire and arc-based AM machine

2. Experimental procedure

A welding robot ARC Mate 100iC, made by FUNAC, was applied to control deposition process, as shown in Figure 2. LINCOLN ELECTRIC R350 POWER WAVE was used as a welding power supply. These machines are generally used for Metal Inert Gas (MIG) or Metal Active Gas (MAG) welding. A wire electrode was mild steel wire of 1.2 mm diameter.

Making process of the strut shapes is as follows. At first, welding torch is moved to target position. Then, arc discharge is caused between the wire tip and a base metal. Arc discharge

melts the wire and the base metal. The molten metal is dropped on the molten pool. The molten pool become almost half-sphere shape under the influence of some factors such as surface tension, gravity and arc pressure. Arc discharge is stopped after about one second later from deposition process started and molten pool finally solidified. This process makes small ball like shape. This process is repeated by changing welding torch tip position.

Table 1. Process conditions

Welding current	A	160
Welding Voltage	V	15
Wire feed speed	mm/min	3.96
Wire material		Mild steel
Wire diameter	mm	1.2
Arc discharge time	s	0.4, 0.5, 0.6, 0.8, 1.0, 1.2
Time interval	s	60
Inclination angle		0, 15, 30, 45, 60
Shielding gas	$Ar + CO_2$	80%+20%
Shielding gas flow rate	l/min	15

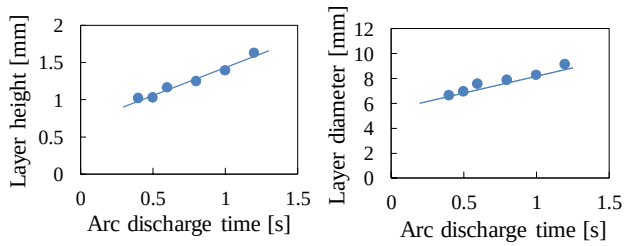

Figure 3. Relationship between arc discharge time and layer geometry

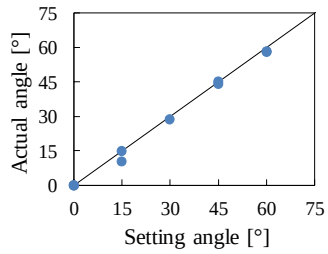

Figure 4. Accuracy of the overhang shape

3. Relationship between layer geometry and process parameters

In this section, strut shapes were built by changing the process parameters. Then, the layer geometry was measured with caliper. Table 1 shows process conditions. Arc discharge time was changed from 0.4 s to 1.2 s. These conditions were decided after several trials. It was found that stable layer geometry could be obtained under these conditions. When lower arc discharge than 0.4 s was applied, roughness of the built object was too high to measure the layer diameter. On the other hand, when higher arc discharge time than 1.2 s was applied, molten metal dripped from top layer.

Figure 3 shows experimental results. The layer height was linearly changed from about 1 mm to 1.6 mm. Also, layer diameter was linearly changed from about 6.6 mm to 9.1 mm. These results shows that layer geometry can be controlled by arc discharge time.

Next, the influence of inclination angle on the dimension accuracy of the built object was investigated. It is because overhanging strut shape have to be built when lattice structures are made. Inclination angle was defined as shown in Figure 1. When strut shape is built vertically, the inclination angle is 0°. When strut shape is built horizontally, the inclination angle is 90°. Inclination angle was changed from 0° to 60° in this experiment. 60° is the maximum inclination angle to make strut shapes without interfearence between substrate and welding torch. In this experiment, arc dischage time was 0.5 s.

Figure 4 shows experimental results. As shown this figure, high dimension accuracy was obtained even if large inclination angle was applied. Actural incilantion angle is tend to be slightly lower than setting angle. It is caused by the influence of gravity.

4. Building lattice structures

In this experiment, lattice structure was made by building overhanging strut shapes. Figure 5 shows geometry of unit cell for lattice structures. The length of a side L was 30 mm. Inclination angle α was 45°. Arc discharge time was 0.5 s and other process conditions were same as shown in table 1. Lattice structures could be built, as shown in Figure 5.

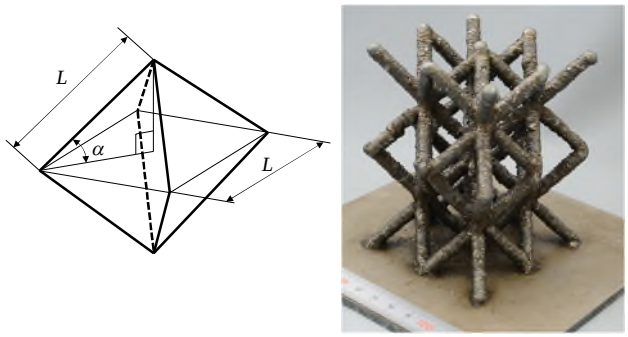

Figure 5. Geometry of unit cell for lattice structures and lattice structure built by wire and arc-based AM

5. Conclusions

In this study, the influence of process parameter on layer geometry was investigated to make lattice structure by wire and arc-based AM. Following results were obtained.

(1) Layer height and layer diameter of the strut shapes were almost linearly increased when arc discharge time was increased.
(2) Inclination angel did not influence on the dimension accuracy of the built object.
(3) Lattice structures composed of strut shapes were successfully built by wire and arc-based AM.

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