Technology

Development of rotary TIG welding technology for wire and arc additive manufacturing

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1. Introduction

Additive manufacturing (AM) using metal 3D printers is becoming more popular year by year as a technological innovation in manufacturing. One of its representative methods is directed energy deposition (DED), which performs manufacturing by melting wire or powder metal material and depositing it at the tip of a torch that is freely moved by a robotic arm or other means. (Figure 1).

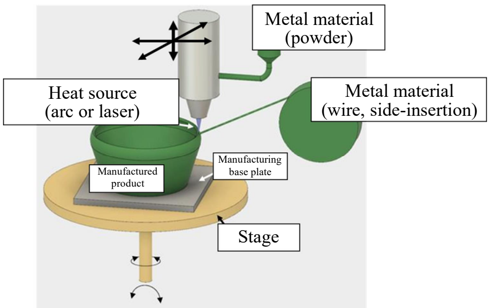

Figure 1 Schematic image of DED method [1)]

Among DED, there are different processes depending on the material and heat source. Wire and arc additive manufacturing (hereinafter referred to as WAAM), which uses arc discharge to melt a welding wire and stack it for 3D additive manufacturing, is attracting widespread attention since it has high manufacturing speed and is suitable for the manufacturing of large products (Table 1).

Table 1 Comparison of major DED metal additive manufacturing processes

Process	Wire-Arc (WAAM)	Wire-Laser	Powder-Laser
Material shape	Metal wire	Metal wire	Metal powder
Heat source	Arc discharge	Laser	Laser
Manufacturing speed [2)]	200-1000 cc/h	100-1000 cc/h	100-200 cc/h
Characteristics	Large and high-speed manufacturing	High-precision	High-precision

Arc welding is classified into two types: MIG welding, which is a consumable electrode type, and TIG welding, which is a non-consumable electrode type. WAAM mainly uses MIG welding since it offers a high degree of freedom in the direction of movement and excellent deposition speed.

MIG welding is superior to TIG welding in terms of deposition speed, but inferior to TIG welding in terms of the amount of spatter generation and the tendency to cause internal defects [3)].

TIG welding is generally capable of producing higher quality manufacturing than MIG welding. However, in the existing TIG welding process, the wire is fed from a fixed direction with respect to the direction of movement, which requires the control of torch direction according to the movement direction (Figure 2).

In addition, 3D additive manufacturing requires a wide variety of movement paths, including turning and right-angle movement paths in some cases (Figure 3). For uniform and stable manufacturing, it is desirable to use a torch structure that allows manufacturing in any direction.

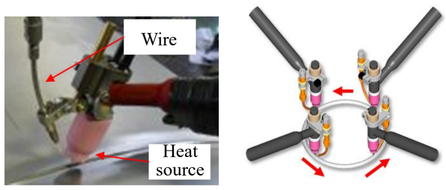

Figure 2　Torch shape and movement path examples of conventional TIG welding torch

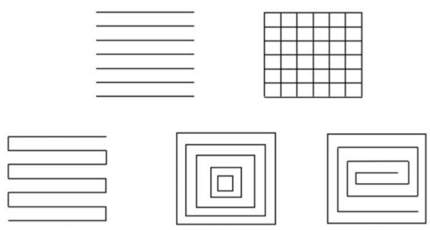

Figure 3　Movement path examples of DED method

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To solve these issues, we have developed a new TIG welding technology that has no directional dependence and allows uniform heat input and wire insertion due to its unique structure.

This paper reports that the new TIG welding technology can solve the issues of conventional methods and is capable of basic manufacturing using stainless steel.

2. Concept of rotary TIG welding technology

Figure 4 shows the external view of the rotary TIG torch and the metal stacking situation. This torch has a structure in which a wire is fed from the center and arc heat is applied by a TIG electrode rotating around the wire. Figure 5 shows an additive manufacturing sample produced by rotary TIG welding. The rotary TIG welding method, which has no directional dependence and allows uniform heat input and wire insertion, achieved stable manufacturing.

In the past, various TIG welding methods have been developed and reported by companies and universities around the world, but no TIG welding technology has achieved a perfectly uniform heat input in the circumferential direction. Our new rotary TIG welding is the world's first innovative new TIG welding technology developed independently by us based on the idea of providing uniform heat input by means of a rotary electrode.

Table 2 compares conventional MIG and TIG welding with the rotary TIG welding. It is indicated that the rotary TIG welding method achieves the advantages of both MIG welding, which has no constraint on the direction of movement, and TIG welding, which provides high-quality welding with fewer internal defects and spatter. Therefore, the rotary TIG welding method is suitable for 3D additive manufacturing, which requires both complex paths and defect-free welding.

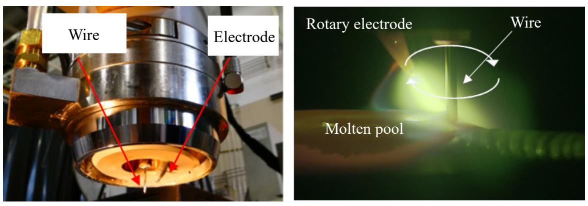


Figure 4 External view and metal stacking situation of rotary TIG welding torch

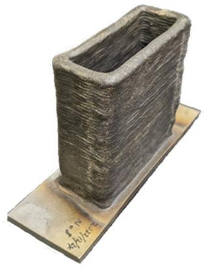


Figure 5 Additive manufacturing sample produced using rotary TIG welding

Table 2 Comparison of conventional arc welding and rotary TIG welding technology

	MIG	TIG	Rotary TIG
Constraint on torch movement direction	Good	Poor	Good Not constrained
Manufacturing speed	Good	Poor	Good Faster than TIG
Internal defects	Poor Oxidizing gas added	Good Inert gas	Good Inert gas
Spatter occurrence	Poor Spatter occurs	Good No spatter occurs	Good No spatter occurs

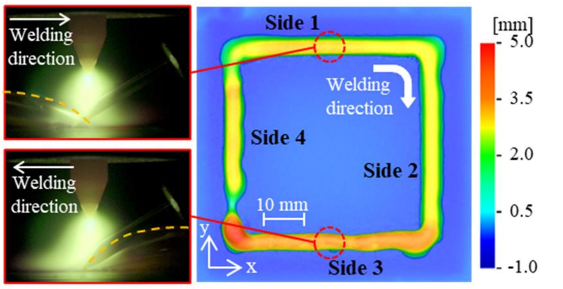
3. Study of basic characteristics

3.1 Comparison of uniform manufacturability between conventional TIG welding and rotary TIG welding [4)]

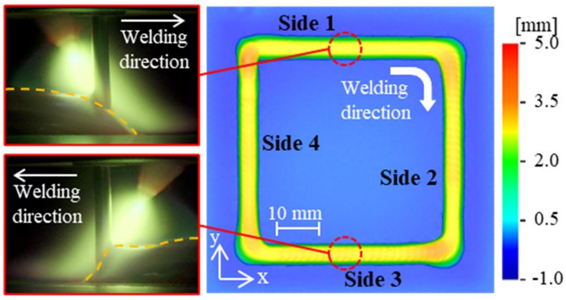
We performed an experiment to compare the rotary TIG welding with conventional TIG welding by using the developed rotary TIG welding torch and a conventional TIG welding torch to perform manufacturing with a 50 mm × 50 mm square path. Table 3 shows the experimental conditions. For rotary TIG welding, the electrode rotation speed was set to 120 r/min, and for conventional TIG welding, the wire feed direction was set always to the minus x-axis direction in the coordinate system shown in the figure. After manufacturing, we measured the height distribution of the manufactured beads using a 3D measuring machine to compare the uniformity of the manufactured shapes.

Table 3 Experimental conditions

Base plate material		SUS304
Wire material		YS308L
Wire diameter	mm	1.2
Current value	A	150
Wire feeding speed	m/min	2.5
Torch movement speed	cm/min	20
Electrode rotation speed	r/min	120
Shield gas		Ar (99.99%)
Shield gas flow rate	L/min	20



(a) Conventional TIG torch



(b) Rotary TIG torch

Figure 6　Comparison of shapes manufactured by square path

The conventional TIG welding produced uneven bead stacking heights depending on the wire feeding direction. On the other hand, the rotary TIG welding developed by us resulted in beads with uniform stacking height without producing bias. It was confirmed that the rotary TIG welding has a high degree of freedom of direction compared to the conventional TIG welding (Figure 6).

3.2　Selection of manufacturing conditions for rotary TIG welding [5)]

We manufactured 50 mm long beads using the rotary TIG welding with the wire feeding speed of 8 m/min, which is the same manufacturing speed as that of WAAM using MIG welding, and different electrode rotation speeds. Table 4 shows the conditions.

Table 4 Experimental conditions

Base plate material		SUS304
Wire material		YS308L
Wire diameter	mm	1.2
Current value	A	400
Wire feeding speed	m/min	8.0
Torch movement speed	cm/min	80
Electrode rotation speed	r/min	120,240,360
Shield gas		Ar (99.99%)
Shield gas flow rate	L/min	20

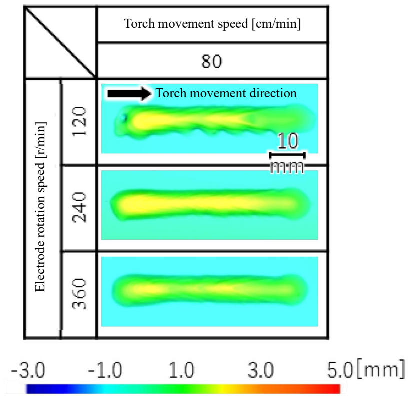


Figure 8　Bead shapes produced under different electrode rotation speed conditions

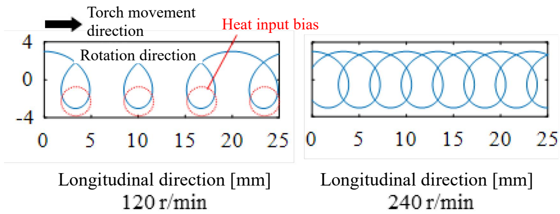


Figure 9　Comparison of electrode movement trajectories by rotation speed

Figure 8 shows the bead height distributions produced under different conditions. It was confirmed that the rotary TIG torch produces a uniform bead at electrode rotation speeds of 240 r/min or higher. On the other hand, when the electrode rotation speed was 120 r/min, the shape of the right side of the bead with respect to the direction of movement collapsed, resulting in a defective shape with an uneven toe. Figure 9 compares the movement trajectory of the torch electrode at a torch movement speed of 80 cm/min between the electrode rotation speeds of 120 r/min and 240 r/min.

Under the electrode rotation speed of 120 r/min, a point where heat input converged every rotation of the electrode was observed. This suggests that the bead shape was broken due to uneven heat input. On the other hand, under the electrode rotation speed of 240 r/min, the occurrence of heat input convergence points due to the movement trajectory was eliminated, which suggests that a uniform bead shape was obtained.

Based on the above results, it was found that the bead shape is affected by the difference in electrode rotation speed, and that a uniform bead shape can be manufactured by selecting an appropriate electrode rotation speed even when the wire feeding speed is as high as 8 m/min.

4. Conclusion

In the field of welding, TIG welding has long been the welding method of choice for welding high-functionality, high-value-added metals and for welding products with high quality requirements where defects are unacceptable. Metal additive manufacturing also targets high-value-added metal parts, and defect-free and uniform quality in the manufactured parts are the most important requirements. For this reason, we believe that there is a demand for the application of TIG welding to WAAM.

As presented in this report, we confirmed that the rotary TIG welding technology we developed is able to achieve both the elimination of the directional dependence, which is an issue in the application of TIG to additive manufacturing, and the high-speed manufacturing, which is expected for WAAM. We also confirmed the basic manufacturing conditions for stainless steel using the developed rotary TIG welding torch. In the future, we will further optimize the torch structure and the manufacturing parameters for metals other than stainless steel, and progress with the development with the aim of implementing this technology in metal 3D printers.

5. Acknowledgments

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References

1) National Institute of Advanced Industrial Science and Technology, Processing Technology Database, 3D Printer (Additive Manufacturing), Type of metal AM methods, http://www.monozukuri.org/mono/db-dmrc/3dprinter/overview/metal.html (referred on December 22,2023)
2) Paul Gradl, et al., Robust Metal Additive Manufacturing Process Selection and Development for Aerospace Components, Journal of Materials Engineering and Performance, Volume 31, p6013-6044 (2022)
3) Tsuneo Mita, A Systemized Exploration of the Development of Arc Welding Technology, National Museum of Nature and Science, p400-401
4) Masahiro Kawabata, Hiroyuki Sasahara, Tomoaki Sasaki, Katsunori Wada, Shuhei Kanemaru, and Yuji Nomura, Development of a rotary TIG torch for WAAM and research of basic characteristics in by bead-on-plate welding, Abstracts of the National Conference of the Japan Welding Society Vol. 110, p32-33 (2022).
5) Masahiro Kawabata, Hiroyuki Sasahara, Tomoaki Sasaki, Katsunori Wada, Shuhei Kanemaru, and Yuji Nomura, Effect of Electrode Rotation Speed on Manufacturing Stability in WAAM Using a Rotary TIG Torch, The Japan Society for Precision Engineering, Collection of papers from academic conferences, p237-238 (2023)