euspen's 18th International Conference &
Exhibition, Venice, IT, June 2018
www.euspen.eu

Metal wire-feed additive manufacturing using a rotating wire feeder

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Abstract
Laser and wire additive manufacturing (AM) is a deposition process used in the production of metal components required by the aerospace, shipbuilding, automobile, and mold repair industries. The principal advantage of metal wire-feed AM is the high deposition rate relative to those of metal powder-feed AM and metal powder-based fusion AM. During wire-feed deposition, the feed orientation is a very important parameter. A better surface finish is attained when the melted wire flows smoothly, and a wire feed direction opposite to the deposition direction yields the best results. To improve the surface quality of metal 3D printing, we designed a rotating wire feeder, the feed direction of which varies with the direction of deposition; all free-form lines thus exhibit identical surface qualities. We use a rotating stage to orient the wire-feed direction, a slip ring to supply electrical power to the feeder motor, and two rotating channeled plates to supply Ar gas and extract fumes. We evaluated the rotating wire feeder by building various parts.

Additive manufacturing, rotating wire feeder, laser metal deposition

1. Introduction

Metal wire-feed additive manufacturing (AM) is important in the production of large components of low complexity. In particular, AM is optimal when fabricating high-cost functional metal components, affording more efficient material utilization and a cleaner environment compared to powder-feed AM. [1]

A laser, an E-beam, an electrical arc, or plasma is generally used as the heat source for melting the wire. During laser and gas tungsten arc welding (GTAM), the wire-feed orientation influences the quality of the deposited surface. Some authors found that front-feeding, where the bead formation and wire feed directions are identical, afforded better results than back- or side-feeding. This is because, during front-feeding, molten wire is supplied to the substrate without interference with pre-deposited beads. During back- or side-feeding, the pre-deposited beads act as obstacles to smooth and continuous next-line deposition, rendering the surface wavy or serrated, and creating porosity. [2–4]

To deal with these issues, a laser head feeding the wire centrally and irradiating the laser beam from the side has been introduced. [5, 6] However, this has limitations during infilling applications such as mold repair confined by a side-wall, where the lateral laser beam will be blocked by the mold wall.

In this paper, we introduce a new omnidirectional rotating wire feeder that affords high surface quality and present some preliminary test results.

2. The rotating wire feeder

To optimize surface quality, the direction of wire feeding should always be opposite to the direction of deposition, as shown in Figure 1. The rotating wire feeder consists of the rotating stage orienting the wire-feed direction, a slip ring supplying electrical power to the feeder motor, and two rotating channeled plates used to supply Ar gas and extract fumes, as shown in Figure 2. The feeder never twists the electrical or pneumatic lines.

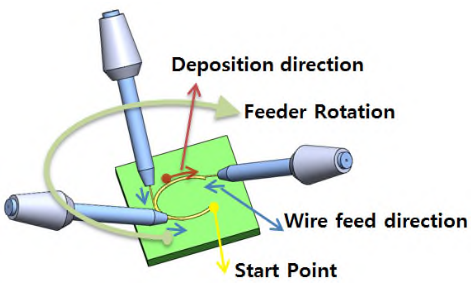


Figure 1. Schematic of the deposition process using the rotating wire feeder

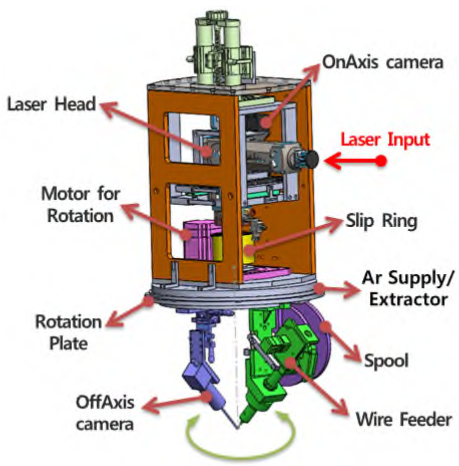


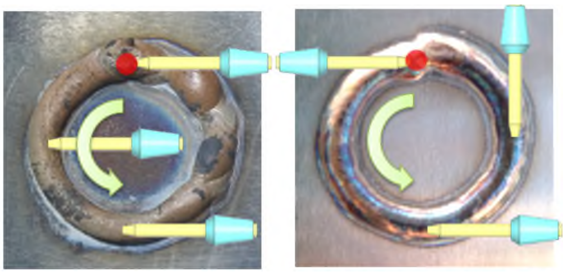
Figure 2. Schematic of the rotating wire feeder with the laser

The rotating wire feeder aligns the feeder direction to be opposite to that of deposition. For example, the bead is formed from the 0, 0 to the 10, 10 position, and the feeder is then rotated to an angle of 45° at the 0, 0 point. When a cylindrical tube of diameter 50 mm is to be formed starting at the 0, 25 position, the feeder is rotated from 0° at the first 0, 25 position to 360° at the next 0, 25 position, thus circling occurs while the Z-axis step height rises during layer-by-layer deposition. Therefore, the surface is formed continuously; motion never ceases and the laser is never off

3. Experimental results and discussion

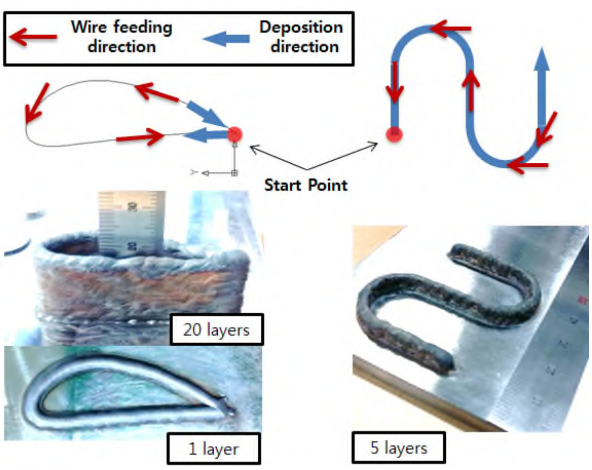
In preliminary tests, we used a fiber laser (IPG Photonics) of wavelength 1,070 nm with the beam focused to a diameter of 1.5 mm. Two kinds of wire material 0.9 mm in diameter were employed. Argon served as the shielding gas at a flow rate of 20 L/min. The angle between the substrate and the wire was fixed at 45°. The table speed and wire-feed rate were held constant at 8 mm/s and 40 mm/s, respectively.

Figure 3 shows a simple comparison of the surface qualities afforded by a fixed feeder (a) and the rotating feeder (b) using Ti-6Al-4V wire and a substrate material in generating a circle bead 20 mm in diameter. The fixed feeder forms beads creating an irregular wavy surface during the side and back feeding. However, the rotating feeder does not create waves. Therefore, it is possible to deposit the next layer smoothly; multilayer deposition quality is good.



(a) (b)

Figure 3. Comparison of fixed (a) and rotating (b) wire feeder



(a) (b)

Figure 4. Deposited samples shaped like an airfoil (a) and "ㄹ" (b)

Figure 4 shows other shapes created using the rotating wire feeder. As the wire feed direction is always opposite to the direction of bead formation, an airfoil (a) with a wing length of 60 mm and a "ㄹ" shape (b) with a total line length of 123 mm are well-formed. At the sharp edge of the airfoil, a hump develops when motion ceases and the laser is turned off because it is difficult to rotate the feeder rapidly when the angle changes abruptly. However, this problem can be solved by decreasing the laser power and slowing the wire feed rate during the feeder rotation that produces the next layer.

As mentioned above, the rotating wire feeder can be used for infilling. If mold repair using KP4 (a plastic mold steel) is required, for example, the damaged part is trimmed to a bottom diameter of 30 mm and a taper angle of 10°, as shown in Figure 5 (a). The wire can be fed and fully melted without any interference with the laser; the beam is not blocked by the side wall when the feeder is tilted and rotated (b). Figures 5 (c) and (d) show the results after deposition of three layers each of height 1 mm, and half-face milling after one additional scan to ensure surface melting. It is difficult to infill using powder feeding, because the unmelted powder becomes stacked inside the mold, adversely affecting later melting and deposition of the next layer.

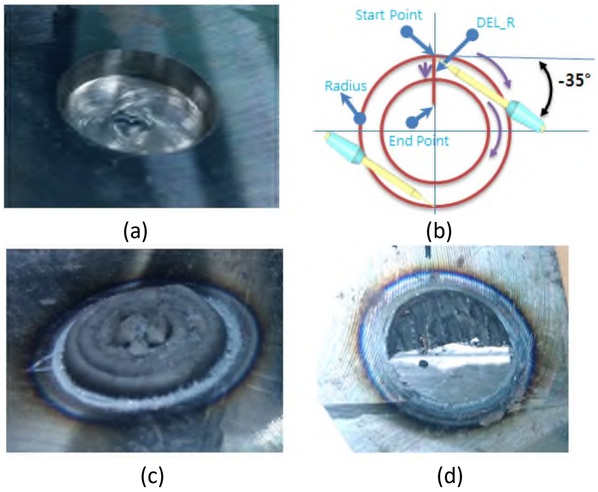


Figure 5. Infilling of a circular trench (a); the processing method (b); a deposited bead with three layers (c); and half-face milling (d)

4. Conclusions

Here, we developed a new rotating wire feeder and showed that it can be used for clean bead formation in a layer-by-layer manner. The wire-feed direction is dictated by a rotating stage; a slip ring is used to supply electrical power to the feeder motor and two rotating channeled plates are employed to supply Ar gas and extract fumes. Therefore, even when rotation is continuous, neither the electric nor pneumatic lines are twisted. Several parts (including an infilled part) were formed to demonstrate the utility of the feeder, which created smoother surfaces than a fixed-wire feeder. The feeder can be used to produce larger components of lower complexity and higher surface quality, and thus saves time and money.

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