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Laser metal deposition with spatial variable orientation based on hollow-laser beam with internal powder feeding technology

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ABSTRACT

In this study, a hollow-laser beam with internal powder feeding (HLB-IPF) head is applied to achieve non-horizontal cladding and deposition of overhanging structure. With the features of this head such as uniform scan energy distribution, thin and straight spraying of the powder beam, the deposition in spatial variable orientation is conducted using a 6-axis robot. During the deposition process the head keeps tangential to the growth direction of the part. In the experiment, a "vase" shaped metal part with overhanging structure is successfully deposited, and the largest overhanging angle achieves 80° to the vertical direction. The "step effect" between cladding layers is completely eliminated with the best surface roughness of Ra=3.864 µm. Cross section of cladding layers with unequal height are deposited for angle change. Test results indicate that the formed part has uniform wall thickness, fine microstructure and high microhardness.

1. Introduction

The Laser Metal Deposition (LMD) emerged in the late 90's of the 20th century is a direct rapid manufacturing technology for metal components, which was developed by combining laser cladding technology and rapid prototyping technology. LMD is superior in forming of high performance metal parts with large size, compact texture, high strength, and the possibility of functionally gradient material [1,2], and it has promising applications on spaceflight and aircraft apparatus, weapons parts and biological replacement bones [3]. Nevertheless, depositing such complex structures is very difficult. For example, in the deposition of overhang, high-inclination, side convex and cavity, LMD has no supporting material compared with powder bed in SLM technology [4]. The molten pool must be formed above the substrate during the deposition process. The present methods to deposit cantilevered part and to clad on non-horizontal surface are generally included as follows:

The first method is to mount the laser cladding head into a multi-axis machine tools [5]. The forming part is deposited on a rotatable and deflectable base. The second method is to deposit an inclined plane in shifting the position of 2 adjacent layers above and below, but the inclined angle (the angle between vertical direction and growth direction of deposition throughout this paper) should be limited. Shang et al. [6] analyzed the limit of the inclined angle and the overlap rate between layers by depositing thin-walled parts. Wu et al. [7] deposited thin-walled parts with inclined angle of 30° . Wang et al. [8] varied the Z-axis-increments to adapt the actual deposition height, and the part was formed with a maximal inclined angle of 36.6°. The third method deposits supporting material synchronously and the cantilevered parts of the main material were then deposited above the supporting material. Merz [9] deposited cupper as supporting material, and after the deposition the cupper was removed by nitric acid. The last method inclines the cladding head during the deposition process. Paul et al. [10] researched cladding and hardening on a vertical surface with a side blown powder feeding tube. Kovacevic et al. [11] fabricated slender structures by means of a mathematical model suggested for the process planning. Bullen and Keicher [12] developed several inclined powder tubes and a rotatable cladding head to deposit overhanging structure.

In this study, a hollow-laser beam with internal powder feeding (HLB-IPF) head is adopted, which is developed by Shi S.H. and his co-workers [13–15]. Similar cladding or brazing head is found from [16]. With help of a 6-axis robot, this cladding head is inclined to varied angles to deposit metal part with overhanging structure.

2. Hollow-laser beam with internal powder feeding (HLB-IPF) technology

The coaxial powder feeding nozzle is at present mostly applied [17–21], whose principle is shown in Fig. 1(a). The solid laser path is installed on the central axis and the multi powder tubes are inclined and symmetrical around the laser path.

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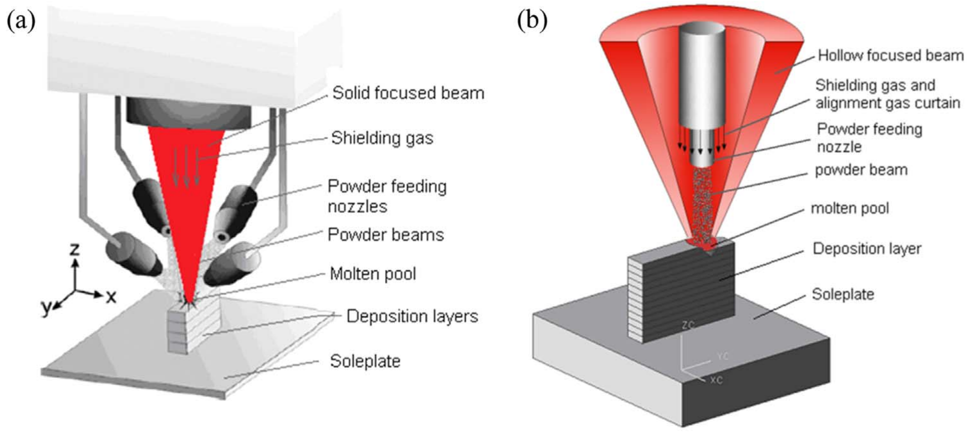

Fig. 1. Comparison of solid laser beam external powder feeding and HLB-IPF, (a) Scheme of solid focused beam+external oblique powder feeding through multiple powder nozzles, (b) Scheme of hollow focused beam+internal straight powder feeding through single powder nozzle.

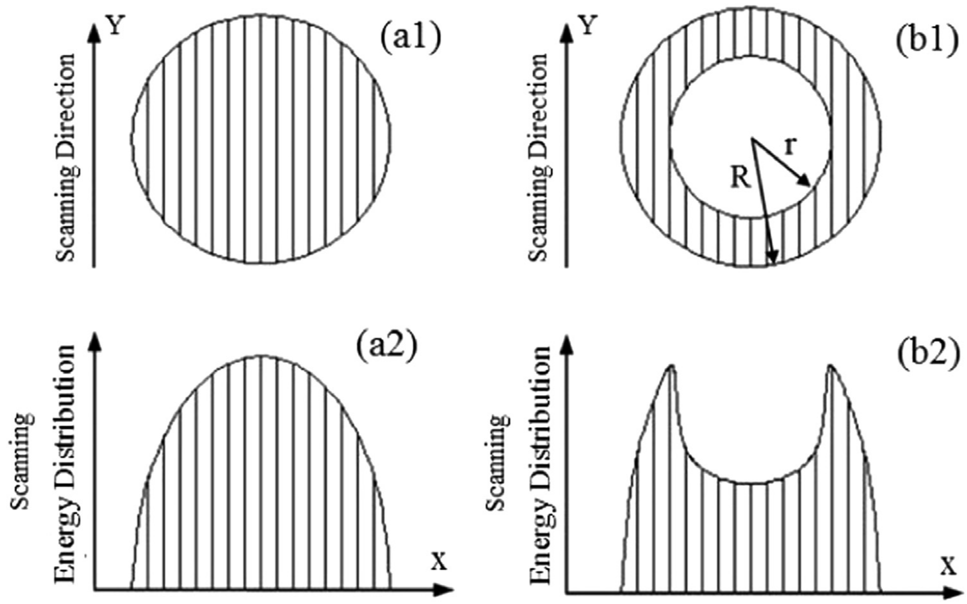

Fig. 2. Laser spot and scanning energy distribution of laser irradiating (a1) Static solid laser spot, (a2) Scanning energy distribution from solid laser spot, (b1) Static ring laser spot, (b2) Scanning energy distribution from ring laser spot.

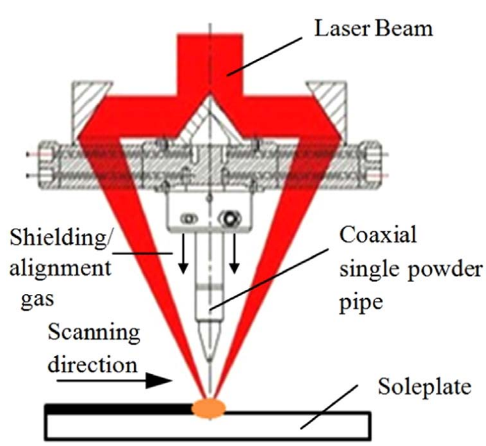

Fig. 3. Schematic principle of hollow laser beam with single powder nozzle and shielding gas curtain.

Fig. 4. A product of cladding head of HLB-IPF technology with series number of JGRF-102-2.

Fig. 1(b) and Fig. 3 show the principle of HLB-IPF technology, which has the following advantages: (1) hollow and conical laser beam generates an annular laser spot. Assume that solid laser spot in