Materials and Design 108 (2016) 707–717

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of beam oscillating pattern on weld characterization of laser welding of AA6061-T6 aluminum alloy

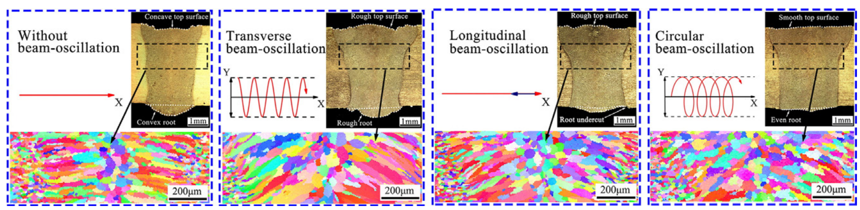
Lei Wang [a], Ming Gao [a,*], Chen Zhang [a,b,*], Xiaoyan Zeng [a]

[a] Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, PR China
[b] School of Mechanical & Electrical Engineering, Wuhan Institute of Technology, Wuhan 430073, PR China

HIGHLIGHTS

- Beam oscillation stabilizes the process and improves weld morphology.
- Beam oscillation increases the fraction of equiaxed grains in weld fusion zone.
- Beam oscillation has no effect on weld strength but obvious effect on elongation.
- Circular oscillation obtains the soundest weld with the best mechanical properties.
- Mechanism is discussed by the stirring effect on laser keyhole and melt flow.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 May 2016
Received in revised form 30 June 2016
Accepted 12 July 2016
Available online 13 July 2016

Keywords:
Laser welding
Beam oscillation
Aluminum
Microstructure
Tensile property

ABSTRACT

Laser oscillating welding was employed to join 4 mm-thick AA6061-T6 aluminum alloy in butt configuration. Three beam oscillating patterns that are transversal, longitudinal and circular were studied. The beam oscillation improved the weld morphologies and promoted the formation of equiaxed grain within the fusion zone due to stirring effect. The circular oscillation obtained the soundest weld, the finest grain and the most amount of equiaxed grains within the weld. The beam oscillation almost had no effect on the tensile strength of the weld, but increased the ductility obviously. The strain of circularly oscillating weld was up to 8%, 38% higher than the weld without beam oscillation. The ductility improvement was attributed to the decrease of weld morphological defects and the increase of equiaxed grains. Besides, the improving mechanisms of weld characterization were discussed by the beam oscillating effect on the behaviors of laser keyhole and melt flow.

1. Introduction

As one of the most important light-weight structural material, aluminum (Al) and its alloys have widely used in automobile, aircraft and high-speed train [1–3]. How to achieve their high quality, high efficiency welding has been the research focus in the welding and joining field. Laser welding would be potential to achieve this goal due to the advantages of high power density, lower heat input, big aspect ratio and narrow heat affected zone (HAZ) [4]. However, the tiny focused beam spot limits the industrial application of laser welding because it requires high accuracy. Ref. [5] claimed that a maximum gap for single-spot laser welding would be no more than 0.2 mm, which is hard to be achieved in most of industrial applications. Besides, laser welding of Al alloys is challenging because of their high reflectivity to laser beam, low viscosity, high thermal conductivity and serious burring-loss of alloying element [6–9], which causes unstable process, high porosity and other metallurgical defects.

Previous studies about electron beam welding demonstrated that beam oscillation has the potential to improve solidification behavior

* Corresponding authors at: Wuhan National Laboratory for Optoelectronics (WNLO), Huazhong University of Science and Technology, Wuhan 430074, PR China.
E-mail addresses: mgao@mail.hust.edu.cn (M. Gao), zhangchentm@163.com (C. Zhang).

http://dx.doi.org/10.1016/j.matdes.2016.07.053
0264-1275/

and pool geometry [10,11]. It has been used to join dissimilar metals [12]. These achievements guide the development of laser welding with beam oscillation, which is called laser oscillating welding for simple. Using the mechanical swing of welding head, Busuttil welded 6xxx serials Al alloys by laser oscillating welding [13]. He found that the beam oscillation reduced both the temperature gradient of molten pool and the weld hot cracking sensitivity. Zhang found that the nitrogen and argon porosity could be suppressed by beam oscillation under the frequency of 20–30 Hz in laser oscillating welding of mild steel with mechanical swing [14]. Rubben obtained sound tailored blanks by using the mechanical swing of laser beam to widen the molten pool [15]. It demonstrated that the beam oscillation can increases the fit-up gap tolerance, and then stabilize the process and improve the bead morphology.

Although some achievements have been obtained by above-mentioned studies, the mechanical beam oscillation has its inherent disadvantages such as low frequency and poor stability. The emergence of high-power galvanometer scanner has promoted the development of laser oscillating welding due to high frequency, high precision and multiple patterns. Some studies of laser oscillating welding with galvanometer scanner have been carried out recently. For example, Kraetzsch and Smith found that the cracks of dissimilar Al/Cu and Al/Ti welds could be reduced by beam oscillation [16,17]. Vänskä found that the assembling misalignment of 5 mm-thick stainless steel tube can be overcome by using beam oscillation to widen the weld [18]. Yamazaki found that the spatters occurred at the beam spot reversal points in laser transversely oscillating welding [19]. Kim and Kang studied the effects of welding parameters on weld cracks with the frequency no more than 50 Hz [20,21]. Berend found that high frequency oscillation could eliminate 'humping' defect of Al alloy weld, and stabilize the process in high speed [22].

All above studies showed that laser oscillating welding is potential to stabilize the process and improve the welding quality. However, most of studies about Al alloys are carried out under low frequency and linear oscillation, and focused on process stability. So far no reports have paid attention on the effects of beam oscillating patterns on weld characterization of Al alloys including microstructure and mechanical properties. Based on the results that the authors had obtained the sound AA6061-T6 welds under three oscillation patterns with high frequency after a series of experiments, this paper aimed to explore the effects of three beam oscillation patterns on the characterization of laser welded AA6061-T6 Al alloy.

2. Experimental procedures

The base material (BM) used was 4 mm-thick AA6061-T6 Al alloy with the size of 200 × 100 mm^2. Before welding, the oxidation film and the oil pollution on the specimens were removed by 10% sodium hydroxide solution at 70 °C and 30% nitric acid solution at room temperature in sequence, and then were cleaned by acetone.

The experimental set-up used was illustrated as Fig. 1, which contained an IPG YLR-6000 fiber laser, a welding head and a six-axis industrial robot. This fiber laser was a continue beam mode with the wavelength of 1070 nm and the beam parameter product (BPP) of 6.9 mm mrad. The radius of focused laser beam spot was about 0.167 mm. The welding head consisted of a collimation unit with focal length 200 mm, a galvanometer scanner unit and an f-theta focusing unit with focal length 250 mm. The welding head was driven by the robot to move linearly, which was named as X-direction. The beam oscillation was controlled by the galvanometer scanner. During welding, the weld surface and root were protected by gas nozzles using pure argon, whose set-up had been represented in previous study [23]. The gas flow of the upper and root nozzles was 20 l/min and 10 l/min, respectively. The molten pool and keyhole were observed by Phantom V710 high-speed camera with Cavitar Cavilux HF illumination, whose frame rate and exposure time were 7000 fps and 1 μs, respectively.

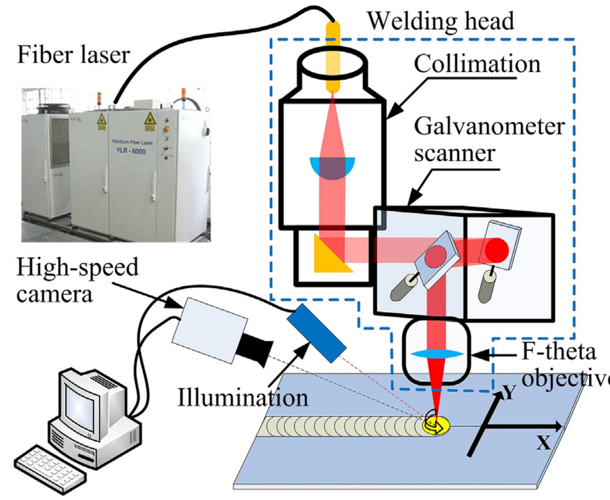


Fig. 1. Schematic diagram of experimental set-up.

In Fig. 2, the oscillating patterns used are three types that were transversal, longitudinal and circular. Since many studies have demonstrated that the porosity reduces the mechanical properties dramatically [24,25], a series of experiments were carried out in each oscillating pattern to optimize the parameters to get sound welds free of porosity previously. Only the optimized parameters were taken into account in this study to investigate the real relationship between microstructure and tensile properties. The optimized parameters used are shown in Table 1.

After welding, as shown in Fig. 3, both the cross-section and horizon-section specimens were prepared for microstructure observation. The microstructure was observed by optical microscope (OM) and electron backscatter diffraction (EBSD). The metallurgical specimens for OM were etched by a solution of 1 ml HF, 1.5 ml HCL, 2.5 ml HNO_3 and 95 ml H_2O with an etching time of 20 s. The EBSD specimens were prepared by electropolishing with an electrolyte of 10 ml perchloric acid and 90 ml ethanol. The Vickers micro-hardness was tested across transverse section using a 0.98 N load and a loading time of 20 s, whose testing position is shown in Fig. 3. The cross tensile specimens were prepared according to the standard of ASTM: E8/E8M-13a, as shown

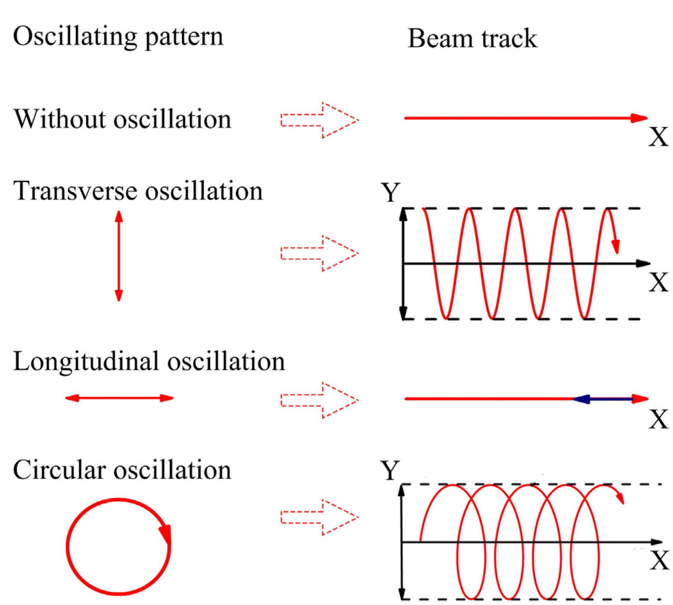


Fig. 2. Schematic diagrams of beam oscillating pattern and the resultant track of laser beam.