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Technical Paper

Influence of steady magnetic field on dynamic behavior mechanism in full penetration laser beam welding

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ABSTRACT

To study influence from external static magnetic field on dynamic behavior interaction between laser beam and EH36 steel, four cases with different magnetic strength (0 mT, 15 mT, 25 mT and 30 mT) are designed to capture high-speed image series of full penetration laser welding through quartz glass. It can be observed that: (1) Part of laser welding energy is compacted in bottom of weld pool to increase penetration and bottom width of bead geometry; (2) Eruption cycle and intensity (height 2.125 mm, width 1.75 mm) of vapor plume are both weakened; (3) Inhomogeneity and fluctuation of energy distribution are prominently dropped off; (4) Cooling period is delayed to reduce thermal gradient, depression area of the final profile is also reduced. Meanwhile, a polynomial model is developed to reveal relationship between thermal density and distance along the weld center. Therefore, external steady magnetic field has influence on dynamic behavior mechanism (weld pool, vapor plume, energy homogeneity, cool down stage) and even the final morphology, while 15 mT is an optimal value of the magnetic strength in these four cases. It can be concluded that selecting an appropriate magnetic field strength is helpful to stabilize laser process and improve welding quality.

1. Introduction

Laser beam welding is widely applied in various industrial fields, particularly in automobile, shipbuilding, aerospace, energy and so forth, for its advantages of small thermal input, high welding speed, large depth-to-width ratio, narrow heat affected zones and so on [1,2]. To stabilize weld quality, it is necessary to study the dynamic behavior mechanism of laser beam welding. However, it is surely difficult to analyze dynamic behavior mechanism owing to extremely complex physical and chemical phenomena of the whole welding procedure.

Meanwhile, many research methods of the dynamic behaviors are similar between arc welding and laser welding, and researchers all over the world have tried many different ways to study this topic from the point of weld pool, spatter, plasma and others. Weld pool width of laser welding 304 steel was captured using infrared imaging [3], and its boundary was further extracted and measured by the local maximum gradient of greyness searching approach and linear interpolation [4]. A mobile sensing system using sensory helmet was proposed by Zhang et al. to real-time measure three dimensional surface of weld pool in gas tungsten arc welding (GTAW) process [5]. It was observed by laser-vision-based sensing method that oscillation frequency of weld pool in full penetration GTAW is lower than that in partial penetration welding [6,7]. Li et al. researched the dynamic keyhole profile of deep-penetration laser welding by joining 304 steel with GG17 glass [8]. The influence of dynamic keyhole behavior on weld defects was also focused by Liu et al. [9]. Numerical computation and experiment verification methods were also applied to discuss the flow [10] and oscillation [11] characteristics of weld pool. Zhang et al. developed a“sandwich” specimen to observe spatter formation mechanisms of laser welding thick plate [12], flying trajectory of spatter was tracked using high-speed image series [13], and further the relationship between spatter and weld pool was also discussed by Li et al. [14]. Integration method of pressure and displacement sensors was proposed to online monitor spatter behavior [15]. Characteristics of plasma plume was analyzed using emission spectrograph [16], generation of thermoelectric currents during laser welding process was revealed by taking into account sheath effects [17], and its relationship with keyhole geometry was studied by Tenner et al. [18]. In addition, transient behavior of humping phenom-

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Table 1
Chemical components of EH36 steel (wt.%).

C	Si	Mn	P	S	Ni	Cu	Ti
0.18	0.1 ~ 0.5	0.9 ~ 1.6	0.035	0.035	0.40	0.35	0.02

Table 2
Laser welding cases with different magnetic strength.

NO.	Magnetic field *B* (mT)
1	0
2	15
3	25
4	30

ena with different weld penetrations was carefully observed using high-speed imaging system [19], and dynamics of vapor plume in transient keyhole was also deeply researched by building incompressible molten liquid model [20,21].

Meanwhile, external magnetic field has been used to improve welding quality in laser welding, because Lorentz force introduced by external magnetic field can change metal flow and heat transfer of weld pool. Zhang et al. researched the influence of external longitudinal magnetic field on weld appearances of SUS301L steel [22]. Chen et al. studied the effect of axial magnetic field on welding quality (microstructure, hardness and shear strength) in laser welding stainless steel to aluminum alloy [23]. For external magnetic field assisted laser welding, Bachmann et al. developed a numerical model to reveal the influence mechanism of magnetic field on weld pool [24,25].

In a word, it is important to research dynamic behavior interaction between laser beam and materials, while external magnetic field can be considered as an efficient method to improve stability of welding process. Therefore, the topic in this paper is focused on the influence of steady magnetic field on dynamic behavior mechanism (weld pool, vapor plume and energy homogeneity) of full penetration laser welding EH36 steel.

2. Experiment design

Base metal is ship steel EH36 with size of 100 × 50 × 4 mm, and its chemical components are listed in Table 1 [26]. The laser welding system is shown in Fig. 1. Laser head and shielding gas torch are fixed on the end position of ABB robot. A sample and quartz glass are both placed on the top surface of the special clamp which can be used to adjust magnetic strength by changing distance between static magnet and the sample. On the boundary of the sample and quartz glass, duration heating operation is completed by fiber laser spot welding, while a high speed camera (Photofocus, Switzerland) with up to 10000 frames per second (fps) is placed at the quartz glass side to observe the dynamic behaviors. The average 1453.5 fps are captured in this experiment. In other words, the time interval Δt between every two pictures is 0.688 ms. Laser power is 3.5 KW, duration time is 200 ms, defocus length is 0 mm, flow rate of argon shielding gas is 1.5 m^3/h. Four laser welding cases with different magnetic strength (0 ~ 30 mT) are given in Table 2. It is important to note that the magnetic strength in Table 2 is measured on the sample upper surface.

3. Statistical analysis method

Furthermore, relationship between the actual welding sample and image obtained using high speed camera should be stated to be convenient to further analyze the material dynamic behavior mechanism in laser welding process. As shown in Fig. 2, the rectangular zones with three different colors present separately upper surface of the sample, welding sample and clamp plates from left to right in turn. Ignoring inclination angle between camera axis and glass surface, the sample thickness (4 mm) in Fig. 2 is 32 pixels that is measured by image software. In other words, a pixel corresponds to 0.125 mm. Actually, area of weld pool is larger than that of bright region in Fig. 2, but these double zones are supposed to be equal to be convenient to analyze the dynamic process of laser beam welding. A measurement line (L1) is marked along axis line of the weld pool to extract grey value and further analyze the dynamic behavior mechanism for fiber laser beam welding, while measuring start point for L1 locates at the upper surface of welding sample.

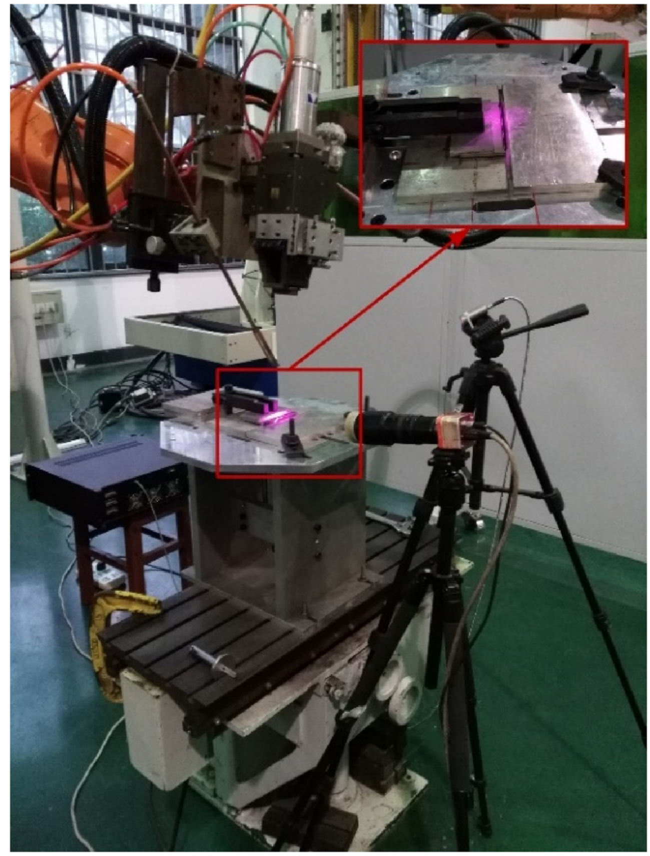

Fig. 1. Laser welding system.

4. Results and discussion

4.1. Transient melting mechanism

Fig. 3 shows images of laser welding from 0 ms to 6.192 ms, while the time interval between two images is 0.688 ms. As shown in Fig. 3(a), a weak beam is lighted on the top surface of EH36 steel at 0.688 ms, and the maximum penetration at 4.816 ms is about 3.2 mm. By increasing duration time, penetration gets deeper

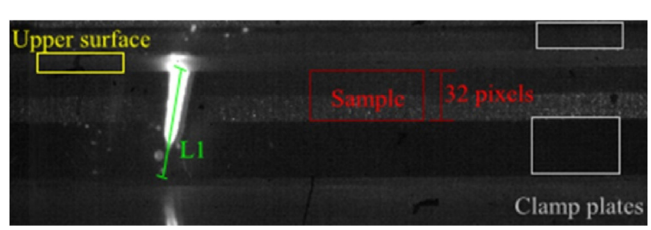

Fig. 2. Image zone of the welding sample.