

Finite element analysis and experimental study on laser welding temperature field of dissimilar metal materials

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Abstract. Aiming at saving defects and cracks of dissimilar metal materials laser welding, the finite element analysis of temperature field and new welding process of stainless steel/Al, stainless steel/Cu were developed in this work. Taking stainless steel/Al, stainless steel/Cu dissimilar materials laser welding for example, the physical model was established, and the finite element simulation of three-dimensional temperature field of laser welding was carried out based on Abaqus CAE. The results show that the simulation of temperature field provides reference for experimental process parameters, fiber laser welding is applicable to stainless steel/Cu, stainless steel/Al with lower laser welding defect. The process parameters were optimized to achieve better welding quality and solve welding defects. The accurate prediction of temperature field distribution in dissimilar materials laser welding is great significance for practical process guidance.

Keywords: Dissimilar materials; Laser welding; Temperature field; Finite element analysis; Welding process.

1. Introduction

Dissimilar materials are widely used in power batteries, new energy vehicles and aerospace manufacturing. A single metal can no longer meet the requirements of the use of metal engineering materials, Dissimilar materials welding is an effective way to solve the component simultaneously and meet the requirements of various performance, the combination of dissimilar materials advantages. Dissimilar materials welding such as stainless steel/Al have made great progress, but the laser welding process is very complex.

At present, many research institutions such as TWI, Aachen university in Germany, Braunschweig university, Osaka university, EWI in the United States and Technical university in Denmark have developed metal material welding technology [1-3]. In 2009, Anawa et al. [4] demonstrated that CO₂ laser can be used for stainless steel AISI316 and stainless steel AISI1008 welding, the welding of ferrite and austenitic steel could be successfully welded by laser, which obtained a small residual stress and heat affected area, and designed experiments to optimize welding parameters. In 2016, Jesper Sundqvist et al. [5, 6] from South Korean investigated welding models of dissimilar materials through finite element analysis. In 2017, Naoyuki Matsumoto et al. [7] used high-power optical fiber laser to conduct welding research on low carbon steel and 6056-T4 and 6016-T6 Al alloy, and established the influence rule of laser power, defocus, welding speed, pulse frequency and shielding gas on steel/Al welding defects. In 2016, Sun daqian et al. [8] systematically studied the characteristics of temperature field, nucleation formation process and microstructure of steel/Al dissimilar metal spot welding, interfacial atomic inter diffusion behavior of steel/Al, interfacial reaction mechanism, intermetallic compound layer growth mechanism, joint crack characteristics and formation mechanism.



In 2018, He xiuli et al.[9] reported the mutual mechanism of welding between stainless steel and nickel heterogeneous metal materials, established the dynamic characteristics of welding pools for these two metals, and established the laser heat transfer and weld pool morphology.

In this study, the finite element simulation of three-dimensional temperature field of dissimilar materials laser welding was carried out to predict the distribution of temperature field based on Abaqus CAE. The physical model was established, and new welding process of stainless steel/Al, stainless steel/Cu were developed in this work.

2. The mechanism of dissimilar materials laser welding

2.1. The mechanism of dissimilar materials laser welding

Mechanism of dissimilar materials laser welding is shown in Figure 1. Dissimilar metal materials laser welding is a complicated process, which contains laser melting and solidification. The theoretical model of heat flow for dissimilar metal materials laser welding is established as follows: the small element is established, and the heat on the element reaches an equilibrium.

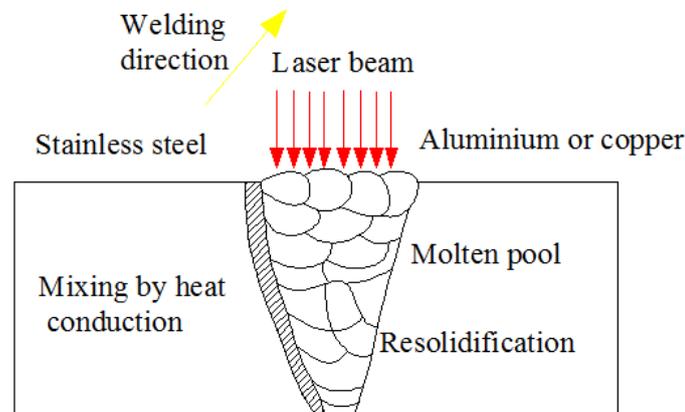


FIG.1.Mechanism of dissimilar materials laser welding

2.2. Lattice heat transfer model of ultrafast laser

According to the size of dissimilar materials laser welding beam size, material size and thermal characteristics, action time, the temperature field can be processed into a three-dimensional model. The temperature field can be divided into stable heat conduction and non-stable heat conduction according to its changing law along with time. The temperature field is described as follows[10]:

$$-\lambda(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z}) = -\lambda \nabla T = q \quad (1)$$

where, q is heat flow vector, ∇T is welding temperature field gradient, λ is coefficient of thermal conductivity, T is temperature of the molten pool. The welding heat conduction equation is described as follows.

$$\frac{\partial}{\partial x} (\lambda \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y} (\lambda \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z} (\lambda \frac{\partial T}{\partial z}) = \rho C \frac{\partial T}{\partial t} + Q(x, y, z, t) \quad (2)$$

where, $\alpha = \lambda / \rho C$ is thermal diffusivity, ρ is density, C is material heat capacity, Q is heat source. Stable heat conduction is simplified to poisson equation.

$$\nabla^2 T + Q / \lambda = 0 \quad (3)$$

Different laser processes can be produced according to the action spectrum of laser power time. There are three main factors affecting the temperature field of laser heat treatment: power density, action time, pulse width or beam interface/welding speed, etc.

$$S = \frac{0.16}{\rho HL} (H^2 t_v - H^2 t_m) \quad (4)$$

where, S is the fusion depth corresponding to the heat flux, L is Latent heat of fusion, H is material constant.

2.3. Simulation calculation

The melting point of dissimilar metal materials varies greatly. Moreover, stainless steel/Cu, stainless steel/Al have the characteristics of high reflectivity and high heat conduction coefficient, so it is difficult to form keyhole in the welding process, and high energy density is needed in laser welding. The model is composed of three plates of dissimilar metal materials, as shown in Figure 2. The mesh is divided after the model is built, as shown in Figure 3. The mesh is refined near the welding site and roughened away from the welding seam during the division to reflect the temperature gradient at the welding site accurately.

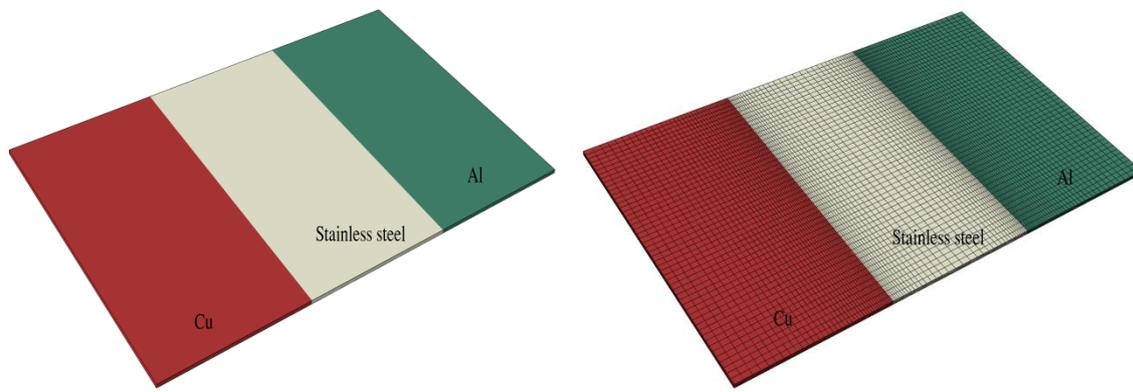


FIG.2.Geometric model of dissimilar materials FIG.3.Three-dimensional mesh model

The temperature field parameters of the flat plate are divided into three types, which are assigned to three plates respectively. Physical and chemical properties of materials, mainly including density, the thermal conductivity and specific heat capacity, are shown in Table 1.

Table 1.Physical and chemical properties of materials

	Density (g/cm ³)	Thermal conductivity (w/m · °C)	Specific heat capacity(J/kg · °C)	Melting point (°C)
Al	2.7	204	0.88	580~740
Stainless steel	7.85	17	0.46	1 399~1 455
Cu	8.96	383	0.39	1084

Figure 4 and Figure 5 are the simulated temperature field of stainless steel/Cu, stainless steel/Al, laser welding respectively. Figure 6 and Figure 7 are the simulated temperature change curve of stainless steel/Cu, stainless steel/Al laser welding respectively. From Figure 4 and Figure 6, it can be seen that the highest temperature of the molten pool reached 1375.3°C. From Figure 5 and Figure 7, it can be seen that the highest temperature of the molten pool reached 1489.6°C.

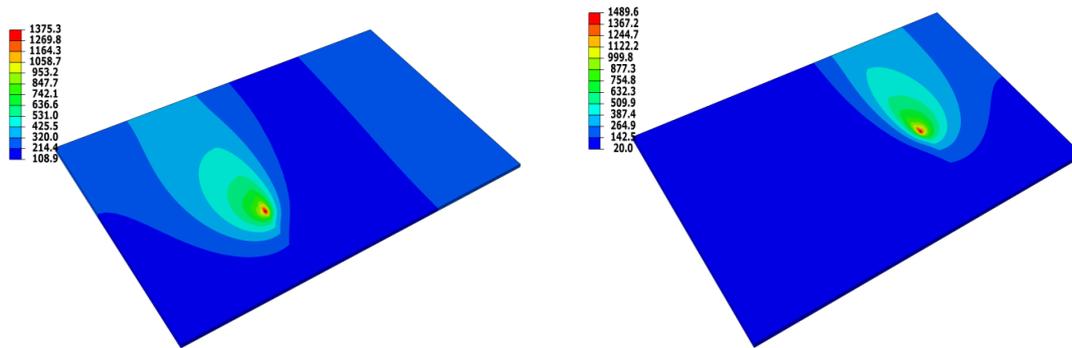


FIG.4.Simulated temperature field of Stainless steel/Cu FIG.5.Simulated temperature field of stainless steel/Al

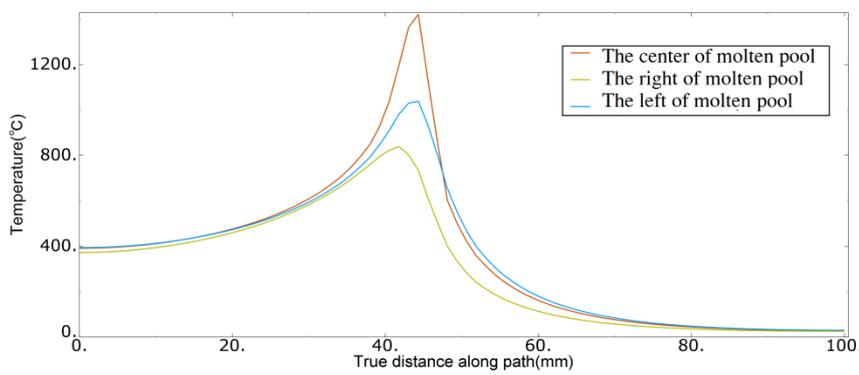


FIG. 6. Welding pool temperature curve of stainless steel/Cu

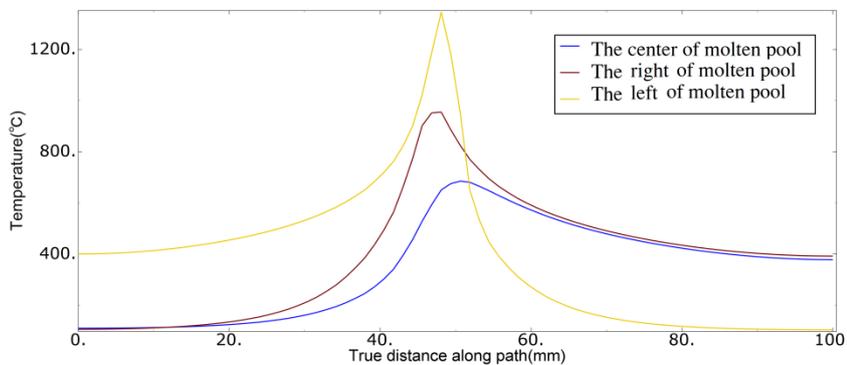


FIG. 7. Welding pool temperature curve of stainless steel/Al

The temperature field of the dissimilar metal materials laser welding pool, that is, the temperature distribution of the pool directly affects its convection, heat and mass transfer, and further affects its solidification process and composition uniformity. Therefore, it is very important for the optimization process parameters.

3. Experimental Analysis

3.1. Experimental Equipment

Fiber laser welding equipment is shown in Figure 8, which mainly consists of fiber laser, control system, vision system, working table, fixture and cooling system. 1000W IPG fiber laser is the core of the whole system. The laser wavelength of the fiber laser welding system is 1064nm, the average power is 1000W, repetition frequency is 10MHz, the spot diameter is 50 μ m after focusing through the 3d scanning galvanometer, and the maximum scanning speed of the galvanometer is 20mm/s.

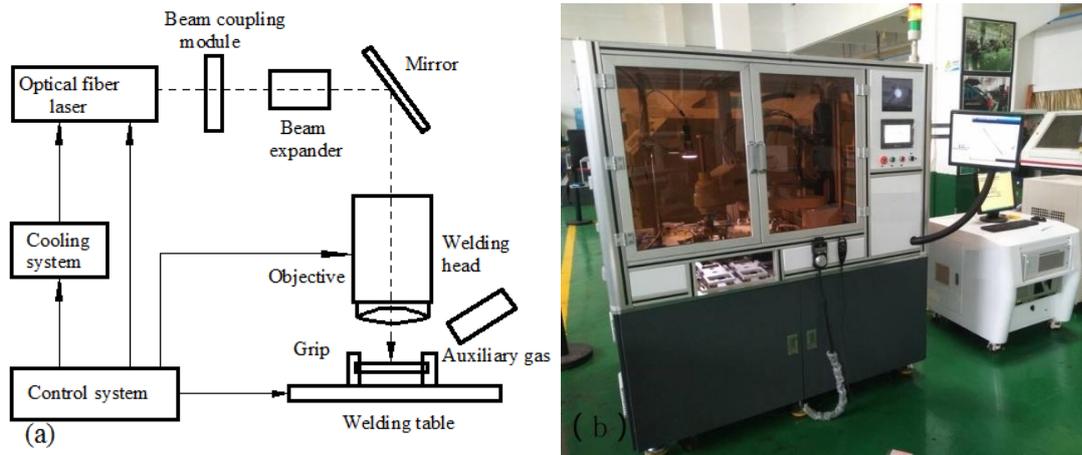


FIG.8.Fiber laser welding equipment (a)Schematic diagram of welding experiment (b)Photograph of fiber laser welding equipment

The parameters of the laser welding system are shown in Table 2.

Table 2.The parameters of laser welding system

Parameters	Value	Parameters	Value
Fiber laser power	1000W	Scanning speed	5-20mm/s
Wavelength	1064nm	Focus diameter	50μm
Repetition frequency	10MHz	Positioning accuracy	0.02mm

3.2. Experimental scheme

Test program includes test equipment, test materials, are shown in Figure 9. Through fiber laser welding experiments, the quality of welding is analyzed by tests.

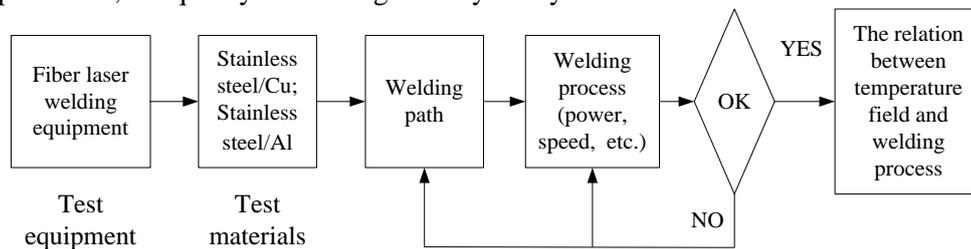


FIG.9.The welding experiment flow diagram

3.3. Experimental results and discussion

To study the influence of process parameters on welding defects, the effects of average power, scanning speed, repetition frequency on the thermal affected area and scanning path are optimized to reduce welding defects. Dissimilar materials welding samples are shown in Figure 10. Figure 10 (a) is stainless steel/Cu, while Figure 10(b) is stainless steel/Al under optimum technology parameter.

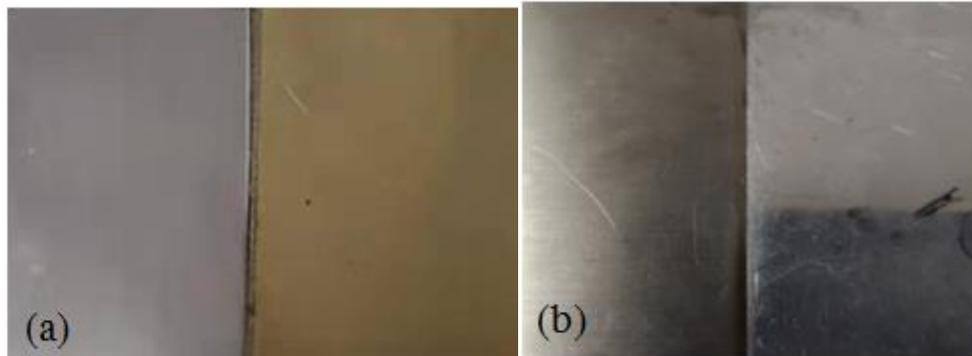


FIG.10.Dissimilar materials welding sample(a) stainless steel/Cu (b) stainless steel/Al

4. Conclusions

(1)The simulated temperature field of laser welding of dissimilar metal materials and its distribution curve along the welding temperature are consistent with the theory. The finite element simulation is used to predict the temperature field to explore the influence rule of welding temperature.

(2)According to the dissimilar metal materials of stainless steel/Cu and stainless steel/Al, the high-power laser welding test is adopted to optimize the laser welding process parameters and establish a new welding process for dissimilar materials. The results show that the optical fiber laser welding is suitable for stainless steel/Cu, stainless steel/Al dissimilar metal materials laser welding defects to achieve a better welding quality by optimizing the process parameters.

Acknowledgments

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