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Laser penetration welding of ship steel EH36: A new heat source and application to predict residual stress considering martensite phase transformation

Youmin Rong[a,b], Gaoyang Mi[c], Jiajun Xu[a,b], Yu Huang[a,b,*], Chunming Wang[c]

[a] State Key Lab of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, Wuhan, China
[b] School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, China
[c] School of Material Science and Engineering, Huazhong University of Science and Technology, Wuhan, China

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ABSTRACT

A weld profile with an accurate distribution of the temperature field is very difficult to simulate, especially for laser penetration welding. In this paper, a peak index increment-double cone heat source model was proposed for laser penetration welding of ship steel EH36. This heat source model was proposed considering the actual weld profile with a geometry of a "V" combined with an inverted "V"; the adjustment parameter was rapidly selected by a simplified linear interpolation method, and the validity of this model was proven by experimental results with an average error of 11.12%. Microstructures of the weld zone, which included ferrite and martensite, were then analysed. Considering the influence of the martensite phase transformation on the strain increment, the distribution of residual stress was simulated by loading the proposed heat source model; the peak values and the high gradient behaviour of the residual stress were intensified. The proposed heat source model was proven to be valid and was applied to predict the residual stress; it can be further used in other welding processes with different metal materials.

1. Introduction

Laser welding is an important manufacturing process because of its advantages of low heat input, large depth-to-width ratio, small deformation, narrow heat-affected zone, and high efficiency. However, it is difficult to distinctly describe the thermal transfer process during laser welding with high heating and cooling rates. Many researchers have performed much valuable work in the heat source model development and further application to compute welding deformation, residual stress, and weld pool.

For transient thermal transfer in laser welding process, it is difficult to accurately detect the temperature distribution, especially for the high temperature zone; further, many heat source models have been proposed and applied to research this topic. A double ellipsoidal model was proposed by Goldak et al. in the 1980s that can be flexibly used to laser welding process [1]. The analytic solution of temperature field was developed for laser penetration welding (LPW) of AISI 304 steel [2]. Wu et al. proposed a rotary Gauss body heat source model to simulate the weld pool of high energy beam welding with a characteristic of high aspect ratio [3]. A variable length heat source model was established to study the residual stress and angular distortion of the J-groove joint [4], and then it was modified by integrating the actual weld geometry [5]. The superposition model of a travelling heat source and the body loads was built by Han et al. to investigate temperature field of laser welding stainless steel [6]. A ray-tracing model was introduced to evaluate heat influx of laser absorption in the keyhole wall [7] and was further applied to analyse the temperature profile of

* Corresponding author. State Key Lab of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, Wuhan, China.
E-mail addresses: ymrong1987@gmail.com (Y. Rong), yuhuang7208@163.com (Y. Huang).

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Table 1
Component of EH36 steel (wt. %).

C	Mn	Si	P	S	Al	Nb	V	Ti	Cu	Cr	Ni	Mo	Fe
0.06	1.38	0.25	0.01	0.004	0.024	0.04	0.05	0.02	0.02	0.02	0.02	0.01	Bal.

thermoplastic composites in laser welding [8]. The electromagnetic energy density of a Nd:YAG laser beam was studied by Courtois et al. to obtain the heat source flux [9]. Kim et al. built a new heat source model considering the defocus length to simulate laser welding deformation of a sandwich panel [10]. Moreover, Chukkan et al. analysed the thermal cycles of laser butt welding using different heat source models (3D conical, 3D conical with double ellipsoidal, and 3D conical with cylindrical shell) [11].

Based on the temperature distribution obtained by the upon heat source models, mechanical behaviours, such as deformation, residual stress, fracture, weld pool flow, are investigated by many researchers. Deformation of thin sheets in laser welding was predicted by coupling thermo-elastic-plastic analysis using the inherent strain method [12]. The residual stress distribution of laser welding aluminium alloy was computed considering the heat flux in the keyhole volume [13], and solid phase transformation was also introduced to improve prediction accuracy [14]. The fatigue performance of laser hybrid welded aluminium alloy 7000 for next generation railway components was analysed by the finite element method and experiment verification [15]. Chang et al. researched the fluid flow characteristics and porosity behaviour in LPW of titanium alloy Ti6Al4V [16], and a 3D transient multiphase model considering the ambient pressure effect was also developed by Pang et al. to deeply explain the interaction among the weld pool, the keyhole and the vapour plume [17].

Despite the interesting work that has been done for heat transfer and even applications in laser welding, the weld profile with an accurate distribution of the temperature field is very difficult to simulate, especially for LPW. Therefore, a new heat source for LPW and further application to predict the residual stress were both studied in this paper.

2. Experimental details

2.1. Experimental design

The base material was ship steel EH36, which is widely used in shipbuilding; its components are listed in Table 1 [18]. As shown in Fig. 1, the sample with the size of 100 mm × 50 mm × 4 mm was fixed on the platform and welded into the butt joint by LPW process. Fibre laser beam was obtained from IPG YLR-4000. The welding path was planned by the teaching programming method and completed by an ABB robot. Before welding, the rust and oil of the sample surface were cleaned by milling process and acetone. The laser power was 4.0 kW, the defocus length was −5 mm, the welding speed was 0.9 m/min, and the shielding gas was argon with flux of 1.5 m^3/h.

2.2. Measurement results of the weld geometry

A typical weld profile of LPW can be obtained by using the measurement software CSM1. Fig. 2 shows details of the defined 8 parameters to describe the weld shape of LPW. Furthermore, the measurement results are presented in Table 2. It was noted that D7 and D8 were both measured and that the whole curve was discretized as many linear segments.

3. Peak index increment-double cone heat source model

For the weld geometry of LPW, the upper width and the bottom width were both wider than the width of the middle zone. The geometry can be further simplified as a “V” combined with an inverted “V”. Moreover, the thermal flow for each tangent plane was

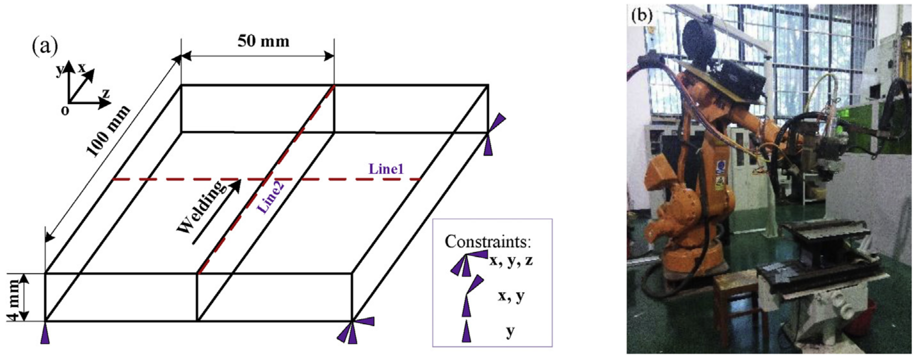

Fig. 1. Laser welding EH36 steel: (a) butt joint and (b) experimental system.