Journal of Materials Processing Tech. 261 (2018) 202–212

Contents lists available at ScienceDirect

Journal of Materials Processing Tech.

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

Numerical study of the effect of the oscillation frequency in buttonhole welding

Won-Ik Cho*, Villads Schultz, Peer Woizeschke

BIAS - Bremer Institut für angewandte Strahltechnik GmbH, Klagenfurter Straße 5, 28359, Bremen, Germany

ARTICLE INFO

Keywords:
Numerical simulation
Laser welding
Wire feeding
Beam oscillation
Buttonhole welding
Chopping frequency

ABSTRACT

A three-dimensional transient simulation was conducted with comprehensive models of the laser welding process with a combination of wire feeding and one-dimensional sinusoidal beam oscillation. Both a realistic filler wire feeding and simultaneous melting by oscillating laser beam were considered. The buttonhole formation, which was shown in the simulations, was affected by the shape of the molten filler wire, e.g. the length and angle. The buttonholes formed at higher oscillation frequencies and became clearer with increasing oscillation frequency. The so-called chopping frequency of the wire, found in the frequency domain through Fourier analysis, became more dominant with increasing oscillation frequency. The wire chopping process seems to affect the number of multiple reflections, the power absorption, and the buttonhole behavior.

1. Introduction

In laser welding of butt joints, the use of additional filler wire offers the advantages of good gap bridging ability and the possibility to control the metallurgical properties. Aalderink et al. (2010) proposed dual beams to additionally increase the gap bridging ability in laser welding with filler wire, while Laskin and Volpp (2016) showed state-of-art beam shaping optics to generate multiple spots that were perpendicular along the optical axis and found that this had a positive effect on laser welding. Salminen (2010) found that the misalignment of the wire could still cause failures within the weld seams. Albert and Starcevic (2016) reported a reduced occurrence of weld seam defects in the case of welds using an oscillating beam without filler material. Coste et al. (1997) suggested a laser welding process with wire feeding in combination with beam oscillation and found that beam oscillation could compensate for misalignments of the wire positioning.

Volpp and Vollertsen (2016) studied keyhole stability in typical laser keyhole welding with a high aspect ratio of the weld pool cross-section and considered surface tension and recoil pressure, mainly in models because the surface tension acts to close the keyhole while the recoil pressure tries to keep it open. A self-sustained hole, which is larger than a typical keyhole, emerges during the welding process of thin sheets. During laser welding of thin metal plates without beam oscillation, Haglund et al. (2013) observed the formation of a big hole and named the process laser donut welding. Eriksson et al. (2014) found that in the pulse welding of thin stainless-steel sheets the existence of such a hole with catenoid shape in the melt pool improved weld seam quality, but in the case of continuous wave welding they recommended avoiding the formation of holes because these could remain as defects in the solidified seam. Aalderink et al. (2007) also observed comparable defects in the laser welding of thin aluminum alloy sheets.

Schultz et al. (2014) observed and investigated a similar phenomenon in the field of laser welding of 1 mm thin aluminum sheets with wire feeding and beam oscillation. Schultz et al. (2015) found that the gap bridging ability was enhanced significantly by this process configuration (maximum gap size > 300% of the thickness of the sheet). Vollertsen (2016) showed that for a specific oscillation frequency, the reproducible formation of the melt pool hole was discovered during experiments with a 1 mm air gap. It seems that the surface of the solidified seam was smoother when the hole formation had taken place during the welding process. The laser welding process with wire feeding, beam oscillation, and hole formation behind the laser spot was named buttonhole welding as a novel process approach for deep penetration welding with high quality seam surfaces. The mechanism of buttonhole formation, the reason for the increased surface quality, and the requirements for the stable existence of the hole have not yet been fully understood.

A numerical approach can be favorable for a detailed understanding of molten pool behavior, such as buttonhole formation. Cho et al. (2012) developed mathematical models for the deep penetration disk laser welding of steel. Cho et al. (2010) modeled wire feeding as molten drops that are periodically generated in the computational domain in CO_2 laser-GMA hybrid welding of steel. Gatzen et al. (2011)

* Corresponding author.
E-mail address: cho@bias.de (W.-I. Cho).

https://doi.org/10.1016/j.jmatprotec.2018.05.024
Received 21 December 2017; Received in revised form 3 May 2018; Accepted 27 May 2018
Available online 15 June 2018
0924-0136/

implemented filler wire feeding with a fixed keyhole shape and boundary conditions in the disk laser welding of aluminum. As the solid and molten parts of the wire are connected to each other, the wire is continuously fed but locally periodically melted due to the laser beam oscillation with a spot size that is smaller than the wire; therefore, comprehensive, realistic models of wire feeding and melting behavior in combination with beam oscillation have been suggested to understand buttonhole welding using computational fluid dynamics (CFD) simulations. Cho et al. (2017) found that the formation of the buttonhole is affected by the molten shape of the wire. In this work, the effect of the oscillation frequency on the molten pool behavior, the number of multiple reflections, and the amount of absorbed power are investigated.

2. Methodology

2.1. Parameters and computational domain

An IPG multi kW fiber laser was used to weld aluminum alloy sheets (AlSi1MgMn) of 1 mm thickness with an air gap of 1 mm in a butt joint configuration. Aluminum alloy filler wire (AlSi5) of 1.2 mm diameter was used to fill up the gap. The laser beam was focused on the surface of the metal sheets and was oscillated in a sine wave transversal to the welding direction by an ILV DC-Scanner. A schematic description of the process is shown in Fig. 1. The welding parameters are given in Tables 1 and 2. Four cases, with oscillation frequencies of 100 Hz, 150 Hz, 200 Hz and 250 Hz, were tested. The frequency of 250 Hz was the maximum oscillation frequency, with an oscillation width of 1.4 mm in this scan system.

Numerical calculations were used for the purpose of analyzing detailed molten pool flows in buttonhole welding. Fig. 2 shows a schematic description of the computational domain (length of 13 mm, width of 10 mm, and height of 7 mm). Filler wire (room temperature) feeding and laser beam oscillation are used and the workpiece moves from left to right with the welding speed. The minimum cell size around the molten pool region is 0.2 mm. The total number of cells is 0.1 million. The thermo-physical material properties of the aluminum used in the numerical simulations are shown in Table 3.

2.2. Governing equations

The governing equations of mass, momentum and energy conservation equations, which are written in Eqs. (1)–(3), were solved to determine the temperature, velocity and pressure distributions in the computational domain. A single-phase, incompressible laminar flow

Table 1
Welding parameters.

Parameter	Value
Laser power	3.0 kW
Focus diameter	100 μm*
Welding speed	6.0 m/min
Wire feeding speed	9.0 m/min
Oscillation frequency	100 Hz, 150 Hz, 200 Hz and 250 Hz
Oscillation width	1.4 mm

* This focus diameter is calculated using the laser and optics parameters listed in Table 2.

Table 2
Parameters of laser and optics.

Parameter	Value
Wavelength	1.07 μm
Polarization	Circular
Beam quality	4.2 mm mrad
Focal length of the focusing lens	200 mm
Focal number*	6
Rayleigh length	0.6 mm

* Focal number = focal length/beam diameter on optics.

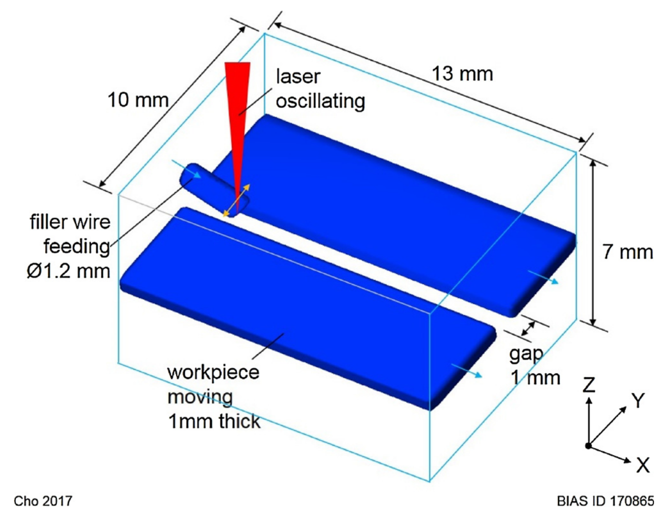

Fig. 2. Computational domain of the laser welding process with wire feeding and beam oscillation.

with Newtonian viscosity was assumed for simplicity.

Mass conservation equation:

$$\nabla\cdot\vec{v} = \frac{m_s}{\rho} \tag{1}$$

where, $\vec{v}$ is the velocity vector, ρ is the density and m_s is a mass source term, e.g. filler wire feeding.

Momentum conservation equation:

$$\frac{\partial\vec{v}}{\partial t} + \vec{v}\cdot\nabla\vec{v} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{v} - K\vec{v} + \frac{\dot{m}_s}{\rho}(\vec{v_s} - \vec{v}) + G \tag{2}$$

where, P is the pressure, ν is the dynamic viscosity, K is the drag coefficient for a porous media model in the mushy zone, $\vec{v_s}$ is the velocity vector for the mass source, G is the body acceleration due to body force.

Energy conservation equation:

$$\frac{\partial h}{\partial t} + \vec{v}\cdot\nabla h = \frac{1}{\rho}\nabla\cdot(k\nabla T) + \dot{h}_s \tag{3}$$

where, h is the enthalpy, k is the thermal conductivity, T is the

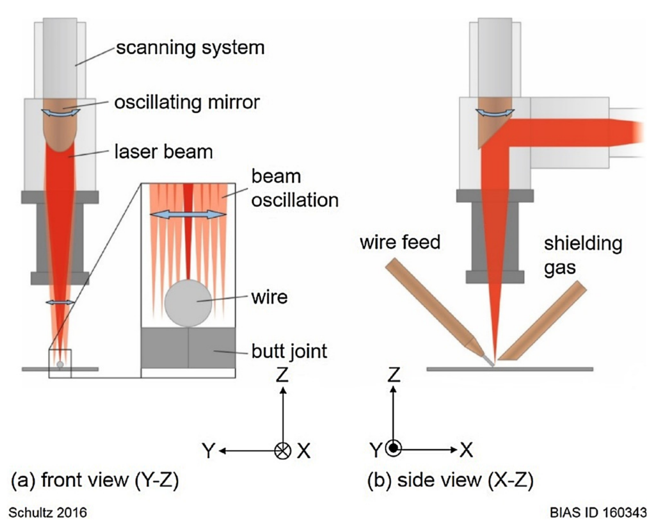

Fig. 1. Schematic illustration of the experimental setup.