International Journal of Heat and Mass Transfer 123 (2018) 826–838

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Macro-micro modeling and simulation on columnar grains growth in the laser welding pool of aluminum alloy

Lei Wang [a,b], Yanhong Wei [a,*], Jicheng Chen [a,c], Wenyong Zhao [a]

[a] College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 211106, China
[b] School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907, USA
[c] Department of Materials Science and Engineering, The Ohio State University, Columbus, OH 43210, USA

ARTICLE INFO

Article history:
Received 7 November 2017
Received in revised form 27 February 2018
Accepted 11 March 2018

Keywords:
Laser welding
Phase field model
Columnar grains
Growth orientation
Competitive growth
Aluminum alloy

ABSTRACT

The heat transfer and columnar grains growth in the laser welding pool of 2A14 aluminum alloy under different welding parameters are investigated through macro-micro modeling and simulation. A macroscopic heat transfer model is proposed to calculate the temperature field in the laser welding pool under different welding parameters. Computed fusion profiles agree well with experimental measurements. The equations of transient pulling velocity, temperature gradient and columnar grains growth orientation during solidification of the laser welding pool are developed. A phase field model coupled with transient pulling velocity, temperature gradient, columnar grains growth orientation and the flow field is developed to simulate columnar grains growth in the laser welding pool under different welding parameters. Laser welding experiments are also carried out to observe columnar grains growth in the laser welding pool under different welding parameters. Simulated columnar grains morphology, spacing and growth orientation give a good agreement with experimental measurements. Competitive growth of columnar grains with different growth orientations is also predicted by the phase field model. Predicted competitive growth process is in accordance with experimental findings.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

Aluminum alloy has been the primary material for lightweight constructions especially in the aeronautical and automotive industry [1,2]. With the development of the laser beam welding technique, which has been used to fabricate aluminum alloy [3–6], with the advantages of fast welding speed, stable process, high energy density, high productive efficiency and small welding deformation. Solidification behaviors and resulting microstructures in the laser welding pool are crucial factors to affect the mechanical properties of the weld [7–10]. Understanding the solidification process and microstructural characteristics in the laser welding pool can provide useful guidance for optimizing and improving laser welding technology. A better understanding the solidification process during the laser welding requires better macro-micro modeling and simulation.

Currently, solidification microstructures in the laser welding pool of aluminum alloy have been investigated by laser welding experiments [11–14]. However, the complicated solidification process in the laser welding pool cannot be reproduced by laser welding experiments. With the development of computational materials science, the complicated solidification process and resulting microstructures in the welding pool can be investigated by using the numerical method. Some scholars used the numerical method to study solidification microstructures in the laser welding pool. Tan et al. proposed a CA-PF (Cellular Automata-Phase Field) model to predict dendritic growth in the laser welding pool of AA2024 aluminum alloy without considering the effects of the flow field [15]. In the study conducted by Wang et al., a Phase Field model coupled with the flow field was developed to predict columnar grains growth in the laser welding pool of aluminum alloy neglect the effects of columnar grains growth orientation [16]. Wei et al. used Monte Carlo approach to simulate three-dimensional grain structure neglecting solute redistribution, microsegregation and undercooling during solidification of the laser welding pool [17]. In the above study, the influence of the columnar grains growth orientation, welding parameters and competitive growth of columnar grains with different growth orientations on the resulting microstructures in the laser welding pool is not investigated in detail.

In this paper, a macroscopic heat transfer model is proposed to calculate the temperature field in the laser welding pool under different welding parameters. Based on macroscopic computed

* Corresponding author.
E-mail address: nuaadw@126.com (Y. Wei).

https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.037
0017-9310/© 2018 Elsevier Ltd. All rights reserved.

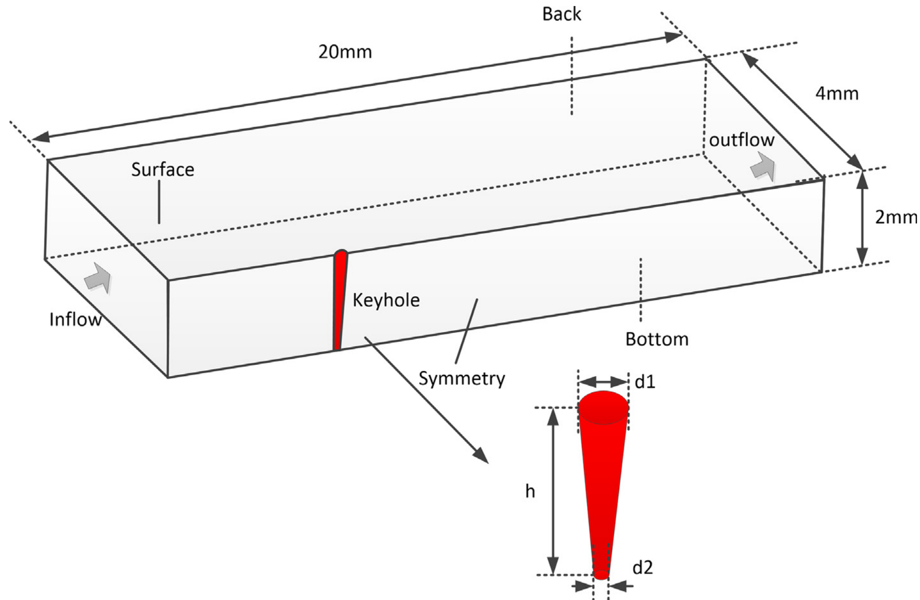

Fig. 1. Computational domain used to calculate temperature field in the laser welding pool.

Table 1
The shape parameters of the irregular cone.

Case	Laser power P (W)	Welding speed V (m/min)	d_1 (mm)	d_2 (mm)	h (mm)
1	2500	2.0	0.4	0.08	2.0
2	2500	2.5	0.36	0.08	1.7
3	2500	3.0	0.32	0.08	1.5

Table 2
Boundary conditions of the computational domain.

Boundary	Momentum	Energy
Inflow	V(m/s)	300 K
Outflow	P = 0	Adiabatic
Keyhole	Free slip	T_p
Surface	Marangoni	Convection, Radiation
Bottom	Marangoni	Convection, Radiation
Back	No slip	Convection, Radiation

results, the equations of transient pulling velocity, temperature gradient and columnar grains growth orientation during solidification of the laser welding pool are developed. A phase field model coupled with transient pulling velocity, temperature gradient, columnar grains growth orientation and the flow field is developed to predict columnar grains growth at the fusion boundary in the laser welding pool of 2A14 aluminum alloy under different welding parameters. Influence of the columnar grains growth orientation, different welding parameters and competitive growth of columnar grains with different growth orientations on resulting solidification microstructures is investigated. The comparisons of the macroscopic and microscopic simulation results with the experimental measurements are carried out to show the accuracy of computed results.

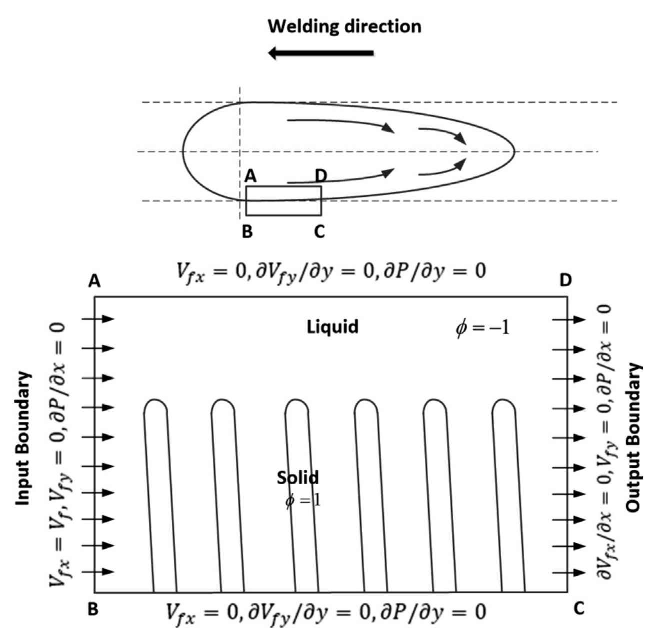

Fig. 2. Computational domain and boundary conditions used to simulate columnar grains growth in the laser welding pool.

2. Models and experiments

2.1. Macroscopic heat transfer model

In order to simulate solidification microstructures in the laser welding pool, the complicated heat transfer process must be analyzed. The complicated heat transfer process during the laser welding has been successfully calculated by numerical methods [18–21]. It is virtually inefficient to apply an absolutely accurate model to calculate the temperature field and the formation of keyhole during the laser welding. Before computing the complicated thermal dynamic process during the laser welding, some basic assumptions must be illustrated:

Download English Version:

https://daneshyari.com/en/article/7054312

Download Persian Version:

https://daneshyari.com/article/7054312

Daneshyari.com