Numerical study of the thermo-fluid flow and weld appearance of 2195 Al-Li alloys in wire feed laser welding

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Abstract. The wire feed laser welding has significant merits in metal joining technology for the manufacturing industry, which including high energy efficiency, high welding speed, automated workflow and narrow heat-affected zone. During to the interaction between weld pool and welding wire, the welding process is more complicated. In this work, a numerical model to the wire feed laser welding for the liquid bridge transition was built. By constructing a movable welding wire entity accurately, the simulation result for flow and heat transfer inside weld pool and welding wire were acquired by the numerical solution. The temperature field, velocity field and weld appearance can be obtained by simulation results. The results shown that the rapid wire feed speed will increase the heat absorption of welding wire, which can improve the hardness due to higher cooling rate. Through the analysis of experimental and simulation results, the quantitative relationship between weld parameters and weld result can be obtained. The numerical simulation can guide the optimization of welding parameters and control the weld appearance.

1. Introduction

Wire feed laser welding need to not only melt the workpiece but also need to allocate energy to melt the welding wire by using high energy laser beam. In this process, it involves multiple physics changes, so it is a very complex physical process. For this reason, the welding process window is narrow. It is challenging to find and optimize a suitable welding technology, because it needs to optimize the welding parameters by a lot of experiments. The thermo-fluid flow field, weld morphology, cooling rate and other parameters in the welding process can be obtained by numerical simulation, which can provide quantitative guidance for the setting of welding process parameters. The numerical model of laser welding can not only simulate the macro heat transfer and fluid flow, but also can solve the transport equation of the wire filling process, which can obtain the element distribution in the weld [1,2]. The process of weld recrystallization also can be simulated by using cellular automata (CA) or phase field methods (PF), and the grain structure was obtained finally[3–5]. Although the numerical simulation of wire feed laser welding can be carried out at various scales, this numerical simulation always depends on the data of heat transfer and flow in the weld pool during the welding process. Therefore, the numerical simulation of fluid flow and heat transfer in welding process is a great significance for the optimization of welding parameters and microstructure simulation.

In this paper, the process of wire feed laser welding was simulated and corresponding experiments also be carried out. The velocity and temperature field, weld appearance and fusion line were obtained...
in this simulation. The accuracy of the numerical simulation can be verified accordingly by comparing calculated and experimental fusion line shapes.

2. Numerical model

Wire feed laser welding is a complicated multiple physics process, so the contributing factors in this process is taken as source term or boundary condition in numerical model, which includes melt, evaporation and solidification process in welding region. This numerical model was simulated by CFD solver, all the contributing factors were showed in Table1.

| Table1. Numerical model contributing factors |
|---------------------------------------------|
| **Flow model**                              |
| Gravity                                     |
| Surface tension + Marangoni shear stress[6]  |
| Recoil pressure[7]                          |
| Solidification damp force[8]                |
| Buoyancy                                    |
| **Heat transfer**                           |
| Evaporation loss[9]                         |
| Surface radiation                           |
| Latent heat of melting                      |
| Convective heat loss                        |
| Solidification releases energy              |

The welding wire is reconstructed by multiphase method, so that the mass and energy transfer between wire and workpiece can be considered into the model. In this simulation, the heat transfer and multiphase flow in the whole region. Mass transfer in the flow process is calculated by discretized continuity equations, fluid flow is calculated by discretized momentum equations in multiphase region, and the change of energy is calculated by discretized energy equation in the whole region.

3. Materials and experiment method

The workpiece is 2195 Al-Li alloys plate, which thickness is 2 mm. Laser source was produce by an Nd:YAG laser machine. The welding wire is fed in front of the laser focus on the workpiece, and their distance is 1 mm. The filler wire had 45° with the workpiece. Shielding gas of pure Argon is set behind the laser focus. The detailed technological parameters are illustrated in Table2. The experiment material is 2195-T8 Al-li alloys, its chemical composition is shown in Table3. The laser beam moved along the butt between two plates.

| Table2. Experimental parameters |
|----------------------------------|
| **Parameter**                   | **Value** |
| Power (W)                        | 1300      |
| Welding speed (mm/s)             | 3         |
| Feeding wire speed (mm/s)        | 2         |
| Shield gas flux (L/min)          | 20        |
| Defocus distance (mm)            | 160       |
### Table 3. Chemical composition of workpiece and filler wire (%)

| Workpiece       | Cu  | Li  | Ag  | Zr  | Fe  | Mg  | Ti  | Al  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 2195 Al-Li alloy| 3.7 | 0.8 | 0.2 | 0.1 | 0.1 | 0.2 | 0.068 | Balance |

#### 4. Result analysis

Fig. 1 shows the simulation results in different. In this simulation result, the welding wire overlaid on the workpiece surface and form the weld appearance. The keyhole was emerged by recoil pressure, which due to metal evaporation. The keyhole wall emerges rapid fluctuations since the welding wire absorbs energy continuously. Fig. 1 gives the curve of keyhole depth change in the simulation process. The maximal depth is about 1.3 mm and dynamic range is from 0.8 mm to 1.3 mm (except the overlap height). Keyhole has narrowed before depth becomes shallow. Fig. 2 (a)-(d) illustrates this phenomenon, fluctuation emerges and the below part of keyhole wall becomes narrow. Afterwards, it will be expanded by recoil pressure again in this region due to laser leam irradiate.

Fig. 2. Keyhole depth evolution process with time.

The velocity and temperature field in simulation were shown in Fig. 3. the velocity magnitude is around 2 mm/s-20 mm/s in weld pool. In order to clearly illustrate the flow field and the region location, the dotted line which can reflect the flow trend and the region which is circled by the yellow line are only marked in Fig. 3. (d). Recoil pressure is the main driven force to push keyhole to expand and overcomes the contracted effect which produced by surface tension and gravity. With the combination of Fig. 3. (a)-(d), the melt flow from bottom of the keyhole wall (region B) to top of the keyhole wall, then melt horizontally flows ahead and mixes with molten welding wire[10]. The molten wire hardly exits any flow trend in the opposite direction of laser movement, it flows downward and forms a vortex flow mixed with molten flow which comes from weld pool.
Fig. 3. Temperature field and flow patterns in different time:

Fig. 4. (a) is the experiment result and Fig. 4. (b) is the temperature field in weld cross-section for simulation result. The vector arrow in Fig. 4. (b) represents the temperature gradient vector. The simulation results are consistent with the growth of columnar crystals along the opposite direction of the temperature gradient and the growth from the boundary of the heat-affected zone. Comparing the heat-affected zone obtained by the experiment in Fig. 4. (a), it can be seen that the temperature field results of the weld pool obtained by simulation in Fig. 4. (b) are more consistent with the experimental results.

Fig. 4. Comparison between calculated and experimental fusion line shape
5. Conclusion
In this work, a numerical simulation was carried out for wire feed laser welding of 2195 Al-li alloys. By using numerical simulation, the temperature field, velocity field, flow trend in weld pool and temperature gradient and fusion line were obtained quantitatively. This simulation result can correspond experiment result, which proves that the validity of this numerical model. Through compare experimental with simulation results, the quantitative relationship between weld parameters and weld result can be obtained. The numerical simulation can guide the optimization of welding parameters and control the weld appearance.

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