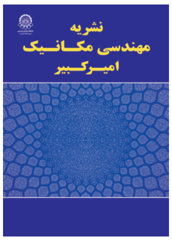

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Numerical Study of Melt Flow and Depth of HAZ in Laser Welding of Titanium Alloy Plate Ti6Al4V

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ABSTRACT: In this paper, temperature distribution, melt flow and depth of heat affected zone in laser welding of Ti6A14V Titanium alloy plate of 1.7 mm thickness have been studied. Due to high costs of practical laser welding experiments, finite volume method was employed to predict the welding behavior on the specimen. Fluid finite volume method and OpenFOAM software were employed in simulation. In order to verify the simulation results, experimental data obtained from weld geometry and temperature distribution were used. Buoyancy and Marangoni forces and Boussinesq assumptions, were considered intently in simulation process. Moreover, thermodynamic properties were assumed independent of temperature and Gaussian heat source was employed for mechanical properties. Numerical results have good agreement with experimental data. The developed model can predict temperature distribution, melt flow in different parts of plate and melt penetration depth properly. This model can also be used for design and evaluation of welded parts.

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1- Introduction

High value of strength to weight ratio, good corrosion resistance and weld ability of titanium and its alloys have led to diverse application in various fields of industries including the medical, nuclear and aerospace. Among titanium alloys, Ti6Al4V with $\alpha+\beta$ phase is widely used. Casalino et al. [1] investigated butt welding of Ti6Al4V alloy sheet using continuous CO_2 laser. Jin and Li [2] studied keyhole shapes in laser deep penetration welding. For this purpose, the laser spot diameter and its intensity distribution were measured using scanning pinhole, and the keyhole shapes were observed with the use of a specially designed setup in laser deep penetration welding of glass GG17. Morphological and mechanical characteristics of butt and lap welding of Ti6Al4V alloy was studied by Caiazzo et al. [3]. A CO_2 laser with two shielding gases and two different gas nozzle were used. Properties and technical parameters of welding sheets of commercial purity titanium via electron beam welding, CO_2 laser beam welding and gas tungsten arc welding using optical microscope were investigated by Yunlian et al. [4]. For butt welding of thick Ti6Al4V alloy sheets, Akman et al. [5] used a Nd:YAG laser with 0.3-50 ms pulse time and 500 Hz maximum repetition rate. Pulse energy and pulse duration were considered as variables and other parameters (repetition rate, welding speed, focal point position and gas pressure) assumed constant. Anawa et al. [6] used a CO_2 continuous laser welding for joining a dissimilar AISI 316 stainless-steel and AISI 1009 low carbon steel plates. Taguchi approach was used as statistical design of experiment technique for optimization of welding parameters with the objective of producing welded joint with complete penetration, minimum fusion zone size and acceptable welding profile.

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In this paper, temperature distribution, melt flow and depth of Heat Affected Zone (HAZ) in laser welding of Ti6A14V Titanium alloy have been studied.

2- Experimental Work

Titanium alloy Ti6Al4V was used as work piece material. The size of each sample was 85 mm long × 35 mm width with thickness of 1.7 mm.

The experiments were conducted in random order using an Optimo model CO_2 laser, provided by OPTIMA Industries. Argon gas with constant pressure of 0.1 bar was used as shielding gas. For metallography, each transverse section of specimen was mounted. Etch solvent with the chemical composition of 2 ml HF+ 10 ml HNO_3+ 88 ml deionized H_2O was employed.

3- Governing equations

The fluid flow and heat transfer in the weld pool are modelled by solving the equations of conservation of mass, momentum, energy and volume fraction equation in three dimensions. The liquid fraction f_L is assumed to vary linearly with temperature for simplicity. The Gaussian distributed heat source was used to describe the heat flux to the material. Q is expressed as:

$$Q = \frac{fP}{\pi abd}\exp(-\frac{fx^2}{a^2})\exp(-\frac{fy^2}{b^2})\exp(-\frac{fz^2}{d^2}) \quad (1)$$

Where Q is the Gaussian distribution of heat transfer, P is the laser power. The parameters a, b, d are taken to be the dimension of heat source.

4- Results and Discussion

Figure 1 shows the computed three-dimensional temperature contours for Ti6Al4V.

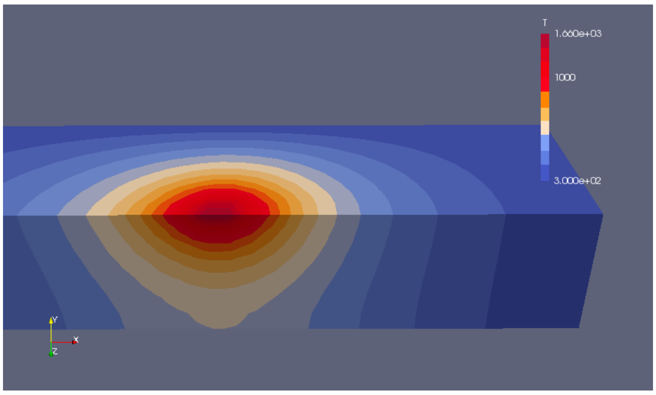

Figure 1. Three-dimensional temperature distribution in depth direction of part after 1 s

Figure 2 shows the variation of temperature versus time in the center of part. As seen, the maximum temperature during welding process is 4200 K after approximately 0.2 s. Temperature decreases with the lapse of time.

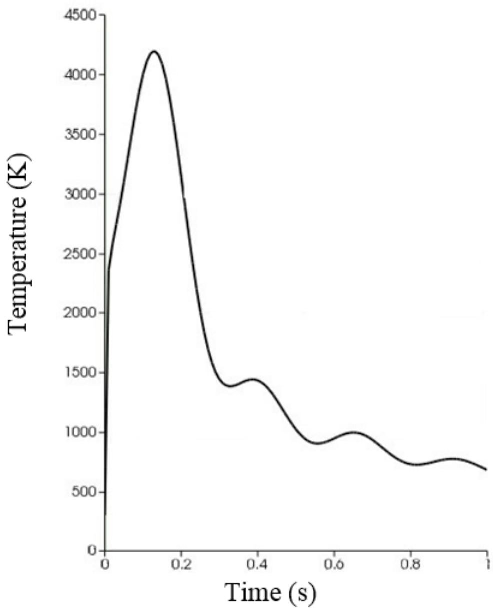

Figure 2. Variation of temperature versus time in the center of part

The molten percent of part is shown in Figure 3. The weld center is melted completely and molten percent decreases with increasing distance from weld center.

Figure 4 shows the comparison of experimental and calculated weld cross-sections. Table 1 summarizes the results of experimental values, numerical simulation and the percentages of error.

5- Conclusions

In this paper, temperature distribution, melt flow and depth of HAZ in laser welding of Ti6A14V Titanium alloy have been studied. The following conclusions are drawn from the results of the investigation:

1. Gaussian heat flux used to simulation heat source is suitable.
2. The velocity of fluid increases in width direction of part and decreases after center of weld due to change the direction of fluid velocity.
3. Mushy zone percent decreases in direction of weld pool depth.

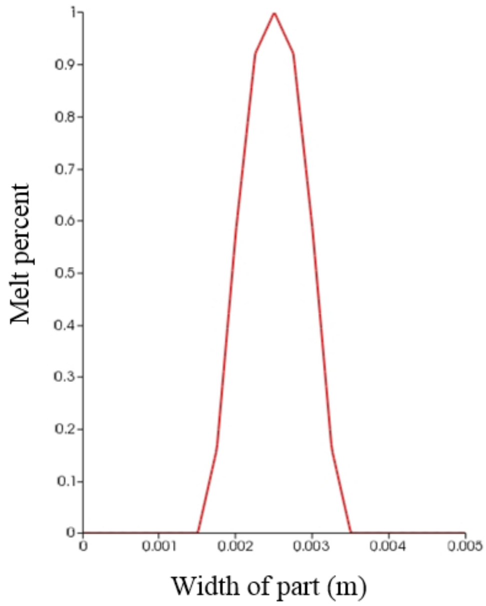

Figure 3. Molten percent versus width of part

Figure 4. Comparison of calculated and experimental weld geometry at laser power of 1700 W, speed of 13.43 mm/s and depth of 0.5 mm

Table 1. Validation results

Parameter	Experimental values	Numerical values	Error
Penetration depth	135	145	7 %
Welded zone width	120	135	12.5 %

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