Modeling of Continues Laser Welding for Ti-6Al-4V Alloys Using COMSOL Multiphysics Software

Haneen A. Salman
Department of Laser and optoelectronic Engineering
University of Technology,
Baghdad, Iraq.
noona_almasoudy1992@yahoo.com

Kadhim A. Hubeatir
Department of Laser and optoelectronic Engineering
University of Technology,
Baghdad, Iraq.

Mohammed M. AL-Kafaji
Department of Production Engineering and Metallurgy, University of Technology,
Baghdad, Iraq.

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Abstract- *A model for laser welding process using finite element method, the model was used for this work using the COMSOL Multiphysics software to predict the distribution of the temperature in the joint and to show the four welding zones (the melting zone, partial melting zone, zone affected by heat, and the material base). CO_2 continues (CW) Laser used in the model welding thin sheets of titanium alloy Ti-6Al-4V. The results of this simulation work have been compared with the experimental works to show good agreement.*

Keywords- *laser welding, finite element method, comsol Multiphysics soft, titanium alloy Ti-6Al-4v.*

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1. Introduction

Titanium alloys (Ti-6Al-4V) usually used in various fields such as the chemical tests, aerospace, energy industries and in medical. They have many properties like good erosion resistance, the biocompatibility, good abilities of temperature and higher resistance for distinct mechanical, which make them irreplaceable in many applications like welding operation. Welding operations play significant role in the productive of many manufacturing processes [1]. Different types of welding techniques are investigated and developed for processing titanium alloys [2]. The laser welding process is implemented due to its small diameter spot, flexibility, high depth to width ratio, high input specific heat, noncontact process, best performance, small heat affected zone, which minimize the distortion and good reliability [1]. There are many types of lasers used in welding processes, such as, CO2, Nd:YAG and fiber lasers [3]. In continuous welding operations the CO_2 lasers have been widely used, because of its provides higher power of continuous wave (CW) beams [4]. Modeling the laser welding process is a development to show the temperature distribution through laser welding by using finite element method, the basic of the finite element equations for elastic analyses written by Zienkiewicz and Taylor [5], In the finite element method, a continuum is divided into a number of elements. Each element consists of a number of nodes, and each node has a number of degrees of freedom that correspond to discrete values of the unknowns in the boundary value problem to be solved [6]. Many researches have been conducted to investigate the Laser welding processes as well as developing models to represents the effect of process parameter on the produced joint. Kazemi and Glodak [7] developed a 3D finite element method for dynamically simulate full penetration laser, and design in ANSYS, the model was used for calculating temperature transient contour and the dimension of melting zone during laser welding process. Yadaiah and Bag [8] studied the influence of the surface-active elements on weld pool formation during gas tungsten arc welding process. Okan et al. [3], found an efficient thermal model using finite element method (FEM), and Proved that conductive welds are

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

usually produced using focused laser beam with low-power, but high-power CO_2 and YAG lasers have been used to welding full penetration for thick sheets. Azizpour [9], constructed 3D finite element analysis of laser welding process for Ti6Al4V sheets to predict the temperature distribution, hardness, and weld geometry using CO_2 laser with the maximum power of 2.2 kW in the continuous wave mode. Recent study, a time-dependent multiphysical simulation, aims to reproduce the development of melted zone between different materials during pulsed and continuous welding mode. In order to validate the model, an experimental study was carried out [10]. In the current work, modeling and simulation of continues laser welding for two sheets of titanium alloy (Ti-6Al-4v) have been welded by continuous CO_2 laser. The finite element method was used to model the laser welding. The results from this model have been improved some influencing of laser beam parameters (laser power and welding speed) on welding profile (penetration depth, and welding width), also compared this results with the experimental procedures to verify this results. The process parameters were CO_2 laser weld titanium sheets thickness 1.6 mm, with power 2.2 KW, welding speed 0.066 m/s, and radius spot 0.06 mm.

2. Finite Element Method Modeling

The FEM model has been build using COMSOL multiphysics software, which is commercial FEM software. In order to build the FEM CO_2 laser, weld titanium sheets case is considered and the results of this case are used to verify the numerical model results. The FEM boundary conditions are taken from this case.

I. Model Parameters

This section describes the model parameter needed to build the numerical model such as materials type, power, welding speed, wavelength, spot radius, and sample dimension's.

II. Material Properties

The material used in this work is a titanium (Ti-6Al-4v) alloy, which has chemical composition shown in Table 1, but the physical and thermal properties which are needed for 3-dimention heat transfer were tabulated in Table 2.

III. Definitions of Functions

The Finite element method is used to define the laser beam path on the top of sheet. This path defined by some type of functions to define the laser beam path orientation in a continuous pattern, the most common function used are Gaussian, ramp, and analytic function. In this, the Gaussian function has been used.

IV. Geometry Modeling and Meshing

One of the most important step in FEM is the geometry and meshing. The model geometry is consisting of two thin sheets. Two 3-D solid blocks of (1 X 1 X 0.16) cm^3 were created. The two parts are meshed using automatic extremely fine meshing technique which is provided by Comsol Multiphrysics. The maximum element size for mesh is 0.04 cm, as shown in Figure 1.

V. Boundary conditions for heat transfer in solid

Thermal conductivity load, heat capacity and the Density for Ti-6Al-4v is important parameters for COMSOL Multiphysics program used them in equation [8]:

$$\rho C_p\left(\frac{\partial T}{\partial t}\right)+\rho C_p u\nabla T+\nabla q=Q+Q_{ted}\ldots\ldots\ \mathbf{(1)}$$

ρ: Density (kg/m^3)

C_P: heat capacity at constant pressure (J/kg.k)

$\frac{\partial T}{\partial t}$: temperature distribution with time.

q: power density (w/m^2)

u: welding speed (m/min)

Q**:** heat source

Equation (1) has been found to model the heat transfer in transmission laser welding process that defined the distribution of temperature within the body based on the law of energy conservation, balancing the rate of heat generated internally within the body's capacity to store this heat [8]. The environmental temperature at the start and initial heat conditions of the plates was supposed to be equal to 300 k.

Table 1: Chemical composition of titanium alloy

N	H	C	Fe	O	V	AL	Ti
0.009	0.0071	0.025	0.08	0.093	4.3	6.26	balance

Table 2: Physical and thermal properties of titanium alloy

Grade	Thermal	Heat capacity	Density	Coefficient of thermal

	conductivity			expansion
(TI-6AL-4V)	23 w/m.k	544 J/kg.k	4420 kg/m^3	9*10^{-6} 1/k

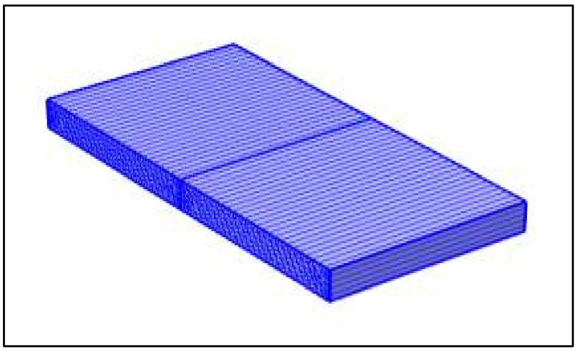

Figure 1:Exteremly fine mesh used(maximum element size from mesh is 0.04 cm)

3. Results and Discussion

I. Appearance of Welding

COMSOL Multiphysics program results can be displayed in various ways, since the program is able to calculate the temperature at any nodal point in the material as a function of time Figures (2 and 3) show temperature distribution on surface and volume.

Four distinct zones can be noticed in the region through welding process (as shown in Figure 4):

1. Melted zone: is the area of the material that melts (red color) in this work at temperature (1873 K).

2. The partial melting zone: Low-melting parts of the base material in the region nearest to the melted boundary often melt partially during processing. In this modeling have temperature about (1600K).

3. 3-Heat-affected zone (HAZ): is the part of the base material that does not melt, which have temperature around (1200 K).

4. Base material: dose not have any change through welding.

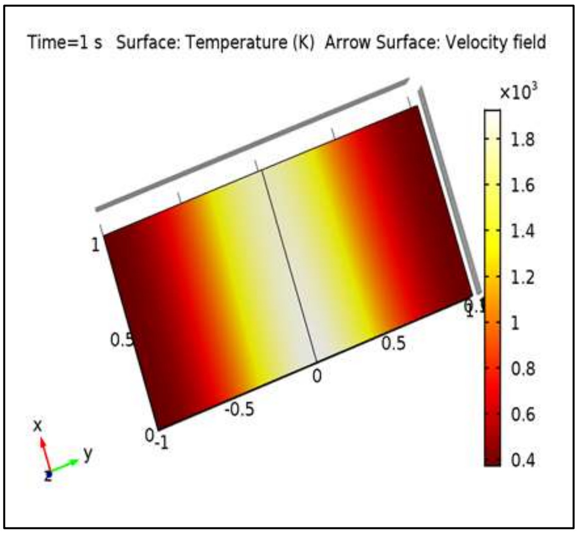

Figure 2:Distribution of temperature on the matrial surfaace

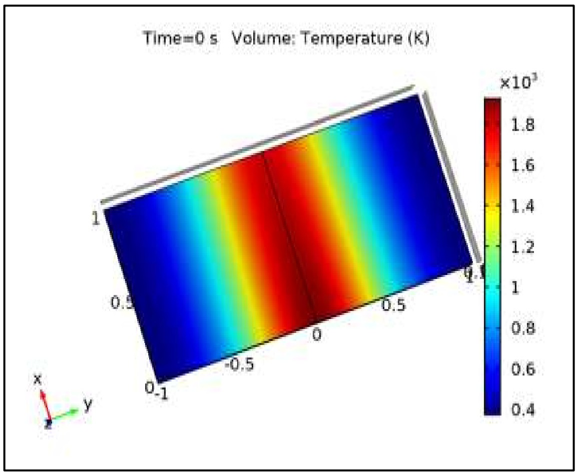

Figure 3:Distribution temperature on the aterial volume

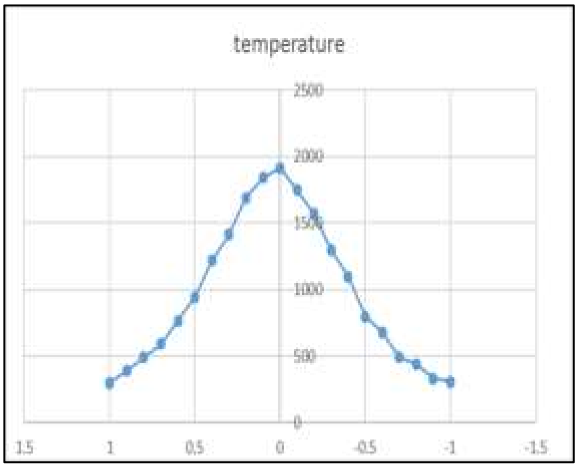

Figure 4: Temperature distribution on four distinct zones in welding region

II. The influencing of laser parameters on welding temperature and profile:

To study the laser parameters influencing on the producing temperature, welding depth, and welding width, some tests were making at different laser powers and speed. In the first test, three values of the welding speed (300, 400, 500) cm/min were taken, at each speed the power was changed gradually (1.2, 2.2, 3.2, 4.2) kw, temperature is increased with increase the power at constant speed, as show in Figure 5. The second test were carried out with the laser power was constant at three values (1.2, 2.2, 3.2) kW at each value the welding speed were changed (300, 400, 500, 600) cm/min, and noticed that when the welding speed increased the temperature produce will decrease, as shown in Figure 6. Sheets from same material used in third test but with larger thickness (20 mm), the needed for high laser power was 16 kW, and welding speed were increased (300, 400, 500) cm/min to show its effected on welding width, results shown in Figure 7. In fourth test, is to study the relationship between welding speed and welding depth, as shown in Figure 8. This noticed that in last test at lower laser power levels the heat affected zone (HAZ) increased linear with power. Nevertheless, this relationship will change after power of 2.2 kW. So, in high levels power the increase of HAZ is observed. This position can be defended with plasma absorption of laser beam at the surface of material, where the available laser power is high this lead to enlarge HAZ [11], as shown in Figure 9.

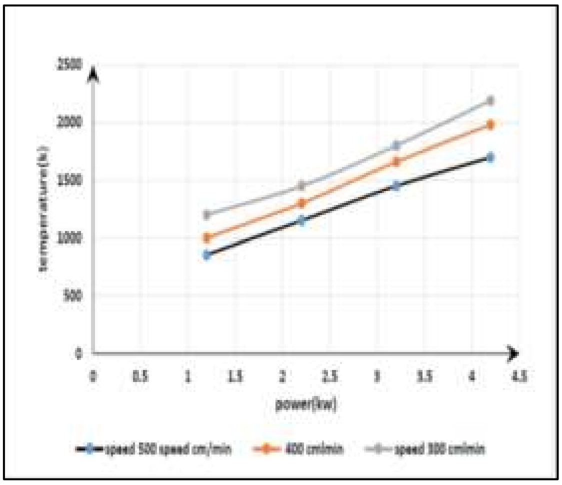

Figure 5: Temperature change as function power at constant speed for CO_2 laser welding

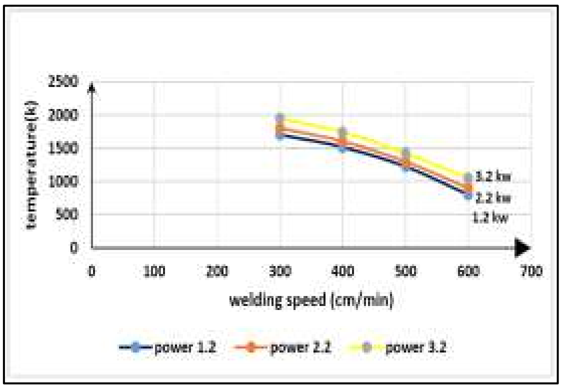

Figure 6: Temperature change as function of welding speed at constant power for CO_2 laser welding case

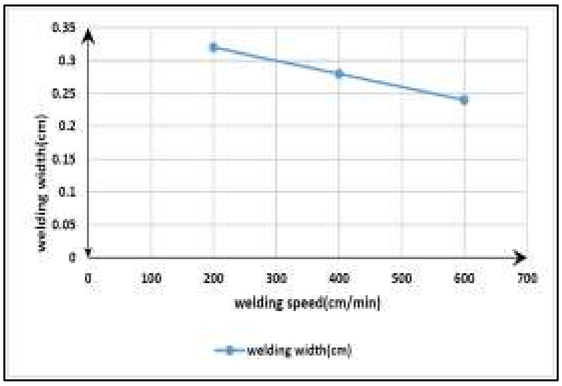

Figure 7: Welding width with respect to welding speed for CO_2 laser

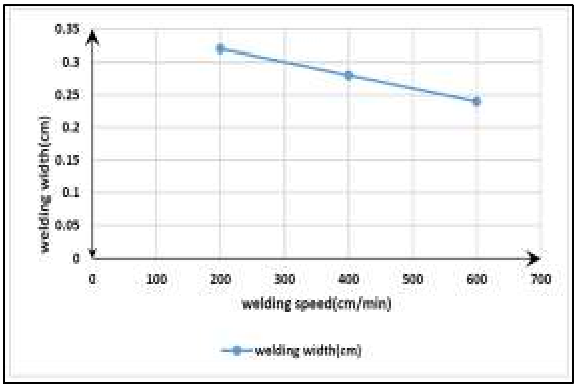

Figure 8: Variation of welding depth with respect welding speed

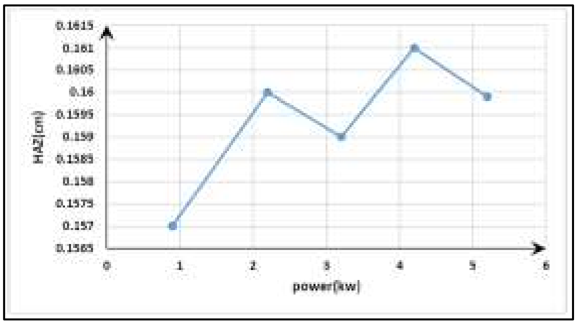

Figure 9: Relationship between the laser power and HAZ

3. Conclusion

Finite element modeling for two sheets of titanium alloy of thickness 1.6 mm welded in butt configuration.From this work it is found that a good matching between the theoretical results (finite element simulation) and experimental results with high compatibility and accuracy. On the other hand, from the previous results it is noticed that control of power and the speed of welding laser is necessary to reach the melting point for material to be welded. From these results of this model, it noticed that the CO_2 laser wavelength 1060 nm is good and fast welding tool for conduction weld.

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Assist. Prof. Dr. Kadhim A. Hubeatir, He received B.Sc. in Physics Science, College of Science, 1980, from AL-Mosul University, and MSC Applied Physics, School of Applied Science, University of Technology, 1986. He received Ph.D. Laser Technology, AL-Rasheed College of Engineering & Science, 2001. He currently working as assistant professor, he Head of Laser Engineering Branch from 2012 up to 2017 in Laser and Optoelectronics Engineering Department, University of Technology, Iraq.

Haneen Abd-Allah Salman, She received B.Sc. in Laser and Electronics Engineering at 2013, from the University of Technology, Iraq. She is interesting in laser welding.

Mohanned Mohammed Hussein Al-Khafaji. Received B.Sc. Production Engineering, 1998, Production and Metallurgy Department, University of Technology Baghdad, Iraq M.Sc. Production Engineering, 2001, Production Engineering and Metallurgy Department, University of Technology, Baghdad, Iraq. Ph.D. production engineering, 2011, Production Engineering and Metallurgy Department, University of Technology, Baghdad, Iraq. He has been Professor in Production Engineering and Metallurgy Department, University of Technology since 2002. Teaching subjects: (programming, computer application, measurement instruments, electrical circuit analysis and engineering control) and laboratories (metalworking and strength of material), and giving some courses how to use nondestructive testing machine like Eddy current, ultrasonic flaw detector, magnetic field detector and penetrated liquid.