Optimization of a parameter in laser heating process

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Abstract. The aim of this work is the parameter modeling of the metal heating process by laser heating. For these simulations COMSOL Multiphysics 5.3a is used. The transient control of the laser beam is modeled by dynamic equations in the code. The used heat transfer module of COMSOL offers two possibilities of modeling the interaction between laser beam and metal. The first one is that the laser beam is regarded as an incoming thermal flow at the metal, at the other way basically the modeling of the laser beam as a local volume heat source is on focus. The results of the modeling, that have been achieved, show a good agreement between model and investigation, being an important part of further research works.

Keywords: modeling; laser processing; simulation; aluminum

1. Introduction

Today, the problem of laser heating process and thermal properties investigation and complex materials are still increasing. Lasers are used in material processing to heat, to melt or to fusion exactly energy of the surface and the inner part stays without changes. The purpose of this work is to control the parameter of laser processing by COMSOL Multiphysics, in order to analysis the effects of laser power, speed, surface emissivity of material, focal point of laser and temperature of laser. For this simulation is used COMSOL Multiphysics to predict the melting energy by lasers. In this paper aluminum is assumed to be rotate on it stage and the heat transport equation is used for the energy (photons) absorption in depth. A model of laser interaction with moving material was created in COMSOL.

2. Materials and Methods

2.1. Thermal Modeling

2.1.1. Heat Equations

The surface of metal is dissipated by laser beam heated on it, according to conduction, convection, and radiation. The modeling can be provided by theoretical approach. So, the heat transport equation can be given as:

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + \alpha \quad (1)$$

where T is the temperature, t is the time, k is the thermal conductivity, Q is the laser heat generation, α is the absorption coefficient, c is the heat capacity and ρ is the density. In addition, radiation and convection losses q_c and q_r are given as:

$$q_c = h(T^\infty - T_{room}) \quad (2)$$

where T^∞ and T_{room} are the gas medium and room temperature, h is the heat convection coefficient and ε is the emissivity, respectively. In the following sections, losses will be provided by domain of interest form of boundary conditions; both T^∞ and T_{room} will be assumed as 20 °C.

$$q_r = \varepsilon(T_{room}^4 - T^4) \quad (3)$$

2.1.2. Heat Source

At firstly, need to description the fundamental mood of the laser heat generation. The fundamental mode of a Gaussian beam is usually better and a Gaussian heat source is given, accordingly. The latter is considered in this paper; namely, the heat generated by a super-Gaussian profile (i.e., a smoothed flat-top profile) of transverse optical intensity of order n can be given as:

$$Q(r) = Q_0 \exp[-2(\frac{r}{\omega_0})^n] \quad (4)$$

where ω_0 is the beam radius over the surface of object, Q_0 is the optimum intensity, and r is the radiate distance from the generation axis. In this paper was implemented by super-Gaussian intensity profile of order 20, based on actual data gain from beam profiler. Under this condition and for P indicate the loading power, the peak intensity in Equation (4) approaches:

$$Q_0 = \frac{P}{\pi \omega_0^2} \quad (5)$$

In addition, the model is purposed to modeling an application of repairing from metal where a defocused beam must be used, processing diameter of 2 mm was defocused by the laser beam.

2.1.3. Material Properties

In this model, the most important is the temperature-dependent of material, to be exactly prediction of the temperature. For this goal, based on the data literature on the properties of aluminum and its alloys, a lot of methods have been included in the background for the properties

involved in conduction, convection, and radiation equations. For create products is used; liquid and solidus temperature of 775 and 911 K, respectively, are given.

At firstly, a functional form for density ($kg.m^{-3}$), depending on the accumulation status:

$$\rho = \theta_{solid} \rho_{solid} + (1 - \theta_{solid}) \rho_{liquid} \quad 775 < T < 911 K \quad (6)$$

Figure 1: The sequence of the control parameters of laser processing

2.1.4. Virtual Specimen and Meshing

The Laser heating was modeled over a virtual specimen by virtual Specimen and Meshing, 50.8 mm wide, 25.7 mm thick, this being the size of the plate in the experimental procedure for validation. For the purpose of improving the consistency of the model, the virtual specimen was divided into 1 domain, 8 boundaries, 18 edges, and 12 vertices of interest (Figure 3). As a consequence of this, mesh must be set along the laser path, whereas a coarser mesh is allowed for the purpose of reducing the simulation time: a triangle mesh of variable size was applied, accordingly, the parameter of element size is between 4.04mm and 0.5mm. The maximum element size gain rate is 1.45.

Initial and boundary conditions are given for domain. Generation Q is provided along the processing path by laser heat; convection and radiation losses are operated at the over surface and convection and radiation losses are operated at each surface; a condition of thermal continuity is given with respect to domain for shared surface. The initial temperature of the domains is supposed as room temperature.

Figure 2. Triangular mesh of variable size on a virtual pattern.

2.2. Geometry of the Fusion Zone

As the all element size of the fusion zone depends on the thermal properties, the model was centralized to be validated upon inspections in a transverse cross-section with the moving direction of the laser beam. The simulation depth of the fusion zone had to be conducted by the indirect measurement: a transverse plane at half-length was considered with respect to the traveling direction. As expected, any increase in the investigated peak temperature produced a proportional increase in the expanse of the fusion zone.

Figure 3: Contour lines to determine the extent of the merge zone for the processing condition.

According to solidify range of the alloy, the temperature zone was decided by melting. In fact, as 715 K is the limit of the solidify range, at any point above this temperature limit was occurred by melting. For each given loading condition, the temperature was compared with the corresponding actual geometry (Table 1).

Table 1: Comparison of different temperatures on the metal

Time (s)	Temperature (K), Domain Probe 1	Temperature (K), Domain Probe 2	Temperature (K), Domain Probe 3	T_max-T_min (K)
58.531	552.95	682.10	518.49	163.62
58.634	552.96	688.67	518.10	170.57
58.736	552.99	686.91	517.71	169.20
58.828	553.01	691.69	517.38	174.30
58.920	553.03	685.50	517.06	168.44
59.012	553.05	687.49	516.76	170.74
59.094	553.07	690.40	516.48	173.93
59.177	553.07	692.28	516.22	176.06
59.260	553.08	697.86	515.97	181.89
59.335	553.07	701.48	515.75	185.73
59.409	553.07	696.39	515.55	180.85
59.484	553.06	706.63	515.34	191.29
59.558	553.06	718.41	515.15	203.26
59.633	553.03	731.15	514.97	216.18
59.707	552.97	738.21	514.79	223.41
59.782	552.82	750.15	514.64	235.51
59.849	552.57	747.59	514.49	233.10
59.916	552.20	738.37	514.36	224.00
59.983	551.68	717.84	514.24	203.60
60.050	551.17	712.97	514.11	198.86

Figure 4: Maximum, minimum and average temperatures as a function of time.

The temperature response at time (max, avg and min) is show in Fig. For the numerical simulation of this experiment, the temperature under the substrate was extracted after simulating heat transfer through powder. The results demonstrate that the maximum temperature laser exposure powder within 0.1s and the average temperature within 10s and the minimum temperature 14s in 450 °C, respectively.

3. Conclusions

The purpose of this research is parameter control of laser heating process. To summarize, results could be divided into three groups, temperature distribution, heat transfer and heating rate. Two parameters and their interaction have a strong influence on the laser process: power and laser scanning speed. The study of influence of laser parameters helps to find the best laser parameter setting to improve the effective of materials. This modeling can be helpful to define the range of real laser parameters for other material, especially difficult to machine materials.

References

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