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Prediction of preheating conditions for inclined laser assisted machining

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Abstract: For laser assisted machining, shape of preheating laser heat source is changed irregularly because of complexity of material shape. So, the preheating temperature should be controlled by adjusting the feed rate or the laser power. Thermal analyses of the laser assisted machining process for inclination planes were performed. By analyzing the obtained temperature profile, a proper feed rate control method was proposed according to the inclination angles. In addition, the temperature distribution of the cross section after feed rate control was predicted. The correlation equation between inclination angles and adjusted proper feed rate was proposed. The results of this analysis can be used to predict the preheating effect on workpiece and can be applied as a preheating temperature control method in laser assisted machining processes.

Key words: laser assisted machining; inclination angle; feed rate control; cross section

1 Introduction

With development of the materials engineering, hard and brittle materials such as fine ceramics, mullite, austenite stainless steel and titanium alloy are used in various fields such as machine, aircraft, and automobile parts [1]. However, these materials are difficult to machine due to brittle fracture. Laser assisted machining is a new machining method that abates breaking strength of the materials below yield strength by preheating the difficult-to-cut materials, causing a plastic deformation [2−6]. The laser assisted machining has been increased by more than 11% annually worldwide. Also, the method shows decreases in processing cost by about 60%−80% [7−9]. However, it is difficult to predict the temperature distribution for a laser assisted milling due to spot heating effect.

ROZZI et al [10−11] carried out a research on the analysis of machining condition and characteristic of surface by an experiment about a laser assisted machining of silicon nitride. Also, temperature distribution of machining area was predicted by three-dimensional heat transfer simulation. YILBAS [12] analyzed the surface temperature using a electron kinetic theory by considering moving heat sources and convection boundary conditions in the laser assisted machining process using short-pulses and the effects according to changes in irradiation speeds. AHN and LEE [13] proposed a new large-area analysis method by adjusting the heat input area, and using finite element method in the laser assisted machining. Recently, milling process products are required more than those of turning in some manufacturing sites. However, the laser heat sources in laser assisted milling processes are irregularly varied according to shapes of workpieces. In this work, the preheating effect in the laser assisted milling with inclination angles was performed as a basic research on the laser heat source in milling process. In addition, preheating temperature is controlled by adjusting feed rate. Also, the relation between inclination angle and adjusted proper feed rate was proposed by an equation.

2 Finite element method

2.1 Analysis conditions

For thermal analysis of laser heat source, Fig. 1 illustrates the four models with inclination angles of 15°, 30°, 45° and 60° for a inclination plane used in the analysis of laser heat source. The mesh size of the area, where the laser heat source is irradiated, is 0.25 mm, and the rest areas, which are less affected by heat relatively, are determined by 1 mm and 5 mm, respectively. Also, area of the laser heat source according to changes in inclination angle is calculated, and it is applied to the thermal analysis.

Table 1 represents the conditions used in this analysis. ANSYS Workbench is used as the analysis software. SM45C is used as a workpiece.

Material properties are changed according to the changes in temperature. Table 2 gives its thermal conductivity and specific heat according to the

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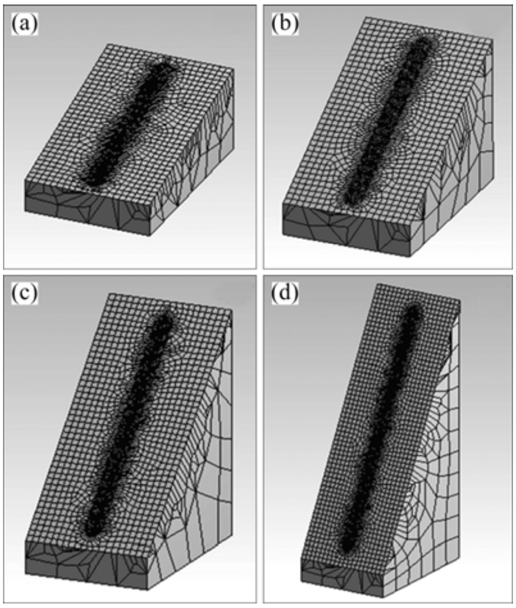

Fig. 1 Analysis model with different inclination angles: (a) 15°; (b) 30°; (c) 45°; (d) 60°

Table 1 Analysis conditions

Material	Block size (0°)	Laser power/ W	Laser feed rate/ (mm·s^{-1})	Convection heat/ (W·m^{-2}·°C^{-1})
SM45C	30 mm× 20 mm× 5 mm	266	20	5

Table 2 Properties of SM45C

Temperature/ K	Thermal conductivity/ (W·mm^{-1}·K^{-1})	Specific heat/ (J·kg^{-1}·K^{-1})
273.15	0.015	523
473.15	0.017	546
773.15	0.021	579
973.15	0.023	601
1 173.15	0.025	623
1 673.15	0.03	618

temperature of SM45C.

2.2 Analysis method

The boundary conditions are given sequentially according to the transfer speed by the overlaps to some extent along the laser route to present the moving heat source, as shown in Fig. 2.

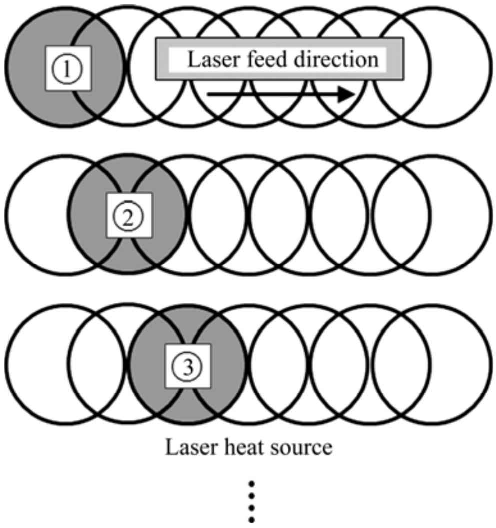

Fig. 2 Sequence of analysis

3 Simulation results

The results of this work are verified by comparing the temperature profile at the plate in the prior work [12] by the present authors.

3.1 Simulation results with inclination angles

The melting point of SM45C is about 1 450 °C. Temperature of about 1 350 °C as proper preheating temperature in laser assisted machining is proposed. Figure 3(a) shows the simulation results in the plate. A circle beam of 3 mm with laser power of 266 W and feed rate of 20 mm/s is applied to the analysis. The total numbers of elements in the workpiece are 12 962 and nodal points are 21 899. Maximum temperature is 1 351.7 °C. Figure 3(b) shows a constant temperature profile with an inclination angle of 0°.

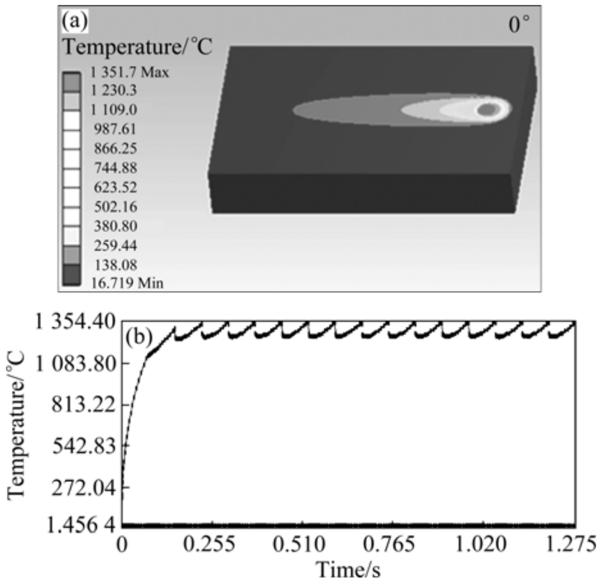

Fig. 3 Simulation results of plate: (a) Maximum temperature; (b) Temperature change according to time

Figure 4 shows the simulation results with inclination angles of 15°, 30°, 45°, and 60°. A circle beam of 3 mm with laser power of 266 W and feed rate of 20 mm/s is also applied to the analysis. Table 3 shows the maximum temperature on the inclination plane according to inclination angles. The maximum temperature is decreased with the increase in inclination

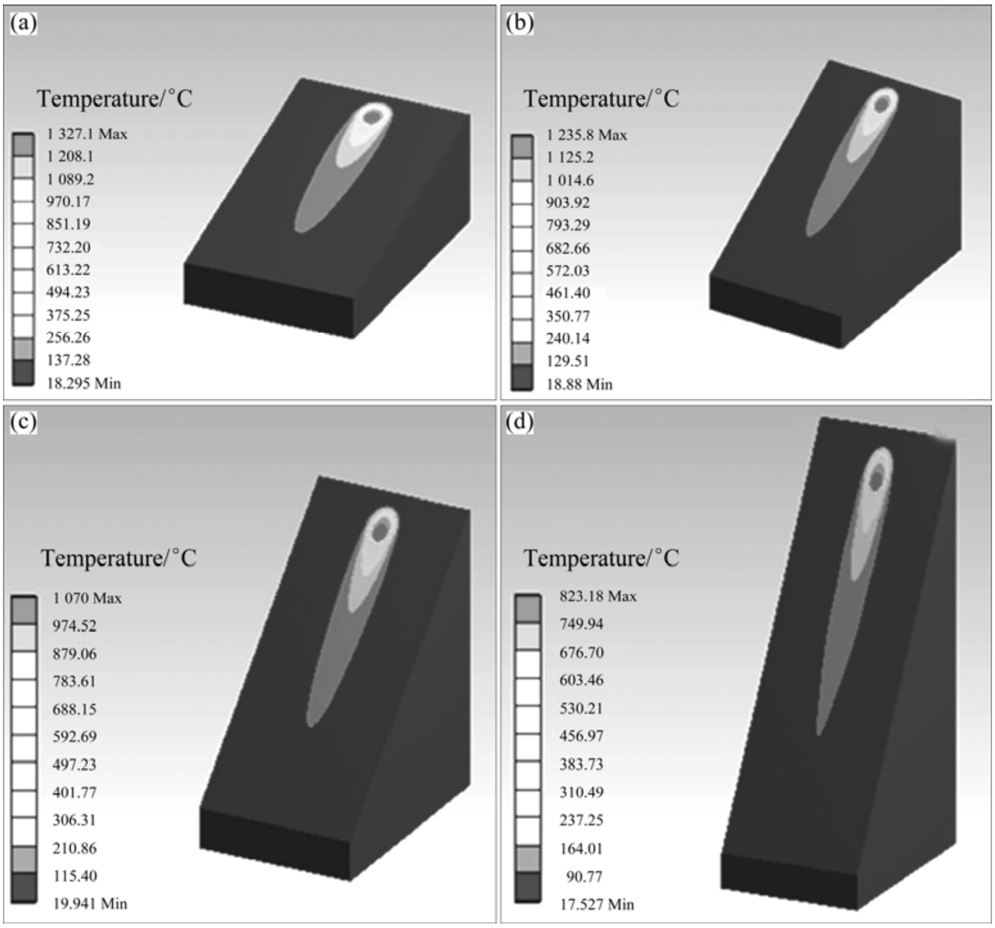

Fig. 4 Simulation results with inclination angles: (a) 15°; (b) 30°; (c) 45°; (d) 60°

Table 3 Maximum temperature according to inclination angles

Angle/(°)	Temperature/°C
0	1 351.7
15	1 327.1
30	1 235.8
45	1 070
60	823.18

angle because the thermal energy per unit area is decreased with the increase in inclination angle.

Machining and heat treatment can occur in the laser assisted machining at the same time. Therefore, it is needed to predict a heat affected zone as well as machining. Figure 5 represents cross sections of the heated workpiece with inclination angle. The range of the heat affected zone shows similar profiles because the feed rate and power for each inclination angle are the same.

3.2 Control of feed rate

In the above results of analysis, it is verified that the increase in inclination angles leads to increase in areas of laser heat source and leads to decrease of temperature.

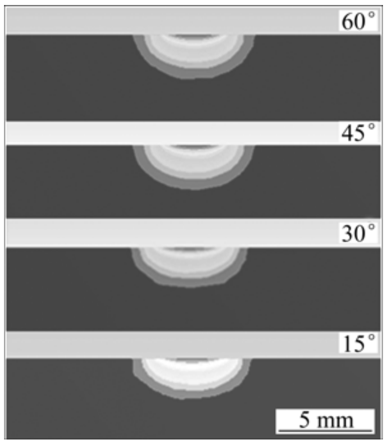

Fig. 5 Temperature distributions in cross section of workpiece

Feed rate is adjusted to obtain the preheating temperature of 1 350 °C, that is considered as proper machining temperature. Figure 6 and Table 4 represent simulation results by control of feed rate and maximum temperature obtained by the control of feed rate. The maximum temperature is about 1 350 °C.

Figure 7 represents the relationship between adjusted feed rate with inclination angle. It is shown that the feed rates need to be decreased according to the increase in inclination angle. Especially, it is verified that

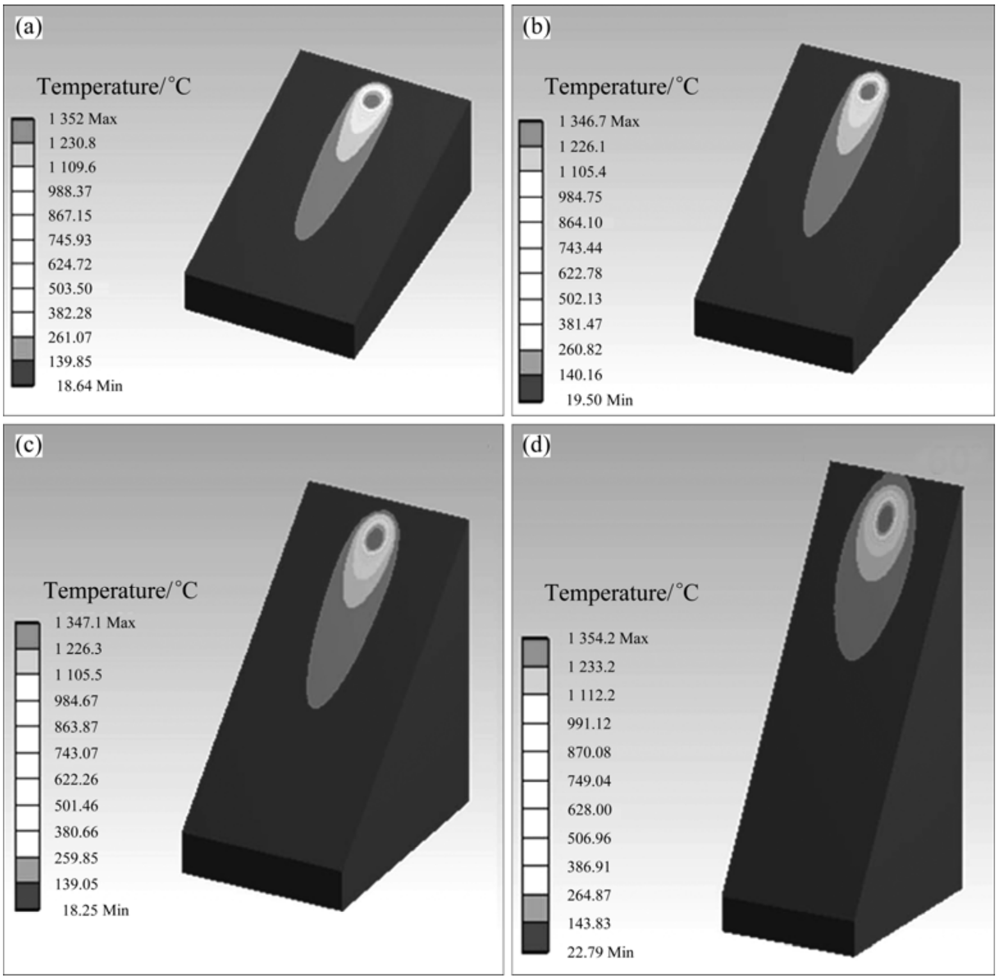

Fig. 6 Simulation results by control of feed rate: (a) 15°; (b) 30°; (c) 45°; (d) 60°

Table 4 Maximum temperature obtained by control of feed rate

Angle/(°)	Feed rate/(mm·s^{-1})	Temperature/°C
0	20.0	1 351.7
15	18.8	1 352.0
30	13.7	1 346.7
45	8.3	1 347.1
60	2.2	1 354.2

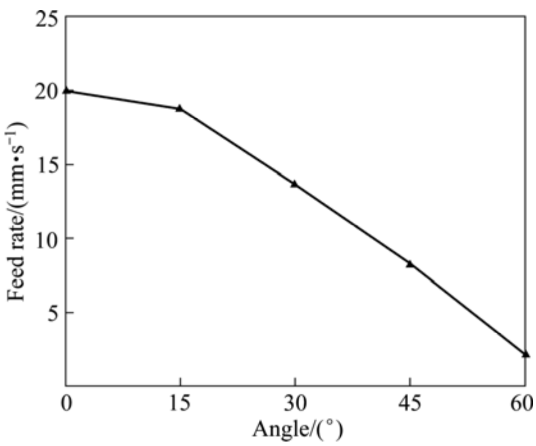

Fig. 7 Control of feed rate with inclination angles

feed rate needs to be adjusted very slowly in large inclination angles such as 60°.

Figure 8 represents temperature profiles of cross sections after control of feed rate. In comparison with Fig. 5, depth and width of the heat affected zone is increased when the feed rate is decreased.

Considering the heat affected zone, the power control is more efficient than the feed rate control.

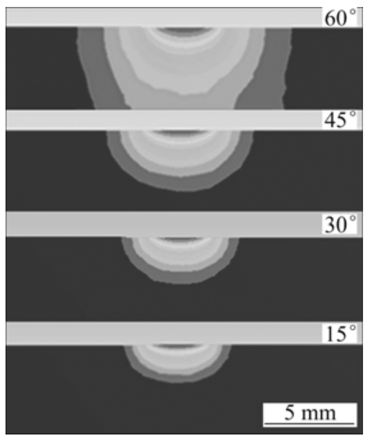

Fig. 8 Temperature distribution in cross section of workpiece after control of feed rate

The recrystallization temperature of SM45C is about 550 °C. Figure 9 represents the heat affected zone with temperature more than 550 °C that has to be removed.

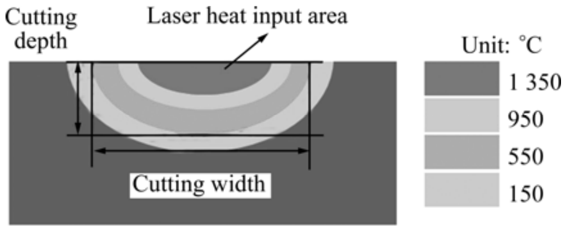

Fig. 9 Heat affected zone

Table 4 represents the width and depth of the heat affected zone with temperature more than 550 °C according to inclination angles. It is verified that the increase in inclination angles leads to increase in the width and depth that has to be cut, and leads to slowed feed rate.

Table 4 Width and depth of heat affected zone with inclination angles

Angle/(°)	Cutting width/mm	Cutting depth/mm
0	3.20	0.78
15	3.21	0.81
30	3.41	0.90
45	3.56	1.12
60	4.33	1.22

In the result data of analysis, polynomial regression equation is proposed to obtain optimum feed rate with the inclination angle as given in Eq. (1). The equation is obtained using software MATLAB R2009, and matrix operators:

$$y=20.973\,4-0.135\,5x-0.003\,0x^2 \quad (1)$$

4 Conclusions

1) The maximum temperature is decreased with the increase in inclination angle because the thermal energy per unit area is decreased with the increase in inclination angle.

2) Feed rate is adjusted to obtain the preheating temperature of 1 350 °C, that is considered as proper machining temperature. The depth and width of the heat affected zone are increased as the feed rate is decreased, especially for the case of inclination angle of 60°.

3) Polynomial regression equation is proposed. Also, relation between inclination angle and adjusted feed rate is analyzed. The control range of feed rate with inclination angle can be predicted by the proposed equation.

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