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Numerical simulation of fusion zone shape of lotus-type porous metals produced by laser welding

TSUMURA Takuya *, NAKAJIMA Hideo ** and NAKATA Kazuhiro *

KEY WORDS: (Lotus-type porous metal) (Laser welding) (Anisotropy) (Thermal diffusivity) (Laser absorption coefficient)

1. Introduction
Lotus- and Gasar-type porous metals had been developed by Boiko et al. [1, 2] and Nakajima et al. [3-5] and these were expected as innovative engineering materials because the directional pore yields various unique properties [6]. Laser weldability of the lotus-type porous copper [7], iron [8] and magnesium [9] was investigated, and the effect of pore direction on laser fusion zone shape of the magnesium [10-12] and the copper [11,12] by using the results of 3D FEM analysis of temperature distribution during welding were demonstrated. These have pointed out that the relation between direction of the pores and the laser irradiated direction appreciably influence weld formation.

In the present paper, we performed 3D FEM analysis of temperature distribution during laser welding for the lotus-type porous iron and compared the fusion zone shape with those cross sections obtained by experiments [8]. We also estimated the anisotropy of thermal diffusivity inherent in the lotus-type porous metals, and the anisotropy of the laser absorption coefficient caused by the phenomenon of multiple reflections of laser on the wall of pores.

2. Experimental procedure and results
Table 1 shows properties of the lotus-type porous metals used; They are Lotus copper [4-6, 7, 13, 14], Lotus magnesium [6, 9, 15-17], and Lotus iron [8, 18]. These metals exhibited different thermal conductivity along and normal to the directional pores [14]. In order to demonstrate the effect of this characteristic on the welding phenomena, three different combinations of relationships - pore direction, applied heat source direction, and welding direction- were considered as shown in Fig. 1.

Fig. 1 Schematic views of the lotus-type porous metals showing combinations of pore direction, applied heat source direction, and welding direction.

Fig. 2 Bead appearance and cross section of Lotus iron welds; laser power of 1.0 kW, laser spot diameter of 1.0 mm, and welding speed of 1 m·min⁻¹ [8].

Table 1 Properties of the lotus-type porous metals and laser irradiate conditions.

<table>
<thead>
<tr>
<th></th>
<th>Absorptivity of base metal (%)</th>
<th>Porosity (%)</th>
<th>Average pore diameters (µm)</th>
<th>Plate thickness (mm)</th>
<th>Irradiate angle (°)</th>
<th>Number of multiple reflection</th>
<th>Absorption coefficient</th>
<th>λ = 1000 nm at R.T. [19]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lotus copper</td>
<td>3</td>
<td>30</td>
<td>100</td>
<td>3</td>
<td>10</td>
<td>5</td>
<td>0.03</td>
<td>0.063</td>
</tr>
<tr>
<td>Lotus magnesium</td>
<td>26</td>
<td>35</td>
<td>150</td>
<td>1.8</td>
<td>10</td>
<td>2</td>
<td>0.26</td>
<td>0.3273</td>
</tr>
<tr>
<td>Lotus iron</td>
<td>41</td>
<td>17</td>
<td>370</td>
<td>2</td>
<td>32</td>
<td>3</td>
<td>0.41</td>
<td>0.4754</td>
</tr>
</tbody>
</table>

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** ISIR, Osaka University, Ibaraki, Japan

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3. Numerical simulation and discussions

3D FEM calculations of temperature distribution of the Lotus iron were performed using ABAQUS with user-defined subroutines. The Lotus iron is modeled as an equivalent orthotropic material. Equivalent density, equivalent specific heat, and thermal conductivity along and normal to the directional pores with temperature dependencies are described by the pore volume content ratio \( \varepsilon \) and the property of non-porous iron (AISI1006) [20].

Fusion shape of the weld metal is estimated by the cross section of maximum temperature exceeding the melting point at half of the \( x \) direction. Figure 3 shows maximum temperature distributions of the Lotus iron. The absorbable laser power is 0.522 kW, laser spot diameter of 1.0 mm, and welding speed of 1 m min\(^{-1}\). The little difference of laser absorption coefficient \( \beta \) and \( \beta' \) for the Lotus iron.

4. Conclusions

The conclusions of this study are summarized as follows.

(1) Fusion zone shape of the weld bead has little difference for three combinations. Calculated shapes and the experimental ones were similar.

(2) The difference between the equivalent thermal diffusivity along and normal to the directional pores is small for the Lotus iron.

(3) The little difference of laser absorption coefficient \( \beta \) and \( \beta' \) for the Lotus iron.

Acknowledgment

This research was supported as part of the entrusted project “development of lightweight high stiffness structural materials and evaluation technology” for the “advanced machining system development project” in the fiscal year 2005 consigned by NEDO. The authors gratefully appreciate this support.

References


Table 2 Estimated thermal properties of material used at room temperature.

<table>
<thead>
<tr>
<th>Base material</th>
<th>Thermal properties of base material (taken from the handbook [21])</th>
<th>Estimated thermal properties of lotus-type porous metals used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \rho (\text{Kg m}^{-3}) )</td>
<td>( C_p (\text{J} \text{K}^{-1} \text{kg}^{-1}) )</td>
</tr>
<tr>
<td>Lotus copper</td>
<td>Copper</td>
<td>8800</td>
</tr>
<tr>
<td>Lotus magnesium</td>
<td>Magnesium</td>
<td>1737</td>
</tr>
<tr>
<td>Lotus iron</td>
<td>Iron</td>
<td>7850</td>
</tr>
</tbody>
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