Deformation Process on Magnetic Pressure Seam Welding of Aluminum Sheets

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Magnetic pressure seam welding is a collision welding process, similar to explosive welding, utilizing electromagnetic force as the acceleration mechanism. True metallic bonding is achieved at the mating interface if contact takes place above an appropriate collision point velocity and collision angle. This paper deals with dynamic deformation process on magnetic pressure seam welding of aluminum sheets. Numerical analysis of the dynamic deformation process of the metal sheets is made by a finite element method. In this analysis, the metal sheets (100 mm width, 1 mm thickness) are assumed to be composed of plane-strain quadrilateral elements. The result shows that the collision velocity was sufficiently reproduced experimental result. The collision point velocity between the metal plate surfaces was very high-speed at the initial collision point, but it decreased continuously during the welding. The collision angle between the metal plate surfaces was 0 degree at the initial collision point, but it increased continuously during the welding.

**Keywords**: magnetic pressure seam welding, deformation behavior, collision behavior

1. Introduction

The Aluminum has higher electric conductivity and thermal conductivity than iron. Welding of aluminum sheet is difficult because of low heating efficiency. There is a report about magnetic pressure seam welding which is welding process suitable for aluminum sheet [1]-[3]. Magnetic pressure seam welding is a collision welding process, similar to explosive welding, utilizing electromagnetic force as the acceleration mechanism. Magnetic pressure seam welding uses electromagnetic force to accelerate one metal sheet (flyer plate) onto another stationary metal sheet (parent plate). When an impulse current from a capacitor bank passes through a flat one-turn coil, a magnetic flux is momentarily generated in the coil. Eddy currents are induced in insulated flyer plate in the coil. A part of flyer plate along the longitudinal direction of the coil bulged toward a parent plate, and then flyer plate is collided and welded with a parent plate. The collision point velocity and collision angle are determined by the primary and induced electromagnetic force. True metallic bonding is achieved at the mating interface if contact takes place above an appropriate collision point velocity and collision angle [4]. This paper deals with deformation process on magnetic pressure seam welding of aluminum sheets. Welding principle is shown in Fig. 1. In addition, current density \(i\) is given by eqn. 1, electromagnetic force \(f\) is given by eqn. 2 and Joule heat \(Q\) is given by eqn. 3. Where \(\kappa\) and \(\mathbf{B}\) are electric conductivity and magnetic flux density at aluminum sheet.
2. Numerical analysis

The analysis was made by non-linear-structure-analysis-program (MARC 2008). An element division model and boundary condition are shown in Figs. 2 and 3. In this analysis, the metal sheets (100 mm width, 1 mm thickness) were assumed to be composed of 28804 plane-strain quadrilateral elements. The deformed plate was an isotropic material. The stress-strain relation is given as following.

\[
\sigma = F e^n
\]  

\(\text{Fig. 1 Welding principle of magnetic pressure seam welding (cross sectional view)}\)

\(\text{Fig. 2 Analytical model of magnetic pressure seam welding}\)

\(\text{Fig. 3 Element division model and boundary condition}\)
The specimens used in this simulation were aluminum sheets. Material properties obtained by a static tension test are shown in Table 1. In the analysis, calculation time was 10.8 μs, and time step width was $2.16 \times 10^{-3}$ μs. The time integration method was single-step houbolt of implicit solution method. The magnetic pressure $P$ - measured magnetic flux density $B$ relations are given as following.

$$P = \frac{B^2}{2\mu} \left\{1 - \exp\left(-\frac{2t}{\delta}\right)\right\}$$  \hspace{1cm} (5)

Where $\mu$, $\delta$ and $t$ are magnetic permeability, skin depth and thickness of metal sheets, respectively. The relationship between time and magnetic pressure are shown in Fig. 4.

Table 1 Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's modulus $E$ / GPa</td>
<td>69</td>
</tr>
<tr>
<td>Poisson's ratio $\nu$</td>
<td>0.33</td>
</tr>
<tr>
<td>Density $\rho$ / kg/m$^3$</td>
<td>$2.71 \times 10^3$</td>
</tr>
<tr>
<td>$F$ value $F$ / MPa</td>
<td>118</td>
</tr>
<tr>
<td>$n$ value</td>
<td>0.0623</td>
</tr>
</tbody>
</table>

Fig. 4 History of magnetic pressure

3. Collision angle

The collision angle and collision point velocity relations [4] are given as following.

$$v_p = 2v_c \sin\left(\frac{\beta}{2}\right)$$  \hspace{1cm} (6)

$$v_p = \sqrt{v_x^2 + v_y^2}$$  \hspace{1cm} (7)

Where $\beta$, $v_c$, $v_p$, $v_x$ and $v_y$ are collision angle, collision point velocity, collision velocity, $x$ direction element of $v_p$ and $y$ direction element of $v_p$, respectively. Spatial relationships of $v_p$, $v_c$ and $\beta$ are shown in Fig. 5.
4. Results

Collision velocity between the metal plates in initial collision point is shown in Table 2. Experimental value was measured by the experiment [5]. Simulation result was similar to the experimental value. In consequence, the collision velocity was sufficiently reproduced experimental result. The relation between distance from initial collision point and collision point velocity is shown in Fig. 6. The collision point velocity was very high-speed at the initial collision point, but it decreased continuously during the welding. The relation between distance from initial collision point and collision angle is shown in Fig. 7. As for being 0 degree at initial collision point is known from the report of Watanabe et al [6]. In this simulation, the collision angle between the metal plate surfaces was 0 degree at the initial collision point, but it increased continuously during the welding. In consequence, the collision velocity was sufficiently reproduced experimental result.

<table>
<thead>
<tr>
<th>Table 2 Collision velocity</th>
</tr>
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<tbody>
<tr>
<td>Simulation</td>
</tr>
<tr>
<td>Experimental value</td>
</tr>
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</table>

![Fig. 5 Definition of collision angles](image)

![Fig. 6 Welding velocity vs distance from center](image)
5. **Conclusions**

1. The collision velocity between the metal plates was sufficiently reproduced experimental results.
2. The collision point velocity between the metal plate surfaces was very high-speed at the initial collision point.
3. The collision point velocity between the metal plate surfaces was decreased continuously during the welding.
4. The collision angle between the metal plate surfaces was 0 degree at the initial collision point, but it increased continuously during the welding.

**Acknowledgement**

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**References**


