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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 $\boldsymbol{i}$ is given by eqn. 1, electromagnetic force f is given by eqn. 2 and Joule heat Q is given by eqn. 3. Where κ and $\boldsymbol{B}$ are electric conductivity and magnetic flux density at aluminum sheet.

$$rot\, i = -\kappa \frac{\partial \mathbf{B}}{\partial t} \tag{1}$$

$$f = i \times \mathbf{B} \tag{2}$$

$$Q = -\frac{i^2}{\kappa} \tag{3}$$

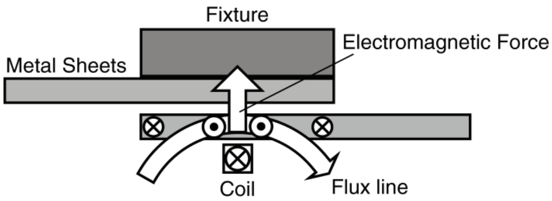

Fig. 1 Welding principle of magnetic pressure seam welding (cross sectional view)

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.

$$\sigma = F\varepsilon^n \tag{4}$$

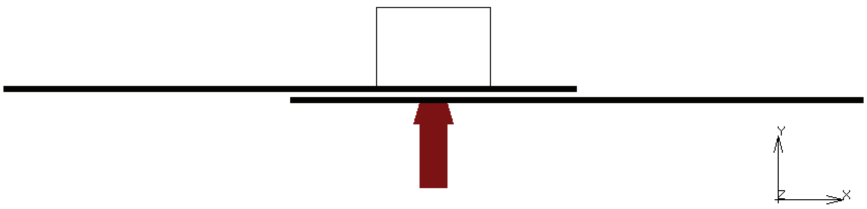

Fig. 2 Analytical model of magnetic pressure seam welding

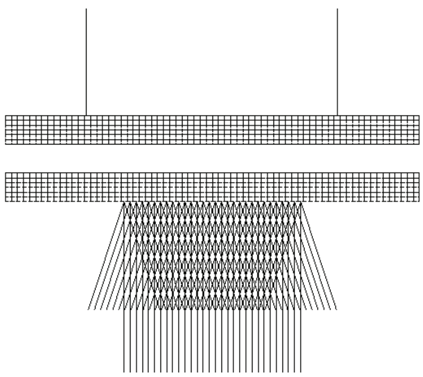

Fig. 3 Element division model and boundary condition

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 2.16×10^{-3} μs. The time integration method was single-step houbolt of implicit solution method. The magnetic pressure P - measured magnetic flux density $\boldsymbol{B}$ relations are given as following.

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

Where μ, δ 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

Young's modulus	E / GPa	69
Poisson's ratio	ν	0.33
Density	ρ / kg/m^3	2.71×10^3
F value	F / MPa	118
n value	n	0.0623

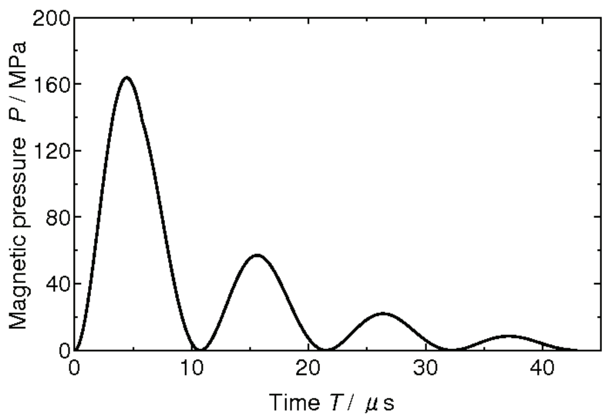

Fig. 4 History of magnetic pressure

3. Collision angle

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

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

$$v_p = \sqrt{v_x^2 + v_y^2} \tag{7}$$

Where β, 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 β are shown in **Fig. 5**.

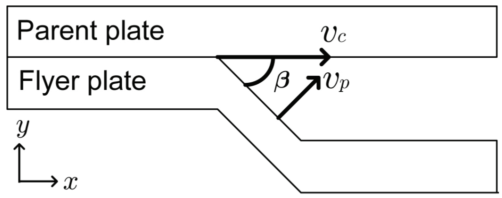

Fig. 5 Definition of collision angles

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 2 Collision velocity

Simulation	297 m/s
Experimental value	270 m/s

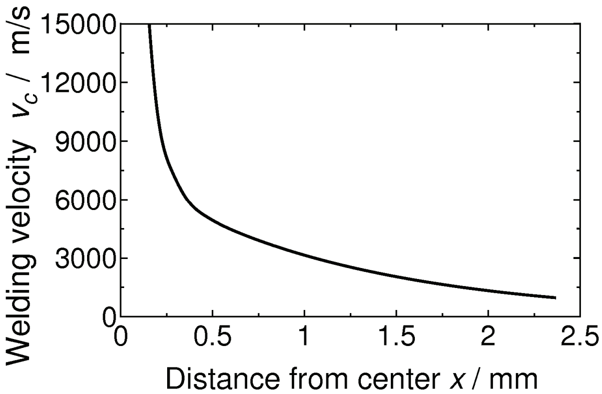

Fig. 6 Welding velocity vs distance from center

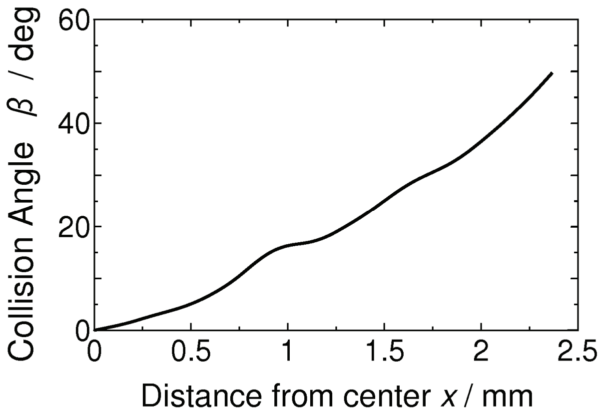

Fig. 7 Collision angle vs distance from center

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

[1] Aizawa T., Okagawa K., Yoshizawa M. and Henmi N.: Proceedings of 4th International Symposium on Impact Engineering, (2001), pp. 827-832.

[2] Aizawa T.: Journal of Japan Institute of Light Metals, **54**-4 (2004), pp. 153-158. (in Japanese)

[3] Miyazaki M., Sasaki K., Okagawa K.: Abstracts of the 115th Conference of Japan Institute of Light Metals, (2008), pp. 169-170. (in Japanese)

[4] Onzawa T., Murakami Z.: High Energy Rate Forming, CORONA Publishing (1993), pp. 68-76. (in Japanese)

[5] Okagawa K., Aizawa T.: Journal of The Japan Society for Technology of Plasticity, **48**-555 (2007), pp. 323-327. (in Japanese)

[6] Watanabe M., Kumai S., Okagawa K., Aizawa T.: Pre-Prints of the 82nd National Meeting of JWS, (2008), pp. 122-123. (in Japanese)