Collision Behavior in various Magnetic Pressure Seam Welding of Aluminum Sheets

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ABSTRACT
Magnetic pressure seam welding attracts attention as a new welding method. Magnetic pressure seam welding is a collision welding process, similar to explosive welding, utilizing electromagnetic force as the acceleration mechanism.

This paper deals with dynamic deformation behavior on magnetic pressure seam welding and parallel seam welding of aluminum sheets. Numerical analysis of the dynamic deformation process of the aluminum sheets is made by a finite element method.

In this analysis, the aluminum sheets is assumed to be a thin plate made of aluminum (A1050-H24, width 100mm, thickness 1mm) and composed of quadrilateral elements of plane strain.

As a result, it was found that the maximum value of the collision velocity was proportional to the discharge energy. It was also found that the smaller the gap, the faster the collision point moving speed. And the analysis from the initial collision point to the outside was similar to that of the single coil.

1. INTRODUCTION

Aluminum has a high electrical conductivity and thermal conductivity than iron. Therefore, it is difficult heating efficiency decreases welding.

In previous studies, there is report on the magnetic pressure seam welding method. Aizawa et al. reported a new welding method suitable for aluminum sheets (thickness 0.5-1.0mm) [1-2]. Okagawa et al. clarified the effect of the gap in the one-sided method of electromagnetic seam welding [3]. The welding method of aluminum and dissimilar metals and the microstructure of the joint interface have been reported. [4-6]. A metal jet at the collision of a pure aluminum plate was reported [7]. When the parameters were changed, the shear strength and weld width were studied [8]. Numerical simulation of aluminum seam pressure welding has been carried out [9]. The application of magnetic pulse welding technology for flexible printed circuit board joints was reported [10]. The composition of dissimilar materials and aluminum metal jet was investigated [11]. A metal jet was observed in parallel electromagnetic seam pressure welding [12]. In-situ observation of magnetic pulse welding process using high-speed video camera has been reported [13]. The effect of the gap in electromagnetic seam welding was examined [14].

Magnetic pressure seam welding is a collision welding process similar to explosive welding and utilizes electromagnetic force as an acceleration mechanism. Magnetic pressure seam welding accelerates and collides a certain metal plate (flyer plate) to another stationary metal

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plate (parent plate) by using electromagnetic force. Also, magnetic seam pressure welding is difficult to deform unless it is aluminum or copper which is a material having excellent conductivity.

When an impulse current from a capacitor bank passes through a flat one-turn coil, a magnetic flux is instantaneously generated in the coil. The eddy currents are induced in insulated flyer plate in the coil. In magnetic pressure parallel seam welding, one-turn coils are arranged in parallel. A part of flyer plate along the longitudinal direction of the coil bulged toward a parent plate, then flyer plate collided and was welded to a parent plate. At the time of the high-speed collision, metal jets are emitted in the welding interface of the specimen [7]. 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 [15]. The purpose of this paper is to discuss, the dynamic deformation behavior of magnetic pressure seam welding and parallel seam welding of aluminum sheets.

2. WELDING PRINCIPLE

The welding principle is shown in Fig. 1. Magnetic pressure seam welding uses electromagnetic force to accelerate one metal sheet (flyer plate) against another stationary metal sheet (parent plate). When a high magnetic field **B** suddenly occurs and enters the metal sheet, eddy current (current density i) passes through the metal sheet. As a result, the electromagnetic force of Eq. 2 acts mainly on the flyer plate and it is accelerated away from the coil and collides rapidly with the parent plate [10]. The eddy current **i**, electromagnetic force f and Joule heat Q are given as follows. κ and **B** are electric conductivity and magnetic flux density at aluminium sheet. When the residual inductance of the electromagnetic forming apparatus is large, it becomes difficult for a large current to flow through the one-turn coil, so the magnetic pressure also becomes small and it is difficult to join. Since the inductance of the coil of the multi-turn coil is higher than that of the one-turn coil, the current flowing through the coil can be increased and the magnetic pressure can be increased.

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

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

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

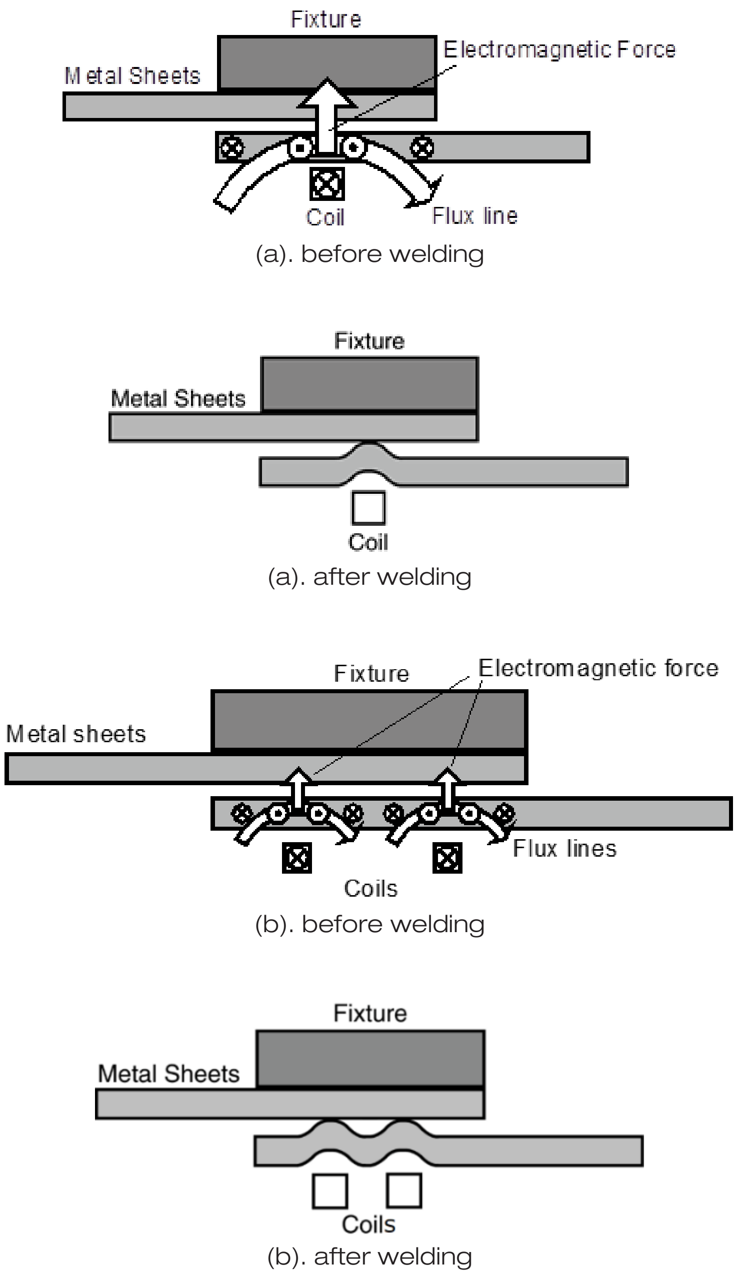


Fig. 1. Schematic illustrations of welding method (cross sectional view). (a) single coil, (b) parallel coil.

3. NUMERICAL ANALYSIS

The analysis was made by non-linear-structure-analysis-program (MARC 2018). An element division model and boundary condition are shown in Fig. 2. In this analysis, the metal sheets (100mm width, 1mm thickness) were assumed to be composed of 20000 plane-strain quadrilateral elements. In the analysis of single coil electromagnetic seam welding,gap length between flyer plate and parent plate was 1.0 mm. In the analysis of parallel electromagnetic seam welding, the gap length between the flyer plate and the parent plate was varied between from 0.5mm to 1.5mm. The deformed plate was an isotropic material. The true stress-true strain relation is given by Eq. 4.

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

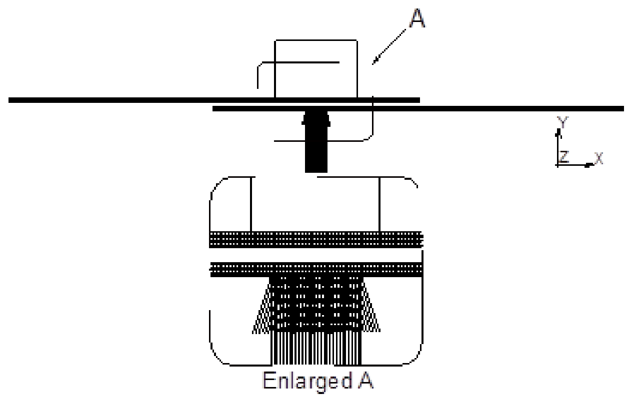
The specimens used in this analysis were aluminum sheets. Material properties obtained by a static tension test are shown in Table 1 [16]. Okagawa et al. reported that deformation of aluminum sheets was finished at the first discharge waveform [17]. In the analysis, calculation time was 10.8μs, and calculation step was 5000. The time integration method was single-step houbolt of implicit solution method. The magnetic pressure P - measured magnetic flux density B relations are given by Eq. 5.

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

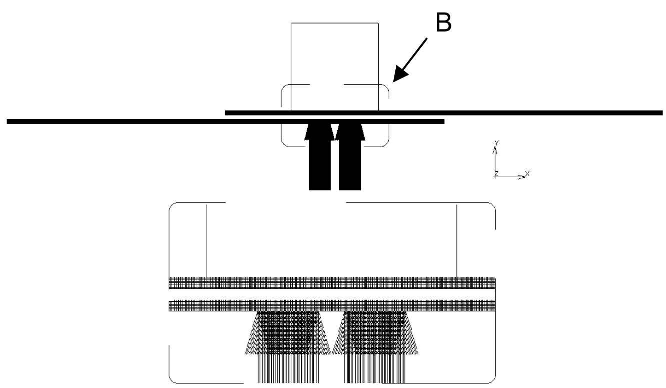
Table 1 Material properties of A1050-H24 sheets

Young's modulus	**E [GPa]**	69
Poisson's ratio	**ν**	0.33
Density	**ρ [kg/m^3]**	2.71×10^3
Strength coefficient	**F [MPa]**	118
Strain hardening exponent	**n**	0.0623

The parameters μ is magnetic permeability, δ and t are skin depth and thickness of metal sheets, respectively. The relationship between time and magnetic pressure is shown in Fig. 3. In the analysis of parallel electromagnetic seam welding, the magnetic pressure P was 1.0kJ.



(a). single coil



(b). parallel coil

Fig. 2. Finite element model of magnetic pressure seam welding and parallel seam welding.

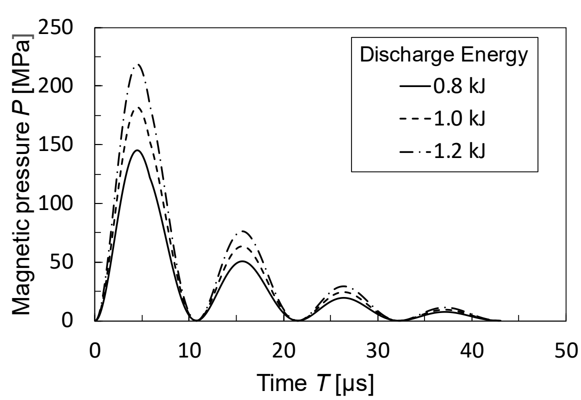


Fig. 3 Relationship between time T and magnetic pressure P.

4. RESULTS AND CONSIDERATIONS

The analysis of electromagnetic parallel seam welding in this study, examined from the initial collision point to the inside and the outside. A model of electromagnetic parallel seam welding is shown in Fig. 4.

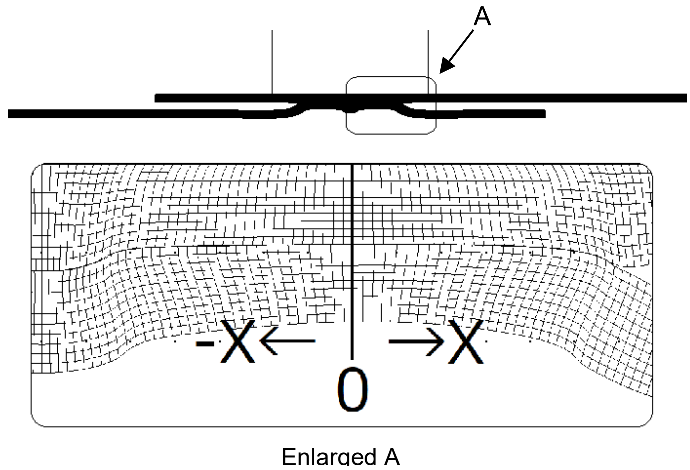


Fig.4 Model of electromagnetic parallel seam welding.

Collision angle, collision velocity, and collision angle velocity are used for joint verification in explosion welding, a process similar to electromagnetic seam welding. It was examined these in this paper.

4.1. Collision angle

The collision angle and collision point velocity relations [15] are given as follows:

$$v_{\mathrm{p}} = 2v_{\mathrm{c}} \sin\frac{\beta}{2} \tag{6}$$

$$v_{\mathrm{p}} = \sqrt{v_{\mathrm{x}}^2 + v_{\mathrm{y}}^2} \tag{7}$$

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.

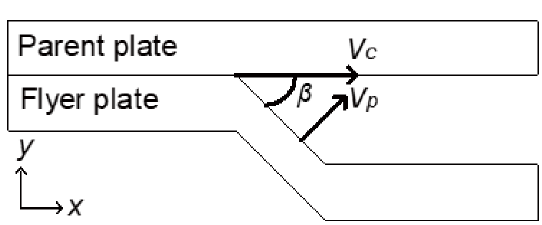


Fig. 5 Definition of collision angle β, collision velocity v_p and welding velocity v_c.

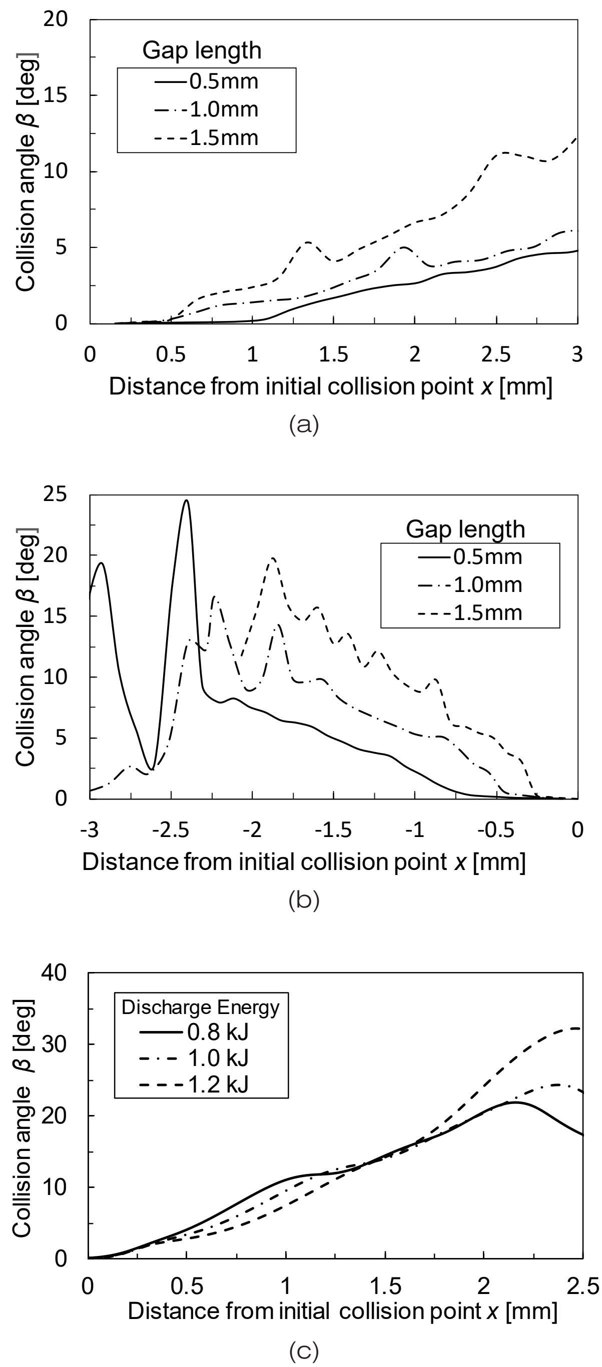


Fig. 6 Relationship between distance from initial collision point x and collision angle β. (a) inside of parallel seam welding, (b) outside of parallel seam welding, (c) single coil.

The relation between distance from initial collision point and collision angle is shown in Fig. 6. Watanabe et al. reported that the collision angle between the metal plate surfaces was 0 degree at the initial collision point [18]. 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. Also, increasing the gap length increased the maximum value of the collision angle. Inside the parallel electromagnetic seam welding, the disturbance of the graph

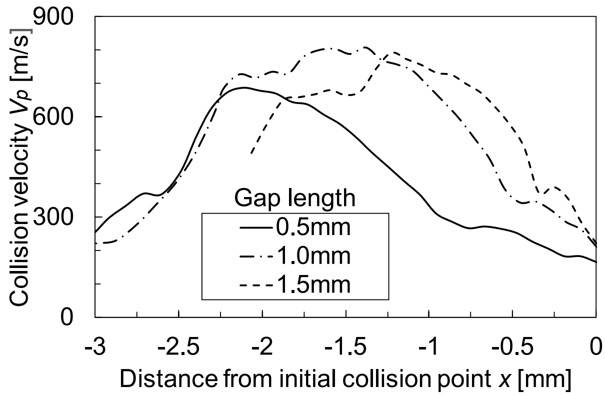
The relation between distance from initial collision point and collision angle is shown in Fig. 6. Watanabe et al. reported that the collision angle between the metal plate surfaces was due to the interaction was observed at 2.5 mm or more. When discharge energy was increased, collision angle was decreased near the initial collision point and the maximum value of collision angle was increased.

4.2. Collision velocity

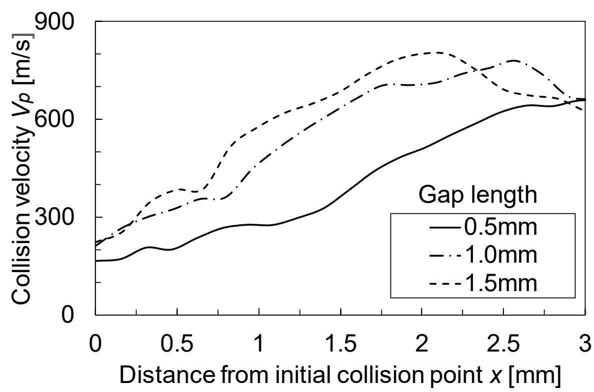
The relation between initial collision point and collision velocity is shown in Fig. 7. Depending on the gap length and the discharge energy increases, the collision velocity become fast. The maximum value of collision velocity and collision velocity at initial collision point have a tendency to become larger as the discharge energy increases. The trend of the latter gave agreement with experimental results [3]. The collision speed became the maximum value at a certain distance away from the initial collision point and decelerated from there. This phenomenon occurs when the movable plate continues to be accelerated by electromagnetic force. The collision speed varies with the electromagnetic force and the mechanical characteristics of the movable plate.

4.3. Collision point velocity

The relation between initial collision point and collision point velocity is shown in Fig. 8. The collision point velocity was very high-speed at the initial collision point, but it decreased continuously during the welding. On the inside in parallel electromagnetic seam welding, disturbance was seen in the graph due to the interaction. As the gap length increases, the initial collision point movement speed in the vicinity of the initial collision point also increases. When surface layer of the metal plate is emitted as a metal jet, strong metallic bond is established on the metal plate [18]. The velocity of metal jet is 2000-3000 m/s [19]. As seen in Fig. 8, the collision point velocity of near the initial collision point is higher than velocity of metal jet. The metal jet is not emitted near the initial collision point. Therefore, the un-welded zone exist near the initial collision point.



(a)



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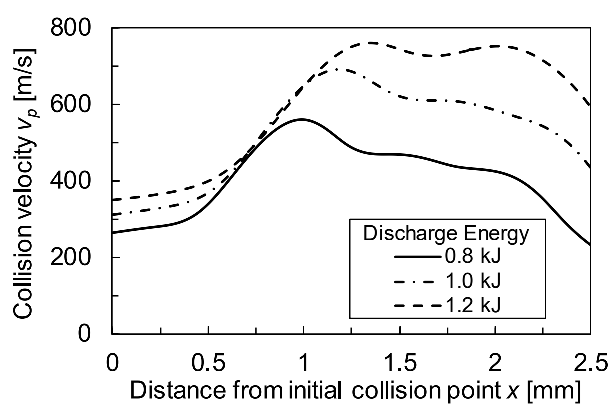
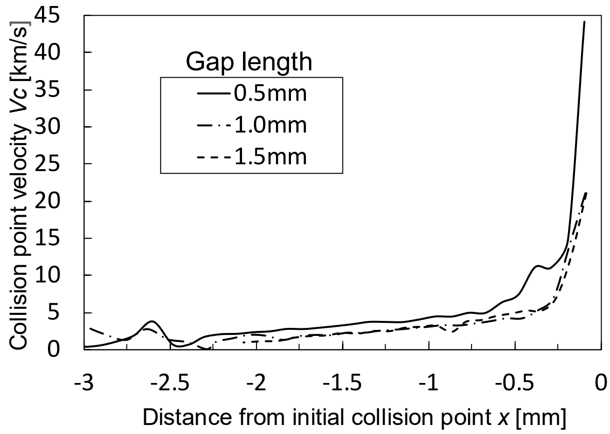
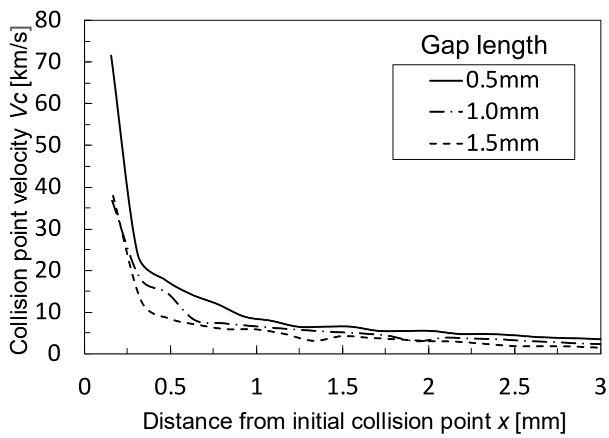


(c)

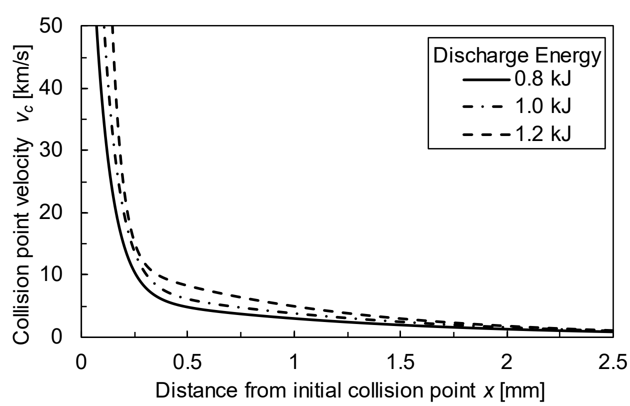
Fig. 7 Relationship between distance from center x and collision velocity v_p. (a) inside of parallel seam welding, (b) outside of parallel seam welding, (c) single coil.



(a)



(b)



(c)

Fig. 8 Relationship between distance from initial collision point x and collision point velocity v_c. (a) inside of parallel seam welding, (b) outside of parallel seam welding, (c) single coil.

5. CONCLUSIONS

1. The collision point velocity is very high-speed at the initial collision point, but it decreases continuously during the welding.
2. The collision angle between the metal plate surfaces is 0 degree at the initial collision point, but it increases continuously during the welding.
3. As the gap length increases, the maximum value of the collision angle increases.
4. The maximum value of the crash velocity tends to increase as the gap length increases.
5. The analysis from the initial collision point to the outside in electromagnetic parallel seam welding is similar to the single coil.
6. The interaction is seen in the analysis from the initial collision point inward in electromagnetic parallel seam welding.
7. The maximum value of collision velocity has a tendency to become larger as the discharge energy increases.
8. When discharge energy is increased, the maximum value of collision angle is increased.
9. These simulations revealed the deformation behavior of parallel electromagnetic seam welding. The use of aluminum can be expected to reduce the weight of automobiles.

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