New Explosive Welding Technique to Weld Aluminum Alloy and Stainless Steel Plates Using a Stainless Steel Intermediate Plate

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Various aluminum alloys and stainless steel were explosively welded using a thin stainless steel intermediate plate inserted between the aluminum alloy driver and stainless steel base plates. At first, the velocity change of the driver plate with flying distance is calculated using finite-difference analysis. Since the kinetic energy lost by collision affects the amount of the fused layer generated at the interface between the aluminum alloy and stainless steel, the use of a thin stainless steel intermediate plate is effective for decreasing the energy dissipated by the collision. The interfacial zone at the welded interface is composed of a fine eutectic structure of aluminum and Fe₄Al₁₃, and the explosive welding process of this metal combination proceeds mainly by intensive deformation of the aluminum alloy. The weldable region for various aluminum alloys is decided by the change in collision velocity and kinetic energy lost by collision, and the weldable region is decreased with the increase in the strength of the aluminum alloy.

I. INTRODUCTION

It is possible to weld most metal combinations using explosive welding, but some of the combinations, e.g., Al-Mg alloy and steel, are known to be very difficult to weld.¹ The explosively welded clad of Al-Mg alloy and stainless steel is currently produced by inserting industrial-pure aluminum, Ti, and Ni plates or inserting silver plate.²,³ In such a case, each of the plates is welded repeatedly and the process costs are very high.

In this investigation, a new explosive welding technique to weld Al-Mg alloy and stainless steel is proposed, and the microstructure at the welded interface is analyzed to understand the mechanism of the explosive welding process in this metal combination. The use of a stainless steel intermediate plate between the driver (aluminum alloy) and base (stainless steel) plates is proposed to decrease the fused region generated at the welded interface. These three plates are welded simultaneously by a single-shot explosion, and this process makes it possible to directly weld Al-Mg alloy and stainless steel and also simplifies the fabrication process.

Since it is very important to achieve a fluid-like behavior at the collision point especially on the aluminum side in order to obtain moderate bonding, the weldable region for various aluminum alloys as well as the Al-Mg alloy is also analyzed in the present investigation.

II. EXPERIMENTAL PROCEDURE

Figure 1 shows the schematic illustrations of the (a) conventional and (b) new explosive welding methods used in this investigation. Four kinds of 4-mm-thick aluminum alloy plates and 9-mm-thick JIS SUS304 stainless steel plates were used as the driver and base plates, respectively (Table I). The thickness of the SUS304 intermediate plate, tₑ, was varied between 0.1 and 1 mm. A powder-type explosive (ammonium nitrate base) was used for the welding. Packing density of the explosive was about 550 kg/m³, and the thickness of the explosive, tₑ, was varied from 15, 21, 28, 38 to 47 mm. Detonation velocity of the explosive, Vₑ, was slightly changed with the thickness of the explosive, tₑ, as shown in Figure 2. Three heights of stand-off distance between the driver and base plates (stand-off 1) were used. Since the welding of the intermediate plate (stainless steel) and base plate (stainless steel) is not very difficult, the distance between the intermediate and base plates (stand-off 2) was fixed at 2 mm. Conventional explosive welding without an intermediate plate was also conducted in comparison with the experiments using an intermediate plate.

The explosively welded materials were cut parallel to the direction of detonation at the center position, and the microstructures at the welded interface were examined. Concentration profiles of each element were calculated by the relative intensity of their characteristic X-ray. An X-ray diffractometer was used for the identification of intermetallic compounds generated at the interface.

Table I. Chemical Compositions of Aluminum Alloy and Stainless Steel used and Their Vickers Hardnesses

<table>
<thead>
<tr>
<th>Alloy (JIS)</th>
<th>Chemical Composition (Mass pct)</th>
<th>Vickers Hardness (Load: 0.98 N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1100</td>
<td>0.05 to 0.2, Mg, Zn, Al &gt;99</td>
<td>31</td>
</tr>
<tr>
<td>A5083</td>
<td>0.1, 4.0 to 4.9, &lt;0.25 bal.</td>
<td>93</td>
</tr>
<tr>
<td>A2017</td>
<td>3.8 to 4.9, 0.4 to 0.8, &lt;0.25 bal.</td>
<td>137</td>
</tr>
<tr>
<td>A7075</td>
<td>1.2 to 2, 2.1 to 2.9, 5.1 to 6.1 bal.</td>
<td>181</td>
</tr>
</tbody>
</table>

C, Ni, Cr, Fe

SUS304: <0.08, 8 to 10.5, 18 to 20 bal. 265
Ram tensile strengths were measured for the specimen, as shown in Figure 3.141

III. ANALYTICAL METHOD

The change in driver plate velocity during the explosive welding process is calculated using a one-dimensional finite-difference analysis.5 The motion of the driver plate accelerated from the detonating gas with constant pressure through the thickness of the explosive was calculated at the initiation of this phenomenon.

The motions of detonating gas elements are calculated based on the following equations:

\[ \rho_0 dz_0 = \rho dz \]  \[ \frac{\delta \rho}{\delta t} + \frac{1}{\rho_0} \times \frac{\partial P}{\partial z_0} = 0 \]  \[ P = P_0 (\rho/\rho_0)^n \]

where \( t \) is the time from the initiation of this phenomenon, \( z \) is the coordinate of each gas element from the initial position of the driver plate, \( \rho \) is the density of the detonating gas, \( P \) is the gas pressure, and \( w \) is particle velocity of the gas. The subscript 0 means the coordinate or quantity at the initial condition, and the coordinates and quantities without a subscript denote the values at time \( t \).

The initial conditions \( P_0, \rho_0, \) and \( n \) are calculated using Hino's equation\(^6\) and consider the change in detonating velocity with the thickness of the explosive, as shown in Figure 2. Hino's equation is expressed as follows:

\[ P_0 = 416 U^2 \frac{\rho_f}{10^3} \left( 1 - \frac{0.543 \rho_f}{10^3} + \frac{0.193 \rho_f^2}{10^6} \right) \]

where \( \rho_f \) is the packing density of the explosive (kg/m\(^3\)), \( U \) is the propagating velocity of the shock wave (equal