Deformation of Coated Materials: Diffusion Bonding by Warm Rolling

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Objectives
The objective of this research is to study diffusion bonding in warm rolling of dissimilar metal strips. Experimental and analytical work is being carried out to investigate the temperature and plastic deformation effects on diffusion bonding of aluminum alloys, nickel alloys, and stainless steel. A fundamental understanding of the temperature and plastic deformation effects on diffusion can lead to the development of advanced cladding technology to produce coated sheet metal products.

Background
Diffusion is the primary mechanism for roll bonding of layered metal sheets such as clad metals. A clad metal sheet can be considered as a metal substrate with a metal coating. The diffusion zone at the interface between layers plays a crucial role in the bonding strength and the formability of clad sheets. Most of the previous study focused on metal diffusion in a vacuum or inert gas environment which is not practical in industry scale cladding operation. An investigation of diffusion bonding under unmodified atmosphere is of significant importance in advancing roll cladding of metal sheets.

Materials & Methods
The metal sheets as component layers used in this study are stainless steel 304 (STS), aluminum alloy 1100 (Al), nickel alloy 400 (N), and copper alloy 110 (Cu). The chemical compositions and melting points of the materials are shown in Table 1. Figure 2 shows the roll bonding process.

Table 1: Composition and melting points of investigated alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Composition (mass %)</th>
<th>Melting Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel 304 (STS)</td>
<td>0.08 C - 0.12 Ni - 0.03 Mn - 0.03 Fe</td>
<td>1454</td>
</tr>
<tr>
<td>Aluminum 1100</td>
<td>0.005-0.01 Cu - 0.15 Si - 0.25 Mg</td>
<td>660</td>
</tr>
<tr>
<td>Nickel Alloy 400 (N)</td>
<td>0.01 Ni - 0.02 Cu</td>
<td>1100</td>
</tr>
<tr>
<td>Copper Alloy 120 (Cu)</td>
<td>-</td>
<td>1085</td>
</tr>
</tbody>
</table>

Under the processing condition of T = 260 to 316 °C, t = 30 minutes, ω = 0.24 rad/s, and thickness reduction of 63%, diffusion bonding of Al/Ni was achieved. Despite of thickness reduction of 87.0%, the strips failed to bond at a less favorable pre-heating condition (T = 260 °C, t = 20 minutes) due to insufficient drive of diffusion and a serious pre-heating condition (T = 350 °C, t = 30 minutes) due to severe oxidation. In warm rolling of AUS/STA strips, successful diffusion bonding was achieved under the processing condition of T = 240 to 400 °C, t = 30 minutes, u = 0.25 rad/s, and thickness reduction of 60% while reducing the pre-heating time and temperature (T = 180 °C, t = 18 minutes) resulted in insufficient diffusion bonding.

Results & Discussions
Both two-layered and three-layered clad metal strips were produced by warm rolling. The two-layered specimens are curved after rolling due to mechanical property mismatch. The symmetrical three-layered specimens remain flat. Figure 3 shows the microstructure images of the Vicker micro-hardness test conducted on an AUS/STA specimen. The hardness reading at the interface is between the hardness readings of Al and STS.

SEM investigation and EDX analysis were performed on a two-layered Al/STS specimen. Figure 4 shows the diffusion zone of STS/Al in AUS/STA specimens under the processing condition of t = 30 minutes, ω = 0.90, and 6 ≤ 75. The mechanical property mismatch of the two-layered specimens were reheated at various temperatures. After reheating, significant improvement in diffusion can be observed for specimens with lower rolling temperatures as shown in Figure 5.

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Conclusions
The project aims at establishing a better understanding of diffusion bonding in warm rolling of layered metal strips in unmodified atmosphere environment. The present study focuses on the time and temperature effects on diffusion bonding. It was shown that diffusion bonding can be analyzed and quantified through experimental techniques. Efforts are being made to develop models to predict diffusion bonding. The research will be extended to investigate the effect of plastic deformation during warm rolling and to evaluate bonding strength of the clad sheets.

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