Abstract- Recently, clad metallic materials, consisting of two or more layers, have been preferred in various industrial applications because of their unique corrosion resistance, specific strength, and surface properties. The present study has been carried out on three ply composite laminate, containing AISI304L austenitic stainless steel on one side and AISI430 on the other side with AA1050 in the core of the blank. Apart from excellent corrosion and mechanical properties of stainless steel three ply composite laminate possesses exceptional thermal and electrical conductivities, which makes it useful for utensils formed by deep drawing process. Circular blanks of composite laminate, produced by cold roll bonding, with a combined thickness of 2.5mm, were procured in the annealed condition from a leading manufacturer. To ensure the bond strength of 3-ply AISI304/AA1050/AISI430 sheets, peel tests on various specimens were performed according to ASTM-D1876-08 standard. Tensile samples as per ASTM E8M standard, were laser cut in three different directions i.e. parallel, inclined at 45° and transverse with respect to rolling direction. Tensile specimens were tested to study the deformational behaviour in uniaxial tension, on a 50kN UTM.

Keywords- Clad metals; Three ply laminate composite; cold roll bonding; peel test; tensile behavior.

I. INTRODUCTION

With the advancement in technology in forming with sheet metals, new clad materials have been evolved and designed for various industrial applications such as automobile, aerospace and electrical industries. These laminated sheets consist of different kind of sheet metals with different mechanical, physical properties and specifications to suit the various applications. Various parameters such as material type, thickness ratio, arrangement and multiplicity of the metals, surface preparation, bonding parameters and post heat treatment results in unique deformational behavior [1-5]. Although, Clad sheets have been produced by several solid state bonding methods such as diffusion, explosive and roll bonding but cold roll bonding (CRB) is the most efficient and cost effective [6,7]. Many researchers have contributed significantly on the various issues related to formability of roll bonded clad sheets. In the recent development of the clad sheets, most widely used material combinations are Al with Cu, Al-Fe, Al with stainless steel, Zn- Al with stainless steel, Al-Cu with steel, Ti with steel etc. [8,9]. Akramifard et al 2014 carried out experimental studies on effect of reduction and subsequent annealing temperatures on mechanical properties and bond strength of three layered AA1050-304L-AA1050 clad sheets, during roll bonding. An important contribution of their work was the correlation of tensile and peel test on the basis of principles of mechanics of materials. The mechanical properties of some laminated composite sheets, mainly of stainless steel/aluminium sandwich sheets, have been the subject of examination for many years. Choi et al. 1997 experimentally investigated the deformation behaviour of Al-STS430 bi-layer clad sheets under uniaxial tension and concluded that a difference in planar and normal anisotropy results in the warping of edges of tensile specimens. The material property of the laminated sheet changes in the thickness direction, their deformation behavior should be affected by the blank placement position during forming by deep drawing, i.e. which side of the sheet would contact punch or die. Because of such interesting formability issues, the behavior of laminated sheets is the subject of much research. However, only a few studies have discussed the combination of 3-ply clad sheets of AISI304/AA1050/AISI430. In view of the above the present study deals with the tensile behaviour of 3-ply laminate composite.

II. METHODOLOGY

A. Selection of material

Selection of material is based on the increasing popularity of multi ply clad sheets in deep drawn utensils, owing to the advantages of excellent formability, good surface finish of class of 2B, uniform heating and better heat transfer. Circular blanks of 3-ply clad sheet of AISI304/AA1050/AISI430 material of effective thickness of 0.4, 1.5 and 0.6mm respectively, that are
joined by roll bonding and thermal treatment, due to a metallurgical bond under high pressure, was procured from a leading supplier in India. The chemical composition of individual sheets were obtained by spectrometry-analysys and are given in Table 1.

B. The peeling test

To investigate the bond strength due to CRB, the peeling test was performed according to ASTM-D1876-08 standard (subsized). Specimens for the peel test were laser cut in the sub-size of 160X 25 mm due to limited availability of the material. Since it is difficult to detach the bonded sheets mechanically, one end of the each specimen was immersed in the solution of sodium hydroxide to dissolve aluminium. The remaining length with intact bond was used for the peel test as shown in Fig. 1. The specimens were prepared in such a way that each bonded sheet of steel i.e. AISI304 and 430 be peeled from aluminium bond respectively. The stainless steel sheet to be peeled was held in the lower fixed jaw and the rest with the upper movable jaw fixed with the cross-head on the 50kN UTM. All the tests were conducted at a cross head speed of 10mm/min.

C. The tensile test

Most common approach to characterize the behaviour of a material is by conducting uniaxial tensile tests. In this work, simple tension tests were carried out on a universal testing machine of maximum capacity 50 kN as shown in Fig. 2.

The tensile test specimens as per standard ASTM-E8M, were prepared by laser cutting of the blank as shown in Fig. 4. The anisotropy of the 3-ply clad sheet metal was investigated by performing tensile tests at specimen orientation of 0°, 45° and 90° to the rolling direction (RD) and are shown in Fig. 5. The tests were carried out include monotonic loadings in tension. Each test is performed at least three times to ensure good reproducibility of the experiments. The tests were carried out at a cross head speed of 2.5mm/min. Typical engineering stress strain curve is plotted on the basis of force and displacement data acquired from the dedicated software.

D. Determination of tensile properties

The strain hardening exponent (n) and the strength coefficient (K) values are calculated from the stress strain data in uniform elongation region of the stress strain curve.
TABLE I CHEMICAL COMPOSITIONS OF SHEET MATERIALS USED IN THE LAMINATE

<table>
<thead>
<tr>
<th>Steel Sheet material</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Al</th>
<th>Ni</th>
<th>Cr</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI304</td>
<td>0.05</td>
<td>1.450</td>
<td>0.820</td>
<td>0.044</td>
<td>9.620</td>
<td>18.03</td>
<td>0.009</td>
<td>0.023</td>
</tr>
<tr>
<td>AISI430</td>
<td>0.12</td>
<td>0.902</td>
<td>0.675</td>
<td>0.038</td>
<td>0.621</td>
<td>17.02</td>
<td>0.023</td>
<td>0.026</td>
</tr>
<tr>
<td>AA1050</td>
<td>0.18</td>
<td>0.018</td>
<td>0.156</td>
<td>Rest</td>
<td>0.032</td>
<td>0.012</td>
<td>0.015</td>
<td>0.034</td>
</tr>
</tbody>
</table>

The plot of $\ln$(true stress) versus $\ln$(true strain) which is a straight line is plotted as discussed below:

The power law of strain hardening is given as:

$$\sigma = K \varepsilon^n$$  \hspace{1cm} (1)

where $\sigma$ and $\varepsilon$ are the true stress and the true strain respectively.

Taking log on both sides

$$\log (\sigma) = \log (K) + n \log (\varepsilon)$$  \hspace{1cm} (2)

![Fig. 4. Laser cutting of tensile specimens](image)

![Fig. 5. Tensile specimens at different orientations w.r.t. RD](image)

This is an equation of straight line and the slope of which gives the value of 'n' and 'K' can be calculated taking the inverse natural log of the y intercept of the line as shown in Fig. 8.

III. RESULTS AND DISCUSSION

To determine the bond strength of AA1050 with AISI304 and 430 respectively, the peel test specimens were prepared and tested on 50kN UTM of Tenius Olsen make. The peeling force and distance data were recorded using a dedicated software Horizon and the plot between them is shown in Fig. 6.

The average peel strength was determined as the ratio of peeling force to the peeling width. The range of the peeling strength of AISI 304 from AA 1050 was between 30 to 51N/mm, whereas peeling strength of AISI430 from AA1050 was found to be between 20 to 26N/mm. The experimental investigation showed that the peeling strength of AISI304 is higher than AISI430 by a factor of 1.5 approximately. In both the peeling tests, the peeling
strength remained stable for an appreciable length of 80mm with a slight dip in between at 40mm of peeling distance.

![Fig. 6. Curve between Peeling force and Peeling distance](image)

The peeling strength of aluminium from AISI 304 was 40N/mm on an average basis, whereas the peeling strength of AISI 430 was 25N/mm. Peeling strength became maximum as the peeling distance reaches near the end of the specimens. Same trend was observed in all the tests conducted.

To investigate the deformational behaviour, tensile tests were performed on the specimens cut at three different orientations i.e. parallel to, inclined at 45° and perpendicular to the RD. The various tensile properties are given in Table 2. In all the tensile tested specimens, nucleation of crack was observed to initiate from 0.6mm thick AISI 430 which may be contributed to the lower ductility of this steel grade. Some waviness or warping were seen at the edges of the tested specimens due to the difference in anisotropy of individual sheets. A typical true stress-strain curve is shown in Fig. 7. Tensile specimens oriented at 45° to the RD showed maximum ductility on an average of 57% whereas least ductility was found with the specimens oriented at 0° to the RD. Highest tensile strength of order of 260MPa was observed in the specimens oriented at 90° to the RD and least strength was seen in specimens oriented at 0° to the RD. The strain hardening exponent (n) as shown in Fig. 8, which is an indicator of workability at room temperature was found to be of order of 0.25 on an average basis. High ductility coupled with excellent strain hardening exponent and strength is required in deep drawing of the utensils.

### Table II: Tensile Properties of Composite Laminate at Different Orientations wrt RD

<table>
<thead>
<tr>
<th>Orientation w.r.t. Rolling Direction (RD)</th>
<th>Yield Stress (0.2%σ_y) (MPa)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Percentage elongation (%)</th>
<th>Strain Hardening Coefficient (n)</th>
<th>Strength Coefficient, (K) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>171</td>
<td>242</td>
<td>44.7</td>
<td>0.234</td>
<td>420</td>
</tr>
<tr>
<td>45°</td>
<td>177</td>
<td>254</td>
<td>56.0</td>
<td>0.256</td>
<td>456</td>
</tr>
<tr>
<td>90°</td>
<td>178</td>
<td>262</td>
<td>47.2</td>
<td>0.255</td>
<td>470</td>
</tr>
</tbody>
</table>
Fig. 7. True stress vs True strain plot for composite laminate oriented at different directions

Fig. 8. ln(True stress) vs ln(True strain) plot for composite laminate

IV. CONCLUSIONS

On the basis of the experimental investigations conducted to study the deformational behaviour in uniaxial tension test of 3-ply laminate composite of AISI304/AA1050/AISI430, following conclusions can be drawn:

1. The peeling strength of the bond of AISI 304 with AA1050 is of order of 40N/mm which is approximately 1.5 times higher than that of AISI 430 with AA1050.
2. The peeling strength increases towards the end of the peeling distance.
3. Tensile specimens oriented at 45° to the RD showed maximum ductility on an average of 57% whereas least ductility was found with the specimens oriented at 0° to the RD.
4. In all the tensile tested specimens, nucleation of crack was observed to initiate from 0.6mm thick AISI430 which may be contributed due to the lower ductility of this steel.
References


