Comparison of surface strain for stamp formed aluminum and an aluminum-polypropylene laminate

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Laminate structures incorporating thin layers of metal and polymer, or polymer composite, can offer significant weight savings for engineering structures, while retaining excellent mechanical and impact performance. Laminates based on thin layers of aluminum and glass-fiber/polypropylene thermoplastic have been the subject of recent study [1, 2], and have exhibited excellent specific mechanical properties and superior specific impact behavior compared to monolithic aluminum. Such materials, therefore, have great potential for widespread application in engineering structures. One such potential area is the automotive industry where weight reduction and impact performance are pertinent issues. Lighter vehicles will result in improved fuel efficiency, and greater energy absorption capability may contribute to improved crash performance. However, for the automotive industry it is necessary to produce components using a high-volume manufacturing process such as stamping. Thermoplastic-based materials and sandwich structures are good candidates for stamp forming as they can be heated to conform to the mold, and then rapidly cooled for removal from the mold. Mosse *et al.* [3, 4] investigated the effects of blankholder force, laminate preheat temperature, tooling temperature, and tool radii on FML formability. It was found that significantly lower levels of springback could be achieved over aluminum, and forming defects could be eliminated by restricting process variables to a given range. In particular, it was found that delamination at the bimaterial interface and within the composite layer was eliminated when the laminate was pre-heated to 160 °C then formed in a heated die. This is significant as delamination would adversely affect the mechanical performance of a formed component. Further, Kim and Thomson [5] found that high forming speed increased the transverse stiffness of polymer-metal laminates, in turn reducing the inter-laminar shear and the degree of springback. They also found that laminates forming at elevated temperatures decreased the rigidity but improved the springback characteristics.

This letter presents some preliminary results from research into stamp-forming aluminum-thermoplastic sandwich materials. Here, the permanent strain on the surface of a channel-formed aluminum-polypropylene laminate is compared to monolithic aluminum. Characterization of the strain is significant as it provides insight into the behavior of the material during formation and assists in the production of parameters for subsequent formation methodologies.

The materials used in this study were 5005-H34 aluminum and a self-reinforced polypropylene (Curv, BP). An aluminum-Curv laminate was made in a 2/1 configuration in a 200 × 200 mm picture frame mold. A 0.9 mm thick layer of Curv was sandwiched between two layers of 0.5 mm thick aluminum cleaned with a solvent (isopropanol). A 50 μm thick layer of a hot-melt polypropylene adhesive (Gluco Ltd., UK) was placed at each bi-material interface. The laminate was consolidated by heating to 160 °C in a platen press followed by rapid water cooling under a pressure of approximately 1 MPa. The nominal laminate thickness was 2.2 mm. Samples of 19 mm width were sectioned from the laminate and from a plain sheet of 2 mm thick aluminum. A 3 mm circular grid etched onto the surfaces enabled post-forming major strain measurements, that is in the direction of the sample length, to be made.

Channel sections were stamped in an open die. Plain aluminum was stamped cold whereas the aluminum-Curv laminates were pre-heated to 160 °C then immediately transferred to the die, which was pre-heated to 80 °C. This enabled a temperature window of 125–140 °C to be maintained during the stamping operation. The channel sections were stamped in an Enerpac 30 tonne press using two tool radii of 3 and 7 mm. The blank holder force was 3.5 kN.

Surface strain measurements were taken from ten grids around the mid-point of the sidewall area of the channel section, shown in Fig. 1, using an optical microscope with a graticule scale of 20 μm resolution. Measurements were taken from the sidewall area as it is likely to undergo significant tensile strain during formation. Microscope examination of the sidewall edge, prior to taking the strain measurements, confirmed the absence of delamination.

The average major surface strain for the aluminum and aluminum-Curv samples is plotted in Fig. 2. (The

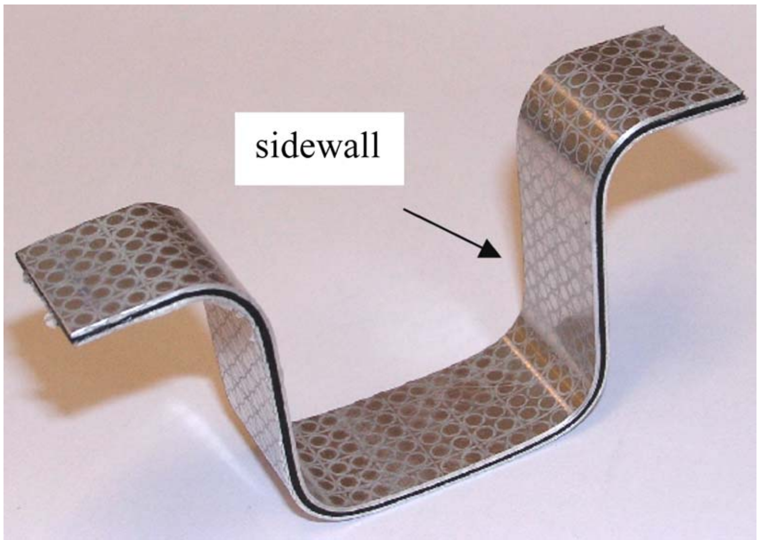

Figure 1 Aluminum-Curv channel section formed with 7 mm tool radii.

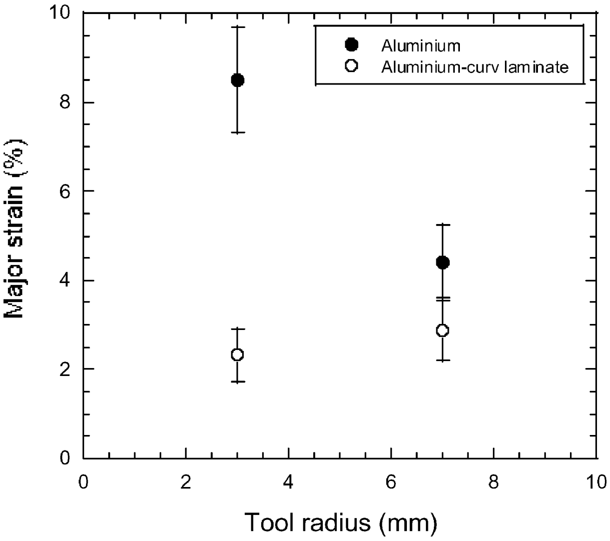

Figure 2 Major strain *versus* tool radii for aluminum and the aluminum-Curv laminate.

error bars signify ±1 standard deviation.) There are two significant conclusions that can be drawn from these results. First, the strain in the aluminum layers of the laminate is lower than in the monolithic aluminum for both 3 and 7 mm tool radii. It is believed that the molten polymer within the laminate has facilitated a different deformation mechanism by allowing the layers to flow over each other and this results in lower surface strain in the laminate compared to the aluminum. Cold-forming aluminum generates a more linear through-thickness strain distribution in a bend region than if the strain distribution is interrupted by a deformable laminate interface such as the molten polymer. The result is greater permanent strain for the monolithic aluminum. Furthermore, the reduced strain in the aluminum layers of the laminate indicates that onset of necking and tearing would occur later in the forming process and would ultimately allow for greater drawing depths. (It is noted that the minor strain was negligible as the two-dimensional channel forming resembles a plane strain condition exhibiting only uniaxial major strain.)

The second point of significance in Fig. 2 is the effect of tool radii. For the monolithic aluminum, the magnitude of the strain for the 3 mm tool radii is twice that of the strain measured for the 7 mm radii. This is expected as smaller tool radii in cold stamping introduce greater strains in the aluminum during the bend-unbend channel forming operation. On the other hand, the aluminum-Curv laminate shows, within scatter, no effect of tool radii on the strain in the aluminum after forming. This is a very significant point for design and high volume production with these laminates. The consistency in the behavior of the aluminum-Curv laminate will allow greater confidence in the material behavior during forming and during subsequent in-service loading.

Overall, the stamp-forming behavior of the aluminum-Curv laminate studied here shows great potential for addressing some problems associated with stamping of traditional monolithic metals. Specifically, the aluminum-Curv laminate exhibits lower strain and is not influenced by a change in tool radii. Further work on the effect of these laminate systems on other important stamping issues, such as springback and dimensional tolerance, is therefore justified.

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Received 2 April
and accepted 30 April 2004