F. Friction-Stir–Joined Aluminum Sheet Materials for Heavy Vehicle Cab Structures

Principal Investigator: Richard W. Davies
Pacific Northwest National Laboratory
P.O. Box 999, Richland, WA 99352-0999
(509) 375-6474; fax: (509) 375-4448; e-mail: rich.davies@pnl.gov

Technology Development Area Specialist: Sidney Diamond
(202) 586-8032; fax: (202) 586-1600; e-mail: sid.diamond@ee.doe.gov
Field Technical Manager: Philip S. Sklad
(865) 574-5069; fax: (865) 576-4963; e-mail: skladps@ornl.gov

Participants:
Scott Wazny, Leon Kaunitz, and Brian Fulbright, Freightliner LLC
Douglas Waldron and Keith McTernan, Advanced Joining Technologies, Inc.
Tom Sanor, Drive Automotive
Gene Paik, Alcoa, Inc.

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Objective

- Develop and deploy friction stir joining (FSJ) as a weight- and cost-saving manufacturing technology for heavy vehicle cab structures.

Approach

- Demonstrate the use of aluminum tailor-welded blanks (TWBs) for heavy vehicle applications.
- Develop and characterize TWBs prepared via FSJ.
- Develop and prototype several cab-in-white structures for Class 8 trucks.

Accomplishments

- Conducted preliminary stamping trials, which indicated that some material combinations and weld geometries can be successfully stamped into parts; this application has the potential for a significant cost and weight savings in heavy vehicle cab structures.
- Investigated new part configurations, using thin-gage heat-treatable alloys and dissimilar alloy combinations (5000 and 6000 series aluminum TWBs).
- Developed welding process parameters to minimize cost and maximize performance of truck components.
- Characterized the formability of welded assemblies through optical strain analysis.
- Characterized the local mechanical properties of the weld metal and surrounding region of AA5052-H32 and AA5182-O TWBs to understand the effect of the welding process on the ductility of the weld metal.
- Assembled successful parts into cabs and conducted full cab durability and crash testing at full truck load.

Future Direction

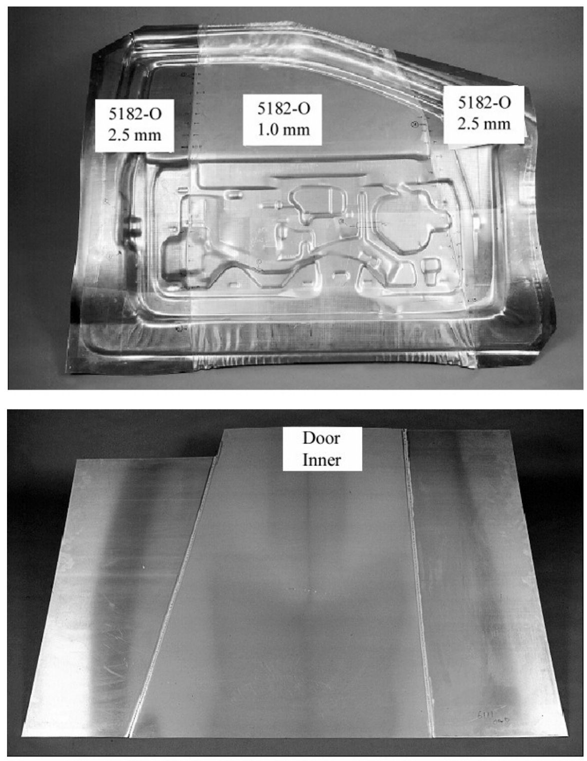
- Continue with the weld process development of 6000 series aluminum to increase the formability.
- Continue with weld process development of aluminum alloy 5052-H32 TWBs and optimize the welding process parameters.
- Investigate the interaction between the weld in the TWB and the joining method used to assemble the blank into the vehicle and determine how this interaction may influence long-term vehicle durability and crashworthiness.
- Develop and optimize the welding process parameters of dissimilar aluminum alloys of different thicknesses (5182-O and 6022 aluminum alloys).
- Conduct a design of experiments on tool development and design to determine the speeds and performances of different tools.
- Focus on FSJ as a low-cost enabler of lightweight, low-cost vehicle assembly (non-TWB).

Introduction

This work is a collaborative effort between Pacific Northwest National Laboratory (PNNL), Freightliner, LLC, Advanced Joining Technologies, Inc., Drive Automotive, and Alcoa. This project aims to develop and deploy FSJ as a cost- and weight-saving manufacturing technology for heavy vehicle cab structures. To date, the project has focused on (1) developing and characterizing TWBs prepared via FSJ and (2) demonstrating their use by prototyping several cab-in-white structures and body panels for Class 8 trucks.

Aluminum TWBs consist of multiple-thickness and multiple-alloy sheet materials welded together into a single, variable-thickness blank. Figure 1 shows a typical fusion-welded TWB before and after a stamping application. A TWB is assembled as a series of flat sheets joined together, which are then submitted to a stamping process. The technology allows production of a weight-optimized, variable-thickness vehicle body component. TWB technology gives automotive and truck designers the ability to selectively vary body panel thickness to optimize the use of material. Successful use of the technology ultimately results in reducing vehicle weight without compromising final strength, stiffness, and durability. The manufacture of TWBs and their application in body panels requires that the weld material deform under biaxial loading during sheet metal stamping. The deformation of weld materials and their limits of formability are important aspects of TWB technology.

The primary challenge of using aluminum TWBs in the past has been the relatively low quality of aluminum fusion welds, which often results in premature fracture or lack of reliability of weld materials during stamping. Improving aluminum weld quality, understanding and describing the formability of the weld region, and predicting its formability



Photos courtesy of Reynolds Metals Company and Ogihara America Corp.

Figure 1. Left: A TWB viewed in the as-welded condition, ready for submission to the stamping process. The shape shown is typical for a door inner stamping operation. Right: Aluminum TWB after stamping to produce a door inner panel.

are the primary technical challenges in using aluminum TWBs.

FSJ is a revolutionary joining technology that employs severe plastic deformation to create solid state joints between wide varieties of different materials. Invented by TWI, Ltd., about 12 years ago, FSJ is capable of producing aluminum alloy welds as good as (or significantly better than) fusion welds in terms of joint efficiency, mechanical properties, and environmental robustness. The advantage of using this solid state joining technique is the ability to avoid liquid metal during joining, where aluminum has low molten viscosity, high reflectivity, and a relatively high propensity to form internal porosity because of the high solubility of hydrogen in liquid aluminum.

Friction stir welding (FSW) can also eliminate hot cracking and minimize heat-affected-zone (HAZ) issues in 6000-series heat-treatable aluminum alloys. Avoiding the liquid phase of the materials also avoids the formation of various large eutectic constituent particles or other undesirable intermetallic particles that develop in particular alloys or with certain types of weld or materials contamination. The use of FSW also better facilitates welding of heat-treatable materials, since the HAZ is normally smaller or less pronounced compared with fusion welding. The use of solid state joining also enables a variety of types of dissimilar aluminum alloy joining not normally possible using fusion welding methods.

FSJ Process Parameter Development

In a previous feasibility study, some alloy combinations were successfully stamped from TWBs fabricated by FSJ. However, weld line failures occurred in many other alloy combinations. The main thrust of this program is to better understand the weld process, forming parameters, and performance characteristics of TWBs and to apply them to a wider range of cab components. The use of FSJ to produce TWBs may result in dramatically improved weld quality and formability of aluminum TWBs—thereby enabling this weight- and cost-saving technology.

In order to develop and use FSJ to make high-quality aluminum TWBs for intermediate- and high-volume truck applications, the FSJ process must be competitive with laser welding and other fusion welding technologies from a production rate perspective. The target weld speeds are 2–5+ meters/minute. The friction stir welds must be of significantly higher formability compared with conventional fusion welds.

This project will develop process parameters to make successful welds in the following weld combinations, as they are representative of typical truck alloys and material thicknesses:

- 5182-O 2 mm to 5182-O 2 mm
- 6022-T4 2 mm to 5182-O 1.6 mm
- 6022-T4 2 mm to 5182-O 2 mm
- 5182-O 2 mm to 6022-T4 1.6 mm
- 5182-O 2 mm to 5182-O 1.6 mm
- 6022-T4 2 mm to 6022-T4 1.6 mm
- 6022-T4 2 mm to 6022-T4 2 mm
- 5052-H111 1.27 mm to 5052-H111 1.27 mm
- 5052-H32 1.6 mm to 5052-H32 1.6 mm

This project will determine, within the "defect-free" process window, where a set of parameters exists that produces a TWB with the best formability (see Figure 2). The process and forming parameters are being developed by FSW test coupons at a range of weld conditions, which are then subsequently tested for strength and formability to establish optimum weld conditions for each material and thickness combination of interest. The following section details the weld characterization performed to determine the optimum joining process parameters.

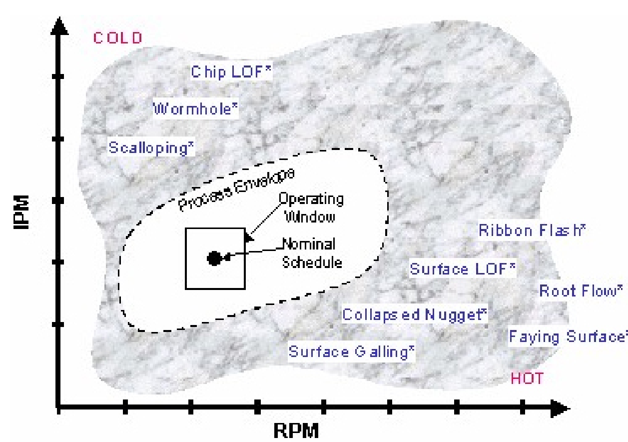


Figure 2. An illustration of the process parameter window to determine the optimum set of parameters that produces a TWB with the best formability.

Weld Characterization

Coupons of the material combinations were friction stir welded by AJT and sent to PNNL for testing and evaluation. These coupons were subjected to limited dome height (LDH) testing, mechanical tensile testing, and microscopic analysis. The results of these studies allow for bracketing of appropriate weld process parameters (i.e., weld speed, heat input, and tool design) that could produce TWBs with the best formability in a stamping process.

LDH testing is used to provide joint metal formability data. Figure 3 shows a typical weld process parameter development matrix. For that particular material combination, the formability increased with weld speed up to 150 ipm, and then the weld quality degraded. Figure 4 shows typical punch-load versus LDH results for ductility and strength of a single population of welded blanks. LDH data also provide strain limits that guide weld placement in die design and predict the chances for successful stamping. Once the most formable FSW process parameters are established, LDH specimens are characterized for surface strains via strain grid analysis. LDH testing can help characterize the maximum strain that can be achieved in the weld or parent material adjacent to the weld. Figure 5 shows a typical illustration of the surface strains measured after LDH testing.

Miniature tensile tests are conducted to characterize the local mechanical properties of the weld metal and surrounding region, as well as to ultimately understand the effects of the welding process on these mechanical properties. Figure 6 is an illustration of the miniature tensile specimen.

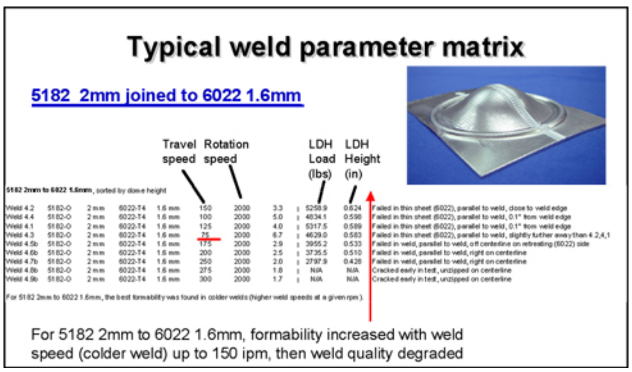


Figure 3. LDH testing conducted to define appropriate weld parameters to produce the highest potential TWB ductility during stamping.

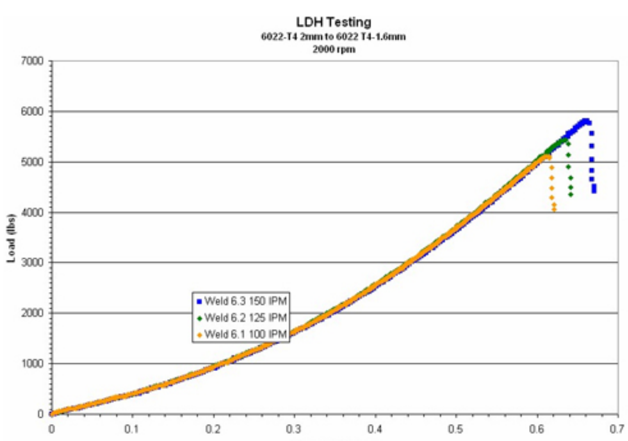


Figure 4. A typical series of LDH tests illustrating ductility and strength trends with changing weld process parameters.

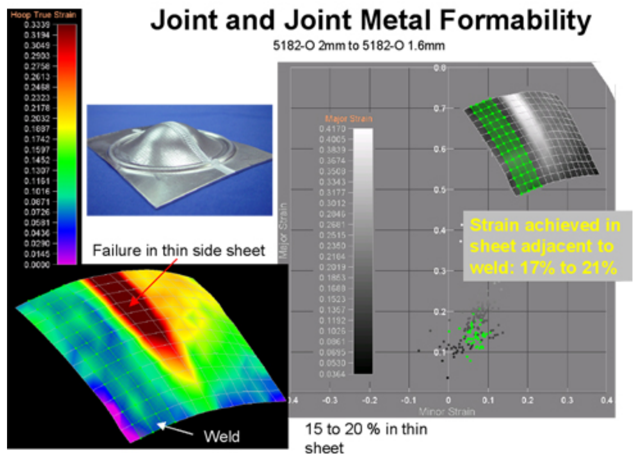


Figure 5. Typical results from LDH strain analysis. Maximum achievable homogeneous true strain in the thin side sheet is 17 to 20% at the point when necking develops.

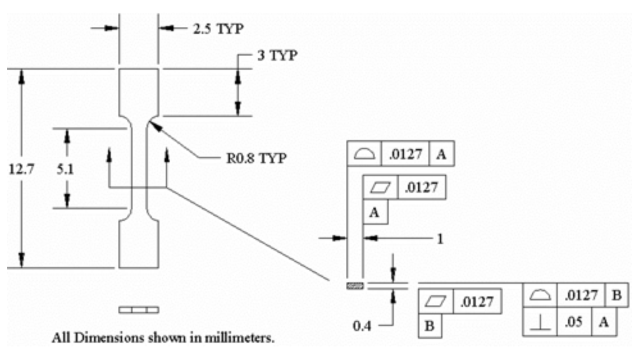


Figure 6. A detailed drawing of the miniature tensile specimen. All dimensions are in millimeters.

Figure 7 shows the location of some specimens extracted from a weld. The miniature tensile results

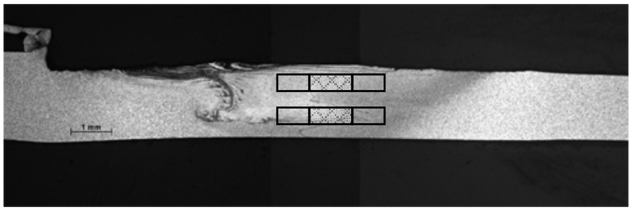


Figure 7. An illustration of miniature tensile specimen locations superimposed in the weld region.

show what mechanical property gradients exist in the weld metal, thermo-mechanically affected zone, HAZ, and parent material. The goal is to match weld metal and parent material flow stresses as well as minimize property gradient across the weld.

For example, miniature tensile specimens were removed from the weld metal and surrounding region of 5052-H32 (1.6 to 1.6 mm) and 5182-O (2 to 1.6 mm) friction-stir-joined TWBs. These experiments showed that significant variations in mechanical properties existed within the weld metal and surrounding regions for 5052-H32 aluminum TWBs, whereas little variation in mechanical properties was observed in 5182-O aluminum TWBs (Figures 8 and 9, respectively).

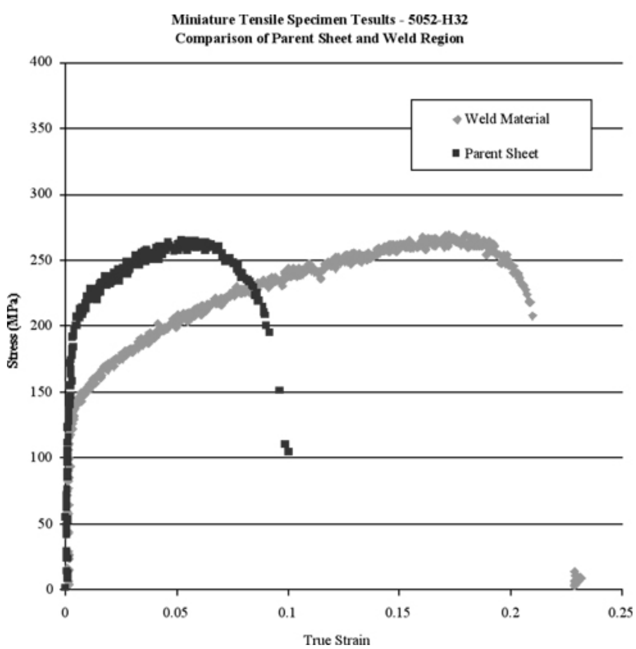


Figure 8. Miniature tensile test results for 5052-H32 aluminum TWB. Specimens shown were extracted from the weld metal and parent sheet material.

Figure 8 shows that the 5052-H32 TWB weld metal is ductile; however, differences in flow stress

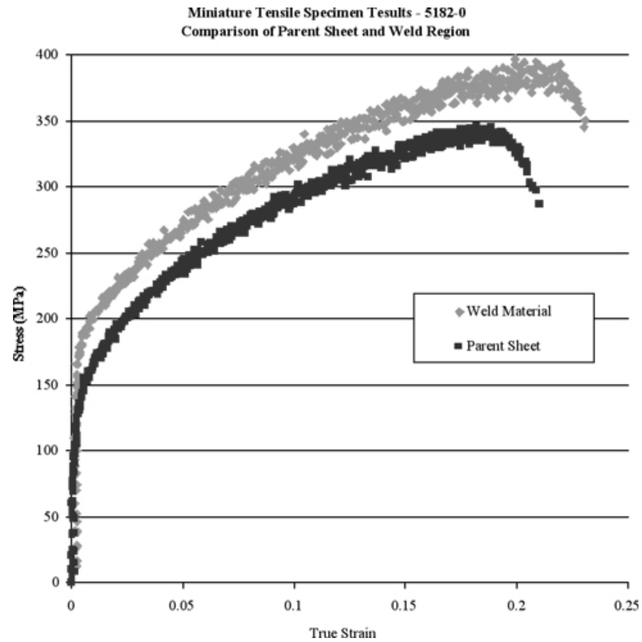


Figure 9. Miniature tensile test results for 5182-O aluminum TWB. Specimens shown were extracted from the weld metal and parent sheet material.

can lead to early localization during forming even though the weld metal shows good ductility. Therefore, one should expect that biaxial stretching (stamping) of the 5052-H32 TWB population will result in greater plastic deformation in the weld than in the parent sheet (and increasing weld failure probability); whereas biaxial stretching of the 5182-O population should result in similar plastic deformation in the weld metal and parent sheet. Further development of the process parameters for 5052-H32 TWBs is needed to determine the optimum joining process for formability.

Conclusions

From this investigation, the following conclusions were derived:

- FSJ appears suitable for fabricating aluminum TWBs.
- The FSJ process is stable, is tolerant, and produces high-quality welds when the weld process parameters are defined.
- The FSJ process is customizable. A wide range of weld heat, plastic work, and weld metal grain-size manipulation is possible with FSW by changing tool design and process parameters. These may be manipulated to achieve the opti-

mum joining process for formability and to create an even property gradient across the weld metal.

- Process parameters can be refined for formability by choosing weld parameters from formability tests (LDH), by adjusting weld heat per unit of weld length to minimize the effect of thermal softening in the HAZ, and by closely matching the weld metal flow stress to that of the parent sheet.

Publications/Presentations

"Evaluation of the Mechanical Performance of Self-Piercing Rivets in Friction Stir Welded Structures," accepted for publication by *Proceedings of Society of Automotive Engineers 2005 World Congress.*

"The Formability of Friction Stir Welds in Automotive Stamping Environments," accepted for publication by *Proceedings of Society of Automotive Engineers 2005 World Congress.*

"Friction Stir Welded Tailor Welded Blanks for Automotive Applications," presented at 2004 TMS Annual Meeting and Exhibition, Charlotte, NC, March 16, 2004.

"Weld Region Mechanical Properties of Friction Stir Welded 5052 and 5182 Aluminum TWBs," proprietary technical report prepared for Freightliner LLC.