WELDING Journal

By Gregory A. Kunkel
and Yuri Hovanski

Fig. 1 — Using high-speed friction-stir-welded aluminum could reduce the mass of a car by more than 40%.

From the Lab to Your Driveway: Aluminum Tailor-Welded Blanks

Auto manufacturers have to improve fuel economy by 60% in less than 10 years, and the welding of aluminum plays a huge role in this change

At current rates of production, more than 235,000 cars and commercial vehicles are produced each day worldwide. The predominant material in the average vehicle is steel, with the metal accounting for 47% of a vehicle (Ref. 1). While abundant and strong, steel is relatively heavy, which is an undesirable trait in the era of eco-friendly, fuel-efficient vehicles.

Indeed, by model year 2025, U.S. regulations mandate the average fuel economy standard meet 54.5 miles per gallon (mpg), a whopping 60% improvement over the 35.5 mpg required of vehicles coming off the line now (Ref. 2). The impending standards literally have auto manufacturers racing to find ways to improve fuel efficiency. Replacing conventional steel alloys is high on the list, and at one third the weight of steel, aluminum ranks as one of the top candidates. Replacing common, high-volume components typically made of steel with parts made of aluminum could reduce the mass of a car by more than 40% — Fig. 1.

Aluminum Replacing Steel?

Even when a thicker gauge of aluminum is needed to meet the same strength and safety standards of steel components, aluminum still comes out lighter. Take the 2015 Ford F-150 — with its aluminum body, the truck comes in as much as 700 lb lighter than its steel predecessor (Ref. 3). Fewer pounds to haul around requires less fuel. Ford can even drop smaller, more fuel-efficient engines in the F-150 while improving performance. All that aluminum and its tertiary benefits results in F-150s that are 5–29% more fuel efficient (Ref. 4). More and more automakers are making the switch to aluminum, as evidenced by Ford's increased aluminum use on the 2015 F-150 and 2017 Super Duty trucks and General Motors' switch to aluminum doors on its 2015 Cadillac CT-6. General Motors (GM) is also now using aluminum lift gates on its Chevrolet Tahoe, Suburban, GMC Yukon, and Cadillac Escalade.

The Price of Fuel Efficiency

The 13th element on the periodic table, aluminum is the most abundant metal in the Earth's crust. But abundance does not diminish its value. According to the Massachusetts Institute of Technology (MIT), in assembly, aluminum can cost 30% more than steel (Ref. 5). But because of its value in terms of recyclability, improved performance, and better fuel economy, aluminum is an increasingly attractive alternative to high-strength steel.

Clearly, for aluminum to become a significant material in car manufacturing, it needs to add value to the automakers. As was the case with the F150, weight reduction added performance benefits — greater towing and payload capacities, and improved power-to-weight ratio for faster acceleration, enhanced handling, and braking responsiveness. Other ways to add value are to reduce assembly and production expenses.

"To lightweight a vehicle and replace steel components with aluminum, the cost of switching process methods needs to be reasonable," said Mark Eisenmenger, director of sales and product development at TWB Company, a leading manufacturer of tailor-welded products. "The entire automotive manufacturing infrastructure is set up for steel. For example, steel uses a lot of magnetics in the assembly line while aluminum uses vacuums. The whole manufacturing process would need to change."

Manufacturing Different Gauges at High Speeds

By leveraging different gauges of aluminum for different parts, auto manufacturers can take advantage of cost savings in using thicker gauges where strength is needed and thinner ones where strength is less of an issue. The cost savings could be huge.

According to Eisenmenger, using two different gauges of aluminum on a door equates to about a $5 savings per door or roughly $20 a car. While not much at first glance, $20 in savings adds up quickly when producing millions of cars per year. To do so, though, would require producing aluminum tailor-welded blanks of different thicknesses at high production speeds, something that previously eluded manufacturers — Fig. 2.

"It's about putting the right amount of material in the right place given the load condition," said Gregory Fata, global automotive technical director at Alcoa, Inc. "Being able to leverage different gauges according to the strength of an alloy allows manufacturers to be much more efficient with their lightweighting efforts. They're able to achieve lighter cars and do so more cost effectively."

Supply Chain Collaboration

At a conference in 2010, Eisenmenger met Yuri Hovanski, a materials processing engineer with Pacific Northwest National Laboratory (PNNL) and a leading expert on friction stir welding (FSW). TWB Company and GM had been working on a way to produce dissimilar-thickness aluminum tailor-welded blanks. Eisenmenger and Hovanski began discussing friction stir welding as a viable means to produce the blanks.

Experiments with laser welding weren't producing adequate results. Turning to a Department of Energy-funded national laboratory for research and development seemed a bit unconventional, but the PNNL had successfully worked with GM in the past, and Hovanski was eager to test the merits of friction stir welding.

A unique collaboration between TWB Company, GM, and PNNL took shape, and shortly thereafter Alcoa joined, rounding out a complete supply chain — materials supplier, advanced R&D, parts manufacturer, and auto manufacturer.

The team first explored several fusion methods — laser welding, laser-hybrid, etc. — to join aluminum for tailor-welded blanks, but the techniques were abandoned due to quality control issues.

"Molten aluminum can be tricky to work with and the fusion methods all employed some degree of melting," said Hovanski. "Fusion techniques increased susceptibility to porosity, hot cracking, and elemental loss in the weld seam, and that is unacceptable when producing welded blanks that are designed for stamping."

Friction Stir Welding Was Too Slow

Friction stir welding (FSW) is a solid-state welding process. As such, it doesn't require melting to join aluminum alloys. The technique uses friction heating and plastic deformation formed by a rotating tool to join metal — Fig. 3.

The high reflectivity of aluminum as well as its low molten viscosity and affinity to form surface oxide can lead to defects in welds when using fusion techniques. Consequently, FSW quickly became the leading contender. Friction stir welding also carries a wider use-case scenario. But, as Eisenmenger put it, "Friction stir welding was very slow."

The technique, while employed routinely in ship and trailer manufacturing, just wasn't fast enough for auto manufacturing, at roughly one third the speed of laser welding. Hovanski and PNNL subsequently set about looking at ways to increase the speed in addition to joining different thicknesses.

Prior to the collaboration, no weld schedules existed that could be modified or adapted to accommodate dissimilar thicknesses greater than a 2:1 ratio — a ratio often needed for automotive tailor-welded blanks. Similarly, there were few instances for the team to benchmark where welding speeds fast enough for auto manufacturing were achieved, and in those few cases the thickness ratios were 1.5:1 or less. Consequently, the team focused on experimenting with a range of different welding parameters, tooling, and fixtures.

Research Breakthrough

Hovanski's research led to the development of high-speed friction stir welding parameters and tooling for the production of aluminum tailor-welded blanks. Utilizing a 12.7-mm-diameter pin tool fabricated from H-13 tool steel and hardened to Rockwell C-45, PNNL achieved welding speeds of 3 m/min. Researchers determined a fixed command position that took into account the deflection of both gantry and spindle bearings to achieve the desired tool penetration and join a 2-mm aluminum sheet to a 1.1-mm sheet. The programmer is able to command a plunge depth. Simultaneously, the machine estimates what the actual plunge depth is, based on known machine deflections.

"We actually found the faster the weld, the better the quality and strength of the joint," said Hovanski. "So, once the parameters and tools for effectively joining dissimilar thicknesses were developed, improving the speed became almost as simple as just accelerating."

Real-World Application

Working with PNNL, TWB Company procured a dedicated FSW machine at its facility in Monroe, Mich. The FSW machine is capable of producing up to hundreds of thousands of parts per year. Based on Hovanski's research,

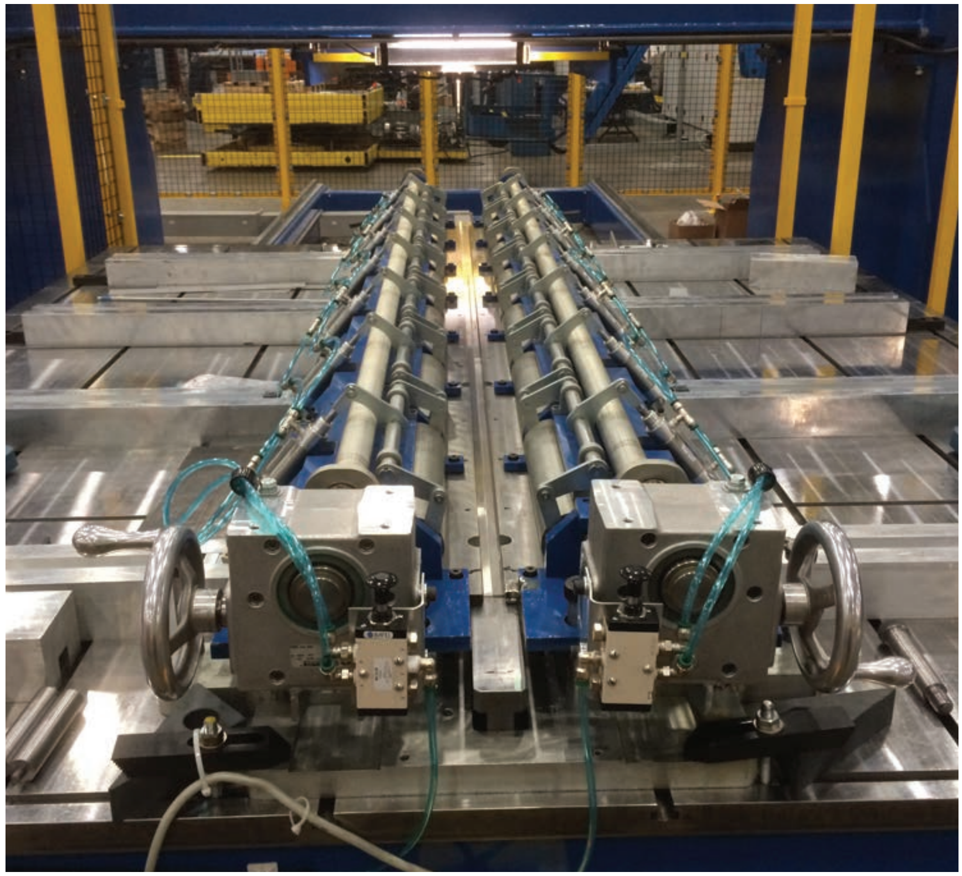

Fig. 2 – New research in friction stir welding may be a key to producing aluminum tailor-welded blanks of different thicknesses at high production speeds.

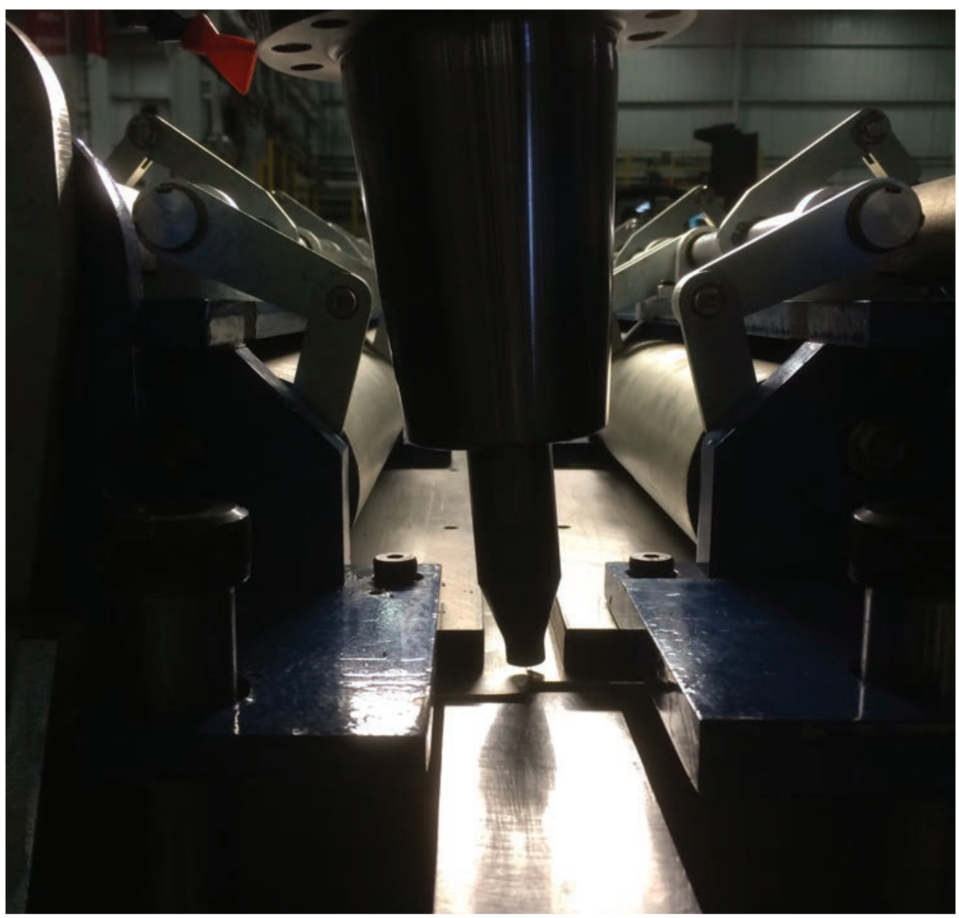

Fig. 3 – Friction stir welding doesn't require melting to join aluminum alloys.

Fig. 4 – TWB Company and GM are both experimenting with high-speeds friction stir welding of their manufactured car parts. TWB can produce welded blanks for an aluminum door that is 62% lighter and 25% cheaper than before.

TWB Company can now produce welded blanks for an aluminum door that is 62% lighter and 25% cheaper than was previously possible — Fig. 4.

In addition to door panels, the same welding technique can be applied to lift gates, body paneling, floor pans, reinforcements, and even engine units. In addition to the machine in Monroe, GM used a machine at its Research and Development Technical Center in Warren, Mich., where GM can experiment with additional applications of FSW.

"Five years from now, there's going to be a lot less steel in cars and a lot more aluminum," said Eisenmenger. "This breakthrough is significant. In theory, all the parts produced from steel tailored blanks could now be made from aluminum."

How fast aluminum encroaches on steel depends largely now on how fast manufacturers can convert their manufacturing processes to aluminum. TWB Company anticipates producing 500,000 doors and 750,000 smaller parts from aluminum tailor-welded blanks in the near future, all rivet free.

The New Normal

The proliferation of aluminum, of course, affects suppliers. "We expect the volume of aluminum used in car manufacturing to continue to increase significantly," said Fata. "Techniques like the one developed by PNNL open a wealth of opportunities for components traditionally not made from aluminum."

Given production cycles, Eisenmenger estimates cars with aluminum parts stamped using the technique developed by PNNL will start trickling out about a year from now. In two to three years, the parts will likely be common components for many manufactured automobiles.

References

1. Kallstrom, Henry. 2015. Raw materials — The biggest cost driver in the auto industry. Market Realist. February 5.
2. United States Environment Protection Agency. 2015. Regulations & standards: Light-duty. Transportation and Climate, Regulations and Standards. December 16.
3. Ford Trucks. 2015. Build & price. ford.com/trucks/f150/.
4. Woodyard, Chris. 2014. Ford sees gas mileage gains in new F-150 pickups. USA Today. November 21.
5. World Auto Steel. 2016. Cost, facing the challenge. worldautosteel.org/why-steel/cost/.

GREGORY A. KUNKEL (gregory.kunkel@pnnl.gov) is technical writer and YURI HOVANSKI (yuri.hovanski@pnnl.gov) is senior research engineer, applied materials and performance, Pacific Northwest National Laboratory, Richland, Wash.