Hybrid Ultrasonic Spot Welding of High Strength Materials

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Introduction

Aluminum and steel are primary materials used throughout automotive and aerospace structures. To join certain alloys or high-strength materials, rivets are often used when adequate welds cannot be achieved. This is not ideal since rivets introduce opportunities for cracks to initiate, increase weight, and add cost. In some cases, these materials can be welded but at the expense of tool damage or accelerated tool wear. Additionally, the material may experience changes in microstructural properties that reduce the strength of the base material at the heat-affected zone creating a weak joint or one prone to cracking.

Background

Ultrasound for welding was first reported in the 1940s as an addition to spot welding and eventually realized to produce welds as a stand-alone technology. In the 1990s, the concept of the hybrid resistance-and-ultrasonic system was reconsidered and conceptualized as a unique or practical joining technique in a handful of patents and publications. Only in more recent years has the hybrid concept has been revisited, but not commercialized.

The hybrid concept, however, should not be overlooked. With the demand of high-strength steels (HSS) and more high-strength aluminum (HSA) being used in vehicles and planes for lightweighting, this joining method shows early indications of being an efficient way to achieve economic and safety goals from a consumer prospective.

The ultrasonic-resistance welding hybrid system works by boosting the individual welding technique's ability to join materials. It is easier to weld aluminum ultrasonically than it is using resistance methods. The high temperatures and fast cooling rates that typically cause cracking of the aluminum during resistance welding do not occur during ultrasonic welding. Instead, the native oxide on aluminum is broken up and redistributed during ultrasonic welding as two sheets of material are scrubbed together at ultrasonic frequencies typically between 20-60 kHz with amplitudes on the order of 25-150μm.

When welding soft aluminum, the ultrasonic sonotrodes can easily displace the surface by grabbing the material to scrub. High strength steel, however, impedes the ultrasonic tooling from adequately holding materials without excessive slipping. In this case, resistive welding is the better option for welding HSS. One of the mechanisms inherent to resistance welding is the ability to reduce the yield strength of the material by applying localized heating through high currents. Implementing this ability could make it possible to weld these HSS, HSA or other difficult materials using ultrasonics. By first applying enough heat to locally soften the material, therefore lowering the yield strength at the interface, asperities can be plastically deformed and sheared without exceeding power draw of the ultrasonic welder.

Hybrid Welding Trials

EWI recently completed a study comparing the hybrid process to ultrasonic metal welding. This paper focuses on the results of the aluminum trials, specifically, aluminum 6061-. This material provided a good baseline for feasibility due to the extensive research and development already published using standard ultrasonic metal welding practices. All test coupons were cut from 1mm thick rolled sheet and were sheared to 25 x 100 mm, deburred, and cleaned with methanol. Test coupons were welded with a 25 mm overlap for shear pull testing.

For the experiments, variables included ultrasonic power and applied current. Time, impedance, and force remained constant for all tests. Baseline ultrasonic welds were made with no applied current and three ultrasonic powers. The same ultrasonic powers were used to make a series of welds with 7kA and 10kA of applied current from the resistance welder.

Results and Discussion

This preliminary study confirmed that ultrasonic welds made with the addition of resistive heating by applied current through the joint are stronger than welds made without resistive heating. All welds made with 7 or 10kA yielded larger weld diameters than those made with ultrasonics alone. Additionally, welds with the applied current required significantly more pull strength to shear apart which can be attributed to the yield strength of the material. Reducing yield strength through resistive heating softened the material, permitted additional plastic deformation of the sonotrode into the material, and enabled more efficient ultrasonic motion to be achieved at the interface. Figure 1 illustrates ultrasonic power versus weld strength for three different current conditions: No applied current, 7kA applied current, and 10kA applied current. All welds with shear strengths over 3400N pulled full weld buttons, including all welds made at 10kA. Some welds at 7kA pulled buttons while welds without any resistive heating remained relatively consistent in strength and no base material was removed during pull testing.

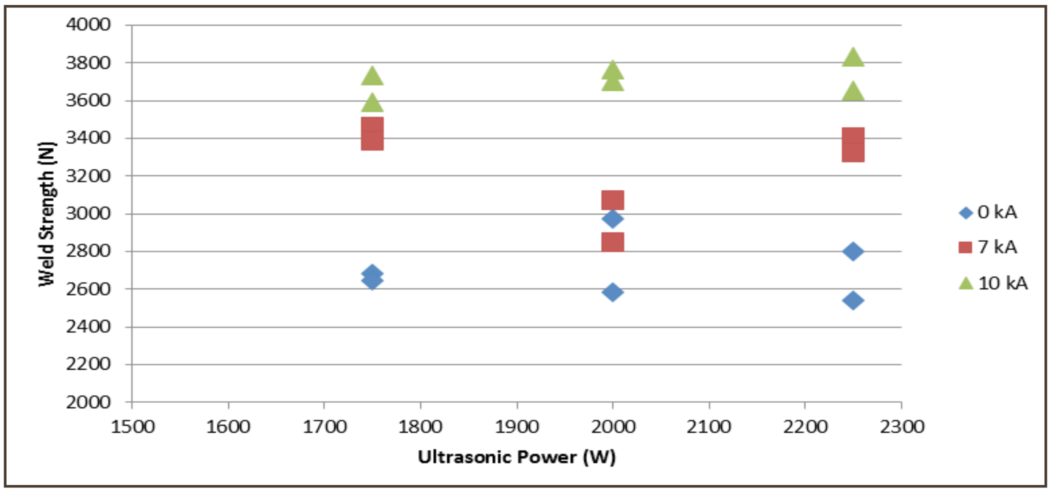

Figure 1: Ultrasonic power vs weld strength at three resistive heating currents. Welds with pull strengths over 3400N pulled full weld buttons.

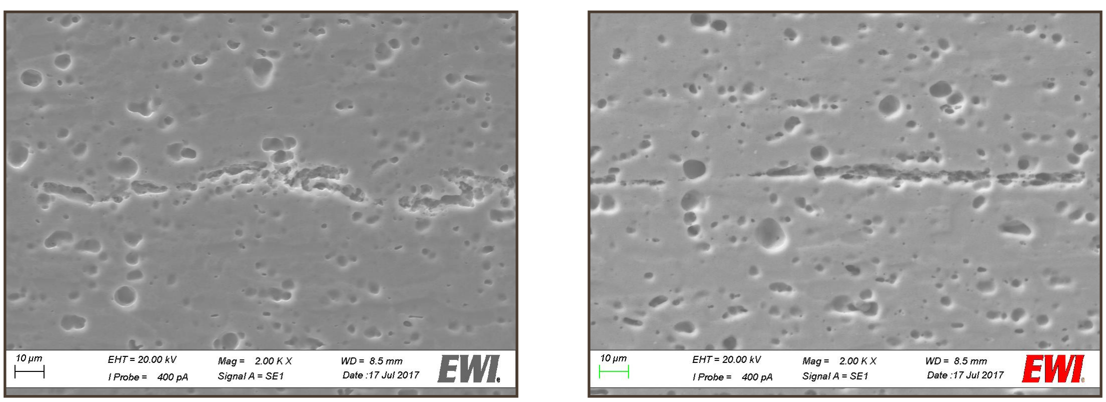

Figure 2: SEM images of aluminum welded using 1750W ultrasonic power. The left image had no applied current, while the right image had 10kA applied current.

Conclusion

A prototype ultrasonic-resistive welding apparatus was used to weld aluminum 6061 to itself. This hybrid process achieved higher strength welds compared to ultrasonic welding alone. The addition of resistive heating during ultrasonic welding enabled pull strengths up to 3800N, and full weld buttons were pulled from the base metal. Without the addition of resistive heating, only interfacial failures were possible during destructive testing.

The success of the ultrasonic-resistive process on an easily weldable material without significant tool damage is leading EWI to the next logical step of proving feasibility with higher strength materials, specifically aluminum 2024 and 7075. Further work is anticipated to continue on these materials as well as on HSS. Dissimilar welding of aluminum to steel will also be explored.

Lindsey Lindamood *is an Applications Engineer specializing in developing techniques for characterizing and monitoring materials using laser and ultrasonic processes. Her specific material knowledge is in aluminum, graphite, and carbon fiber epoxy composites with an emphasis in non-contact ultrasonic evaluation of these materials. She is currently developing processes for monitoring ultrasonic metal welding, advancing capabilities of ultrasonic metal welding, and expanding applications of lasers and ultrasonics.*