Laser Weld-Bonding of Sheet A5754

Joel Bell[1] , Orion Craigue[2] , and Robert W. Messler, Jr.[3]

Abstract

Increased utilization of aluminum alloys in automobiles hinges on development of joining techniques more suited to this material compared to steel. The combination of laser spot welding with adhesive bonding in hybrid weld-bonding seems to offer structural, logistical, and economic benefits. This preliminary study assessed laser weld-bonding compared to laser spot welding and adhesive bonding alone, and found clear evidence of improved shear and peel load-carrying capability, increased energy absorption, and improved performance to 100°C, and a strong indication of synergistic improvement in fatigue limit at 10^6 cycles. Complications in laser welding through structural adhesives appear resolvable using soon-to-be-tested changes in process set-up, adhesive application, or adhesive type.

Introduction

Automobiles have been made predominantly from steel since the emergence of the industry due to the alloys relatively low cost, widely available product forms, well-established design and manufacturing databases, and, perhaps most importantly, diversity of joining methods. In modern manufacturing, a car is assembled while traveling along a production transfer line with most operations being automated, frequently using robots. Speed, efficiency, and consistency are critical to production economics; therefore a fast, reproducible, and reliable method for joining is essential. Resistance spot welding of stacked skins, stiffeners, or structural members using nuggets formed at high-resistance part-to-part interfaces has predominated. This process has its challenges for process control and its share of flaws, but provides acceptable joints when properly executed.

In an effort to reduce weight and, in turn, consumption of resource-limited and polluting hydrocarbon fuels, manufacturers are looking at alternative construction materials. Aluminum alloys are frequently said to offer the possibility of significant

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[1] Joel Bell is a senior in Composites Engineering at Winona State University, Winona, MN, who spent the Summer of 2001 at Rensselaer Polytechnic Institute's Materials Science & Engineering Department as a participant in the National Science Foundation's Research Experiences for Undergraduates.

[2] Orion Craigue is a junior in Mechanical Engineering at Rensselaer Polytechnic Institute who participated in its Undergraduate Research Program as a GM Scholarship recipient for CY2001.

[3] Robert W. Messler, Jr., is Professor of Materials Science & Engineering and Director of Materials Joining at Rensselaer Polytechnic Institute, where he advised Messrs. Bell and Craigue on the GM-sponsored Laser Weld-Bonding Project.

weight savings along with other benefits such as ease of cold-forming, resistance to rusting, superior aesthetics (at lest when unpainted), and economically more-advantageous recyclability. However, for aluminum alloys to be phased into the automobile production line, certain issues must first be addressed; perhaps most notable is the ability to join details into sound structural assemblies.

Welding of aluminum is complicated compared to steel due to its tendency to form a tenacious, refractory, and high-resistance, ever-present oxide. Amenability of aluminum to structural adhesive bonding is only offset by limitations in out-of-plane load-carrying capability (i.e., peel) known to be important in automobiles for crash-worthiness, and, in some areas of the vehicle, to lowered joint strength due to moderately elevated temperatures (e.g., 100°C). The combination of spot welding and adhesive bonding into what is known as “weld-bonding” has been purported to be the ideal solution. This preliminary study sheds some light on the realities of the process of weld-bonding for aluminum-intensive automobile assembly.

Experimental Procedure

Single-lap static tensile shear, coach (T-coupon) peel, and single-lap shear fatigue tests were performed on three different two-ply thickness combinations of AA5754 sheet, with and without an Alcan-proprietary mill-applied dry lubricant, joined by laser spot welding alone, structural adhesive bonding alone, and laser spot welding either through the adhesive or at gaps in the adhesive, namely 1mm-1mm, 1mm-2mm, and 2mm-2mm sheets. All spot welding was done using a 1700 watt CO_2 laser system operated in the continuous mode to produce spots 3mm in diameter at the interface of two-ply stack-ups containing a 1mm sheet and 5mm in diameter for stack-ups consisting of only 2mm sheets. The adhesive employed was a one-part, high-performance, heat-curing, structural epoxy adhesive (Betamate 4601).

Static tensile shear and shear fatigue coupons 1.5” (38.1mm) wide by 5” (127mm) long were overlapped 8mm for specimens containing a 1mm sheet and 15mm for specimens containing only 2mm sheets so as to force failure in the joints by shear. Overlap areas were masked to keep any adhesive out of areas it wasn’t wanted (e.g., intentional gaps to allow laser welding without necessitating interaction with the adhesive). Coach peel specimens consisted of two sheets bonded face-to-face in a masked-off area 1.5” (38.1mm) long. Adhesive thickness was maintained at 0.010” (0.25mm) by embedding 0.25mm diameter glass beads in the adhesive at the bondline. In all cases where adhesive was used, it was heat cured prior to welding and/or testing.

Static tensile shear and coach peel testing was performed in an Instron 4204 machine with a 50 kN loadcell and 1.5” wide grips. Fatigue testing was performed according to ASTM D3166-99 “Standard Test Method for Fatigue Properties of Adhesives in Shear by Tension Loading” using an Instron 8500 machine and 50 kip loadcell. Three tests were performed for each tensile shear and coach peel test condition, while six specimens were used to generate an S-N curve of fatigue behavior for the various test conditions.

Results and Discussion

For bonded-only samples, there was no apparent effect of the dry lubricant on the aluminum, which was expected because the adhesive was designed to work with the adhesive. Lubricant seemed to degrade welded-only shear strengths, seemingly due to porosity, but had no noticeable effect on weld-bonded joint shear strengths. Joint element thickness had no noticeable effect on the bonded-only samples, as expected from the known secondary effect of adherend thickness on joint properties, but joint element thickness did effect the welded-only and weld-bonded samples, with the 1mm-to-2mm combination exhibiting the highest shear strength; seemingly due to the spot size at the sheet-to-sheet interface. Testing temperature had the expected effect of lowering the strength of bonded-only samples, given the viscoelastic behavior o polymeric adhesives, but had no effect on welded-only or weld-bonded samples where the test temperature was very low compared to the aluminum alloy (spot weld) absolute melting temperatures.

For single-lap static tensile shear tests, there was a slight synergistic effect in weld-bonded samples, as the shear strength in the hybrid was slightly greater than the sum of shear strengths observed in samples joined by the individual methods. This effect was much more pronounced in certain thickness combinations, with no explanation at this time. A similar positive synergistic effect of combined welding and bonding was observed in some of the thickness combinations for the fatigue tests; with the fatigue limit at 10^6 cycles being higher than the pure sum of the individual joining processes. This has been logically attributed to the softening effect of the load-spreading viscoelastic adhesive on the stress concentrating effect of discrete spot welds. Coach peel tests showed a clear synergistic effect of the combined processes on energy-absorption, particularly in the thin-to-thick joint element combination. This is logical in that the presence of the adhesive likely slows energy propagation to fracture (or pull-out) spot welds.

Conclusions

Varying degrees of synergistic effects on static tensile shear strength, coach peel, shear fatigue, and joint tolerance of moderately elevated temperature by combining spot welding with structural adhesive bonding to weld-bond aluminum alloys for automobile assembly are offset by complications in joint production. Laser beams clearly interact with polymeric adhesives to cause their thermal decomposition, with sometimes “explosive” outgassing, molten metal expulsion from the weld nugget, and severe charring, as well as their temperature-activated thinning and flow. However, several promising approaches have been identified for future testing, including: modification of the laser spot-welding set-up (to more closely replicate the resistance spot welding process known to work well in weld-bonding); revised adhesive applications procedures (involving altered masking and process sequencing); and even adhesive modifications that permit weld-through without detriment to either adhesive or weld.