

E. Mechanics and Mechanism of the Ultrasonic Metal Weld in Aluminum
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Introduction

Ultrasonic welding of automotive aluminum alloys is a complex solid state bonding process involving rapid frictional and shearing plastic deformation and heating at the faying surfaces, as well as at the tooling interfaces of the parts. While these mechanics-based conditions do not create a bond, they do bring about the conditions for subsequent metallurgical bonding, so that their understanding is critical to any full understanding, including modeling, of the ultrasonic welding process. Further, because forces, velocities and temperatures are all part of describing the process mechanics, they become potential measurement tools for sensing and control of welding. This paper will report on progress in developing a mechanics-based model for the mechanism of ultrasonic welding.

Technical Approach

A mechanics-based model of ultrasonic welding demands the ability to isolate and define the forces and kinematics acting on elements of the welded material or parts, and the defining of properties of the materials/parts in a continuum sense. For the present case, this requires defining the shearing and contact forces at the faying surfaces, and at the tool interfaces, and accounting for the fact that the plastic yielding of the materials is temperature dependent (although temperatures are well below melting). An additional critical feature of the process which must be modeled are the time-varying nature of the deforming contact areas at the faying surface. Finally, it is found that overall part dynamics plays a critical role in welding, and must be accounted for by wave propagation analysis in the structure. These various areas are tied together in an overall mechanics model.

Results/Discussion

Elastic-plastic analysis of the tool-part interface provides force excitation limits before failure in the top part occurs. Likewise wave propagation analysis of part dynamics permits establishing operating windows for successful welds, including conditions of antiresonance where no weld is produced and tool sticking occurs. With these results, it is possible to focus on modeling the shear forces at the faying surfaces, believed to be the governing parameter of the process mechanics. Using evidence on weld area growth gathered from experimental observations, a simple law is postulated for the progressive growth of the weld during the process cycle. This provides the basis for predicting plastic deformation, and therefore heating, during the cycle. Using known data on yield strength as a function of temperature permits the expression for the time-varying shear force in the weld to be determined. An extension of the model was made to include the effects of friction forces outside the immediate weld zone.

Experimental studies on verifying the force and temperature predictions of the model were carried out, the former through use of a unique, shear force sensor, the latter through use of infrared imaging and thermocouples. Results from shear force measurements showed good agreement with trends of data for various conditions of welding, as did correlation of very poor welds with antiresonant vibrations in the parts.

Conclusions:

The mechanics-based model of the ultrasonic welding process, developed in this study, showed good results in predicting some of the main process features. Nevertheless, empirically-based assumptions, such as on weld area growth, are contained that must be replaced by succeeding more accurate developments of the model.