LU 2008 Laser Ultrasonics, Montréal

1st International Symposium on Laser Ultrasonics: Science, Technology and Applications

July 16-18 2008, Montreal, Canada

Laser Ultrasonic Inspection of Adhesives Used in Auto Body Manufacture

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Abstract
Adhesive bonding is widely used in automotive production, especially for body assembly. It is critical to be able to measure the strength of adhesive bonds during manufacture in a nondestructive, effective and rapid manner. There is no current means for inspecting these bonds in real time. The specific inspection requirement is to (1) map the adhesive spread, (2) measure the thickness over the full area, and (3) measure the bond strength. All inspections must be performed from one side and must be able to function on contoured surfaces with ~1 mm spatial resolution. The ideal tool must be able to perform the above measurements simultaneously (i.e., in one pass across the bond). We have applied the technique of laser ultrasonics to the adhesive inspection requirements described above. In this paper, we describe the preliminary results of our study.
Keywords: Nondestructive testing, adhesives, laser ultrasonics, manufacturing

1. Introduction

Adhesive bonding is widely used in automotive production, especially for body assembly. The most common use is the lap joining of two or three sheet metal panels. Adhesive bonding adds strength, and thus allows the use of lighter components at equal performance. Adhesive bonding allows the joining of dissimilar materials such as aluminum and steel. Modern adhesives (especially epoxy resins) have excellent fatigue and thermal shock resistance, and less critical design tolerances because of their gap filling capabilities. Their service range extends from space environments to high temperatures. It is critical to be able to measure the strength of these bonds during manufacture in a nondestructive, effective, and rapid manner.

The most important manufacturing issues that can influence the strength of an adhesive bond are the maintenance of the proper fit-up and proper surface preparation. While adhesive bonds are tolerant of some range of gap between the panels, if the gap is too large, the adhesive will not cover the required area, and the intrinsic strength of the adhesive itself is reduced. If surface contamination (e.g., oil, grease, surface oxides, corrosion, or water infiltration) is present, the bond adhesion will be reduced. In the limit of very low adhesion, weak or "kissing" bonds may have intimate contact, but little or no bond strength.

The corresponding requirements for the nondestructive evaluation of adhesive bonds fall into three areas: (1) mapping of the adhesive coverage, (2) measurement of adhesive thickness, and (3) measurement of the adhesion of each metal/adhesive bond. All inspections must be performed from one side and must be able to function on contoured surfaces. The ideal tool must be able to perform the above measurements simultaneously (i.e., in one pass across the bond).

At the current time, nondestructive inspection is not performed during the bonding process. The common quality control techniques now implemented are careful process control, machine-vision inspection of the adhesive bead before joining, and selective destructive evaluation. A nondestructive technique for the in-line measurement of adhesive integrity would reduce scrap and warranty costs, and thus allow wider use of adhesive joining.

Laser ultrasonics offers an attractive approach for nondestructive evaluation over a broad range of applications. The laser beams can be scanned rapidly over large areas. The pulses are high in bandwidth, thereby providing the high depth resolution required for thin sheets and bonds. The spot sizes on the part can be much less than 1 mm in diameter, thereby providing high spatial resolution.

2. Samples provided

We have received a number of samples for testing. As an example, we show the layout of Samples A1 (uncured) and A3 (cured) in Figure 1. The samples consist of a two-sheet stackup with three adhesive joints distributed along the length of the samples, each joint having a spot weld near the center. The middle adhesive joint also contained a section of Teflon tape to simulate a kissing bond.

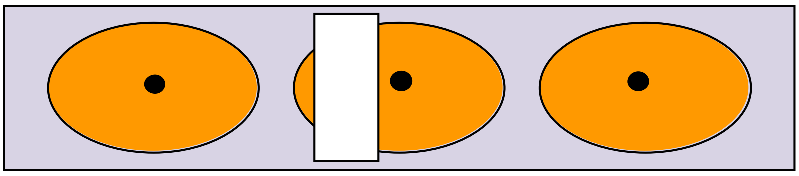

Figure 1. Schematic layout of Samples A1 and A3.

3. Sample scans

Typical maps or C-scans of the center portion of Sample A3 are shown in Figure 2. The amplitude map captures the adhesive spatial coverage and detects the presence of the (unbonded) section of Teflon tape. The time-of-flight map contains grey scale variation that is indicative of the varying thickness of the adhesive. In this latter map, the areas with no ultrasonic arrivals (no adhesive or Teflon tape) appear with random amplitude, as the software is processing only noise.

The maps in Figure 2 were taken with 3 mm steps to speed the data acquisition. An amplitude zoom scan of the left portion of Figure 2 with 1 mm step size is shown in Figure 3. The edges of the adhesive are now resolved to a level required for factory implementation.

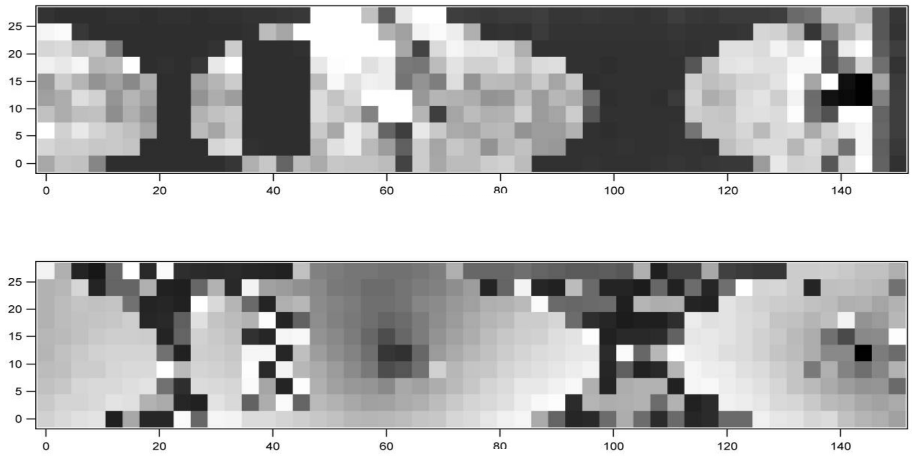

Figure 2. Through transmission C-scans of Sample A3 based on amplitude (top) and time-of-flight (bottom). Step size=3 mm.

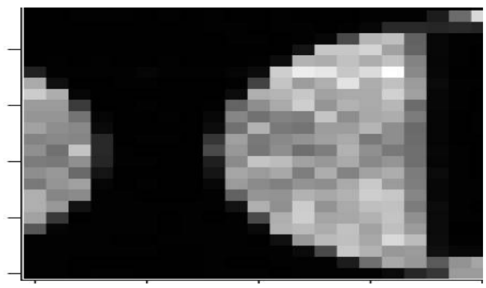

Figure 3. Zoom image of left portion of Figure 2 (top). Step size=1 mm.

All subsequent measurements were performed with both beams on the same side (pitch-catch configuration) and spaced 1-2 mm apart. In this configuration, multiple echoes are expected from both the A and B interfaces (with A the adhesive interface closest to the measurement head, and B the adhesive interface furthest away from the measurement head). The value of the reflectivity at these interfaces is dependent on the impedance values of each material. Specifically, the reflectivity of a steel/adhesive interface (~0.9 in amplitude) is smaller than that of a steel/air interface (very close to 1.0). This difference is not large, but it is sufficient to yield a measurable difference in the amplitude of the interface echoes. We also expect that phase changes could alter the shape of the arrivals. We wish to use these characteristic changes as a means of mapping the adhesive.

In Figure 4, we show a same-side B-scan on a similar sample (F14) in which the beams pass over a gap in the adhesive between position x=-9 mm x=+9 mm. Our beam configuration produces very strong multiple reflections in the front sheet. As indicated above, the reflection coefficient from the back surface of the front sheet is slightly larger when adhesive is absent than it is when adhesive is present. Thus, the reflected wave amplitude is larger over the gap, and the difference from the adhesive areas increases with each reflection. This effect is clearly visible in Figure 4. The clarity of this difference is directly associated with the optimized beam configuration that we have determined. In spite of the clear amplitude difference in Figure 4, it is risky to rely on amplitude alone as an indicator of the spread of adhesive, as many other experimental factors can change the amplitude and possibly give a false positive indication. We are currently developing signal processing algorithms that will define the adhesive boundary and measure thickness in a robust manner.

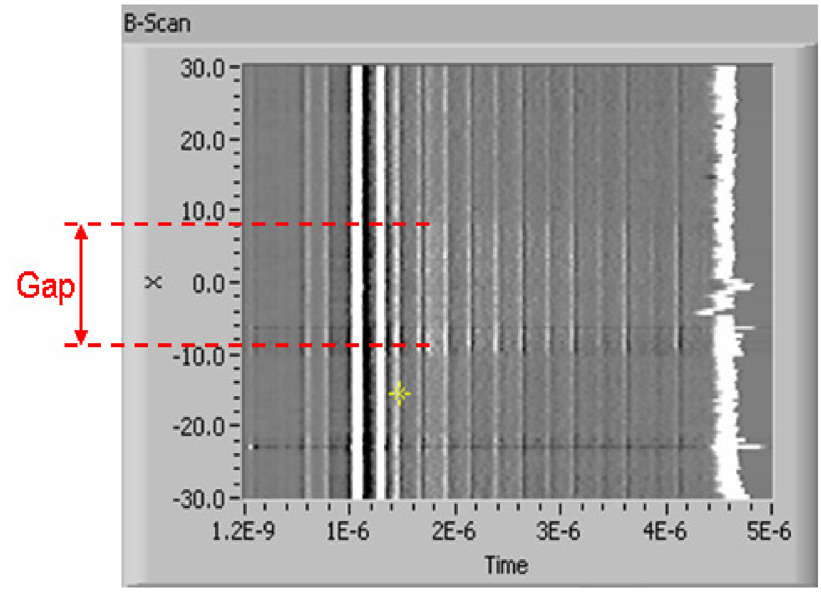

Figure 4. B-scan across 60 mm on Sample F14.

4. Conclusions

Laser ultrasonics has a number of strong benefits for the inspection of adhesives used in auto body manufacture. We have successfully applied laser ultrasonics for this requirement. Techniques have been developed to map the adhesive spread and measure the thickness. Robust signal processing algorithms are now being developed to automate the process.

Acknowledgements

We acknowledge contract support from the U.S. Department of Energy.