

Ultrasonic Inspection of Adhesive Bonds

by

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Abstract

This paper describes work undertaken as a collaboration between the Industrial Research Institute Swinburne and the School of Engineering Science at Swinburne University of Technology. The objective of the research program was to study the nature of adhesive bonds and to determine the feasibility of developing a non-destructive testing approach for the identification of “good” and “bad” bonds. This paper provides an overview of the types of non-destructive evaluation techniques that have been identified thus far, and their suitability for the purpose of detecting various bonding flaws.

1. Introduction

Adhesives have been widely used in recent years as they offer many advantages over other methods that could be used for the same purpose. Advantages, such as the ability to join dissimilar materials, improved stress distribution in the joint, more flexibility in product design and improvement in corrosion resistance, have made them attractive to use. However, limitations, such as necessity for surface pre-treatment, temperature limitations and non-destructive quality testing has hindered their application considerably in the cases where high reliability is required. In the automotive and aerospace industries, adhesives are used very cautiously, due to the extreme consequences in case of failure. They are either over designed to satisfy generous safety factor requirements or used as an additional fastening element where other methods are used as primary fasteners.

Ideally, a non-destructive testing technique that would be able to confidently separate the “good” from the “bad” adhesive bonds would provide a solution to the dilemma of using adhesives liberally in all applications. This paper presents the results of work done toward identifying defects in structural adhesives using Ultrasonic inspection. The materials used are taken from applications in the automotive industry.

2. Adhesive Bond Defects

Defects in adhesive bonds¹ may be generally divided into those that are within the adhesive bulk and those that occur at the interface between the adherent and adhesive. Defects within the adhesive material, due to inclusions of foreign bodies, voids, porosity or cracks, normally affect the strength of the adhesive bulk. Bond failure may also occur due to defects at the interface. These are primarily due to a disbond, in which case there is no contact between adherent and adhesive, or due to a weak bond where the adhesive is in contact with adherent but will become disbonded with lower than expected loads. Figure 1 shows these defects schematically.

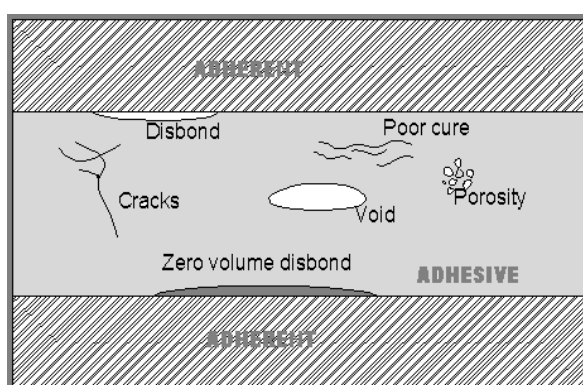


Figure 1 – Typical Bond Defects

3. Normal Incidence Ultrasonic Test Method

The principle of this method is based on the propagation of sound through a medium and its partial reflection in cases where density changes occur in the bulk of the material. These density changes may be due to voids, imperfections, cracks etc that either cause total or partial reflection of the sound wave. When the ultrasonic signal encounters a different density medium than the one it travels, it will be reflected to a certain degree and/or dispersed depending on the nature of the second medium. In the case of normal incidence, this effect can be shown² schematically as in Figure 2(a), where P_i is the incident wave, P_r is the reflected wave and P_t is the transmitted pressure wave and U_i , U_r , U_t , the velocity of incident, reflected and transmitted waves.

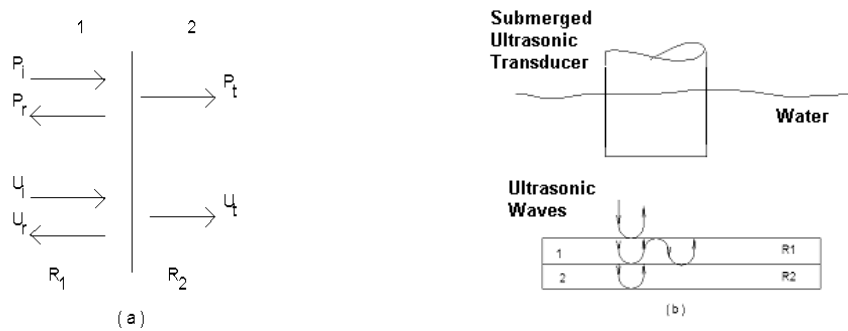


Figure 2 – Normal Incidence Techniques

Referring to specimens used in this research, material (1) is the steel plate and material (2) is the structural adhesive. The sound reflection from the interface of the two materials, will normally depend on the characteristics of the bond. A typical response from this region is shown in Figure 3 where the decay will depend on the impedance of material 1, as well as the ability of the ultrasound signal to penetrate through the interface. Due to the structural characteristics of the adhesive, and the high frequency of the ultrasonic signal, 10 MHz, the wave that enters the adhesive is heavily attenuated³, hence there is no signal returning from the other side of the bonding material.

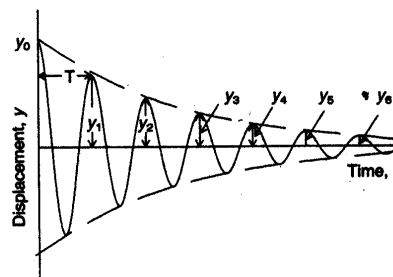


Figure 3 – Typical Bond Characteristics

Based on the principle of signal attenuation at the adherent / adhesive interface, a number of experiments were designed to verify the detection of defects in the bondline.

4. Instrumentation

Figure 4 shows the type and layout of the instruments used for all experiments carried out. The materials used were mild steel sheet, 0.6 mm thick and OrbsealTM 20000 structural adhesive⁴.

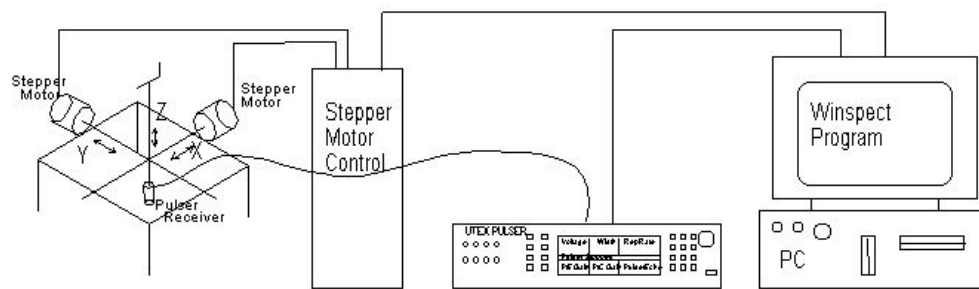


Figure 4 – Experimental Layout

5. Bondline Defect Identification

Firstly, a series of defects were introduced at the interface followed by c-scan tests to confirm that they were clearly detectable and the clarity of detection. The results of this experiment are shown in Figure 5.

A number of intentional defects were placed onto the interface between the adherent and adhesive. These were rectangular pieces of paper cut arbitrarily at different sizes and measured. Figure 5a shows the layout of the paper pieces while the outer rectangle represents the 0.6 mm steel sheet, the inner lob-sided sketch indicates the adhesive patch.

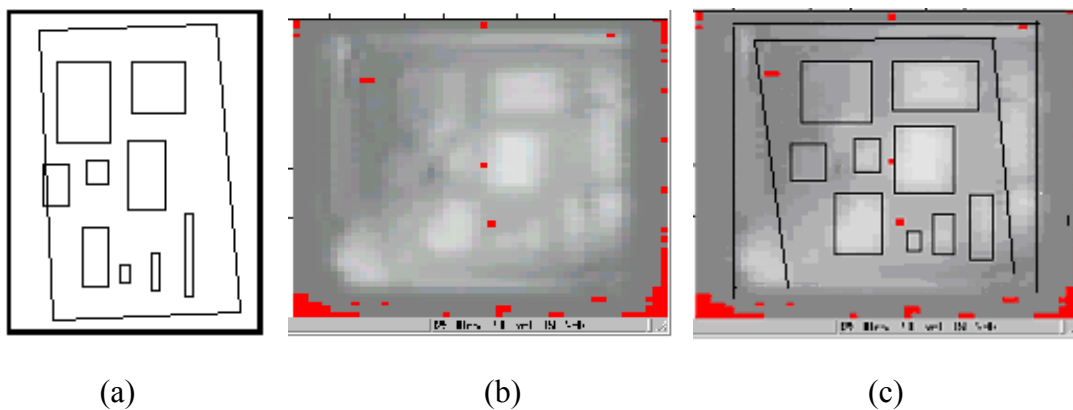


Figure 5 – Bondline Defect Identification

An ultrasonic c-scan was carried out in a water bath with a 10 MHz probe. Figure 5b shows the results of the c-scan when viewed from the steel side. The grey scale image ranges from dark, indicating lower levels of energy returning to the probe to light indicating higher levels of energy returning. The conclusion to be drawn from here is that the better the contact at the bond line, the more ultrasound energy was transmitted through the material hence the lower the amplitude of returning signal.

Therefore the lighter areas indicate defective bonds. One can view the level of correlation between the placement of defects and their detected location, Figure 5c.

6. Bond Failure Prediction

A second experiment was designed to determine whether it was possible to predict, through an ultrasonic c-scan, the areas of failure in an adhesive bond.

A specimen was prepared to determine whether there was a correlation between ultrasonic c-scans of the adhesive bond line and the location of subsequent bond failure. Figure 6 shows the plan and elevation of the specimen, dashed lines showing the adhesive area with a 10 mm strip defect introduced at the center of the adhesive.

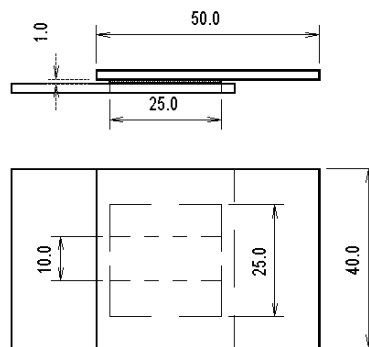


Figure 6 - Specimen

Figure 7a shows the results of the c-scan with varying shades of gray indicating bond line quality.

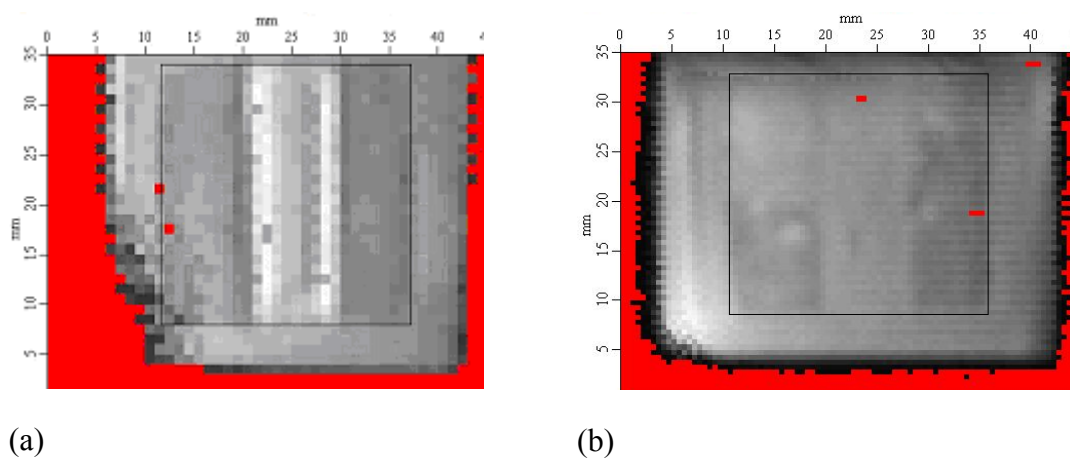


Figure 7 – C-Scan Results

The specimen was subsequently stretched to destruction and the results of the disbanded areas are shown in Figure 7b. Darker gray areas indicate the location of adhesive that did not fail while lighter gray areas indicate where the adhesive was partially or fully disbanded. The results confirm failure predictions.

7. Data and Image Processing

The results from ultrasonic tests are mostly based on analogue signals representing one or more characteristics of the returning wave eg amplitude, spectral properties, form etc. However, the raw data from ultrasonic tests can also be used for further processing without the need of specialized software. Figure 8 shows images from Experiment 2 where the difference between pre and post-destructive test of ultrasonic c-scans were compared. The small (dark) values of the result indicates good correlation between the two. The software Image J^{TM5} was used for the image calculations.

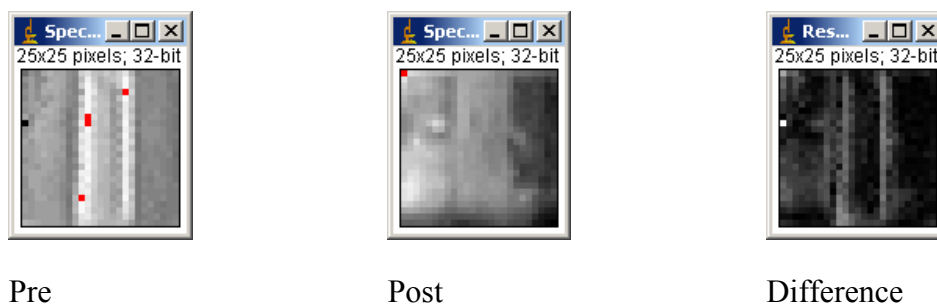


Figure 8 – Images from Experiment 2

8. Conclusion

Non-destructive evaluation of adhesive bonds is an area of great interest to researchers as there has not yet been a universal solution that is capable of evaluating the quality of bonding to acceptable confidence levels. In a DDIAC newsletter⁶, this area was described as one of three “Holy Grails of NDE”. However, as this research and associated references, have shown, science and technology has come a long way towards reliable means of evaluating adhesive bond quality. It may not be a universal solution researchers should be aiming at, but rather specialized techniques for each specific application.

9. References

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