STRENGTH OF ADHESIVE BONDED JOINTS

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ABSTRACT

A Non-Destructive Technique using Acousto-Ultrasonic principle was developed to evaluate aluminum shear lap joints. The technique permits strength prediction of the joint with 99% confidence level (or any other required level) and is simple to use. The theoretical background has been provided and experimental results have been put forward. The basic features of fractured adhesive surfaces, as examined under a zoom microscope, have also been described.

KEYWORDS

Acoustic-Emission, Acousto-ultrasonics, Adhesive-bond, Confidence interval, Shear-lap-joint, Stress-wave-factor, Ultrasonics

INTRODUCTION

An Adhesive Bonded Joint is the union of materials by adhesives, which according to ASTM definition is a substance capable of holding materials together by surface attachment. Not only do adhesive bonds succeed in transferring loads from one component to another, but they do this so efficiently that problems such as stress concentrations in and around rivets/bolt holes and thermal stresses around welds are dramatically reduced. In addition to better fatigue strength and fuller utilization of the bulk-material, adhesives also result in weight reduction(Cagle, 1968 a).

EXISTING TECHNIQUES AND THEIR RELATIVE MERITS

Visual inspection of assemblies for discrepancies such as wrinkles and voids along visual bond line, alongwith coin or mallet tapping for determining the bond quality qualitatively, is the oldest form of Non Destructive Evaluation of joints. The technique involves problems associated with operator, and therefore, can not be regarded as reliable.

Liquid crystal inspection and birefringent coating inspection involve indirect measure of heat conduction property of the joint. The unbond portions have lower heat conduction due to presence of a convective air layer between the two panels. X-radiography, microwave testing and the ultrasonic testing (Raisch,1979) are also being used for determining unbond areas. These techniques, however, do not provide reliable quantitative data for prediction of joint strength.

Sonic test systems, eddy-sonic system and Fokker-bond test system involving measurement of the acoustic response of the joint, permit joint strength prediction with certain degree of accuracy, but are not fully satisfactory because of one reason or the other (Cagle, 1968 b).

TECHNIQUE EMPLOYED

As is well known, a wave changes its wave-form in a complex manner depending upon the internal features of the medium through which it passes. This characteristic was exploited to evaluate the quality of adhesive bonds. Ultrasonic wave-trains of similar type may be injected into the bond from one adherend and the wave form emerging from the other adherend, possibly containing all informations about the bond may be studied. To study wave-form use of Acoustic emission technique shall prove quite beneficial. It is quite possible that if ultrasonic wave-train is injected from the reverse side and sensed, the waveform could be different than the previous one. To overcome this, one may inject ultrasonics from the reverse side as well.

Another approach for evaluation of bond quality may be based on the following argument. If the bond quality is good,application of load shall result in the movement of adherends on macroscopic level and dislocations on the microscopic level. These movements shall be less as compared to movements for poorly bonded joints. Since, these movements cause acoustic emissions, the emissions can predict bond quality. Therefore, one may load the joint suitably and then measure the Acoustic Emission Counts. The commonsense logic of more the activity, more the chances of bond being poorly bonded and vice versa appears to hold good.

PRINCIPLES OF ACOUSTIC EMISSIONS AND ACOUSTO-ULTRASONICS

Acoustic emissions may be defined as elastic waves spontaneously generated, within the volume of the material, due to release of stored elastic energy as the material undergoes plastic deformation, phase transformation or fracture.

Acoustic Emission testing involves deformation of materials,picking up of emissions thus produced by a suitable piezoelectric transducer and processing the signal to obtain meaningful inferences. A typical method of processing is to count the number of times the emission signal exceeds a predetermined signal amplitude threshold. By this method, a single event may be counted several times and large signals are weighed more heavily than smaller ones. These counts are known as 'ring-down counts'. Another method is that of counting the events, which are defined as starting at the first threshold crossing and ceasing to exist when there has been no further crossings for a set period of time known as the "lock-out time" (of the order of 100 microseconds) (Prakash, 1980). A further simple way is to use a RMS meter to provide mean pulse amplitude as a function of elapsed time during a test.

The usual approach in Acoustic Emissions is to wait for spontaneous signals, and therefore, it can monitor only growing defects. This makes the process irreversible (Kaiser effect)and the repeatability is lost. In acousto-ultrasonic method, ultrasonic pulses are injected to simulate stress-waves in the material. The modified stress-waves are then picked-up by the acoustic emission transducers and processed electronically to obtain useful data (Vary, 1979). This technique has also been used for characterizing composite materials (Vary, 1982).

EQUIPMENT USED

For the experimental work, an acousto-ultrasonic equipment(Model 206 AU) was employed. This consists of three main sections, viz.

pulser section, acoustic emission section and display section.

Using a broadband transducer, the Pulser Section injects ultrasonic pulses into the material. The resulting waveform is sensed by "sensor" (receiving transducer) and processed by Acoustic Emission Section. The Display Section consists of an oscilloscope display which presents the continuously repeating bursts of the received signals and includes a three and a half digit LED display which counts the number of threshold crossings in a set (adjustible) period of time.

The instrument can also be used as a stand alone Acoustic Emission monitoring device. The Fixed and Automatic (floating) threshold capabilities augment the counting function. The floating threshold rectifies the continuous background noise, then sums this voltage with the dc threshold voltage. This produces a dead-band which inhibits the counter from accumulating counts caused by noise.

TEST METHOD

'Simple Lap Shear' specimens (Fig. 1) were prepared according to ASTM D1002-72 procedure. Commercially available epoxy adhesive under the trade name "Aral Lite" was used for bonding the Lap-Coupons. The surface treatment and cure procedure were varied to obtain bonds of different strength. Chemical surface treatment using sulfuric acid (22.5 parts by weight), Sodium dichromate (7.5 parts by weight) and water (70 parts by weight)

(Martin,1967) was given to coupons at different temperatures for varying lengths of time. Room temperature cure was done,for 24 hours under a slight pressure (to just keep the coupons aligned) as specified in the instruction sheet for use of the "Aral Dite" adhesive. The joined panels were sawed using a power saw to yield three specimens.

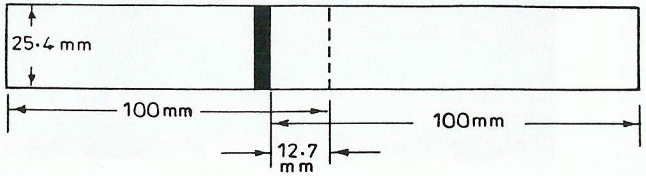

Fig. 1. Bonded Shear Lap joint.

Using a suitable fixture, readings of SWF (stress wave factor) were taken in both 'Fixed' and the 'Auto' threshold mode. The process was repeated on the reverse side of the specimen also. Probe assembly was always pressed with a constant dead weight of 5 kgf against walls of the fixture. This allowed transducers to be pressed only by their internal spring forces. To permit evaluation of all the layers and sublayers of the adhesive bond ultrasonic pulses were made to enter the bond through one adherend and were sensed through the other (Fig. 2).

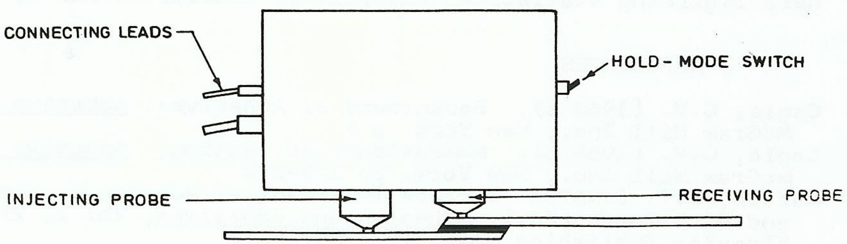

Fig. 2. Probe Assembly on specimen during Acousto-ultrasonic Test.

Acoustic Emission Evaluation was performed while determining the actual strength of the bond destructively on a Hounsfield tensometer. The specimens were loaded slowly and total Acoustic Emission Counts were recorded in 'Fixed' threshold mode. Readings were taken at 5 kgf, 10 kgf and 15 kgf loads. The final load at which the specimens broke was recorded as its "bond strength". All these tests were performed at a time when the noise interference was a minimum.

RESULT AND DISCUSSIONS

The following seven independent variables (predictors) were used to predict the bond strength :

Maximum and minimum values of SWF at fixed threshold.
Maximum and minimum values of SWF at Auto threshold.
Cumulative ring-down counts at 5 kgf, 10 kgf and 15 kgf loadings.

Using the aforementioned predictors, linear multiple-regression was done on a computer.

It was observed that the breaking load has best correlation with the maximum value of SWF at 'Fixed' threshold and next best correlation exists between breaking load and minimum value of SWF at 'Fixed' threshold. (The respective Correlation Coefficient values obtained were 0.9235 and 0.6788.)

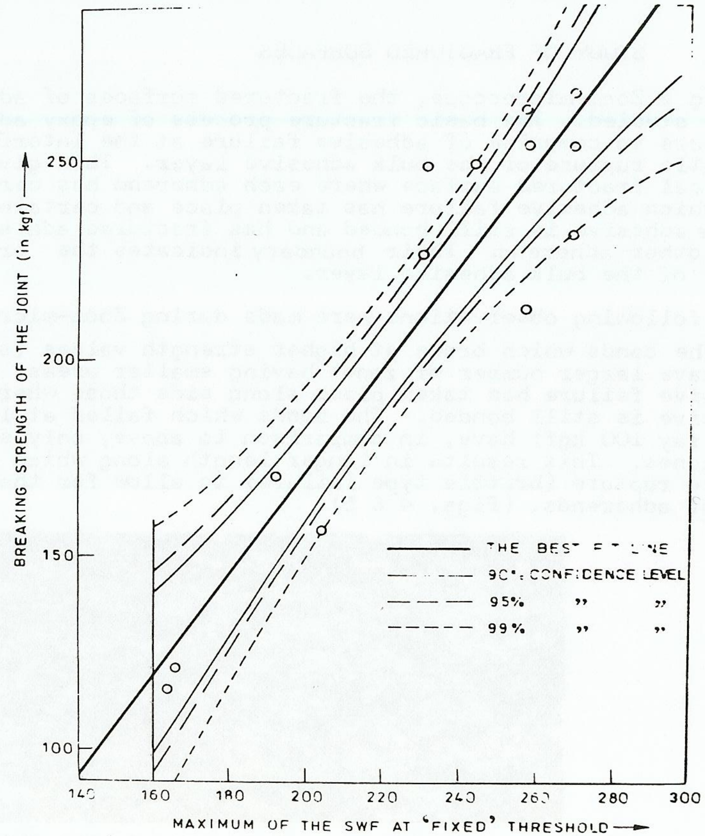

Fig. 3. Correlation Curves for different Confidence levels.

If one takes into account a linear combination of predictors, the accuracy increases marginally. However, the student t-values for most of the predictors decrease with the increase in number of predictors. Also multiple-predictors model is more complex in nature. Hence, the single-predictor model was used. The result obtained using single predictor model is given as Fig. 3.

The confidence level curves were also obtained and drawn as shown by three distinct pairs of curve in Fig. 3. These three pairs are corresponding to 90%, 95% and 99% confidence levels.

The confidence level should be selected according to the job requirement, i.e. greater the criticality of the joint, higher is the confidence level required.

The shown curve is for a particular epoxy adhesive, subtrate material and the joint geometry and dimensions. Therefore, if any of the above is changed, new curves must be plotted for correlation.

STUDY OF FRACTURED SURFACES

Using a Zoom-microscope, the fractured surfaces of adhesive joints were studied. The basic fracture process of epoxy adhesive bonds appears to comprise of adhesive failure at the interface, and brittle rupture of the bulk adhesive layer. This gives rise to a typical fractured surface where each adherend has certain areas on which adhesive failure has taken place and certain others where adhesive is still bonded and has fractured adhesively from the other adherend. Their boundary indicates the brittle rupture of the bulk adhesive layer.

The following observations were made during Zoom-microscope study:

1. The bonds which broke at higher strength values (say 250 kgf) have larger number of zones having smaller areas, where adhesive failure has taken place along side those where the adhesive is still bonded. The bonds which failed at lower loads (say 100 kgf) have, in comparison to above, only some such zones. This results in longer length along which the bond has to rupture (brittle type failure) to allow for the seperation of adherends. (Figs. 4 & 5).

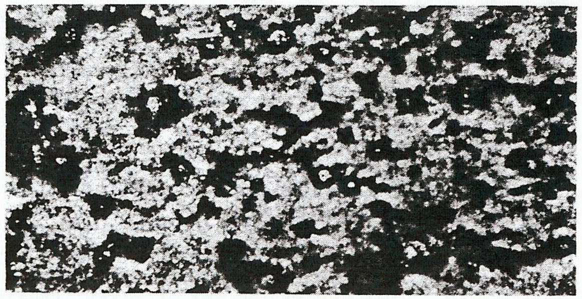

Fig. 4. Micrograph of fractured bond which broke at 250 kgf.

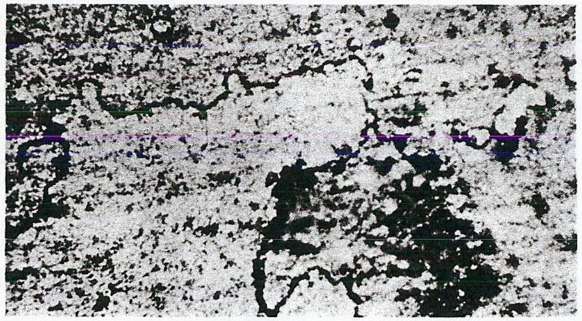

Fig. 5. Micrograph of fractured bond which broke at 100 kgf.

2. The above mentioned zones have sharp edges in case of bonds which fractured at lower loads, than the zones for the bonds which fractured at higher loads.

3. The type of fracture in the bulk adhesive layer is brittle.

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REFERENCES

Cagle, C.V. (1968 a). Background of Adhesives, Adhesive Bonding, McGraw Hill Inc., New York. p 5

Cagle, C.V. (1968 b). Nondestructive Testing, Adhesive Bonding, McGraw Hill Inc., New York. pp 229-272

Martin, J.T. (1967). Surface Treatment of Adherends. Houwink, R. and G. Salomon (Ed.), Adhesion and Adhesives, Vol 2, 2nd. ed. Elsevier Publishing Company, p 89.

Prakash, R. (1980). Non-destructive testing of composites. Composites, Vol 11, No 4, 217-224

Raisch, J.W. and J.L. Rose (1979). Computer-Controlled Ultrasonic Adhesive Bond Evaluation. Materials Evaluations, Vol 37, No 6, 55-64

Vary, A. (1982). Acousto-Ultrasonic Characterization of Fibre Reinforced Composites. Materials Evaluations, Vol 40, No. 6, 650

Vary, A and R.F. Lark (1979). Correlation of Fibre Composite Tensile Strength with the Ultrasonic Stress Wave Factor. Journal of Testing & Evaluation, Vol 7, No 4, 185-191