ACOUSTIC EMISSIONS IN EPOXY ADHESIVE DYNAMIC PEEL SPECIMENS CONTAINING INTERFACIAL LAYERS.

H. Taylor, W. C. Law, J. P. E. Pyykkö, D. L. Chadwick and R. E. Davis*

Reliable applications of adhesive bonded joints require understanding of the stress distribution along the bond-line and the stresses that are responsible for the joint failure. To properly evaluate factors affecting peel strength, effects off defects such as voids on the stress distribution in the overlap region must be understood. It is found that the acoustic emission signals for the fracture of adhesive bond containing voids showed more and greater peaks than void-free adhesive bonds. The strength of the bonds with no voids is greater than the void-free bonds. There is not a significant difference in acoustic emission in the bonds containing little or no interfacial layer. Bonds containing interfacial layers generated smaller and fewer acoustic signals during fracture than bonds without interfacial layer.

INTRODUCTION

Adhesive bonding has been used extensively in the aerospace and other high-technology industries and has a great potential for applications in other areas of manufacturing. It is attractive because it distributes stress over the entire bond area and eliminates the stress concentrations, which can occur with mechanical fasteners. Bonded joints have the potential advantages of a good strength-to-weight ratio, design flexibility and ease of fabrication. Failure of epoxy resins is often due to crack initiation at or near the interface and the substrate. Pao (1), Knollman (2) and Crompton (3) have identified interfacial layers between aluminium substrates and epoxy adhesives which differ in chemical composition and mechanical properties from the bulk adhesive. Pao (1) has shown that in single lap shear bonds the stress intensity factors and fracture parameters of interfacial cracks are strongly influenced by the ratio of the Young's modulus of the interfacial layer and that of the bulk adhesive.

The bonding of automotive structures constructed from galvanised steel sheet is currently being evaluated and in previous work the authors (4) have identified filler barren layers between a calcium-silicate filled single-part epoxy adhesive and both galvannealed and hot dip galvanised steel substrates. This work assessed the effect of such interfaces on the mechanical properties of single lap shear joints and the impact strength of such metal-to-metal bonds.

Department of Chemistry and Materials, Manchester Metropolitan University.
Ford Motor Co. Dunton Research Centre.

Applying a mechanical load to a composite material can result in many types of damage: debonding between the reinforcement and the matrix material, matrix cracking, failure of the reinforcement and delamination in the case of layered composites. To create a better understanding of the initiation, growth and interaction between different types of damage, damage monitoring during mechanical loading is very important. Acoustic emission is the only non-destructive test technique capable of detecting all of the above damage types in composites.

The acoustic emissions from such samples, which are converted from the time domain to the frequency domain, show a reduction in the higher frequency components in bonds containing filler barren layers. The impact energies and acoustic signals from a range of substrates are presented which show a relationship between the incidence of filler barren layers, the reduction in impact energies and the change in the frequency content of the acoustic signatures.

EXPERIMENTAL PROCEDURE

The substrates used in this work were hot dip galvanised and mild steels. The hot dip galvanised steels were minimised spangle and normal spangle. They were both chromate finished. The mild steel substrate was prepared by removing the Zn-Fe surface layer from the galvanised steel using 50% HCl. The adhesive used to bond these substrates was Ciba Geigy XB5315 epoxy. From previous work [4] it is known that substantial qualities of interfacial layer material exist in bonds involving minimised spangle, chromate-finished galvanised steel. Smaller amounts were found with normal spangle, chromate-treated galvanised steel, whilst no interfacial layers were present in the bonds with the mild steels.

Two sets of bonded samples were prepared using different techniques. The initial technique produced voids in the epoxy whilst the later technique avoided void formation. The initial specimens were prepared by cutting the sheet metals into 20 mm x 70 mm trips and cleaning with 1200 emery cloth and acetone. They were subsequently dried with methanol and stored in desiccator for 24 hours prior to bond assembly and cure. A PTFE tape was wrapped around the substrate to ensure the bond length was 30 mm and removed after cure. To assure the thickness of adhesive bond, 0.25 mm diameter of glass beads was used. The specimens were cured at 180°C for 30 minutes. Each specimen was bent to an angle of 4° at the end of bond length after curing. An instrumented Drop Weight Impact Machine (figure 1) was used in the tests. Specimens were placed on top of a stationary wedge and struck by a weight that was travelling with a velocity of 2 ms^{-1}. A piezoelectric load cell, model M208A05 of PCB, was positioned at the end of the weight to record the forces during impact testing. An acoustic emission transducer was located at one of the unbonded ends of the specimen to monitor the acoustic signal during fracture. The transducer was fastened by a rubber band to the specimen to ensure that they did not separate during impact testing. Lubricant was applied between the transducer and the substrate to avoid damaging to the sensitive sensor. Acoustic transducer, model R6D of Physical Acoustics Corporation, was linked to 60dB preamplifier with plug-in 20KHz high pass filter. Acoustic signals and the forces generated during fracture were collected and analysed by a PC with PC414 A2 card and PC414WIN software. Load-time and amplitude-time graphs were produced and the total energy absorption of each test during fracture was calculated.

Preparation of the void-free specimens was the same as described except copper wire spacers and insulation tapes were used instead of glass beads and rubber bands. The substrates were baked in the air furnace at 130°C for 24 hours before bonding. Initially substrates were 20 mm x 75 mm and the bond lengths were 35 mm. These were cut down to the correct size after curing. A 0.28 mm diameter wire spacer was placed at the top of the epoxy bond and the PTFE tape was wrapped around the substrate to maintain the bond thickness (figure 2). Adhesive was then applied to the substrates and left in desiccator for another 24 hours. After curing, 5 mm of adhesive (including the wire spacer) from the top of the bonded joint with the wire was discard. The PTFE tape was also removed before bending to the correct angle.

RESULTS AND DISCUSSION

Table 1 shows the results of the total energy absorption of the tests. The strength of the bonds which containing no voids are greater than the bonds with voids in all the combinations. The mild steels/epoxy bonds are stronger than the galvanised steels/epoxy bonds in all four cases. Minimised spangle; chromate-finished galvanised steel spangle/epoxy bond, which high volumes of interfacial layers were found, gives the lowest bond strength

Typical load-times graphs and acoustic emission signals in the frequency range 90kHz-100kHz for the fracture of bonds with and without voids are shown in figure 3a-b & 4a-b. There is a sharp peak from both of the load-time graphs. It is believed that they are caused by fracture of the bonds or crack propagation although there is no stronger evidence related to the acoustic emissions. The signals show more peaks for specimen containing voids and the amplitude of the peaks is greater. Some of the acoustic emissions from the fracture of adhesive bonds containing voids may be caused by the breaking of the glass beads or by the sliding of the acoustic transducer during fracture. Nayeb-Hashemi [5] suggested that cumulative acoustic emission (AE) ringdown counts and cumulative acoustic energy were decreased with increasing void size. It would be expected that smaller bonding areas would give rise to reduced crack propagation and therefore decreased cumulative acoustic energy. Although, the results obtained from the present experiments disagree with those of Nayeb-Hashemi, further analysis of the acoustic signal and attempts to raise the frequency range are continuing.

Bonds in which little or no interfacial layers were found (i.e. with normal spangle, chromate treated galvanised steel and mild steel) showed similar acoustic emission signals. This was true for both bonds containing voids and bonds that were void-free. A figure 5a shows that the force for the fracture of the bond which containing interfacial layers (minimised spangle, chromate-finished galvanised steel) is very low. This fracture of bonds produced emission signals with fewer peaks and less background noise (figure 5b). Microcracks are often associated with interfacial layers. These defects may be caused by shrinkage during the formation of the interfacial layer in the bulk adhesive [4]. The presence of the microcracks may explain why the acoustic signals and the required forces are small, as less crack propagation is required for fracture.

CONCLUSION

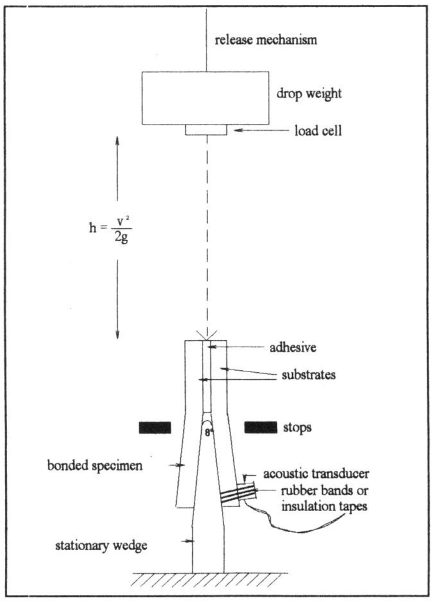
- The acoustic emission signals for the fracture of adhesive bonds containing voids showed more and greater peaks than that of void-free adhesive bonds whilst the total energy absorption for the fracture of the bonds with voids was lower than that of the bond without voids.
- No significant differences in acoustic emissions were produced from the fracture of bonds containing little or no interfacial layers.
- Adhesive bonds with interfacial layers were displayed the lowest bond strength.
- Bonds which containing interfacial layers generated smaller and fewer acoustic signals during fracture than bonds without interfacial layers.

REFERENCE

1. Pao Y.H., Morman K.N. and Dickie R.A., On the Effect of an Interfacial Layer on The Fracture Behavior of Interface and Subinterface Cracks in Single-Lap Shear Joints, Journal Adhesion Sciences Technology, 1990, Vol4, No. 6, pp503-520.
2. Knollman G.C. & Hartog J.J., Experimental Determination of the Variation in Shear Modulus Through the interfacial Zone of an Adhesive, Journal of Adhesion, 1985 Vol17 pp251-272.
3. Crompton J.S., Interfacial Properties and Stability in Bonded Aluminium, Journal of Materials Science, 1989 Vol 24 pp1575-1585.
4. Taylor H., Chadwick D.L. and Law W.C., Fracture of Epoxy Bonded Dynamic Peel Specimens Containing Interfacial Layers, Layered Structural Materials '97, The Institute of Materials, The Royal Society, London, 28 November 1997.
5. Nayeb-Hashemi H. and Jawad O.C., Theoretical and Experimental Evaluation of the Bond Strength Under Peeling Loads, Journal of Engineering Materials and Technology, Oct 1997, Vol 119, pp415-421.

Specimens	Voids				Voids-free			
	Normal spangle, chromate		Minimised spangle, chromate-finished		Normal spangle, chromate-finished		Minimised spangle, chromate-finished	
	GS	MS	GS	MS	GS	MS	GS	MS
Total Energy Absorption	2.6 ±0.3	6.4 ±2.3	22.4 ±0.3	5.0 ±1.3	13.5 ±0.3	16.5 ±0.5	11.5 ±1.7	12.5 ±4.6

Table 1. Total Energy absorption for the fracture of galvanised steel (GS)/epoxy and mild steel (MS)/epoxy bonds.



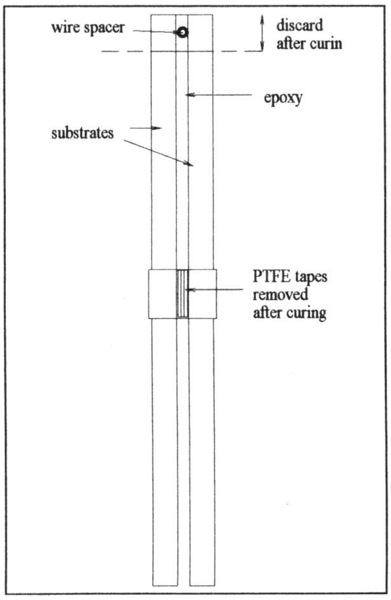


Figure 1. Schematic of the Drop weight impact.

Figure 2. Peel test specimen.

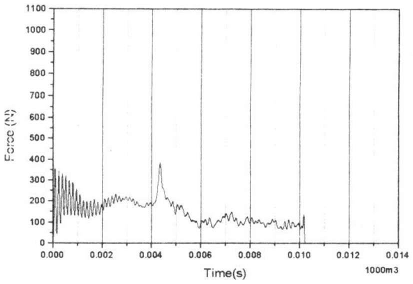


Figure 3a. Load-time curve for the fracture of the bond containing voids.

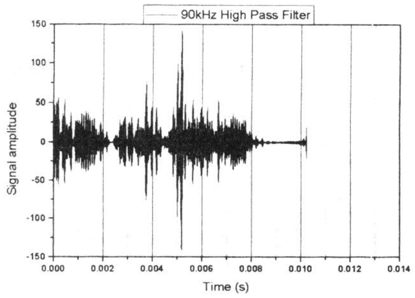


Figure 3b. Acoustic signals for the fracture of the bond containing voids

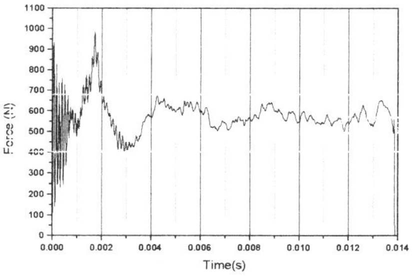


Figure 4a. Load-time curve for the fracture of the bond without voids.

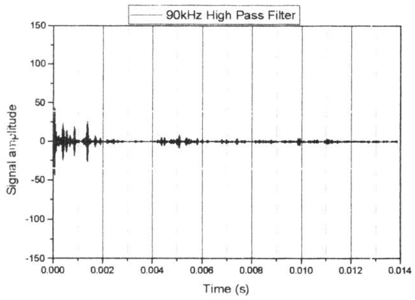


Figure 4b. Acoustic signals for the fracture of the bond without voids.

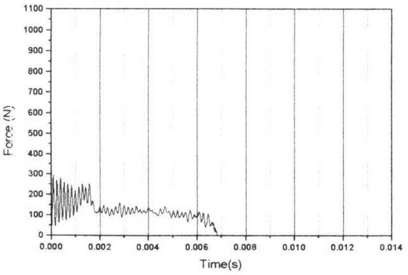


Figure 5a. Load-time curve for the fracture of the bond with interfacial layers.

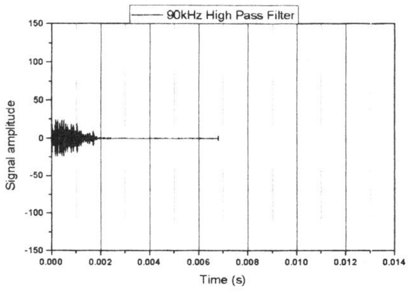


Figure 5b. Acoustic signals for the fracture of the bond with interfacial layers.