Investigating the Effect of Displacement Rate on Deformation and Failure Mechanisms in Bonded Elastomers

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Introduction

Bonded sandwich laminates are being used widely in various industries. They have been successfully used in aircraft and space structures, pipes, chemical tanks, ship hulls, and in other structural applications in which a high strength-to-weight ratio is a desirable feature.

Joining structural components with adhesives provides a number of advantages. Bonding does not require rivet holes, which are stress raisers and may cause premature failure either under static or fatigue loading. In fact, it has been shown that the fatigue strength of a stiffened panel in an aircraft structure is considerably improved when the stiffeners are bonded to the panel. The bonding of damping materials to metal sheets, to form a sandwich structure, currently is being considered as an effective way to control noise-induced fatigue (sonic fatigue) of airframes. In solid rocket motor design, the bonding of insulation materials to motor casings is used to protect the casing from high temperature after the motor is fired.

In this study, the effects of displacement rate on strain distributions and the failure behavior in a bonded bi-material specimen under three displacement rates, 0.0254 cm/min, 0.254 cm/min, and 2.54 cm/min, were determined using the computer aided speckle interferometry (CASI) technique (1-2). Two different viscoelastic materials were used to make sandwiched specimens. The experimental data were analyzed and the effect of applied displacement rate on strain distributions and interfacial failure mechanisms, consisting of interfacial crack initiation and propagation, in the bonded specimen are discussed.

The Experiments

In this study, bonded specimens were used to study the deformation behavior of the specimen. The specimen consisted of three layers. The middle layer of the specimen was bonded to the two outer layers with an adhesive material, known as KALEX urethane. The two outer layers were made of a particle-reinforced rubber, whereas the middle layer was a non-reinforced rubber. The heights of the outer layers and the middle layer were 5.08 cm and 0.254 cm, respectively. The thickness of the specimen was 0.508 cm and the width of the specimen was 1.25 cm. The specimens were loaded by tension with a constant displacement rate under an Instron 1000I test machine. Three displacement rates (0.0254 cm/min, 0.254 cm/min and 2.54 cm/min) were considered. During the test, images were captured by a CCD

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUL 2005**	2. REPORT TYPE **Extended Abstract**	3. DATES COVERED **00-07-2005 to 00-07-2005**

4. TITLE AND SUBTITLE
Investigating the Effect of Displacement Rate on Deformation and Failure Mechanism in Bonded Elastomers

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Chi Liu; Fu-Pen Chiang

5d. PROJECT NUMBER
2302

5e. TASK NUMBER
0378

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory (AFMC),AFRL/PRSM,10 E. Saturn Blvd.,Edwards AFB,CA,93524-7680

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Bonded sandwich laminates are being used widely in various industries. They have been successfully used in aircraft and space structures, pipes, chemical tanks, ship hulls, and in other structural applications in which a high strength-to-weight ratio is a desirable feature. Joining structural components with adhesives provides a number of advantages. Bonding does not require rivet holes, which are stress raisers and may cause premature failure either under static or fatigue loading. In fact, it has been shown that the fatigue strength of a stiffened panel in an aircraft structure is considerably improved when the stiffeners are bonded to the panel. The bonding of damping materials to metal sheets, to form a sandwich structure, currently is being considered as an effective way to control noise-induced fatigue (sonic fatigue) of airframes. In solid rocket motor design, the bonding of insulation materials to motor casings is used to protect the casing from high temperature after the motor is fired. In this study, the effects of displacement rate on strain distributions and the failure behavior in a bonded bi-material specimen under three displacement rates, 0.0254 cm/min, 0.254 cm/min, and 2.54 cm/min, were determined using the computer aided speckle interferometry (CASI) technique (1-2). Two different viscoelastic materials were used to make sandwiched specimens. The experimental data were analyzed and the effect of applied displacement rate on strain distributions and interfacial failure mechanisms, consisting of interfacial crack initiation and propagation, in the bonded specimen are discussed.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES **5**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

camera (Kodak) at various time intervals and they were processed on a personal computer. In particular, a CMOS high-speed digital camera (FASTCAM-X 1280 PCI) was used in the highest speed (2.54 cm/min) case. These images were then analyzed by CASI so as to determine the displacement fields of the specimen. In order to enhance speckle quality, aluminum powder (20 micron), was sprayed on the surface of the specimen.

Results and Discussion

A plot of load versus displacement curves is shown in Fig. 1. According to Fig.1, for a given applied strain, the load increases with increasing displacement rate, or the slope of the curve of higher displacement rate is larger than that of lower displacement rate (2.54 cm/min > 0.254 cm/min > 0.0254 cm/min), which indicates the viscoelastic behavior of the two materials. Experimental data also show that, for a given displacement rate, the load versus displacement curves for three specimens tested are almost the same except one set of data for displacement rate equal to 2.54 cm/min.

For displacement rate equal to 0.0254 cm/min, the test usually lasted about 27-33 min and the ultimate displacement was 0.69-0.84 cm. For most cases, very shallow surface cracks along the interfaces appeared at 8-12 min. For the displacement rate equal to 0.254 cm/min, the duration of the test dropped quickly and just lasted about 3-4 min and the ultimate displacement was 0.76-1.02 cm. The first surface cracks appeared at 60-80 sec. For the displacement rate equal to 2.54 cm/min, the duration of the test lasted about 0.3-0.4 min and the ultimate displacement was 0.76-1.02 cm. The first surface cracks appeared around 6-8 sec.

The failure mechanisms in the bonded specimens were investigated. Experimental results revealed that, in general, the interfacial failure mechanisms consisted of interfacial crack initiation and propagation. It was observed that very shallow interfacial cracks were formed along the interfaces between the adhesive layer and the outer layers of the specimen. As the applied load was increased, large surface cracks developed at different locations in the interfaces. The interfacial surface cracks propagated in the horizontal and the thickness directions along the interface. In general, the initiation and evolution of failure mechanism of all the specimens was insensitive to the displacement rate.

After the specimens were broken, the separated sections were observed. A typical image, showing the separated interface, for 2.54 cm/min displacement rate is shown in Fig.2. From Fig.2, it is seen that, the cracks propagate mostly along the interface, but they kink into the outer layer of the specimen to some extent. Experimental findings indicate that increasing the displacement rate, by a factor of 10 or even a factor of 100, doesn't cause any significant change in the crack growth mechanism.

As we have mentioned before, the bonded specimens were loaded by tension with different displacement rates. By using a CCD or CMOS camera, the speckle images of the specimen surface were taken at various time intervals. Then using a CASI program, the deformation between two speckle images was calculated. The displacement increment along Y direction between the (i-1) and (i+1) min, Δv is calculated by CASI. The strain increment $\Delta\varepsilon$ can be obtained by the numerical differentiation of Δv with respect to Y. Then, the average strain rate of the ith min can be calculated as

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$$\dot{\varepsilon} = \Delta\varepsilon / \Delta t \qquad (1)$$

Where Δt are 300 sec, 20 sec, and 2 sec for displacement rate equal to 0.0254 cm/min, 0.254 cm/min, and 2.54 cm/min, respectively.

Fig.3 is a typical Δv distribution along Y direction. This is an average result of fifty sections along the width of the specimen. It has been noted that the Δv curve can be fitted by 5 linear sections, AB, BC, CD, DE and EF. Points B and E are located at the upper and lower interfaces, respectively. It is interesting to see that there exist two interphase layers BC and DE, which are located in the middle layer. The strain increments of the five areas, top outer layer (AB), upper interphase (BC), middle layer (CD), lower interphase (DE), and the bottom outer layer (EF), can be approximated by the slopes of each linear section respectively. Then using equation (1), the average strain rate can be obtained. The slopes of the Δv curve in the interphase layers are higher than those in the center and the outer layers of the specimen, indicating the strain rate in the interphase layers are higher than that in the center and outer layers. A typical plot of strain rate versus time for the 5 different sections is shown in Fig. 4. According to Fig.4, the average strain rates in the two outer layers are almost constant, which is close to the global strain rate. On the other hand, prior to the formation of interfacial cracks, the strain rates in the interphase layers and the center layer continue to increase with time, and they are significantly higher than those in the two outer layers. It is interesting to note that, once the cracks appear, the strain rates in the interphase layers increase slowly or even drop down. This is due to the crack formation resulting in the relaxation of constrains at the interfaces and the stresses re-distribution.

These phenomena discussed above exist in all of 0.0254 cm/min, 0.254 cm/min and 2.54 cm/min cases. The effect of changing displacement rate by a factor of 10 or 100 alters the strain rate magnitude but the strain rate verses time curves are of the same general form.

Conclusions

In this study, deformation and failure mechanism in a bonded specimen were investigated under three different displacement rates (0.0254 cm/min, 0.254 cm/min and 2.54 cm/min). Experimental results indicate that the effect of displacement rate on the deformation behavior is considered small and the failure process of all the specimens are of a same general form, with debonding taking place along the interfaces. Experimental results also indicate that the strain rates in the two outer layers are close to the constant global strain rate. However, the strain rates in the middle and the interphase layers increase with increasing time and they are significantly higher than that in the outer layers.

References

1. D.J. Chen and F.P. Chiang, Applied Optics 3, 225 (1993).
2. D.J. Chen, F.P. Chiang, Y.S. Tan, and H.S. Don, Applied Optics, 32 1839 (1993).

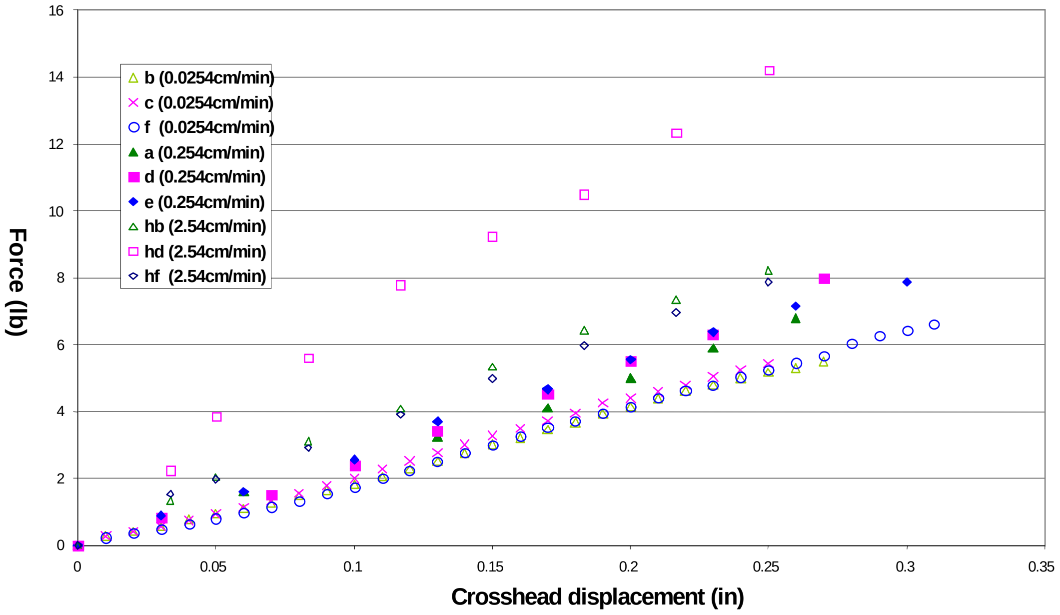

Fig.1. Force versus Crosshead Displacement

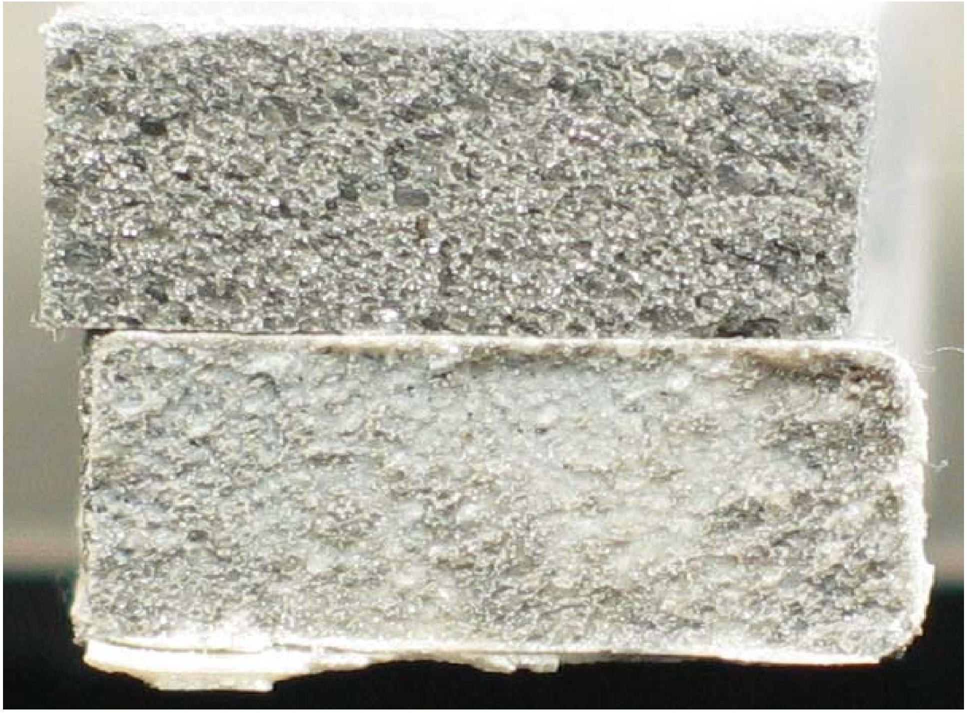

Fig.2. Fracture Surface (Displacement Rate = 2.54 cm/min).

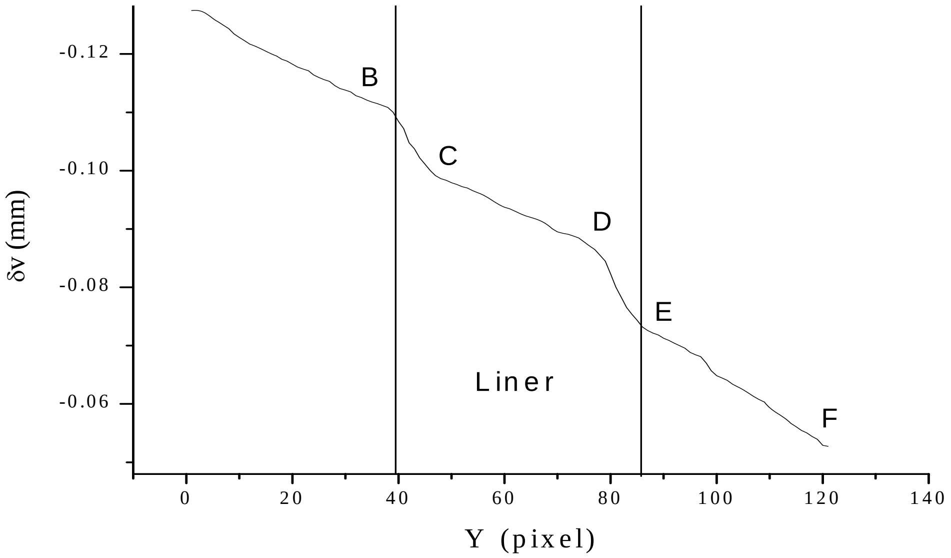

Fig.3. A Typical Plot of Displacement Increment Distribution along Y Direction.

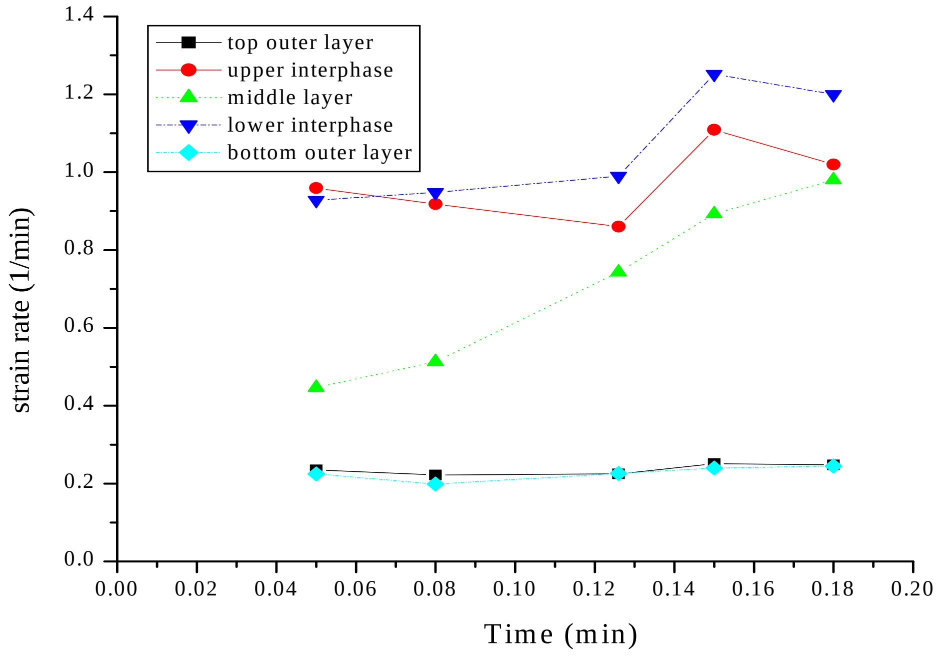

Fig.4 Strain Rate versus Time (Displacement Rate = 2.54 cm/min)

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