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RECENT ADVANCES IN GLASS/VINYL ESTER COMPOSITE DURABILITY CHARACTERIZATION FOR NAVY APPLICATIONS

[J. Richard Speckart*]: richard.speckart@navy.mil
Jason Cain, Nathan Post**, Aixi Zhou**, Scott W. Case**, John J. Lesko****
***U.S. Naval Surface Warfare Center—Carderock**
****Virginia Polytechnic Institute and State University**

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1 General Introduction

Fatigue resistance is often cited as one of the many advantages of composite materials. Collectively, these advantages have led to the increased use of composite applications in navy applications. However, this resistance to fatigue is difficult to quantify. This difficulty in adequately measuring and predicting composite durability has limited the use of composite materials in fatigue critical applications—applications where they may be of significant value if properly characterized.

This paper briefly describes composite durability research undertaken at Virginia Tech to improve understanding of the glass/vinyl esters typically used for U.S. Naval applications. This work has included random spectrum loadings, as well as changes in stress ratio and frequency. Additionally, the framework for a residual strength durability model has been developed from these results. Current work includes the refinement of the residual strength model for anticipated naval loads and environments, and ultimately the recommendation of material knockdowns.

2 Glass/Vinyl Ester Characterization

The primary materials used in this study are Glass/Vinyl Esters, specifically Derakane 510A and 8084 resins and Vetrotex 324 woven roving E-glass. Currently these materials are used in the majority of naval composite applications.

2.1 Residual Strength Model Development

Using extensive tension-tension (R=0.1) fatigue data of the Derakane 510A material, the remaining strength model has been developed, using a general model developed by Reifsnider and Case [1]:

$$Fr(n) = 1 - \left[\int \left\{ \frac{(1 - Fa(n))^{1/j}}{N(Fa)} \right\} dn \right]^j$$

where n is the number of cycles, Fa is the normalized maximum load applied to the critical element, Fr is the normalized residual strength, $N(Fa)$ is the total number of cycles to failure at the applied loading, and j is the residual strength fitting parameter.

Overall, the residual model represents the test data well. Figure 1 shows the normalized residual strength curve fits and data for the R=0.1 loading. The model seems to miss initial strength loss at low cycle counts while the fit improves for longer lifetimes at each stress level. A revised model will attempt to better address this initial loss of strength.

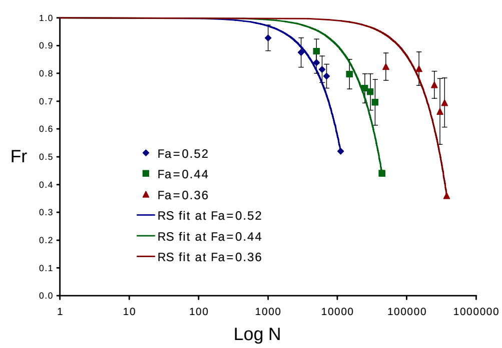

Fig. 1. Normalized Residual Strength, Fr, experimental results and residual strength model fits for R=0.1 loading of e-glass/510A vinyl ester composite

2.2 R-Ratio Effects

Due to compression loads commonly found in navy structures, compressive fatigue loads are of critical importance. The r-ratio effects portion of this study is not detailed here, but is in a separate presentation at this conference.

2.3 Spectrum Loadings

After the residual strength model had been compared to and improved by constant amplitude residual strength test data, spectrum loading was investigated. Initially, the loading spectrum was arranged as either high-to-low or low-to-high. Both loading arrangements had similar results and agreed well with residual strength predictions. The next series of residual strength tests arranged the same load spectrum randomly, rather than large arranged blocks. For all samples, failure occurred before the random spectrum fatigue loadings were completed, far earlier than predicted, showing a strong sensitivity to changes in load amplitude.

2.4 Frequency

Acceleration of fatigue testing is necessary to simulate decades of cyclic loadings within a reasonable amount of time, typically days or weeks. Of critical importance is that the accelerated testing directly relate to the fatigue life, damage mechanisms, and material behavior to actual naval applications.

For this study, the fatigue lifetime testing for both the 510A and 8084 materials were conducted at frequencies from 0.1 to 40 Hz at a stress ratio of R=0.1. The resulting S-N curves are statistically identical (95% confidence) for 1 to 15 Hz for both materials.

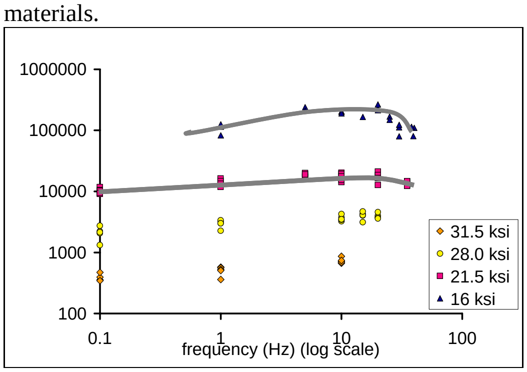

Fig. 2. Fatigue life as a function of frequency for the e-glass/510A vinyl ester composite

3 Current Work

Present efforts have been focused on improving the existing residual strength model for anticipated loading conditions. Of primary importance is an improved understanding of random spectrum loadings, and the associated effect of changes in load amplitude. Present experimental efforts include block loading variations to aid in detecting and quantifying damage associated with load amplitude change. Also, tension-compression and compression-compression fatigue loadings are being closely investigated to develop accurate methods for fatigue modeling. Again, this stress-ratio portion of the study is addressed in a separate presentation.

Fig. 3. Fluid cell used to insure continual saturation and temperature during fatigue testing

Also of note is the current evaluation of several NDE approaches for monitoring damage in fatigue specimens during testing. Successful monitoring techniques can be used for damage prognosis during service. Ideally, selected approaches will automatically record the level of damage throughout a fatigue test. Evaluated methods include embedded fiber optic Bragg gratings, ultrasonic transmission of pulsed waves, energy released due to acoustic emissions, and infrared imaging.

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4 Conclusions

The extensive fatigue testing and modeling to date has illuminated aspects of fatigue damage, some of which are critical and require continued investigation. The developed residual strength model is adequate for large block, tension-tension loadings, but requires further modification for the random-spectrum, tension-compression loadings of actual composite navy structures.

References

[1] Reifsnider K., Case S. "*Damage tolerance and durability of material systems*". 1st edition, John Wiley & Sons, New York, 2001.