APPLICATION NOTE

Fatigue Degradation of C/PPS Composite

Storage Modulus and Creep Behavior of PPS Matrix After Fatigue Loading

Introduction

Carbon fiber/polyphenylene sulfide (C/PPS) composite materials have been successfully used in components on the leading edge of Airbus A340 and A380 wings, decreasing the mass of the aircraft by hundreds of kilograms. PPS is a thermoplastic and brings advantages of high chemical resistivity, insensitivity to moisture, and good fatigue performance. This application note studies the effect of fatigue on the mechanical properties of the PPS matrix.

Stress distribution can vary due to the orientation and distribution of the carbon fibers. If the regions most prone to degradation can be identified, lifetime of composite parts can be predicted. Therefore, highly localized measurements of mechanical properties of the PPS matrix are required.

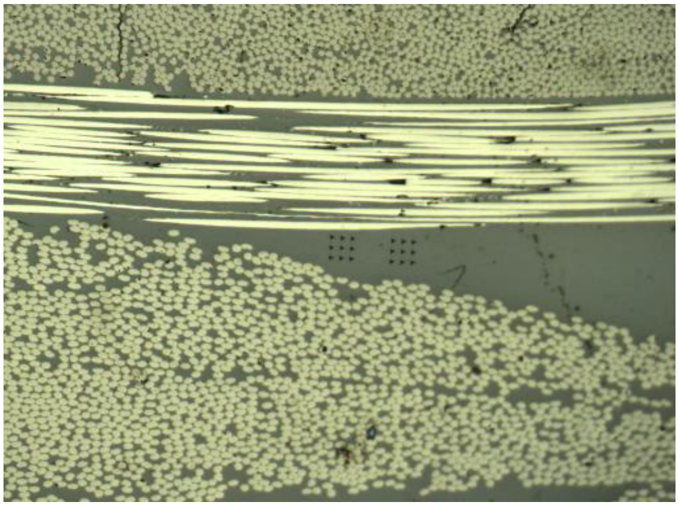

Figure 1: Optical image from **TriboIndenter**® optics shows the cross-section of C/PPS composite. Two 3x3 indentation arrays are clearly visible, with a single array each dedicated for the studies for frequency effects and creep. The arrays are placed between two perpendicular plies of carbon fibers.

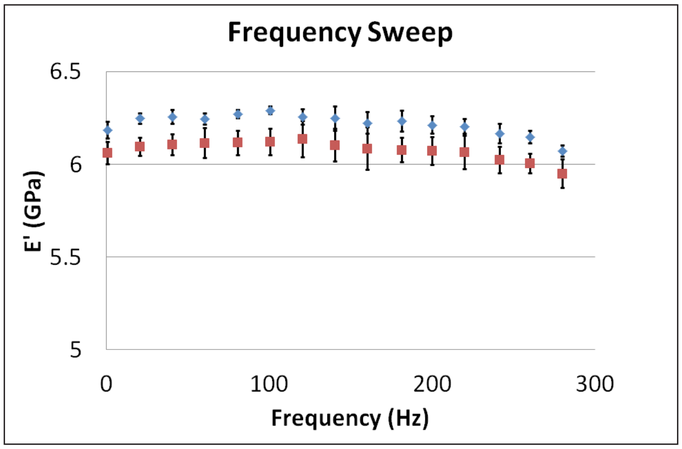

Figure 2: Comparison of the fatigued sample (red) to a reference sample (blue) shows minimal frequency (strain rate) dependence. However, the minor change in the elastic storage modulus is observed due to the high reproducibility of the testing.

An evaluation of the mechanical performance for these fatigued samples is centered on two different test mechanisms. Adjusting the frequency of the test allows the user to observe the strain rate dependence (Figure 2) while creep testing shows time dependent material properties.

Procedure

Hysitron's **TI 950 TriboIndenter**® enables the study of mechanical properties in precisely defined regions of the composites (Figure 1). An automated test method was used for acquiring data sets of indentation tests from multiple locations on two samples - a reference sample and one after 745,200 fatigue cycles. The **nanoDMA**® **III** package was used in two testing modes: frequency sweep (range 1-280Hz) and creep for 20 minutes. Both tests employed Hysitron's unique reference frequency technique in order to eliminate drift during the long term testing. Maximum force applied for all tests was 5mN.

Cross-sections of C/PPS composite plies of two samples were polished by emery paper followed by alumina suspension on cloth. Polishing modifies the properties of the material in the near surface layer of the thermoplastic. Measuring the depth profile of mechanical properties by continuous measurement of modulus (*CMX* method) revealed the affected zone (Figure 4a). The properties of interest were then measured at depths larger than this superficial layer.

Results

The results of storage modulus, E' introduced in Figure 2, consistently show very low standard deviations (represented by error bars below). This experimental reproducibility allows for determining the change in the E' due to fatigue with statistical significance. The change of a few hundred MPa in the E' is a result of the fatigue process. For creep testing, a higher contact depth at maximum load on the fatigued sample indicated reduced mechanical integrity, which is also supported by comparison of storage modulus and indentation hardness in figures 2 and 3. The strain rate at constant force, Figure 4b, calculated as *1/s•ds/dt*, shows a slight difference between the samples.

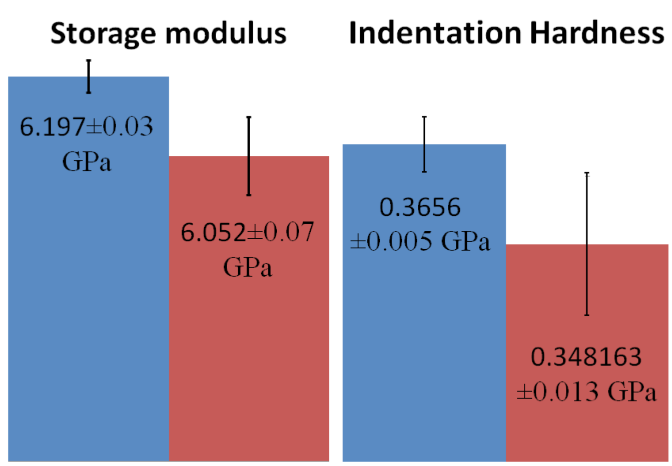

Figure 3: Comparison of storage modulus and indentation hardness from reference segment at frequency of 220Hz for both reference material (blue) and the fatigued composite (red).

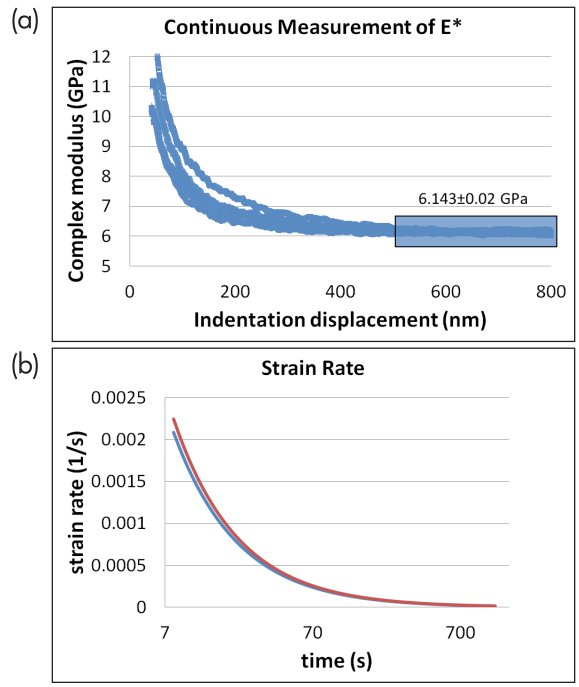

Figure 4: (a) The *CMX* (Continuous Measurement of X) technique clearly indicates the mechanical properties as a result from sample polishing in the depth profile. However, homogenous mechanical properties can be identified and used for creep and frequency sweep measurements at depths larger than the affected layer. (b) Monitoring strain rate *1/s•ds/dt* within the time shows that the creep in the fatigued sample was larger by a statistically relevant amount compared to the reference sample.

Conclusion

Despite the small difference between the average values of E' - only a few hundred MPa - the change in material behavior can be verified statistically. It would be extremely difficult to achieve such high testing reproducibility/ low standard deviation without the reference frequency technique, which negates drift present during the test. Creep testing is particularly affected by thermal drift. However, the use of the reference frequency technique allows for repeatable measurements in excess of 20 minutes. From these tests, one can conclude that the mechanical degradation of the PPS matrix due to fatigue is very low. PPS is known to be resistant to fatigue.

Dynamic Mechanical Analysis and creep testing together with the reference frequency technique can also be combined with Hysitron's heating solutions. Testing at elevated temperatures opens access to other material parameters such as transition temperatures, Tg, T_M or activation energy analysis.

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