Abstract #1766, 224th ECS Meeting, © 2013 The Electrochemical Society

Evaluating Adhesive Bonds with Carbon-Composites Using Electrochemical Impedance Spectroscopy

Guy D. Davis, FECS
Consultant
Baltimore, MD 21228

Composites are increasingly used in response to the need for lighter weight, stiffer structures with higher performance. Joining of composite structures and components to other composite components, metal components, or even concrete is most successfully achieved with adhesive bonding, which has many advantages over mechanical fastening or other joining methods.[1,2] As with most processes, there are disadvantages as well. Two concerns of adhesive bonds are durability and inspectability, especially inspectability of structures that are beginning to degrade, but have not reached the point of separation or delamination. Moisture is the leading cause of environmental degradation of adhesive bonds.[3,4] Thus, the ability to detect and track moisture ingress into a composite-adhesive bond would greatly increase the confidence in the structure and allow more complicated or higher performance structures without compromising safety. Adhesively bonded repair patches would be inspectable and acceptable for more critical repairs. Furthermore, monitoring of moisture intrusion into aging systems would facilitate condition-based maintenance (CBM) and enable safe, reliable life extension.

Davis and coworkers have used electrochemical impedance spectroscopy (EIS) to study moisture absorption by adhesives and composite bonds.[5,6] They correlated the impedance spectra of GFRP-CFRP, CFRP-CFRP, and Al-CFRP (glass-fiber and carbon-fiber reinforced plastics) lap shear specimens to their bond strength following exposure to high humidity at three temperatures. The correlations include the low-frequency impedance as well as different parameters from the equivalent circuit modeling.

Examples of the EIS spectra for a CFRP-CFRP specimen are given in Figure 1. Initially, the spectra are capacitive (slope of –1). Upon exposure to the high humidity, two changes in the spectra occur: 1) the magnitude spectra shift downward and 2) the low-frequency impedance decreases further and becomes nearly independent of frequency. Both effects are caused by the absorption of moisture. As the adhesive and the CFRP absorb moisture, their conductivity rises leading to the decreased low-frequency impedance and the increased low-frequency phase angle. Additionally, the dielectric constants of the CFRP and the adhesive increase with moisture content. This results in a higher capacitance and is reflected by the magnitude spectra shifting downward at all frequencies. The correlation of low-frequency impedance with bond strength is shown in Figure 2.

In addition to the low-frequency impedance measurements, the impedance spectra were modeled with an equivalent circuit. Of the different circuit parameters, the capacitance and constant phase element (CPE) also correlated with bond strength.

To determine if the adhesive strength degradation at 90°C was reversible upon removal of moisture, some specimens were placed in a vacuum oven before pulling. There was no significant improvement in strength with vacuum drying nor change in the locus of failure. These results suggest that the hygrothermal degradation of the adhesive bond under these conditions is irreversible.

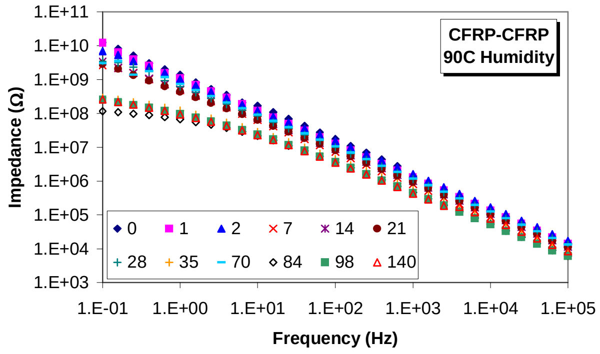

Figure 1. EIS spectra (Bode Magnitude Plots) for a CFRP-CFRP specimen exposed to 90 °C/95%RH. The number of days of exposure is given in the legend.

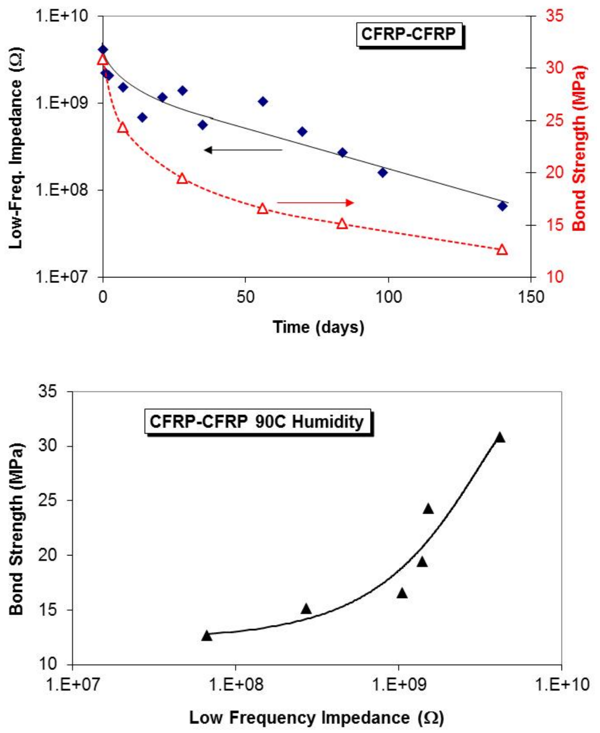

Figure 2. CPE and bond strength as a function of 90 °C exposure time for GFRP-GFRP specimens and their correlation.

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