NDE using Electro-Chemical Impedance Spectroscopy (EIS)

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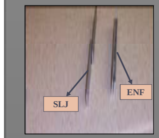
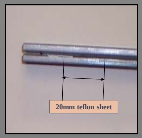
DYNAMIC RESPONSE OF ALUMINUM BONDED JOINTS AND NANOPARTICLE REINFORCED PLASTICS USING EIS AND VIBRATION TECHNIQUES

Specimens And Pressure Sensitive Tapes





Adhesive Transfer Tapes			
Tape ID.	Thickness	Color	Density
	(ml)		lb/ft³
85	5	Clear	NA
69	5	Clear	NA
73	10	Clear	NA

Acrylic Foam Tapes			
Tape ID.	Thickness	Color	Density
	(ml)		lb/ft³
50 (Harder)	45	white	50
41 (soft)	45	Gray	45
52 (softer)	45	Black	37

Experimental Program

Samples Prepared

1. Single Lap Joint (SLJ)
2. End Notch Flexure (ENF)

Single Lap Joint
Tapes used: -
Acrylic Foams ID# - 41, 50, 52
Adhesive Tapes ID# - 69, 73, 85

Base Samples
4-samples in each tape

Freeze Thaw 21 Days
(6 cycles / day)
4-samples in each tape
Cycling temperature- (50-10-50 F) all samples

Temperature Cycling 21 Days (3 cycles / day)
4-samples in each tape
Acrylic- at 90% of 250F
Adhesive-at 90% of 350F

NDE Tests (through 21 days)
1. EIS (Every 3-days)
2. Frequency, Loss factor (Every 3-Days)

Destructive Test s (After 21 days)
1. Impact
2. Lap Shear

End Notch Flexure
Tapes used: -
Acrylic Foams ID# - 41, 50, 52
Adhesive Tapes ID# - 69, 73, 85

Environmental Conditions
Single sample in each tape was prepared.
1. Base Data
2. Freeze Thaw 21 Days
3. Temperature cycling 21 Days

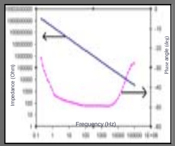
NDE Tests (through 21 days)
1. EIS: -
Impedance measured for every 3-days for all environmental conditions

Destructive Tests (After 21 Days)
2. ENF 3-point bend test:-
EIS for every 10mm of deflection during three-point bend test to monitor crack growth.

Electrochemical Impedance Spectroscopy-EIS

- EIS is used for monitoring corrosion and degradation of actual structures
- Small AC voltage varied from 100 kHz to 0.1 Hz applied across bonded joints
- Resulting changes in Resistance and Capacitance provide an early measure of deterioration before visual indication and predicts performance
- Ability to detect 'kissing' cracks

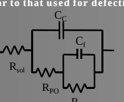
EIS Setup



Raw Impedance Plot

Equivalent Circuit Modeling for Bonded Joints

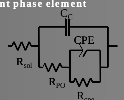
More information can be obtained by using an equivalent circuit, similar to that used for defective coatings



Capacitance
- Bonded Area
- Moisture
- Thickness

Resistance
- Moisture content

Rpo, Cc: Coating resistance and capacitance
Cf, Rf: Interface capacitance and resistance
CPE : Constant phase element



Courtesy : Inspection of Composite and Metal Adhesive Bonds with an Electro Chemical Sensor - G.D. Davis

Impedance

$$\text{Impedance } Z = Z_o e^{j\phi} = Z_o \cos(\phi) + jZ_o \sin(\phi)$$

$Z_o \cos(\phi)$:- Resistive Behavior Z_o:- Magnitude
$jZ_o \sin(\phi)$:- Capacitive Behavior ϕ :- Phase angle
$Z_R = R$, $Z_C = 1/j\omega C$ (function of swept frequency)

CPE is used to represent distributed properties

$$Z_{CPE} = A(j\omega)^{-\alpha}$$

$\alpha = 1$ (maximum value), CPE is equivalent to a capacitor with $A = 1/C$
$\alpha = 0$ (minimum value), CPE is equivalent to a a resistor with $A = R$

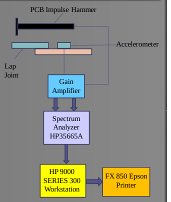
Capacitance

Capacitance depends on bonded area, bond-line thickness, and moisture content

$$C = \varepsilon \varepsilon_0 A/d$$
$$\varepsilon = \varepsilon_{Ad} + (\varepsilon_w - \varepsilon_{Ad}) M$$

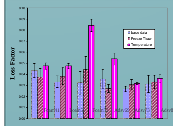
ε= dielectric constant of adhesive joint
ε_w = dielectric constant of water (80)
M = Moisture Concentration
A= Bonded area
d= Adhesive thickness
ε_o = permittivity of free space

Vibration Frequency Response Measurements

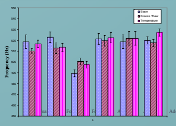


Impulse technique for exciting the flexural modes of single-lap bonded joints

NDE Vibration Technique - Results

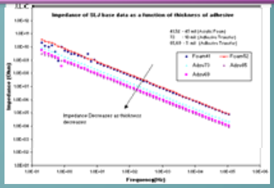


Loss factor (Damping) of SLJ for various environment conditions

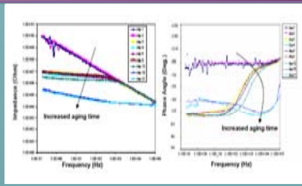


Frequency of SLJ for various environmental conditions

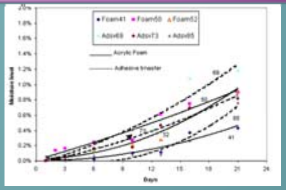
Impedance of single-lap joints as a function of adhesive thickness



Effect of accelerated aging by freeze-thaw cycling (bonded with acrylic Foam 41)



Moisture intake of single-lap joints as a function of time



References

A. Al-Ostaz, P. R. Mantena, M. Anakapali and S. J. Wang, 2007, "Evaluation of High Performance Pressure Sensitive Adhesives and VHB Acrylic Foam Tapes Bonded Aluminum Joints Subjected to Environmental Aging" *J. Adhesion Sci. Technol.* Vol. 21, No. 3-4, pp.339-361.

CONCRETE MOISTURE CONTENT MEASUREMENT USING EIS

Objective

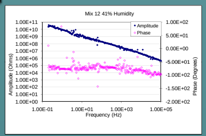
EIS is used to measure moisture content of concrete.

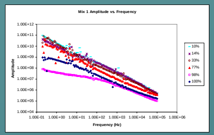
Experimental Setup

EIS

Embedded moisture sensor SHT75

Results





Conclusions

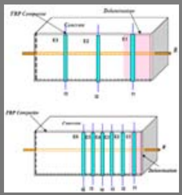
EIS results show merit in interpreting moisture content but further research is required.

MONITORING DELAMINATION AND MOISTURE UPTAKE IN CFRP-REINFORCED CONCRETE STRUCTURES USING EIS

Objective

Electrochemical impedance spectroscopy (EIS) sensors have been used to inspect carbon fiber-reinforced polymer (CFRP)-reinforced concrete structures exposed to a variety of laboratory test conditions (salt fog, Alternate immersion in fresh water, alternate immersion in salt water, 100% relative humidity, 50% relative humidity, elevated temperatures, and below-freezing temperatures)

Experimental Setup



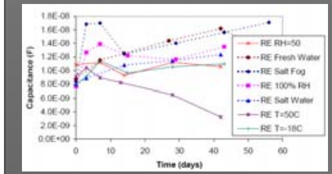
Short specimen and long specimen showing placement of internal and external sensors

The concrete specimens were exposed to several conditions to promote degradation or to act as controls.

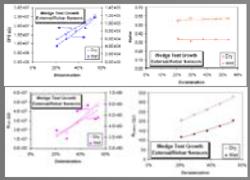
The exposure conditions for the short specimens included:
- T=50°C (120°F)
- T=-18°C (0°F)
- T=23°C (74°F), 50% RH
- T=34°C (93°F), 100% RH
- Salt fog (ASTM B117)
- Alternate immersion (2 hr wet, 10 hours dry) in fresh water
- Alternate immersion (2 hr wet, 10 hours dry) in salt water

The long specimens were Two different exposure conditions were used:
- Dry
- Pre-exposed

Results



Capacitance of the CFRP as a function of exposure time for different exposure conditions



Circuit parameters as a function of delamination size for the external electrode/rebar pari

Conclusions

- The EIS sensors can be used on CFRP-reinforced concrete structures to determine both moisture content and detect delamination
- Simple single-frequency measurements may be suitable for moisture detection, but equivalent circuit modeling is needed to analyze data for delamination and more reliable moisture determination.
- Impedance spectra from the external electrode/rebar pair provide the best correlation to moisture and bonded area.
- These measurements are global in nature (at least up to the size of our largest laboratory specimens) so that a high density of sensors is not needed.
- Using a commercially available portable potentiostat, measurements can be taken in the field.
- EIS offers potential as a non-destructive method to interrogate the structural integrity of the bond between CFRP to concrete used in civil transportation structures.

References

G.D.Davis, M.J.Rich,R.S.Harichandran, L.T.Drzal,T.Mase, and A.Al-Ostaz. Development of an Electrochemical Impedance Sensor to Monitor Delamination and Moisture Uptake in CFRP-Reinforced Concrete Structures, TRB 2003 Annual Meeting CR-ROM