Sensing of Carbon Fiber Reinforced Polymer Strand-Cement Interface Degradation under Pull-out Testing Using Impedance Spectroscopy

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Abstract
In this study, the interface of embedded fiber reinforced polymer strands with sensing cement was investigated. Impedance Spectroscopy (IS) was used to monitor the interface degradation under pull-out loadings. The interface electrical material parameter changed by 20% and the failure stress was 1380 kPa.

1. Introduction
Several methods, such as X-ray diffraction, scanning electron microscopy and ultrasonic methods have been used to assess the interface degradation of cementitious material with embedded reinforcements. However, these methods are image-based, qualitative and destructive methods that cannot be applied in the field in real-time monitoring. The use of sensing materials with application of Impedance Spectroscopy represents an effective nondestructive method that can be used to characterize, quantify and monitor the interface degradation of cementitious material reinforced with FRPS.

2. Objective
The objective of this study was to quantify and monitor the interface degradation of cementitious material reinforced with Carbon FRPS under pull-out loading.

3. Materials and methods
In this study, class-H cement with water-to-cement weight ratio of 0.3 was used. A conductive filler was added by ratio 0.03 % (by weight of cement) to produce the sensing cement composite material. For the direct tension and bending tests, the conventional instrumentations consisted of (a) a load cell with capacity of 10 kip was used to measure the load; (b) a digital dial indicator was used to measure the displacement. The specimens were equipped with embedded wires for IS measurements using E4980AL Precision LCR Meter.

4. Modeling of the interface: The equivalent circuit adapted to model the IS experimental measurements for the bulk, contact and interface properties is represented as follows:

$$Z_A = R_b + \frac{R_c}{1+\omega^2 R_c^2 C_c^2} + \frac{R_i}{1+\omega^2 R_i^2 C_i^2} - J\left(\frac{\omega R_c^2 C_c}{1+\omega^2 R_c^2 C_c^2} + \frac{2\omega R_i^2 C_i}{1+\omega^2 R_i^2 C_i^2}\right) \quad (1)$$

Where:
ω = angular frequency, R_b= Bulk electrical resistance, R_c= Contact electrical resistance, C_c= Contact electrical capacitance, R_i= Interface electrical resistance, and C_i= Interface electrical capacitance.
$R_i C_i$ = Interface electrical property index.

5. Results and Analysis:

The electrical interface property RiCi corresponding to the interface FRPS –Cement started to change slowly and the rate of change gradually increased during the loading. A higher interface property change was recorded for the ultimate stage corresponding to the maximum bond stress as shown in figure 4.

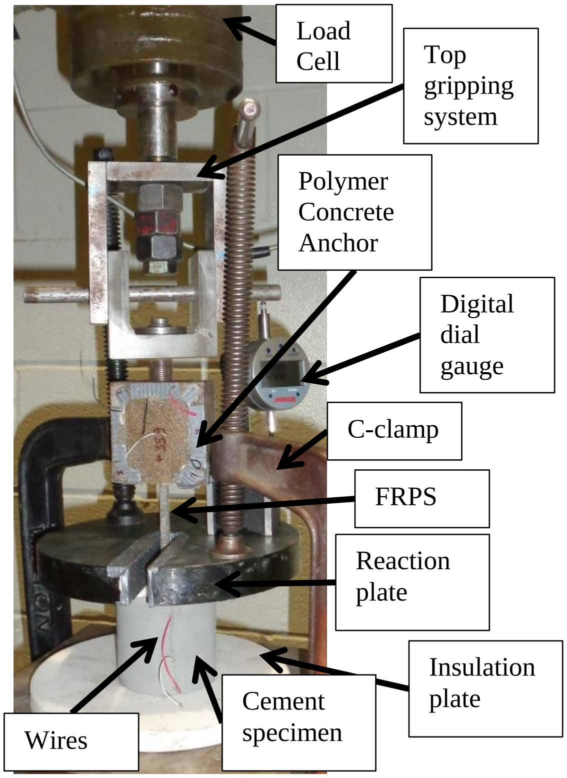

Figure 1. Pull-out Test Setup

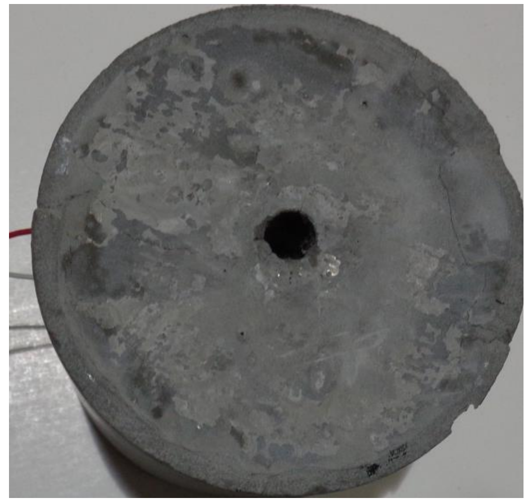

Figure 2. Pullout failure of cement-FRPS interface.

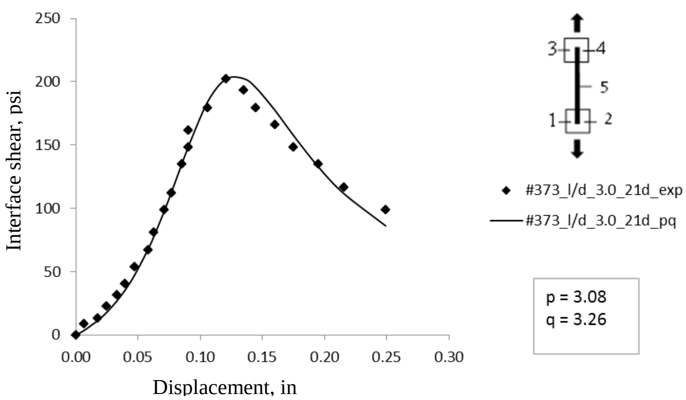

Figure 3. p-q interface model of the bond-slip relationship.

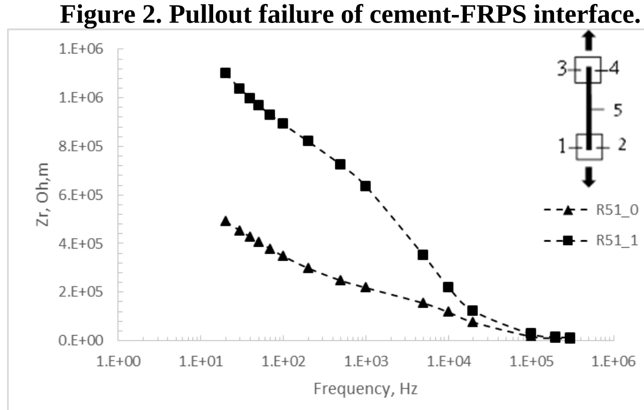

Figure 4. Impedance-frequency Interface responses.

4. Conclusion

The application of impedance spectroscopy to monitor the FRPS- Sensing Cement interface degradation was presented. The results showed the sensitivity of the method to monitor the electrical properties change that was related to the bond-slip mechanism.

5. Acknowledgment

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6. References

[1] Vipulanandan, C. and Prashanth, P., "Impedance Spectroscopy Characterization of a Piezoresistive Structural Polymer Composites bulk Sensor," Journal of testing and Evaluation, Vol. 41, No. 6, 2013, pp. 898-904, doi: 10.1520/JTE20120249. ISSN 0090-3973.

[2] American Concrete Institute. Committee 440. 2012. "Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures". American Concrete Institute.