**Intrinsically smart polymer-matrix structural composites**

**Topic 4**

*Chung, Composite Materials, Ch. 13.*

*No. 81, under “Publications – polymer” in website http://www.wings.buffalo.edu/academic/department/eng/mae/cmrl*

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**Functions**

- Structural
- Self-sensing
- Electromagnetic (e.g., shielding, low observability)
- Lightning protection
- Heating (e.g., deicing)
- Self-healing

**Types of sensing**

- Strain/stress sensing
- Damage sensing
- Temperature sensing
- Process monitoring

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**Importance of sensing**

- Structural health monitoring
- Hazard mitigation
- Structural vibration control

**Methods of sensing**

- Electrical methods
- Optical methods
- Acoustic methods
Electrical methods

- Resistance measurement
- Impedance measurement

Resistance methods

- Volume resistance
- Contact resistance

Piezoresistivity

Change in electrical resistivity with strain

Continuous carbon fiber polymer-matrix composites

For lightweight structures

Composite configuration

- PAN-based carbon fiber
- Epoxy matrix
- Unidirectional
- 8 laminae in laminate

Volume resistance

- Fiber direction
- Through-thickness direction
Tensile stress in the fiber direction
- Resistance in the fiber direction
- Resistance in the through-thickness direction

Strain sensing
- Tensile strain in the fiber direction – causes the resistance in the fiber direction to decrease reversibly and causes that in the through-thickness direction to increase reversibly
- Compressive strain in the fiber direction – opposite to the above

Probable origin of piezoresistivity
Increase in the degree of fiber alignment upon tension

Fatigue monitoring
- Cyclic tension in fiber direction
- Resistance in the fiber direction
Gage factor

Fractional change in resistance per unit strain

- Unidirectional composite, longitudinal tension and resistance: -36
- Unidirectional composite, longitudinal tension and through-thickness resistance: +34
- Crossply composite, longitudinal tension and resistance: -6
Fatigue monitoring

- Through-thickness resistance
- Cyclic tension in the fiber direction
- Crossply composite
- 12 laminae

Damage monitoring

- Fiber breakage – causes the resistance in the fiber direction to increase irreversibly
- Delamination – causes the through-thickness resistance to increase irreversibly
Flexure

Dimensions in mm

Impact damage monitoring

16-lamina quasi-isotropic composite

Flexure Dimensions in mm

Impact damage monitoring

16-lamina quasi-isotropic composite

Top resistance

Bottom resistance

Oblique resistance

Through-thickness resistance

Impact damage monitoring

16-lamina quasi-isotropic composite
Contact resistance

Interlaminar interface

Contact resistivity

Contact resistance
X contact area

Interlaminar interface as an impact sensor
Interlaminar interface as a thermistor

Interlaminar interface as a thermal damage sensor
Thermocouples in the form of structural composites

- Dissimilarity by choice of reinforcing fibers – Seebeck effect in the longitudinal direction
- Dissimilarity by choice of interlaminar filler - Seebeck effect in the through-thickness direction

Longitudinal Seebeck effect

- P-type carbon fiber in one lamina
- N-type carbon fiber in the adjacent lamina
- Interlaminar interface as the thermocouple junction
- 82 µV/°C.

Through-thickness Seebeck effect

- Tellurium particles as interlaminar filler in one composite
- Bismuth telluride particles as interlaminar filler in the adjacent composite
- The interlaminar junction of the two composites as the thermocouple junction
- 34 µV/°C.
Self-healing concept
- Embedding microcapsules of monomer in composite
- Having catalyst in composite outside the microcapsules
- Upon fracture of microcapsule, monomer meets catalyst, thereby former a polymer which fills the crack.

Problems with self-healing
- Toxicity of monomer
- High cost of catalyst

Conclusion 1
- Multifunctional polymer-matrix structural composites with continuous carbon fibers have been attained by exploiting the electrical behavior of the composites.
- The functions attained include the self-sensing of strain, impact, damage and temperature.

Conclusion 2
- Strain self-sensing was made possible by piezoresistivity, in which the electrical resistivity in the longitudinal or through-thickness direction changes with strain.
- Damage self-sensing was made possible by the effect of fiber fracture and delamination on the longitudinal and through-thickness resistivity respectively.
- Damage self-sensing was also attained by measuring the oblique resistance.

Conclusion 3
- Temperature self-sensing involved using the interlaminar interface as a thermocouple junction or as a thermistor.
- The thermocouples involve thermoelectricity in longitudinal or through-thickness directions.