Intrinsically smart cement-matrix composites

Topic 5

Reading assignment

- Chung, Composite Materials, Ch. 13.
- No. 130, under "Publications – cement" in website http://www.wings.buffalo.edu/academic/department/eng/mae/cmrl

Functions

- Structural
- Strain/stress sensing
- Damage sensing
- Temperature sensing
- Electromagnetic interference (EMI) shielding
- Vibration reduction
- Self-heating

Applications of strain-stress sensing

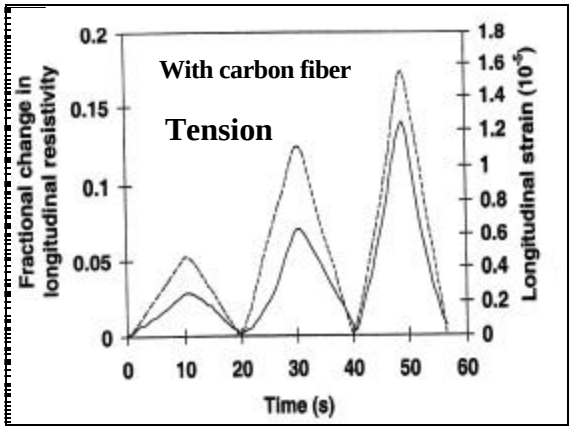
- Structural vibration control
- Traffic monitoring
- Weighing (including weighing in motion)
- Building facility management
- Security

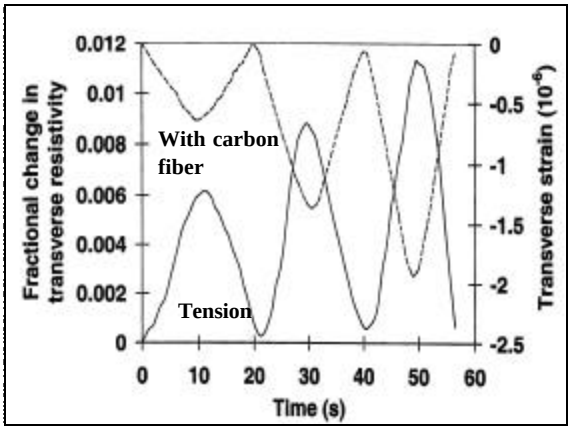
Strain/stress sensing

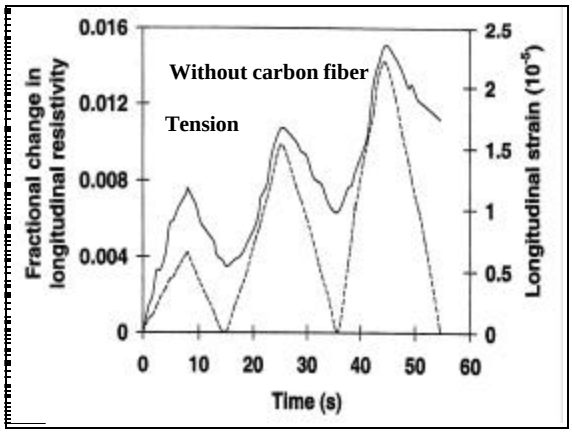
- Piezoresistivity
- Direct piezoelectricity

Piezoresistivity

- Change of electrical resistivity due to strain
- Gage factor = fractional change in resistance per unit strain
  (more than 2)
- Gage factor up to 700 attained in carbon fiber reinforced cement







Applications of damage sensing

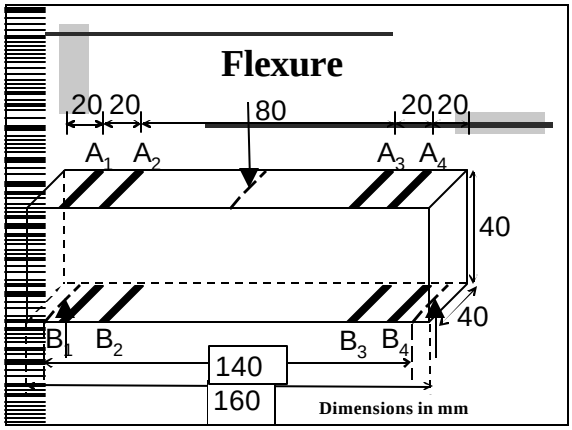
- Structural health monitoring
- Damage/microstructural evolution study

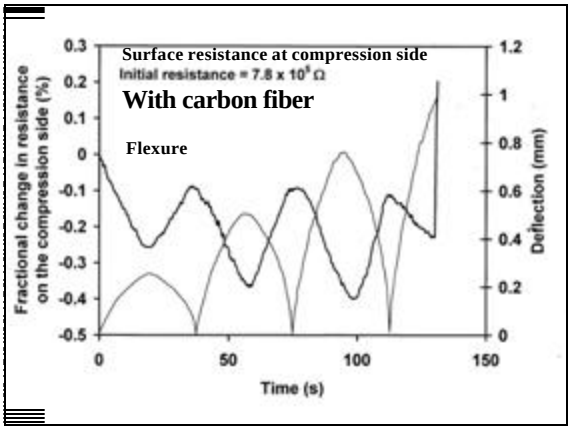
Damage sensing methods

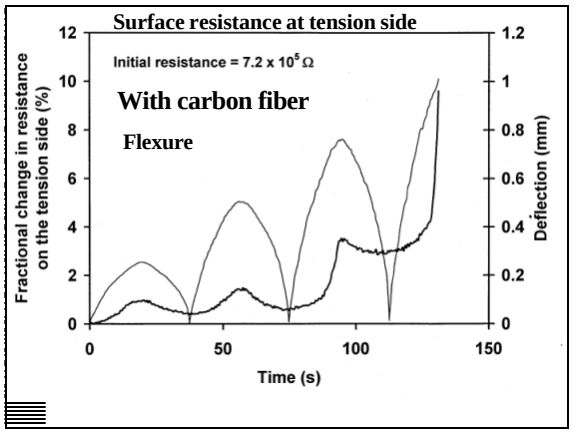
- Acoutic emission
- Electrical resistivity measurement
- Optical fiber sensor embedment

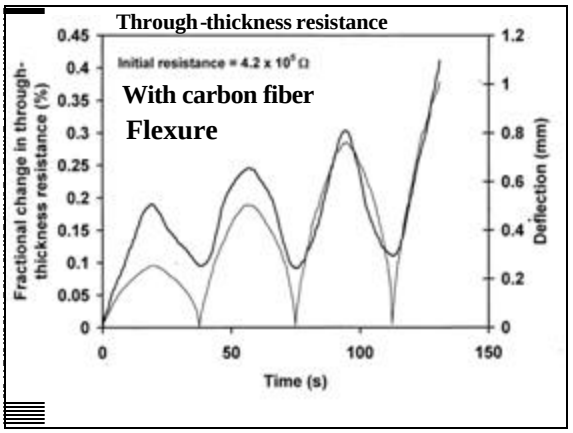
Resistance measurement methods

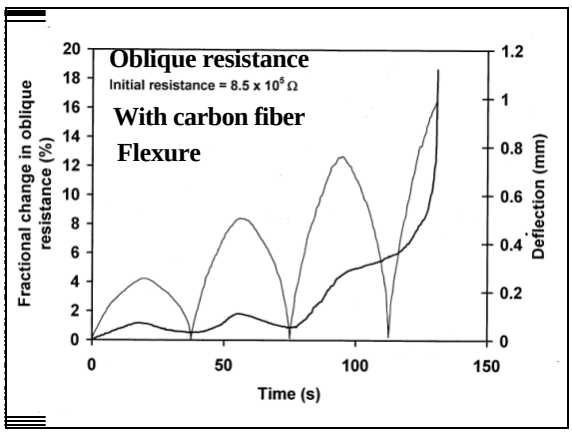
- Volume resistance (for sensing the damage of a volume)
- Surface resistance (for sensing the damage of the surface)
- Contact resistance (for sensing the damage of an interface)
- Apparent volume resistance (for sensing the damage of an interface between dissimlar materials)

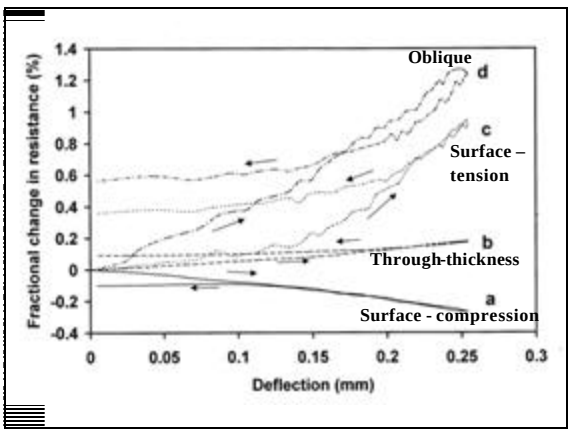

Flexure
20 20
80
20 20
A1 A2
A3 A4
40
40
B1 B2
B3 B4
140
160
Dimensions in mm


Surface resistance at compression side
Initial resistance = 7.8 x 10^5 Ω
With carbon fiber
Flexure
Fractional change in resistance on the compression side (%)
Deflection (mm)
Time (s)

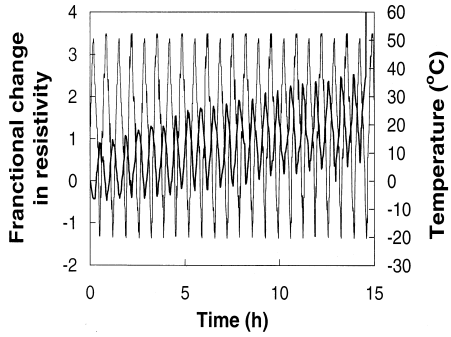

Surface resistance at tension side
Initial resistance = 7.2 x 10^5 Ω
With carbon fiber
Flexure
Fractional change in resistance on the tension side (%)
Deflection (mm)
Time (s)

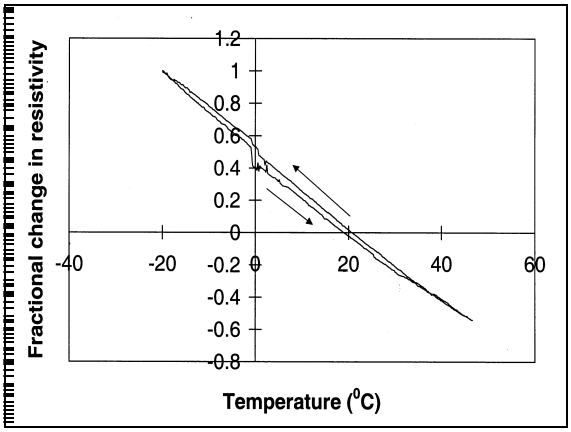

Through-thickness resistance
Initial resistance = 4.2 x 10^5 Ω
With carbon fiber
Flexure
Fractional change in through-thickness resistance (%)
Deflection (mm)
Time (s)


Oblique resistance
Initial resistance = 8.5 x 10^5 Ω
With carbon fiber
Flexure
Fractional change in oblique resistance (%)
Deflection (mm)
Time (s)

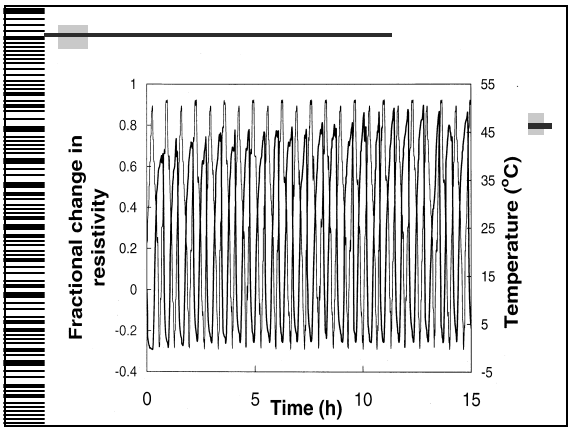

Oblique
d
c
Surface – tension
b
Through-thickness
a
Surface - compression
Fractional change in resistance (%)
Deflection (mm)

Mortar (without fiber) during freeze-thaw cycling

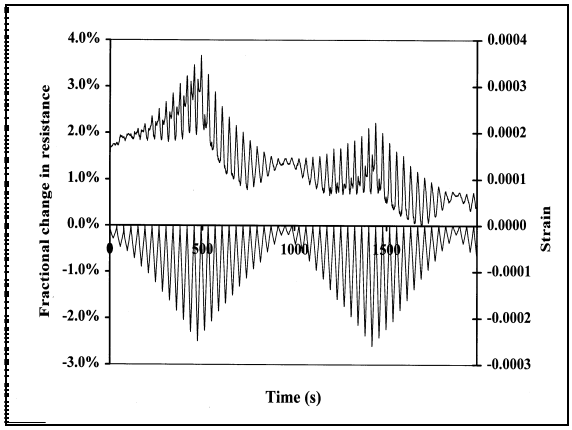


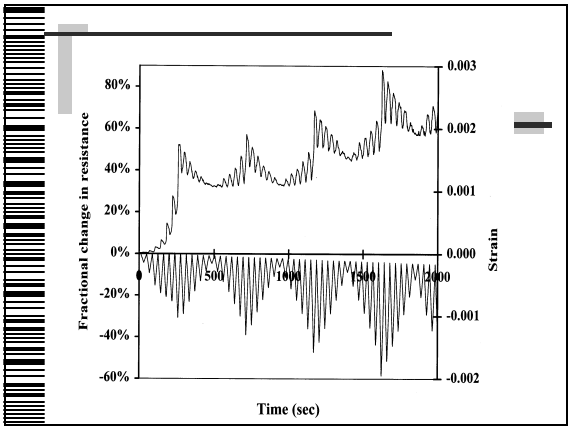


Without freezing

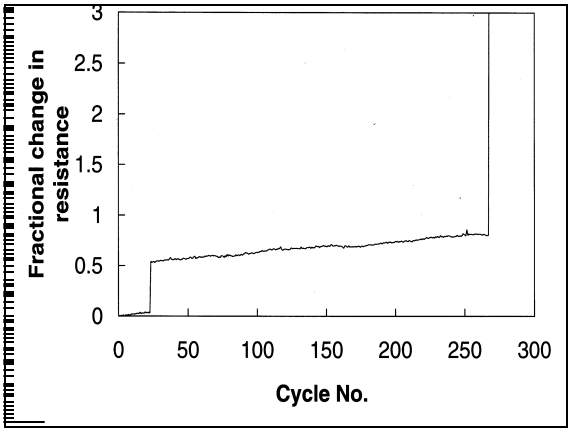


Carbon fiber concrete under repeated compression

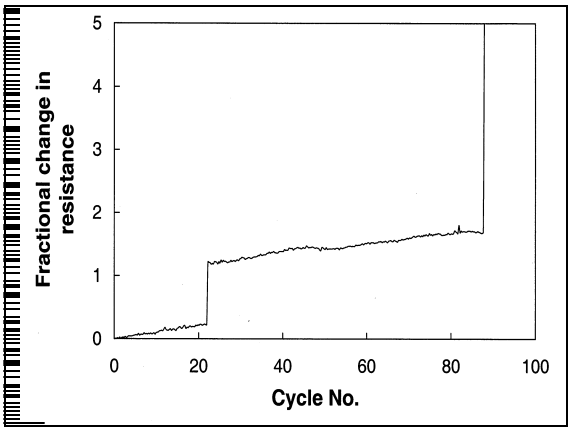




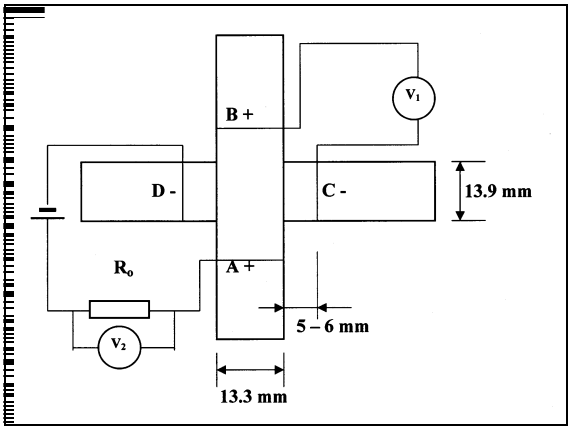
Interface between concrete and steel rebar under cyclic shear

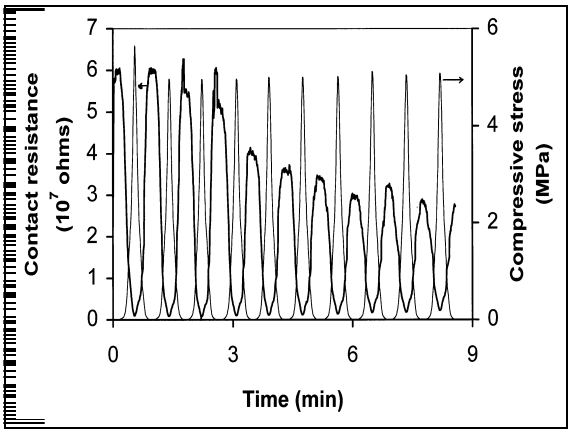


Interface between old and new mortar under cyclic shear

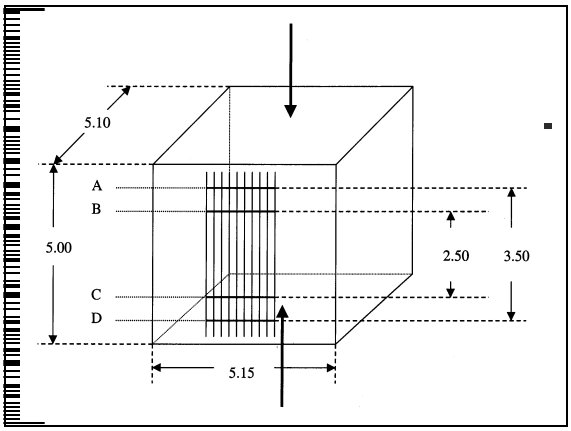


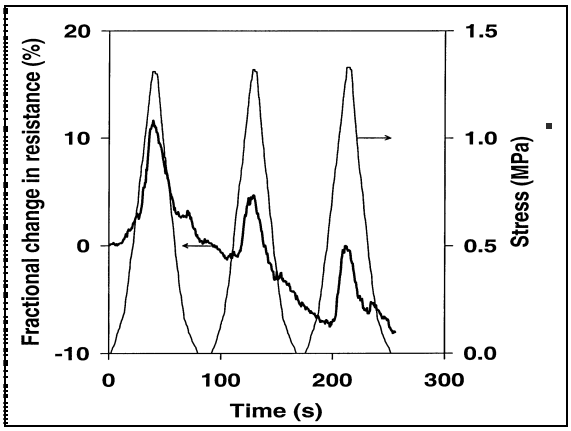
Interface between unbonded mortar elements under cyclic compression





Interface between concrete and its carbon fiber epoxy composite retrofit





Applications of temperature sensing

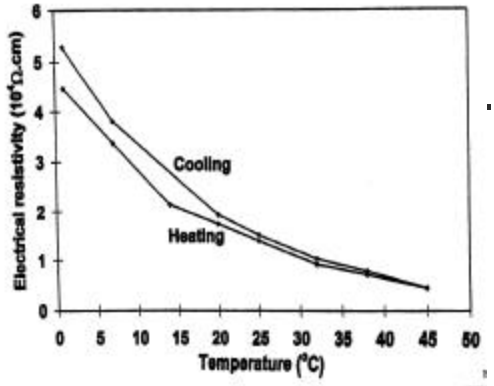
- Thermal control
- Structural operation control
- Hazard monitoring

Temperature sensing methods

- Thermocouples
- Thermistors

Cement-based thermistor

- Carbon fiber reinforced cement
- Activation energy = 0.4 eV



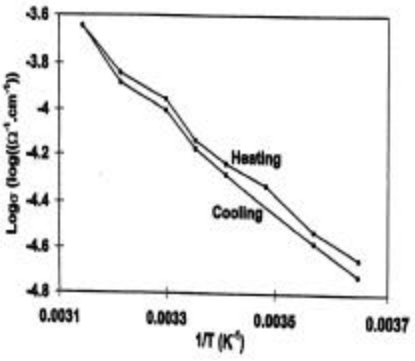
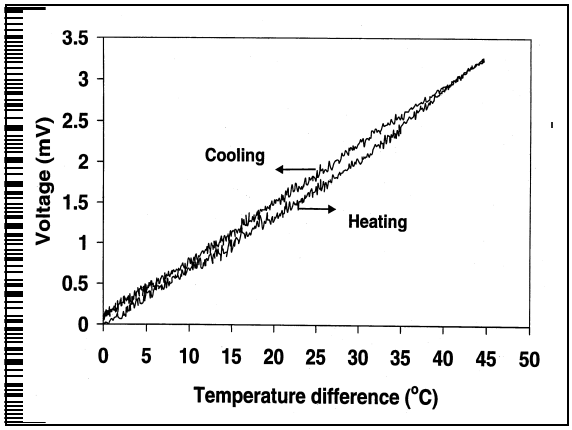


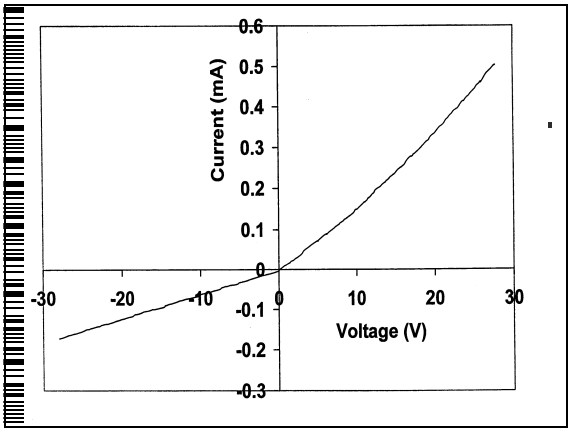
Table 2.2 Resistivity, critical voltage and activation energy of five types of cement paste.

Formulation	Resistivity at 20°C (Ω-m)	Critical voltage at 20°C (V)	Activation energy (eV)	
			Heating	Cooling
Plain	$(4.87 \pm 0.37) \times 10^3$	10.80 ± 0.45	0.040 ± 0.006	0.122 ± 0.006
Silica fume	$(6.12 \pm 0.15) \times 10^3$	11.60 ± 0.37	0.035 ± 0.003	0.084 ± 0.004
Carbon fibers + silica fume	$(1.73 \pm 0.08) \times 10^2$	8.15 ± 0.34	0.390 ± 0.014	0.412 ± 0.017
Latex	$(6.99 \pm 0.12) \times 10^3$	11.80 ± 0.31	0.017 ± 0.001	0.025 ± 0.002
Carbon fibers + latex	$(9.64 \pm 0.08) \times 10^2$	8.76 ± 0.35	0.018 ± 0.001	0.027 ± 0.002

Cement-based thermocouple

- Carbon fiber reinforced cement (p-type)
- Steel fiber reinforced cement (n-type)
- pn-junction
- 70 microvolts/degree C

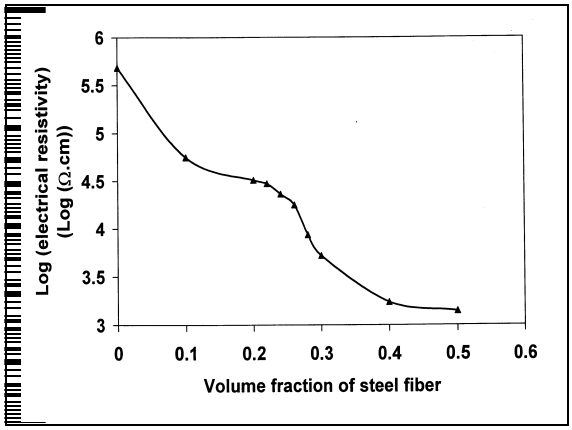


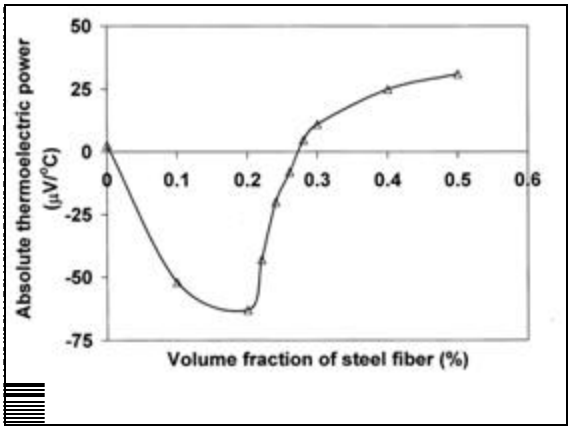


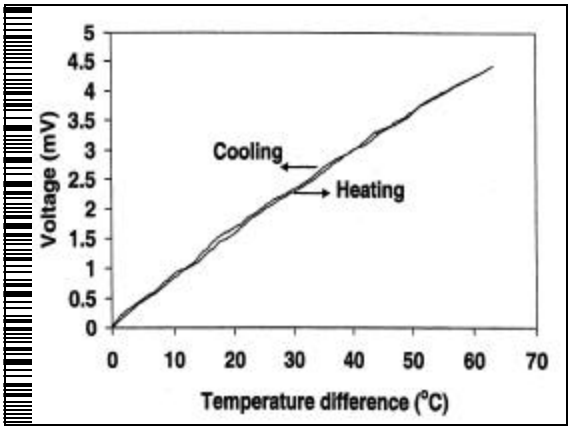
Thermoelectric cement-based materials

- Absolute thermoelectric power tailored by using conductive admixtures
- Carbon fiber for p-type behavior
- Steel fiber for n-type behavior

Effect of stainless steel fiber (60 micron diameter)

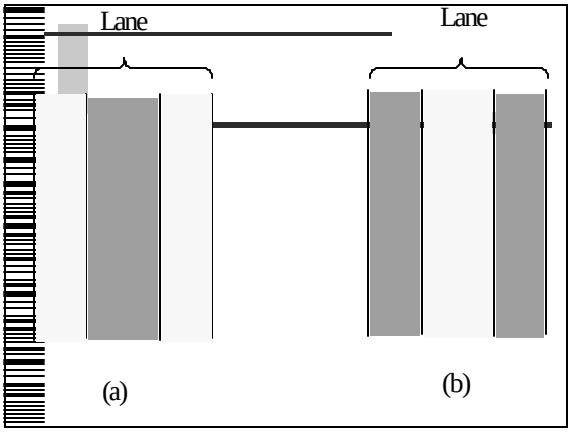


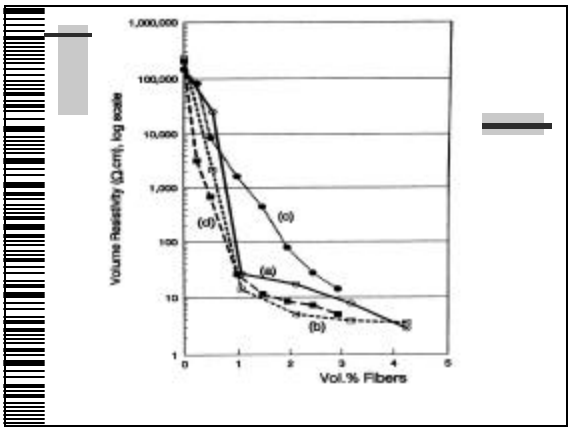


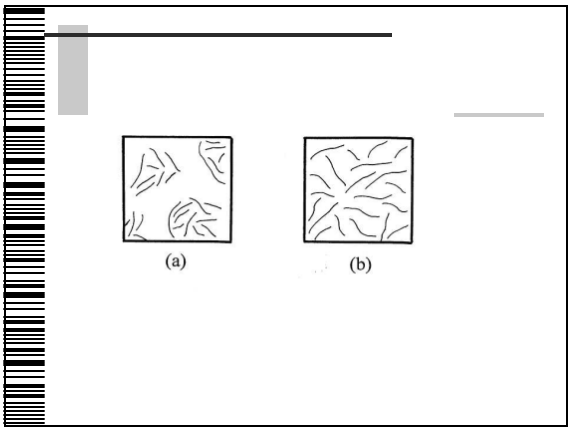


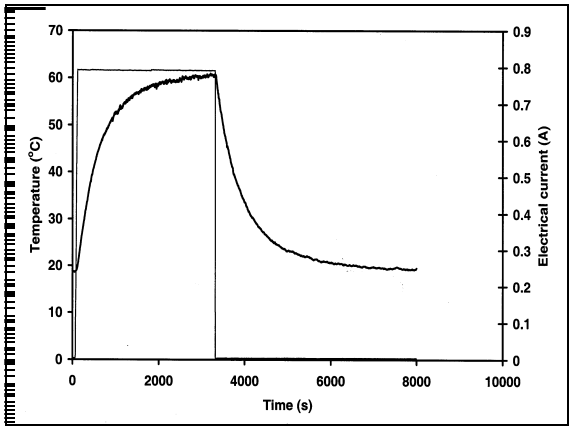
Applications of electrically conducting cement-based materials

- **EMI shielding**
- **Electrostatic protection**
- **Lightning protection**
- **Cathodic protection**
- **Self-heating**
- **Lateral guidance in automatic highways**









Cement pastes (with 1 vol.% conductive admixture)

- **Steel fiber (8 microns) 40 ohm.cm**
- **Carbon fiber (15 microns) 830 ohm.cm**
- **Carbon nanofiber (0.1 micron) 12,000 ohm.cm**
- **Graphite powder (0.7 micron) 160,000 ohm.cm**
- **Coke powder (less than 75 microns) 38,000 ohm.cm**