SIS Triblock Copolymers and Their Performance in Flexible Electrothermal Composite Heaters

Hiruni Dedduwakumara, Christopher Barner-Kowollik, Deepak Dubal, Nathan Boase
Queensland University of Technology

Challenge

Minimizing the excessive energy consumption while improving battery capacity in cold conditions

Solution

Electrothermal Heaters

At -7 °C outside temperature, EV’s range reduction is 41%

Winter happens..

Delos R., IEEE Transactions on Vehicular Technology 2016, 65 (6), 4016-4022
Why electrothermal heaters?

Conventional materials:
- Transparent conductive oxides
  - Aluminium-doped zinc oxide
  - Indium tin oxide
  - Fluorine-doped tin oxide

Advantages:
- Flexibility
- Adaptable
- Efficient heating
- Low cost

Drawbacks:
- Rigid, non-flexible structure
- Scarcity of materials like Indium

Applications:
- Smart windows,
- De-icers & Defoggers,
- Displays,
- Thermotherapy pads,
- Sensors,
- Concers

Thermally conductive polymeric materials

Research problem

Polymers → Composites → Thermal conductive materials → Electrothermal heaters

✓ Industry viable
✓ Cost-effective
✓ Efficient
✓ Flexible
✓ Enhanced heat stability
Copolymer structures and isomerism

1,4-SIS

3,4-SIS

SEPS

Hypothesis:

• Double bonds are important to achieve the electrical performance require in electrothermal applications

• It might be a source for polymer degradation

Carbon black
Experimental plan

1. Presence of double bond of isoprene block
   (3,4 SIS copolymer & SEPS copolymer)

2. Position of double bond in isoprene block
   (1,4 SIS and 3,4 SIS copolymers)

3. Loading of carbon black
   (Neat polymers, 16% and 28%)
   TGA in N₂ and air
   DSC, GPC
   NMR, FTIR

Heater efficiency
   vs I, V vs T

Resistance & conductivity

Thermal diffusivity

Specific heat

Heater stability
   Electrical failure test
   Stability at high voltage (V vs T)

GPC
TGA, DSC, FTIR & NMR
How does the copolymer structure and CB loading affect thermal stability?

Hydrogenation ➞ thermo-oxidative stability of polymer

CB addition ➞ thermo-oxidative stability of composite

Thermally stable up to 200 °C in air
How does the copolymer structure and CB loading affect composite thermal performances?

\[ \lambda(T) = \alpha(T) \times C_p(T) \times \rho(T) \]

- \(\lambda(T)\) - Thermal conductivity at \(T\) (W m\(^{-1}\)°C\(^{-1}\))
- \(\alpha(T)\) - Thermal diffusivity of the material (mm\(^2\)S\(^{-1}\))
- \(C_p(T)\) - Specific heat capacity at \(P\) (J kg\(^{-1}\)°C\(^{-1}\))
- \(\rho(T)\) - Relative density (kg m\(^{-3}\))

Thermal Diffusivity

- Laser Flash analysis (LFA)

Specific heat capacity

- DSC, ASTM E1269-11 standard

What is the impact of copolymer structure and CB loading on thermal conductivity?

- Increasing CB loading increase the thermal conductivity
- Olefinic structure enhance thermal conductivity (by increasing segmental rotation stiffness by conjugated π-bonds)

1) Huang, C.; Materials Science and Engineering: R: Reports 2018, 132, 1-22
How does the copolymer structure affect electrothermal performances of prototype heaters?

Highest thermal, electrical conductivity leads to highest steady state temperature.
How does the copolymer structure affect the electrical failure of prototype device?
How does the heating affect the battery performance?

- Heating cover improve the battery capacity
- Composite heater was stable more than 7 hours per day around 30 – 40 °C for 3 days
Olefinic structure affects the electrical and thermal performances of heaters.

It has negligible effect on chemical and electrical stability of heater.
Acknowledgments

Supervisory Team:
- Dr. Nathan Boase
- Prof. Christopher Barner-Kowollik,
- Prof. Deepak Dubal

Korea Evaluation Institute of Industrial Technology (KEIT) grant funded by the Korean government (MOTIE) (Grant No. 20014690).

How does the copolymer structure affect the electrical failure of prototype device?