Thermoelectric Materials By Design: Mechanical Reliability
(Agreement 14957)

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This presentation does not contain any proprietary or confidential information.
Outline

- Purpose of work
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Purpose of Work

• Contribute to achievement of 21% thermal efficiency of thermoelectric (TE) devices by 2012.

• Contribute to achievement of 10% improvement in engine thermal efficiency by harvesting exhaust waste heat.

• Interpret stress development in TE devices.

• Generate needed thermomechanical property data of TE materials for:
  – Material selection
  – TE device modeling to:
    • Achieve maximum capability
    • Optimize designs
    • Promote long term reliability
• TE materials purposely have low $\kappa$, are purposely subjected to an operational thermal gradient, and can have a large $\alpha$; consequential thermal stresses must be managed in a TE device to prevent their fracture.

• TE materials are brittle; must engineer and process microstructures that produce maximum strength.

$$R_T = \frac{\sigma(1 - \nu)\kappa}{\alpha E}$$

- $R_T$ = Thermal shock parameter
- $\sigma$ = Tensile stress or strength
- $\nu$ = Poisson’s ratio
- $\kappa$ = Thermal conductivity
- $\alpha$ = Coeff. thermal expansion
- $E$ = Elastic modulus
• Develop finite element analysis (FEA) models of TE devices to examine stress development and enable design optimization.

• Measure $E$, $v$, $\alpha$, $\kappa$, and Weibull strength distributions of contemporary and developmental TE materials. Characterize temperature and directional dependencies.

• Fractography to ID strength-limiting flaw types in TE materials.
Performance Measures

- Identify and rank which material properties and geometrical parameters have the largest effect on TE leg survivability in TE devices.
- Identify a strength-limiting flaw type in a TE material and identify how much smaller its size need to be in order to increase strength by 50%.
- Identify dimensional changes in TE legs that can reduce their operational stress by 25%.

Example of a thermal gradient in a TE device
• Developed a general FEA model of a TE device to evaluate thermomechanical stresses.

• Developed a test matrix to quantify statistically significant thermomechanical properties of a commercially available n- and p-type Bi$_2$Te$_3$. Data will greatly benefit designing.

• Purchased n- and p-type Bi$_2$Te$_3$ and fabricated necessary fixtures for their testing.
Technology Transfer

- A developed design optimization method can be used by TE device manufacturers and end users.

- Marlow Industries wishes to use our thermomechanical property data on $\text{Bi}_2\text{Te}_3$ for cooling with a TE device.
Activities for Next Fiscal Year

- Complete thermomechanical test matrix of Bi$_2$Te$_3$.
- Model TE device stress state using and TE leg survivability using Bi$_2$Te$_3$ data.
- Test developmental TE materials and contrast properties with those of Bi$_2$Te$_3$.
- Develop in-situ test method to measure strength of TE material with imposed temperature gradient.

Example of the thermally induced 1st principal stresses in a TE device
Summary

• Utilization of TE devices for automotive waste heat recovery will decrease fuel consumption rate.

• Systematic TE material property generation.

• FEA model of a TE device constructed.

• Our work will enable improvements in TE device design, optimization, and maximum reliability.

• Next year will involve:
  – Continued TE material database generation.
  – TE modeling and contrasting performance against the hypothetical use of developmental TE materials.
  – In-situ strength test of TE material with thermal gradient.