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
- Barriers
- Approach
- Performance measures and goals
- Technology transfer
- Plans for next fiscal year
- Summary

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

Barriers

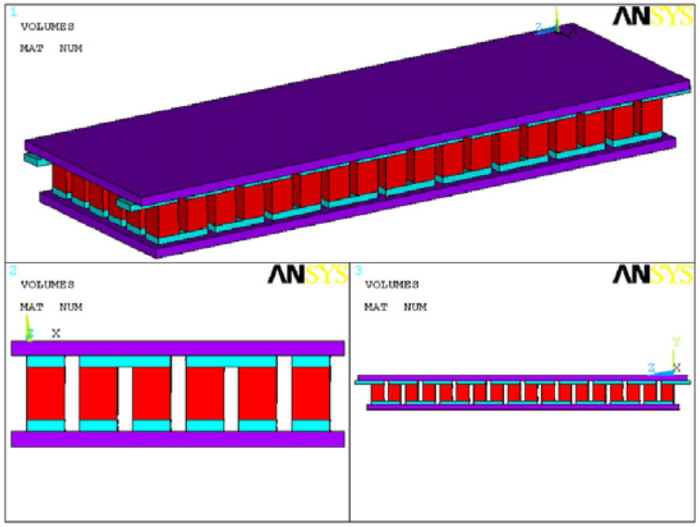
- TE materials purposely have low κ, are purposely subjected to an operational thermal gradient, and can have a large α; consequential thermal stresses must be managed in a TE device to prevent their fracture.
- TE materials are brittle; must engineer and process microstructures that produce maximum strength.

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

R_T = Thermal shock parameter
σ = Tensile stress or strength
ν = Poisson's ratio
κ = Thermal conductivity
α = Coeff. thermal expansion
E = Elastic modulus

Approach

- Develop finite element analysis (FEA) models of TE devices to examine stress development and enable design optimization.
- Measure E, ν, α, κ, 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.

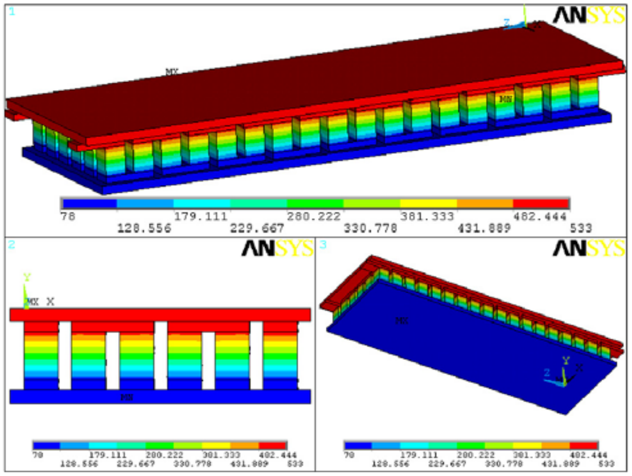


Example of
a FEA model
of a TE device

Performance Measures

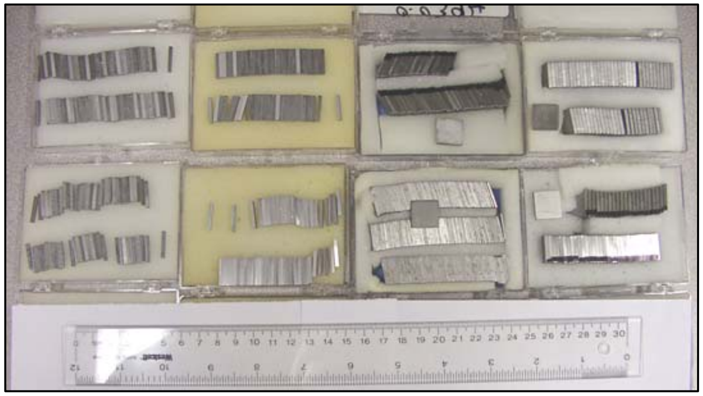
- Identify and rank which material properties and geometrical parameters have the largest effect on TE leg survivability in TE devices.
- Identify a strength-limiting flaw type in a TE material and identify how much smaller its size need to be in order to increase strength by 50%.
- Identify dimensional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

Example of a thermal gradient in a TE device

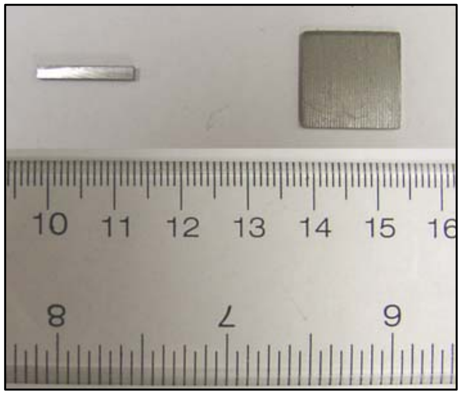


Accomplishments/Progress/Results

- 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_2Te_3. Data will greatly benefit designing.
- Purchased n- and p-type Bi_2Te_3 and fabricated necessary fixtures for their testing.



Bi_2Te_3
Test
Specimens

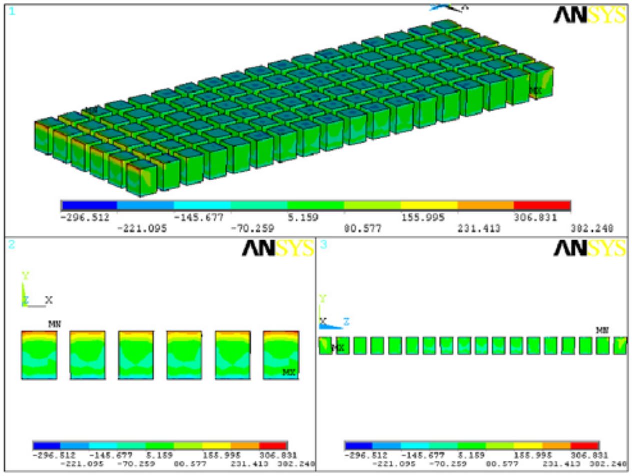


Technology Transfer

- 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 Bi_2Te_3 for cooling with a TE device.

Activities for Next Fiscal Year

- Complete thermomechanical test matrix of Bi_2Te_3.
- Model TE device stress state using and TE leg survivability using Bi_2Te_3 data.
- Test developmental TE materials and contrast properties with those of Bi_2Te_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.

Publications, Presentations, Patents

- O. M. Jadaan and A. A. Wereszczak, “Probabilistic Design Optimization and Reliability Assessment of High Temperature Thermoelectric Devices,” presented at 32nd International Conference and Exposition on Advanced Ceramics and Composites, Daytona Beach, FL, 31Jan08, in review, *Ceramic Engineering and Science Proceedings*, 2008.