MODELING OF THERMAL JOINT RESISTANCE OF POLYMER–METAL ROUGH INTERFACES

Majid Bahrami¹
M. M. Yovanovich¹
E. E. Marotta²

¹Department of Mechanical Engineering
University of Waterloo
Ontario, Canada

²Department of Mechanical Engineering
Texas A&M University
College Station, Texas, U.S.A
OVERVIEW

• Motivations and Objectives
• Problem Statement
• Thermal Resistance of Microcontacts
• Deformation Mode of Asperities
• Present Model
• Comparison with Experimental Data
• Conclusions
MOTIVATIONS AND OBJECTIVES

• polymers are being used in many engineering applications

• most of Thermal Interstitial Materials (TIM) used in microelectronic cooling are polymers filled with conductive particles

• only a few studies, mostly experimental, exist in the literature

• develop a compact model for predicting the TCR of polymer-metal interface in a vacuum
only conduction through microcontacts

\[ R_j = R_s + R_b \]
\[ R_b = \frac{t}{A_a k_p} \]
CONFORMING ROUGH JOINTS

assumptions

- Gaussian roughness, isotropic
- surfaces are conforming
- microcontacts do not interfere
- only normal forces
- deformation mechanics is determined only by equivalent rough surface

\[ \sigma = \sqrt{\sigma_1^2 + \sigma_2^2} \]
\[ m = \sqrt{m_1^2 + m_2^2} \]
PLASTIC AND ELASTIC MODELS

- plastic model: Cooper, Mikic, Yovanovich (1969)
- elastic model: Mikic (1974)

  - assumed \( \frac{A_{\text{elastic}}}{A_{\text{plastic}}} = 1/2 \)

  - proposed an “effective elastic microhardness” \( H_e \)

\[
H_e = \frac{E'm}{\sqrt{2}} \quad \text{where}
\]

\[
1 = \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2}
\]

- a priori assumption of deformation mode could lead to physically impossible “effective elastic microhardness” values

\[
H_e > H_{\text{mic}} \quad \text{impossible}
\]
plasticity index introduced by Mikic (1974)

\[ \gamma = \frac{H_{\text{mic}}}{E'm} \]

\[ \frac{1}{E'} = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2} \]

\[ \begin{cases} 
\gamma \leq 0.33 & \text{plastic} \\
0.33 \leq \gamma \leq 3.0 & \text{transition} \\
\gamma \leq 3.0 & \text{elastic} 
\end{cases} \]

• Mikic concluded, as Greenwood and Williamson did, that the mode of deformation is not sensitive to applied load

• almost all polymer asperities deform plastically
PRESENT MODEL

• surface asperities have Gaussian distribution
  • “equivalent rough surface” approximation was used
• microcontacts deform plastically
  • microhardness was measured for polymers studied
• microcontacts constriction/spreading and polymer bulk resistances are assumed to be in series
  • Bahrami et al. [17] plastic model was used

\[ R_j = \frac{0.565 H_{mic} (\sigma / m)}{k_s P A_a} + \frac{t_0 (1 - P / E_p)}{k_p A_a} \]

• joint temperatures are less than polymer glass temperatures
COMPARISON WITH DATA

Modeling of Thermal Joint Resistance of Polymer-Metal Rough Interfaces
COMPARISON WITH DATA

Modeling of Thermal Joint Resistance of Polymer-Metal Rough Interfaces
a non-dimensional parameter is proposed

\[ R_j^* = \frac{R_j}{R_b} = 1 + \Theta \]

\[ \Theta = \frac{R_s}{R_b} = \frac{0.565k^*(\sigma/m)}{P^*t_0(1-P/E_p)} \quad k^* = k_p / k_s \quad P^* = P / H_{mic} \]

based on non-dimensional parameter

\[
\begin{cases} 
\Theta << 1 & R_b \text{ controls } R_j \\
\Theta \approx 1 & R_b, R_s \text{ important} \\
\Theta >> 1 & R_s \text{ controls } R_j
\end{cases}
\]
Modeling of Thermal Joint Resistance of Polymer-Metal Rough Interfaces

**COMPARISON WITH EXPERIMENTAL DATA**

<table>
<thead>
<tr>
<th>Material</th>
<th>Rs/Rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delrin1, FM</td>
<td>⊗</td>
</tr>
<tr>
<td>Delrin2, FM</td>
<td>⊖</td>
</tr>
<tr>
<td>Poly, FM</td>
<td>⊖</td>
</tr>
<tr>
<td>PVC, FM</td>
<td>⊖</td>
</tr>
<tr>
<td>Delrin</td>
<td>⊖</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>⊖</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>⊖</td>
</tr>
<tr>
<td>Teflon</td>
<td>⊖</td>
</tr>
<tr>
<td>ABS</td>
<td>⊖</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>⊖</td>
</tr>
<tr>
<td>PVC</td>
<td>⊖</td>
</tr>
</tbody>
</table>

- Present model
- Bulk resistance asymptote
- TCR asymptote

127 data points
Relative RMS difference between model and data 12.7%

FM: Fuller and Marotta 2001 data

---

Modeling of Thermal Joint Resistance of Polymer-Metal Rough Interfaces
SUMMARY AND CONCLUSIONS

- It is shown that the deformation mode of asperities is plastic in most of polymers studied.

- A compact model is developed that assumes plastic deformation in asperities.

- Comparison of the present model with experimental data shows good agreement.

- A non-dimensional parameter is introduced that specifies the significance of the microcontacts constriction/spreading resistance over the polymer layer bulk resistance.
ACKNOWLEDGMENTS

• Natural Sciences and Engineering Research Council of Canada (NSERC)

• The Center for Microelectronics Assembly and Packaging (CMAP)