Thermal Contact Conductance of Metal/Polymer Joints

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TCC of Metal/Polymer Joints

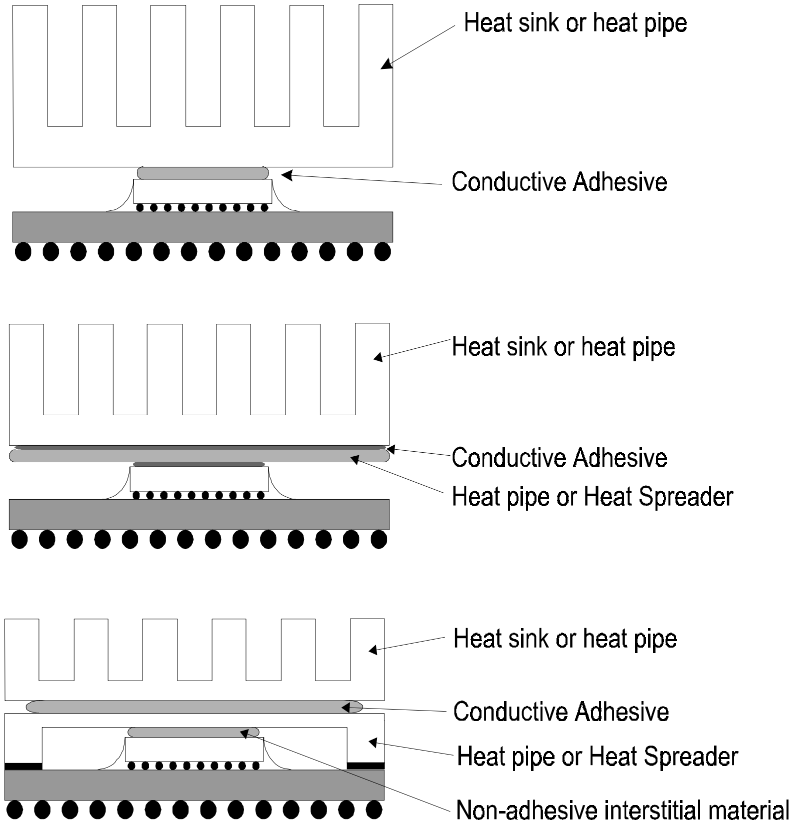
- Objective
- Introduction
- Literature Review
- Problem Statement
- Summary and Discussion
- Conclusions
- Recommendations

TCC of Metal/Polymer Joints- Objective

- Obtain a verifiable and usable analytical model for the prediction of the thermal joint resistance of a metal/polymer joint
- Investigation first limited to assuming nearly optically flat surfaces at a uniform interface pressure and to the class of thermoplastic and elastomeric polymers

TCC of Metal/Polymer Joints- Introduction

- Important in chip-packaging design
- Polymers and organic materials are being employed to a greater extent
- Currently, a usable and verifiable model does not exist for predicting the thermal performance of metal/polymer joints



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TCC of Metal/Polymer Joints- Literature

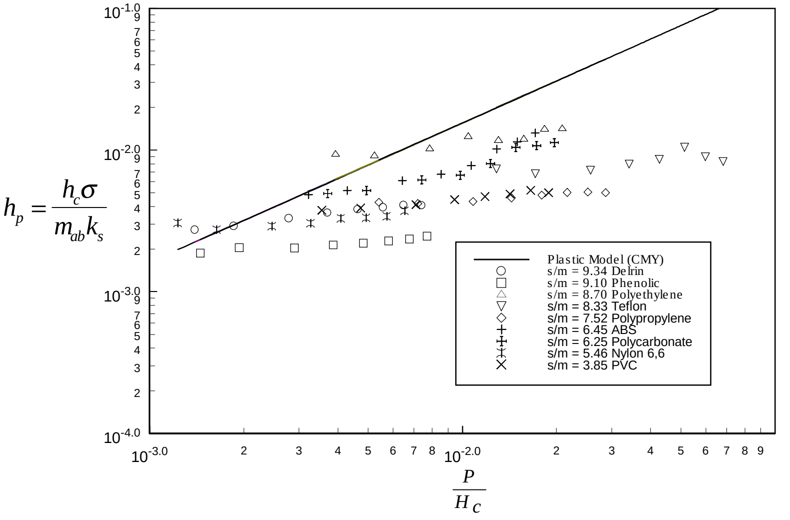
- Quilliet et al. studied thermal characteristics of interface during injection molding
- Narh and Sridhar measured the joint thermal resistance of polystyrene as a function of thickness at constant temperature and pressure
- Parihar and Wright studied the thermal contact resistance of a (SS304)/silicone rubber/(SS 304) joint

TCC of Metal/Polymer Joints- Literature

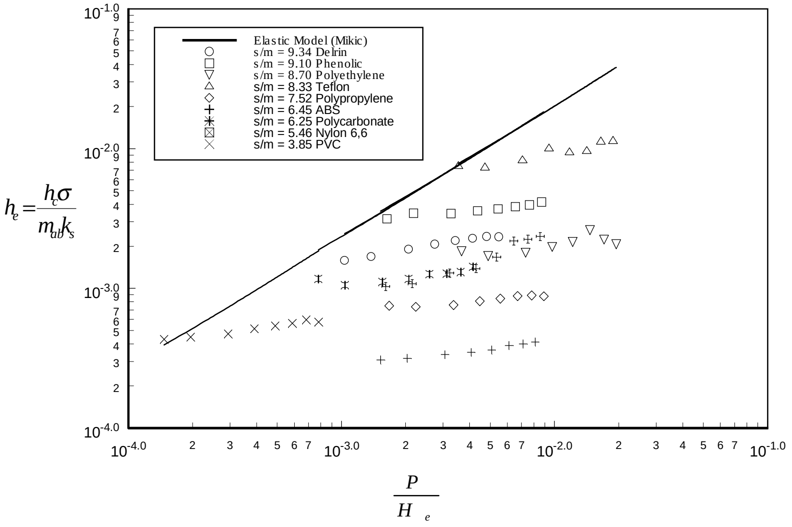
- Marotta and Fletcher measured the thermal conductivity and the thermal contact conductance of several widely available thermoplastic and thermosetting polymers

- They compared the experimentally measured data to the elastic model developed by Mikic and the plastic contact model developed by Cooper, Mikic and Yovanovich (CMY)

TCC of Metal/Polymer Joints- Literature



Comparison of Polymer Experimental Data versus the CMY Plastic Model



Comparison of Polymer Experimental Data versus the Mikic Elastic Model

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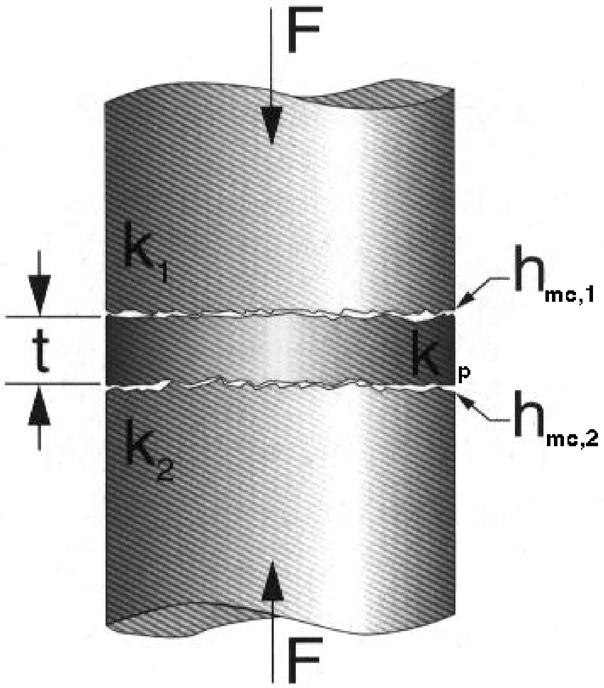
TCC of Metal/Polymer Joints- Problem

- Defining joint resistance

$$R_j = R_{micro,1} + R_{bulk} + R_{micro,2}$$

- Defining joint conductance

$$h_j = \frac{1}{1/h_{micro,1} + 1/h_{bulk} + 1/h_{micro,2}}$$



TCC of Metal/Polymer Joints- Thickness

- A very important parameter is the thickness (t) of the polymer layer

- Makushkin derived an expression that calculates the critical thickness (t*) above which the substrate will not influence the deformation of the polymer layer

$$t^* = 16.8\left(\frac{\sigma_t \rho}{E_p}\right)\left(\frac{\left(E_p / E_s\right)^{0.11}}{\upsilon_p^{0.41}\,\upsilon_s^{0.003}}\right)$$

POLYMER	TEFLON	DELRIN	PVC	POLY
t*(μm)	80.0	26.1	17.2	28.2
Thickness (μm)	1524	1524	1524	1524

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TCC of Metal/Polymer Joints- Microscopic

- Possible candidate for the microscopic model is the already established Mikic elastic model for metal/metal contacts

$$h_c = \frac{k_s}{4\sqrt{\pi}} \frac{m_{ab}}{\sigma} \frac{\exp\left(-\lambda^2/2\right)}{\left[1-\sqrt{\tfrac{1}{4} erfc\left(\lambda/\sqrt{2}\right)}\right]^{1.5}}$$

- Possible problem is that the Mikic model does assume the elastic deformation of the asperities, but the elastic hardness is defined for metal/metal contacts by assuming asperity contact on a rigid flat surface

$$\lambda = \sqrt{2} erfc^{-1}\left(\frac{4P}{H_e}\right)$$

$$h_{mikic} = 1.55 \frac{k_s m_{ab}}{\sigma}\left(\frac{\sqrt{2}P}{E`m_{ab}}\right)^{0.94}$$

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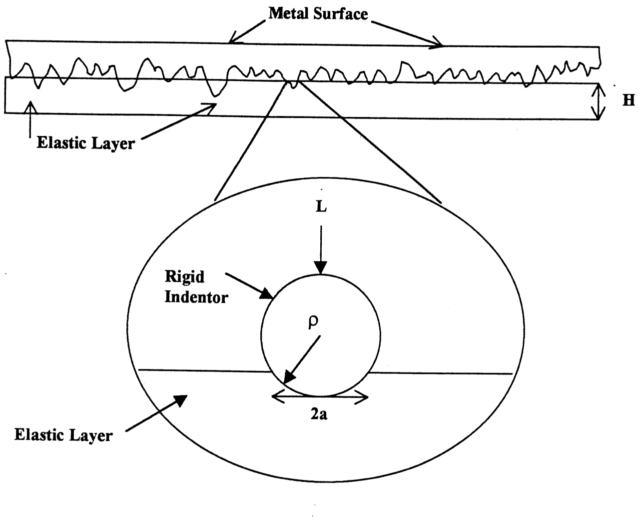
TCC of Metal/Polymer Joints- Microscopic

- A microscopic model can be derived by assuming the contact of a rigid indentor into an elastic layer
- By following studies done by Finkin and Vorovich and Ustinov a contact radius can be derived
- They determined the contact radius in terms of an asymptotic series in powers of non-dimensionalized layer thickness



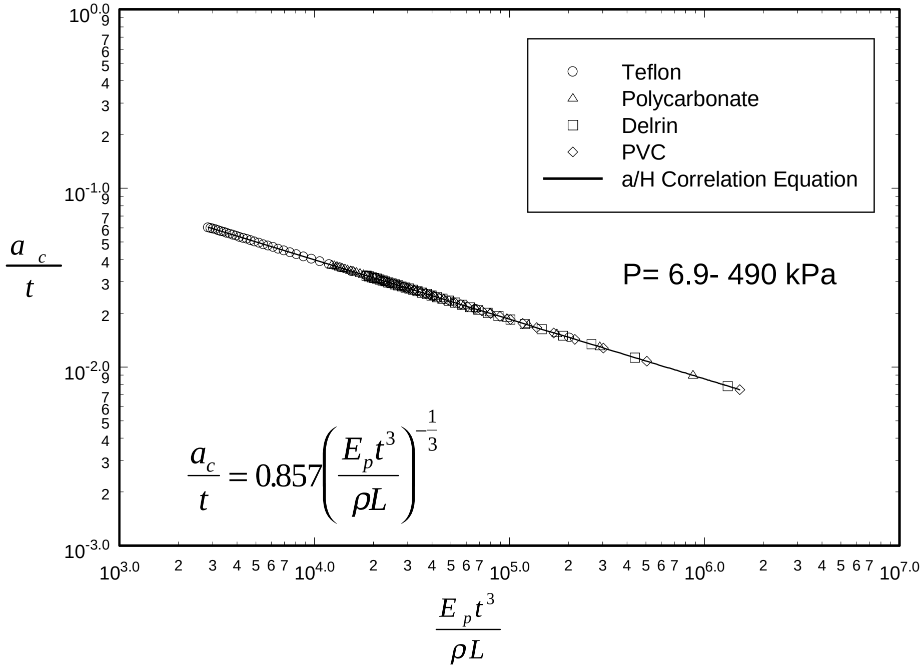
$$a_o = \left[\frac{3L\rho\left(1-\upsilon_p^2\right)}{4E_p}\right]^{\frac{1}{3}}$$

$$\frac{a_c}{t} = \frac{a_o}{t} - 0.113\left(\frac{a_o}{t}\right)^4 + 0.114\left(\frac{a_o}{t}\right)^6 + 0.025\left(\frac{a_o}{t}\right)^7 - 0.004\left(\frac{a_o}{t}\right)^8$$

TCC of Metal/Polymer Joints- Microscopic

- By using the equations derived by Vorovich and Ustinov and employing Buckingham Pi Theorem an easy to use correlation for predicting the contact radius was found

- $$a_c = 0.857\left(\frac{\rho L}{E_p}\right)^{\frac{1}{3}}$$



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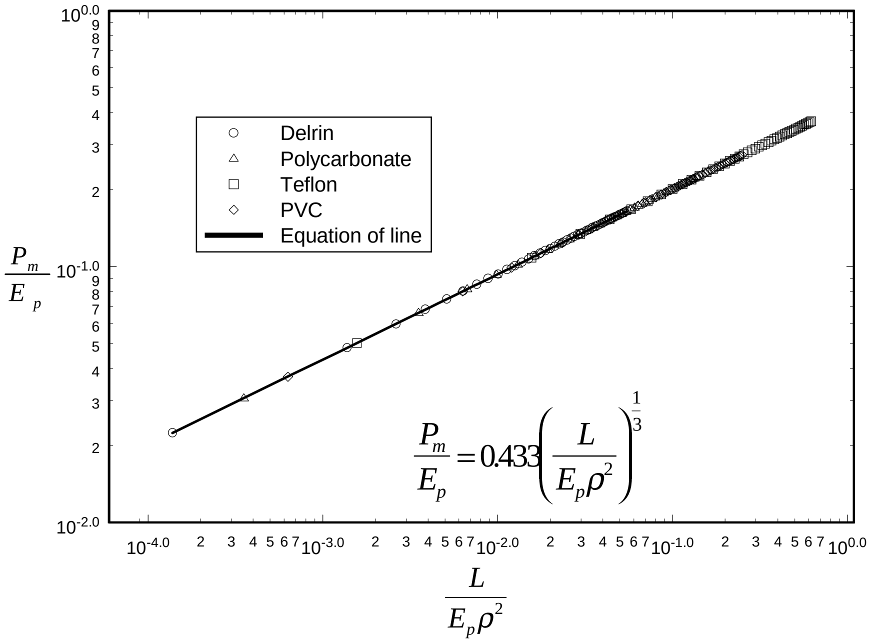
TCC of Metal/Polymer Joints- Microscopic

- The next step is to define a new ‘elastic polymer hardness’
- Greenwood and Williamson define an elastic contact hardness that controls the area of contact by:

$$H_{elastic} = CE`m_{ab}$$

- The constant C is found by plotting dimensionless mean pressure versus dimensionless load
- The new elastic polymer hardness can be defined by

$$H_{ep} = \frac{E_p m_{ab}}{2.3}$$



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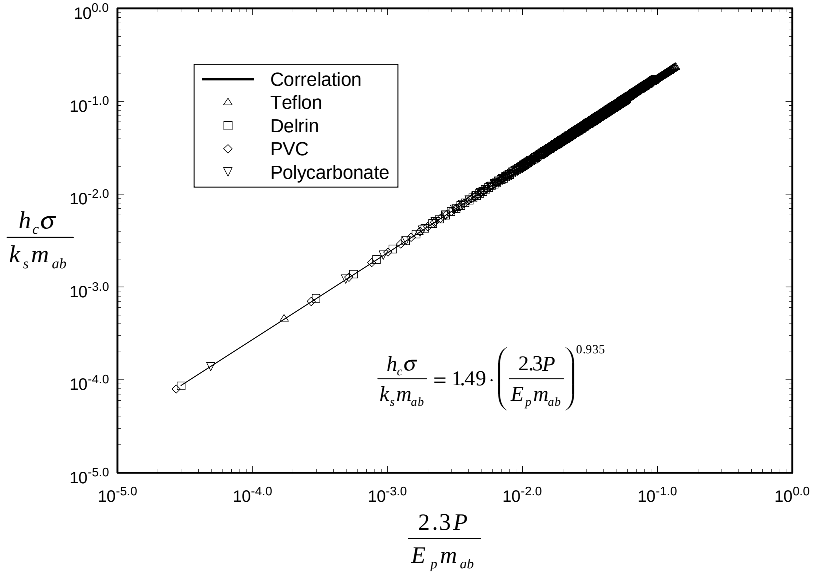
TCC of Metal/Polymer Joints- Microscopic

- Next by following the procedure defined by Mikic, assuming optically flat surfaces and a Gaussian distribution of asperity peaks, a correlation for the dimensionless contact conductance for a rigid indentor into an elastic layer can be found.

$$\frac{h_{micro}\sigma}{k_s m_{ab}} = 1.49\left(\frac{2.3P}{E_p m_{ab}}\right)^{0.935}$$



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TCC of Metal/Polymer Joints- Bulk

- The bulk conductance is defined by dividing the thermal conductivity of the polymer by the final thickness of the polymer

$$h_{bulk} = \frac{k_p}{t_f}$$

- Since a polymer or elastic layer is compressible the change in thickness due to loading should be accounted for. By applying contact mechanics an equation for the final thickness can be derived

$$t_f = t_o\left(1 - \frac{P}{E_p}\right)$$

- The final bulk conductance equation is:

$$h_{bulk} = \frac{k_p}{t_o\left(1 - P/E_p\right)}$$

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TCC of Metal/Polymer Joints- Summary

- The joint conductance model was then plotted with published data of Marotta and Fletcher
- The experimental data of Marotta and Fletcher was gathered with thermal grease applied to contact surface 2.
- The thermal grease effectively allows the $1/h_{mc,2}$ to be negligible. Thus the joint conductance equation reduces to the following:

$$h_{j,p} = \frac{1}{\dfrac{1}{h_{micro,1}} + \dfrac{t_o\left(1 - {}^{P}\!/_{E_p}\right)}{k_p}}$$

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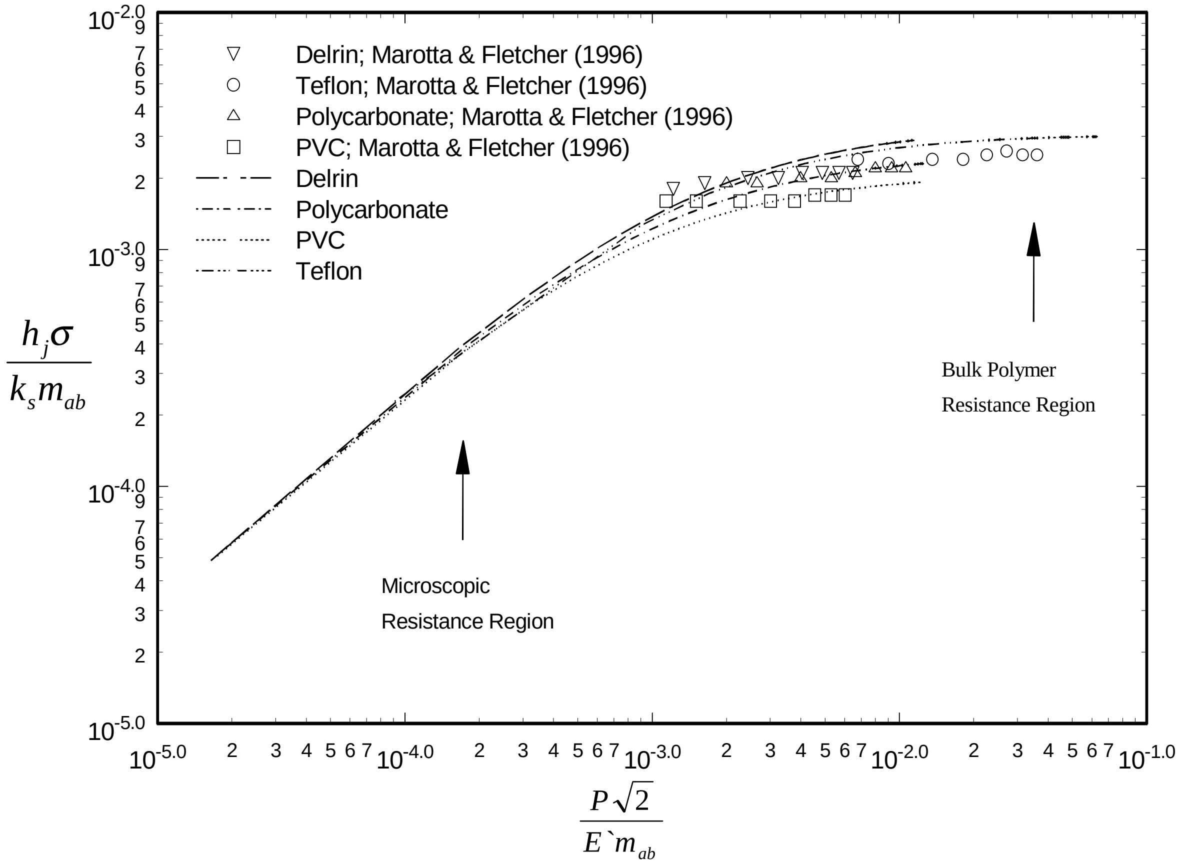
TCC of Metal/Polymer Joints- Summary



Microscopic Resistance Region

Bulk Polymer Resistance Region

Dimensionless Joint Conductance vs. Dimensionless Load: Mikic Elastic Model with Experimental Data

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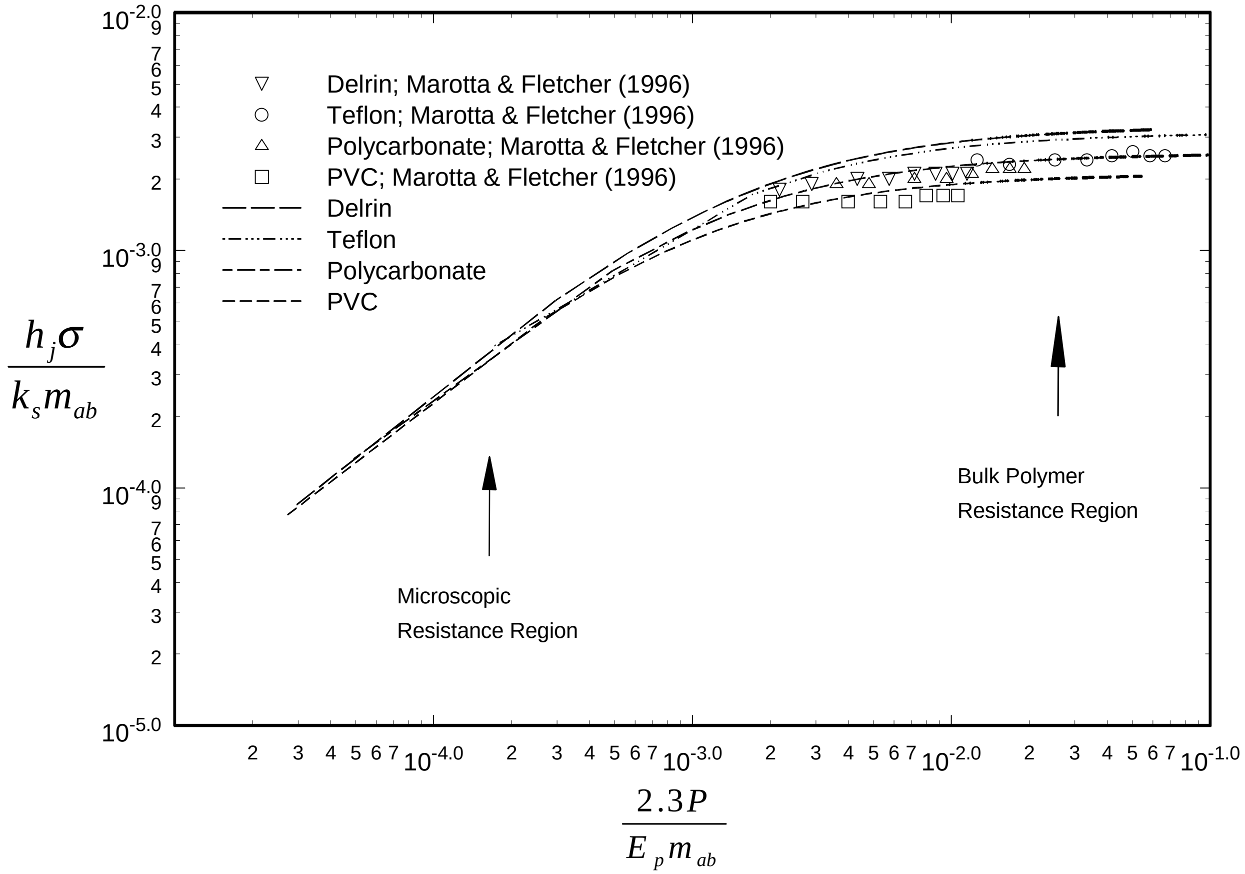
TCC of Metal/Polymer Joints- Summary



Dimensionless Joint Conductance vs. Dimensionless Load: Joint Conductance Model with Experimental Data

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TCC of Metal/Polymer Joints- Conclusion

- The experimental data was predicted well by the joint conductance model

- Two regions were defined by the joint conductance model:

  - Microscopic region - where the contact resistance dominates
  - Bulk region - where the bulk resistance of the polymer dominates

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TCC of Metal/Polymer Joints- Recommendations

- Due to limited amount of published data, an experimental study is needed to completely verify the joint conductance model, especially at light loads.
- Changes to joint conductance model: In real applications the Young's modulus of a polymer is both a function of temperature and time.
- Desired to include an expression for $E=f(T,t)$ into the the joint conductance model and the effect of non-uniform pressure distribution

TCC of Metal/Polymer Joints- Recommendations

Linear Viscoelastic Behaviour

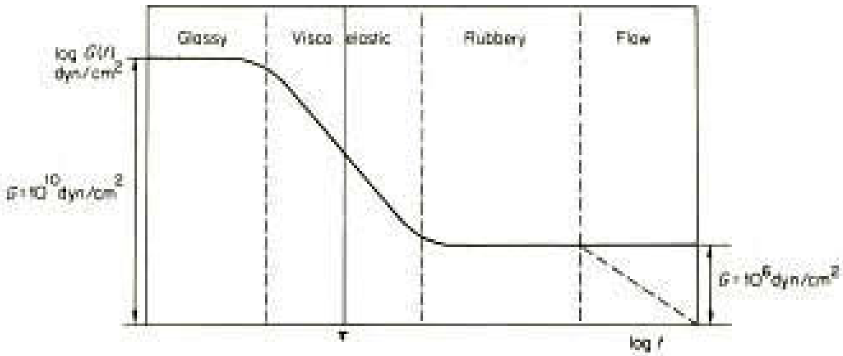
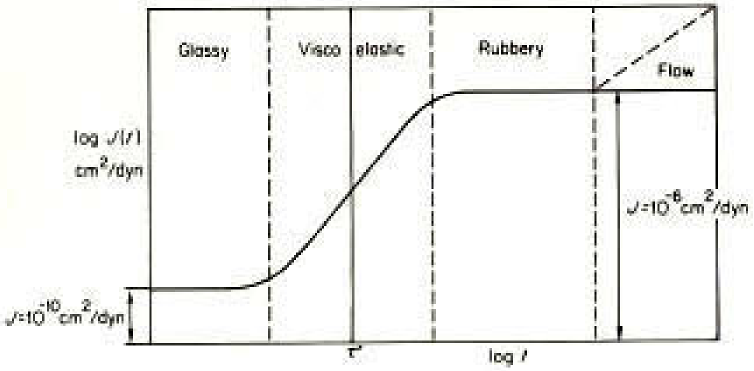


Figure 5.5. The stress-relaxation modulus $G(t)$ as a function of time t. τ is the characteristic time (the relaxation time).



The creep compliance $J(t)$ as a function of time t. τ' is the characteristic time (the retardation time).

- Most polymers exhibit linear viscoelastic behavior

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