Effect of Asperity Deformation on Thermal Joint Conductance

M.R. Sridhar
Larsen and Toubro Ltd.
EPC Centre, Chhani
Vadodara, Gujarat, India

M.M. Yovanovich
Microelectronics Heat Transfer Laboratory
Department of Mechanical Engineering
University of Waterloo
Waterloo, Ontario, Canada

Outline

- Introduction, Objectives
- Review of contact, gap and joint conductance models
- Develop dimensionless joint conductance expressions
- Model validation
- Summary
- Acknowledgements

Introduction

- Plastic gap conductance model developed by Yovanovich (1983)
- Accurately predicts experimental results (Hegazy, 1985) for nitrogen environment
- Large differences between model and measurements for helium

Objectives

- Study the effect of asperity deformation on gap and joint conductance
- Reduce existing experimental data using an elastoplastic model
- Test hypothesis that poor model agreement for helium due to improper values of TAC

Definitions

- Dimensionless contact conductances:

$$C_j = C_c + C_g$$

where:

$$C_j = \frac{s\ h_j}{m\, k_s} \qquad C_c = \frac{s\ h_c}{m\, k_s} \qquad C_g = \frac{s\ h_g}{m\, k_s}$$

and:

$$s = \sqrt{s_1^2 + s_2^2} \qquad m = \sqrt{m_1^2 + m_2^2} \qquad k_s = \frac{2\, k_1\, k_2}{k_1 + k_2}$$

Dimensionless Gap Conductance

- Yovanovich et al. (1983)

$$C_g = \frac{k_g / k_s}{m\sqrt{2p}} \int_0^\infty \frac{\exp[-(Y/s - t/s)^2/2]}{(t/s + M/s)} d(t/s)$$

- Converted to elastic or plastic model using the appropriate model to predict (Y/s)

Dimensionless Mean Plane Separation

- For elastic deformation (Mikic, 1974 and Sridhar and Yovanovich, 1994):

$$\left(\frac{Y}{s}\right)_e = \sqrt{2}\,\mathrm{erfc}^{-1}\left[\frac{4P}{H_e}\right]$$

- Dimensionless elastic contact pressure:

$$\frac{P}{H_e} = \frac{\sqrt{2}\,P}{E'm} \qquad E' = \left[\frac{1-n_1^2}{E_1} + \frac{1-n_2^2}{E_2}\right]^{-1}$$

Dimensionless Mean Plane Separation

- For plastic deformation (Yovanovich, 1982 and Sridhar and Yovanovich, 1994):

$$\left(\frac{Y}{s}\right)_p = \sqrt{2}\ \mathrm{erfc}^{-1}\left[\frac{2P}{H_c}\right]$$

- Dimensionless plastic contact pressure (Song and Yovanovich, 1988):

$$\frac{P}{H_c} = \left[\frac{0.9272\ P}{c_1 (1.62 s\ / m)^{c2}}\right]^{\frac{1}{1+0.071\, c_2}}$$

Gas Parameter Definitions

- Effective temperature jump distance: $M = a\, b\, \Lambda$
- Accommodation parameter: $a = \dfrac{2 - a_1}{a_1} + \dfrac{2 - a_2}{a_2}$
- Gas parameter: $b = \dfrac{2g}{(g + 1)} \dfrac{1}{\mathrm{Pr}}$
- Gas mean free path: $\Lambda = \Lambda_0 \dfrac{T}{T_0} \dfrac{P_{g0}}{P_g}$

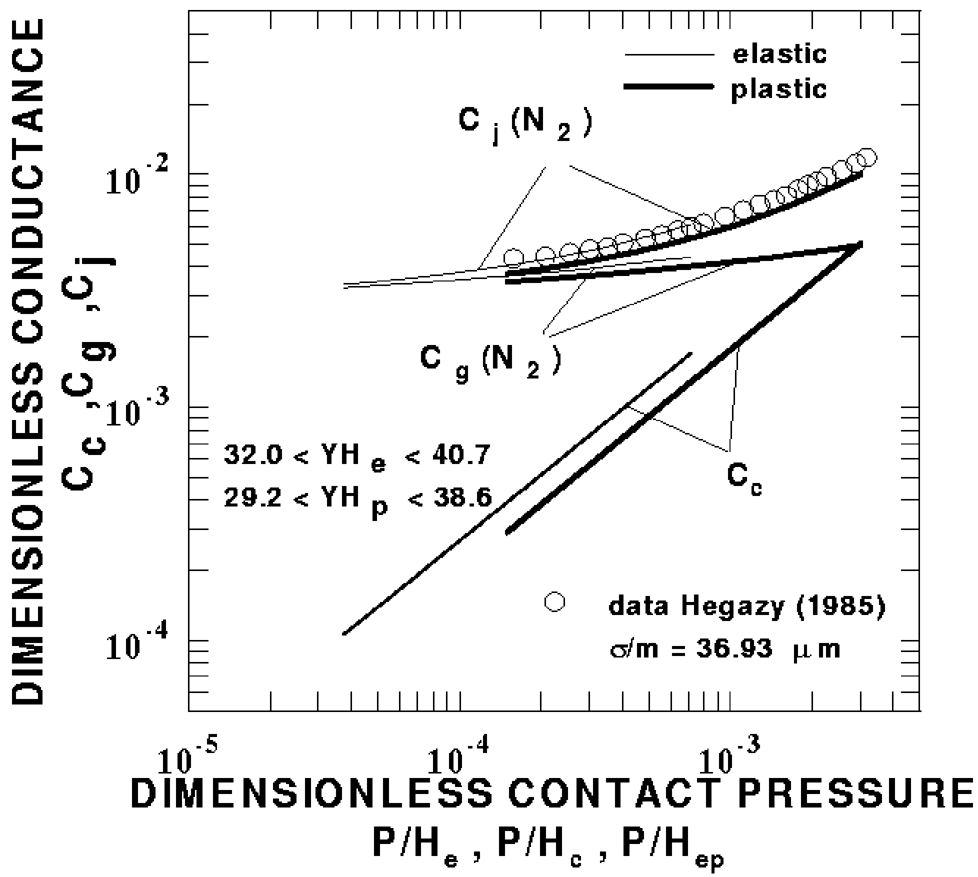
Nitrogen and Helium Properties

Property	*Nitrogen*	*Helium*
k_g (W/mK)	$2.502 \times 10^{-2} + 5.844 \times 10^{-5}\, T(^{o}C)$	$14.543 \times 10^{-2} + 3.24 \times 10^{-4}\, T(^{o}C)$
a	0.9	$0.425 - 2.3 \times 10^{-4}\, T(K)$
g	1.405	1.667
L_0 (nm)	63.0	186
Pr	0.691	0.667

Surface Properties of SS304 Interfaces

Pair	*s (mm)*	*m (rad.)*	*s / m (mm)*
SS1	5.65	0.153	36.93
SS2	5.61	0.151	37.15
SS3	6.29	0.195	32.26
SS4	4.02	0.168	23.93

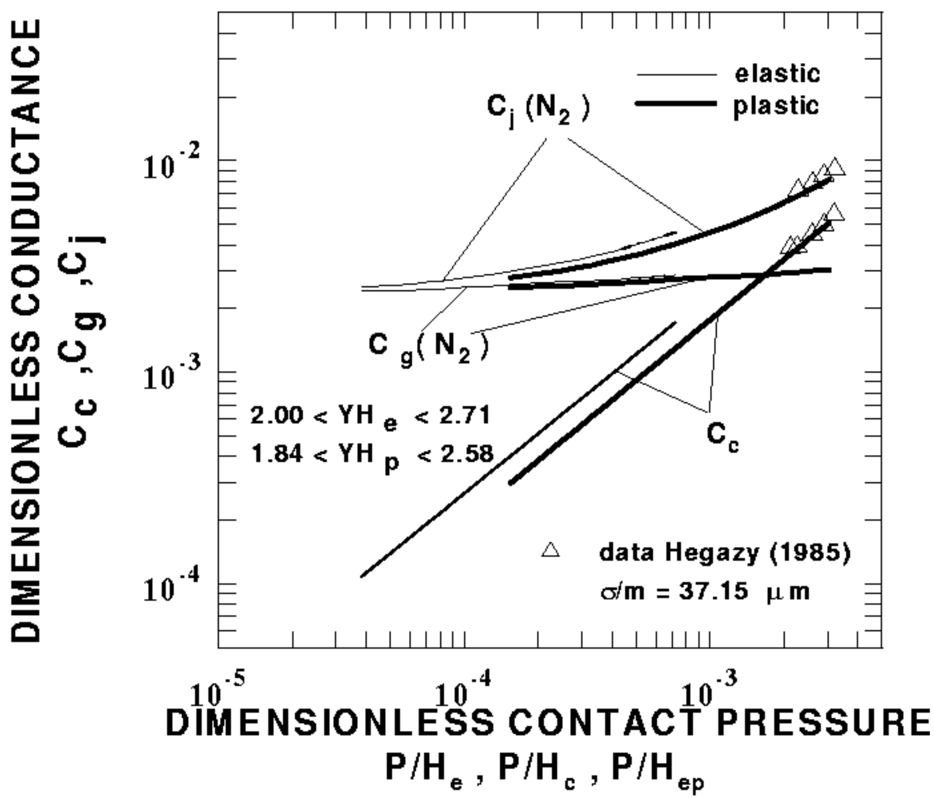
Model Validation by SS1 Data in Nitrogen



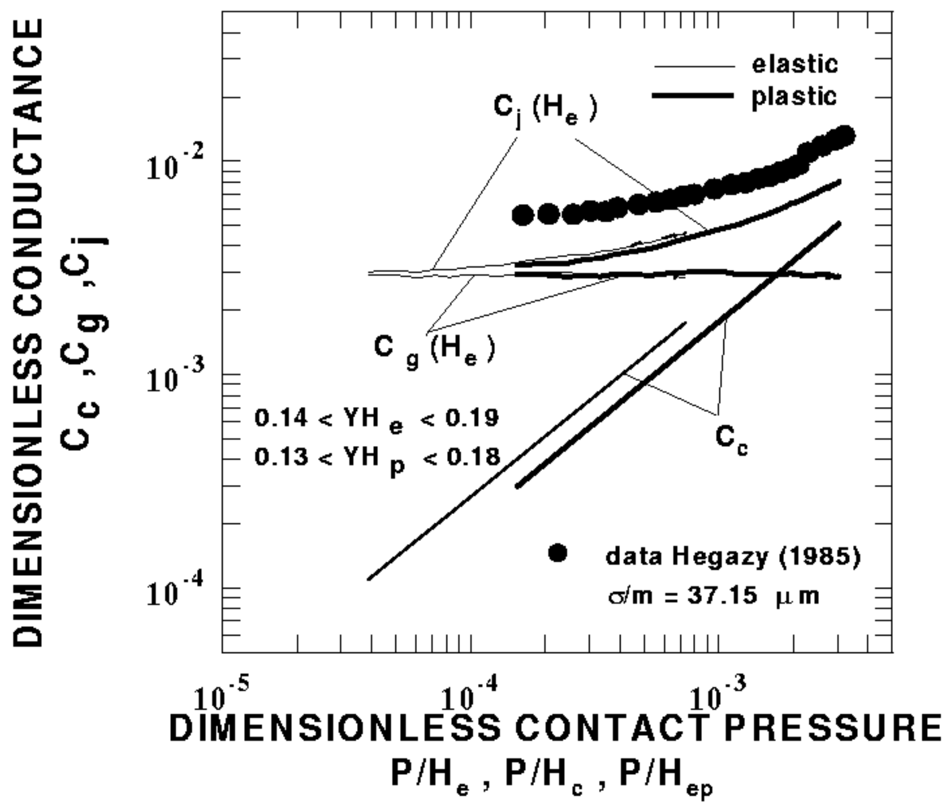
- Gap-temperature jump parameter:

$$YH = \frac{Y/s}{M/s}$$

Model Validation by SS2 Data

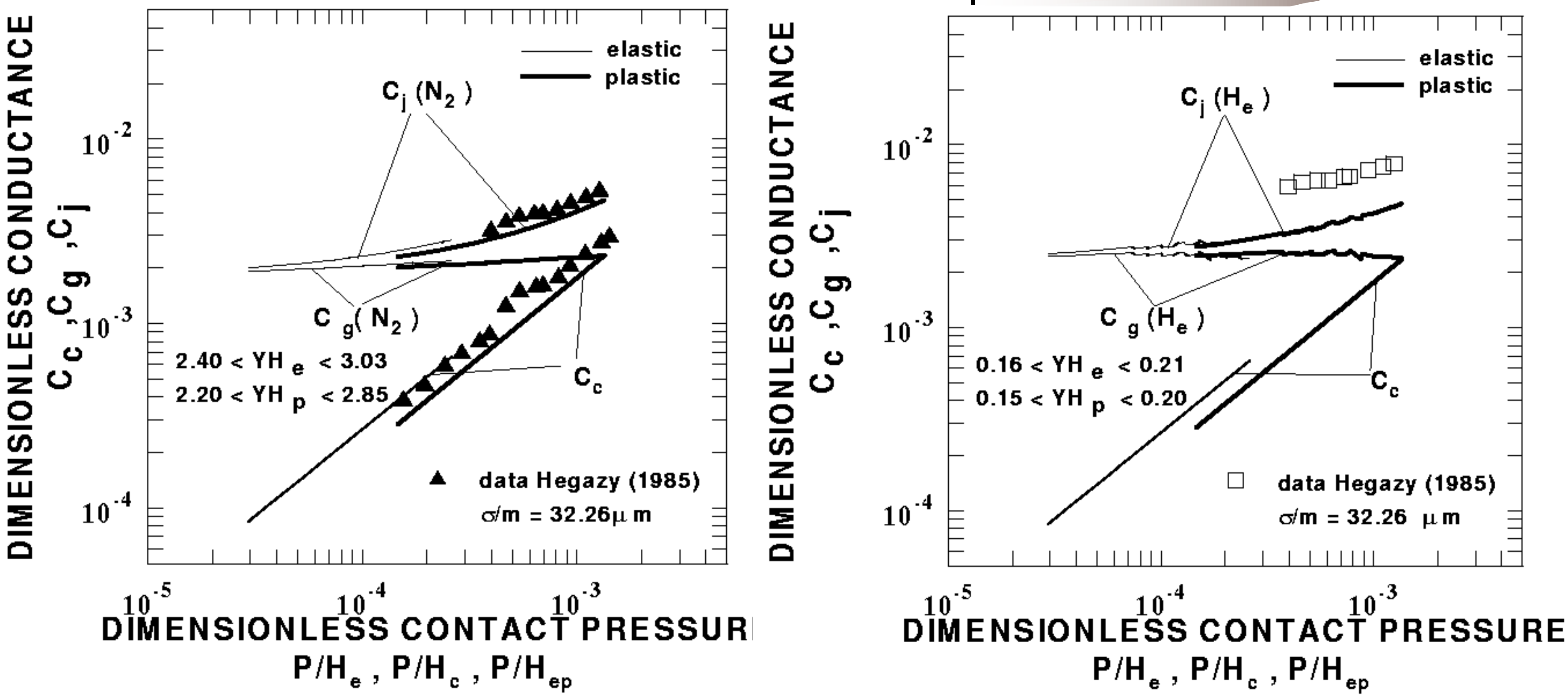


a) Nitrogen / Vacuum



b) Helium

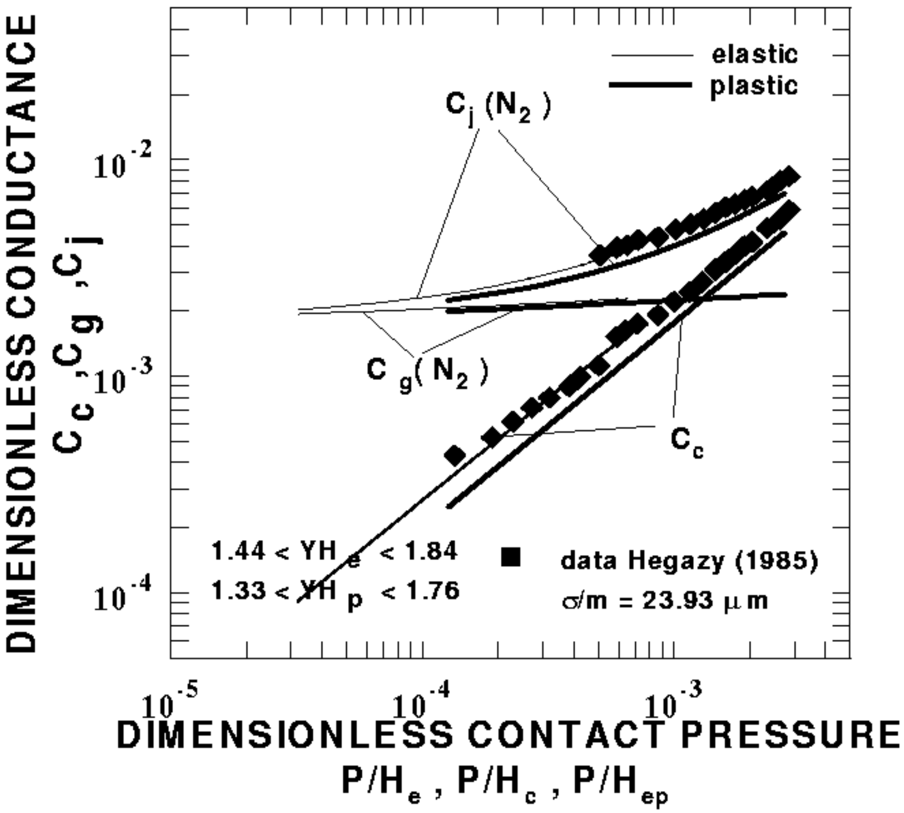
Model Validation by SS3 Data



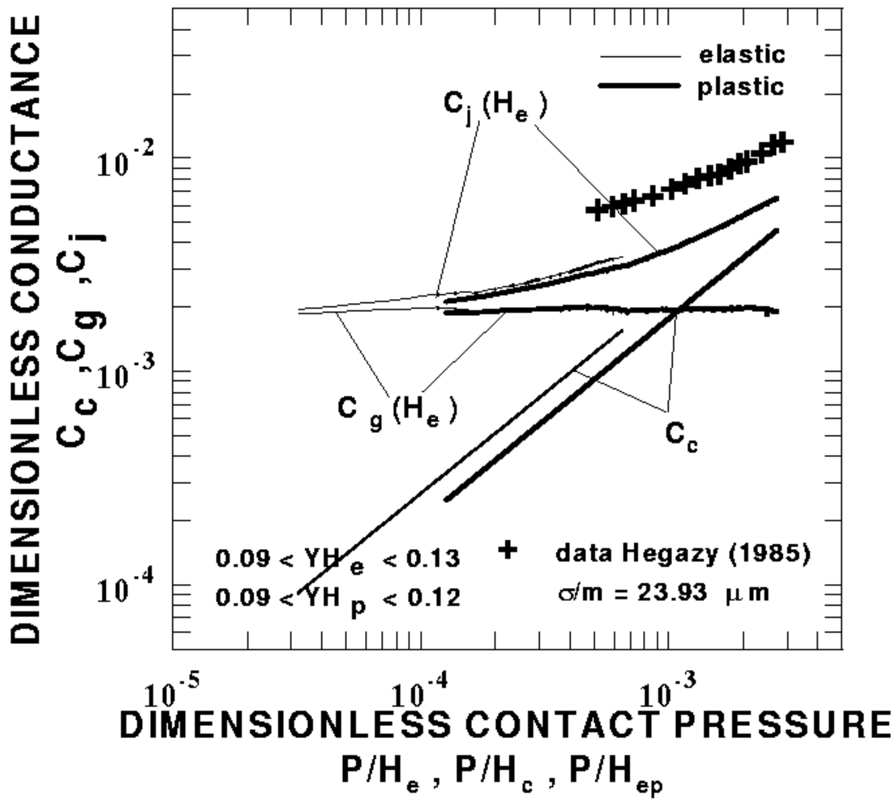
a) Nitrogen / Vacuum

b) Helium

Model Validation by SS4 Data

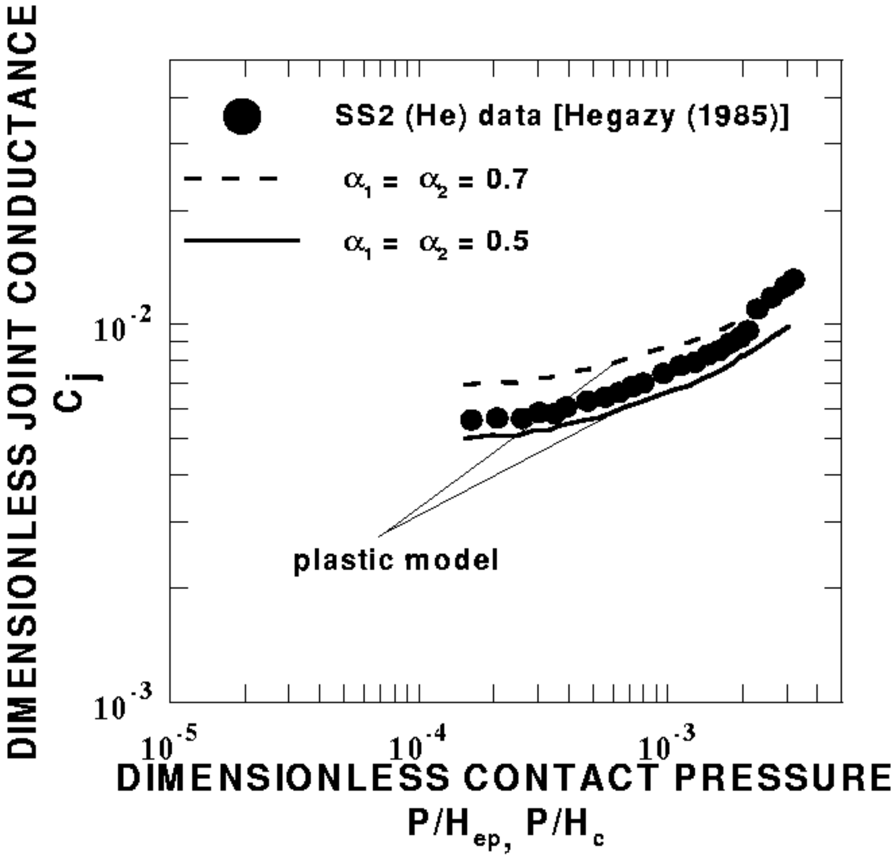


a) Nitrogen / Vacuum

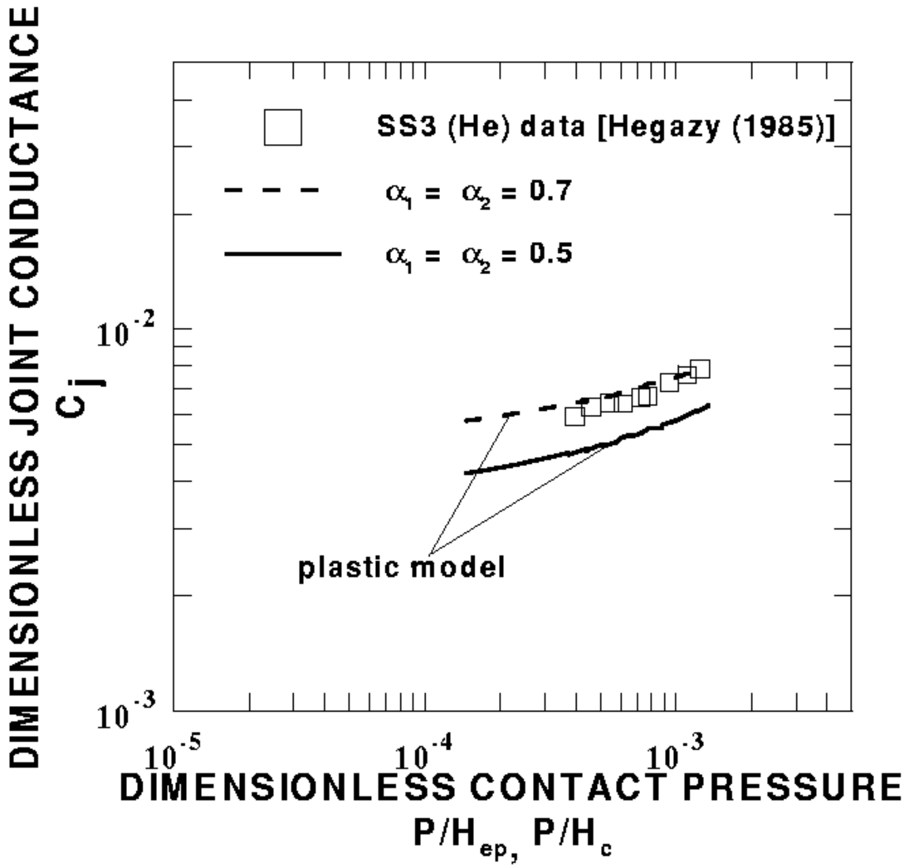


b) Helium

Model Validation

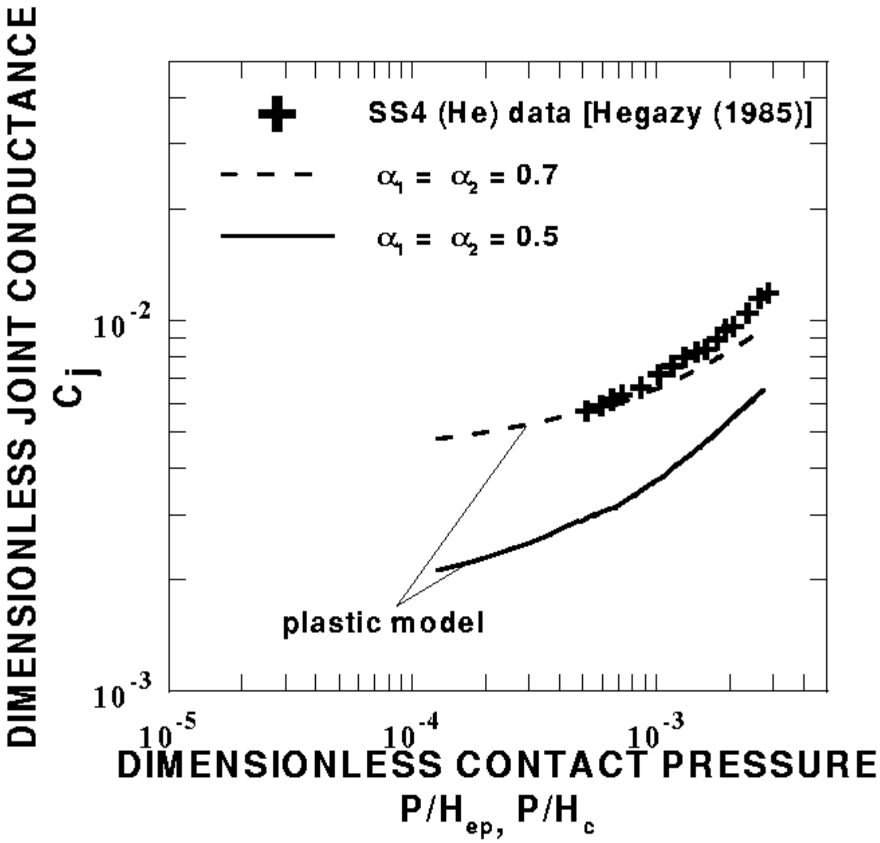


a) SS2 Helium Data

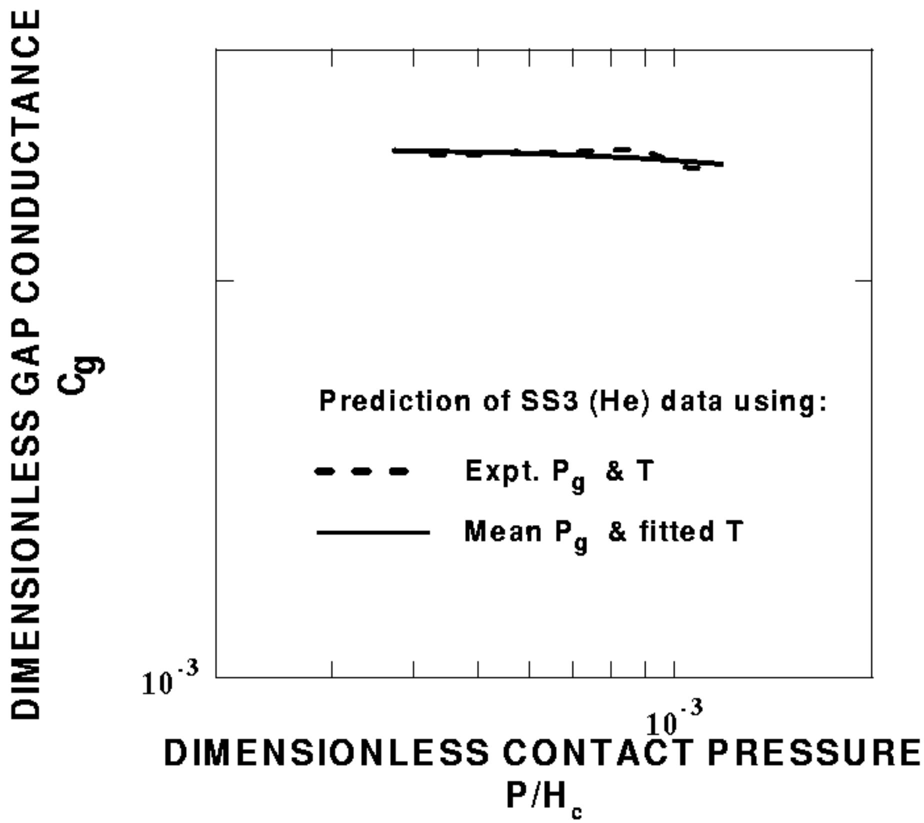


b) SS3 Helium Data

Model Validation



a) SS4 Helium Data



b) SS3 Helium Data

Summary

- Contact and joint conductance have similar behavior with respect to deformation
- Excellent agreement between models and nitrogen data for all tests
- Large differences between models and helium data are independent of deformation type
- Model predictions for helium improve when a “proper” TAC value is used

Acknowledgements

The authors wish to acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada for Professor Yovanovich.