GLAST Epoxy Thermal Shear Stress

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Abstract

This technical note summarizes the results of an epoxy layer shear stress analysis. The subject epoxy layer attaches the GLAST silicon detector segments to the detector tray assemblies. The stresses are generated by an assumed –50° C temperature change that could be expected while the instrument is in storage prior to launch. Stresses are computed as a function of total adhesive contact area and as a function of epoxy shear stiffness. In general, the stresses are reduced with larger contact area and with reduced epoxy shear stress.

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Rev.	Date	Author(s)	Summary of Revisions/Comments
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1. Summary

Epoxy layer shear stresses resulting from a negative 50 degree Celsius temperature change are calculated using finite element approximations and closed form methods. The analyses simulate candidate epoxy adhesive configurations that attach the silicon detector segments to the detector trays. Discrete attachment pads, line attachment segments, and total area attachments are examined with a structural finite element model. Where applicable, the finite element model results are verified by closed form expressions. Shear stress distributions as a function of attachment configuration and epoxy shear modulus are computed. The calculated results show that the shear stress increases with increasing shear modulus and that there is a tendency for the shear stress to decrease with increasing adhesive contact area.

2. Finite Element Models

2.1 General description

Finite element methods[1] are used to construct finite element models (FEM) and obtain coefficient of thermal expansion (CTE) induced stresses in simulated epoxy attachment models. The models represent the attachment of the GLAST detector segments to the underlying support trays. Three "layers" are simulated in the models; the first layer is a substrate, the second is the epoxy layer, and the third is the simulated silicon detector layer. Each layer is modeled using solid finite elements and isotropic material properties. Each model is represented by a 63 mm square area where a repeating section is a 9 by 9 mm area. A typical cross-section view showing a discrete pad arrangement is shown in Figure 1.

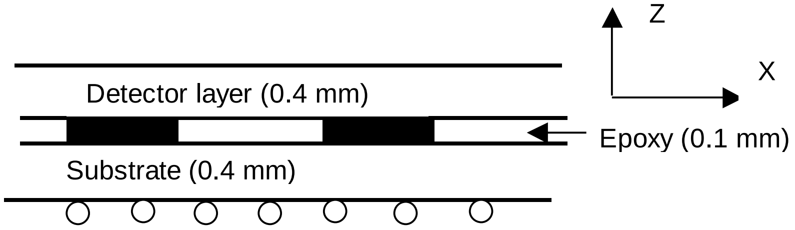


Figure 1: Cross-section view of model layers.

2.2 Material properties and dimensions

Table 1 lists layer material properties and layer thickness dimensions. The properties listed are Young's modulus, Poisson ratio, shear modulus, and coefficient of thermal expansion (CTE). As indicated, the Young's modulus for the epoxy layer is calculated for isotropic properties from the selected shear modulus and Poisson ratio.

Layer	Young's modulus E	Poisson ratio ν	Shear modulus G	CTE	Layer thickness (mm)
1-Substrate	100 GPa	0.3		0.7E-6	0.4
2-Epoxy	(1)	0.3	100psi – 1GPa	50E-6	0.1
3-Detector	130 GPa	0.3		2.5E-6	0.4

(1) Epoxy E=2(1+ν)G

Table 1: Material properties and thickness dimensions.

2.3 Attachment pad layouts

Epoxy attachment topology consist of small pads (or dabs) of adhesive at 3mm or 5mm per side, line attachments at 3mm wide, and full surface coverage outlining the 3mm pad array. The epoxy attachment arrangements are shown in a subsequent section that presents the calculated shear stresses.

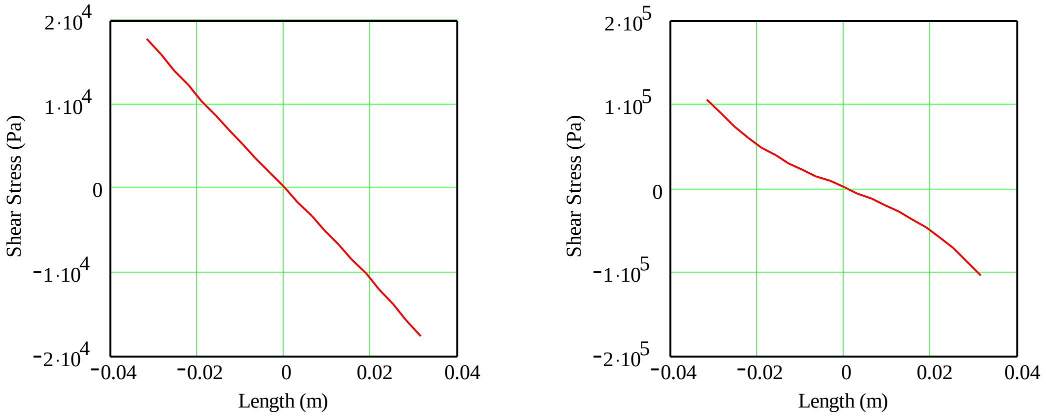
3. Closed Form Method

Epoxy shear stresses can be computed using the following expressions. The subscripts refer to the layer numbers used in Table 1 where subscripts 1, 2, and 3 are the lower substrate, epoxy bond layer, and top layer; respectively.

$$C = \sqrt{\frac{G_2}{t_2}\left[\frac{1}{E_1 t_1} + \frac{1}{E_3 t_3}\right]} \tag{1}$$

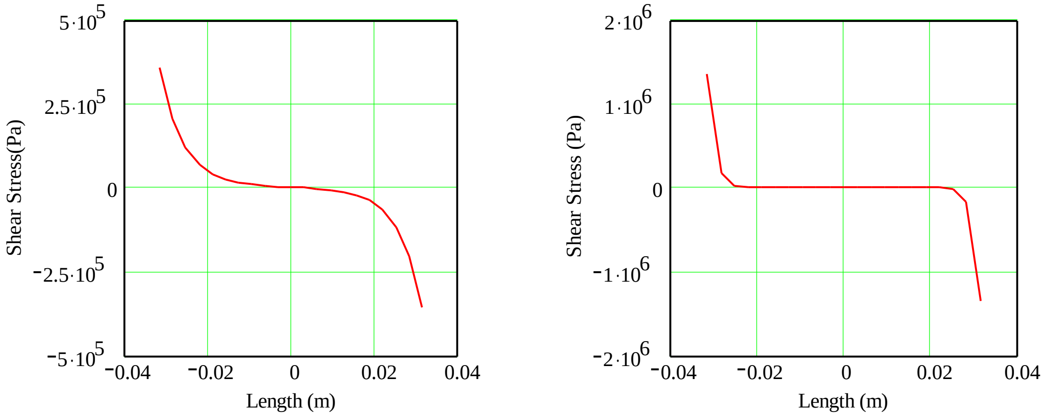
$$t\,(x) = \frac{G_2}{C\,t_2}\left[\left(a_3 - a_1\right)\Delta T\,\frac{\sinh(C\,x)}{\cosh(C\,{}^{L}\!/_{2})}\right] \tag{2}$$

In the first expression *G*, *t*, and *E* refer to the shear modulus, thickness, and Young's modulus; respectively. In the second expression t, α, *DT*, and *x* refer to the epoxy shear stress, coefficient of thermal expansion, temperature change, and distance along a continuous strip; respectively. Calculated results for several epoxy modulus and a temperature change of –50° C are shown in Figure 2. These curves may be compared to the FEM results shown in Figure 6 (epoxy *G*=6.895E6 Pa (1000psi)), Figure 7 (epoxy *G*=6.895E7 Pa (10,000psi)), and Figure 8 (epoxy *G*=1.0GPa).



Epoxy G = 6.895E5Pa (100psi)

Epoxy G = 6.895E6 Pa (1000psi)



Epoxy G=6.895E7 Pa (10,000psi)

Epoxy G=1.0GPa (145,000psi)

Figure 2: Theoretical epoxy shear stress distribution for a bond strip simulating the COMOS FEM.

4. Finite Element Model Stresses

Figure 3, Figure 4, and Figure 5 display the shear stress distribution in the XZ plane for epoxy shear modulus of 6.89E65Pa (1000psi), 6.895E7Pa (10,000psi), and 1.0GPa (145,000 psi); respectively.

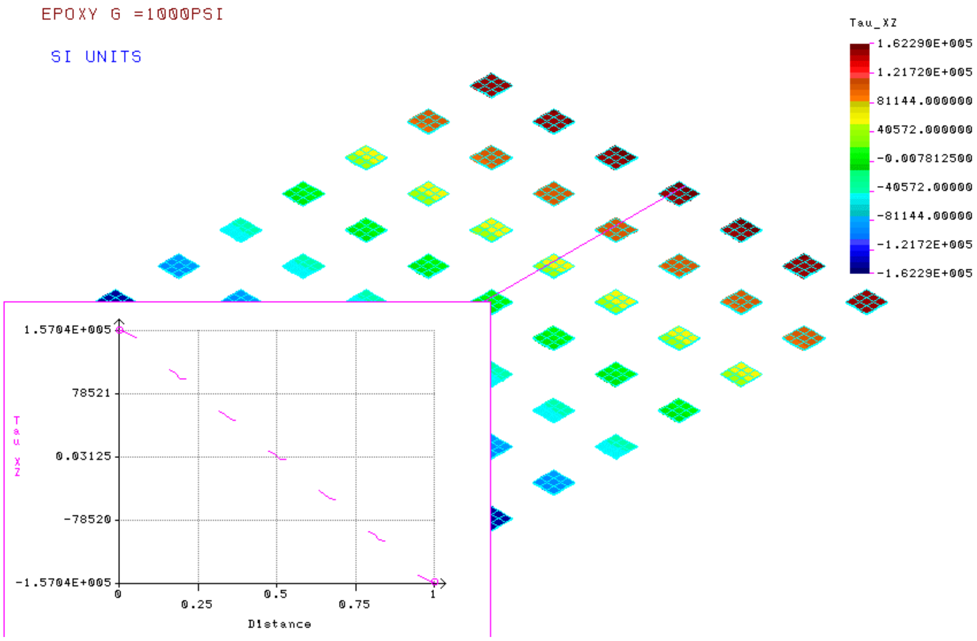


Figure 3: Shear stress distribution for epoxy modulus of 6.895E6Pa (1000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

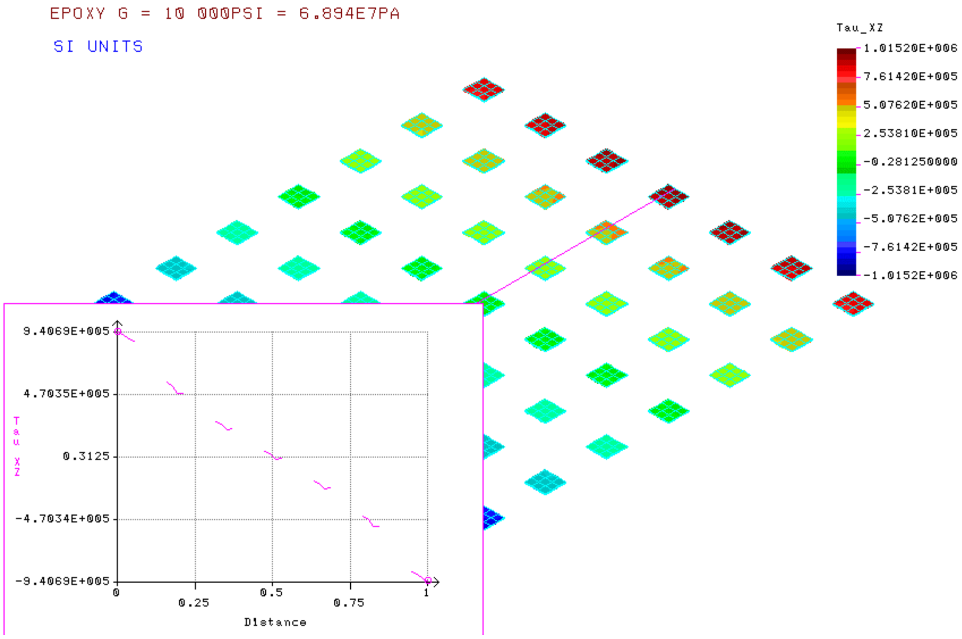


Figure 4: Shear stress distribution for epoxy modulus of 6.895E7Pa (10,000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

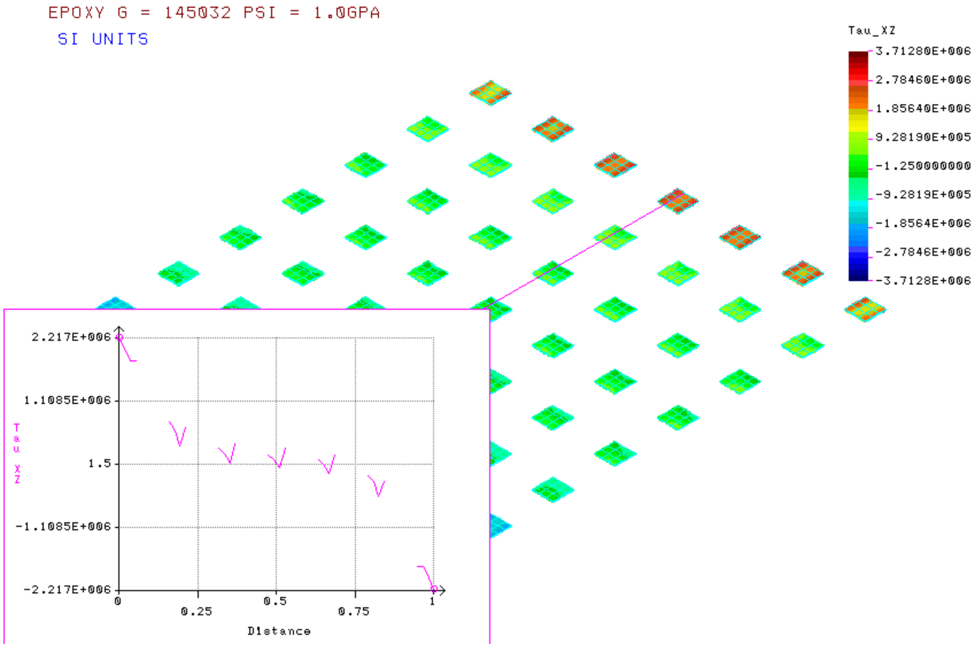


Figure 5: Shear stress distribution for epoxy modulus of 1.0GPa (145,000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

Figure 6, Figure 7, and Figure 8 display shear stress distributions for a 3mm wide strip model with the shear modulus at 6.895E6Pa (1000psi), 6.895E7 (10,000psi), and 1.0GPa (145,000psi); respectively.

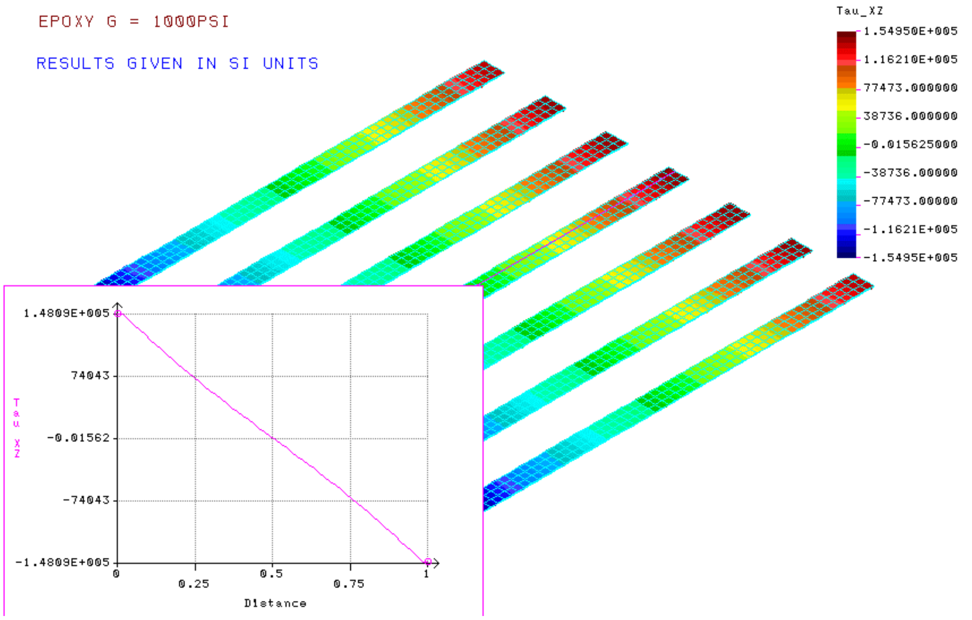


Figure 6: Strip model shear stress distribution for epoxy shear modulus of 6.895E6Pa (1000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

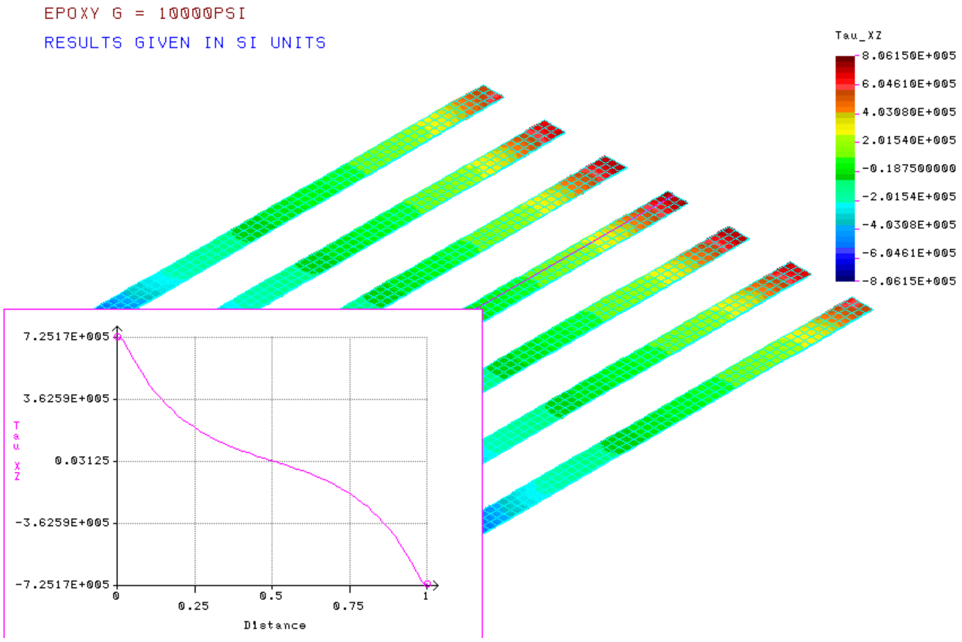


Figure 7: Strip model shear stress distribution for epoxy shear modulus of 6.895E7Pa (10,000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

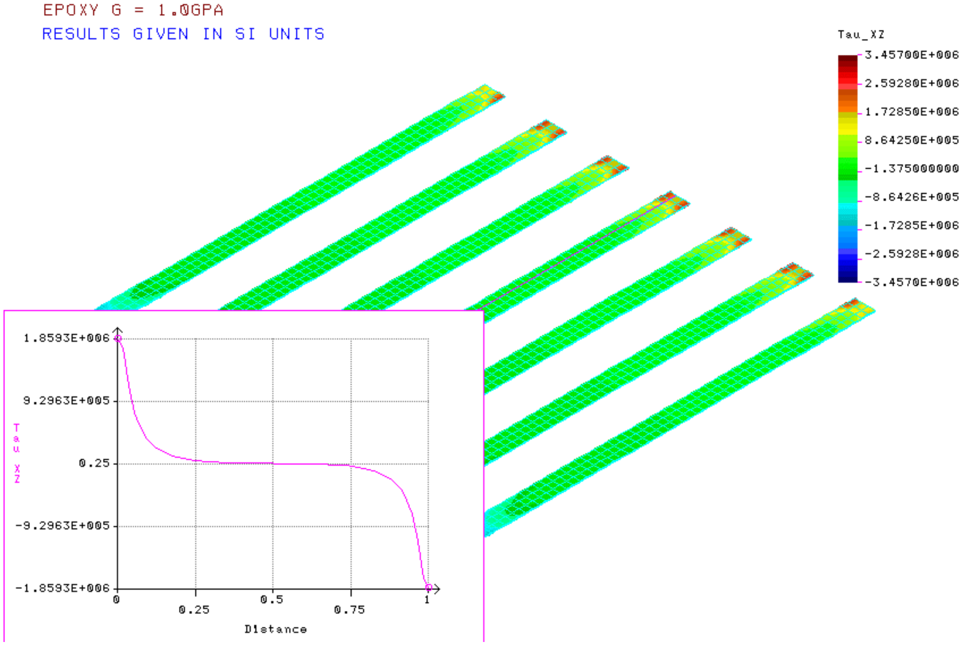


Figure 8: Strip model shear stress distribution for epoxy shear modulus of 1.0GPa (145,000psi). Lower left plot shows stress as a function of position along the *X* axis for a representative section.

A typical shear stress distribution pattern for the full surface epoxy treatment is displayed Figure 9.

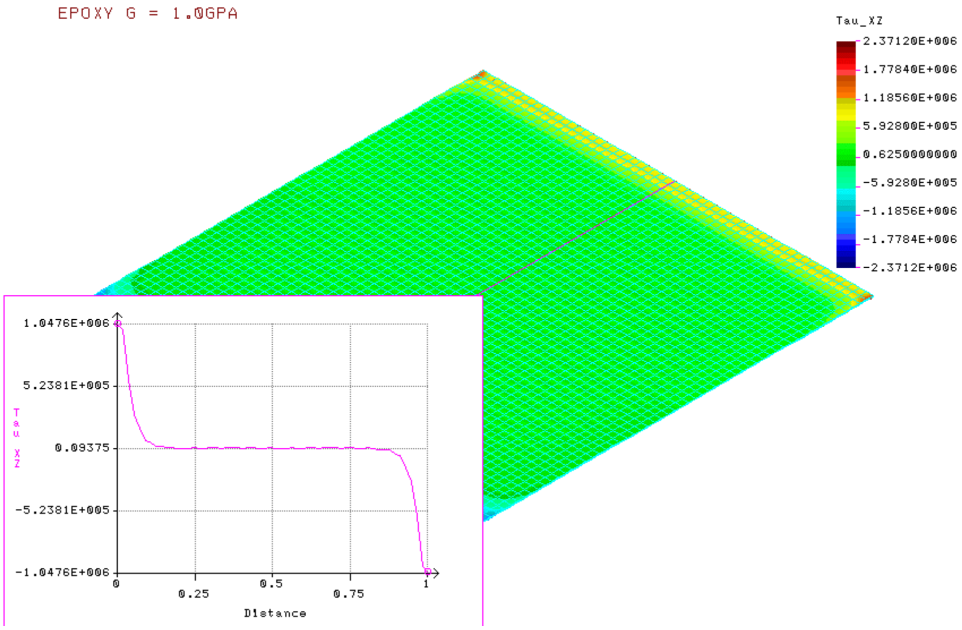


Figure 9: Full surface epoxy shear stress distribution for epoxy shear modulus of 6.895E5Pa (100 psi).

5. Shear Stress Trends

5.1 Shear modulus effects

The effect on maximum epoxy shear stress as a function of shear modulus and attachment pattern is presented in Figure 10.

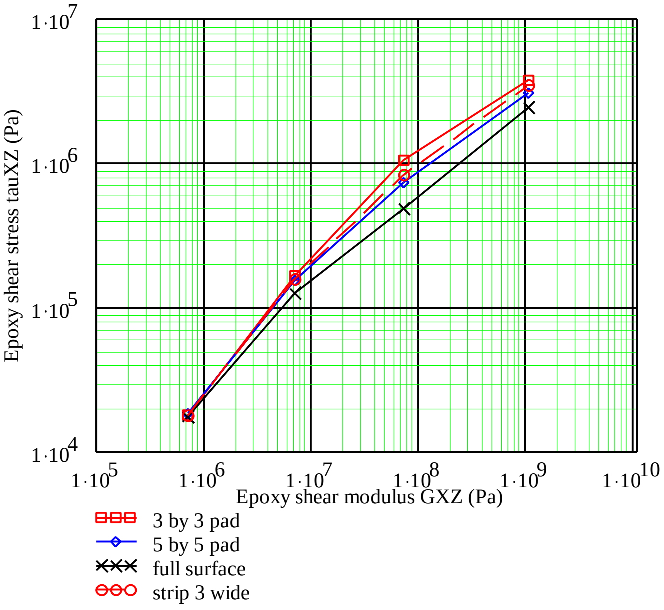


Figure 10: Epoxy shear stress as a function of epoxy shear modulus plotted for the four attachment topographies examined.

Inspection of Figure 10 reveals that the maximum shear stress is attenuated with generally additional applied epoxy surface area. It should be noted that the curves are plotted on a log-log scale so that the actual differences would appear much larger on a linear plot scale.

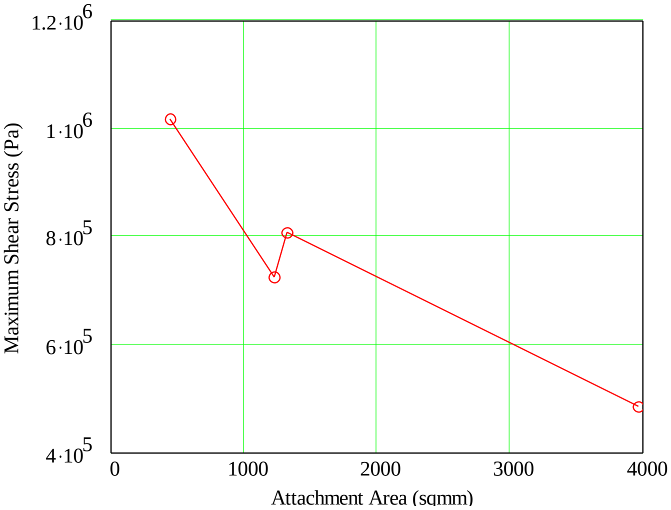


Figure 11: Maximum epoxy shear stress as a function of effective epoxy attachment area for epoxy G=6.895E7Pa (10,000psi).

Figure 11 illustrates the effect of attachment area on the maximum epoxy shear stress. In general, the shear stress decreases with an increase in epoxy area. The first point to the left on the curve is the calculated for the 3mm square pad, the second point is the 5mm square pad, the third point is for the 3mm wide strip, and finally, the last point to the right is the full surface area. Note that although the area for the strip application is greater than the 5mm square pad, the maximum stress is less than the 5mm square model.

6. Conclusions

Several conclusions regarding epoxy shear stress behavior are apparent from the FEM and closed-form calculated results.

- The maximum shear stress tends to decrease with an increase in total bond attachment area.
- The maximum shear stress increases significantly with an increase in the epoxy shear modulus. The more rigid epoxy material (i.e. higher shear modulus) “push” the peak shear stress toward the outside edge toward greater maximums.
- A corollary to the previous conclusion is that the lower epoxy shear modulus distribute the shear stress more evenly thus reducing the maximum peak.

7. References

1. COSMOS/M Finite Element Analysis System, Structural Dynamics Research and Analysis Corporation, Los Angeles, CA.