# ANALYSIS AND DESIGN OF CARBON-CARBON CONSTRAINING CORES FOR THERMAL MANAGEMENT OF ELECTRONIC COMPONENTS

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## INTRODUCTION

Carbon-carbon (C-C) composites are being investigated for potential use in coefficient of thermal expansion (CTE) constraint and thermal plane applications for printed wiring boards (PWB's). C-C containing high conductivity graphite fibers greatly assist in the dissipation of heat from the electronic PWB's, thereby allowing significantly more electronic chips to be mounted to them. The CTE of the PWB must conform to the chip materials mounted on it so that stresses at the joint of the chip and the PWB due to thermal expansion mismatch will be as small as possible. Current CTE constraining core materials include copper-invar-copper, which is relatively heavy. Thus C-C offers advantages in the areas of increased conductivity and weight savings.

In all of the PWB applications being considered, glass-polyimide (Gl-Pl) laminates are the material of choice due to their low dielectric constants. The PWB thickness is 0.060 inch and two PWB's will be mounted on a single thermal plane, one on each side. In the work reported here, the PWB's are constrained to a CTE of 3.2 ppm/°C by means of a 0.020 inch C-C constraining core positioned between each PWB and the thermal plane. Adhesive bond layers on the top and bottom of the C-C constraining core are used to assemble the Standard Electronics Module, Format E (SEM-E). The thermal plane examined in the current study is a graphite/aluminum (Gr/Al) metal matrix composite (MMC) which has a CTE in the vicinity of the 3.2 ppm/°C goal.

The most challenging requirement placed on the SEM-E is the survival of the assembly when subjected to a minimum temperature of -55°C. Due to the thermal expansion mismatch between the various material components of the unit, severe stresses are placed on the adhesive joints and the C-C. The influence of these stresses on the final design of the SEM-E is the subject of this paper.

## TECHNICAL APPROACH

Figure 1 shows the exaggerated displacements in a quarter model of the SEM-E resulting from a -100°C temperature change. The right-hand edge of the model illustrates the shear lag phenomenon, in which high shear stresses cause distortion of the free edges of the assembly. Since the laminate has no loads acting on it, the axial stresses in each layer must always be zero at the free (right-hand) edge. Temperature changes cause in-plane axial tensile or compressive stresses in the various layers, depending on the individual layers' CTE relative to the effective assembly CTE. Each layer's axial stress begins as zero at the free edge and builds up to a constant tensile or compressive stress a short distance away from the free edge. This is made possible by shear stresses between each layer at the free edge, which are a maximum at the free edge and dissipate to zero after transferring axial load into the layers. The shear stresses cause the edge distortion and also account for high transverse tensile stresses acting to pull apart the materials at the edge. Thus edge shear and edge transverse tensile stresses are of great interest in the design.

Stress analysis of the Advanced SEM-E Design was performed using measured properties [1] for the C-C constraining core and Gr/Al MMC thermal plane.
A generalized plane strain finite element model was constructed to perform the residual stress analysis. As shown in Fig. 1, the model consisted of the PWB, an adhesive bond layer, the C-C constraining core, a second adhesive bond layer, and one-half of the 0.100 inch Gr/Al thermal plane. Symmetry displacement boundary conditions were used so that only one-quarter of the design was modeled. The baseline analysis case was a unit temperature change of -100°C, allowing stresses to be calculated at the critical temperature of -55°C for any adhesive layer stress-free temperature, which depends on the adhesive bond cure temperature used in the SEM-E assembly construction.

## RESULTS OF STRESS ANALYSIS

Using the peak calculated stresses, required material strengths were plotted as a function of the adhesive stress-free temperature. Figure 2 shows the required C-C compressive strengths and required adhesive tensile strengths. At a stress-free temperature of 100°C, the required C-C compressive strength is approximately 22,300 psi. From thermal cycling tests performed on hybrid laminates consisting of GI-PI facesheets bonded to a C-C core, the in-situ C-C compressive strength is at least 20,691 psi and possibly higher. This value was computed using measured moduli and CTE for the hybrid constituents and a known cure temperature for the adhesive layers. Also from Figure 2, at -55°C the required adhesive tensile strength is approximately 6060 psi for an adhesive stress-free temperature of 100°C. Thus neither of these stresses should cause failures for adhesive cure temperatures less than 100°C.

Required C-C across-ply (A/P) tensile and adhesive shear strengths are plotted as a function of the adhesive stress-free temperature in Figure 3. Even at a cure temperature of 25°C, the required C-C A/P tensile strength exceeds the highest measured strength value, indicating that the C-C constraining core will develop peel mode cracks at the corners and edges. There is also concern over the adhesive shear stresses, which are very close to measured lap shear strengths.

## CONCLUSIONS

The edges of the outside layer of the PWB material must be tapered in order to relieve the edge C-C A/P tensile stress and adhesive shear stress. Analyses of the hybrid composites indicate lowest stresses when the taper reduces the PWB edge thickness to zero. Figure 4 shows the effect of the slope of the edge taper on the critical stresses. Experiments to verify these trends and select an edge taper slope are being performed. The results of these tests will provide input to the final design of the PWB edge taper in the Advanced SEM-E Design assembly.

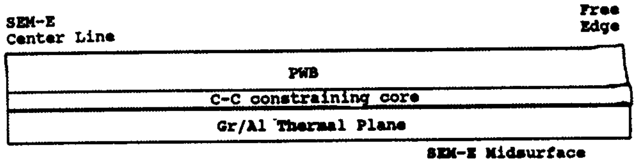

Figure 1. Exaggerated displacement for ΔT=-100°C in SEM-E assembly with untapered GI-PI PWB's.

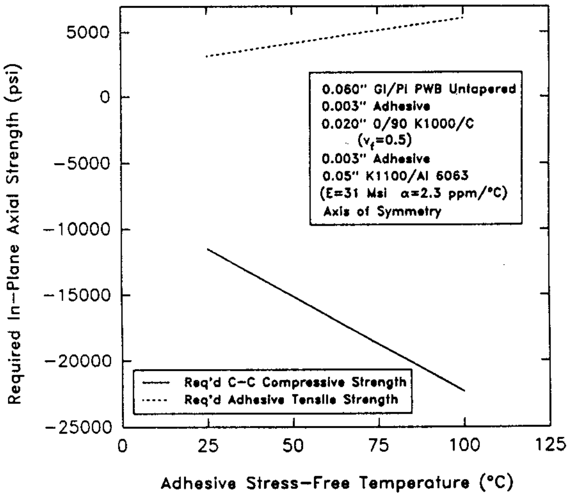

Figure 2. Required in-plane axial strengths for constituents of SEM-E assembly with untapered GI-PI PWB's.

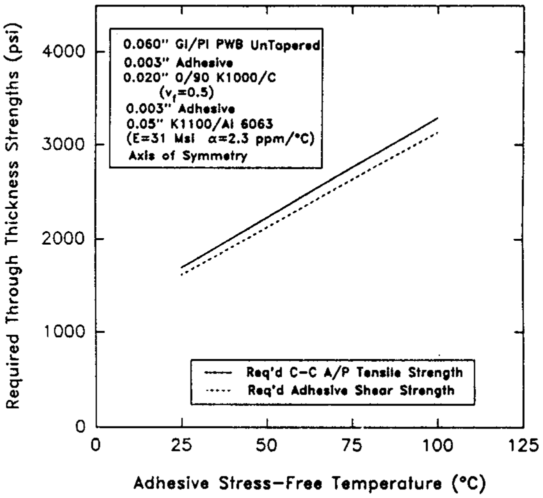

Figure 3. Required C-C transverse tensile and adhesive shear strengths for SEM-E with untapered GI-PI PWB's.

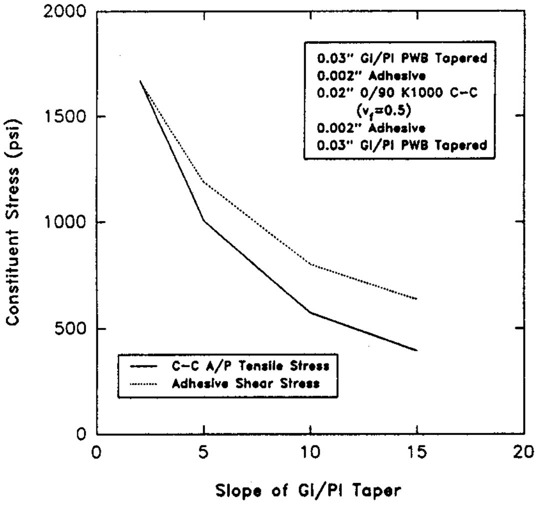

Figure 4. Effect of GI-PI edge taper slope on critical stresses in GI-PI/C-C/GI-PI hybrid laminates for ΔT=-100°C.