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Stress and Strain Modeling of Low-Temperature Cofired Ceramic (LTCC) Seal Frame and Lid

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Abstract

Low-temperature cofired ceramic (LTCC) is established as an excellent packaging technology for high-reliability, high-density microelectronics. LTCC multichip modules (MCMs) comprising both 'surface mount' and 'chip and wire' technologies provide additional customization for performance. Long-term robustness of the packages is impacted by the selection of the seal frame and lid materials used to enclose the components inside distinct rooms in LTCC MCMs. An LTCC seal frame and lid combination has been developed that is capable of meeting the sealing and electromagnetic shielding requirements of MCMs. This work analyzes the stress and strain performance of various seal frame and lid materials, sealing materials, and configurations. The application for the MCM will impact selection of the seal frame, lid, and sealing materials based on this analysis.

Keywords: LTCC, EMI, shielding, isolation, Kovar

I. Introduction

Ceramic multichip modules (MCM-Cs) have been utilized in high-speed, high-reliability, and high-density microelectronics for more than 30 years [1]. Low-temperature cofired ceramic (LTCC) permits the use of high-conductivity internal metallization for improved high-frequency performance. Wolf *et al.* have developed a thin-film metallization system compatible with LTCC, which extends the high-frequency performance and robustness of MCM-Cs [2]. Kovar is a common material chosen for seal frames and lids to provide environmental protection to the components housed within the MCM-C due to its low coefficient of thermal expansion (CTE). Müller *et al.* describe various configurations of seal frames and lids in respect of hermetic LTCC packages in their work [3]. This work evaluates a newly developed LTCC seal frame and lid, shown in Fig. 1, in comparison to a more traditional Kovar seal frame and lid [4].

LTCC [5] and alumina ceramic have also been utilized for planar covers without seal frames to MCM-Cs in cases where all of the components are positioned in a cavity that does not require additional clearance provided by a seal frame. Alumina 'cap style' covers have been used on ceramic substrates as well; however, they cover only a single 'room' and lack Faraday cage closure. The planar alumina and LTCC covers provide a close or exact match in CTE to the substrate material, but are not a suitable geometry for many designs that include tall surface-mount components or that lack cavities for components.

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The thermally induced stresses and strains in the LTCC substrate, attachment joint, and seal frame and lid are presented here for multiple attachment materials and seal frame/lid materials. The geometry of the MCM-C is held constant in this study for all attachment and seal frame and lid materials.

The use of MCM-Cs in RF applications has accommodated a desire to create isolation between functions within an MCM from electromagnetic interference (EMI) [6]. Previous work has detailed various configurations to create Faraday cage structures within the LTCC substrate (Fig. 2) and evaluate the impact of those configurations on the stress and strain of the LTCC substrate [7] and seal as well as on EMI isolation performance [8].

Fig. 3 shows a cross-sectional view of a technique presently used. These previous studies utilized Kovar as the seal frame and lid material and 63/37 Sn/Pb solder as the attachment material.

Here, the stress/strain relationships vs. temperature for selected materials are presented. The configuration and materials included in the evaluation are DuPont 951 LTCC substrate with seal frame trench, thin-film multilayer conductor Ti-Cu-Pt-Au[2], Kovar or DuPont 951 seal frames and lids, and Ablebond LMI 84 – 1 silver-loaded epoxy, Diemat 6030 HK silver-loaded epoxy, or 63/37 Sn/Pb solder as the seal frame attachment material. In the case of the Kovar seal frame and lid, attachment of the seal frame is conducted prior to component placement and attachment. Then the lid is seam-sealed onto the frame as a final step. In the case of the LTCC seal frame and lid, the package is sealed after all components have been placed and attached since the seal frame and lid are monolithic in this situation.

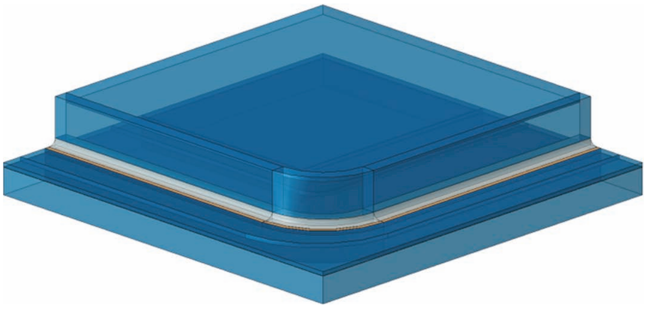

Fig. 1: 3D computer model of LTCC seal frame/lid combination shown attached to an LTCC MCM.

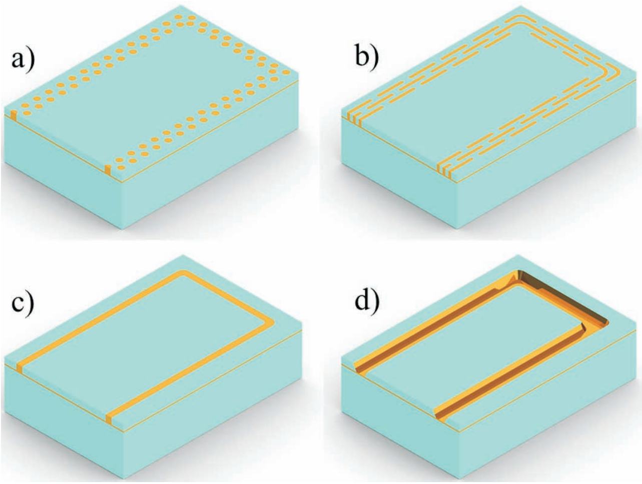

Fig. 2: Progression of Faraday cage structures in LTCC [8]. a) typical via fence b) staggered "racetrack" slot c) FTTF forming continuous isolation [1] d) green-state-milled "trench" with thin film [7].

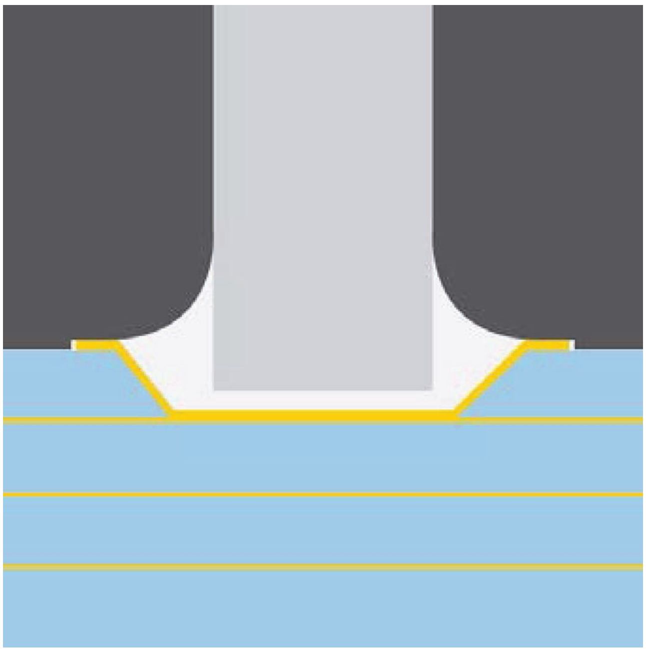

Fig. 3: Cross-section of green-machined, open recess with seal frame soldered into the recess [8].

II. Background

Balancing the need to reduce corner stress in the seal frame-to-LTCC joint for increased thermal cycle life performance and maintaining EMI isolation structures, a replacement for the Kovar seal frame and lid was developed [4]. LTCC was chosen as the replacement seal frame and lid since the CTE matches that of the substrate, which can lead to reduced stresses in the substrate/seal frame joint. The replacement LTCC seal frame/lid is uniformly coated with Ti/Cu/Pt/Au thin film for solderability and to provide EMI isolation when mated to the matching Faraday cage structure in the LTCC substrate (Fig. 4).

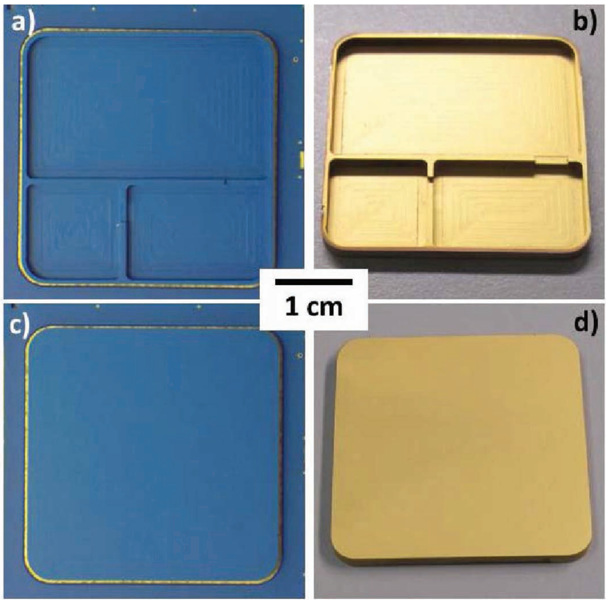

Fig. 4: Prototype LTCC seal frame/lid a) as-fired interior, b) metallized interior, c) as-fired exterior in LTCC substrate open recess, d) metallized exterior.

Modeling and simulation have been performed to determine the actual impact on solder or epoxy joint stress owing to the replacement seal frame/lid. Epoxies are known to be lower-strength materials than solder; however, it was desirable to assess the ability to use epoxy as an alternative to solder where lower processing temperature is required or additional manufacturing flexibility is needed.

III. Model

The FEA model was created and meshed in Abaqus CAE 6.12. The model is a quarter-symmetry representation of a 3.8-cm-square LTCC box (Fig. 1). The square box model was created so that solder and epoxy fillet shapes and lid material properties could be exchanged allowing for stress and strain comparisons under thermal cycle conditions. The model represents an LTCC seal frame/lid and substrate, solder or epoxy sealing material, bulk thin-film layer, and gold ground plane layer. Fig. 5 is a cross-sectional representation of the substrate, seal frame, lid, and joining material with FEA elements shown.

Each model starts at a temperature assumed to be the zero stress state for the model's respective sealing material; cure temperatures for the epoxy models, and solder reflow temperature for the solder model. Cure shrinkage effects of the epoxy were unknown and not included in the epoxy material models. Quarter symmetry boundary conditions were applied to sides of the assembly, and a pinned boundary condition applied to the center of the box at its base. The analysis type was Abaqus' Static, General; an implicit solver good for this type of thermal cycle simulation. The model assumes uniform temperature through the materials, and doesn't capture heat transfer effects. Stress, deformation, plastic strain, and reaction forces were collected as field outputs during the simulation from stress-free temperature to cold service temperature of the model.

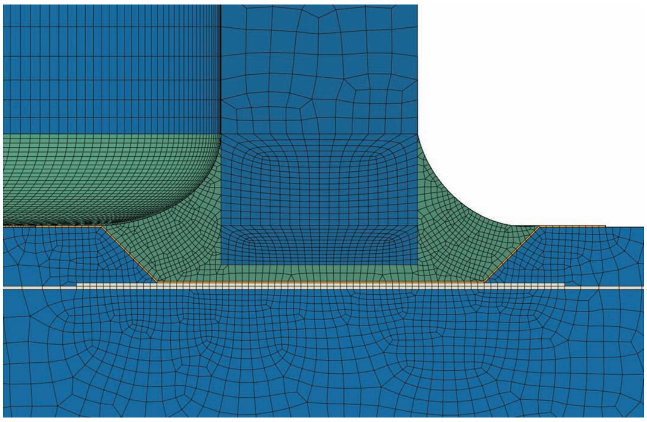

Fig. 5: Quarter-symmetry cross-section view of model.

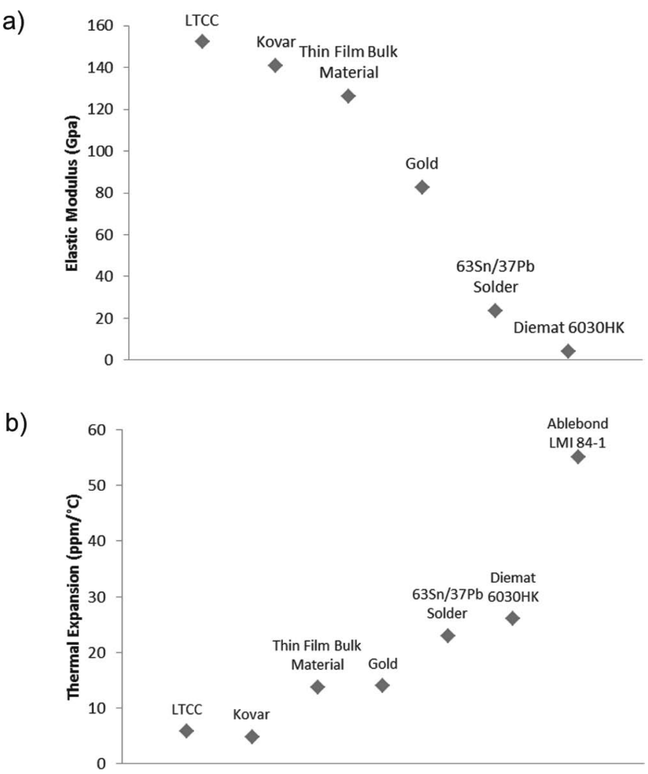

Fig. 6: a) Elastic modulus for selected materials b) Thermal expansion for selected materials.

Table 1 contains the elastic modulus and coefficient of thermal expansion (CTE) for materials of interest to this study (elaboration for 84 – 1 in Table 2.) Tables 1 and 2 are also displayed graphically in Figs. 6 a and b, and 7 respectively. Table 3 includes temperatures used for determining stress-free states. All material property data values in this study were nominal or average values only, as standard deviations of the data were unavailable in the data sets used.

Table 1: Material properties of selected materials for this study.

Material	Elastic Modulus (GPa)	CTE (°C)
LTCC	152	5.8×10^{-6}
Kovar	141	4.81×10^{-6}
Thin-Film Bulk Material	126	13.8×10^{-6}
Gold	83	14.04×10^{-6}
63Sn/37Pb Solder	23	23.0×10^{-6}
Diemat 6030HK	4	26.0×10^{-6}
Ablebond LMI 84 – 1	See Table 2	55.0×10^{-6}

Table 2: Elastic modulus versus temperature for Ablebond LMI 84 – 1.

Elastic Modulus (GPa)	Temperature (°C)
8.27	-65
7.58	25
5.45	100
0.537	150
0.386	200
0.462	250

Table 3: Cure/Reflow Temperature for selected bonding materials.

Material	Stress-Free Temp. (°C), Cure/Reflow Temp.)
63Sn/37Pb Solder	183
Ablebond LMI 84 – 1	125
Diemat 6030HK	200

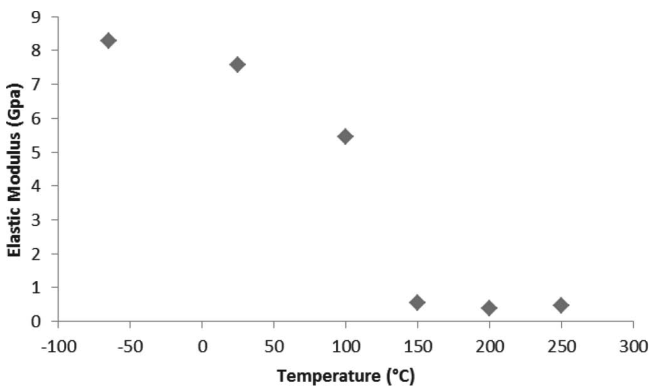

Fig. 7: Elastic modulus over temperature range for Ablebond LMI 84 – 1.

Fig. 8 shows values for the stress-strain behavior of 63Sn/37Pb solder at various temperatures found in literature [10].

IV. Results and Discussion

Four simulations were created to observe the differences in sealing material stress levels with both the original Kovar seal frame/lid design, as well as for the LTCC seal frame/lid (Fig. 9). It was assumed that the Ablebond cured to a wetted shape similar to that of solder, making the seal joint geometry the same between both materials. The solder models were ramped from 183 °C to -55 °C while the epoxied models were ramped from 125 °C to -55 °C to reflect the cure temperature of Ablebond 84 – 1 and 200 °C to -55 °C for Diemat 6030HK.

While Kovar has a similar CTE to LTCC, a completely LTCC seal frame/lid has a better matched contraction to the substrate in this case, at low temperatures, than a combination LTCC and Kovar seal frame/lid. Because of this, lower stresses were observed in the seal joints for both LTCC seal frame/lid models.

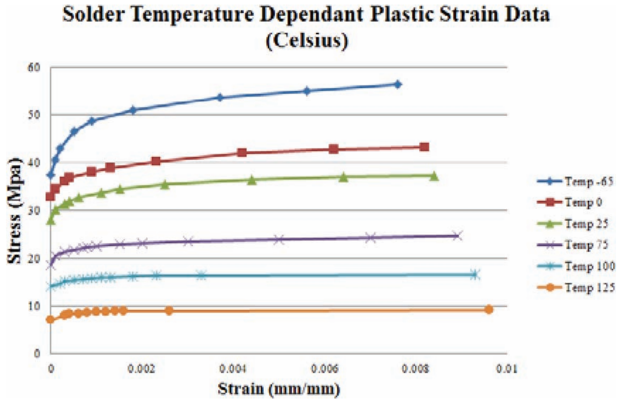

Fig. 8: Stress/strain curves for 63/37 Sn/Pb solder over temperature range [10].

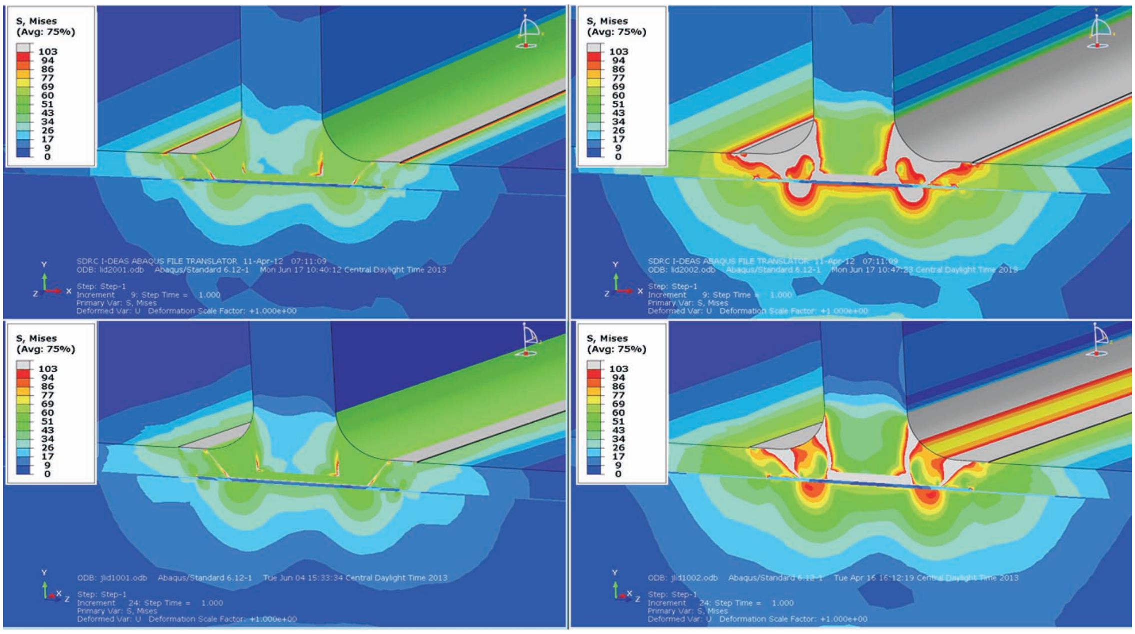

Fig. 9: Above left – Solder joint with Kovar seal frame/lid. Above right – Ablebond joint with Kovar seal frame/lid. Bottom left – Solder joint with LTCC seal frame/lid. Bottom right – Ablebond joint with LTCC seal frame/lid. Stress plotted in MPa. Grey regions above 103 MPa.

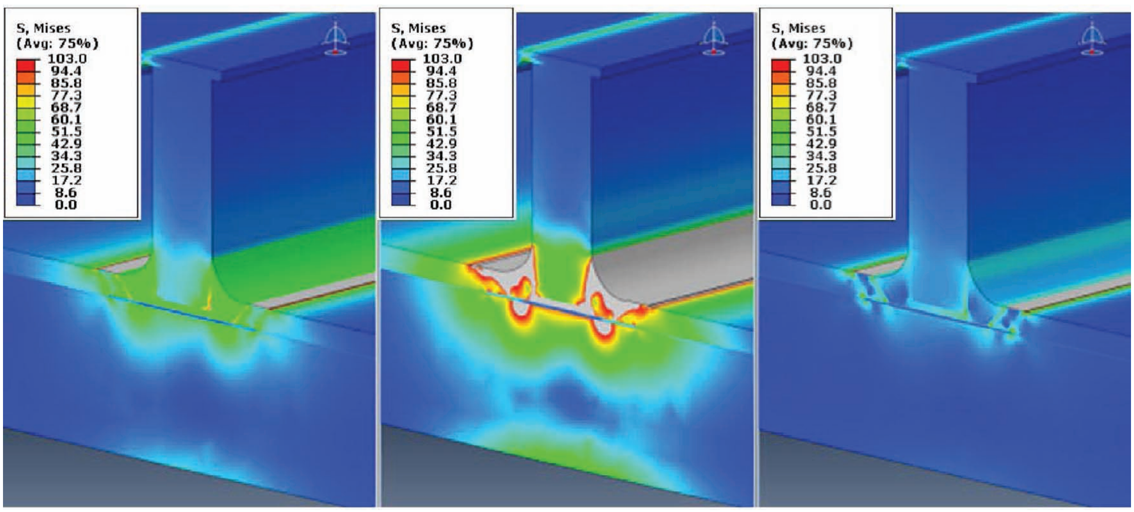

Fig. 10: Left to right – Solder, Ablebond, and Diemat joints with Kovar lid. Stress plotted in MPa. Grey regions above 103 MPa.

A fifth simulation was run to compare Diemat, Ablebond, and Solder in the same wetted joint shape with the Kovar seal frame/lid. These results showed that Diemat, with its lower CTE and softer modulus, would be preferred among the epoxies. While it appears the Diemat clearly outperforms the solder, it actually slightly elevated the stress in the thin-film layer when compared to the solder as shown in Fig. 10.

For two reasons, in both simulations above, 103 MPa was used as the high cutoff Mises stress (areas in grey). First, failure criteria for the epoxies are unknown at this point, and 103 MPa is a reasonable but higher level of Mises stress for failure. Because crack propagation and epoxy damage wasn't captured by the simulation, one would assume that anywhere that the epoxy exceeded 103 MPa, cracking or separation would occur, thus relieving some stress in the joint. Second, 103 MPa would be considered the upper limit of potential tensile strength of thin-film adhesion.

Because the final wetted profile of the epoxies was still an unknown, two models were created to simulate a thicker seal joint (Fig. 11). It turned out that additional sealer material would be worse for the thin film and more likely to cause cracks and seal material separation from the thin film and LTCC.

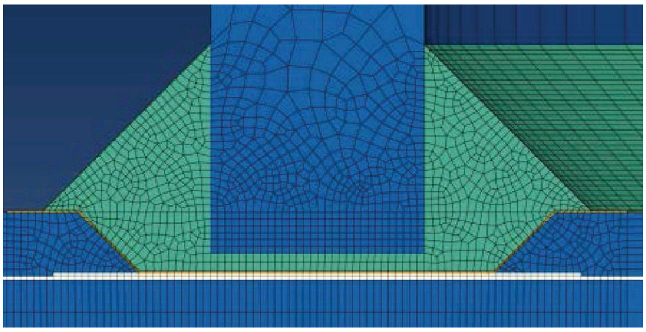

Fig. 11: Alternate/thicker epoxy profile.

Both simulations ramped the models from their epoxy cure temperatures to the cold service temp of -55 °C. Simulation results (Fig. 12) showed Diemat clearly outperformed Ablebond, even though the assembly went through a 75-°C-greater drop in temperature. However, as shown in Fig. 13, stress levels in the thin film for the Diemat were still near the threshold for thin film adhesive strength. Diemat's low CTE is clearly advantageous in environments with large temperature ranges; however, unknowns about the material (cure shrinkage, material temperature sensitivity, etc.) do provide an amount of uncertainty. More material testing to characterize Diemat would be necessary to determine long-term reliability

Fig. 13: Elevated stress near LTCC, thin film, and Diemat epoxy interface.

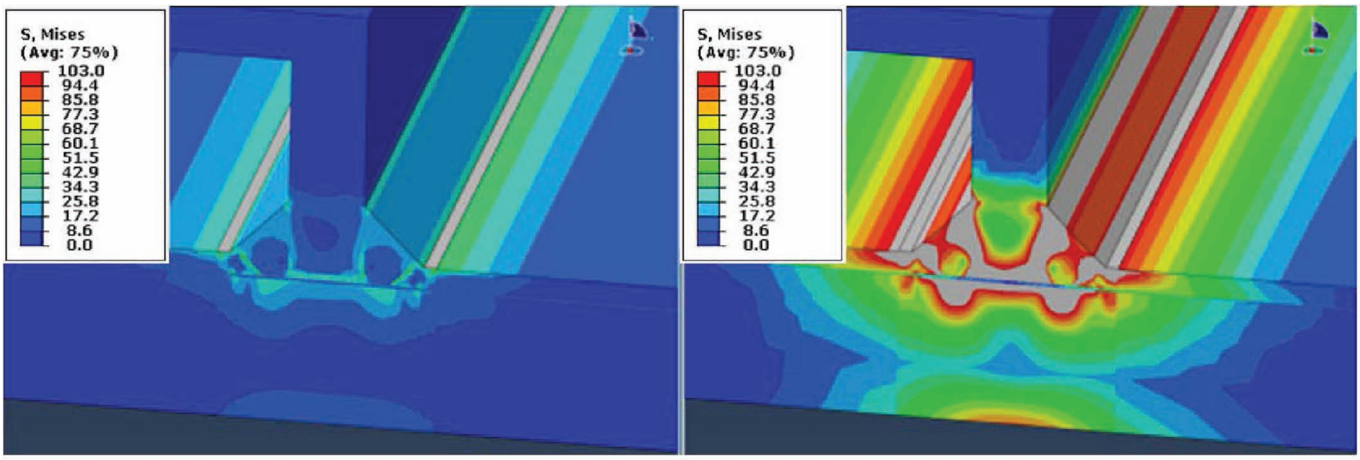

Fig. 12: Left to right – Mises stress in Diemat and Ablebond. Stress plotted in MPa. Grey regions above 103 MPa.

V. Conclusions

An approach to replacing the conventional metallic seal frame and seam-sealed metallic lid with a monolithic LTCC frame/lid combination is feasible. Evaluation shows the epoxy attached or solder attached approach can be within the required stress-strain requirements. Epoxy attachment would fit better into the existing processing hierarchy. Additional materials analysis is needed to add fidelity to the model.

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