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New elevated temperature mold compound adhesion test method using a dynamic mechanical analyzer

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Abstract

This paper outlines the development and application of a testing technique for measuring the adhesion strength of a mold compound to leadframe material, that utilizes a dynamic mechanical analyzer in the film tension mode. This technique allows for the utilization of standard transfer molding processes and equipment coupled with a standard electronic device configuration. The technique allows for rapid heating and equilibration of the sample to the test temperatures and the accurate determination of the yield tensile shear force associated to the adhesion failure of the mold compound leadframe interface. The data that will be presented highlights the profound effects that device conditioning, mold compound chemistry, and leadframe composition have on the adhesion properties of these interfaces. It will be shown that the sensitivity of this technique can differentiate adhesion performance relating to effects of conditioning, mold compound chemistries, and leadframe material selection. The resulting data will be used for correlation to other analytical techniques for proper materials selection, and as criteria for FEA modeling verification to improve the predictive performance of materials and processing.
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Keywords: Dynamic mechanical analyzer; Mold compound; Adhesion yield strength

1. Introduction

The standard industry method for characterizing the adhesion of mold compounds to leadframe materials is the Button Shear Test [9]. This method requires the molding of a mold compound sample (button) onto substrate material using specialized molding equipment and processes. This methodology does not duplicate the actual process by which electronic devices are assembled and therefore is not able to characterize the processing condition variations that can and do occur in real world manufacturing. The sample is then sheared off utilizing a shear tester that measures the force required to attain the yield strength of the entire button from the substrate. In most applications of this technique, the resulting data is generated at room temperature. As stated, this technique requires the special fabrication of a molded button sample that does not conform to the assembly design of real world product and is therefore at best qualitative to the performance characterization of the adhesion properties of the mold compound leadframe interface.

One of the key characteristics of adhesion performance of this dissimilar material interface, is the adhesion failure associated to moisture and high temperature exposure of the device during the circuit board population process. Normally, the failure of this adhesion interface occurs during the rapid exposure to solder reflow temperatures of 230–260 °C. This elevated temperature exposure is coupled with some exposure to moisture either through standard manufacturing environments, or through controlled reliability testing procedures. In order to best understand the adhesion characteristics of this interface, it is imperative to analyze this property at temperatures above the glass transition temperature of the mold compound. One alternative technique that has been put forth for the evaluation of this adhesion property is the use of a vertical tensile tester coupled with an environmental oven chamber. However, the exposure time to elevated temperature can be grossly unrealistic due to the temperature equilibrium time associated to the large mass of the clamping fixture and the size of the oven chamber. This excessive exposure to temperatures at which most polymer systems begin to breakdown would artificially bias the resulting data.

The TA Instruments Q800 DMA with film tension clamp, has the capability of controlled ramping of the drive force from 0.0001 to 18 N. This low mass clamping configuration resides within a very accurate low mass furnace that ensures accurate

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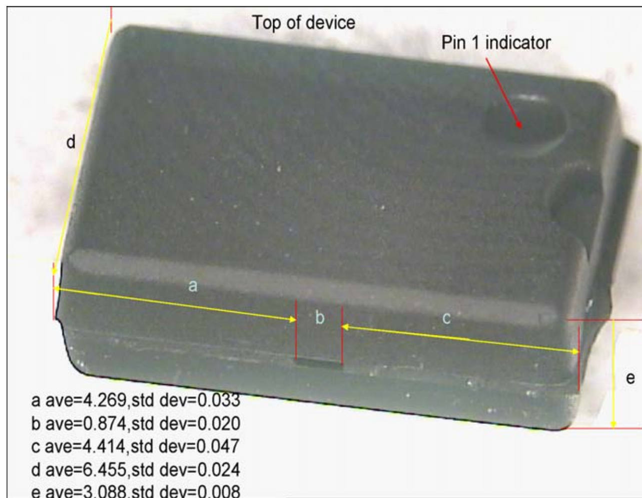

Fig. 1. Mold compound PDip dimensions units are in millimetres.

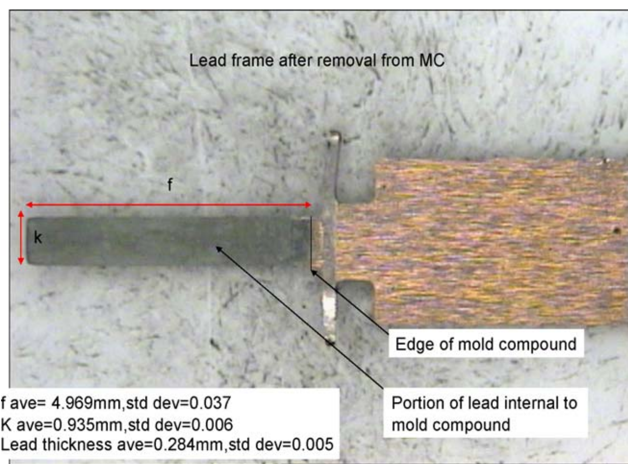

Fig. 2. Lead dimensions.

and rapid heating of the sample environment. A standard electronic device body (PDip—plastic dual in line package) was utilized for molding the sample. This allowed for the use of a standard transfer mold and manufacturing process. A leadframe was developed that incorporated one 1.0 mm or 0.75 mm lead to be molded into each PDip package. Fig. 1 presents the configuration of the mold compound portion of this experimental device and Fig. 2 presents the 1.0 mm lead configuration. Fig. 3 displays the leadframe that allows for the standard molding of these experimental devices. The leadframe could be manufactured with any standard plating surface and has been tested with numerous plating combinations as well as with bare copper.

2. Experimental

Two mold compounds (identified as A and B) were selected for this study along with seven different plated leadframe surfaces (see Table 1 for the list of plating surfaces). Copper was the base metal for all of the leadframes.

A series of 10 adhesion testing devices were transfer molded and post mold cured for each leadframe condition with each of the two mold compounds. Five devices from each of these subsets were then subjected to five cycles of temperature cycling (−65 to 150 °C), and moisture soak for 168 h at 85% relative humidity and 85 °C. Immediately after this moisture soak condition the devices were subjected to three passes through an IR reflow chamber with a peak temperature of 260 °C. This conditioning was performed in accordance with JEDEC standard J-STD-020C [1]. A total of three devices from each of the 28 subsets (7 leadframes × 2 mold compounds × 2 conditions) were tested using the Q800 DMA with the Film Tension Clamp assembly. Prior to any sample analysis, all clamp calibrations and compliance measurements were performed. Samples of polycarbonate (dual cantilever clamps) and PET film (Film Tension Clamps) were analyzed to verify instrument performance. In order to insure linearity of the lead from the device with the lower clamp of the Film Tension Clamp assembly, the lower clamp jig was shifted forward in the assembly by 1/2 the width of the device (see Fig. 4). This shift in the lower clamp precluded additional performance verification, however after all samples were tested, the lower clamp was re-aligned and PET film was run for instrument performance verification. The sample was mounted first in the upper clamp, such that the actual clamp contact was on the top 1 mm of the mold compound (above the theoretical location of the internal lead). The clamp was

Table 1
Leadframe plating surfaces

Leadframe no.	Description
8	MEP std NiPdAu plate
9	Std NiPdAu plate
10	NiPdAu plate with S1 anti EBO
11	NiPdAu pale with S2 anti EBO
12	Std NiPd without Au
13	Std NiPdAu with high Au
14	High NiPd plate without Au

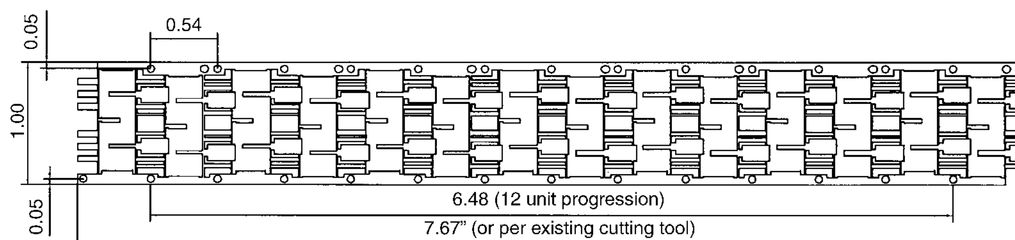

Fig. 3. Leadframe design with 1.0 and 0.75 mm leads—26 devices per leadframe.

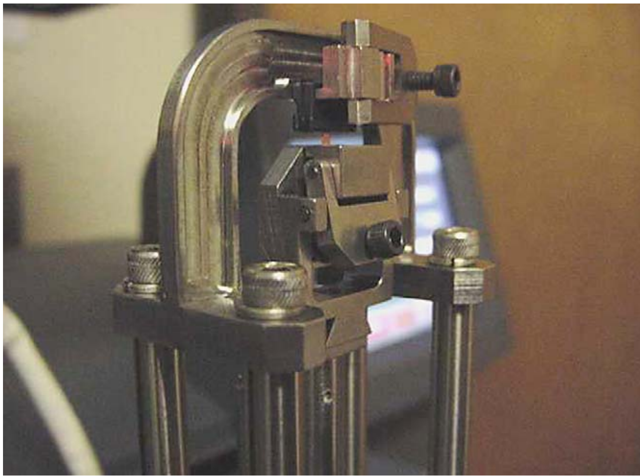

Fig. 4. Lower clamp with offset-device loaded.

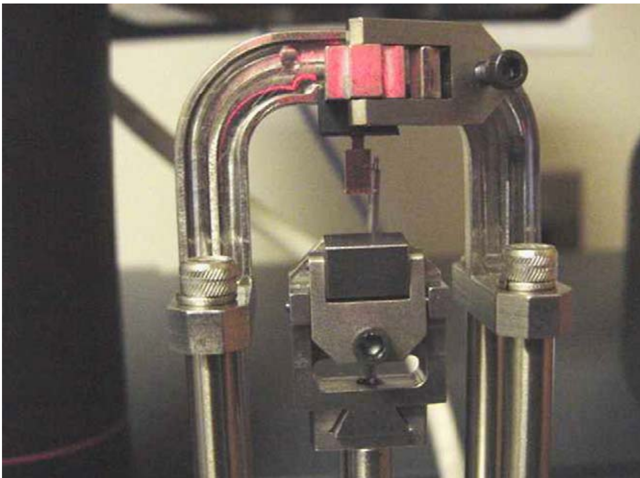

Fig. 5. Top clamp secured, lead tab ready for bottom clamp.

then tightened to 2–3 in-lbs. The lower clamp was then raised such that the actual clamping surfaces were on the leadframe tab below the actual lead. This clamp was also then tightened to 2–3 in-lbs (see Fig. 5). Once the sample device was clamped in place, the furnace was lowered and the following method was set up and run (mode = controlled force):

1) data storage on;
2) equilibrate at 260 °C (maximizes the heating rate and then allows the instrument to stabilize at temperature);

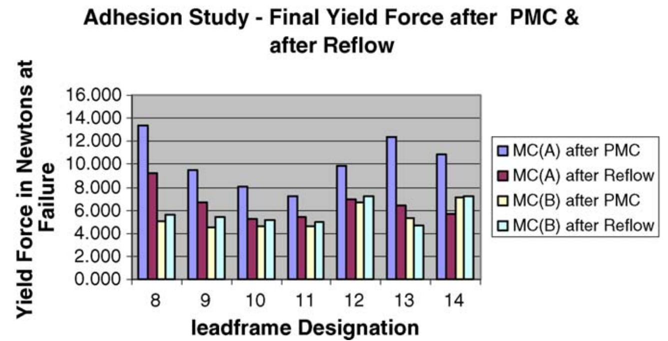

Fig. 6. Adhesion data presented by leadframe designation.

3) isotherm for 10.0 min (insures that the total mass of the clamps and sample are at equilibrium temperature of 260 °C);
4) mark end of cycle 1 (separates the data associated to the heat up from the next segment);
5) ramp force 1.000 N/min to 18.000 N (the experiment will automatically terminate once a yield strength has been attained).

After the experiment was completed, and the lead was removed from the lower clamp and the length and width of the lead that resided within the mold compound was accurately measured using a Micro Dynascope optical comparator. These measurements were then used for all subsequent data analyses.

A series of 150 devices were molded without leadframes so as to be represented as mold compound only samples (identified as dummy devices). These devices were manufactured utilizing standard production processes including post mold cure (PMC). These dummy devices were utilized to generate the materials properties identified in Table 3 (noted as input parameters).

3. Results

Adhesion testing data—Table 2 and Fig. 6, present the adhesion yield strength data by leadframe composition. In all samples the lead removed cleanly from the mold compound (MC) and did not exhibit evidence of cohesive failure (No evidence of MC residue on leads). Reviewing the % strain/stress curves of all adhesion data sets, an additional qualitative difference between mold compounds emerged. It appeared that the Mold Compound A samples had a decidedly elastic response (linear slope in % strain/stress curve) up until the point of adhesion yield force. Whereas, Mold Compound B samples appeared to exhibit deformation in the % strain/stress curve prior to yield (see Fig. 7

Table 2
Adhesion yield strength in newtons

Mold compound and conditioning		Leadframe		Designation			
	8	9	10	11	12	13	14
MC(A) after PMC	13.337	9.483	8.020	7.261	9.849	12.360	10.843
MC(A) after reflow	9.261	6.660	5.250	5.384	6.985	6.440	5.710
MC(B) after PMC	5.044	4.547	4.611	4.643	6.694	5.308	7.143
MC(B) after reflow	5.600	5.393	5.170	4.971	7.193	4.702	7.197

Values listed are the final yield force in newtons at the moment of adhesion failure between LF and MC—all values are the average of 3–5 sample analyses.

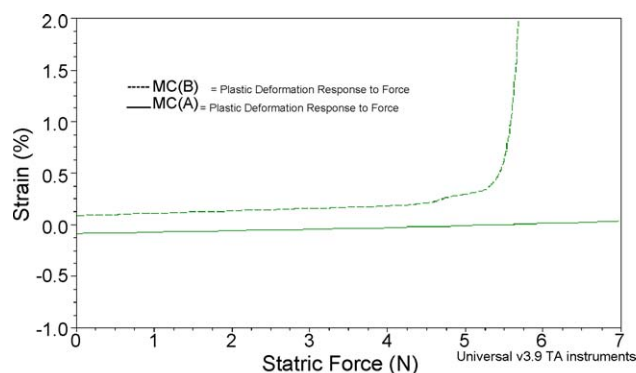

Fig. 7. DMA % strain/stress curve overlay both samples were after reflow for leadframe 13.

for an example of this comparison). In general, these selective responses were consistent within each mold compound series of subsets.

Materials properties characterization for both mold compounds is presented in Table 4. Dry DSC and TMA data are on dummy devices that have been vacuum desiccated for no less then 48 h. Wet DSC and TMA data are on dummy devices that have been conditioned at 85 °C/85% RH for 168 h. DSC data was generated on a Q1000 DSC at a ramp rate of 10 °C/min from 0 to 250 °C. The sample was cooled in place and then re-run at 10 °C/min to 250 °C. The designation of run 1 and run 2 relate to the first and second thermal ramp data. TMA data was generated on the Q400 TMA at a ramp rate of 5 °C/min from 10 to 250 °C, using an expansion probe with a cross sectional area of 6.13 mm^2 and a force of 0.18N. Run 1 and run 2 designation correlate to the same definition as with the DSC data. The moisture solubility and diffusivity data as well as the % moisture gain data were generated following the JEDEC standard JESD 22-A120 [2]. The hygroscopic coefficient data was generated utilizing a method developed by Wong [3] utilizing TMA and TGA for simultaneous measurement of dimension change versus weight loss after equilibrating samples at a given temperature and humidity condition. Shear modulus was performed on dummy devices using the AR2000 parallel plate rheometer with the solid state clamp configuration. Time temperature superpositioning (TTS) was performed using data generated on the AR2000 and incorporated a frequency sweep of 0.1–100 Hz for temperatures from 30 to 240 °C at 10 °C intervals. This data was provided to the modeling group to provide viscoelastic properties data as identified by Miyake [4], and Sham [8].

4. Discussion

The data from Table 3 indicates that the after PMC adhesion yield strength of Mold Compound A is significantly higher than that of Mold Compound B. However there is a noticeable drop in adhesion yield strength comparing the PMC to after reflow data for MC A. This drop in yield strength was evident

Table 3
Materials characterization properties on “dummy devices” for each mold compound

Input parameter	Units	MC A	MC B
DSC T_g-dry (run1/run2)	°C	145.1/145.3	114.1/118.0
TMA T_g-dry (run 1/run 2)	°C	146.4/137.6	106.2/118.9
Alpha 1 CTE < T_g (ppm)-dry (run1/run2)	ppm	15.2/13.0	8.2/9.8
Alpha 2 CTE > T_g (ppm)-dry (run1/run2)	ppm	18.7/32.9	11.39/24.25
DSC T_g-wet (run 1/run 2)	°C	115.5/143.1	110.4/114.0
TMA T_g-wet (85%RH/85C)-(run 1/run 2)	°C	108.3/146.2	107.4/119.5
Alpha 1 CTE < T_g (ppm)-wet (run 1/run 2)	ppm	7.5/8.2	9.36/10.07
Alpha 2 CTE > T_g (ppm)-wet (run 1/run 2)	ppm	19.5/29.8	13.9/27.3
Average percent moisture weight gain	%		
30 °C @ 85% RH		0.258	0.171
60 °C @ 85% RH		0.3033	0.193
85 °C @ 85% RH		0.363	0.238
Device volume	cm^3	0.076	0.075
JESD22-A120 D(T) (30,60,85C @85%RH)	mm^2/s	4.17E−7, 5.59E−7, 6.27E−7	4.67E−7, 6.31E−7, 6.34E−7
JESD22-A120 Ea	eV	9.00E+06	7.00E+06
JESD22-A120 Csat (30,60,85C @85%RH)	mg/cm^3	5.7, 5.8, 6.22	3.47, 3.68, 4.07
Hygroscopic coefficient (TMA-TGA method)	mm^3/mg	0.0794	0.0516
Maxwell viscoelastic properties			
E’ (flexural modulus) 32.0 °C	MPa	3.04E+4	3.03E+4
E’ (flexural Modulus) 260 °C	MPa	2.46E+3	1.22E+3
G’ (shear Modulus) 29.0 °C	MPa	1.45E+4	1.60E+4
G’ (shear Modulus) 260 °C	MPa	1.80E+3	1.13E+3
TTS based on shear modulus			
5 master curve reference shift temperatures	°C	Curves generated	Curves generated
WLF calculated shift factors		For modeling	For modeling
TGA calculated filler content	%	83.30	86.70

on all leadframe materials for MC A. Mold Compound B however did not exhibit a reduction in yield strength after reflow (compared to the initial PMC data) and there appeared to be an arguable increase in adhesion strength after reflow on some of the leadframes tested. It was also noted that leadframes 12 and 14 exhibited the highest adhesion strength for MC B. Both of these leadframes were composed of nickel palladium without gold.

It is well documented that absorbed moisture plays an important role in facilitating the delamination between the mold compound and various dissimilar surfaces within the PEM (plastic encapsulated microcircuit) [5,6] at elevated temperatures. The stress model for calculating package stress induced during reflow put forth by Tee [7] suggests that the major sources of stress are vapor pressure, hygro-mechanical stress, and thermo-mechanical stress. Comparing the moisture absorption characteristics of these two mold compounds, it becomes evident that Mold Compound A absorbs approximately 35% more moisture at all temperature/humidity levels than Mold Compound B. When normalized for the hydrophilic component of the composite, the actual percentage weight gain of moisture however is significantly higher, since the mold compound is made up of between 83% and 87% by weight of silica filler (which does not absorb moisture). Additionally, the hygroscopic coefficient (relating to hygro-thermal stress) was also approximately 35% higher for MC A.

Another component of interfacial adhesion between the mold compound and the leadframe is associated to the formulation chemistry of the composite. Mold compound manufacturers routinely add adhesion promoters to the formulation, as well as coupling agents to improve the adhesion between the mold compound and the silicon die. From ongoing characterization work, and discussions with several mold compound suppliers, it appears that the ambient modulus of the mold compound is controlled by the silica filler loading and the elevated temperature (above T_g) modulus is controlled by the resin chemistry. Comparing the modulus of Mold Compounds A and B it is noted that while the ambient modulus is similar, the 260 °C modulus of MC B is approximately 1/2 the modulus of MC A (even though MC B has a higher filler loading). This would suggest that MC B contains some form of flexiblizing adhesion promoter designed to reduce stress at elevated temperature. This hypothesis is supported by the adhesion % strain/stress curves that indicate a deformation prior to adhesion yield with MC B, while MC A exhibits an elastic curve to yield. Therefore it is suggested that this deformation (noted in MC B) would result in a more "forgiving"/stress dampening system under elevated stress (at elevated temperatures).

The results of these experiments suggest that depending on the environmental exposure of the PEM's (moisture/reflow sensitivity classification J-STD-020C), MC A would be preferred if the PEM's were not exposed to high moisture environments prior to reflow (MSL 3), and MC B would be preferred if the PEM's were not restricted to storage conditions (MSL 1). These results also highlight the added significance of including elevated temperature adhesion testing to the other materials properties characterization that are routinely performed. Since the

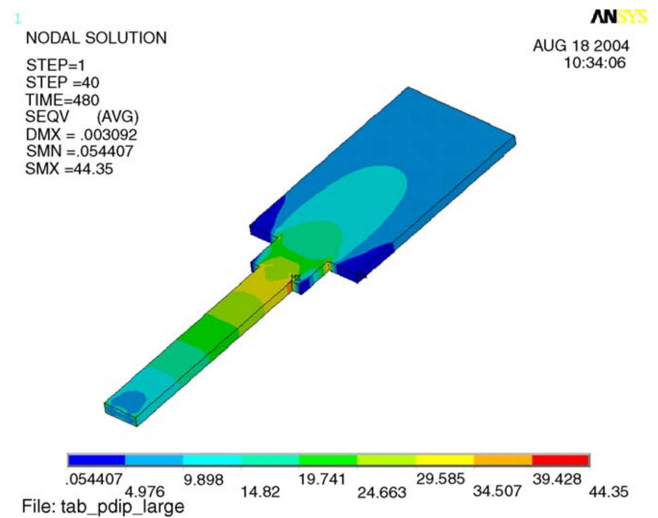

Fig. 8. ANSYS model of lead component of adhesion test device with associated stress areas.

failure mechanism associated to adhesion/delamination occurs during the reflow process of device mounting, it is critical that adhesion strength is characterized at these reflow temperatures (above the T_g of the mold compounds).

Presently, the data that is presented in Table 3 is being integrated into an FEA modeling program with the adhesion yield strength data identified as a criteria performance measurement to verify the model. The use of this data for criteria purposes would allow for the verification testing of the stress properties model and would enable the comparative analysis for the determination of yield stress threshold associated to adhesion performance at elevated temperatures. The initial modeling (PMC dry state only) identifies the Von-Mises stress of MC B as being greater at the embedded edge than the yield stress of the lead and would result in earlier failure of this interface. The Von-Mises stress of MC A is lower than the yield stress of the embedded edge of the lead and therefore would result in later failure of this interface (see Figs. 8–11Figs. 8 through 11). This

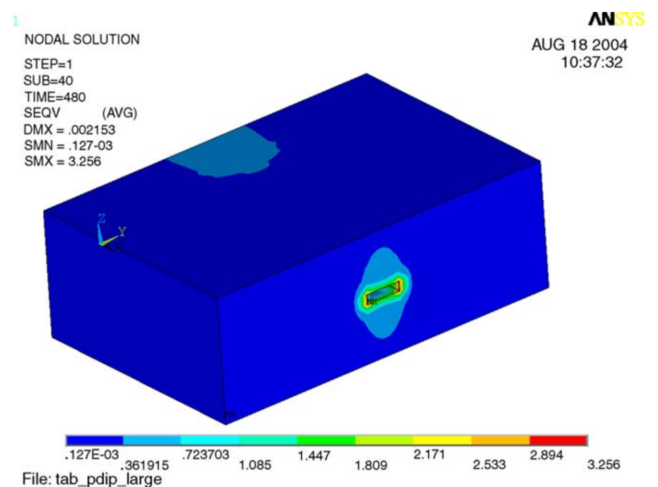

Fig. 9. ANSYS model of MC component of adhesion test device with associated stress areas.

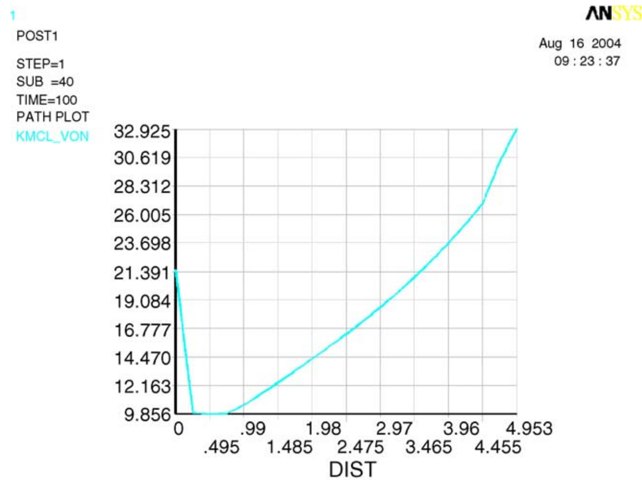

Fig. 10. Von-Mises stress for MC A as a function of location on embedded lead area exhibiting a lower stress at the embedded edge (distance 0).

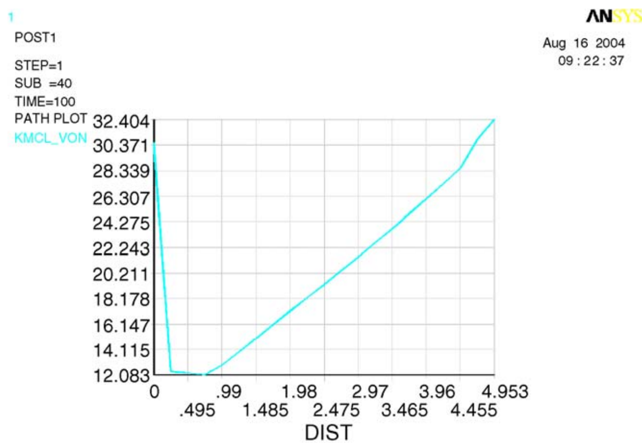

Fig. 11. Von-Mises stress for MC B as a function of location on embedded lead area exhibiting a higher stress at the embedded edge (distance 0).

initial modeling data would seem to correlate well with the PMC adhesion data for each mold compound. Additional work is ongoing to identify the appropriate methodology for the incorporation of the moisture interaction data to generate the models associated with the adhesion forces after moisture and reflow exposure.

Finally, in order to directly correlate the localized adhesion failure noted in the reduction of adhesion yield strength, additional experimentation should be performed to utilize continuous scanning acoustical microscopy (C-SAM) on the devices prior to testing. This testing would provide data associated to interfacial delamination between the mold compound and the leadframe material. Unfortunately, the C-SAM testing requires the emersion of the PEM in water during the analysis. This could exacerbate the vapor pressure induced stress during the heat up and equilibration time associated to the adhesion test.

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