TRACE LABORATORIES-EAST

Technical Spotlight

Thermal Expansion Measurements of Insulative Materials and the Effect of the TMA Furnace Thermal Gradient

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Abstract

The Thermomechanical Analyzer (TMA) has long been the standard means of measuring the Coefficient of Thermal Expansion (CTE) of materials. In previous work, we have demonstrated that a significant vertical thermal gradient exists within the TMA furnace when testing materials of low thermal conductivity. The thermal gradient was measured to be approximately 2.5 to 3°C per millimeter. (1)

This paper studies the impact of this thermal gradient on thermal expansion measurements of materials with varying thermal conductivity characteristics and thickness. The TMA instrument thermocouple location versus sample thickness was varied for each material type and the variation in the coefficient of thermal expansion was determined.

Introduction

This study focuses on the determination of the Coefficient of Thermal Expansion measurements by TMA methodology. The typical sample measuring 0.25 by 0.25 inches by the thickness (0.75 inches maximum) sits on a quartz sample stage. A quartz probe exerting a light force contacts the top of the sample and records the sample movement along the thickness direction. The sample and probe are enclosed in a furnace chamber, Figure 1, where the temperature is controlled to ramp at a specified rate over a temperature range. As the temperature ramp progresses the expansion is plotted versus temperature. The thermal expansion can be calculated from the curve.

Figure 1 Arrangement of the sample on the TMA stage under the probe and the position of the thermocouple.

It has been observed that differences exist in the coefficient of thermal expansion of insulative materials relative to sample thickness. The suspected cause was a temperature gradient across the thickness of the sample within the TMA furnace chamber coupled with the low thermal conductivity of the material. With the TMA thermocouple located at the level of the sample stage the temperature at the top of the sample, depending on thickness, may reach a higher temperature than at the bottom of the sample. The temperature gradient results in an approximate 20°C difference between the top and bottom of a 7 mm thick specimen.

Experiments and Results

Three materials of low thermal conductivity were prepared at varying thickness. The materials were tested over a temperature range below the glass transition temperature. The TMA thermocouple was positioned at but not touching the sample stage. The instrument was calibrated with the thermocouple in this position.

Assuming a sample thickness of 6 mm (approx. 0.25 inch) a temperature difference between the top and the bottom of the sample is $3^oC/mm * 6\ mm = 18^oC$. Therefore during the temperature ramp, for example to 100^oC, the bottom of the sample is at 100^oC but the top of the sample is at 118^oC. Because of the low thermal conductivity of the material, temperature equilibrium is never reached across the sample thickness. The result of this equilibrium imbalance is the top of the specimen is expanding at a greater rate than the bottom of the specimen thus skewing the results toward higher thermal expansion values.

Material A, an Acrylic polymer, was tested at thickness values of nominally 1.3, 6.8, and 12.2 mm. Calculation of the CTE values indicated a clearly increasing CTE versus thickness trend. The results are presented in Figure 2 as a comparative representation of the increasing trends of thickness, CTE, and percent increase in CTE. The CTE increase from the thinnest, 1.3 mm, to the thickest, 12.2 mm, sample was 23% or 2.1% increase in CTE/mm increase in thickness. Figure 3, a plot of the thickness versus CTE values, indicates the increasing CTE values are linear over the thickness range.

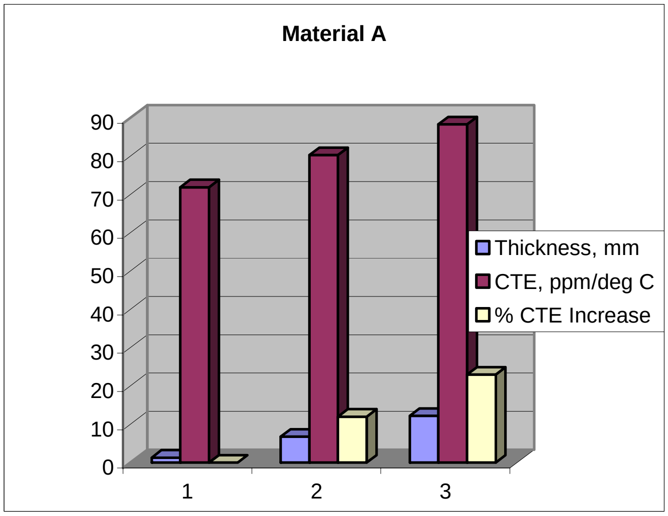

Figure 2 Comparative test results from Material A.

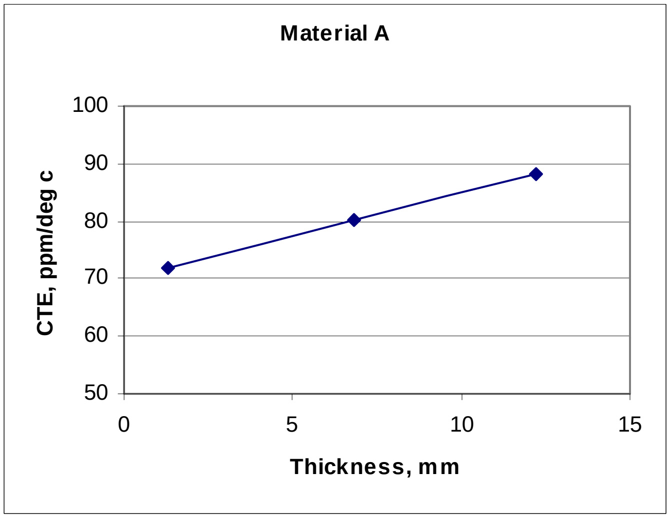

Figure 3 CTE versus sample thickness for Material A.

Material B, Rexolite 1422 ®, was tested at thickness values of nominally 1.6, 12.3, and 16.5 mm. The CTE values increased with each thickness increment. The results are presented in Figure 4 as a comparative representation of the increasing trends of thickness, CTE, and percent increase in CTE. The results in Figure 4 indicate an increase of 18% from the 1.6 mm sample to the 16.5 mm sample. A 14% increase in the CTE was calculated between the 1.6 and 12.3 mm specimens. The increase in CTE/mm increase in thickness = 1.7%. Figure 5, a plot of the thickness versus CTE values, indicates the increasing CTE values are linear over the thickness range.

Material C, a glass/epoxy laminate, was tested at thickness values of nominally 1.1, 5.3, and 14.5 mm. The CTE values increased with each thickness increment. The results in Figure 6, a comparative representation of the increasing trends of thickness, CTE, and percent increase in CTE, illustrates a CTE increase of 10% from the 1.1 mm sample to the 5.3 mm sample and a 32% increase in the CTE between the 1.1 and 14.5 mm specimens. The increase in CTE/mm increase in thickness = 2.4%. Figure 7, a plot of the thickness versus CTE values, indicates the increasing CTE values are linear over the thickness range.

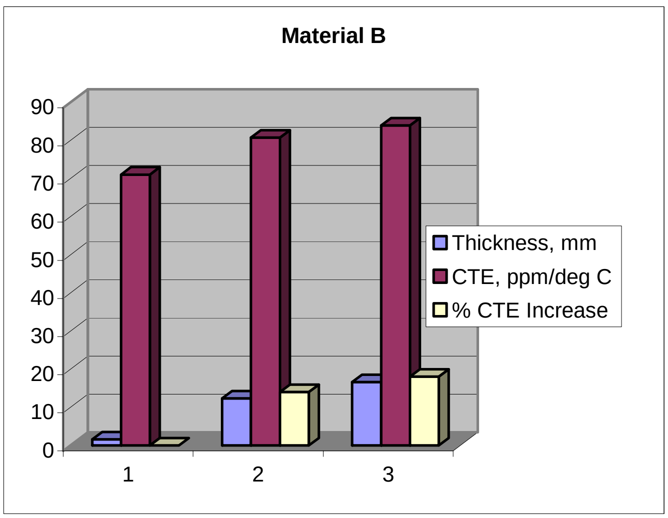

Figure 4 Comparative test results from Material B.

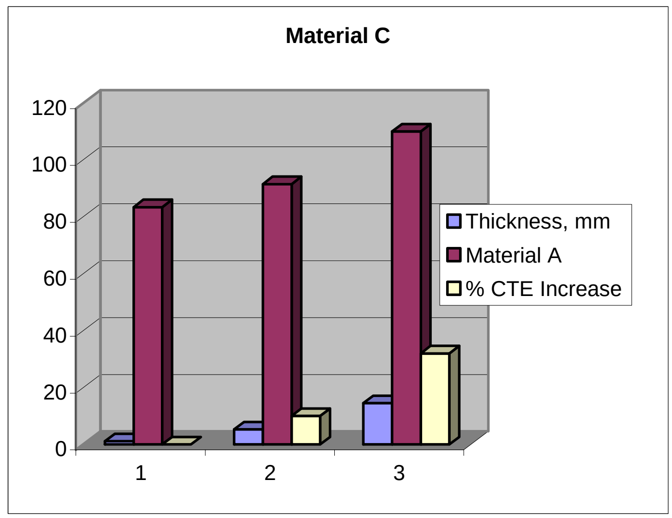

Figure 6 Comparative test results from Material B.

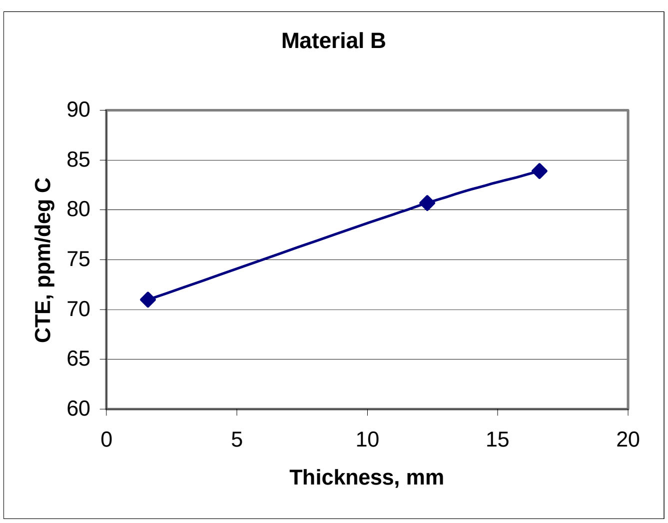

Figure 5 CTE versus sample thickness for Material B.

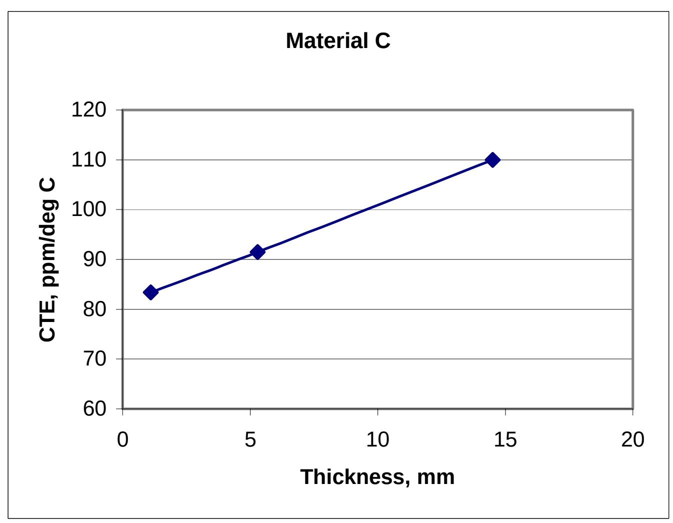

Figure 7 CTE versus sample thickness for Material C.

Copper control samples were tested at similar conditions to determine if CTE differences occur with thermally conductive material. Testing over the thickness range of 1.5 mm to 10.4 mm resulted in a CTE increase of approximately 4%, or an increase in CTE/mm increase in thickness = 0.4%. Figure 8. These results indicate thermally conductive materials exhibit significantly less CTE variation versus thickness than thermal insulators.

Figure 9 suggests the rate of CTE increase is dependent upon the thermal conductivity of the material. The slope of the lines for Materials A and C are nearly parallel. These materials have more closely matched thermal conductivity values than Material B. The rate of CTE increase versus thickness is lower for the more thermally conductive Material B.

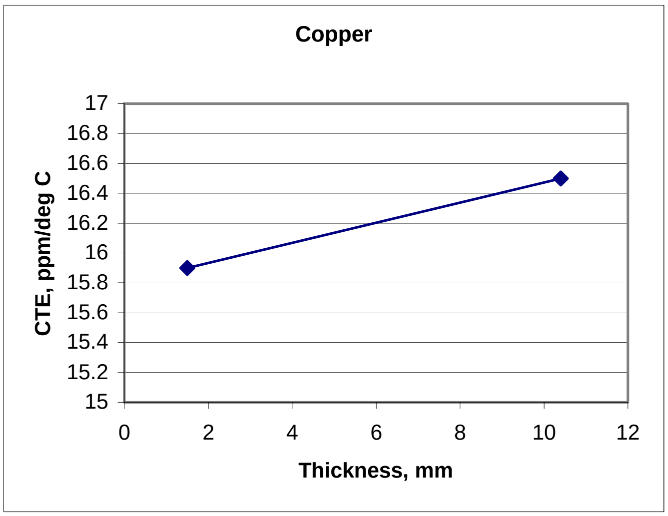

Figure 8 CTE versus sample thickness for Copper.

Conclusion

From previous work it is known that a thermal gradient exists within samples in the TMA furnace while testing materials of low thermal conductivity. The thermal gradient is considerably less pronounced for high thermal conductivity materials such as copper (TC = 398W/mK).

The materials selected for the experimental procedures were of low thermal conductivity, Material A = 0.14 W/mK and Material B = 0.56 W/mK represent the lower and upper ends of the thermal conductivity scale for polymers, and Material C = 0.20 W/mK is typical for circuit board laminate.

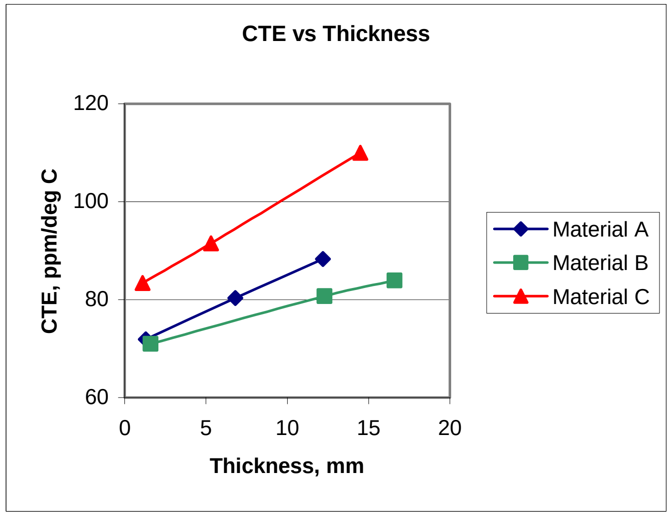

Figure 9 CTE versus sample thickness for Materials A, B, and C.

The test results indicate that higher CTE values are obtained as a function of increasing sample thickness when tested in a TMA at the typical thermal ramp rate of 10°C/min. The CTE increase versus material thickness was linear for all three materials although the rate of increase was greater for the less thermally conductive samples. The less thermally conductive samples, Materials A and C, exhibited a CTE increase/mm increase in thickness of 2.1 and 2.4%, whereas more thermally conductive Material B exhibited an increase in CTE/mm increase in thickness of 1.7%. High thermal conductivity materials such as copper the increase in CTE/mm increase in thickness becomes nearly negligible at 0.4%.

The varying CTE values could have serious implications in tight tolerance or highly critical applications. When practical, the material should be tested as close to the application thickness as possible, within the confines of the analytical instrument, at conditions simulating actual operating thermal environments. Similar improvement may be possible by adjusting the temperature ramp rate of the instrument to allow more time for thermal equilibrium to occur within the test specimen.

References

1. Z. Mei, M. Hu, K. Ogle, J. Radman, R. Michalkiewicz, "An Issue in Time to Delamination (T_{260}) Testing for PCBs", Electronic Circuit World Convention 10 Technical Conference Proceedings, February 27, 2005

For more information concerning these topics or any other testing needs, please contact Trace Laboratories – East at (410) 584-9099 (traceeast@tracelabs.com). Visit us on the web at www.tracelabs.com/east.