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Multicavity Dilatometer for Testing Circuit-Board Materials and Plastics[1]

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A new quartz rod-type dilatometer is described that is intended for testing material specimens that are available only in flat plate shapes, such as electronic circuit boards, RIM (reaction injection molded), and other plastics. The dilatometer itself employs quartz rod elements satisfying the requirements set forth by applicable ASTM standards and accepted industry practice. By eliminating the need for a quartz tube, the specimens are allowed to be fully supported along their entire length on the furnace wall itself. As a result, even metallic foils as thin as 0.005 in. were successfully tested without buckling at a rate many times faster than can be done with tube-type dilatometers, due to the inherently faster heat transfer offered by this new configuration. The instrument covers a broad temperature range in a single sweep (-150 to $500°C$) and is able to accommodate low- and high-expansion materials with the same ease. Representative data on FR-4 circuit-board materials with varying amounts of copper cladding are presented.

KEY WORDS: circuit board; dilatometer; epoxy–glass; foil; plastic; reaction injection molded (RIM); thermal expansion.

1. INTRODUCTION

Ideally, the dimensions of a dilatometer test specimen are determined by the testing apparatus alone [1]. For this to be true, however, a material has to be available in large, homogeneous pieces, from which samples can be cut and shaped to fit a particular instrument's length and diameter requirements. Unfortunately, all too often materials are not available in such ideal sizes and shapes. In particular, there are many materials that are

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made only in sheet or plate form. The configuration of a specimen obtained from them is then limited in at least one dimension, sometimes two.

Common problems that prevent the effective testing of single layers of such materials in tube-type dilatometers are buckling and partial softening at elevated temperatures. These limitations have been combated to some extent [2] by constructing a laminate specimen with the laminate direction along the longitudinal axis (parallel to the dilatometer tube). The individual layers are either joined with adhesive or held together mechanically. The major drawback is the time-consuming nature of the process. The laminating method is also used with the laminate direction perpendicular to the dilatometer axis. In addition to the time involved in preparation, problems caused by slight buckling or deformation of layers can cause a large cumulative net expansion error. The surfaces must be joined with a high degree of uniformity, using thin adhesive films to minimize the effect the adhesive may have on the overall thermal expansion characteristics. Foils that do not lend themselves to lamination are often creased or folded along the axis to present a more rigid body. This can create undesirable internal stresses in the specimen, which may then change the expansion characteristics.

To maintain a uniform temperature in a tube-type quartz dilatometer with a cylindrical sample, it is necessary to heat or cool at a slow, uniform rate. Due to the thermal impedance of the quartz tube, the intervening air gaps, and the thermal conductivity and mass of the specimen, there is a practical limit to this rate that can be performed while still retaining a uniform temperature within the specimen. This problem is further compounded when the specimen is in the form of a flat plate. The much larger air gap between the specimen and the quartz tube further limits the response time of the system. Related to the same geometrical consideration is the difficulty of accurately sensing the temperature of these thin, flat specimens. Normally, a cylindrical specimen will have a thermocouple placed in a drilled hole. With flat plate specimens, it is difficult or, often, impossible to do this. Attaching the thermocouple to the surface of the specimen frequently restricts movement or simply warps the sample.

A solution to many of these problems is presented with the construction of an integral chamber and metal block furnace which maintains an intimate contact with a large portion of the specimen. As a result, the response of the system is maximized and a uniform temperature is ensured throughout. Most importantly, the complete support prevents buckling.

Adding to the attractiveness of this configuration is the greatly simplified sample preparation. Usually punched-out, rough-cut, or sheared platelets suffice, with only the two longitudinal ends required to be machined parallel.

Conventional quartz dilatometers are historically intended for the laboratory environment, where personnel are well trained and, as a matter of course, take the necessary precautions when operating an instrument. Testing time is usually not a major factor. Most quartz tube-type dilatometers can test only one sample at a time and are not well suited when high-volume testing and a fast turnaround time are required. Quite frequently, however, dilatometers are being used as quality-control tools. In this role it is necessary to provide ruggedness, while retaining accuracy and resolution. In the production environments, turnaround time is usually a major factor that is well adressed by the multiple-specimen testing capability of the presently described machine.

2. DESCRIPTION

To maintain conformance with existing standards, the Unitherm Model 1052 dilatometer (Fig. 1) was constructed in such a fashion that only quartz components are used to transmit length changes of the specimen to the gauge. Figure 2 shows the schematic configuration of the new design. The quartz rods (A and B) are made from the same stock and

Fig. 1. The Unitherm Model 1052 dilatometer.

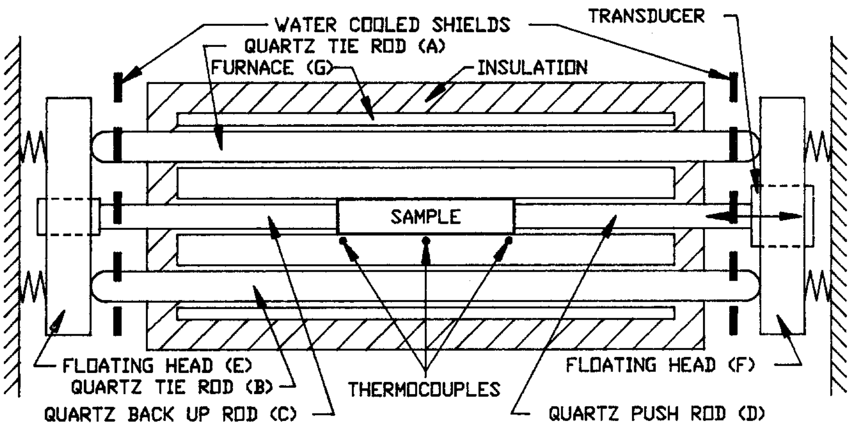

Fig. 2. Schematic representation of the dilatometer.

are of the same length. They move freely between the two floating heads (E and F) and maintain the reference between the gauge and the sample. They pass through the furnace, alongside the specimen, and in essence perform the function of the quartz tube. The fixed quartz rod (C) rests against the end of the specimen opposite that of the push rod and is fixed to the floating head (E). The uartz rod (D) is fixed to the measuring gauge and is used in the same way a conventional push rod is used to transmit the length change occurring in the specimen. All quartz components are protected and are, therefore, less vulnerable to breakage during the loading or unloading process.

The furnace is made of an aluminum block (G), with embedded heaters and internal cooling channels. The specimen chamber is a cavity (Fig. 3) within the block, and it allows the specimen to be in intimate contact over its entire surface with the inner chamber wall. The specimen also rests on the bottom of the chamber; thus support is provided in both axes normal to the testing axis.

The thermocouples used to sense specimen temperature are embedded just below the surface of the inner chamber wall on which the sample rests. This location provides complete protection for the thermocouples yet allows the specimen's temperature to be sensed accurately.

The tracking force of the push rod is adjustable and can be set to a value which is sufficient to maintain contact between the push rod and the specimen throughout a test. Loading and unloading of specimens are simplified via a push-rod retracting mechanism allowing the specimen to be lifted up and out of the furnace chamber with ease. This design was

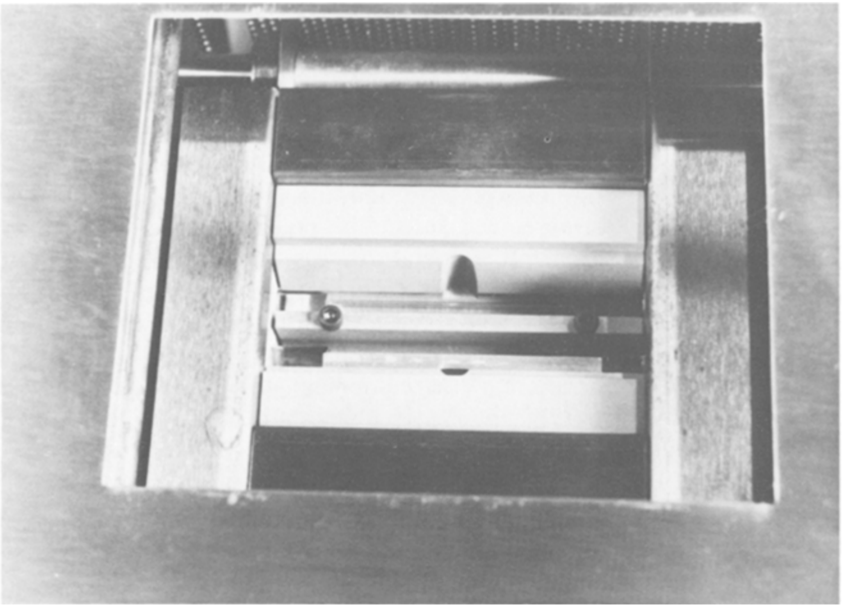

Fig. 3. The specimen cavity.

successfully adapted to a multichamber furnace of four specimens to achieve a higher volume of testing.

The temperature control and sense circuitry allow an equilibrium condition to be controlled and held to within 0.1°C. Digital adaptive algorithms used in furnace heating and control ensure sample temperatures within 1°C of the desired temperature within a very short time. The accuracy of the temperature measurement is within $\pm 0.5\%$ over the entire range. The analog temperature signal is converted into digital form using an integrating V/F technique. The system is virtually noise-free.

Length measurement is accomplished with an optical encoder-type digital linear gauge, having a resolution of ± 0.00002 in. and a linearity and repeatability of 0.00004 in. The displacement is converted to digital form at the gauge itself; thus no noise is introduced when the signal is transmitted to the computer over a digital data highway. The absence of analog transducers [linear variable differential transformers (LVDTs)] has substantially improved short- and long-term stability and accuracy.

3. PERFORMANCE CHARACTERISTICS

Calibration of the system was accomplished by running one or more tests using a known material with published data. Standard Reference Materials, supplied by the National Bureau of Standards, such as SRM 731 borosilicate glass, were used in this work. Certified data were compared to the average of a series of five tests and the difference was used as a calibration factor for subsequent tests. The polynomial representing this difference as a function of temperature was generated and used for calculating the correct values from the test data at each temperature point. All corrections and data reduction became automatic once the calibration correction values were installed into the software.

To check the operation of the equipment after the calibration was completed, NBS-SRM 732 sapphire [3] and NBS-SRM 736 copper [4] were tested. Figures 4 and 5 show the results, respectively. The data compared favorably to published values and show that the instrument is capable of generating data comparable to those obtained using conventional tube-type dilatometer. The overall accuracy and precision of the measurement of the coefficient of thermal expansion in routine tests were found to be within $\pm 1.5\%$, suggesting that very careful operation can yield

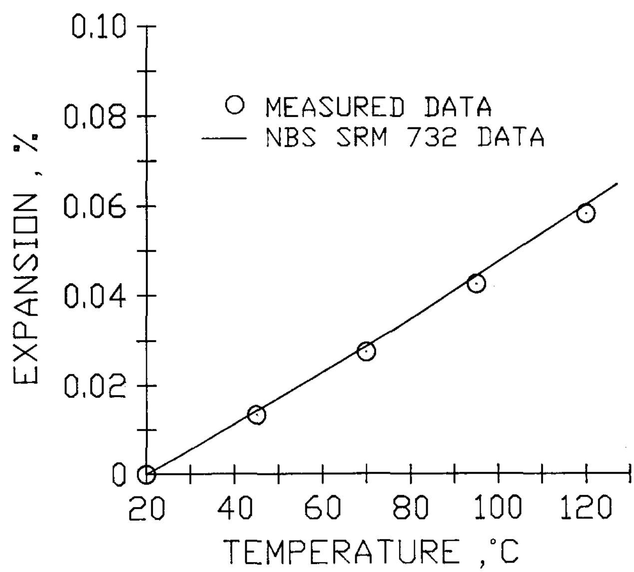

Fig. 4. Linear thermal expansion of NBS-SRM 732 single-crystal sapphire.

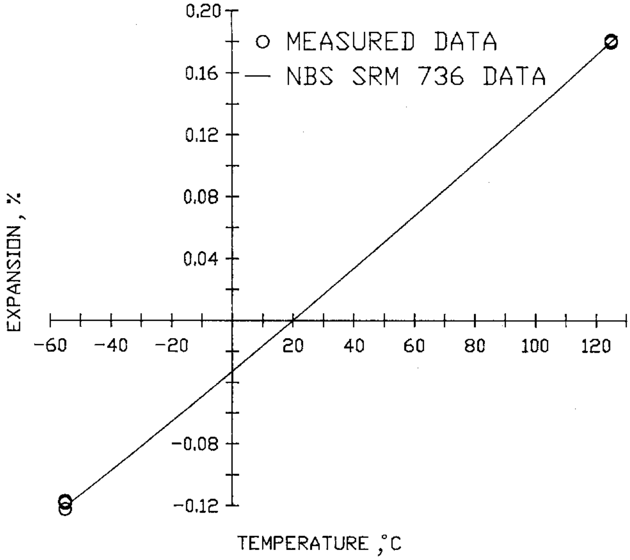

Fig. 5. Linear thermal expansion of NBS-SRM 736 copper.

results better than 1%. Test data, however, will depend on the stability of the material being tested, the standard used for calibration, and the overall expansion produced.

4. EXPERIMENTAL

A commercially produced specimen of FR-4 epoxy–glass circuit-board material with copper cladding on both sides was obtained, and a number of samples were sheared from it in two mutually perpendicular directions. To show the dependence of expansion as a function of orientation, tests were performed on several of these samples. The results are summarized in Fig. 6. It shows a small but readily measurable difference (approximately 10%) between samples which are mutually perpendicular. This could be explained by the oriented nature of the glass-fiber reinforcement in the epoxy matrix.

To determine whether repeated temperature cycling of the material significantly changes the expansion characteristics, two identical tests were performed on each of several samples. The results are shown in Fig. 7 and indicate that changes as high as 25 to 30% occur in repeated cycling. This was probably due to secondary resin curing and points to the importance of the choice of temperature program used in performing any tests on this

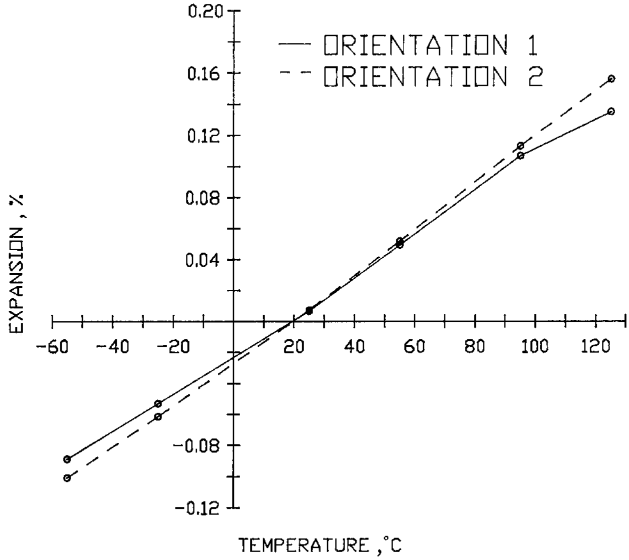

Fig. 6. Linear thermal expansion as a function of orientation for circuit-board material.

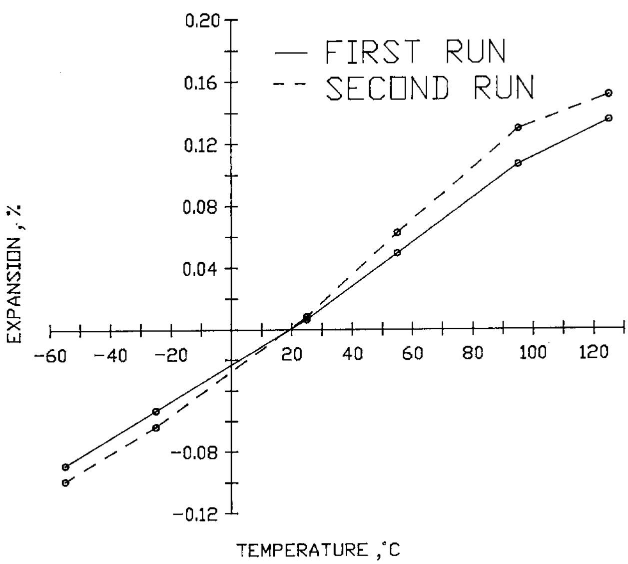

Fig. 7. Results of multiple test sequence.

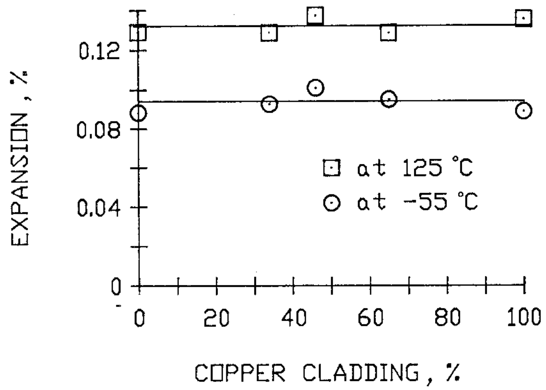

Fig. 8. Effect of cladding on the expansion of the composite circuit board.

type of material. Slow heating rates or prolonged soaks at elevated temperatures will be likely to produce different data than rapid heating with minimal soaks. It is therefore very important to note these test parameters along with the test data reported. All tests in this study were conducted at a rate of 5°C/min with 15-min soaks at the two end points.

To correlate the amount of copper cladding with the overall thermal expansion of the material, portions of the copper on both sides of several samples were etched away in different percentages with respect to area. The amount of copper remaining varied from 100% (full cladding on both sides) to 0% (no cladding on either side). Tests were performed at the two extreme service temperatures for circuit boards: −55 and 125°C. Results from these tests are summarized in Fig. 8.

It can be seen that the amount of copper cladding does not contribute significantly to the overall expansion of the sample. This is possibly caused by the relative thinness of the copper as compared to that of the substrate (1:100). In this case, the expansion characteristics of the substrate far outweighed those of the copper. There is a possibility that the substrate is formulated to be similar in expansion characteristics to the cladding. However, this was found not to be true in this case, when data representing the 0% copper cladding are compared to the expansivity of pure copper.

5. CONCLUSIONS

The design described does away with the fragility of the quartz tube dilatometer and provides a more rugged system. It speeds up loading and unloading and permits operators with little or no experience to produce consistent and accurate results.

Testing cycles can be sped up because of the intimate contact between the furnace and the specimen, assuring a uniform temperature distribution. The temperature of the specimen is sensed without attaching a thermocouple directly to it, a special advantage in testing very thin samples.

Simple specimen preparation methods, such as shearing and cutting, can be used successfully, especially with flat plate or sheet materials.

The principles of the new design conform with existing ASTM and other standards on quartz dilatometry. The accuracy and repeatability of the system for routine testing are within $\pm 1.5\%$ when well-defined materials of moderate expansion are tested. Careful calibration and testing procedures can further improve this figure.

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