APPLICATION NOTE

Thermal Analysis

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Thermomechanical Analysis Basics: Part 2 Mechanical Testing

Introduction

Thermomechanical Analysis (TMA) remains one of the most basic tools of material science and its basis is discussed in Part 1.[1] The PerkinElmer TMA adds expanded testing capabilities to the traditional TMA measurements.

The TMA is designed to precisely apply forces and measure dimensional changes at the nanometer level. Hence many of the tests performed in large mechanical testers like stress-strain curves, creep recovery experiments and even dynamic mechanical analysis experiments can be run on the TMA.

More "real world" TMA tests

A powerful tool in the analytical laboratory, many TMA measurements are closer to mechanical or traditional physical properties tests than one might realize. As coefficient of thermal expansion (CTE) curves can occasionally be difficult to interpret, several methods have been developed in the industry.

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These either mimic the standardization tests[2] like heat deflection or softening point or use different geometries (Figure 1) to make the data easier to interpret. Many of these methods have been formalized into ASTM® procedures.[3] Both approaches take advantage of the rapid heating and precise temperature control of the TMA. Films are run in extension geometry under light loads (1-5 mN) for CTE as well as under heavier loads to see the resulting size changes that occur with the loss of stiffness at transitions. These can also be used to measure inducted transitions like the heat set temperatures in fabrics. Small bars or splinters of samples can be run under prescribed stresses in flexure or three-point bending and the defection point calculated. Odd shaped pieces can be run under even higher loads in penetration to measure the softening point. A general trend can be seen where the Tg increases (Figure 2) with the method when measured by CTE, flexure and penetration.[4]

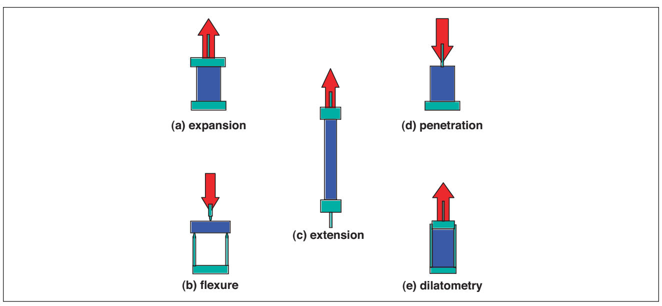

Figure 1. Testing geometries used in the TMA are similar to those used in standard mechanical testing: (a) expansion which is used for both compression and CTE studies, (b) flexure or three-point bending, (c) extension or tensile, (d) penetration and (e) dilatometry or bulk.

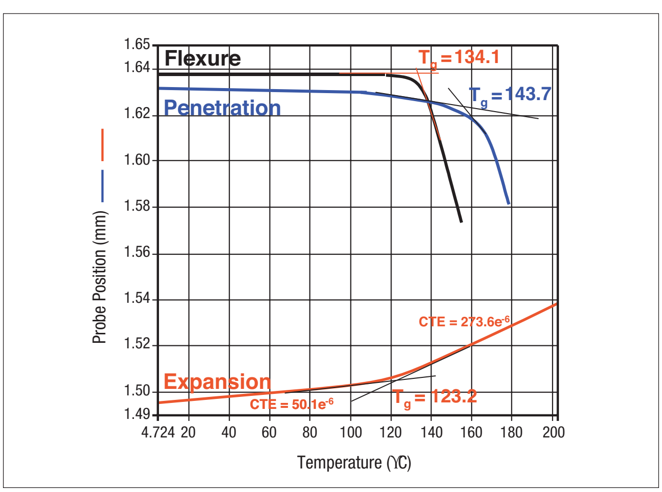

Figure 2. Comparison of Tg by CTE, flexure and penetration.

Sometimes samples need to be tested in solution as is required for swelling studies in rubbers or for materials that will be in constant contact with solvent during their use life. Some of the heat deflection tests are also traditionally run in oil baths and running the same way in the TMA gives the best agreement with historical data.

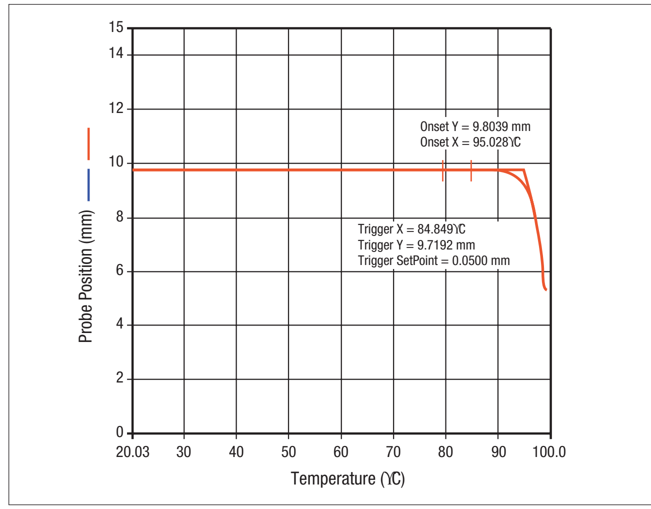

Figure 3. An HDT performed on a TMA with liner gives 84.9 °C compared to 85.5 °C for a standard test.

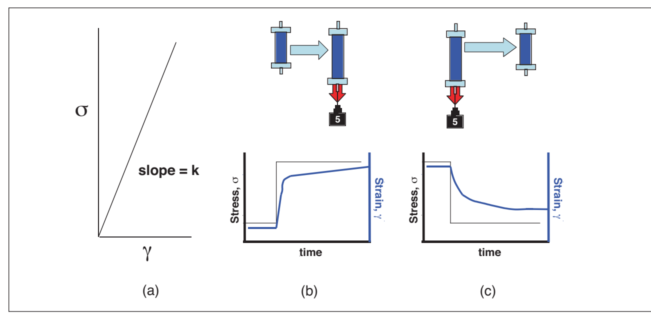

Figure 4. (a) A stress strain curve. (b) and (c) A creep-recovery experiment with the loading and unloading represented above.

Stress strain curves

Because the TMA has the ability to ramp stresses at variable rates as well as excellent temperature control, it is often advantageous to use a TMA to run flexure and tensile tests rather than a large test machine (Figure 4a). Although the TMA lacks the force to test composite or metallic parts to failure, it can be used on rubbers and plastics as well as for the determination of Young's Modulus.[5] Because of the small sample size, elevated temperature runs with uniform heating are easily and quickly performed.

Creep and creep recovery

One of the most useful material characterization tests is the creep and creep-recovery test.[6] Creep recovery mimics what happens to materials in use when they are loaded and unloaded over periods of time. It has been used to study everything from aerospace materials, heart valves, seat cushions to hair spray (on the hair strands). Creep data (Figure 4b) can be easily collected in the TMA and then analyzed or exported in ASCII format for use in engineering programs. By applying a stress quickly to the material and after a hold period removing it, the TMA tracks the strain as a function of time. This shows how much a material deforms and how quickly (Figure 4c) it recovers (if ever).

DMA experiments

A full discussion of DMA experiments is beyond the scope of this paper but is addressed in the DMA Basic series[7] as well as several references.[8] It should be noted that simple dynamic mechanical analysis (DMA) tests can also be run on some TMAs such as the PerkinElmer TMA. The advantage of DMA is its extreme sensitivity to transitions and its ability to scan modulus as a function of temperature and frequency quickly. Many users just need the former relationship and for them, the TMA supplies all the DMA abilities they require.

Conclusion

Mechanical testing provides basic sample information on a broad range of materials. Now TMA instrument technology, such as the PerkinElmer TMA, provides a convenient tool for performing mechanical testing in most laboratories.

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