APPLICATION NOTE

Thermal Analysis

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TMA of Packaging Materials

Background

The packaging of food and other consumer products is a competitive and rapidly evolving business. The use of plastic containers, plastic wrappers, bubble wrap, etc. allows products to be displayed to best advantage along with printed messaging, consumer information and logos. Besides the display requirements, plastic packaging must seal in the product using a rapid, automated process; it must be cost effective, and increasingly there are requirements for recyclability. Thermal analysis, including dynamic mechanical analysis, has played a role in developing new packaging materials and adapting existing materials to new packaging products and processes. One piece of the materials puzzle is a dimensional piece, namely, determining the dimensional changes that take place in the material as a function of temperature as a result of stresses built up during the production and sealing processes. PerkinElmer has recently developed a moderate cost thermomechanical analyzer (TMA), the TMA 4000, described elsewhere, which is well adapted to testing coefficients of expansion and stress relief dimensional changes which are often of critical interest in the varied fields of plastics processing.

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This note presents examples of analysis of plastic film products using the PerkinElmer TMA 4000. In each case a sample of a roughly 10 mm finished piece of packaging material is analyzed in extension in the X and Y plane, and in compression in the Z direction perpendicular to the plane. The force applied to the TMA probe is minimal to allow the accumulated stress in the material to be relieved by way of expansion or contraction. Because the authors have little technical information on the material being tested the emphasis here is on the analytical method and instrumental performance. As used in an industrial setting, the TMA focus would likely be on problem solving and specific packaging product improvements.

Food wrapper

Typical requirements of a food wrap are, first, barrier properties to ensure taste quality and safety from contamination, and then also printability, transparency, ease of opening, and critically, processing throughput. To achieve these disparate goals a multilayer film is often employed. Because the film layers will have different coefficients of thermal expansion (CTE) the sealing process might be expected to produce stress that will result in deformation on softening.

To interpret behavior at an inter-molecular level may require analysis by both differential scanning calorimetry (DSC), to interpret heat flow, and by TMA to record dimensional change. The DSC 8000 was used to observe the heat flow behavior, including interpret the glass transition (Tg) region and crystalline melting. The Pyris software facilitates comparing data from multiple thermal analysis techniques, such as DSC, TMA, TGA and STA.

Figure 1 shows the DSC heat flow scan of an aluminized, multilayer polyethylene terephthalate (PET) wrapper used for an individually wrapped health food bar. From the DSC data can be seen two distinct melting endotherms, the high temperature one of which is likely polyethylene terephthalate (PET). The absence of an exotherm indicates the PET is in a crystallized form such as that of biaxially-oriented polyester familiar to many under the trade name Mylar™.

Figure 2 shows the TMA analysis of this snack food wrapper analyzed in compression, observing the softening and contraction of the film in the z-direction, perpendicular to the plane of the film. Six layers of film were sandwiched in a DSC pan to amplify the displacement while avoiding any cleanup after the melt.

Figure 3 shows the TMA machine and transverse-direction of the same wrapper. For the first 60 °C the wrapper shows expansion in both machine and transverse directions. At 150 °C there is differential contraction accompanying the first melt.

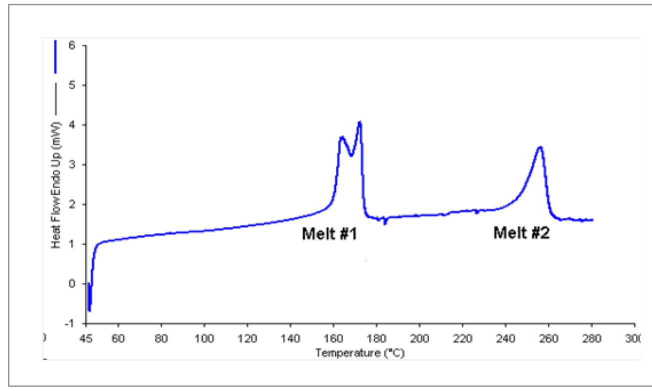

Figure 1. DSC heat flow analysis (endothermic up) of pictured snack food wrapper

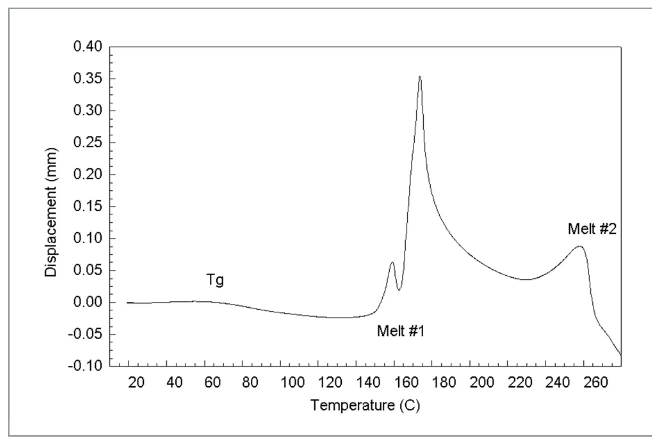

Figure 2. Z-axis expansion and shrinkage of 26 micron film used as snack food wrapper

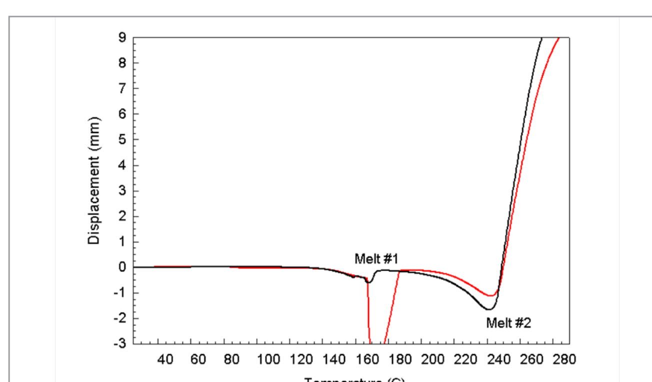

Figure 3. TMA extension of snack food wrapper in machine and transverse direction. Downward slope indicates contraction; upward slope indicates softening or elongation

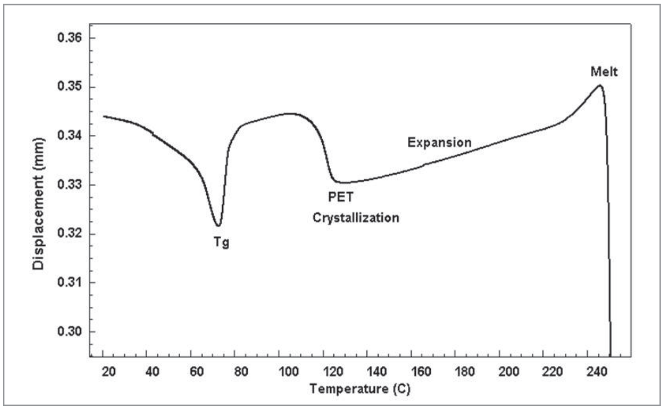

Figure 4. TMA data of PET clamshell showing displacement in Z-direction under compression

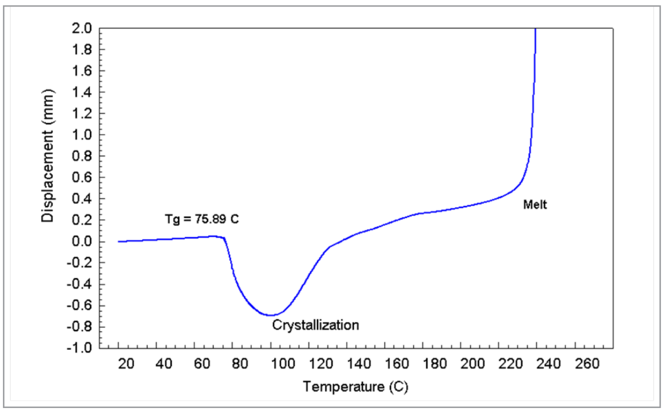

Figure 5. TMA data of PET clamshell showing displacement in the XY plane in extension

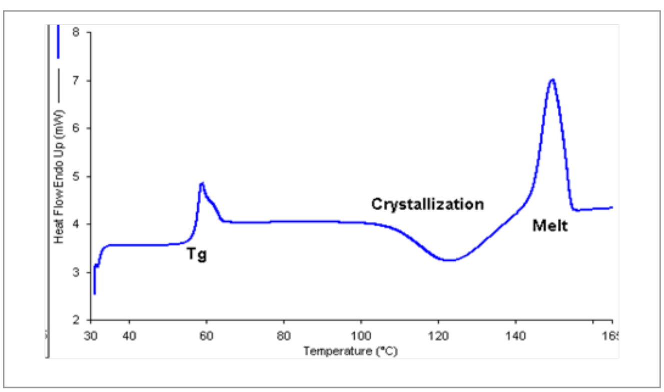

Figure 6. DSC of PLA showing heat flow (positive deflection is heat absorbed)

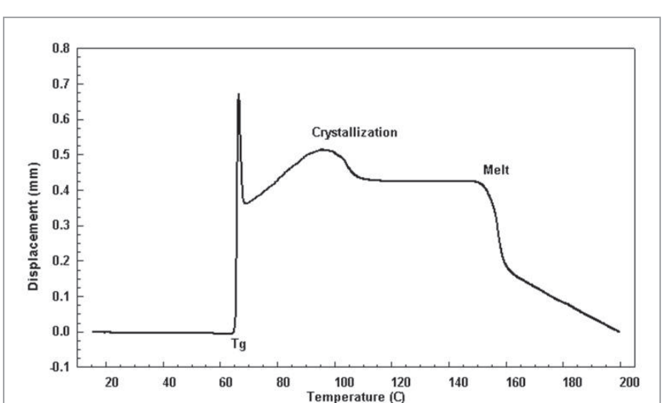

Figure 7. PLA clamshell in Z-direction – zero force in compression

Further heating results in contraction up to the extension at the final melt. Because of the wide dynamic range of the TMA 4000 the displacement can be followed for several millimeters either expansion or shrinkage. Because of the damped suspension, low force (~1g) can be employed without inducing undue noise. There is very little stress relief at Tg since the stress has been relieved in the rolled and drawn film production.

Clam shell packaging

Clam shell packaging—typically of amorphous PET—displays a different story to that described for the PET food wrapper. Here there is substantial stress release at the glass transition from the molding process followed by a reciprocal dimensional recovery during cold crystallization. See Figures 4 and 5.

A newcomer to the clamshell scene is the amorphous PolyLactic Acid (PLA) clamshell which is used in carry-out applications where recycling is problematic. The PLA clamshell material is biodegradable in a weathering environment. While manufacturing problems for PET have been largely worked out over the past decades, thermal information on PLA is less extensive. Figure 6 shows the DSC heat flow scan at 10 °C/min showing some of the same characteristics of amorphous PET, namely, a predominate glass transition followed by crystallization, followed by melt. These events can also be seen in the TMA expansion in the Z-direction shown in Figure 7.

Figure 8 shows the expansion of PLA in the XY plan, showing two samples taken at 90 degrees to one another, one radial with respect to the center of the clamshell, the other tangential.

Tips for running films in extension

When running fibers or fragile film samples the key to obtaining good dimensional change data under low load is attention to careful sample preparation and mounting. The sample should be cut to dimension without creating stress, and it should be mounted linearly in the clamps with the analyzer force evenly distributed. The clamps should be absolutely parallel and in line to one another. The loading fixture shown in Figure 9 is invaluable to perform this task. This fixture which was designed for performing dynamic mechanical analysis in extension forces the clamps to be perfectly parallel and rigidly held as the sample is clamped in place and its length measured.

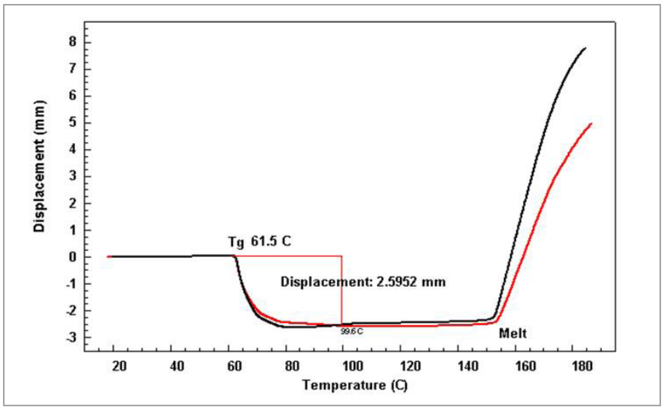

Figure 8. PLA clamshell measured in the XY (radial & tangential) plane of the film in extension

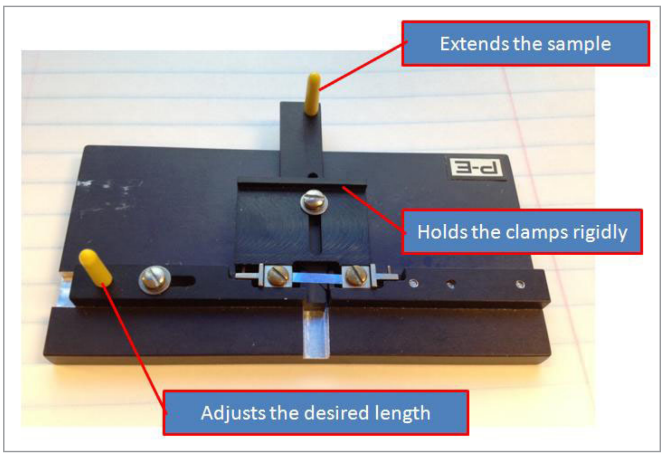

Figure 9. Aligning clamp fixture for extension

Summary

While dynamic mechanical analysis can determine the modulus of a plastic product, such as a film used in packaging, often the TMA, a much simpler technique, can more easily reveal the source of production problems related to the mechanical aspects of processing, especially those related to stress relief. It is clear from the above examples that finished plastic films exhibit measurable dimensional changes due to stress relief upon heating. The TMA 4000 thermomechanical analyzer was designed for the demanding sensitivity of measuring the small coefficients of expansion of materials used in the electronics industry, but it also has the wide dynamic range and low force capability to analyze production problems in the packaging industry, or in other plastics industries.

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