Exponential Business and Technologies Company

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Temperature Controlled Tensile Testing of Thin Films on a DMA

Freestanding thin films are used in many applications such as plastic wrap, aluminum foil, tape, packaging, and paper. These products require a wide range of mechanical properties to optimize their functions. Some thin films need to stretch and change form while others need to be rigid and unyielding. Tensile measurements are one of the most useful and direct methods to characterize the mechanical properties of thin films.

Tensile testing measures the amount a sample stretches when placed under a tensile load, typically reported in terms of stress and strain. The material's Young's modulus, yield strength, and ultimate yield strength are determined from the stress vs strain plot and represent the material's stiffness, onset of permanent deformation, and point of failure, respectively. Dynamic Mechanical Analyzer (DMA) can be used to measure key mechanical properties as a function of temperature, load, frequency or time to accurately predict material's performances in different applications and environments.

In this application note, the tensile properties of different thin film materials: aluminum foil, polyethylene terephthalate (PET) film, and polyethylene (PE) packaging samples were measured under tensile testing mode on a DMA. The DMA used was a TA Instruments Q800, a versatile DMA works at temperatures between -150 °C and 600 °C and frequencies of 0.01Hz – 200Hz. and has 0.01 mN force resolution and 1 nm displacement resolution. The thin film samples were tested at room temperature under a force ramp from 0.5 N to 18 N at a rate of 1.0 N/min until fracture occurred. The stress-strain curves shown in Figure 1 were analyzed to determine the Young's modulus, ultimate yield strength, and strain at fracture of each material.

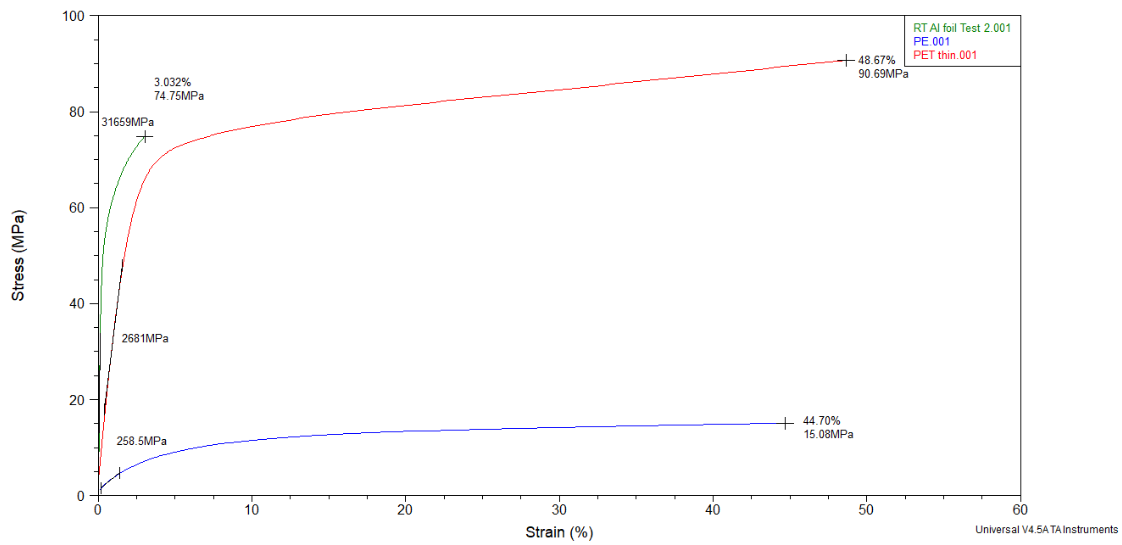

Figure 1. Tensile stress vs. strain curves of all three samples obtained using DMA.

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The test results found in Table 1 show just how widely the tensile mechanical properties can vary among materials. Aluminum foil exhibits much higher rigidity and Young's modulus than the polymeric films, but fractures after only 3.03% strain. That the lower measured Young's modulus of the aluminum foil than the value for known bulk aluminum was considered due to coatings that was found on the aluminum foil. Interestingly, the PE packaging sample has a Young's modulus comparable to low density polyethylene (LDPE), but an ultimate tensile strength comparable to high density polyethylene (HDPE). This may be an example of a designed product that utilizes the flexibility and elasticity of LDPE, but needs the strength of HDPE.

Table 1 Tensile Test Results for Each Sample at Room Temperature

Sample	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)	Elongation at Fracture (%)
Aluminum Foil	31.66	74.75	3.03
PET Film	2.68	90.69	48.67
PE Packaging	0.26	15.08	44.70

DMA is a very useful tool, not just due to its ability to work with thin films, but also due to its capability to work at varying temperatures and frequencies. This is especially important for testing materials that experience harsh environments, for example, rubber at sub-zero temperatures or at near its melting temperature.

To illustrate how mechanical properties are affected by temperature, aluminum foil was tested at 100 ˚C, 200 ˚C, 300 ˚C, and 400 ˚C. Table 2 and Figure 2 present the tensile testing results of aluminum foil at elevated temperatures. It is obvious that the Young's modulus and ultimate tensile strength of the foil decrease as a function of temperature. From 100 ˚C to 400 ˚C, the Young's modulus and ultimate tensile strength decreased 71.3% and 67.5%, respectively, but the elongation at fracture showed an increasing trend. As the temperature rises, atoms can diffuse or creep more easily to accommodate plastic deformation. This leads to decreased stiffness and ultimate strength, but increased ductility.

Table 2 Tensile Test Results for Aluminum Foil at Elevated Temperatures

Temperature (˚C)	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)	Elongation at Fracture (%)
100	38.68	63.24	3.27
200	27.17	46.94	4.08
300	14.09	31.00	4.36
400	11.08	20.56	3.45

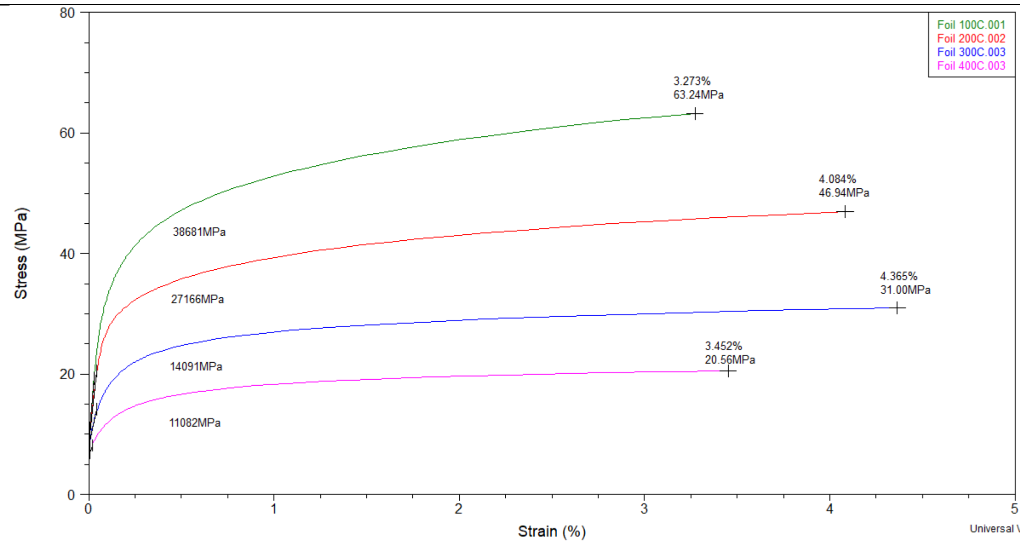

Figure 2. Tensile stress vs. strain curves of aluminum foil at 100 ˚C, 200 ˚C, 300 ˚C, and 400 ˚C obtained using DMA.

Thin films are used in every industry, and each application has different needs for the mechanical properties of films. Plastic and metal films will behave very differently when placed under tensile loads, and the properties will change as a function of temperature and frequency. These materials tend to soften at elevated temperatures, causing the material to stretch more before failure, but fail at lower stresses. Tensile testing using DMA is an excellent choice for determining the mechanical properties of parts that may be too small or fragile to undergo tensile testing on a conventional universal test machine (UTM) and for films used in extreme environments. The utility of DMA is supreme due to its ability to measure and test material properties under a wide range of operating conditions.

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