Investigation of Nylon 6 Using Controlled Humidity Dynamic Mechanical Analysis

ABSTRACT

This paper discusses the dynamic mechanical analysis of Nylon 6 under varying conditions of temperature and relative humidity.

INTRODUCTION

Nylon 6 exhibits outstanding physical, thermal, and chemical properties, plus good resistance to fatigue, abrasion, sunlight, and microorganisms. As such, Nylon 6 is used in a wide range of applications, including use in bristles for toothbrushes, sutures for surgery, hosiery, knitted garments, and a large variety of threads, ropes, filaments, nets, and tire cords. However, many of these applications require the nylon resin to be in contact with water or atmospheres of varying relative humidity. Nylon 6 is strongly plasticized by water; as a result the mechanical properties of this polymer will be strongly dependent on the surrounding relative humidity.

The TA Instruments DMA-RH Accessory allows the mechanical properties of a sample to be analyzed under constant and/or varying conditions of both relative humidity and temperature. It is designed for use with the Q800 Dynamic Mechanical Analyzer. The DMA-RH accessory is an integrated unit and contains the following components:

Figure 1: The TA Instruments Q800 Dynamic Mechanical Analyzer and DMA-RH Accessory

1. The sample chamber mounts to the DMA in place of the standard furnace and encloses the sample. Peltier elements in the chamber precisely control the temperature to within ±0.1°C. The sample chamber accommodates standard DMA clamps including tension, cantilever, and 3-point bending, and can be easily removed for rapid conversion back to the standard DMA furnace.

2. The DMA-RH Accessory contains the humidifier and electronics which continuously monitor and control temperature and humidity of the sample chamber. The DMA Q800 and the DMA-RH Accessory are fully software-integrated.
3. A heated vapor transfer line is maintained above the dew point temperature of the humidified gas in order to avoid condensation and provide accurate results.

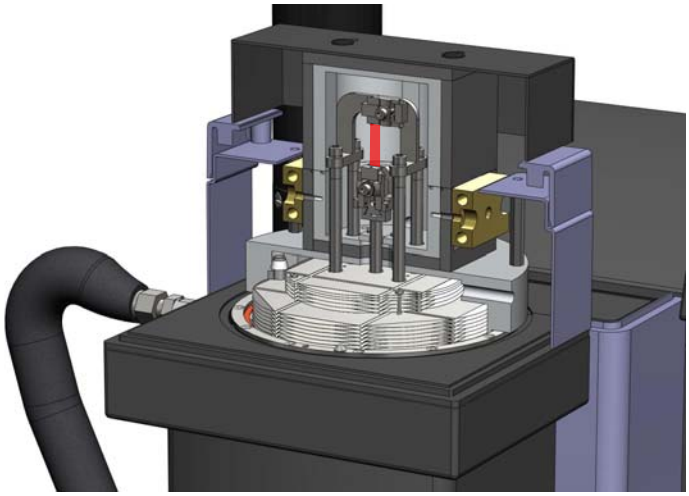

Figure 2: Sample Chamber of the DMA-RH Accessory

The DMA-RH accessory allows for the control of temperature over the range 5-120°C, and humidity over the range 5-95% RH. As such, it is well-suited to investigate the Nylon 6 and other polymeric materials which exhibit a glass transition within this temperature range.

RESULTS & DISCUSSION

A rectangular Nylon 6 sample of dimension 10.8 mm x 12.8 mm x 0.83 mm was cut from a larger sheet and placed into a single cantilever clamp on the DMA Q800. It is important to minimize the thickness of the sample to facilitate efficient water transfer throughout the polymer matrix. The sample was analyzed at a frequency of 1 Hz and amplitude of 15 µm (~0.03% strain) over the temperature range 10-100°C at a variety of constant humidity conditions; 5%, 20%, 50% and 80% RH. The resultant storage modulus and tan delta are shown in Figure 3.

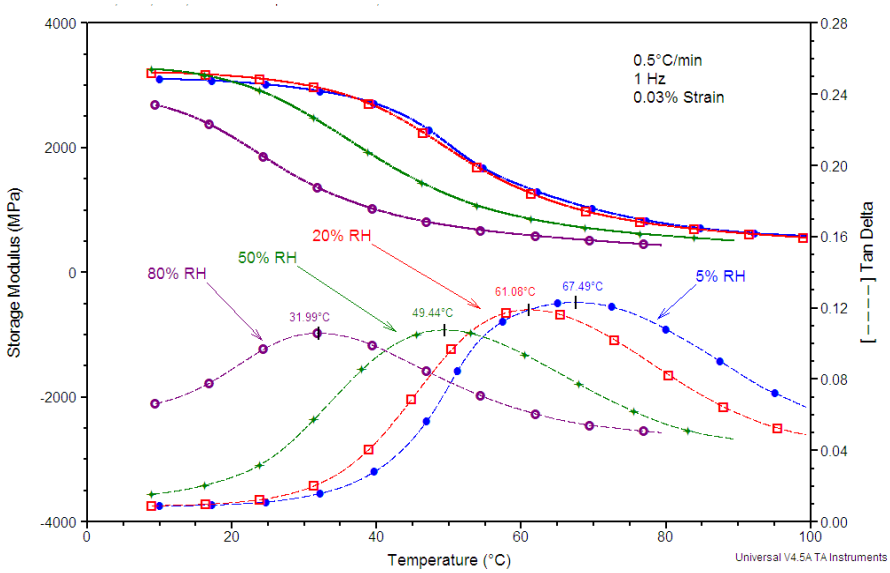

Figure 3: DMA Results for Nylon 6 at a Variety of Constant RH Conditions

The data in Figure 3 clearly demonstrate the effect of relative humidity on the mechanical properties of Nylon 6. As expected, the increased water activity in the atmosphere allows for plasticization of the Nylon resin. Note that the most dramatic effect is seen at RH levels above 50%, where a 30% increase in RH causes an 18°C shift in the glass transition temperature (as measured by the peak in tan delta).

The DMA-RH Accessory allows for flexibility in control of the temperature/RH combination. Experiments can also be performed under dynamic humidity control, while holding temperature constant. The data in Figure 4 contain the results Nylon 6 held isothermal at 50°C, while increasing the humidity at 0.2% RH/min[i] over the range 5-95% RH. Under these dynamic RH conditions, the glass transition of the Nylon 6 is identified by the peak in tan delta at 50% RH.

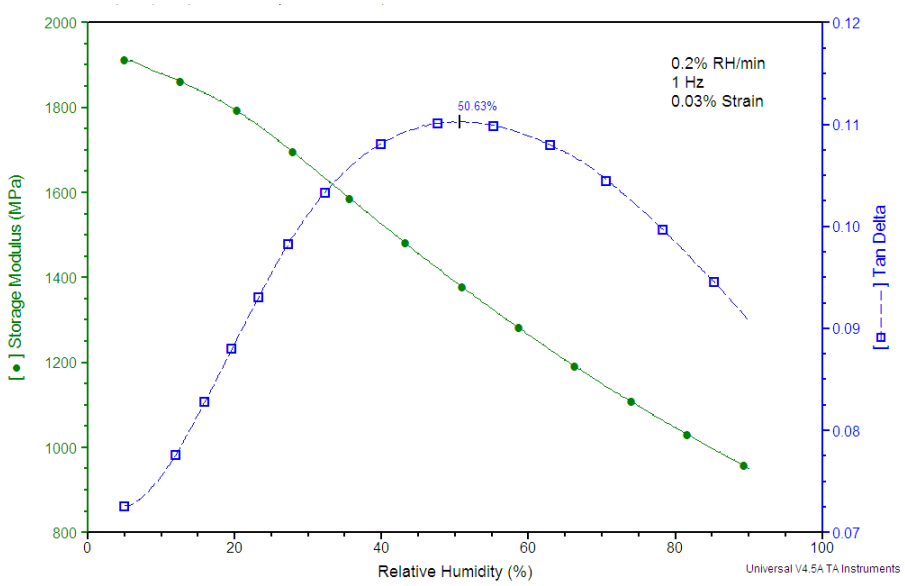

Figure 4: Glass Transition of Nylon 6 at 50°C as a Function of Relative Humidity

CONCLUSIONS

The data presented illustrates the plasticizing effect of water on Nylon 6. The glass transition temperature of the resin is a strong function of the imposed relative humidity. It is also possible to detect an isothermal glass transition as a function of dynamic RH conditions. The TA Instruments Q800 DMA and DMA-RH Accessory provide the ideal platform for the study of relative humidity effects on the mechanical properties of polymeric materials.

[i] The RH ramp was composed of a series of short isohume steps, 1%RH /5 min hold.

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