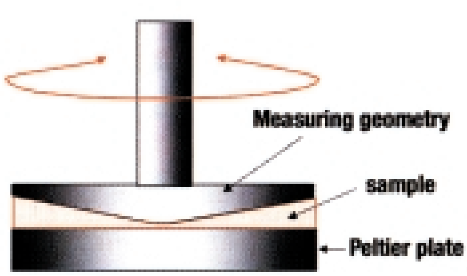
USE OF CONTROLLED-STRESS RHEOLOGY TO QUALIFY AND PREDICT ADHESIVE PERFORMANCE

By Steven R. Aubuchon, Ph.D.
TA Instruments – Waters, LLC., New Castle, Del.

The mechanical and rheological properties of pressure sensitive adhesives (PSAs) will dictate the long-range performance of the adhesive. Tack and peel behavior and shear resistance have historically been measured to determine and/or predict the performance of PSAs, and to engineer their properties as well.

Historical tests (180° peel, loop tack, etc.) have been very effective in measuring relative properties of various adhesives, but these tests often suffer from a lack of precision and reproducibility. In addition, the results can be significantly influenced by operator bias. In this article, controlled-stress rheology is presented as an effective tool in the evaluation and prediction of PSA performance. Tack and peel qualities can be directly and quantitatively measured and compared. The use of time-temperature superposition can extend the measurable range of the instrument and assist in long-term product performance.

Figure 1. Controlled-Stress Rheometer Design



Theory

The controlled-stress rheometer is a cone-and-plate or parallel-plate design in which the material of interest is sheared between a rotating geometry and a stationary base plate (Figure 1). Often the base plate is a Peltier heating element so that the temperature of the system can be controlled very accurately.

The sample is mechanically oscillated at a strain that does not exceed the linear viscoelastic region (LVR) of the material. In most controlled-stress rheometers, both the frequency of the oscillation and the temperature of the sample can be controlled independently. This provides for the measurement of the mechanical response of the material at a wide range of temperatures and frequencies. The most useful signals in PSA analysis are G′ (the shear modulus) and G″ (the loss modulus). G′ is a direct measurement of the tack strength of an adhesive, and G″ is a direct measurement of the peel strength.

The main limitation of most commercial rheometers lies in the frequency range. Frequencies above 100 Hz are often hard to achieve, and frequencies below 0.01 Hz require significant time investment to collect data. For this reason, time-temperature superpositioning is used to predict material performance over a wide frequency range.

The underlying bases for time/temperature superpositioning (TTS) are (1) that the processes involved in molecular relaxation or rearrangements in viscoelastic materials occur at accelerated rates at higher temperatures and (2) that there is a direct equivalency between time (the frequency of measurement) and temperature. Hence, the time over which these processes occur can be reduced by conducting the measurement at elevated temperatures and transposing (shifting) the resultant data to lower temperatures. The result of this shifting is a master curve where the material property of interest at a specific end-use temperature can be predicted over a broad time scale.

Figure 2 contains the raw data from a TTS experiment performed on a PSA. Note that the G′ and G″ values are measured over a wide range of temperatures and frequencies. In the raw form, it is difficult to interpret this data, much less to draw conclusions about the tack and peel strength of the PSA.

Assigning a reference temperature to model around, and through the use of TTS shifting software, the data in Figure 2 can be converted into a master curve (Figure 3). This master curve clearly indicates the relative tack strength (G′) and peel strength (G″) of the PSA, modeled around the reference temperature of 20°C.

Once the master curve for the PSA has been generated, it is possible to analyze the data by creating a performance grid. Several parameters for quantitative significance must be assigned to the performance grid. It is assumed that the application of the adhesive (tack test) would occur at an angular frequency near 0.1 rad/sec. It is further assumed that the peel test would approximate the higher frequency of 10 rad/sec. These parameters in place, it is now possible to qualify various adhesives as candidates for a particular application.

Figure 4 shows the performance grid comparison of two PSAs versus a hot melt adhesive (HMA). The G′ range of 50,000 to 200,000 Pa is accepted as ideal for PSA performance. Note that PSA1 exhibits ideal performance, as G′ is independent of frequency across the entire range. This suggests moderate tack and peel strength. PSA2 is similar, with slightly elevated G′ at higher frequencies. This suggests that PSA2

Figure 2. Raw TTS Data for PSA

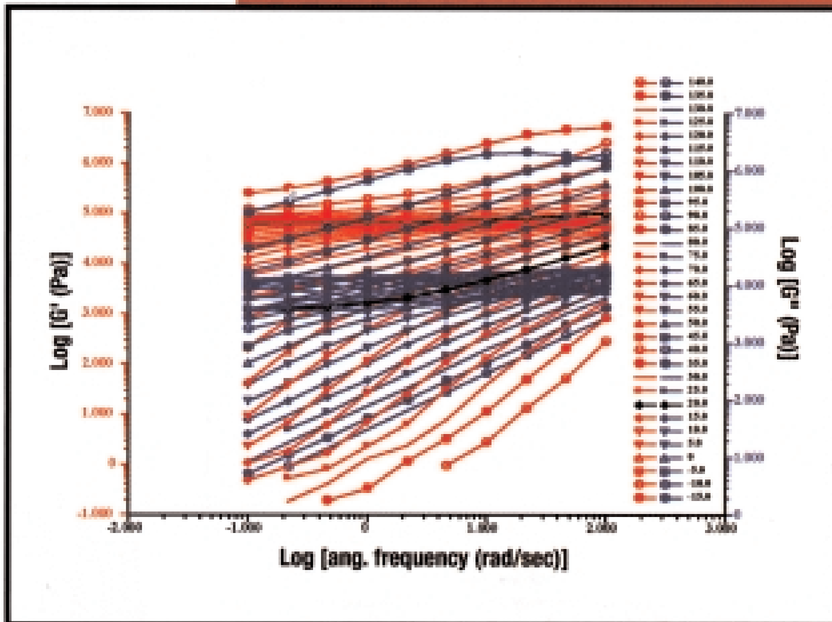
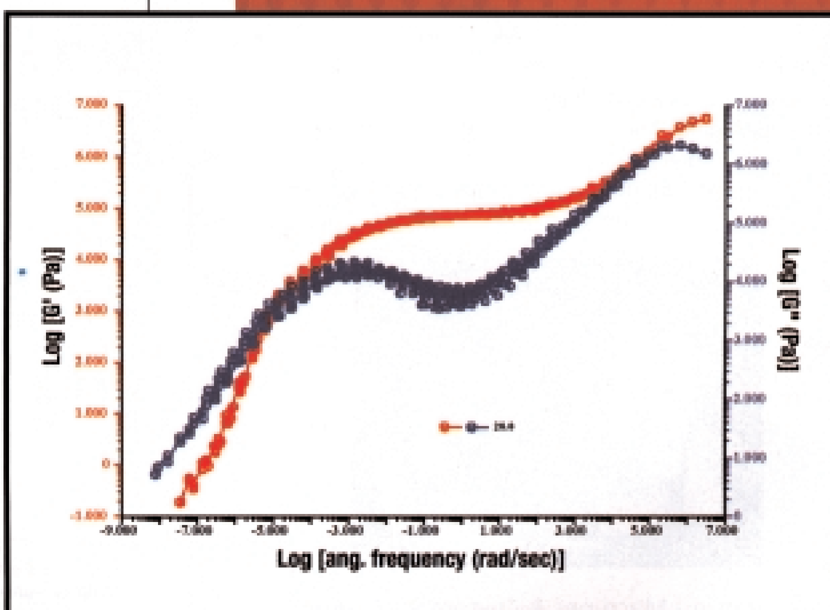


Figure 3. TTS Master Curve for PSA



would show higher peel strength under shorter time scales. Finally, the hot melt adhesive performance is not suitable under PSA guidelines. First, the G′ value is too low under tack conditions, which indicates too much compliance or flow on application. In addition, the G′ value is extremely high at elevated frequencies. This suggests a high peel strength, again unsuitable for PSA applications.

Summary

Controlled-stress rheology is a useful tool for measuring and predicting the performance of adhesives. Through the use of time-temperature superpositioning, the performance of two PSA materials has been evaluated and compared to a hot melt adhesive. The quantitative G′ and G″ values obtained from the rheometer can be used to qualify and predict adhesive performance. ● ASI

For additional information on controlled-stress rheometers, contact TA Instruments, Inc., 109 Lukens Drive, New Castle, DE 19720; phone 302-427-4000; fax 302-427-4001; e-mail info@tainst.com; or visit the Web site http://www.tainst.com. Or Circle No. 65.

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Figure 4. Performance Grid for PSA