DATA BASE OF THE DYNAMIC PROPERTIES OF MATERIALS

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ABSTRACT

Measurements of the damping properties of materials continues to be a major effort at Anatrol to provide the basis for using both the damping and isolation technologies. The current library of the damping properties at Anatrol contains over a thousand materials and is being expanded on a daily basis. Those materials have been completely characterized for their damping properties and are stored on the computer in terms of:

* temperature and frequency
* dynamic and static non-linearities
* creep and relaxation behavior
* aging, outgassing, etc.

The properties for most of these materials have been measured by more than one technique covering wide ranges of temperatures and frequencies to ensure their accuracies and to arrive at the appropriate shift factor reducing the data.

This paper will give examples of the properties for various families of materials currently on the data base and how they can be accessed by various users working in the damping and isolation areas.

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I. INTRODUCTION

Reducing noise and vibration levels in various products has been receiving more and more attention in recent years. This increased level of awareness has been caused not only by the need to build better, more efficient items, but also because products with low noise and vibrational response are now being perceived as having better quality. Products with low noise and vibrational characteristics can be designed by implementing both passive and active control systems. The approach for passive control systems consists of mainly using structural modifications, damping, and isolation. Before either the damping and/or the isolation technologies can be properly utilized, however, a good knowledge of the dynamic behavior of the materials as functions of different environments needs to be known. Without such properties on hand it becomes very difficult to perform the analysis and optimize the design for a given system.

Available information on the properties of materials, either from manufacturers or in the open literature, is limited, has considerable scatter, and covers only some environmental ranges. To overcome these limitations, Anatrol has undertaken the task of measuring and evaluating the dynamic properties of materials under various conditions. This information has been gathered to establish an extensive data base used to assist in the design and implementation of passive control systems. Over the past fourteen years, measurements have been made on several thousand different materials including structural adhesives, PSA's, plastics, enamels, rubber materials, foams, and composites.

The various techniques that have been used to measure the dynamic properties of materials at Anatrol, include those that are in the frequency domain, such as the impedance and beam techniques, and those that are in the time domain, such as the relaxation and creep techniques. From those measurements the properties of the specific material of interest is then generated in terms of temperature, frequency, static non-linearity, dynamic non-linearity, and time under load. Those properties are then curve fitted with analytical expressions and stored on the computer as analytical functions along with other information, such as their form of availability, resistance to solvents, outgassing, aging effects, and so on.

The purpose of this paper is to describe the current data base that is now available at Anatrol, and how it can be accessed by users to design various passive control systems. Specific details regarding the measurement techniques, presentation of the data, and the curve fitting analysis can be found in Reference [1].

II. MEASUREMENT TECHNIQUES

Different measurement techniques are needed to evaluate the dynamic properties of materials because such properties vary greatly with the different environments, and currently there is no one technique that is capable of covering such extreme ranges. Another important reason for generating the data by more than one technique is to cover wide temperature and frequency ranges for the measurements to establish confidence in using the temperature-frequency superposition principle. Without having measured the data over such wide temperature and frequency ranges and verified the accuracy of the shift factor, the use of the temperature-frequency superposition principle is likely to be questioned. Anatrol has put forth the extra effort to make the measurements by several techniques and over wide temperature and frequency ranges to establish good confidence in the data base.

The various techniques that have been primarily used to generate the material properties in the data base include, the beam technique, the impedance technique, and the relaxation and creep techniques. Both the beam and impedance techniques are used to measure the dynamic properties of materials in the frequency domain at different temperatures and dynamic loading conditions. The creep and relaxation techniques are used to measure the relaxation modulus and the creep compliance as functions of time under different loading conditions.

II.1 BEAM TECHNIQUE

The beam technique is used to measure the dynamic properties of materials in either shear or tension/compression over wide temperature and frequency ranges, in the linear region of the material in terms of strain amplitude. The frequency range where this technique is typically used is between from about 50 to 5,000 Hz. The technique is based on combining the material of interest to a metal beam and making measurements on the composite system. By knowing the frequencies of the various modes of vibration and their damping values along with the geometry of the beam, the dynamic properties of the material under test can be computed independent of the geometry. Typical properties for a material measured in shear by the beam technique are given in Figure 1.

II.2 IMPEDANCE TECHNIQUE

The impedance technique consists of applying a known force into a sample and measuring the resultant displacement. The force and displacement signals and the phase angle between them are used to compute the dynamic properties of the materials. Loading is typically applied in either tension/compression or shear, depending on the geometry of the sample, to generate either Young's modulus or the shear modulus. The impedance technique can cover frequency ranges from as low as 10^{-5} Hz to 1000 Hz. It is difficult to use the impedance technique at higher frequencies because of fixture resonances. Also, it is difficult to use this technique for may materials when testing in the glassy region because the test specimen can approach the stiffness of the fixture. Even with such limitations however, the material properties can be generated over wide temperature and frequency ranges. Also, by using simple geometry and varying the force, the behavior of the material in terms of loading (static or dynamic) can be measured.

Figure 2 represents the results measured by the impedance technique in shear over a wide frequency range and at some selected temperatures.

II.3 RELAXATION AND CREEP TECHNIQUES

The relaxation and creep techniques are used to determine the response of the materials under load as a function of time. With the relaxation technique, a fixed displacement is applied to the sample and the resultant force is measured as a function of time. From such a measurement the relaxation modulus as a function of time can be computed. On the other hand, the creep technique is based upon applying a fixed force to the sample and measuring the resultant displacement as a function of time, which will yield the creep compliance as a function of time. The relaxation technique is usually used for soft materials while the creep technique is used for stiff materials. Tension/compression or shear specimens could be used with either technique.

Not only the behavior of the material under load as a function of time can be determined from such measurements, but the results can also be used to compute the dynamic properties of the material at extremely low frequency, by transforming the measured data from the time domain into the frequency domain.

Figure 3 represents typical results for the relaxation modulus measured at different temperatures with time.

II.4 CORRELATION OF THE PROPERTIES

Figure 4 combines the results of Figure 1 and 2 together. It can be seen here that good correlation has been achieved between the two techniques even though those measured by the impedance technique are for low frequencies, while those for the beam technique are for high frequency. This kind of correlation gives confidence in the shift factor used to collapse all the data. Figure 4 is curve fitted with analytical expressions which are then stored on the computer for later use.

The correlation of the measured results by the impedance, beam, and relaxation techniques is shown in Figure 5 for several samples. The agreement between the various techniques illustrates that each technique is being well used within its limitation and no erroneous data is generated.

III. DESCRIPTION OF THE DATA BASE

III.1 MEASUREMENT CONDITIONS

All materials in the data base are measured either in tension/compression to generate the properties in extension (Young's modulus and loss factor) and/or in shear to generate the properties in shear (shear modulus and loss factor). If the properties are measured in both states of stress, then Poisson's ratio can be computed. If the properties are measured in one state of stress only, and the material has a rubber-like behavior, then Poisson's ratio can be assumed to be almost 0.5 and the properties in the other state of stress can be computed. Figure 6 represents the properties for the material of Figure 4 but for both states of stress.

All materials in the database are measured over wide temperature and frequency ranges to enable curve fitting of the data with analytical expressions as shown in Figure 4. Such analytical expressions are then stored on the computer for later analysis or literature search as necessary. In the following Figures, the analytical expressions are used to describe the material properties in terms of temperature for some discrete frequencies. Other frequencies could be generated from the stored curve fitted data as necessary.

In addition to the above conditions, many of the materials in the data base are also measured in terms of static non-linearity, dynamic non-linearity, aging, exposure to high temperatures, and exposure to fuel and oil, and others. Figures 7 through 10 represents the effects of such environments on the measured properties.

III.2 TYPES OF MATERIALS

Although it is difficult to classify all the materials in the data base, some classifications could be used as follows.

ELASTOMERS

This heading includes all materials with rubber-like behavior at room temperature. Specifically, such materials include the silicones, natural rubbers, vitons, butyls, nitriles, ABS, and so on. Figure 11 through 14 illustrate the properties of some of the materials in this category. Such materials are used in various isolation systems, tuned dampers, and some constrained and unconstrained layer damping treatments.

PRESSURE SENSITIVE ADHESIVES

Pressure sensitive adhesives are widely used as the damping materials in constrained layer damping treatments. Such materials could be of the acrylic, silicone or rubber base type. Figure 15 and 16 give the properties of some of these materials.

PLASTICS

Many plastics are used as structural materials and as damping materials at high temperatures. Those materials could include the various vinyls, styrenes, PMMA, PEEK, PVC, polypropylenes, polysulphones, nylons, and so on. Figure 17 and 18 contain the properties of some of the plastics from the data base.

FOAMS

Foams can be made from several materials such as acrylics, polyurethanes, silicones, etc. and therefore, can have varying properties, as shown in Figures 19 and 20.

SPRAYABLE MATERIALS

Materials in this category include those that could be sprayed on the structure, for ease of application. The use of such materials is to provide extensional damping over wide frequency ranges. Figures 21 and 22 illustrate the dynamic properties of only two of the materials.

AUTOMOTIVE BODY PANEL MATERIALS

The materials under this heading, which are called "Mastics", are usually applied to automotive body panels to provide damping. The materials can be either of the heat bondable type or the type that requires a pressure sensitive adhesive for application. These materials have good damping properties around room temperature as shown in Figures 23 and 24.

DAMPED LAMINATES

Laminates are now being used in various sheet metal applications in the automotive, aircraft, and appliance industries to provide high damping. Because such materials are sold in the laminate form (two layers of metal sandwiching a very thin layer of damping material), the properties are given in Figure 25, in terms of the composite properties for the indicated configuration.

PRESSURE SENSITIVE FOAM TAPES

Pressure sensitive foam tapes have been used as damping materials in constrained layer surface damping treatments and in damping link configurations. These materials are generally acrylic, rubber, or urethane based, and are generally available in thicknesses on the order of 1mm thick. Figures 26 and 27 give sample properties of several of these materials.

COMMERCIAL FOIL BACK TAPES

These products are often utilized as off-the-shelf constrained layer damping systems. They combine acrylic or rubber based pressure sensitive adhesives, with an aluminum constraining layer. These products are commonly utilized by the aircraft industry in fuselage skin damping applications. Figure 28 describes the damping performance of several foil back tape systems.

POLYMERIC STIFFENERS

These products are designed to provide reinforcement to automotive body panels. They generally consist of a thermosetting, resin impregnated, glass fiber reinforced sheet stock, which is cured after application. Figures 29 and 30 show sample properties.

AIRCRAFT FUEL TANK SEALANTS

These materials generally consist of two parts, room temperature curing polysulphide, and elastomers. They are resistant to jet aviation fuels, hydraulic oils, salt water, and to some dilute acids. Figure 31 demonstrates properties for one of those materials.

ENAMELS

Enamels are used not only as protective and decorative coatings, but also as damping materials at high temperatures. This is because such materials exhibit good damping capabilities within their softening region before the meltdown. Enamels are typically used in a free-layer damping treatment and therefore the dynamic properties are usually measured in tension/compression and over wide temperatures and frequencies. Different materials have been identified to cover ranges up to 2000°F, and Figures 32 and 33 represent the properties of two such materials.

STRUCTURAL ADHESIVES (EPOXIES)

The dynamic properties of epoxies and/or structural adhesives have been evaluated for better understanding of their use. As a result of this evaluation a number of structural adhesives have been found to have good damping properties in addition to their high modulus, as can be seen in Figures 34 and 35.

III.6 COMPOSITES

The data base includes both metal matrix composites and resin reinforced composites. Those composites are usually measured assuming they are homogeneous materials, and such properties are shown in Figures 33 and 37.

IV. ACCESS OF THE DATA BASE

The data base at Anatrol can be accessed in two ways. The first is for Anatrol to perform a literature search for the customer on a job-by-job basis. This search will be based on the customer specifying to Anatrol, the material properties of interest, and the environmental factors to be considered in the search. The second is for Anatrol to install parts, or all of the data base on the customer's computer. For either case, Anatrol will discuss the specific requirements and scope of this service with the customer and quote it accordingly.

REFERENCE

1. A.D. Nashif, D.I.G. Jones and J.P. Henderson, Vibration Damping, Wiley Interscience, 1985.

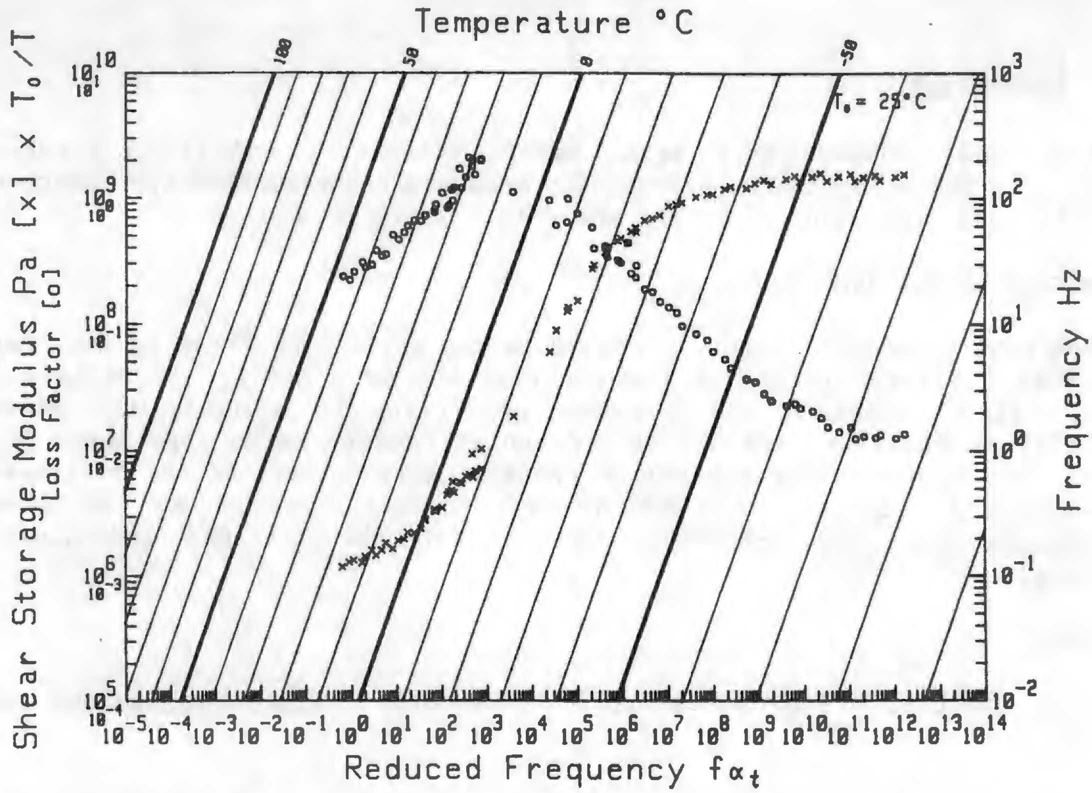

Figure 1: **Reduced Frequency Nomogram for a Typical Material in Shear Using the Vibrating Beam Technique [Library #580 - Vinyl Rubber]**

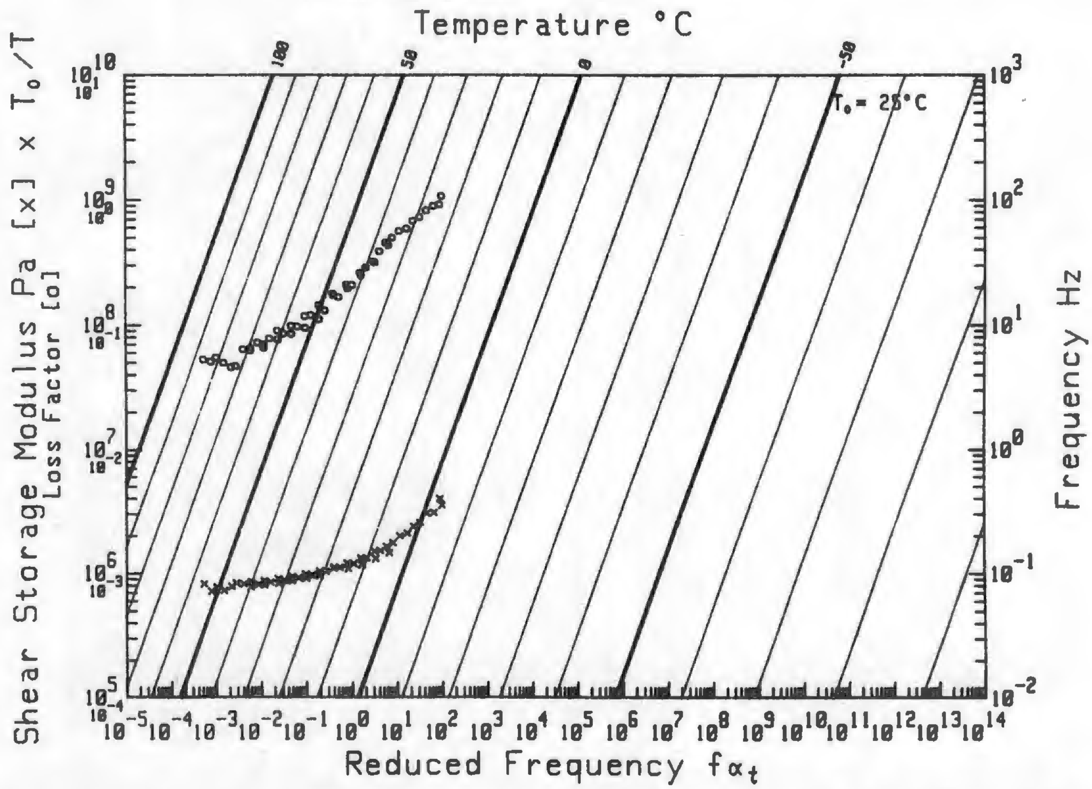

Figure 2: **Reduced Frequency Nomogram for a Typical Material in Shear Using the Impedance Technique [Library #580 - Vinyl Rubber]**

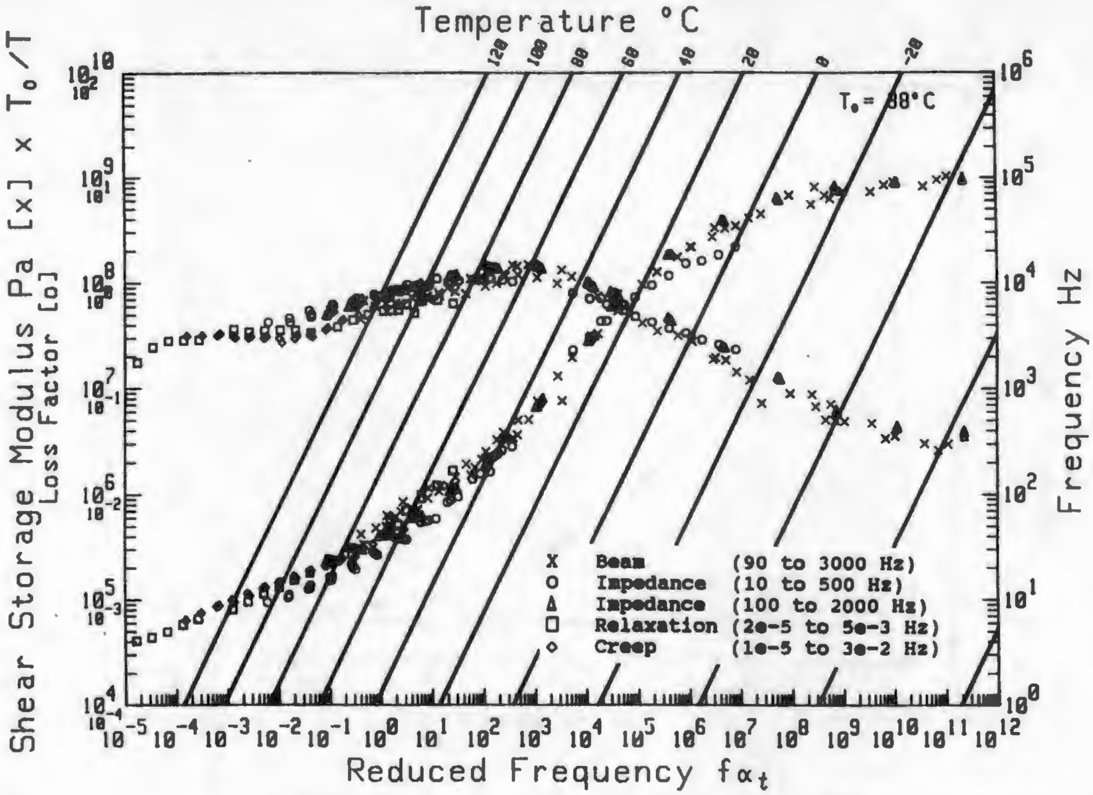

Figure 5: **Reduced Frequency Nomogram for a Typical Material Using Various Measurement Techniques**

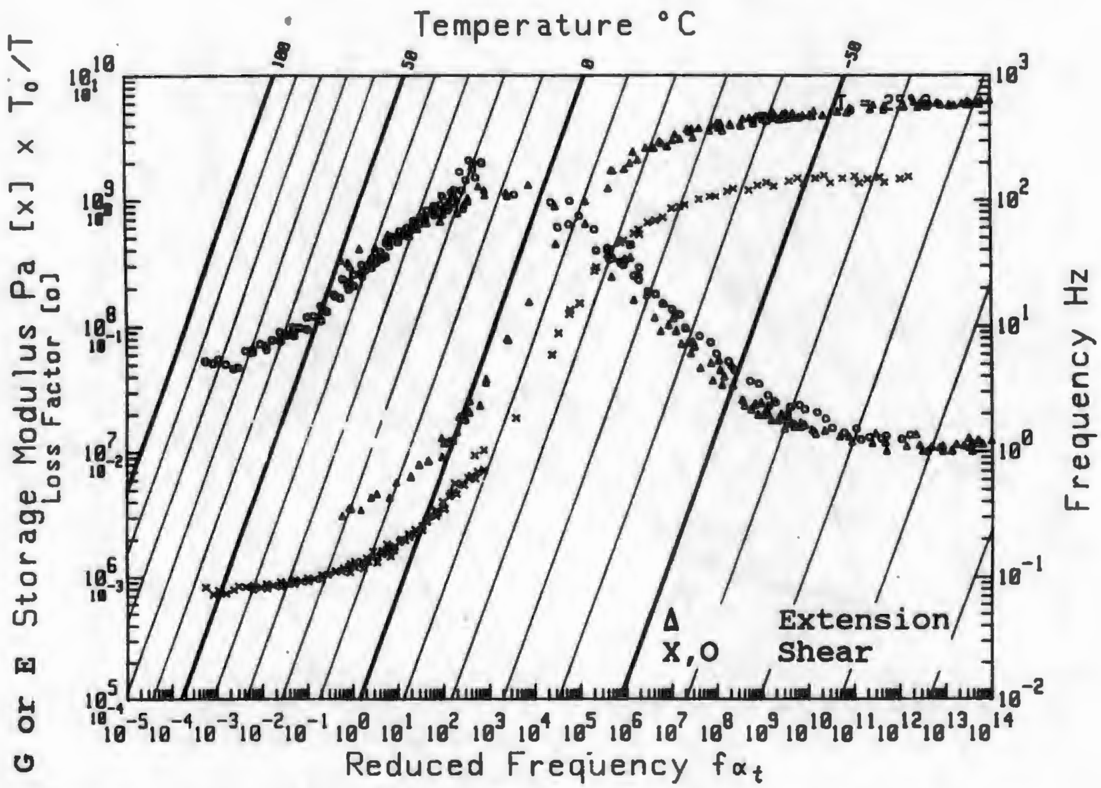

Figure 6: **Material Properties for Shear and Extension Using the Vibrating Beam and Impedance Techniques [Library #580 - Vinyl Rubber]**

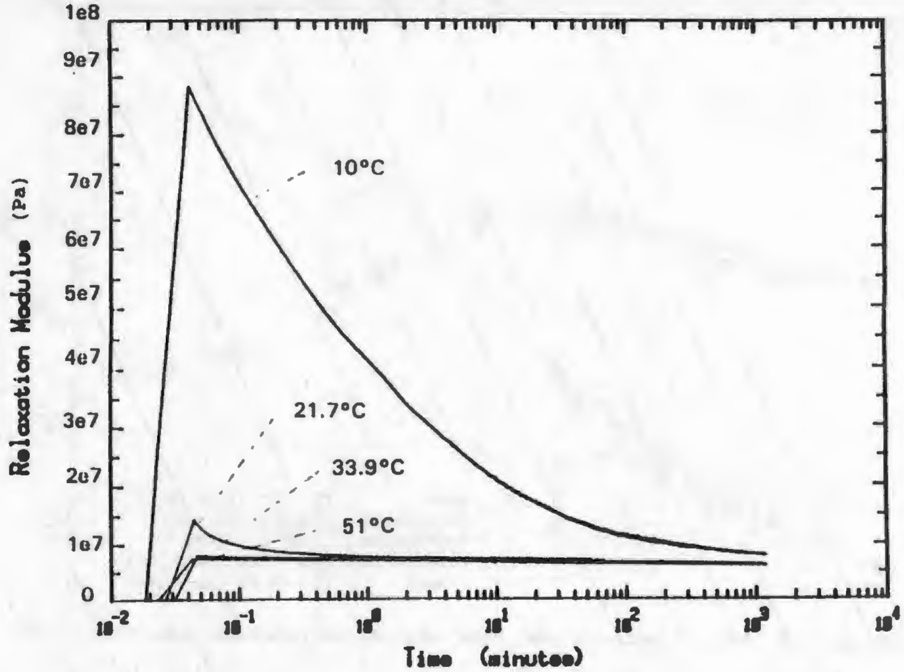

Figure 3: **Relaxation Modulus Properties for a Typical Material at Various Temperatures over Time**

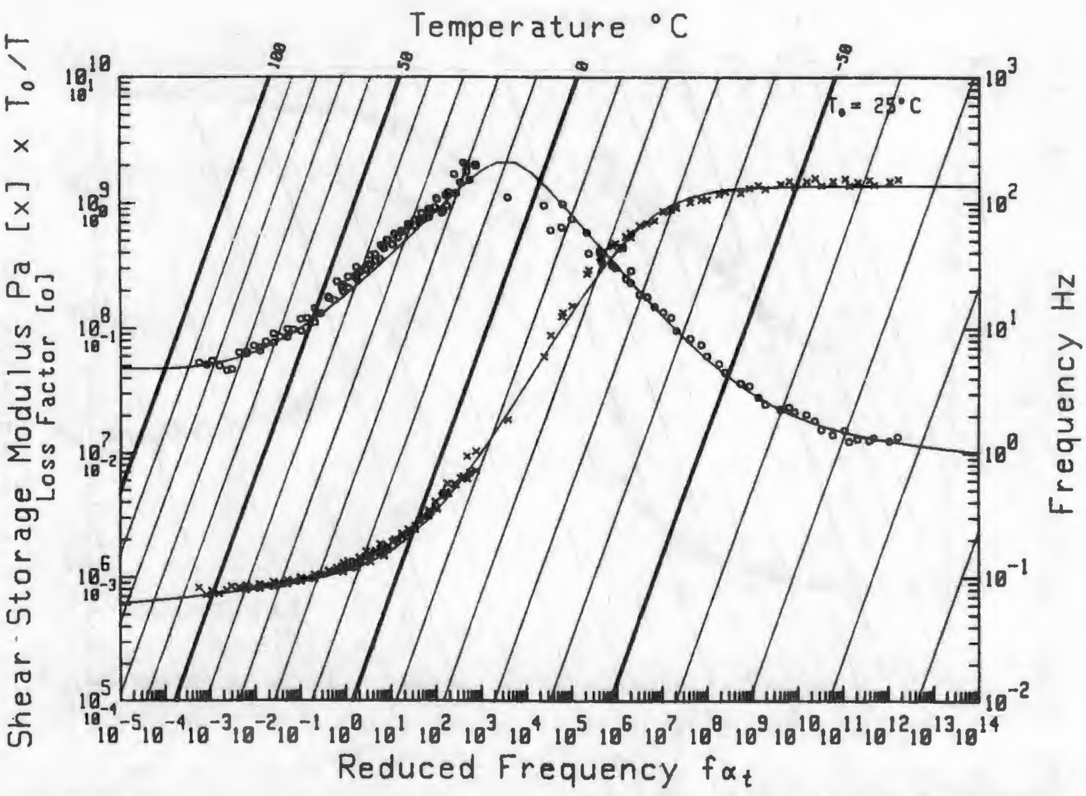

Figure 4: **Reduced Frequency Nomogram for Both the Vibrating Beam and Impedance Techniques in Shear [Library #580 - Vinyl Rubber]**

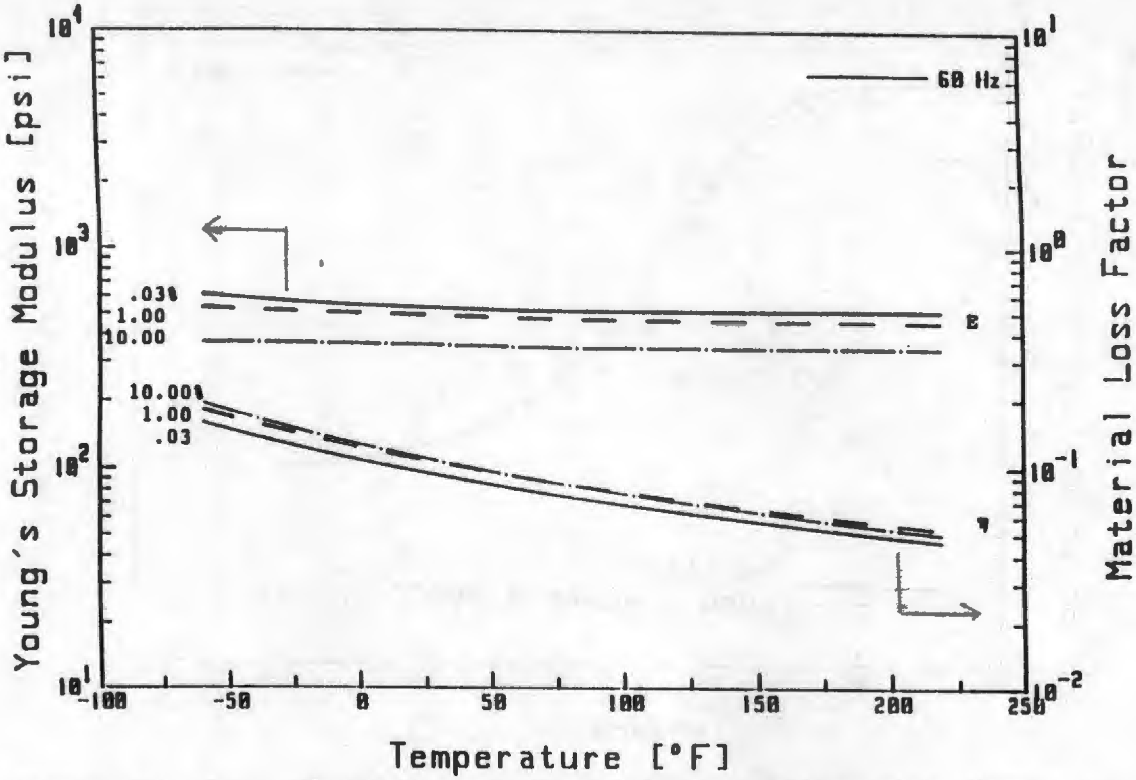

Figure 7: **Variation of Material Properties with Strain Amplitude and Temperature for 60 Hz [Library #380 - Silicone]**

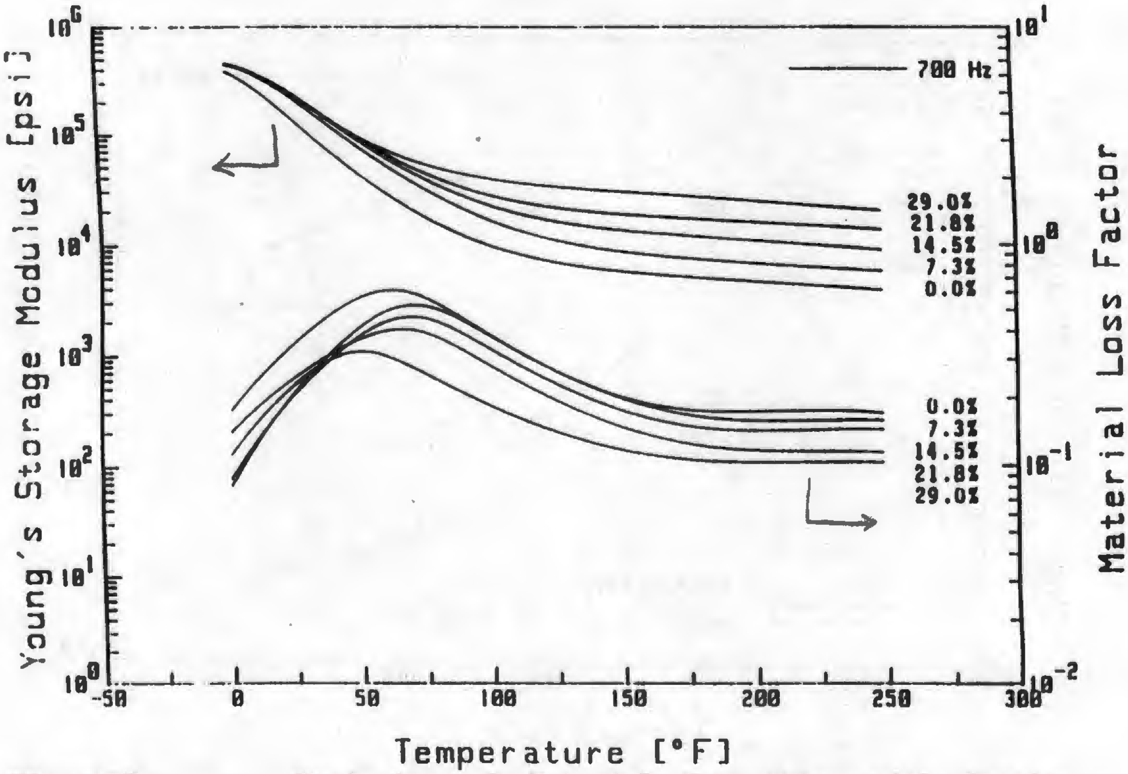

Figure 8: **Variation of Material Properties with Static Preload and Temperature for 700 Hz [Library #241 - Rubber Compound]**

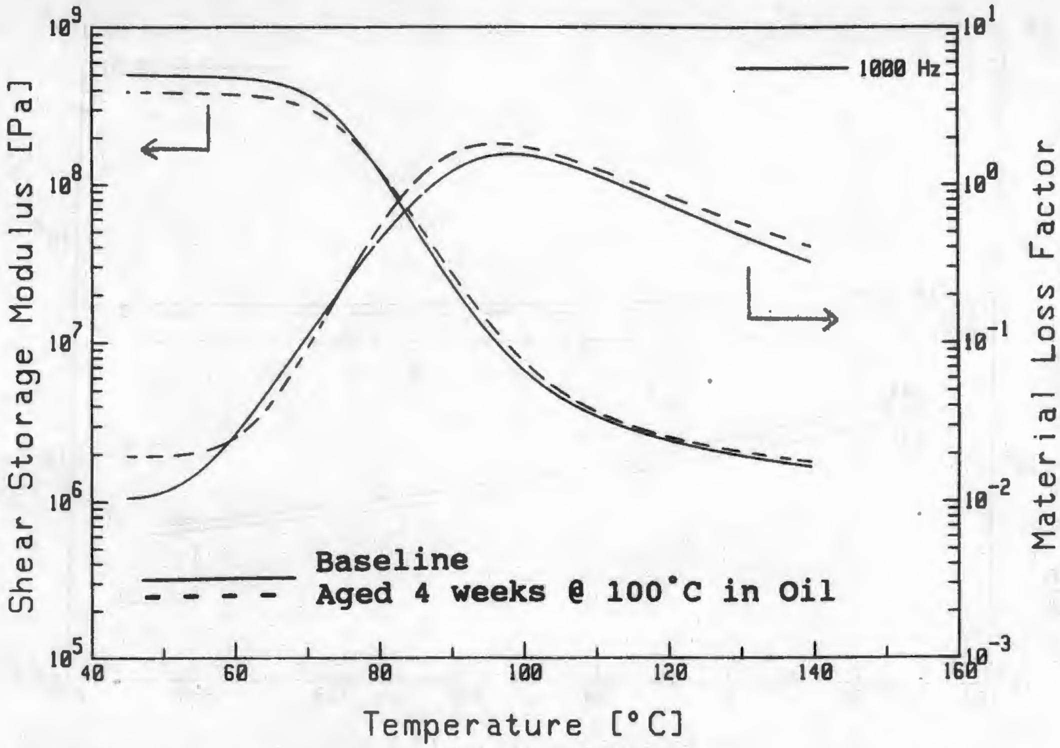

Figure 9: **Effect of Heat Aging and Oil Exposure on the Properties of a Typical Material for 1000 Hz**

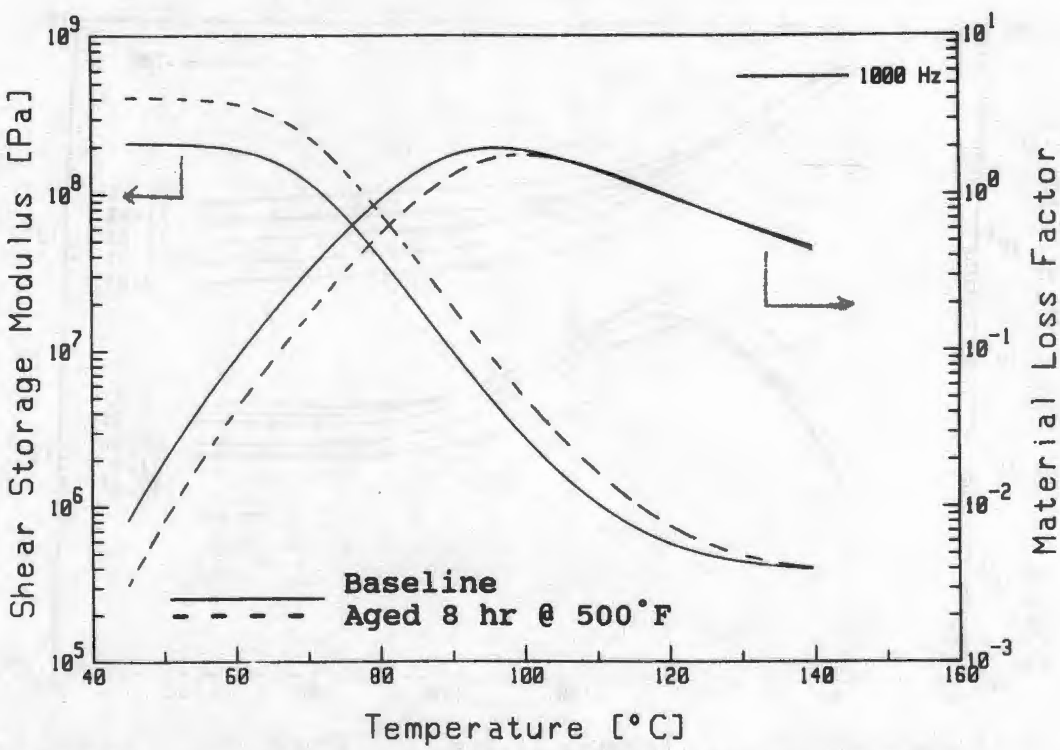

Figure 10: **Effect of Heat Aging on the Properties of a Typical Material for 1000 Hz**

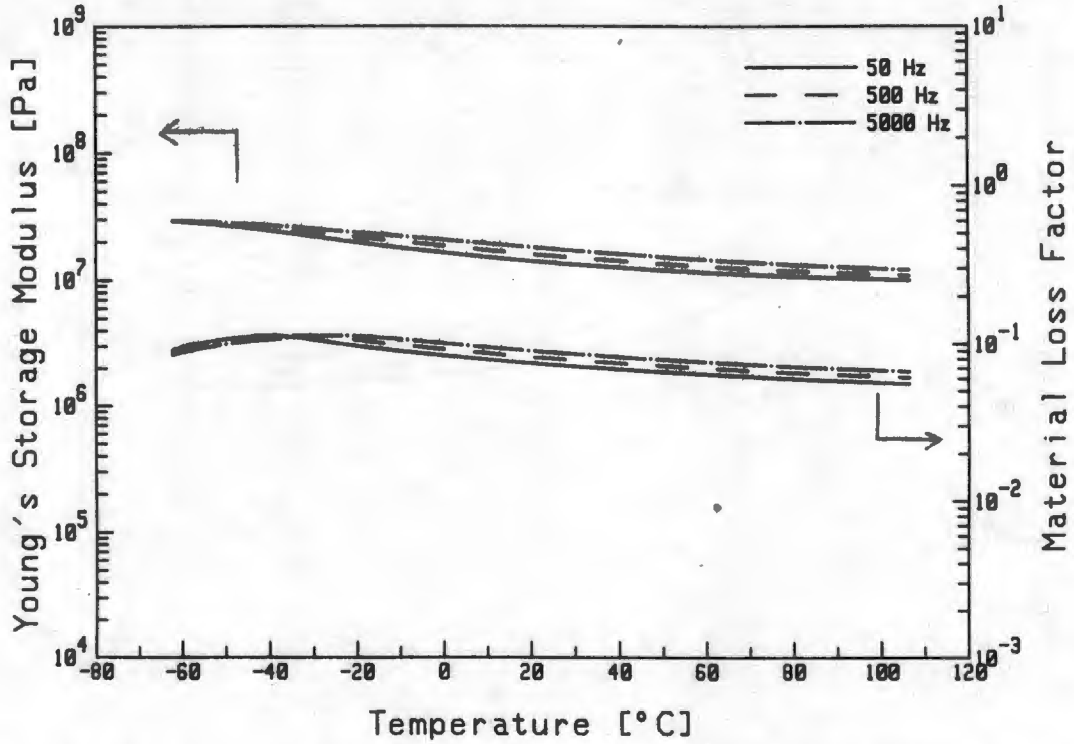

Figure 11: **Variation of Material Properties with Temperature for Various Constant Frequencies [Library #743 - Silicone Elastomer]**

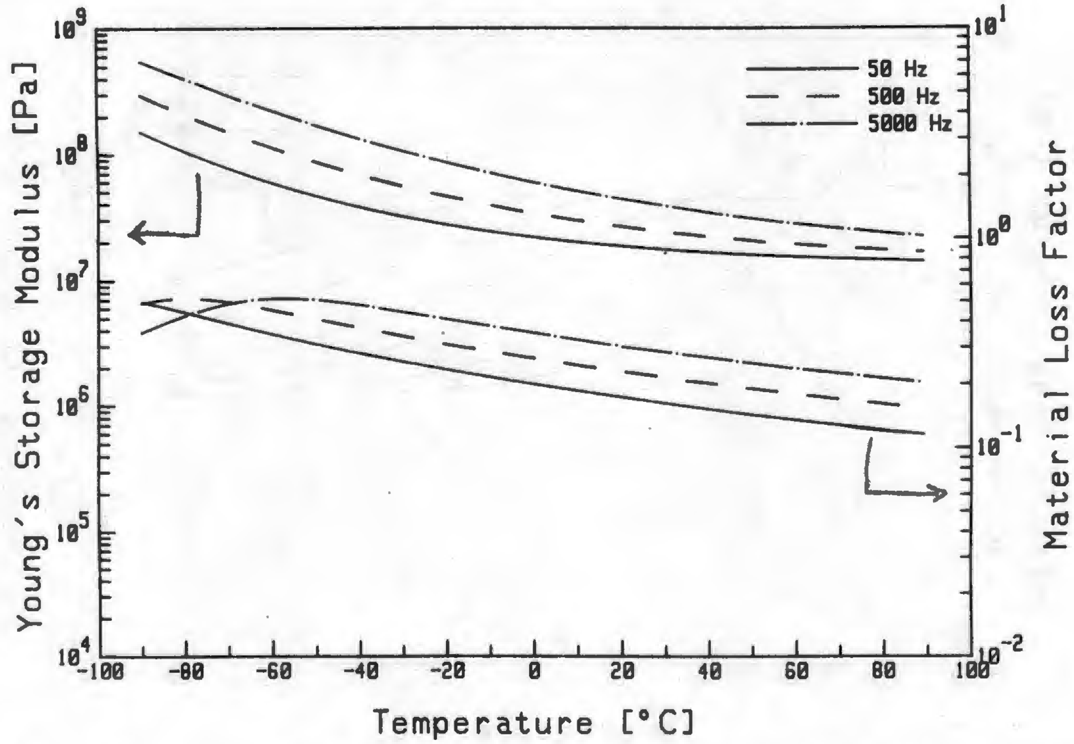

Figure 12: **Variation of Material Properties with Temperature for Various Constant Frequencies [Library #351 - EPDM Elastomer]**

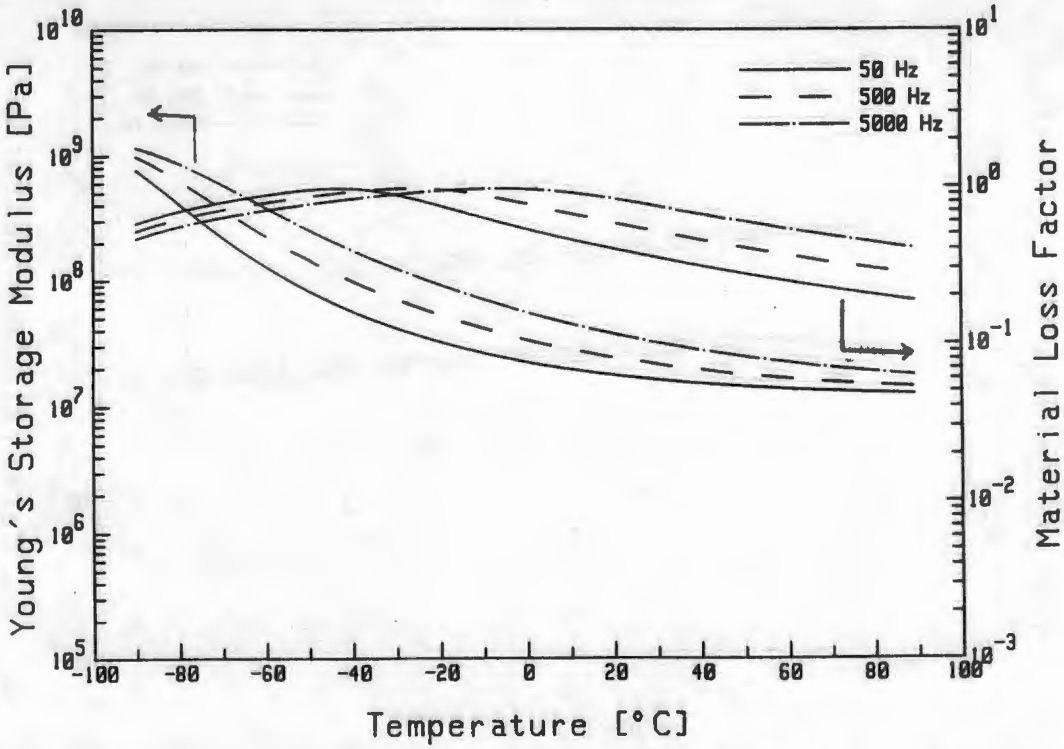

Figure 13: **Variation of Material Properties with Temperature for Various Constant Frequencies [Library #496 - Butyl Elastomer]**

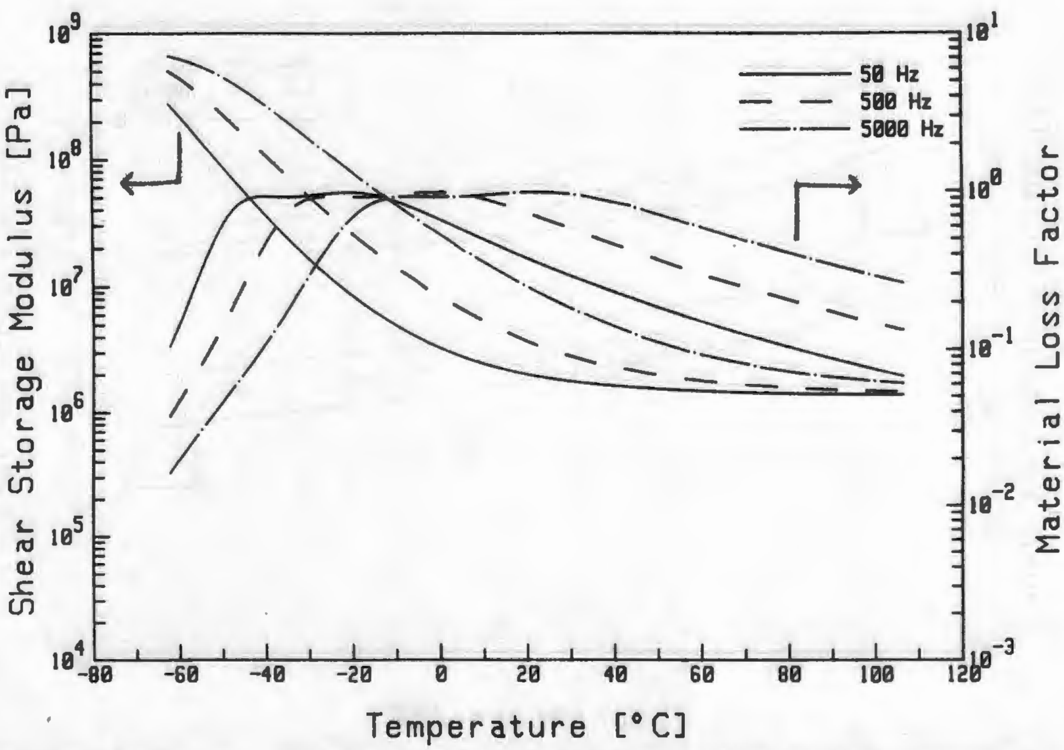

Figure 14: **Variation of Material Properties with Temperature for Various Constant Frequencies [Library #519 - Polyphosphazene Elastomer]**

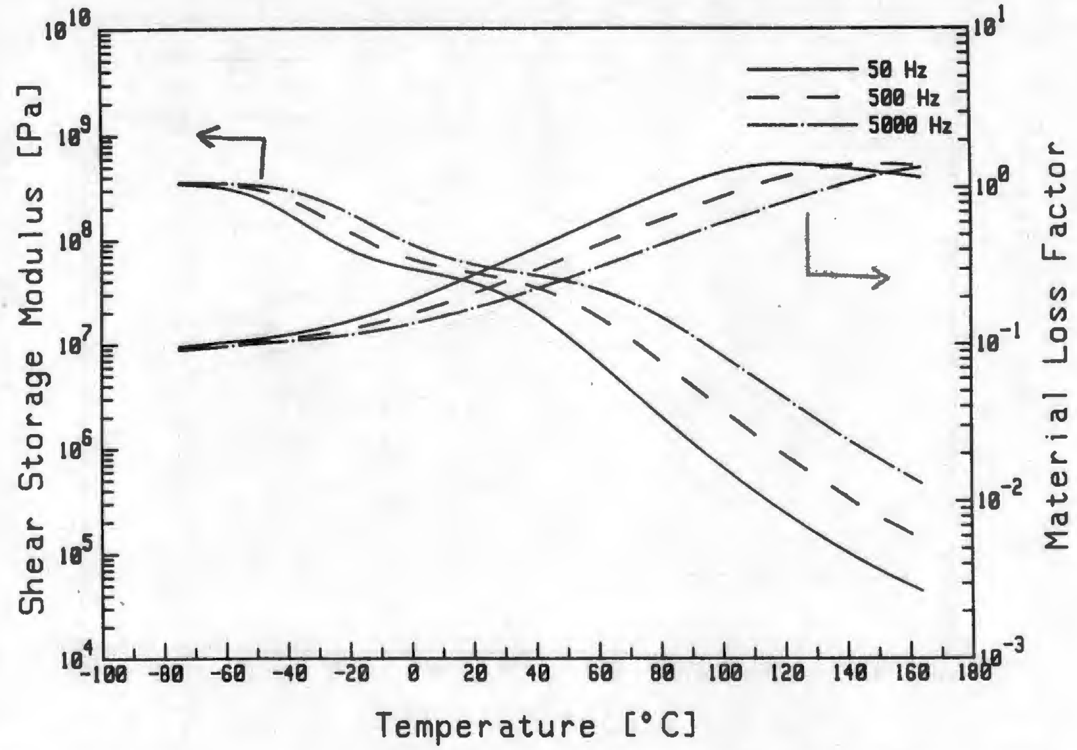

Figure 15: **Variation of Material Properties with Temperature for Various Constant Frequencies [Library #766 - Silicone Pressure Sensitive Adh.]**

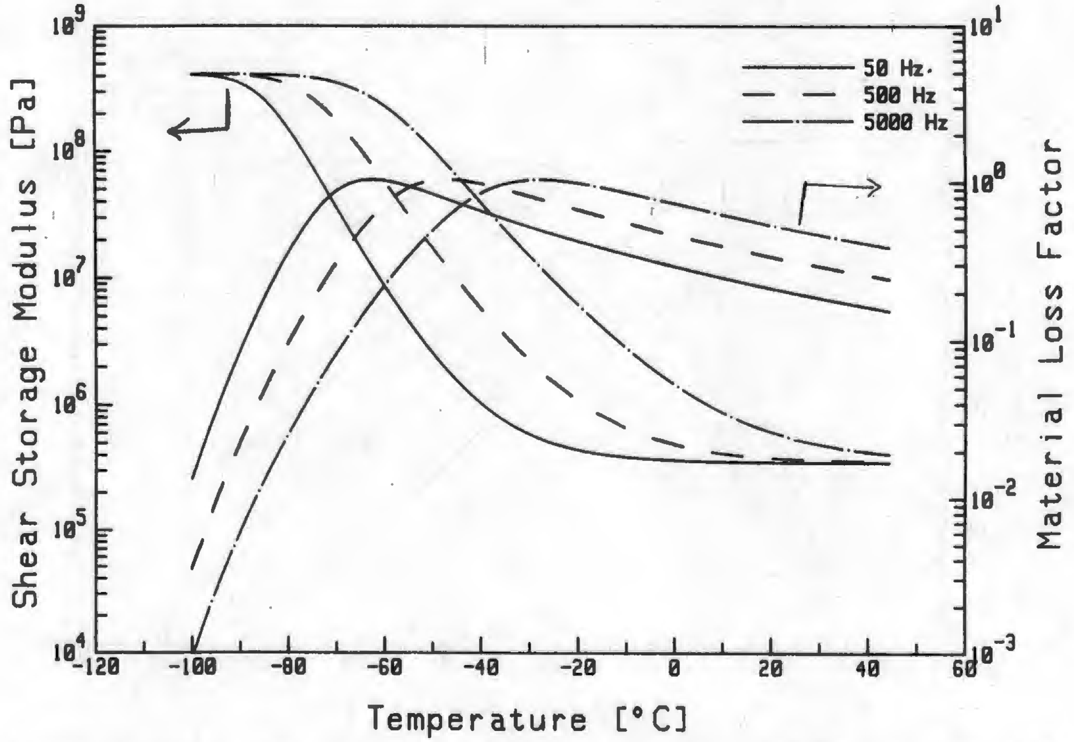

Figure 16: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #14 - Rubber Base PSA]**

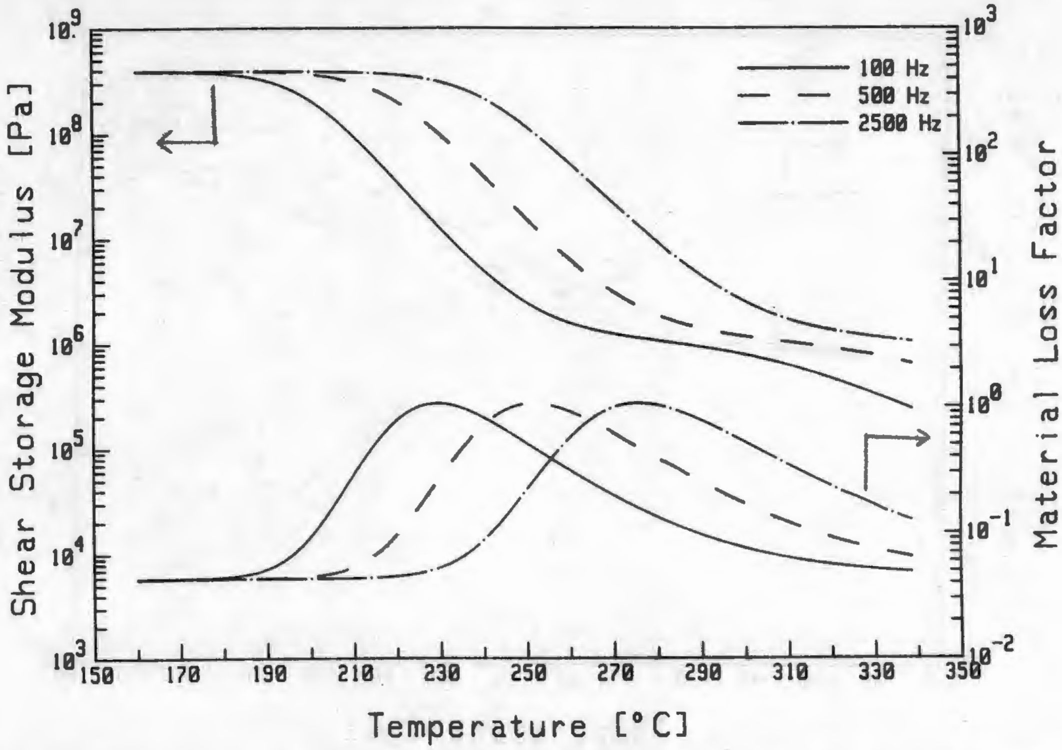

Figure 17: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #380 - Polyetherimide Plastic]**

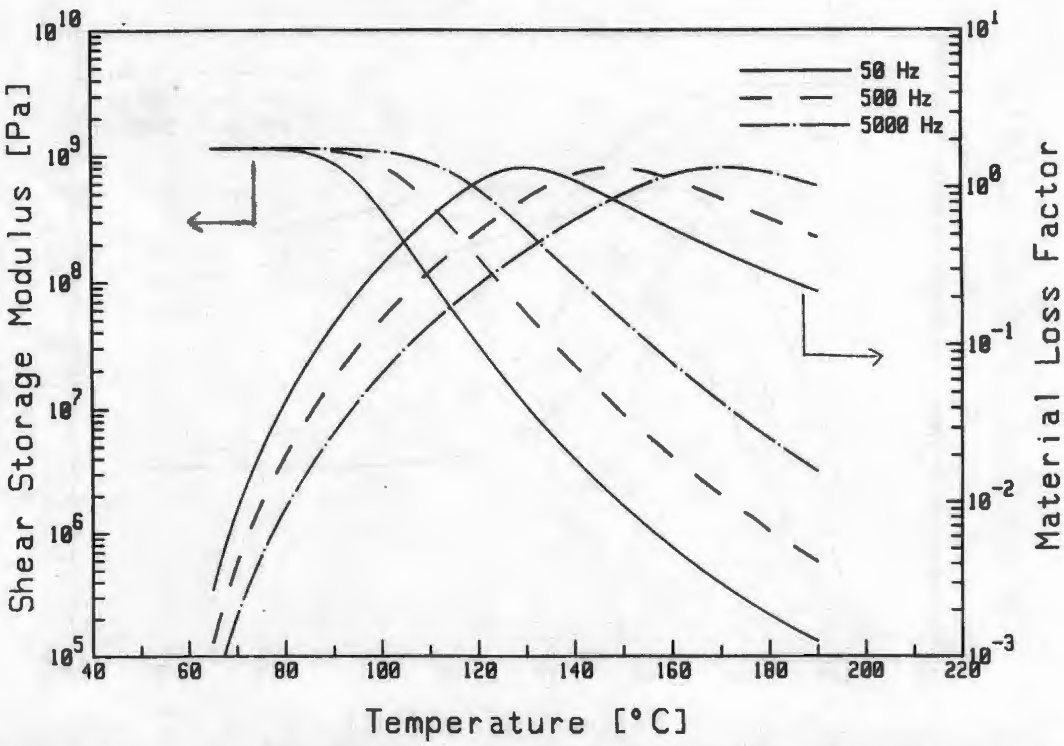

Figure 18: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #181 - Plexiglass Plastic]**

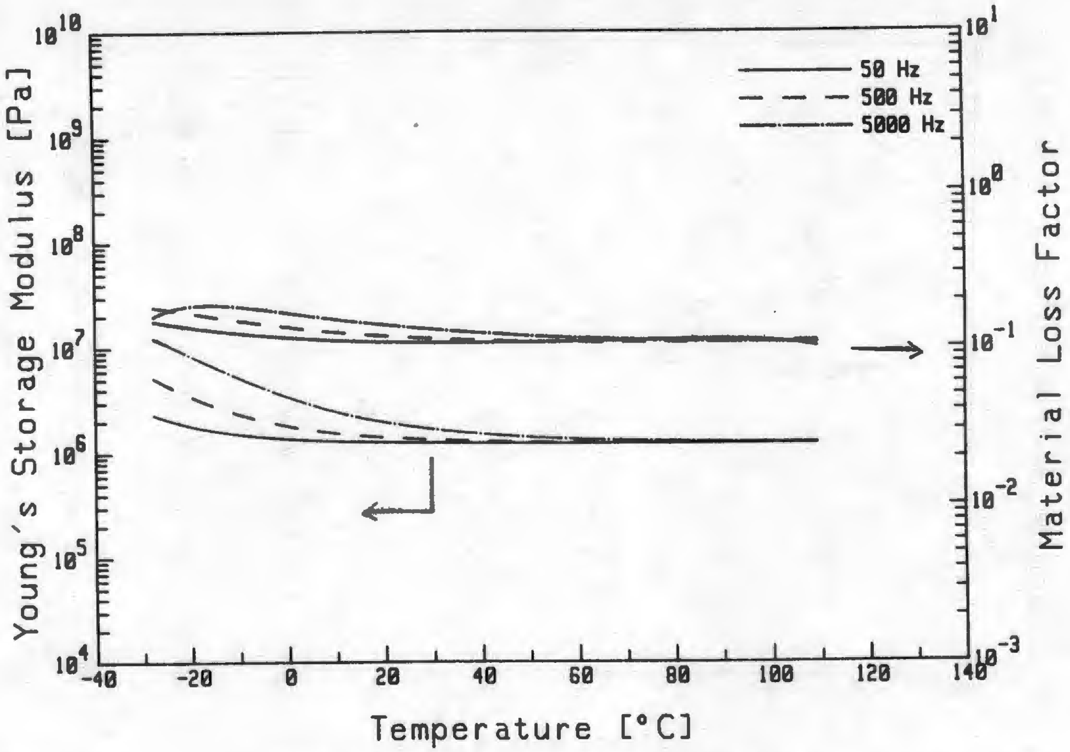

Figure 19: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #717 - Foam]**

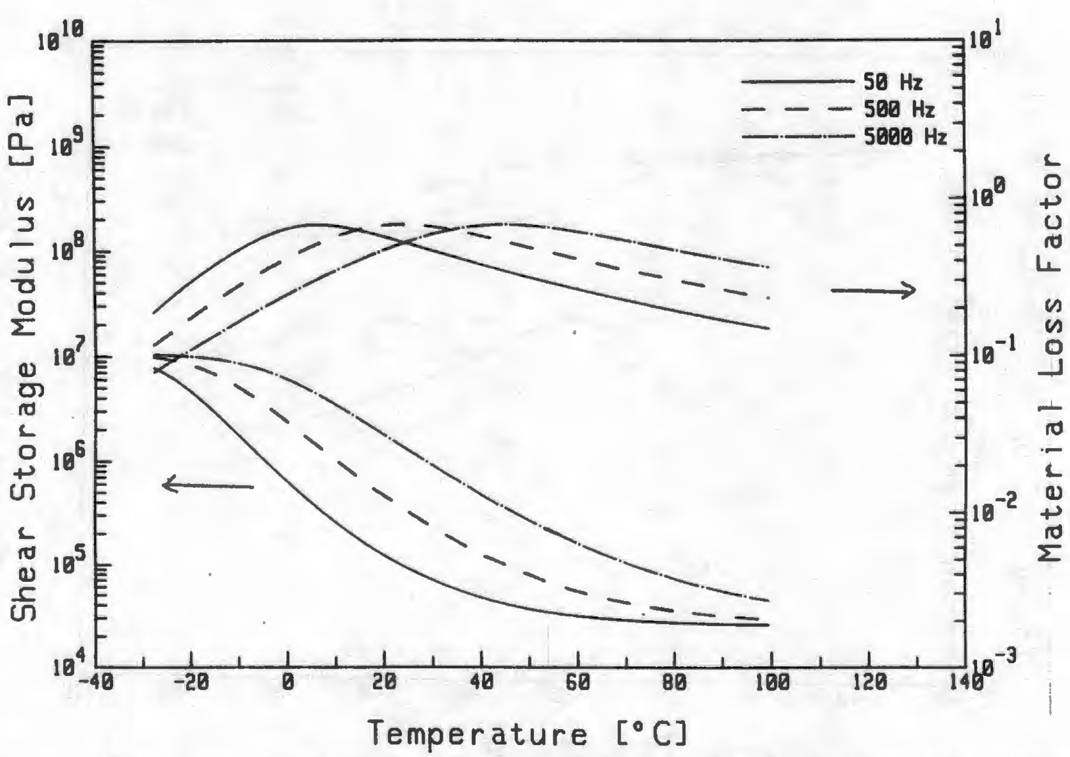

Figure 20: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #674 - Foam]**

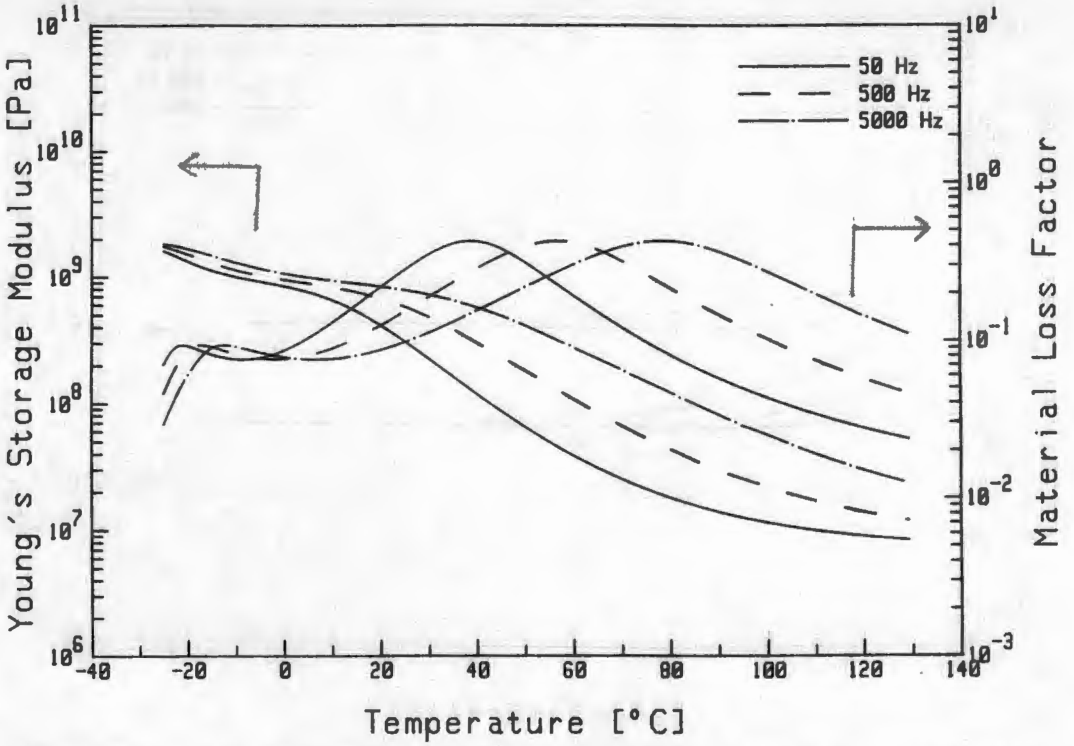

Figure 21: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #543 - Sprayable Free Layer Damping System]**

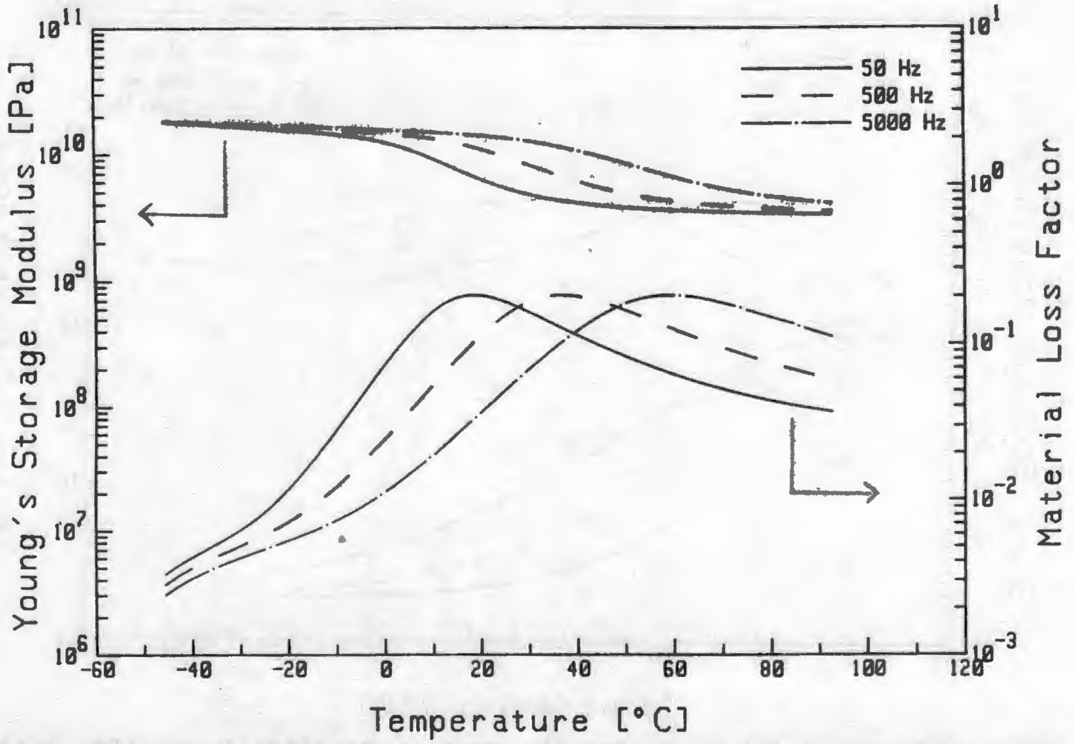

Figure 22: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #630 - Sprayable Free Layer Damping System]**

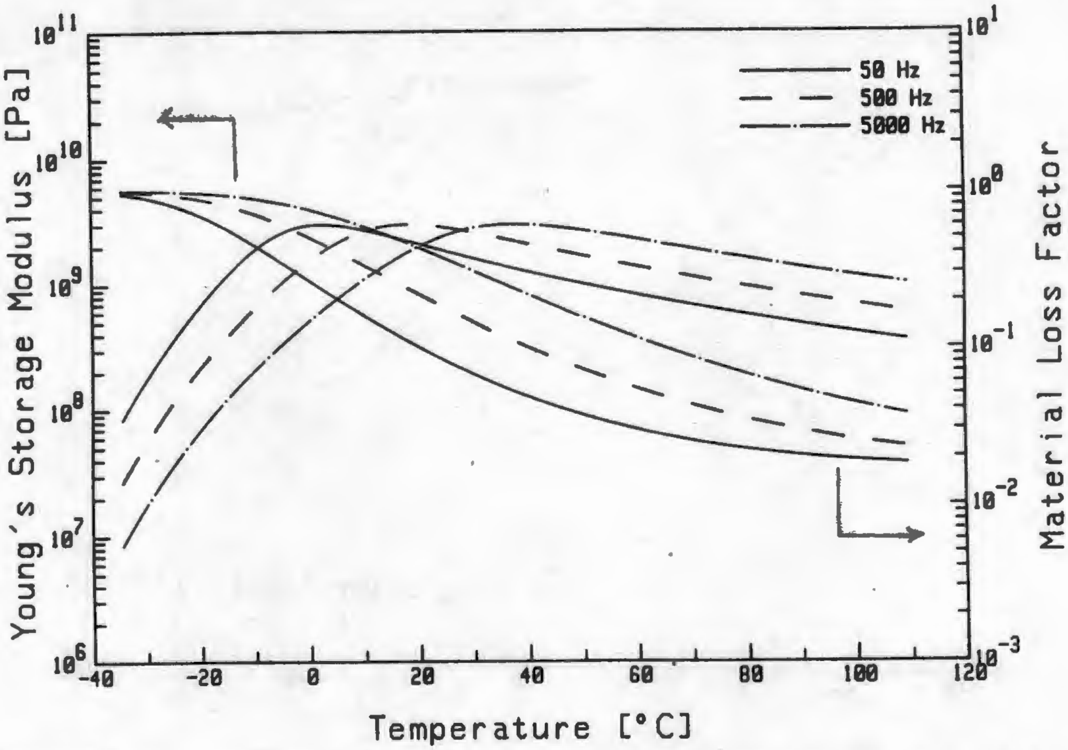

Figure 23: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #279 - Commercial Add-On Surface Treatment]**

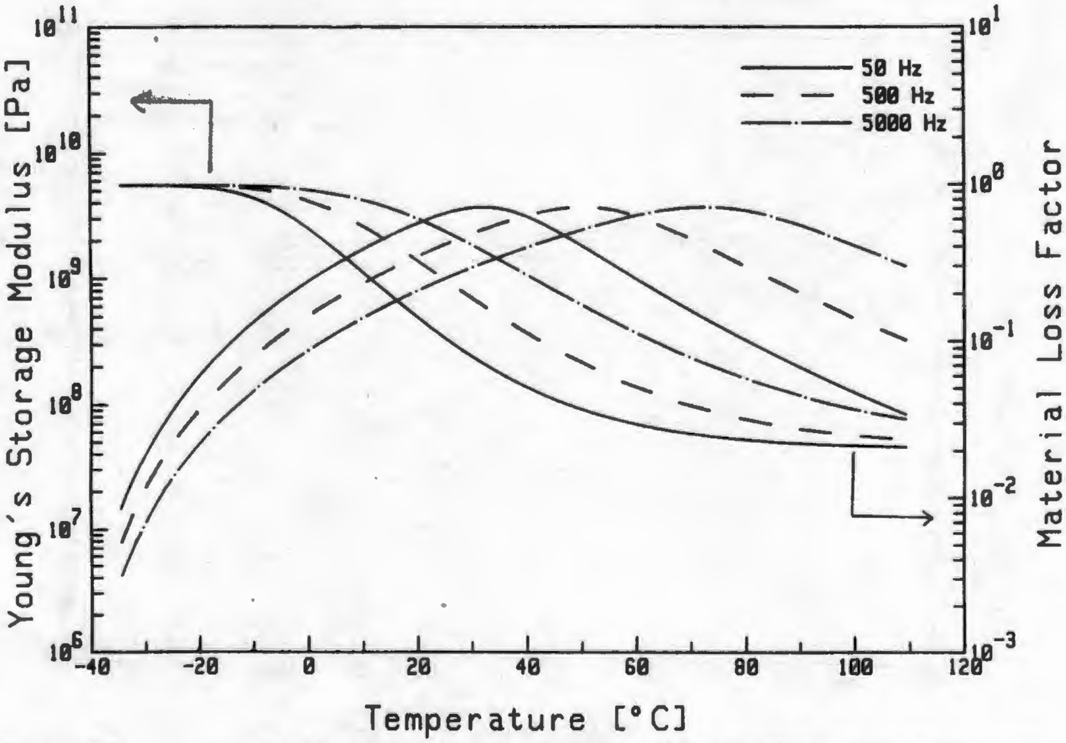

Figure 24: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #278 - Commercial Add-On Surface Treatment]**

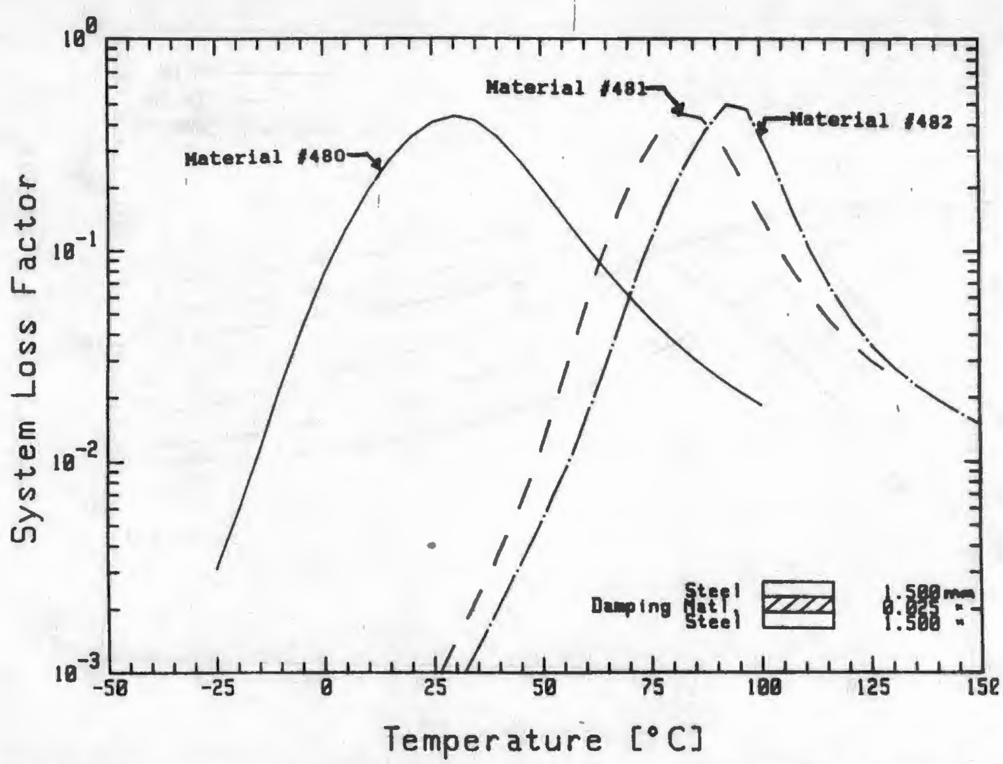

Figure 25: **Loss Factor Properties of Various Laminates at 1000 Hz [Library #480, #481, #482]**

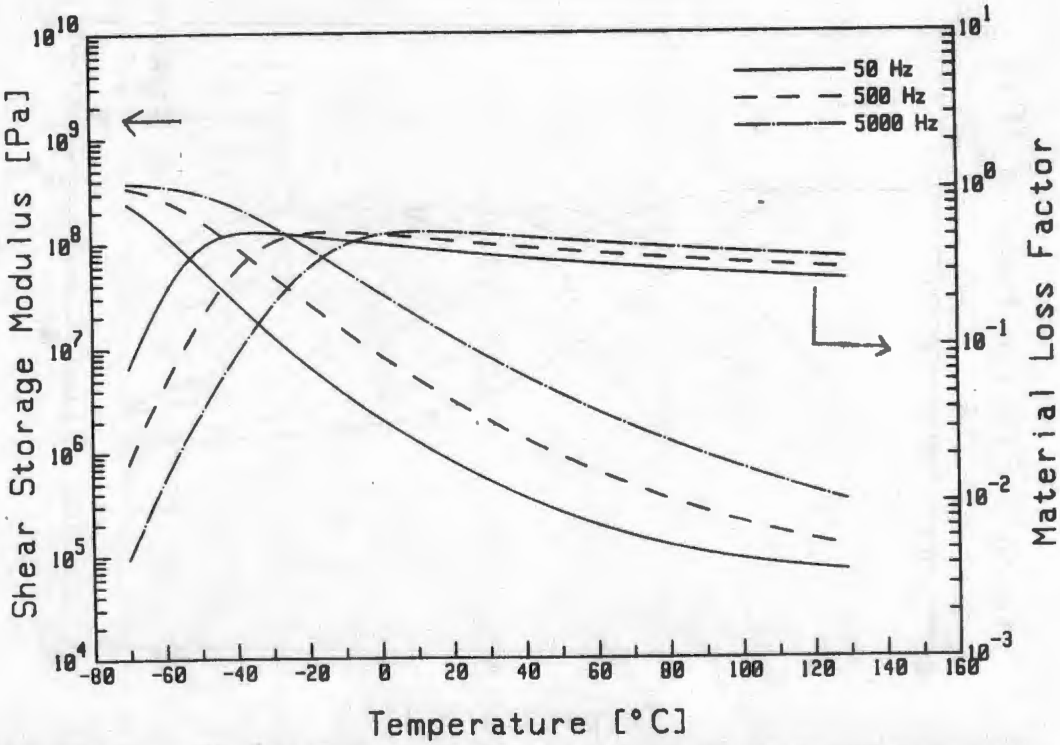

Figure 26: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #57 - Pressure Sensitive Foam Tape]**

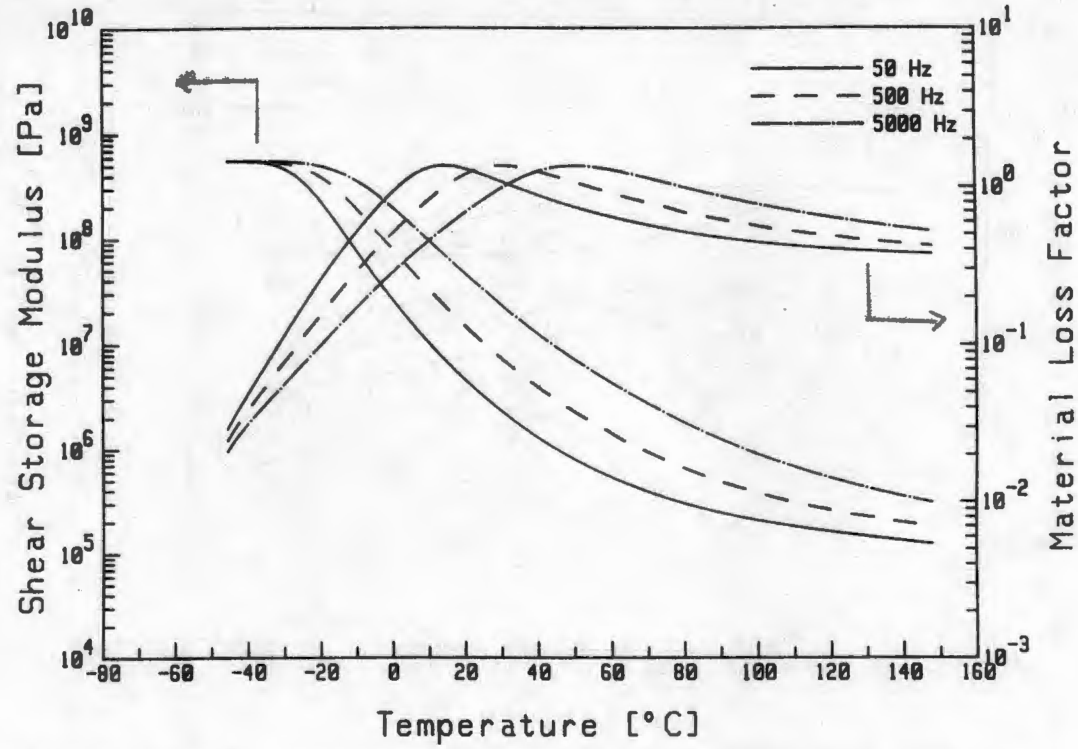

Figure 27: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #242 - Pressure Sensitive Foam Tape]**

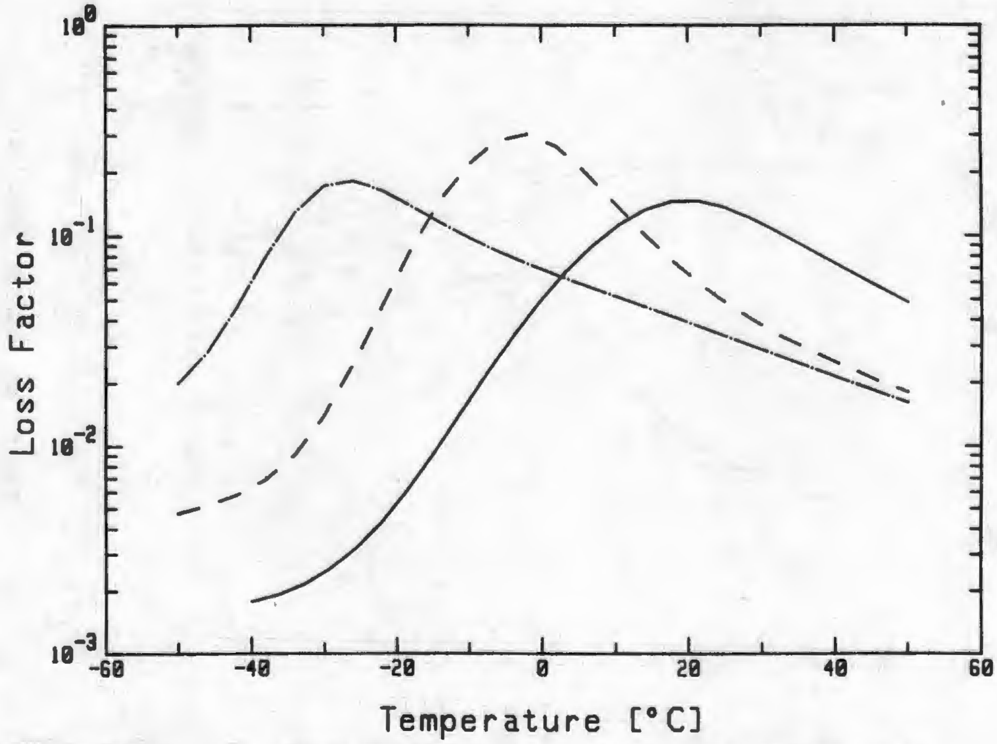

Figure 28: **Damping Properties of Typical Commercial Foil Back Treatments**

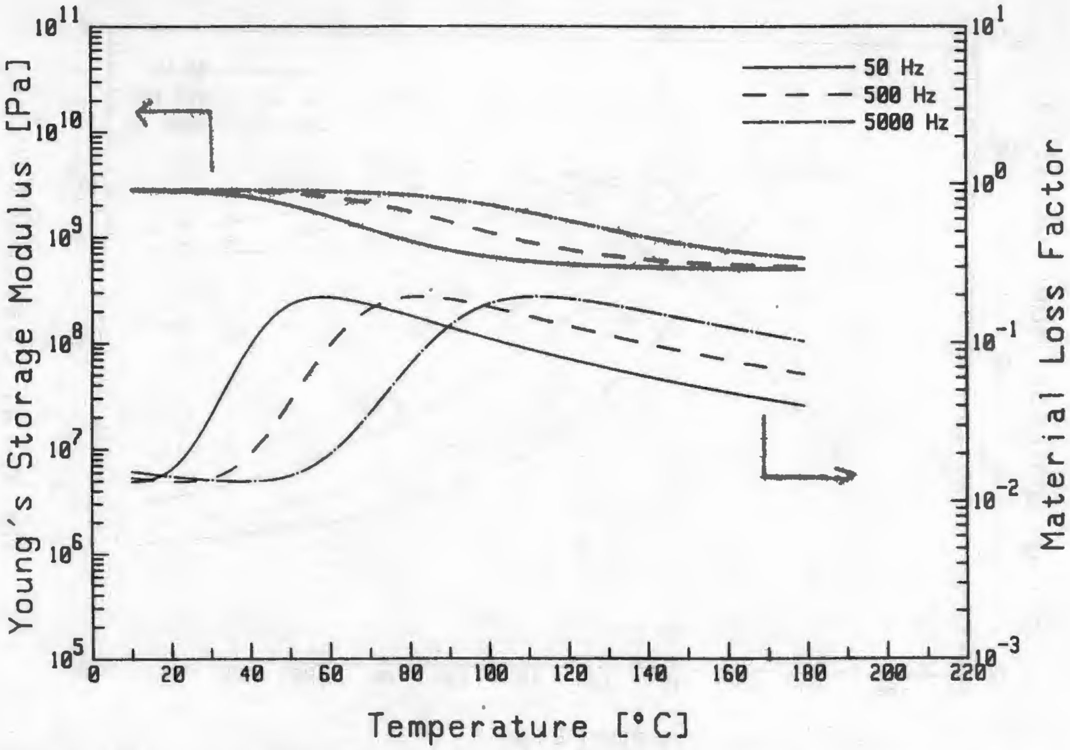

Figure 29: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #749 - Polymeric Reinforcement System]**

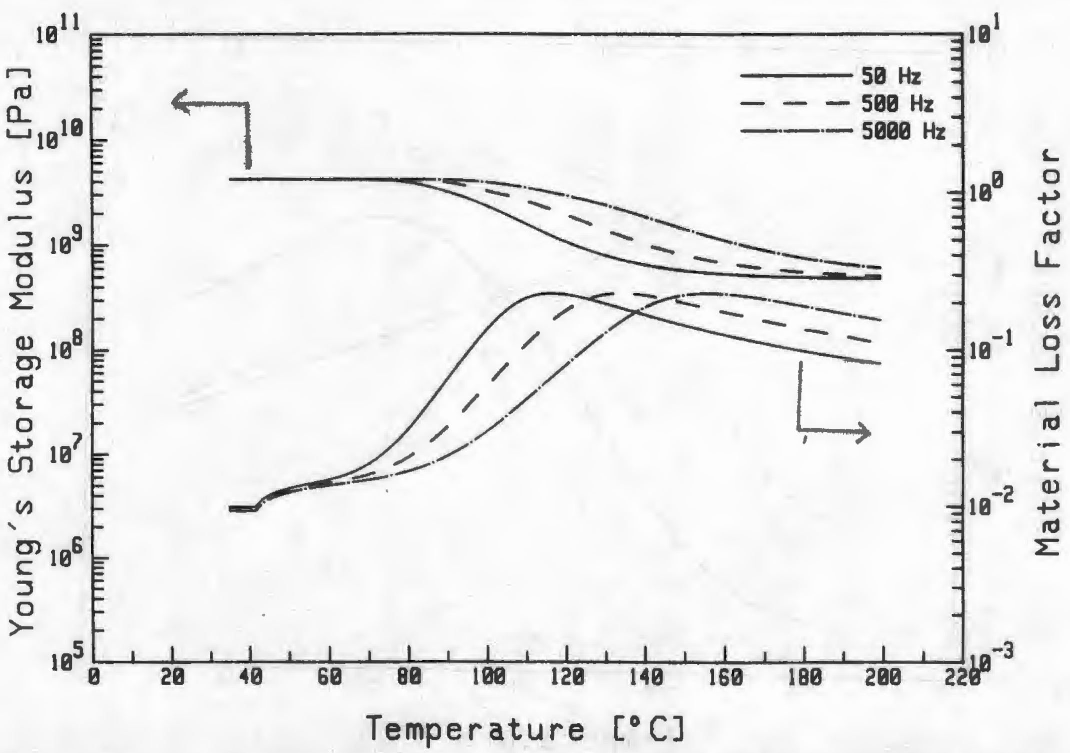

Figure 30: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #616 - Polymeric Reinforcement System]**

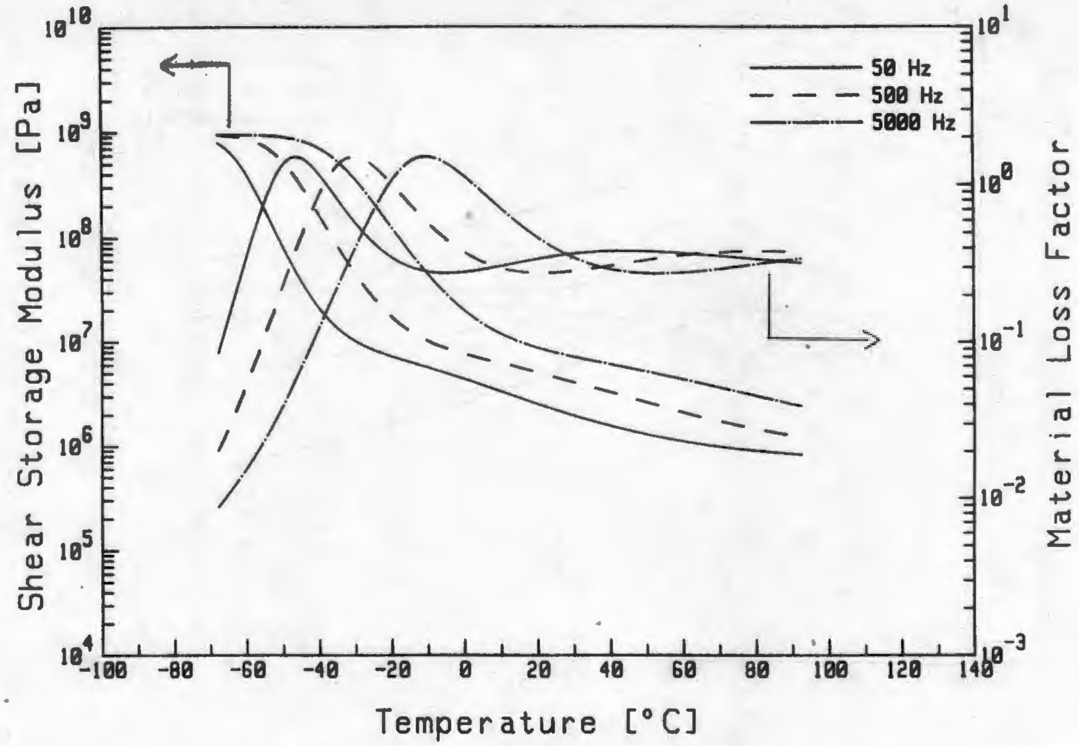

Figure 31: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #513 - Polysulfide Sealant]**

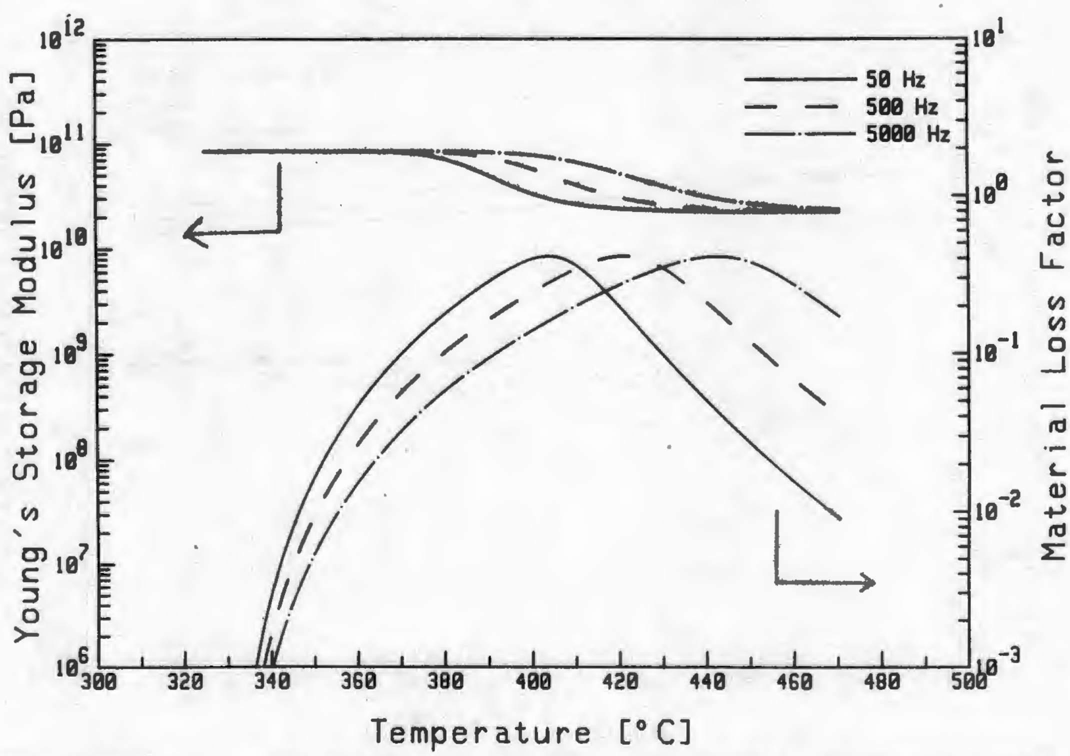

Figure 32: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #2 - Glass Enamel]**

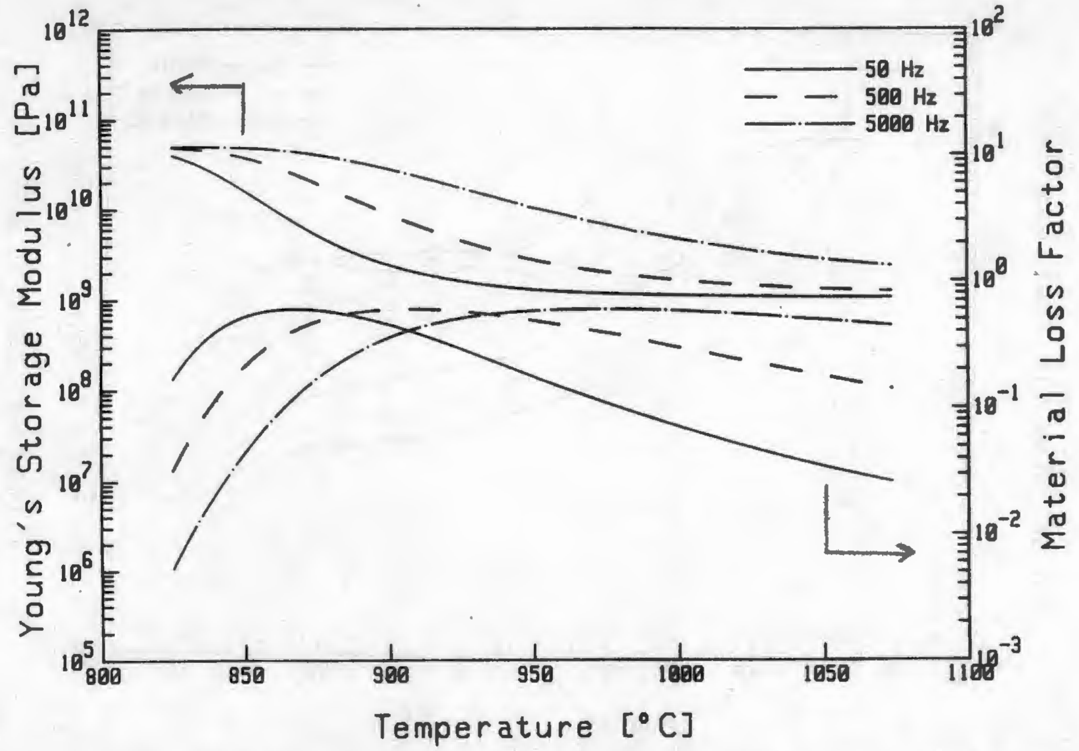

Figure 33: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #843 - Glass Enamel]**

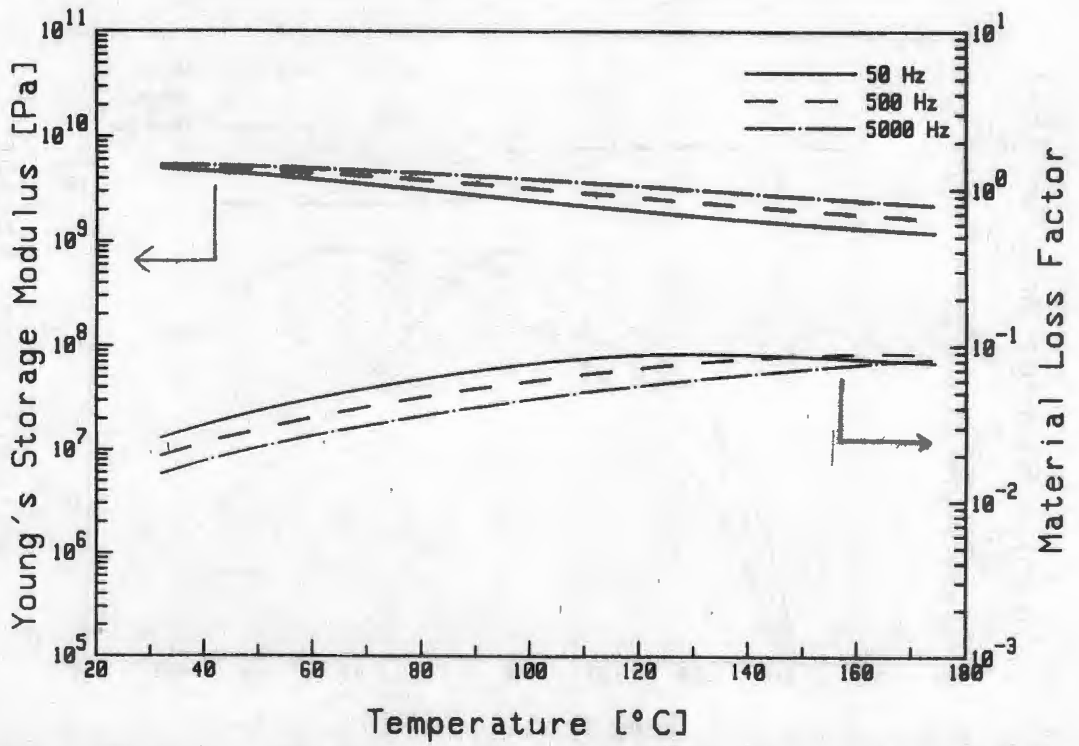

Figure 34: **Variation of the Dynamic Material Properties with Temperature of the Indicated Constant Frequencies [Library #284 - 2 Part Structure Adhesive]**

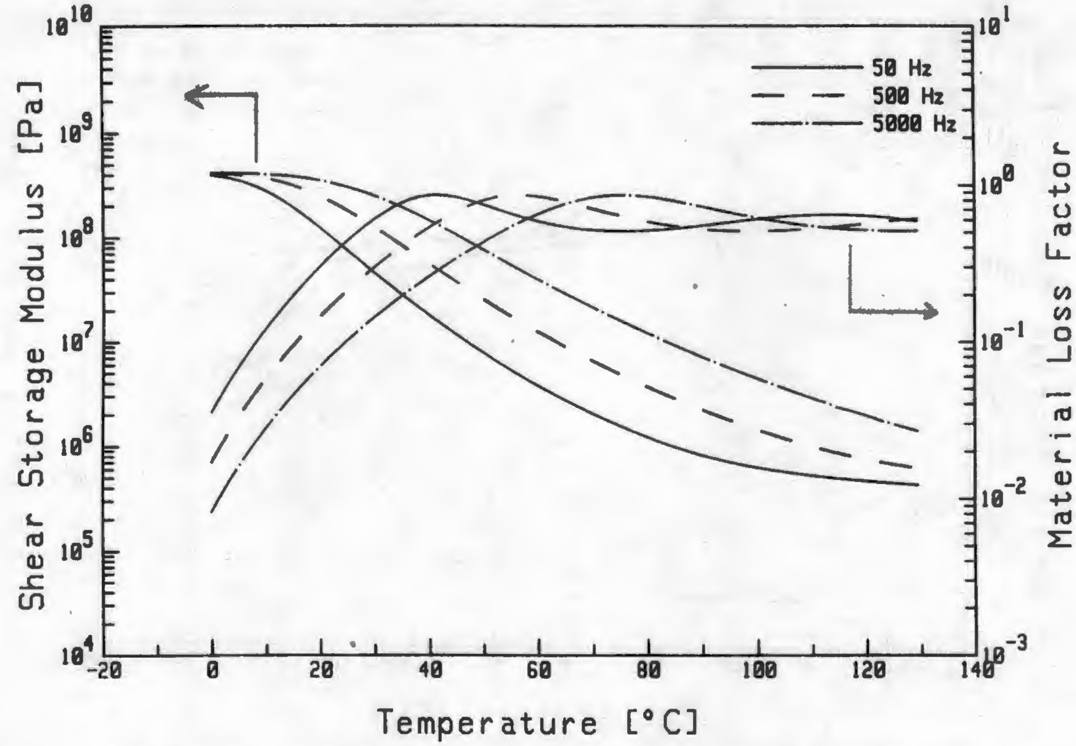

Figure 35: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #330 - Structural Adhesive Film]**

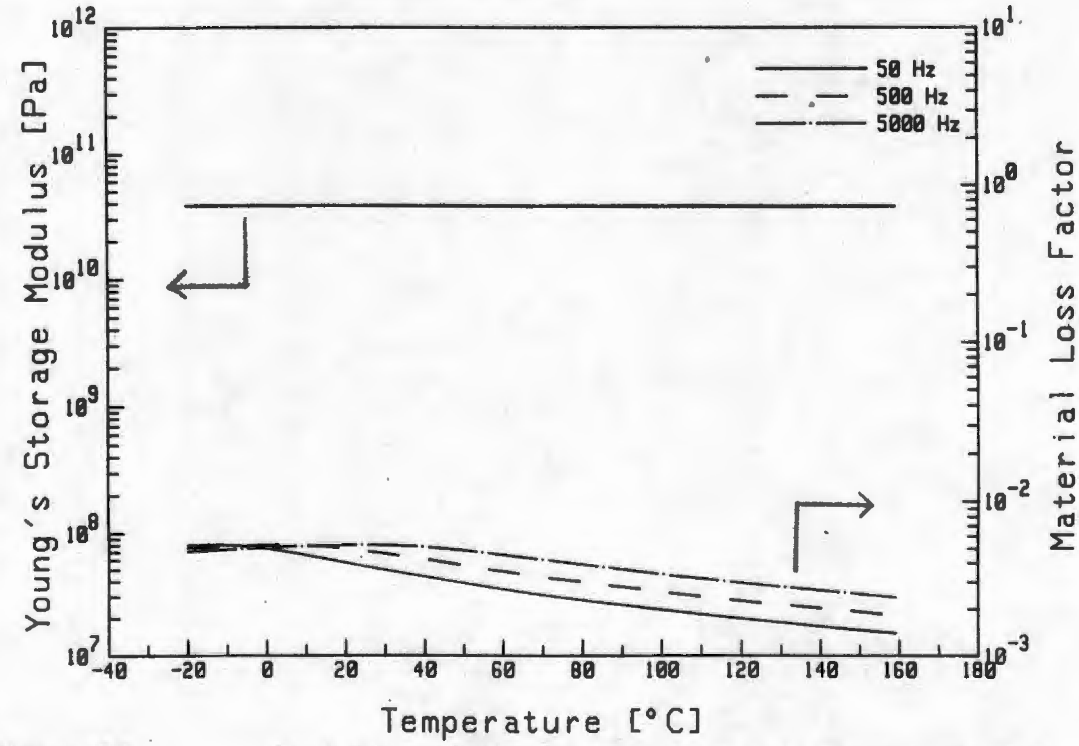

Figure 36: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #52 - Graphite Composite]**

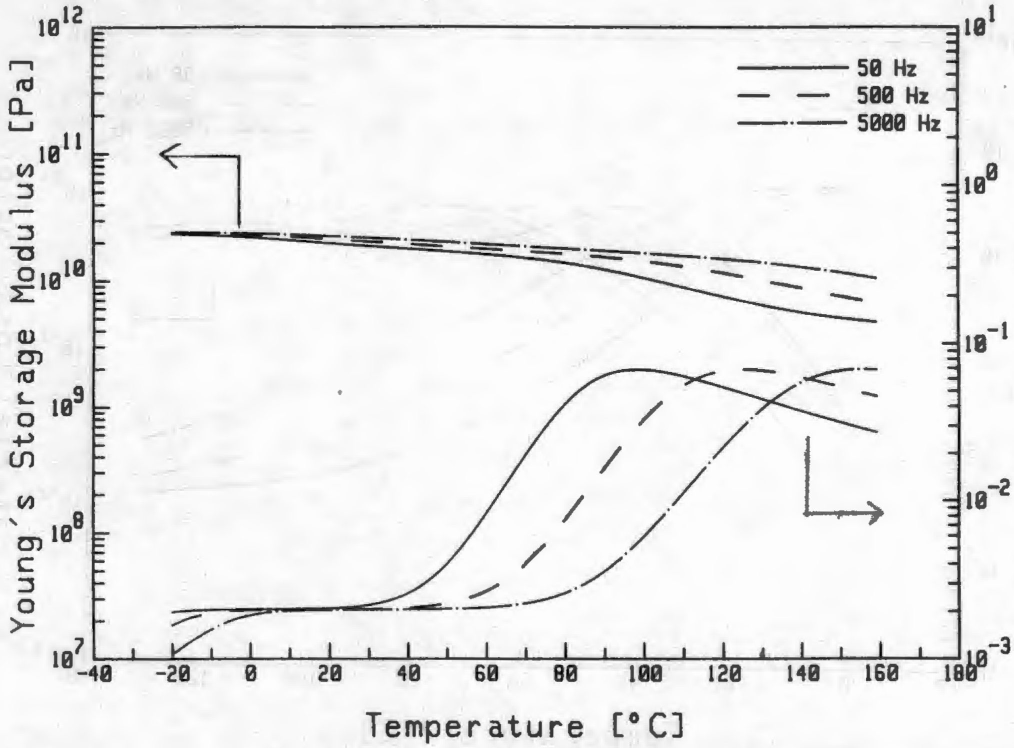

Figure 37: **Variation of the Dynamic Material Properties with Temperature for the Indicated Constant Frequencies [Library #488 - PPS Plastic Composite]**