

METHODS FOR IMPROVING DAMPING. Part 3: damping material data

1. NOTATION AND UNITS

		<i>SI</i>	<i>British</i>
E	real part of Young's modulus*	N/m ²	lbf/in ²
f	frequency	Hz	Hz
G	real part of shear modulus*	N/m ²	lbf/in ²
K	real part of bulk modulus	N/m ²	lbf/in ²
T	temperature	°C	°C
α_T	shift factor on reduced-temperature nomogram		
β	shear loss factor		
η	extensional loss factor		
ν	Poisson's ratio of damping material		

* E and G are often referred to as storage moduli.

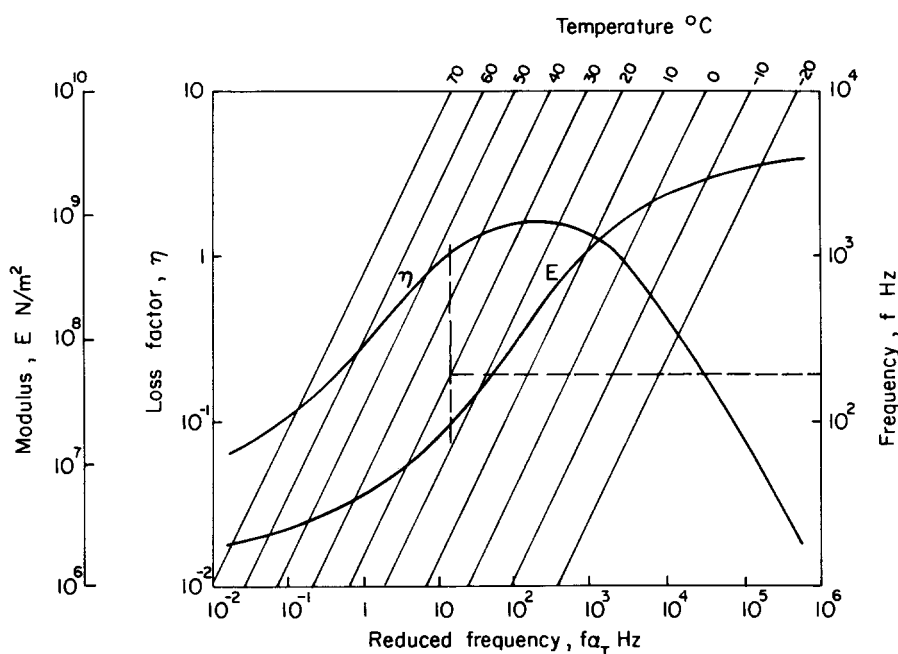
2. INTRODUCTION

This Item is the third in a series of Items providing information on improving damping in structures. Data are provided on the properties of typical materials that are used for applied damping treatments. These data are the necessary inputs for the computational procedures, described in Item No. 91013, for the analysis of layered damping treatments on beam and plate-like structures. General properties of damping materials and their dependence on temperature, frequency and cyclic dynamic strain are discussed in Item No. 91012.

When deciding on an appropriate damping treatment for a particular application, attention should be given to the information provided in Item No. 91012, on the recommended approach to the design of damping treatments, and to the guidelines set out on good practices in damping treatment designs.

3. PRESENTATION OF DAMPING MATERIAL PROPERTIES

A convenient way of presenting damping material moduli and loss factors, accepted by most manufacturers of these materials, is in the form of reduced-temperature nomograms*. Such a nomogram allows the effects of frequency and temperature on damping parameters to be considered simultaneously. The use of a reduced-temperature nomogram was described in Section 6.4 of Item No. 91012 and is repeated here for convenience. The typical form of a reduced-temperature nomogram is shown in Sketch 3.1. To use the nomogram for particular values of f and T , a horizontal line is drawn through the value of f on the frequency scale to intersect the oblique temperature line for temperature T . The vertical line through that intersection point cuts the modulus and loss factor curves at the required values of E and η . The construction for using the nomogram is illustrated by the dotted lines on Sketch 3.1.



Sketch 3.1 Reduced-temperature nomogram

* There is no theoretical basis for the shift factors used in the construction of the reduced-frequency nomograms. The nomograms are constructed using engineering techniques and give the best method for presenting damping material data.

4. MEASUREMENT AND RELIABILITY OF DAMPING PARAMETERS

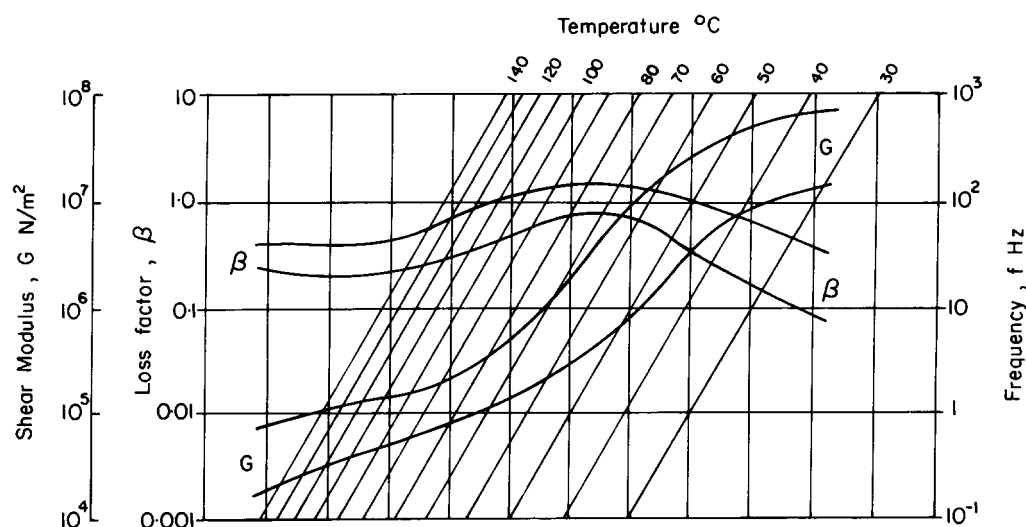
There are various methods for measuring complex modulus data of damping materials. Commonly used measurement techniques are described, for example, in Derivations 1 and 3. To define fully the damping parameters for all uses, data are required over a wide range of frequencies and a temperature range wide enough to cover the rubbery, transition and glassy regions of the material behaviour. However, most test methods give accurate data over only a narrow range of frequency and may give rise to significant errors in material parameters if used beyond their reliable frequency limits. In Derivation 3, a summary is given of the modulus and frequency zones of effective operation of several test systems. Variations in damping material parameters occur both between different test procedures and between different test laboratories as shown in References 4 to 6. Differences between sets of damping data can arise from limitations in the theoretical method of data analysis as well as from the testing procedures and the selection and sizing of test specimens. A procedure has been developed that can highlight spurious data within a set of test data. The procedure involves the analysis of a graph obtained by plotting, on logarithmic scales, the measured values of loss factor against those of modulus. This plot is usually referred to as a "Wicket Plot" and its use is illustrated in Reference 6. Because of the potential problems associated with the measurement of damping material properties, it is recommended that more than one test method be used if data are required over a wide range of moduli as would be the case for a temperature range wide enough to include the rubbery, transition and glassy regions of the material behaviour. Even for more restricted ranges of data, the use of more than one test procedure will lead to higher confidence levels in the derived damping parameters.

In addition to the testing problems mentioned above, it is essential that the material under test be subjected to low cyclic strain amplitudes to ensure linear response (*i.e.* the damping material must behave in accordance with linear viscoelastic theory). Also very close temperature control should be exercised throughout the test with sufficient dwell time at each temperature to allow the material to heat-up fully, or cool down, to the required temperatures. Temperature control is particularly important since the properties of most damping materials are very sensitive to temperature changes.

The reliability of test data can be illustrated by considering a particular test procedure (Derivation 2). This procedure involves the vibration of an Oberst beam on which damping material is attached to either one or both sides (for the measurement of Young's modulus and extensional loss factor) or the damping material is sandwiched between two metal beams (for the measurement of shear modulus and loss factor). The test procedure is applicable over the frequency range 50 Hz to 5 kHz. The estimation of the damping material properties is based upon the measured differences between damped and undamped systems which usually involves small differences between large numbers. It has been estimated that, for individual temperature-frequency evaluations, the coefficient of variation* should not exceed 25% for extensional loss factor and 20% for modulus. The variation in modulus obtained using the sandwiched damping layer is greater, such that the coefficient of variation for the shear modulus should not exceed 45%.

Some manufacturers set engineering tolerances on the damping parameters which are used to assess each batch of damping material. The damping material, in a particular batch, is rejected if the modulus value falls outside the specified range or if the loss factor falls below the set minimum value. Typical tolerance bands for one specific viscoelastic polymer damping material are shown in Sketch 4.1.

* The coefficient of variation is given by $100s/\bar{X}$, where s is the standard deviation and $\bar{X}$ is the mean value.



Sketch 4.1 Tolerance bands

It is essential that users of complex modulus data are aware of the potential problems associated with the measurement of these data and appreciate that properties may change from batch-to-batch. With that knowledge, appropriate allowances for the variability of damping properties can be made when assessing the efficiency of damping treatments for a particular structural application.

5. APPROXIMATE RELATIONSHIPS BETWEEN ELASTIC PROPERTIES OF DAMPING MATERIALS

Many damping materials have mechanical properties that are independent of the direction of measurements, *i.e.* they are isotropic. Typical examples are the polymeric rubbers and non-crystalline glasses whose structures comprise molecular chain segments distributed randomly throughout the material. Bulk forms of partially crystalline polymers, or plastics reinforced with short fibres, will also be isotropic if the crystalline or fibre axes are randomly orientated throughout the material. For isotropic materials the following relationships are given by the classical theory of elasticity:

$$E = \frac{9KG}{3K + G} \quad (5.1)$$

and
$$E = 2G(1 + \nu). \quad (5.2)$$

For elastomeric materials in their medium and high temperature ranges, and particularly in their rubbery region, it is usual that the bulk modulus, K , is very much greater than the shear modulus, G . Therefore, from Equation (5.1), it follows that $E \approx 3G$ and then using Equation (5.2), $\nu \approx 0.5$. In the lower temperature range, where the elastomer is very stiff, $\nu \approx 0.33$ and so $E \approx 2.66G$.

Throughout this series of Items on methods of improving damping, a distinction has been made between extensional loss factors and shear loss factors. However, because of scatter in measured loss factor data, it is not possible to distinguish between the measurements of these two values. Therefore, when using measured loss factors, it is reasonable to assume that the extensional and shear loss factors are equal.

6. SELECTION AND APPLICATION OF DAMPING MATERIALS

When selecting a damping material for a particular application it is necessary to pay particular attention to the variation of both loss factor and elastic modulus with temperature and frequency. Selected materials must perform well both at the resonant frequency at which the response is to be damped, and in the normal operational environment. Addition of a damping treatment will both increase the mass and stiffness of the structure and may change the resonant frequency at which damping is required. Some of the other factors to be considered when selecting a damping material are listed.

- (i) Resistance to water and other fluids that might be encountered in service.
- (ii) Resistance to cyclic heating and cooling.
- (iii) Outgassing.
- (iv) Recommended continuous service temperature limits.
- (v) Flammability.
- (vi) Fungal and bacterial resistance.
- (vii) Abrasion resistance.
- (viii) Ozone resistance.
- (ix) Ultraviolet resistance.
- (x) Aging qualities of the adhesive.

For efficient damping it is important that there is good bonding between the damping material and the structure over the whole area of the treatment. For this to be achieved it is important that the structural surface should be clean and dry prior to the application of the treatment and that air bubbles are not trapped under the damping layer. For any particular damping material, the manufacturers recommended bonding cycle, which may involve the application of both heat and pressure, should be rigorously followed.

Having identified a material that seems suitable for a particular damping application, it is recommended that the manufacturer should be consulted on the availability of that material. Some manufacturers do not normally sell their damping materials in roll or sheet form but only as part of a custom fabricated item.

7. DATA PROVIDED

In this Item, properties of typical damping materials are provided in the form of reduced-temperature nomograms. The use of these nomograms is described in Section 3. The data provided are taken directly from product information supplied by the material manufacturers. Manufacturers of damping materials who have provided product data are listed in Appendix A. It must be realised that damping materials are subject to batch-to-batch variations and manufacturers may from time-to-time change the composition or processing of a particular material. Also the limitations of the test methods and general reliability of test data (see Section 4) should be borne in mind when determining the loss factor for a specific frequency/temperature condition. Consequently the data provided in this Item should be used only as a guide for selecting materials for a specific application. The user must determine whether a particular material is fit for a particular purpose and suitable for their method of application.

Table 9.1 lists the damping data for which material properties are provided and gives the figure number for those data. In Table 9.1, data are listed in order of their peak performance temperature range with the higher temperature materials at the top of the list. That table also gives the material density when that information is available.

Figures 1 to 27 provide modulus and loss factor data in the form of reduced-temperature nomograms. Data provided are for samples of the damping material only. Extrapolation of data to higher or lower temperatures than shown on the nomograms should be done with care as the temperature scale is non-linear.

It is recommended that, when estimating the structural loss factor, structural stiffness and resonant frequency for a particular damping treatment, a spread of damping data should be considered. This will allow an assessment to be made of the sensitivity of each of the structural characteristics to changes in the damping material properties.

8. DERIVATION AND REFERENCES

Derivation

This derivation lists selected sources that have assisted in the preparation of this Data Item. Manufacturers of damping materials, who have supplied data used in this Item, are listed in Appendix A.

1. READ, B.E.
DEAN, G.D. *The determination of dynamic properties of polymers and composites.* Adam Hilger Ltd, Bristol, 1978.
2. ASTM *Standard method for measuring vibration-damping properties of materials.* ASTM Standard, Designation: E756-83, Vol. 04.06, pp. 766 – 772, American Society for Testing and Materials, Philadelphia, 1983.
3. JONES, D.I.G. *A critique of complex modulus test methods. Damping 1986 Proceedings.* Air Force Wright Aeronautical Lab. tech. Rep. AFWAL-TR-86-3059, Vol.I, pp. AII-56, Wright-Patterson Air Force Base, Ohio, May 1986.

References

The following references are recommended sources of information supplementary to that in this Item.

4. DRAKE, M.L.
SIRCAR, A. *Comparison of complex modulus data generated by three different measurement techniques. Damping 1989 Proceedings.* Wright Research Development Center tech. Rep. WRDC-TR-89-3116, Vol.II, pp. FAB1-16, Wright-Patterson Air Force Base, Ohio, November 1989.
5. JONES, D.I.G. *Results of a round robin test series to evaluate complex moduli of a selected damping material. Proceedings of Damping '91.* Wright Laboratory tech. Rep. WL-TR-91-3078, Vol. II, pp. EBD1-18, Wright-Patterson Air Force Base, Ohio, August 1991.
6. JONES, D.I.G.
KHOURI, M.
LEWIS, T. *Correlation of complex modulus data by direct stiffness and indirect resonant beam techniques. Proceedings of Damping '91.* Wright Laboratory tech. Rep. WL-TR-91-3078, Vol. II, pp. EBB1-16, Wright-Patterson Air Force Base, Ohio, August 1991.

9. DAMPING MATERIALS

TABLE 9.1 DAMPING MATERIALS AND DATA LOCATION

Material code	Manufacturer (See Appendix A)	Typical Application	Material Density kg/m ³	Operating, or peak performance temperature range	Fig. No. for Data
0010	CORNING	Free-layer damping in high temperature environments.	–	600°C to 700°C	1
8871	CORNING	Free-layer damping in high temperature environments.	–	570°C to 620°C	2
7556	CORNING	Free-layer damping in high temperature environments.	–	500°C to 560°C	3
8463	CORNING	Free-layer damping in high temperature environments.	–	470°C to 570°C	4
7570	CORNING	Free-layer damping in high temperature environments.	–	500°C to 560°C	5
SOUNDFOIL D	SOUNDCOAT	Constrained-layer damping at high temperature.	–	60°C to 138°C	6
DYAD 609	SOUNDCOAT	Constrained-layer damping for thick plate vibration at high temperature.	1100	49°C to 115°C	7
ISD 110	3M	Constrained-layer damping.	1100	40°C to 110°C	13
C-1100	EAR	Vibration isolation and constrained-layer damping.	1282	35°C to 63°C	17
SOUNDFOIL N	SOUNDCOAT	Constrained-layer damping.	1160*	16°C to 66°C	8
C-1105	EAR	Vibration isolation.	1287	27°C to 54°C	18
DYAD 606	SOUNDCOAT	Constrained-layer damping for thick plate vibrations at room temperature.	1100	10°C to 66°C	9
ISODAMP SD	EAR	Free-layer damping.	1495*	0°C to 70°C	19
ISD 112	3M	Constrained-layer damping at room temperature.	1100	0°C to 60°C	14
C-1002	EAR	Vibration isolation and constrained-layer damping.	1289	13°C to 40°C	20
C-2003	EAR	Free-layer and constrained-layer damping.	1714	0°C to 50°C	21

TABLE 9.1 DAMPING MATERIALS AND DATA LOCATION (Continued)

ISODAMP CN	EAR	Free-layer and constrained-layer damping.	1490	0°C to 50°C	22
C-2204 NAVY DAMP 2	EAR	Free-layer and constrained-layer damping. (Vibration damping tiles.)	1418	13°C TO 27°C	23
SOUNDFOIL M	SOUNDCOAT	Constrained-layer damping at room temperatures.	1160*	–1°C to 38°C	10
PORON 4701-01	ROGERS	Gasketing, shock and vibration energy absorption (cellular urethane).	320	–40°C to 70°C	25
PORON 4701-05	ROGERS	Gasketing, shock and vibration energy absorption (cellular urethane).	320	–40°C to 70°C	26
PORON 4701-09	ROGERS	Gasketing, shock and vibration energy absorption (cellular urethane).	320	–55°C to 70°C	27
C-2203 NAVY DAMP 1	EAR	Free-layer and constrained-layer damping. (Vibration damping tiles.)	1418	0°C to 13°C	24
DYAD 601	SOUNDCOAT	Constrained-layer damping for thick plate vibrations at low temperature.	1100	–23°C to 38°C	11
ISD 113	3M	Constrained-layer damping at low temperature.	1100	–40°C to 20°C	15
SOUNDFOIL LT	SOUNDCOAT	Constrained-layer damping at low temperatures.	492*	–40°C to –5°C	12
ISD 830	3M	Constrained-layer damping at low temperatures.	1100*	–60°C to –10°C	16

* Approximate material density. The mass density is supplied by the manufacturer in terms of mass per unit area of a combined damping layer and constraining layer.

Material : 0010

Manufacturer : CORNING

YOUNG'S MODULUS

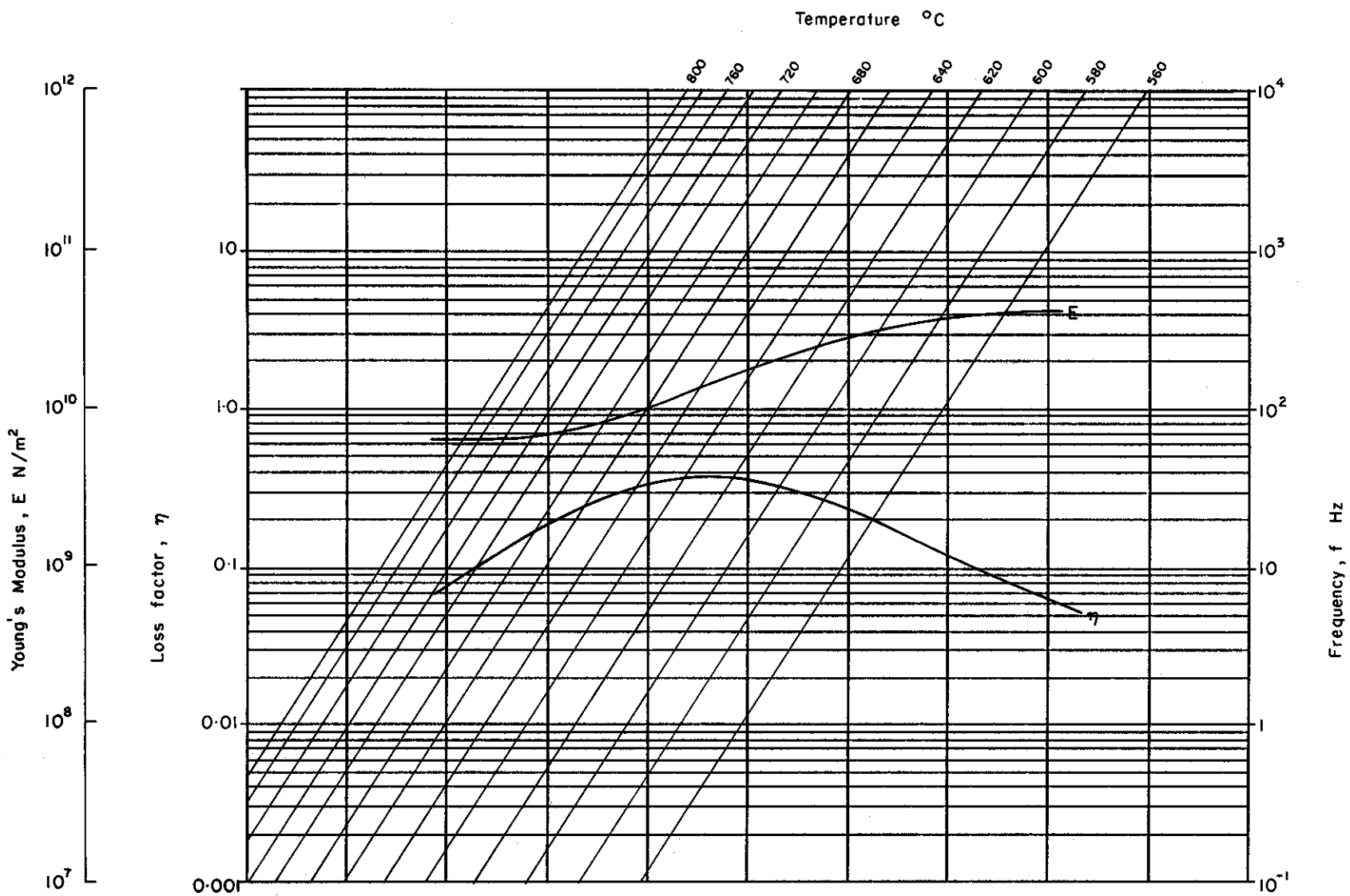


FIGURE 1

Material : 8871

Manufacturer : CORNING

YOUNG'S MODULUS

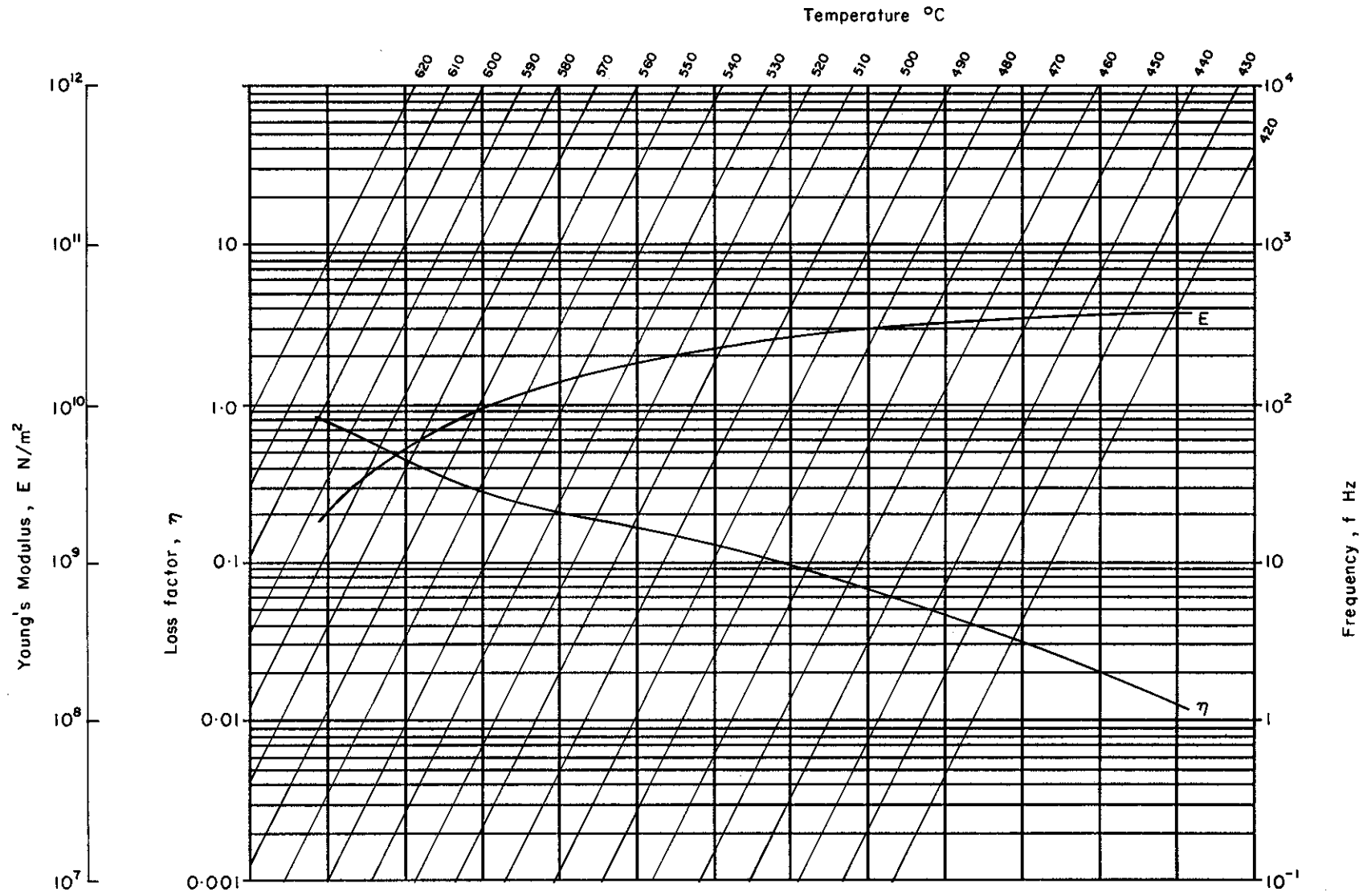
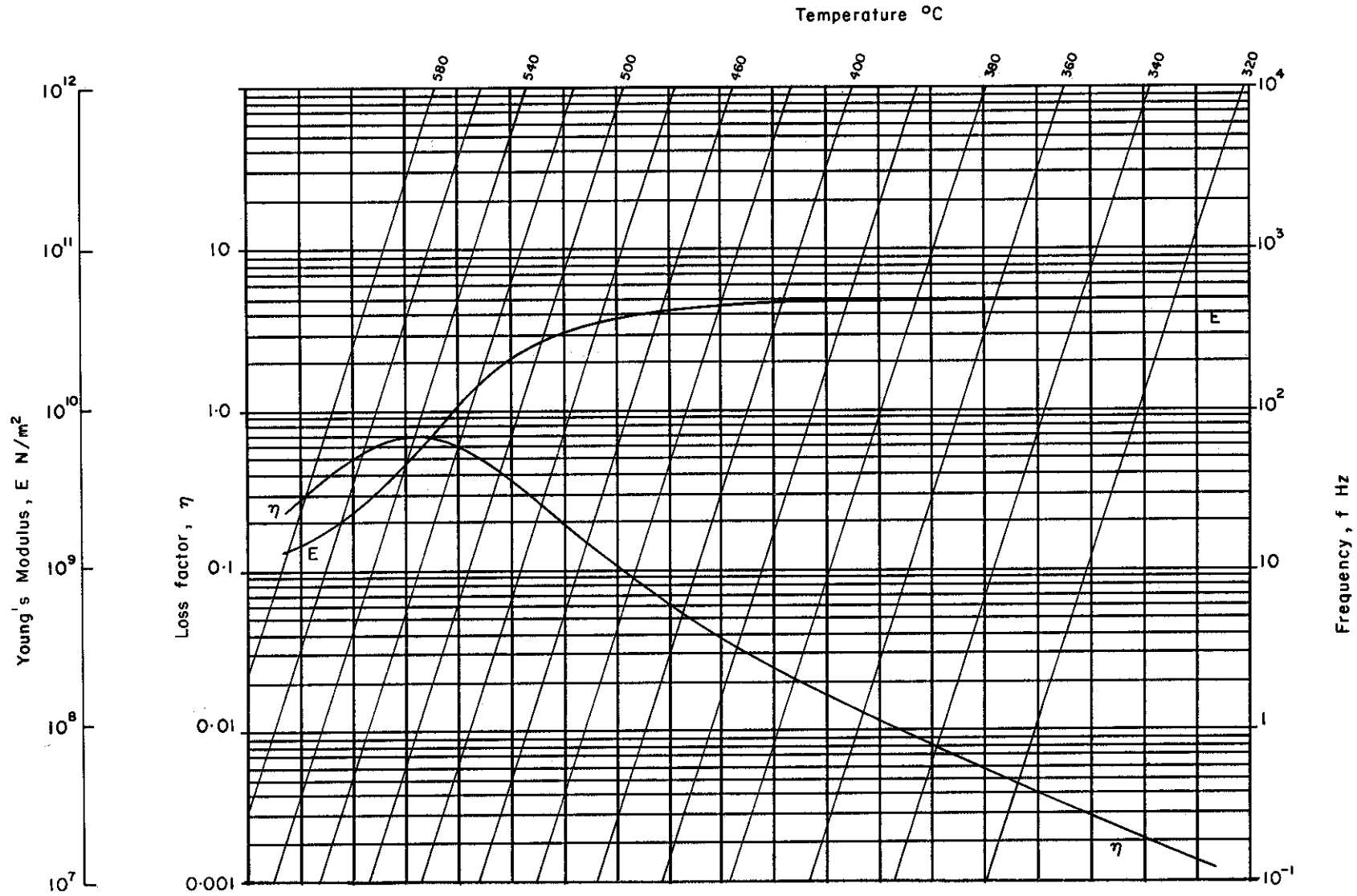


FIGURE 2

Material: 7556

Manufacturer: CORNING

YOUNG'S MODULUS



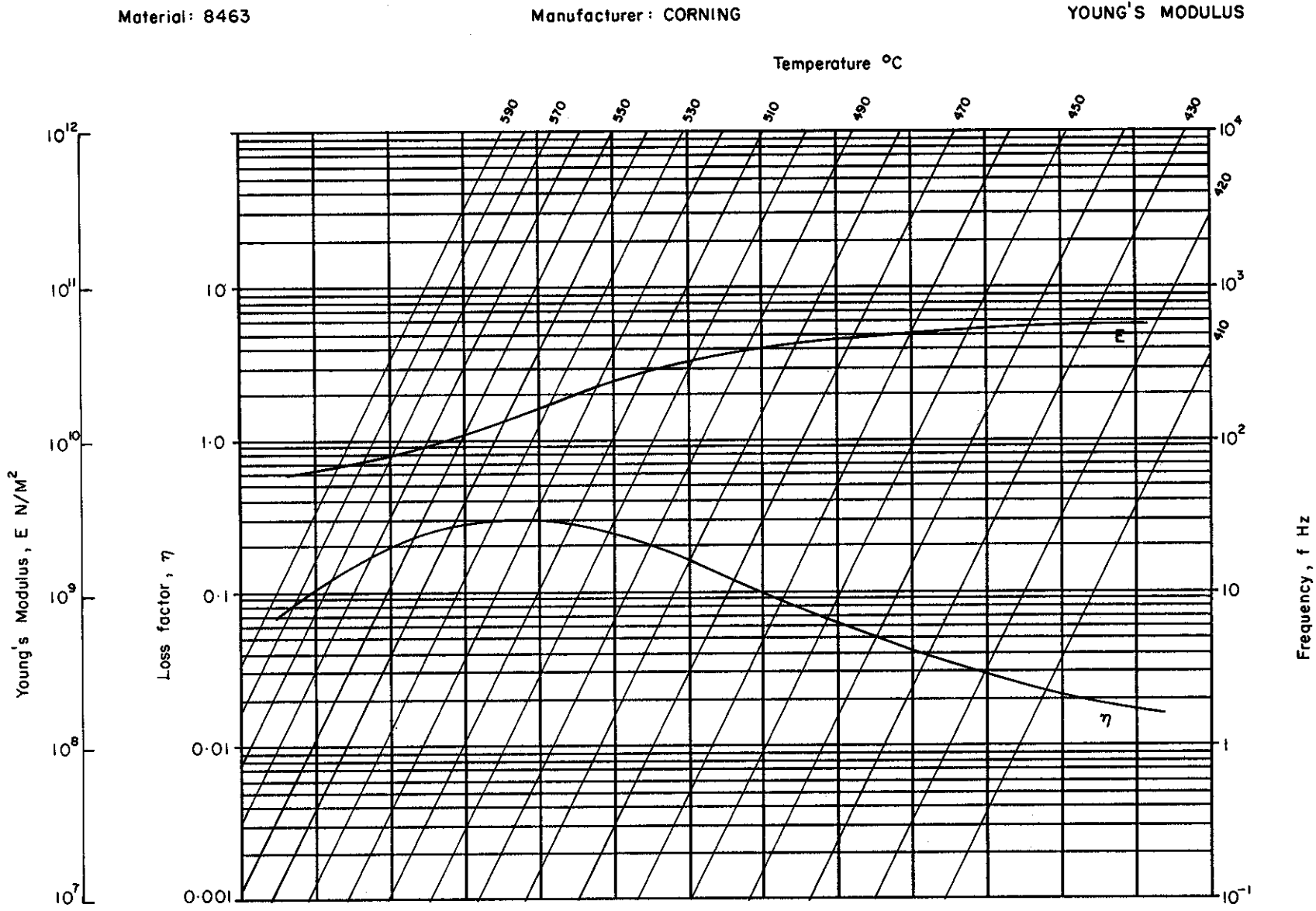


FIGURE 4