Part of ADA241312 Digitized 4/28/2021

Development of Low Modulus Damping Material for Precision Mounting Platforms

S. Kirshenbaum[1], D. Hill, and C. Stahle

General Electric - Astro Space Division

ABSTRACT

A damped precision mounting platform requires a viscoelastic damping material with a shear modulus an order of magnitude lower than existing General Electric Astro Space Division SMRD™ damping material formulations. Existing SMRD™ formulations were modified to achieve low shear stiffness and high damping over a broad range of temperature and frequency. New formulations were dynamically and mechanically characterized test results are presented. Five new formulations met the low modulus, high damping objectives resulting in an efficient, highly effective damped platform design.

INTRODUCTION

The current trend toward larger and more accurate sensing instruments on precision space structures which are growing in size and flexibility has created a need for improved dynamic stability. This can be accomplished through integral use of passive damping with viscoelastic material (VEM). The damped precision mounting platform design shown in Figure 1 is a dual honeycomb sandwich with a layer of damping material in the center. The damping material is positioned in the center of the panel to recover maximum shear strain as the panel is deflected. This provides a high composite loss factor and the desired degree of improved stability. Design studies on the platform have shown that the most effective damping configuration can be achieved with a thin layer of low modulus damping material.

GE Astro Space Division produces VEM called SMRD™ which has been utilized in space applications for over 20 years. However, in past applications the damping material covered a smaller percentage of the structure requiring relatively stiff damping material for peak performance. The current precision mounting platform design with full coverage requires damping material with a shear modulus up to an order of magnitude lower than the conventional SMRD™ formulations. Past development work has shown that the properties of SMRD™ can be tailored by varying the constituents. A General Electric funded program was undertaken to develop new low modulus VEM formulations for precision platforms. The results of this successful study are presented in what follows.

---

[1] Dr. Steven Kirshenbaum, GE Astro Space, 234 Goddard Blvd., King of Prussia, PA, 19406, (215) 354-6551

Confirmed public via DTIC 4/28/2021

VEM MATERIAL REQUIREMENTS

The need for a low modulus, space compatible VEM has already been discussed. Specific material property requirements for the precision mounting platform are shown in Table 1. The conventional SMRD™ formulations, 100F90 and 100F50, meet the damping and strength requirements but have shear modulli from 2000 to 4000 psi. The platform is thermally controlled, but temperatures may vary between 40 F and 75 F. Major orbital responses range in frequency from 15 to 100 Hz, and the launch acoustic loading can be significant through 2000 Hz. The VEM must maintain a high loss factor over the temperature range and frequency range of interest during launch and on orbit. The static strength requirement, 50 Psi, is low by design, although the strain to failure of the material is exceptionally high.

The outgassing requirements of less than 1 percent total mass loss (TML) and less than 0.1 percent collectible volatile condensable material (CVCM) have been established by NASA. Low outgassing is a key requirement for spacecraft materials. Material which is lost not only degrades the performance of the component, but may condense on sensors or solar array panels affecting the performance of the payload. Many commercially available damping materials meet the strength and shear modulus requirements, but have high outgassing, and are therefore unacceptable for space applications. The SMRD™ formulations have low outgassing(1) and are desirable for space applications.

DEVELOPMENT PLAN

The developmental flow plan, Figure 2, indicates the iterative nature of this study. Candidate formulations were prepared and cured in a small specimen dish for qualitative evaluation. Some formulations were rejected at this level because they separated or they never fully cured. Material formulations which looked promising on a small scale were cast into full size panels (12 inch by 12 inch by 0.25 inch) for further evaluation. In a few instances, formulations which initially looked promising were rejected at this point because of separation or incomplete curing. The remaining formulations were subjected to modified Oberst Beam tests which served as a screening test for damping characterization. Based on this data, one formulation was selected for further characterization with the Direct Complex Stiffness technique. Mechanical properties were measured with a Universal Test Machine.

MODIFICATION OF EXISTING SMRD™ FORMULATIONS

It is well known that peak damping for a VEM occurs near the glass transition temperature. In general, the glass transition can be affected by crosslink density, molecular packing, chemical constituents, cure conditions, and fillers. Because of the low outgassing requirement for space applications, modifications to the material formulation and process are limited to those which will not increase outgassing. The proprietary nature of the formulation and production process of SMRD™ precludes a detailed discussion, but it may be noted that chemical constituents and fillers were

Confirmed public via DTIC 4/28/2021

varied in the work reported here. The properties of SMRD™ can be tailored to the needs of the application using these variables alone. Effort concentrated on reducing crosslink density to increase backbone flexibility. Plasticizers were not pursued based upon past experience which indicated the addition of these constituents caused difficulty in bonding the material to structure.

INITIAL SCREENING - MODIFIED OBERST BEAM TEST

The Modified Oberst Beam test is a relatively simple and reliable technique for measuring the damping characteristics of viscoelastic materials. Through the measurement of the natural frequencies and damping of the Oberst Beam specimen, the shear modulus and loss factor of the VEM can be determined as a function of temperature and frequency. The accuracy of the measurements, however, is limited by the beam specimen configuration, temperature control, and test technique.

A typical modified Oberst Beam configuration is shown in Figure 3. The beam is made up of an aluminum base block with a protruding arm consisting of two VEM layers bonded to an aluminum sheet. A set of 5 to 6 modified Oberst Beams were tested together inside a thermally controlled environmental test chamber. Temperature in the chamber can be maintained to 2 C. Measurements were made in 5 C increments from -5 C to 40 C. Damping and natural frequencies were determined via tap test. An instrumented hammer was used to tap the beam and the response was measured with an Endevco 2222 accelerometer attached to the tip of the beam. The input force and response acceleration were collected and reduced with a HP 5423 two channel analyzer. Each measurement consisted of 5 taps and 5 averages of the input and response.

Damping and natural frequencies of the composite beam and the density of the VEM are the raw data necessary to calculate the shear modulus and loss factor of the VEM. The data was reduced based upon equations given by Nashif(2).

Material properties of ten SMRD™ VEMs are presented in Table 2. The 100F90 and 100F50 are the original SMRD™ materials. The results indicate that seven formulations have met the material property requirements of Table 1. Five of the materials (U1015-10E, B50T2B, B50T5B, B37UF, and B37T2B) have shear modulli less than 500 Psi in the required temperature and frequency ranges, which is particularly desirable for the precision mounting platform. The peak loss factor has been increased above 1.5. As expected, the microballoon filled formulations have a lower density and higher modulus than the equivalent unfilled systems (compare 100F50 with 100F50 UF). The unfilled systems also exhibit higher loss factors.

An indication of the data quality is determined by a wicket (or inverted U) plot. If a plot of the loss factor versus storage modulus, G, forms an inverted U with small scatter, then the entire range of VEM modulus from rubbery region through the transition phase and into the glassy region is well represented. A wicket plot for the B37-T2B material is shown in Figure 4. In general, the results show some scatter, especially in the rubbery region, which is characteristic of the Oberst Beam test. This amount of scatter, however, is acceptable for initial screening tests.

DETAILED TESTING - DIRECT COMPLEX STIFFNESS TECHNIQUE

Exceptional material properties and potential performance enhancement were demonstrated by five of the new SMRD™ formulations. Time restraints limited detailed testing to only one formulation. The B37T2B was selected; it possessed one of the lowest shear modulli, providing the lightest weight configuration, and one of the highest loss factors.

The B37T2B was further characterized at CSA Engineering with the Direct Complex Stiffness technique(3) as part of a separate program. This nonresonant technique involves application of force in the form of a sine burst across the material in shear and measurement of the resulting displacement. This burst random technique allows measurement at all frequencies simultaneously. Specimen temperature is critical to the accuracy of the results and was held to within 0.1 C by a fluid convection system.

The test results presented in the reduced temperature nomogram (Figure 5) and the subsequent wicket plot (Figure 6) show almost no scatter in the data and represent all three regions (rubbery, transition and glassy) of the B37T2B material behavior. The data points measured by the Oberst beam method are also plotted in Figure 5 for comparison. The Oberst beam data shows good agreement with the Direct Complex Stiffness test results. The confirmed peak loss factor of 1.6 is an exceptional increase from the 1.0 peak loss factor of the standard 100F90 formulation.

MECHANICAL PROPERTY TESTING

The damping material experiences the highest stress condition during launch. Design of a passively damped structure must address the two possible failure modes of the VEM, namely failure under an axial load (tension) and failure in shear. During launch the VEM is exposed to tensile stress and shear stress simultaneously. Effects of rate at which the material is strained (strain rate) and temperature have a marked influence on the material properties(4)(5) and must also be addressed. The temperatures typically experienced by a protected structure during launch conditions range from 50 F to 75 F. The strain rate depends upon the application, but typically ranges from 40 in/in/min to 150 in/in/min.

Tensile testing of VEM followed ASTM standard D638. Tests at strain rates 6.67 in/in/min or lower were performed on a 1000 lb. mechanical Instron at controlled temperatures. Tests at strain rates 33.3 in/in/min and higher were performed on a hydraulic Instron at room temperature conditions only. Strains up to 0.50 in/in were measured with an extensometer with a 1.0 inch gage length. Ultimate strains were determined by the crosshead motion. The modulus was measured as the secant of the stress-strain curve at 2 percent strain. Ultimate stress was recovered from the failure load.

TENSILE TEST RESULTS

Mechanical properties of four materials at 6.67 in/in/min strain rate and 65 F are compared in Table 3. Young's modulli measured at 2 percent strain follow the same trend as the shear modulli presented in Table 2. The modulus of the filled material (100F90) is an order of magnitude higher than the modulli of the three unfilled materials. Ultimate stress of the four materials is related to Young's modulus, although the two properties are not directly proportional. Even at this low strain rate, the ultimate stress of all four materials is higher than the 50 Psi minimum requirement. In the comparison between materials, ultimate strain appears inversely proportional to Young's modulus. All materials exhibited exceptional strain to failure enabling a great deal of flexibility in their design and use.

Mechanical property variation of the SMRD™ VEM materials with strain rate and temperature will be demonstrated with results for the B37T2B material. Young's modulus, E, as a function of strain rate, temperature held constant at 65 F is presented in Figure 7. Young's modulus ranging from 80 psi to 400 psi is observed. This wide range can be explained by examining Figure 5. At the slow strain rates, the B37T2B is in the rubbery portion of the curve. Testing at higher strain rates acts to shift the material state to the transition or glassy regions of the curve with the same effect as an increase in frequency. Young's modulus is related to a shear modulus by

$$G = E / 2(1 + \upsilon) \tag{1}$$

where υ is Poisson's ratio. For VEM material in the transition region, the Poisson's ratio approaches 0.5. Thus, the shear modulus can be estimated as 1/3 of the Young's modulus. The shear modulus at the higher strain rates appears to correlate to the shear modulus measured dynamically with the modified Oberst beam (Table 2).

Ultimate stress as a function of strain rate (at 65 F) is presented in Figure 8. The ultimate stress of 40 psi measured at 0.07 in/in/min strain rate is doubled at the highest strain rate. Ultimate stress measured at 50 F, Figure 9, also increases with an increase in strain rate. However, at a constant strain rate, the ultimate stress measured at 50 F is double that measured at 65 F. This indicates that at 50 F the B37T2B is closer to the glassy region.

Ultimate strain as a function of strain rate and temperature is presented in Figure 10. Limitations in the hydraulic test machine crosshead displacement precluded ultimate strain measurements at the higher strain rates, but it is known that all specimens failed over 100 percent strain.

CONCLUSIONS

Development of a low modulus, space compatible VEM has been presented. Existing formulations were modified and tests were performed to screen viable candidates.

Five new material formulations have shear modulus and damping properties which meet the requirements of a precision mounting platform. One formulation was subjected to detailed characterization confirming earlier modified Oberst beam results.

Mechanical tensile test results show that Young's modulus, ultimate stress, and ultimate strain of SMRD^{TM} VEM are dependent upon both temperature and strain rate. The existence of a relationship in the data between strain rate in mechanical testing and frequency in dynamic testing has been established. Recommendations for future work include mechanical shear tests and further investigation in the relationship between strain rate and frequency.

REFERENCES

1. Stahle, C.V., Staley, J.A., Strain, J.C., "RELSAT - Reliability for Equipment in Environmental Vibration," Final Report, AFWAL, June, 1990.

2. Nashif, A.D., "New Method for Determining Damping Properties of Viscoelastic Materials," Shock and Vibration Bulletin, No. 86.4, 1967.

3. Austin, E.M., et al, "Test Report for DAMMPS Phase I Testing of Viscoelastic Materials," CSA Report No. 90-10-01, October 1990.

4. Faupel, J.H., Engineering Design, John Wiley and Sons, New York, 1962, Chapter 5.

5. Landel, R.F., and Fedors, R.F., "On the Phenomenology of Rubberlike Behavior," Deformation and Fracture of High Polymers, Battelle Institute Materials Science Colloquia, Kronberg Germany, September 1972.

Table 1 VEM Material Requirements for a Precision Mounting Platform

Temperature Range (F)	40 to 75
Frequency Range (Hz)	15 to 2000
Shear Modulus Range (Psi)	50 to 1200
Loss Factor	1.0 minimum
Outgassing - TML (Percent)	1.0 maximum
Outgassing - CVCM (Percent)	0.1 maximum

Table 2 Modified Oberst Beam Test Results

Material Designation	Peak Damping Data					
	Filled (F/U)	Density (g/cm^3)	G (Psi)	Loss Factor	Temp. (F)	Freq. (Hz)
100F90 *	F	0.7	4000	1.0	65	55
100F90UF	U	1.0	1000	1.2	67	20
100F50 *	F	0.8	4200	1.0	59	90
100F50UF	U	1.0	600	1.4	50	16
U1015-5E	U	1.0	40	1.5	40	9
U1015-10E	U	1.0	80	1.6	71	57
B50T2B	U	1.0	380	1.3	61	85
B50T5B	U	1.0	370	1.1	60	84
B37UF	U	0.9	60	1.6	71	57
B37T2B	U	1.0	90	1.5	60	78

* Historical Data

Table 3 Tensile Test Results at 6.67 in/in/min strain rate and 65 F

Material Designation	Filled (F/U)	E (Psi)	Ultimate Stress (Psi)	Ultimate Strain (Psi)
100F90	F	1250	400	0.8
100F50UF	U	130	145	1.2
B50T2B	U	82	92	1.4
B37T2B	U	92	70	1.7

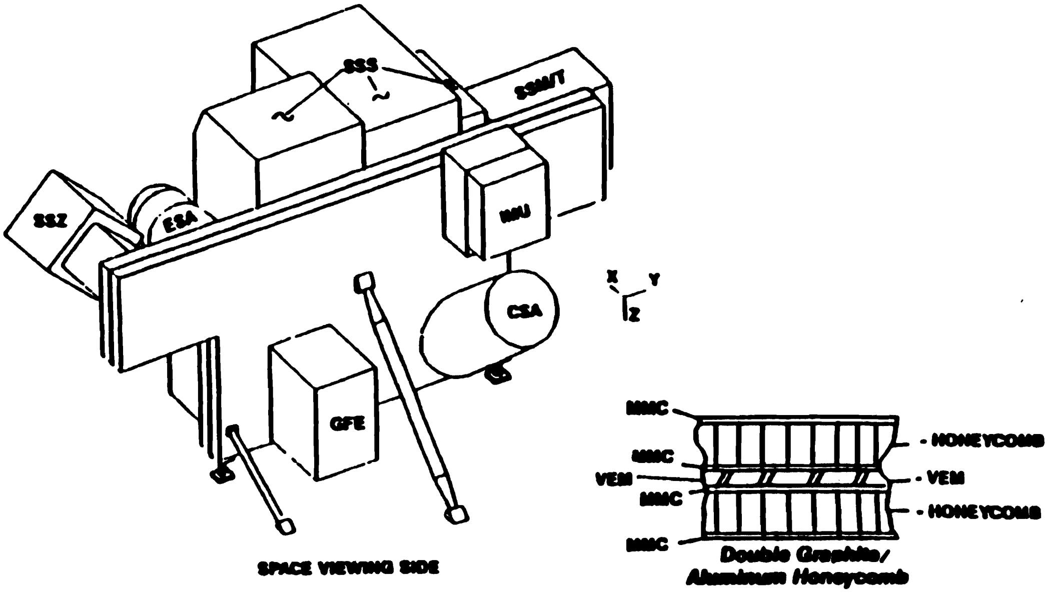


Figure 1 Damped Precision Mounting Platform Design

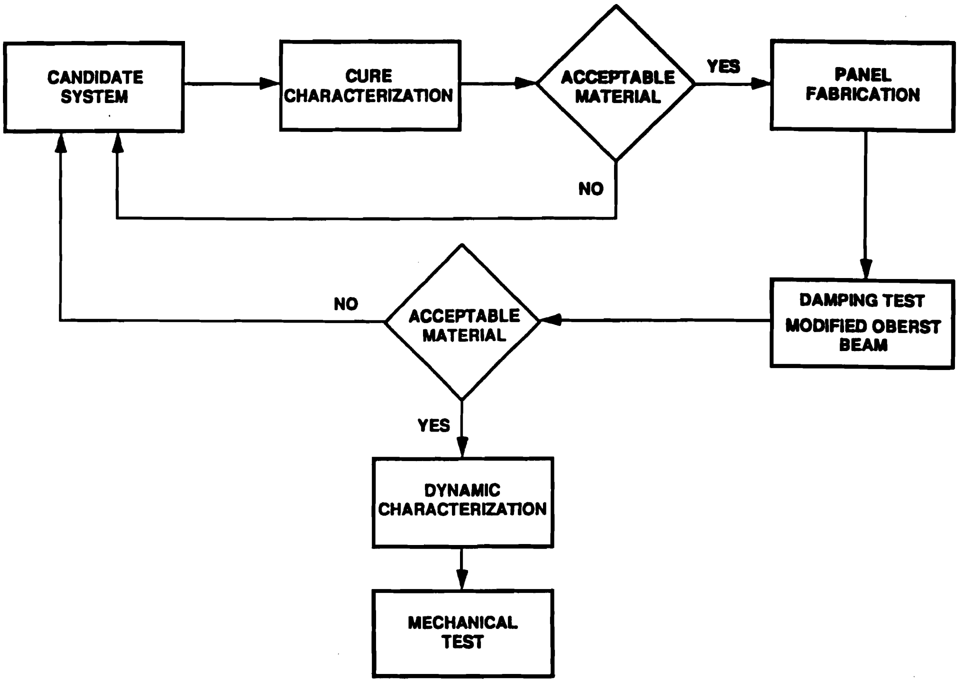


Figure 2 Damping Material Development Flow Plan

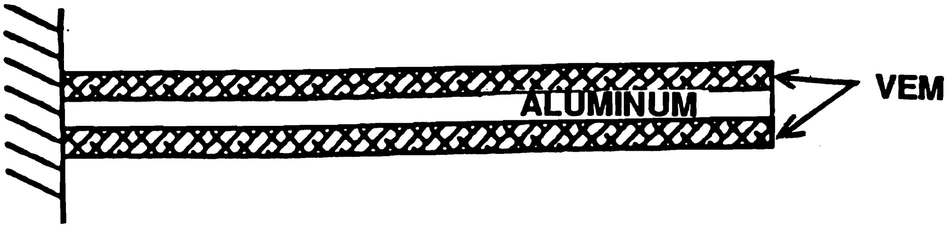


Figure 3 Modified Oberst Beam

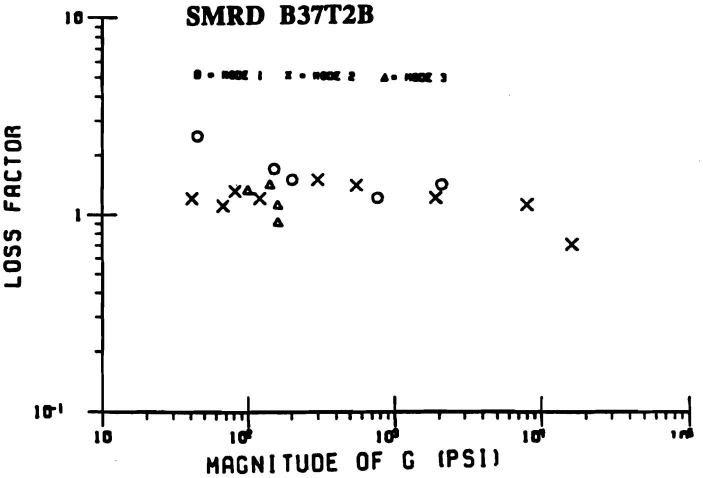
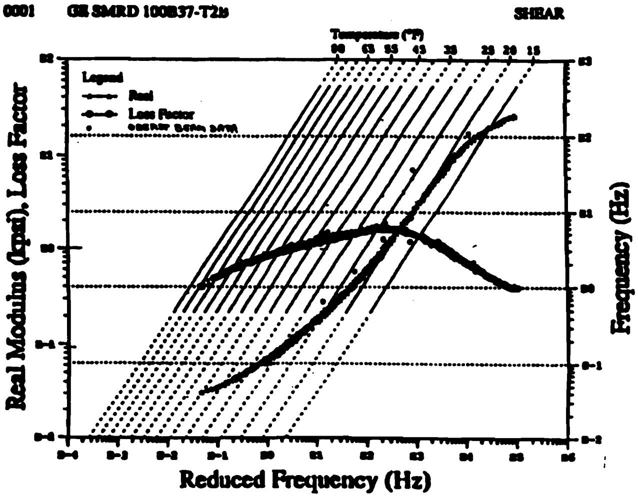


Figure 4 Wicket Plot for B37T2B Modified Oberst Beam Test Data



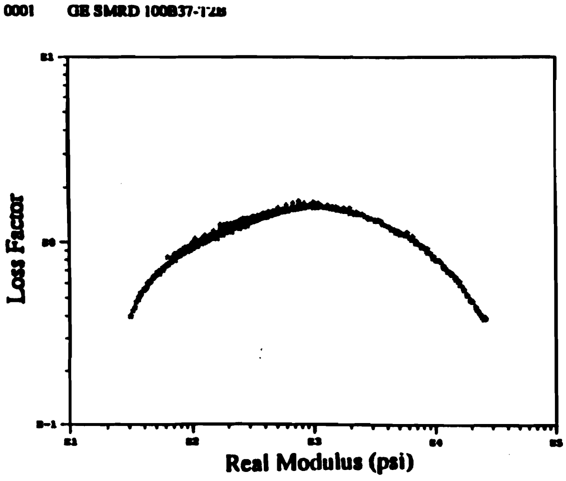


Figure 5 Complex Stiffness Test Results for B37T2B

Figure 6 Wicket Plot for B37T2B Complex Stiffens Test Data

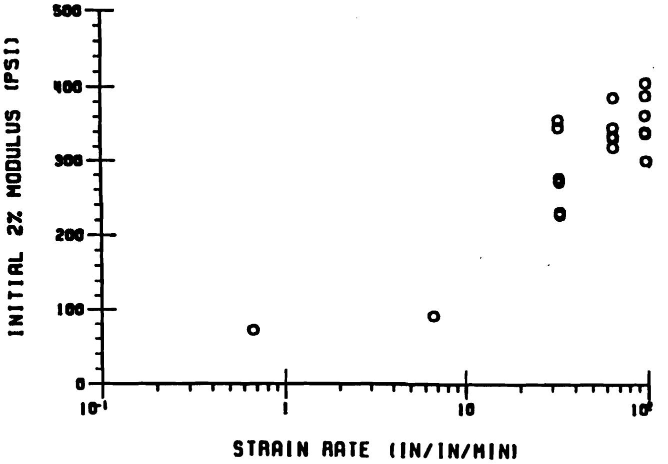


Figure 7 Variation of B37T2B Young's Modulus With Strain Rate

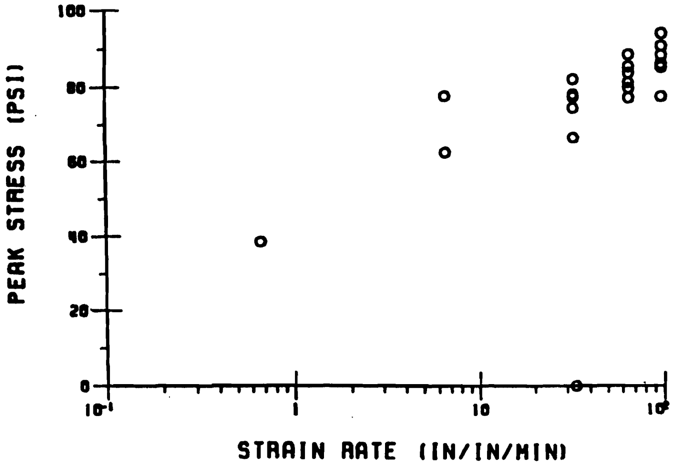


Figure 8 Variation of B37T2B Ultimate Stress With Strain Rate

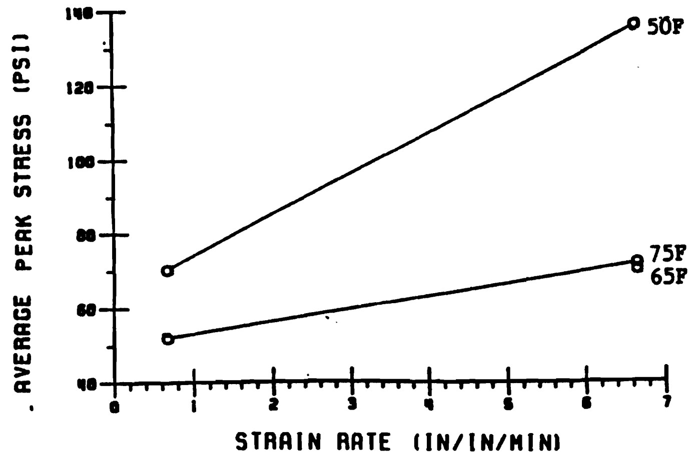


Figure 9 Variation of B37T2B Ultimate Stress With Temperature

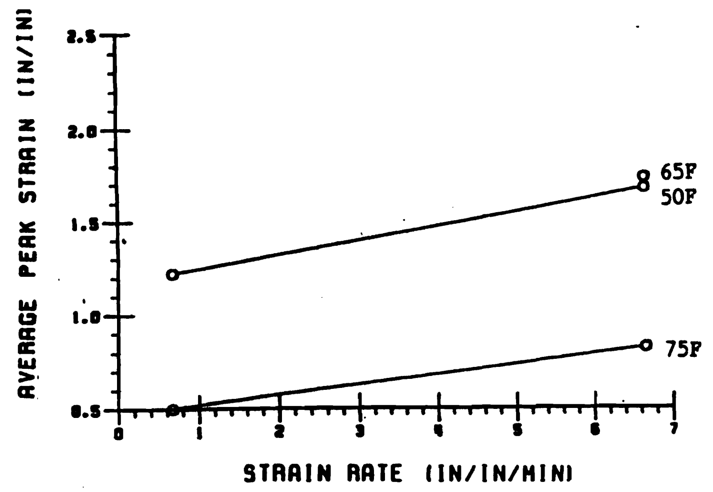


Figure 10 Variation of B37T2B Ultimate Strain With Temperature