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Elastic Moduli of Ultem and Noryl at Cryogenic Temperatures Using Vibrating Beam Specimens

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AD/RHIC/RD-21

RHIC PROJECT

Brookhaven National Laboratory

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Conclusions

The results of the program of testing are given in Figures 1 and 2.

• The room temperature values of elastic modulus agree very well with the data published by the material manufacturer.

• The cold temperature results show that the materials attain most of their added stiffness due to cooling upon reaching liquid nitrogen temperatures.

• Ultem and Noryl are about 30 percent stiffer when cold.

•Ultem is about 30 percent stiffer than Noryl.

•Noryl appears to have a higher damping factor than does Ultem.

•The damping factor measured for Noryl was slightly higher at helium temperature than at nitrogen temperature. Although counter-intuitive, this effect was observed on another material as well.

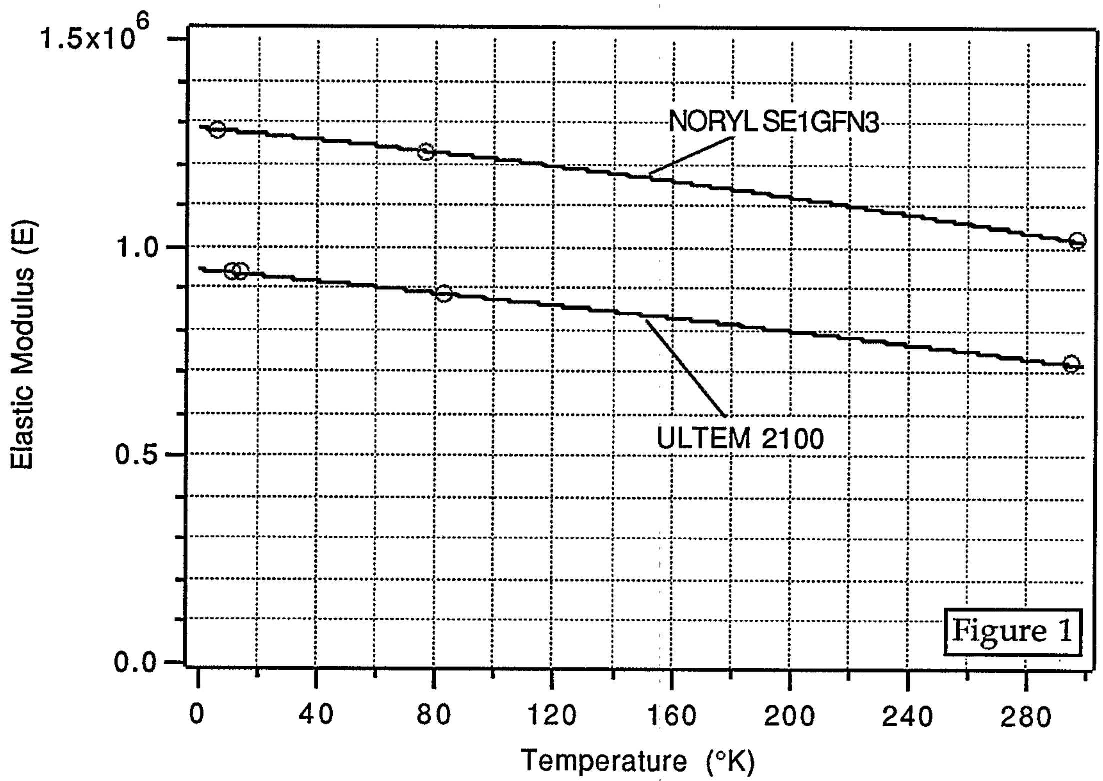

Figure 1

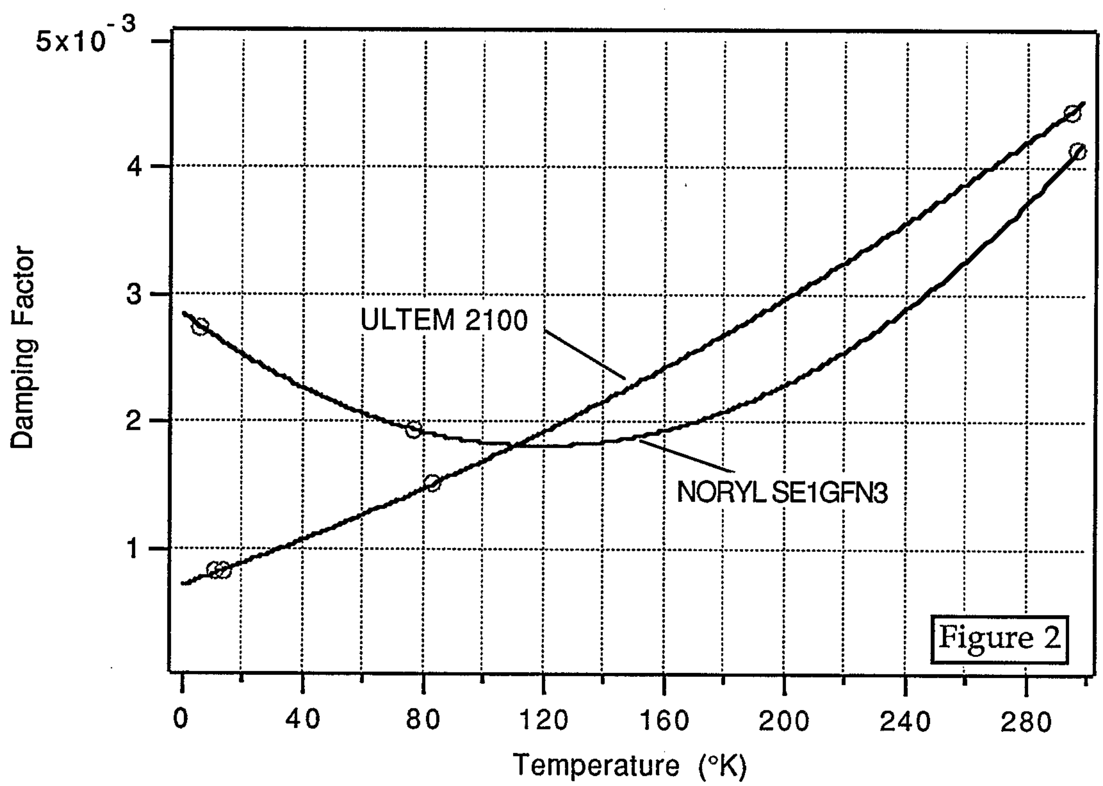

Figure 2

Background

Two materials are being evaluated for use in the injection-molded composite posts for the RHIC Magnets. They are Ultem 2100 and SE1GFN3 Noryl. Both are thermoplastics reinforced with fiberglass chop. Ultem 2100 is composed of 10% fiberglass by weight and GFN3 Noryl is 30% fiberglass. These materials are of interest because they have low thermal conductivity, high strength and low material and fabrication cost.

A program of tensile testing at cryogenic temperatures has been undertaken and is continuing. Tensile tests have given reliable values for strengths, but the tensile test results using crosshead travel for the elastic modulus (or stiffness) of these materials have been disappointing. They were unreliable to the point of producing lower stiffnesses at liquid helium temperature than at room temperature. The problem appears to be mechanical play in the test fixture. The very small elastic elongations are lost in the variability of the fixture. Attempts to correct experimentally for the fixture elasticity did not give repeatable results.

Since the modulus of elasticity is important for predicting the stiffness of the cold mass on the new posts and also for the stress and vibration analysis of the posts, a vibration test was conducted in addition to the tensile tests. This testing was based upon the lateral vibration of a small cantilever beam of the material. Vibration testing has the advantage or giving some comparison of the vibration damping characteristics of the materials in addition to their elastic moduli.

Procedure

The tests of the cantilever beams, nominally eight inches long, one-half inch wide and one-eighth of an inch thick, were first conducted in air at room temperature. This test was followed by one in a vacuum which showed no discernable difference. Then the test was repeated at liquid nitrogen temperature and finally at liquid helium temperature.

Test beams of Noryl and Ultem were prepared by cementing strain gages near the base support and cementing a small piece of iron foil near the free end. The prepared beams were mounted in the fixture shown in Figure 3. The fixture was suspended in a bath of the liquid cryogen. When the temperatures stabilized, the beam was vibrated by applying an alternating current to the electromagnet. The electrical current frequency was swept until the lowest mechanical resonance was found. That frequency was read from a frequency counter. After the frequency was obtained, the magnet current was interrupted, and the beam vibration was allowed to die out freely while the strain gage signal was photographed on the oscilloscope screen.

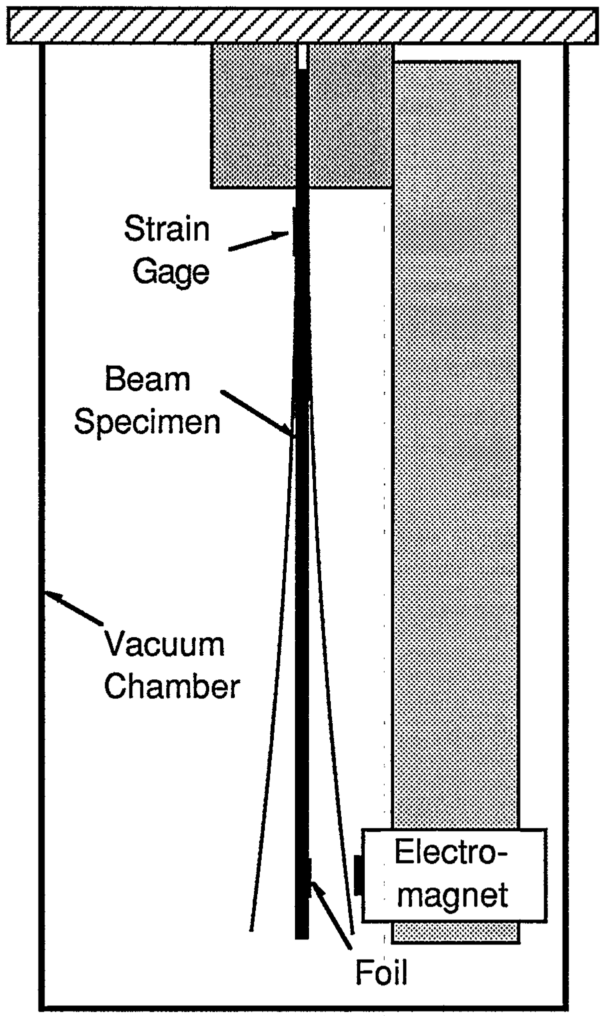

Figure 3. TheTest Beam and Exciter.

Data Reduction

The signal traces from the oscilloscope had the form shown in Figure 4. The natural frequencies, f_n, were read directly from the frequency counter. The test beams were weighed and measured in order to compute their densities, which agreed closely with manufacturer's data. The well-known formula (1)[1] for the natural frequency of a cantilever beam was used to calculate the elastic modulus, E:

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[1] T. Baumeister, Editor; *Marks'Standard Handbook for Mechanical Engineers, 7th Edition*; McGraw Hill Book Co.; N.Y., N.Y.; 1967; p5-101.

(1)
$$f_n = .560\sqrt{\frac{gEI}{wL^4}}$$

where I = the beam cross-section moment of inertia,
w = the weight per unit length,
L = the beam length, and
g = the gravitational acceleration.

For a rectangular cross section, $I = bh^3/12$, where b is the beam width and h is the height.

The weight per unit length, w, is equal to γbh, where γ is the weight per unit volume.

Making these substitutions and solving for E give the formula for elastic modulus in terms of f_n:

(2)
$$E = 38.26\frac{\gamma f_n^2 L^4}{gh^2}$$

The damping factor is determined from the logarithmic decrement, δ, which is computed from the amplitudes at two sample points, y_o and y_n, as shown in Figure 4.

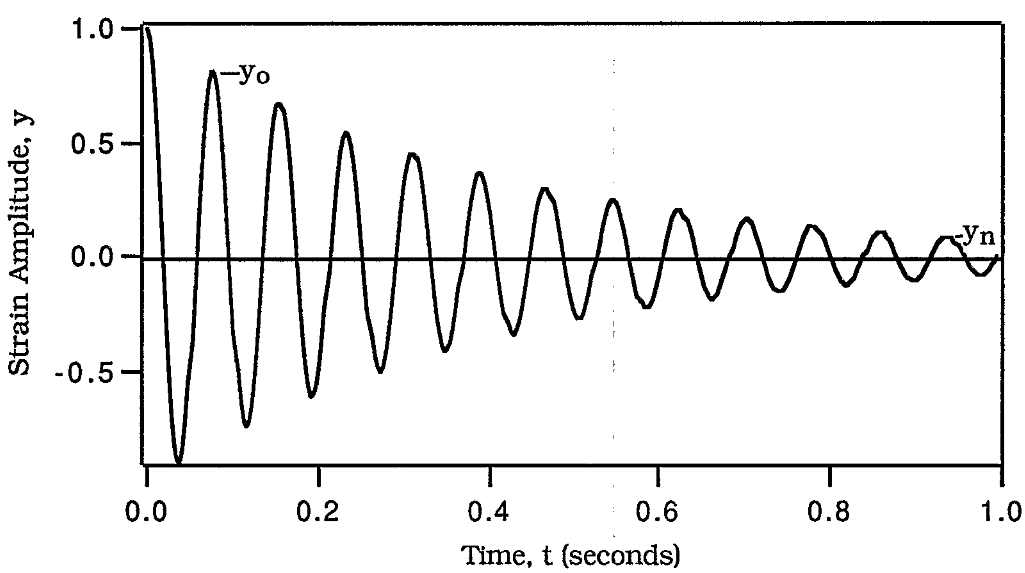

Figure 4. A Vibration Decay Curve.

(3) $$\delta = \frac{\ln y_o - \ln y_n}{N}$$

where N is the number of cycles between sample points.

The damping factor, c/c_c, is related to the logarithmic decrement by:

(4) $$\frac{c}{c_c} = \frac{\delta}{\sqrt{4\pi^2 - \delta^2}}$$

where c is the damping and c_c is the critical damping.