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by

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INTRODUCTION

Linen-base phenolic laminate is inexpensive and of high compressive mechanical strength and can be easily fabricated. It has been widely used for substructures in large bubble chamber magnets[1] and large MHD magnets[2,3].

Pultruded polyester fiberglass can be easily made in very long lengths and shaped into complicated crosssections. Pultrusion produces a product of very long, unidirectional strands of fiber which yields great strength in the longitudinal fiber direction. Pultruded fiberglass polyester can be conveniently shaped into turn-to-turn insulation, coil banding material or any insulation with a complicated crosssection.

A & B Epoxy Putty is a room temperature cure filler that will be used to fill the void space within the coil structure. It has high compressive strength and relatively low thermal expansion coefficients at cryogenic temperatures.

METHODS OF MEASUREMENTS

To find the modulus, compressive and tensile stress and strain, an Instron machine, a Tinus-Olsen testing machine, a Wheatstone bridge and a strain gauges were available.

The Instron machine has a sample holder designed to operate at cryogenic temperatures. The machine has a cross head speed of 0.05 -0.5 cm/min. and

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a load capacity of 10,000 kg. The upper end of the specimen to be tested is attached to the stationary load at the top of the Instron by a long stainless steel rod. The bottom end of the specimen is fixed to the cage, which moves up and down with the moving beam of the machine. A unique feature of the apparatus is that a specimen can be tested under unidirectional cyclic mode of tension and compression. The apparatus is shown in Fig. 1.

Specimen preparation followed two articles: Standard Method of Test for Tensile Properties of Plastics[4] and Standard Method of Test for Compression Properties of Rigid Plastics[5].

In the thermal contractional measurements, the sample, was instrumented with a copper-constantan thermocouple, and cooled in a liquid nitrogen container. The length of sample was measured using either a micrometer or a differential thermal analyzer with a dilatometer capable of operating at cryogenic temperature Only the thermal contraction or integral thermal contraction in the range of 293 K to 77 K was measured.

MICARTA

Micarta is a kind of plastic called Phenol-Formal-Dehyde Resin (Phenolic). The samples used are grade L phenolic laminate. Micarta fibers criss-cross in two perpendicular directions and are compressed in the third direction. The former two directions will be called the longitudinal directions and the latter called the cross-sectional direction.

In the tensile strength test, the problem encountered was making specimen break at the right place where the strain gauge is installed. Because Micarta is not a very uniform material, it tends to break at weak points. So, we were forced to trim the middle more so that the middle section will receive the most tension. Figure 2 shows the samples used in the tensile test along the longitudinal direction. The data obtained are shown in Table 1. It is seen that the ultimate breaking tensile stress for Micarta is an order of magnitude lower than its breaking compressive stress. A representative tensile stress strain curve is shown in Fig. 3. Data from various samples indicated that the modulus of Micarta is about 9653 MN/m^2 (1.4×10^6 psi) at room temperature and about 12411 MN/m^2 (1.8×10^6 psi) at either 77 K or 4.2 K. Nevertheless, samples from different suppliers or even from different stock sheets of the same supplier may have slightly different mechanical properties. For instance, since Sample No. 6 is a different batch from Sample Nos. 1 to 5, modulus of Sample No. 6 at liquid helium temperature is slightly smaller than that of Sample No. 4 at liquid nitrogen temperature. In general, the tensile properties at 4.2 K of a given sample is very close to those at 77 K.

In the compressive strength measurements, compressive loads were applied along both the cross sectional and the longitudinal directions. The sample dimensions, the ultimate breaking stresses, and the modulus are tabulated in Table 1. The measured compressive modulus is about 4137 MN/m^2 (0.6×10^6 psi) at room temperature and about 8274 MN/m^2 (1.2×10^6 psi) at either 77 K or 4.2 K. Figures 4 and 5 show the representative compressive stress-strain curve for the cross sectional and the longitudinal compression respectively. It is clearly seen that Micarta compressive bearing strength is very high.

The integral thermal contraction was measured to be about 850×10^{-5} in the cross sectional direction and about 300×10^{-5} to 580×10^{-5} in the longitudinal direction. This difference in the thermal contraction (300×10^{-5} and 580×10^{-5}) is probably due to the difference in fiber count between the two perpendicular directions.

A & B EPOXY PUTTY

A & B Epoxy Putty is an epoxy compound recommended for use in filling, sealing, bonding or repairing. It will stick to damp surfaces and will cure under water. It will not shrink or sag. Its hardening time is about

60 minutes at 24 °C. If a more rapid cure is desired, heating gently with a hot air gun will shorten the curing time. The epoxy compound is manufactured by the Biggs Company, El Segundo, California.

At room temperature, a compressive strength of 83 MN/m^2 (12,000 psi), a bonding strength of 2.6 MN/m^2 (375 psi), a tensile strength of 21 MN/m^2 (4000 psi) and a dielectric strength of 12000 volt/mm are quoted by the manufacturer.

At liquid nitrogen temperatures, cylindrical samples of about 1.346 cm diameter by 1.27 cm length were made by the machine shop. The ultimate bearing stress measured averaged at 152 MN/m^2 (22,000 psi).

At liquid helium temperature, cylindrical samples of 1.27 cm diameter by 1.27 cm length were tested. A compressive load was applied along the longitudinal direction. The measured ultimate compressive bearing stresses averaged 179 MN/m^2 (26,000 psi). A small fluctuation in the mechanical properties is probably due to the different amounts of air bubbles trapped during sample preparation.

The thermal coefficient of contraction from 300 K to 77 K is measured and plotted as shown in Fig. 6. It is seen that an integral thermal contraction of 359 x 10^{-5} from 293 K to 77 K is observed. For comparison, the integral thermal contraction of annealed OFHC copper is 310 x 10^{-5} and that of annealed 304 stainless steel is 260 x 10^{-5}.

PULTRUDED FIBERGLASS LAMINATE

The pultruded fiberglass is a fiberglass Hetron polyester laminate. Pultruded fiberglass is employed as the turn-to-turn insulation as well as the layer-to-layer banding in the Superconducting MHD Magnet to be used at the Coal-Fired Flow Facility at the University of Tennessee Space Institute[2]. Therefore, transverse compressive strength to the fiber direction and the tensile stress-strain curve is of great interest. The effects of both the transverse crush strength and the tensile properties at cryogenic temperature are important in its application to the large superconducting magnet technology.

In the compressive crush test, the sample is about 0.635 cm thick, 1.85 cm wide, and 7.5 cm in length.

Two pressing pads, each 0.635 cm in diameter and 0.635 cm in axial length, sandwiched the pultruded fiberglass sample in between. At room temperature, the measured crush strength is 96 MN/m^2 (13.9 kpsi) and the modulus is about 8274 MN/m^2 (1.2×10^6 psi). At liquid helium temperature, a maximum bearing pressure of 198 MN/m^2 is observed. On the other hand, if the applied load is parallel to the fiber direction, the maximum bearing strength is 138 MN/m^2 (20,000 psi) at room temperature and 414 MN/m^2 (60,000 psi) at liquid helium temperature.

In the tensile stress-strain measurements, samples must be thin or the sample fiber will be sheared cut before it reaches breaking strength. The samples used are 10 mm wide, 0.95 mm thick and 25.4 cm long. Both ends of sample were glued to two pieces of 6061-T6 aluminum sample holder. The epoxy used is Stycast 2850 FT room temperature cured epoxy. At 4.2 K, the stress strain characteristics is shown in Fig. 7.

The sample used in the measurement of the thermal contraction coefficient of pultruded fiberglass is a 15.9 cm long rod, 0.95 cm in diameter. The sample was thermally cycled from room temperature (297 K) to liquid nitrogen temperature (77 K). The measured thermal contraction coefficient along the fiber direction is plotted in Fig. 6.

TABLE 1

TENSILE AND COMPRESSIVE STRESSES OF MICARTA AT CRYOGENIC TEMPERATURE

Stress	Sample No.	Temperature K	Modulus MN/m^2	Ultimate Stress MN/m^2
Tensile	T1	300	--	55
	T2	300	7930	49
	T3	77	12618	63
	T4	77	13445	67
	T5	300	7930	62
	T6	4.2	11377	81
	T7	4.2	--	76
Cross-sectional Compressive	1A	300	3792	282
	2A	77	7860	--
	3A	77	--	447
	4A	77	--	471
	5A	4.2	7722	479
Longitudinal Compressive	1B	300	3861	239
	2B	77	--	--
	3B	77	850	525
	4B	77	--	525
	5B	4.2	--	463

Samples T1 to T7 -- 1.27 cm wide x 0.635 cm thick x 5.72 cm high

Samples 1A to 2 A and 1B to 2B -- 1.27 cm wide x 1.27 cm thick x 2.54 cm high

Samples 3A to 5A and 3B to 5B -- 0.794 cm wide x 0.794 cm thick x 2.54 cm high

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3. S.-T. Wang, L. R. Turner, L. Genens, W. Pelczarski, J. Hoffman, J. Gonczy, H. Ludwig, R. C. Niemann, K. Mataya, and E. Kraft, "The Final Design of A Superconducting MHD Magnet for the Coal-Fired Flow Facility at the University of Tennessee Space Institute, Paper KD-3, Volume 25, Advances in Cryogenic Engineering.

4. pp. 192-199, 1975 Annual Book of ASTM Standards, Part 35, American Society for Testing and Materials, Philadelphia, PA.

5. pp. 236-242, 1975 Annual Book of ASTM Standards, Part 35, American Society for Testing and Materials, Philadelphia, PA.

FIGURE CAPTION

Figure 1 Instron Machine with Cryogenic Sample holder.

Figure 2 Micarta Tensile Test Samples

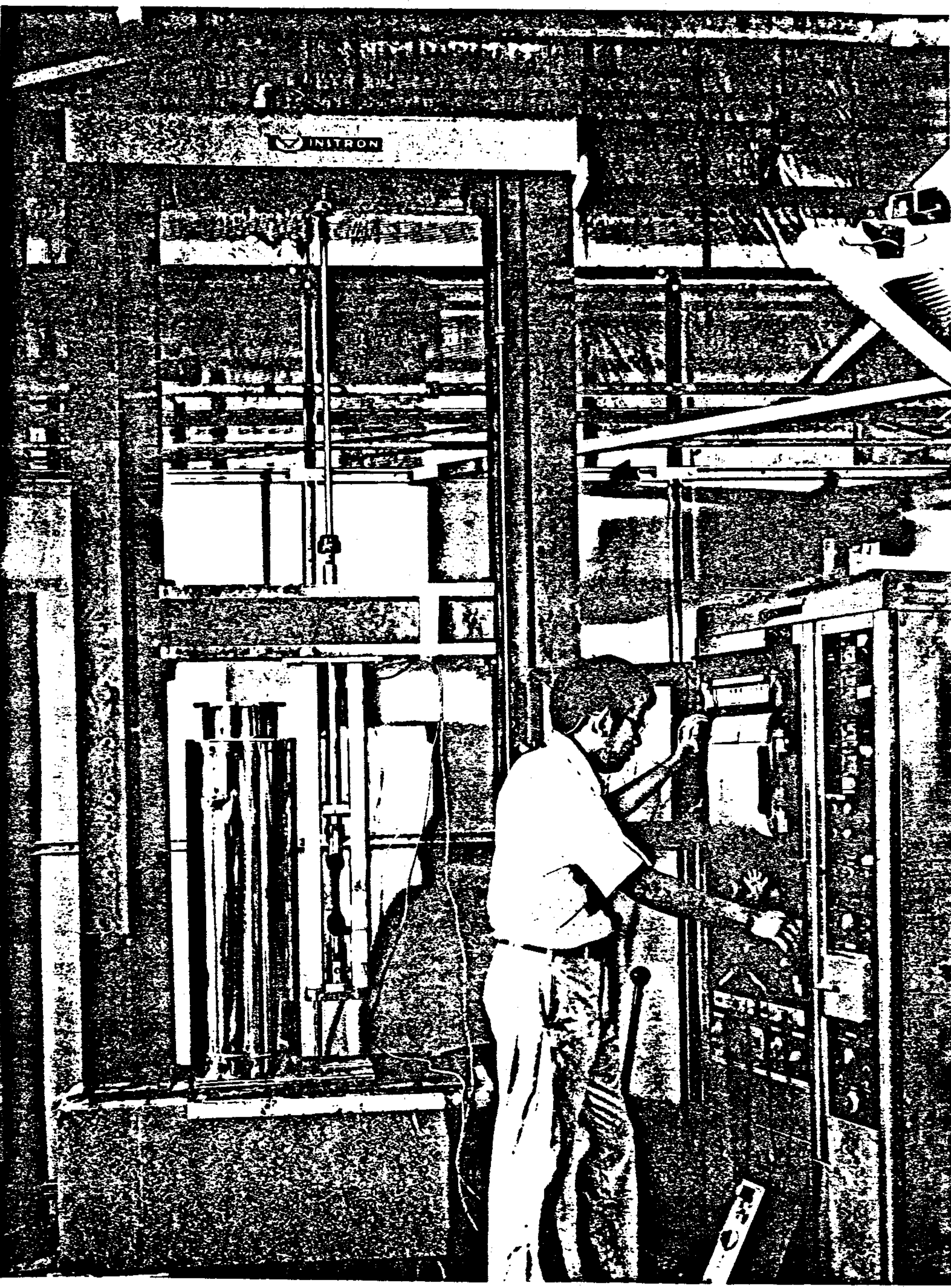
Figure 3 Tensile Stress-Strain Characteristics of Micarta

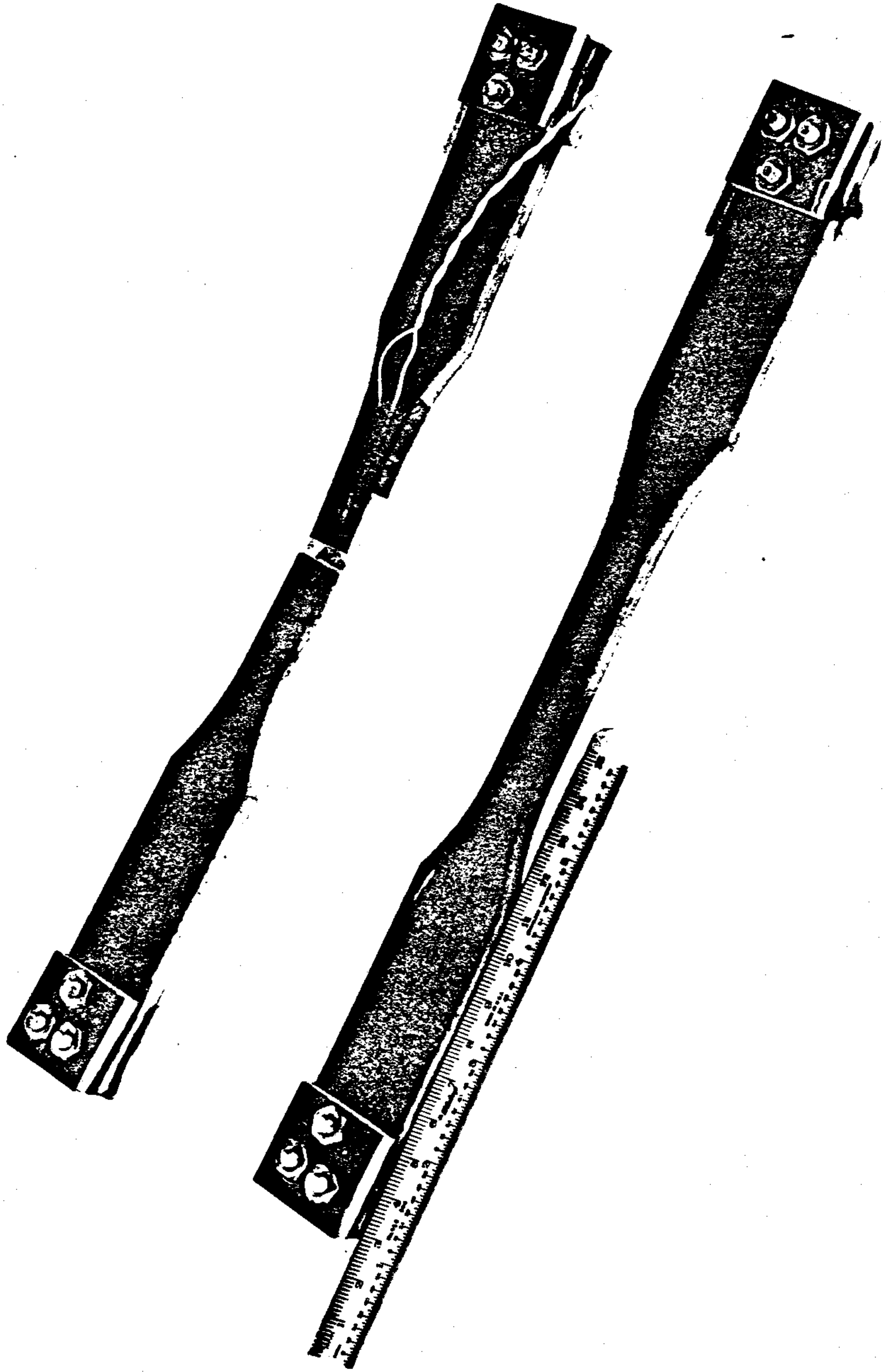
Figure 4 Cross sectional Compressive Stress-Strain Characteristics of Micarta

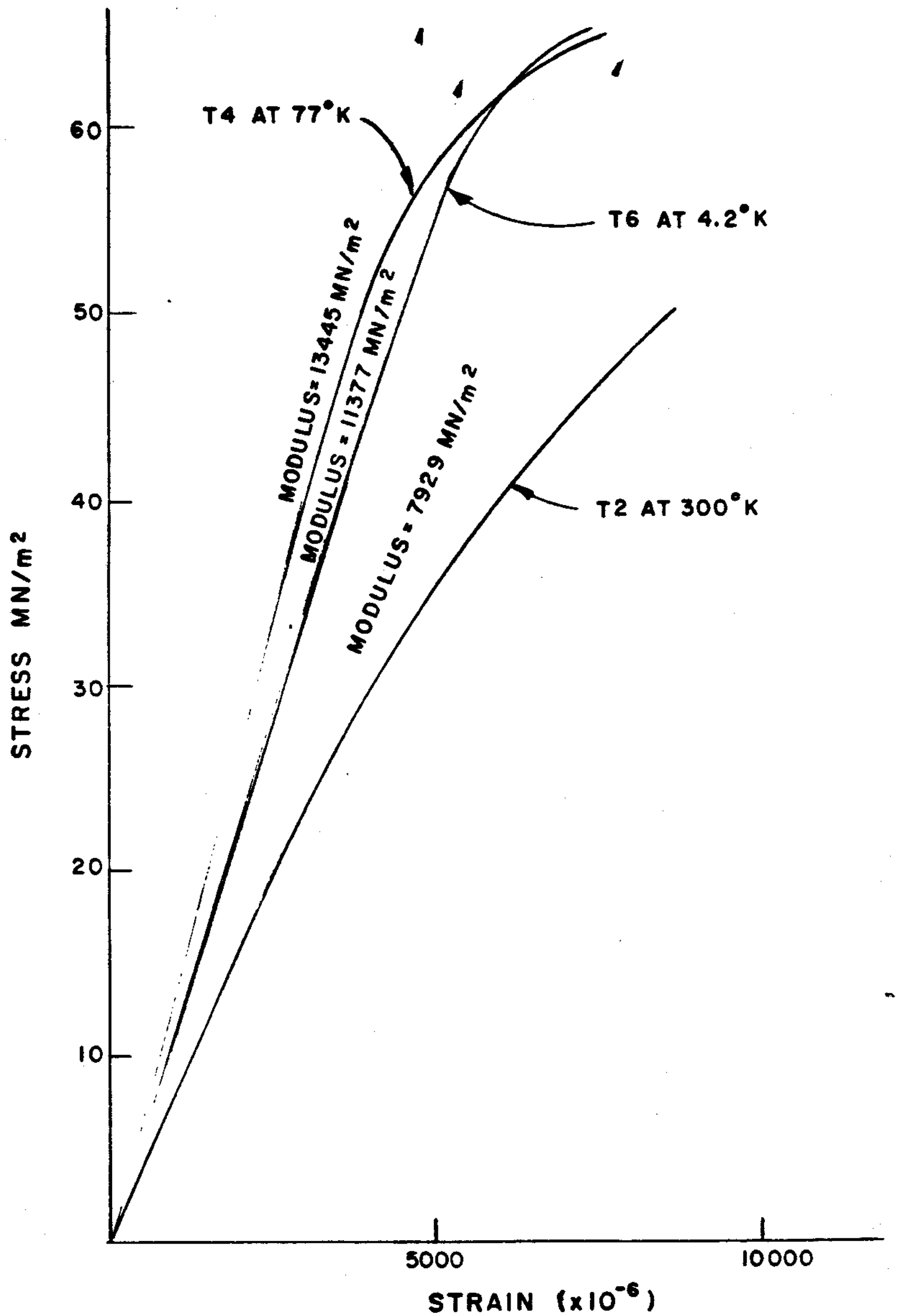
Figure 5 Longitudinal Stress-Strain Characteristics of Micarta

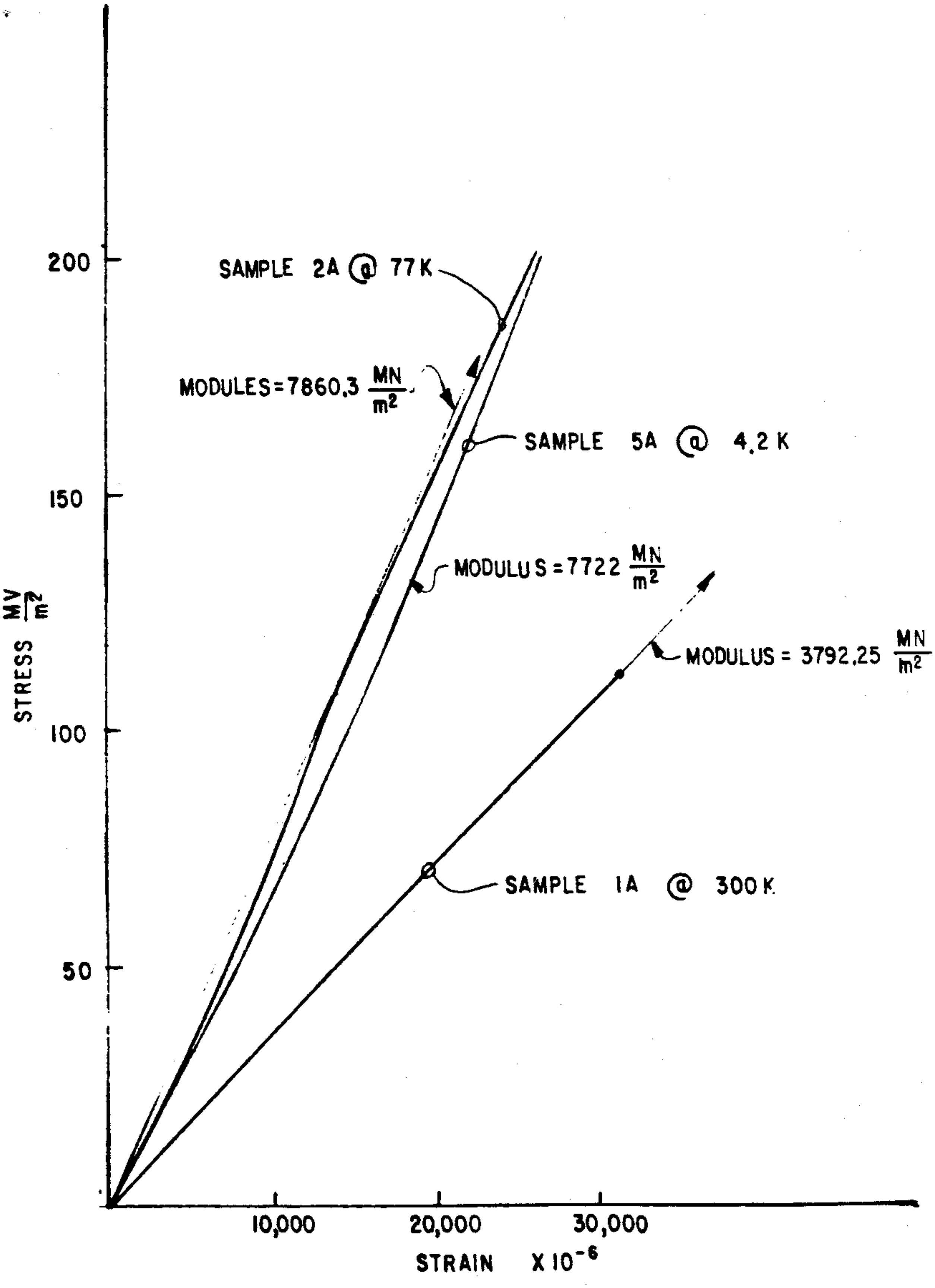
Figure 6 Integral Thermal Contraction of A & B Epoxy Putty and Pultruded Fiberglass Laminate

Figure 7 Tensile Stress-Strain Characteristics Pultruded Fiberglass Laminate at 4.2 K

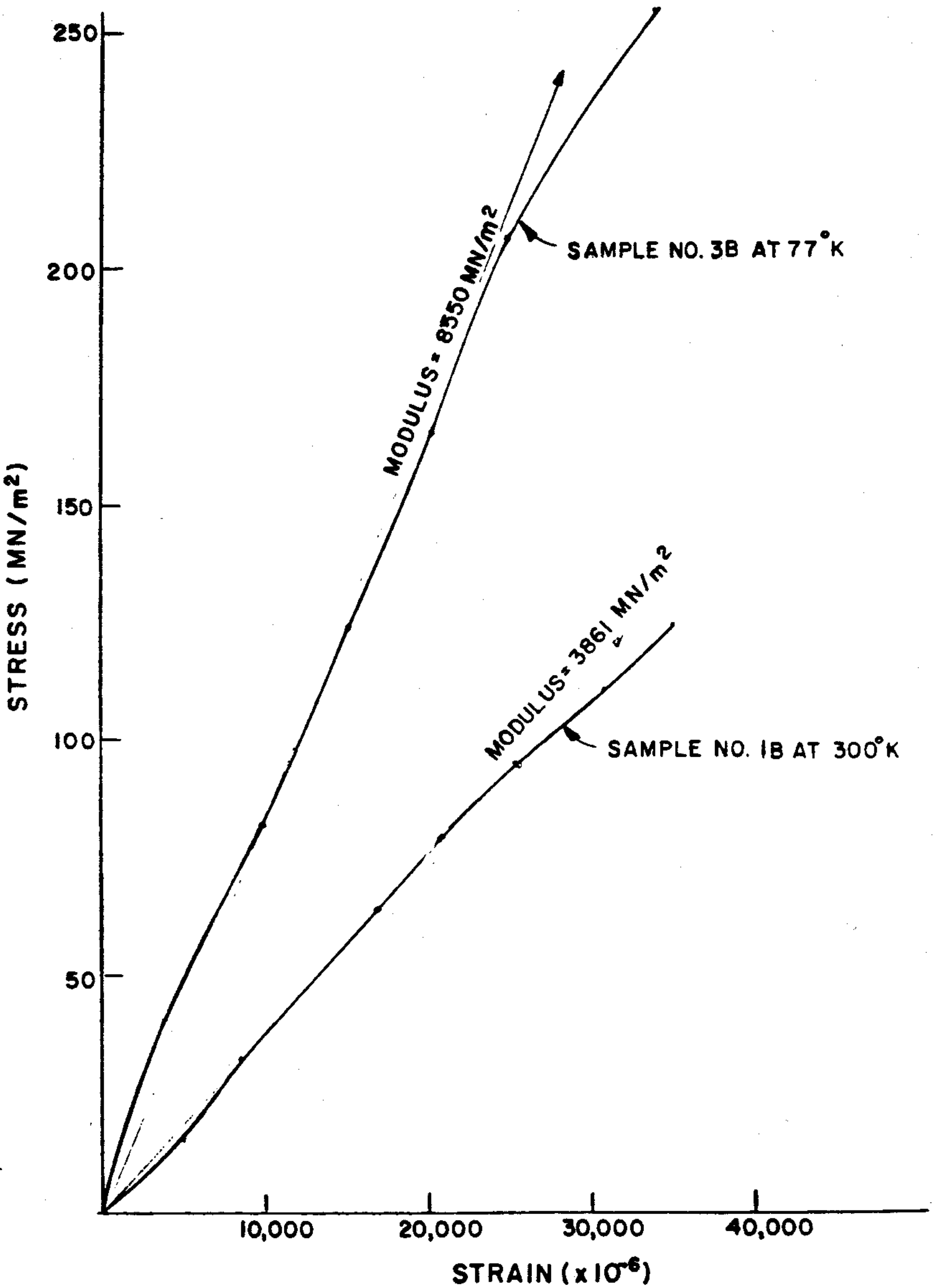

INSTRON



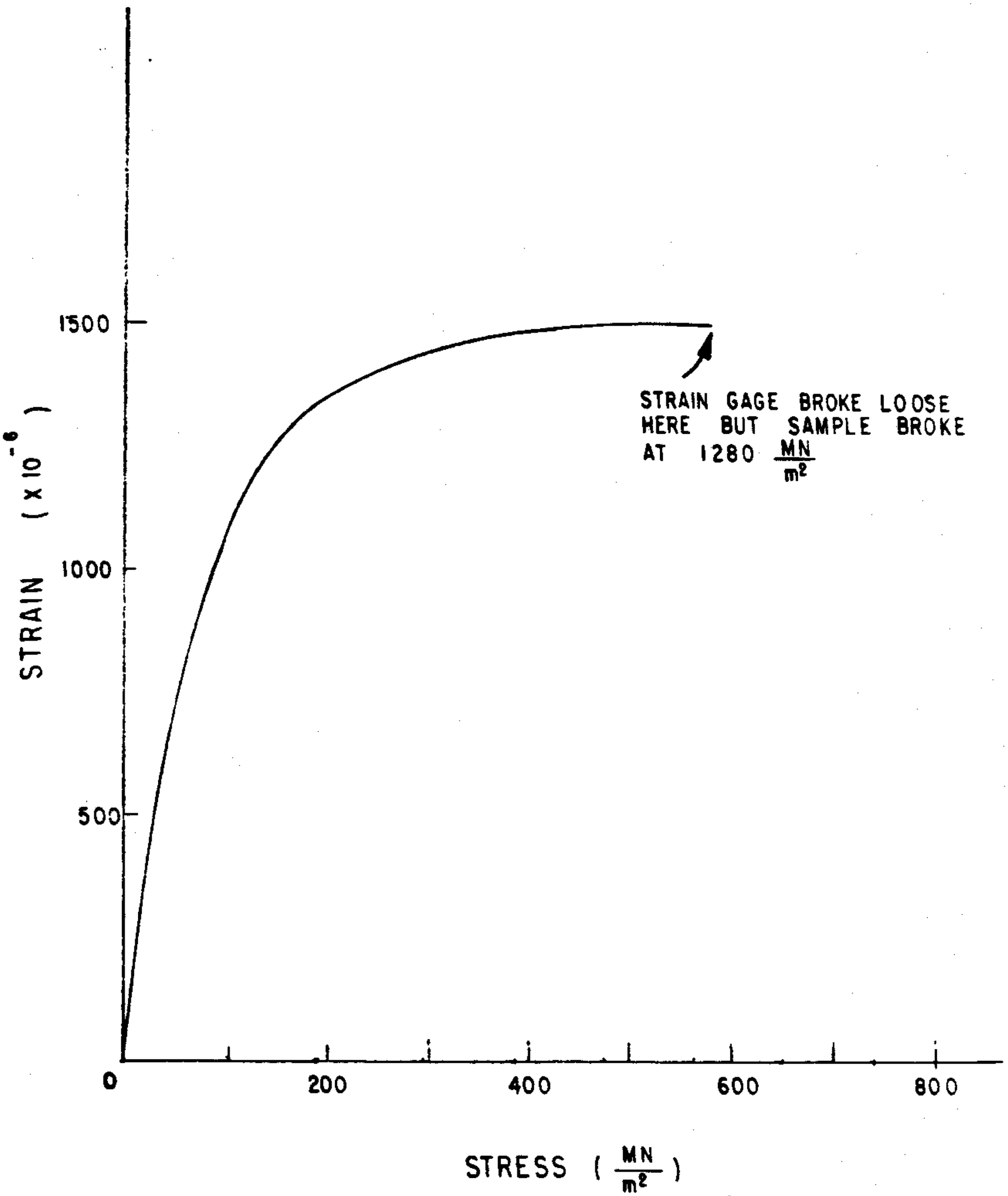

T4 AT 77°K
T6 AT 4.2°K
T2 AT 300°K
MODULUS = 13445 MN/m2
MODULUS = 11377 MN/m2
MODULUS = 7929 MN/m2
STRESS MN/m2
60
50
40
30
20
10
5000
10000
STRAIN (x10-6)



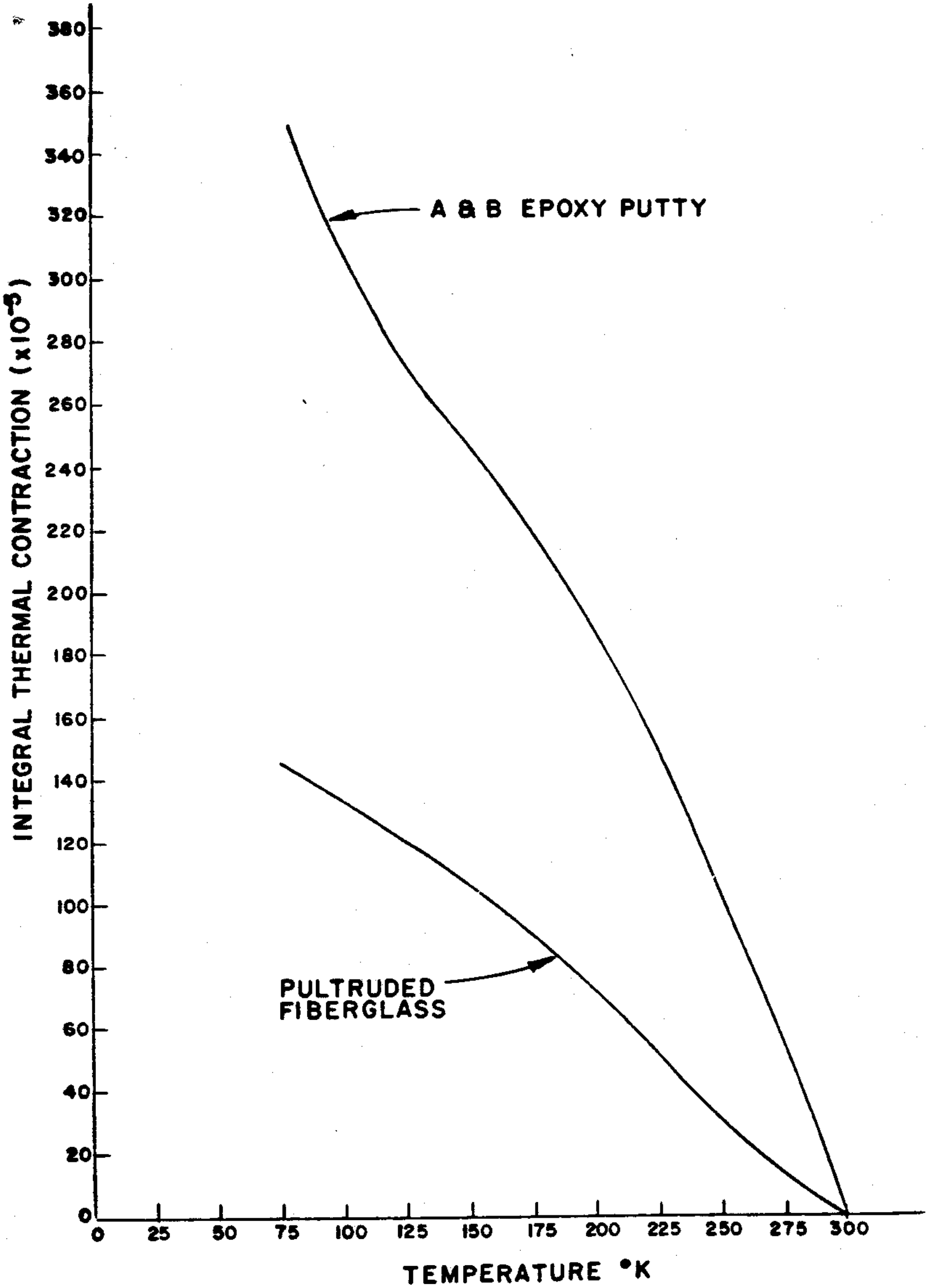
200
150
100
50
STRESS MV/m²
SAMPLE 2A @ 77 K
MODULES = 7860.3 MN/m²
SAMPLE 5A @ 4.2 K
MODULUS = 7722 MN/m²
MODULUS = 3792.25 MN/m²
SAMPLE 1A @ 300 K
10,000
20,000
30,000
STRAIN X 10⁻⁶



250
200
150
100
50
STRESS (MN/m²)
10,000
20,000
30,000
40,000
STRAIN (x 10⁻⁶)
MODULUS = 8550 MN/m²
SAMPLE NO. 3B AT 77°K
MODULUS = 3861 MN/m²
SAMPLE NO. 1B AT 300°K



1500
1000
500
STRAIN (x 10^{-6})
STRAIN GAGE BROKE LOOSE HERE BUT SAMPLE BROKE AT 1280 $\frac{MN}{m^2}$
0
200
400
600
800
STRESS ($\frac{MN}{m^2}$)


A & B EPOXY PUTTY
PULTRUDED FIBERGLASS
INTEGRAL THERMAL CONTRACTION (x10⁻⁵)
TEMPERATURE °K
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
0
25
50
75
100
125
150
175
200
225
250
275
300