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THE LOW TEMPERATURE TENSILE STRENGTH OF BERYLLIUM SHEET*

by

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Beryllium sheet and foil are often used as material for beam windows in cryogenic targets and other nuclear detectors. As such devices are frequently operated at pressures higher than atmospheric, a knowledge of the strength of the window material is required. To supplement the very sparse amount of published information[1] on the low temperature mechanical properties of beryllium, the effective yield strength and the ultimate tensile strength of beryllium sheet were determined at ambient temperature, liquid nitrogen and liquid hydrogen temperatures.

Before beryllium powder is extruded, rolled or otherwise processed in the various ways that lead to preferred grain orientation, the grains are somewhat randomly oriented with respect to one another. In this condition the material exhibits brittleness at room temperature with ductilities of less than 2 to 3 percent. When the material is rolled into sheet or foil the grains assume a preferred orientation with a concomitant increase in the ductility of some 10 to 15 percent. The mechanical properties differ in the longitudinal and transverse direction. In cross-rolled sheet this difference tends to disappear and the material becomes anisotropic in the "c" direction, i.e., normal to the rolling direction. It is also known that the stress-strain variations with the BeO concentration depend on temperature to a certain extent.

The characteristics of the materials used in the present investigation are summarized in Table 1.

Standard test coupons prepared according to the ASTM specification E8-65, paragraph 4.3 (sheet metal), were used for all the measurements.

To eliminate errors due to grip slippage and thermal effects in the tester, the strain was measured directly on the coupons with Baldwin-Lima-Hamilton FNH-100-12 Nichrome V foil strain gauges. Although this type of gauge has a relatively large temperature coefficient of resistance which causes a shift in the gauge resistance during cool-down, past experience has shown that once temperature equilibrium is established, the gauge exhibits a fairly uniform gauge factor at the temperature of the cryogen.

Table 1

Characteristics of Beryllium Sheet

Supplier: The Brush Beryllium Company

Condition: Hot rolled, stress relieved, ground and pickled

Sheet No:	Sheet size
466B2	$0.3175 \times 30.48 \times 30.48\ cm^3$
793A2	$0.3175 \times 30.48 \times 30.48\ cm^3$

Chemical Analysis: Percent

Sheet No:	Be Assay	BeO	Fe	Si	Al	Mg	C	Any other metallic elements
466B2	98.2	1.78	0.124	0.04	0.055	0.008	0.11	Less than 0.04
793A2	98.6	1.41	0.13	0.04	0.090	0.010	0.13	

Mechanical Properties – certified at room temperature:

Sheet No.	Test Direction	Ultimate Stress $Kg\ cm^{-2}$	Yield Stress $Kg\ cm^{-2}$	Elongation %
466B2	Longitudinal	6230	4880	16.5
	Transverse	6190	4950	22.0
793A2	Longitudinal	5260	3540	10.0
	Transverse	5520	3640	18.0

In materials exhibiting abrupt yielding characteristics, the yield point stress is a more significant parameter than the stress at the point of 0.2% deviation from elastic proportionality. On this basis the determination of unit strain or the ratio of stress to strain up to the yield point or yield strength point then becomes most meaningful. Accurate relative strain data beyond the yield point were therefore not considered essential. In addition, since measurement uncertainties which are difficult to evaluate were also involved, absolute values for the unit strain were not measured under low temperature conditions. The method used, however, does permit a comparison of relative strain at the various test temperatures, and, as all measurements were made in the same manner, a comparison with data obtained by standard test methods at room temperature becomes trivial.

The results of the measurements are summarized in Figs. 1 and 2. It is evident that the elastic range of the material is extended and the plastic range is reduced as the temperature is lowered. At room temperature the coupons made from sheet with the lower BeO content exhibit lower yield points and a comparatively wide range of plastic strain, resulting in a relatively high ultimate strength. In liquid nitrogen the plastic region is significantly reduced. At 21°K, however, there is less difference between the yield points and the strengths of the sheets with a different BeO content. At this temperature, there is no evidence of a plastic region in either material. The elongation changes from some 14 percent at room temperature to not more than 3 percent at 78°K and to less than 0.5 percent at 21°K. The effect of low temperature on the ultimate strength is less clearly defined: it appears that the ultimate strength values at liquid nitrogen temperatures are some 10 percent below the room temperature values. This decrease is not well understood, but it is believed that excessive twinning of aligned beryllium crystals may result in the premature failure.[2]

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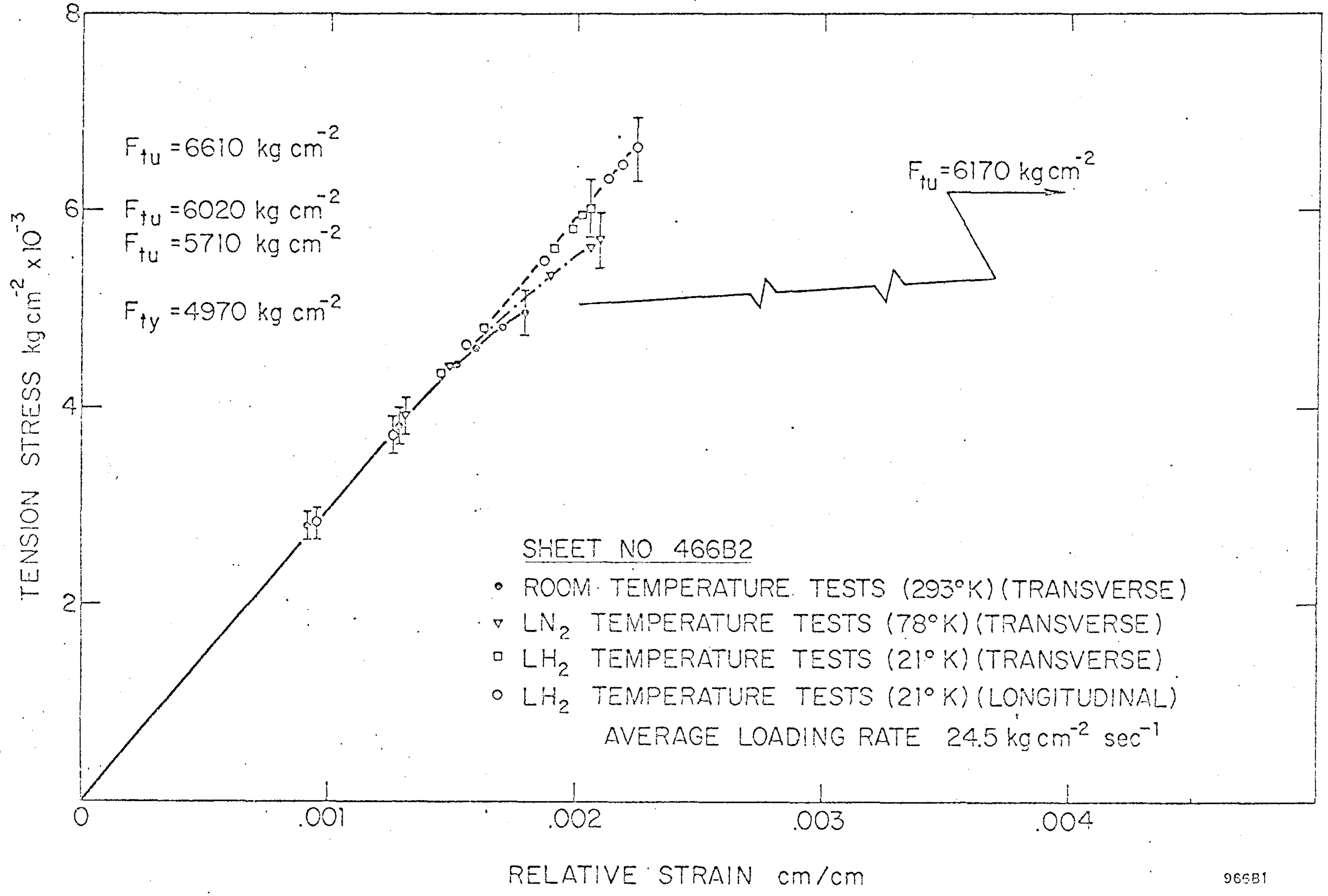
References

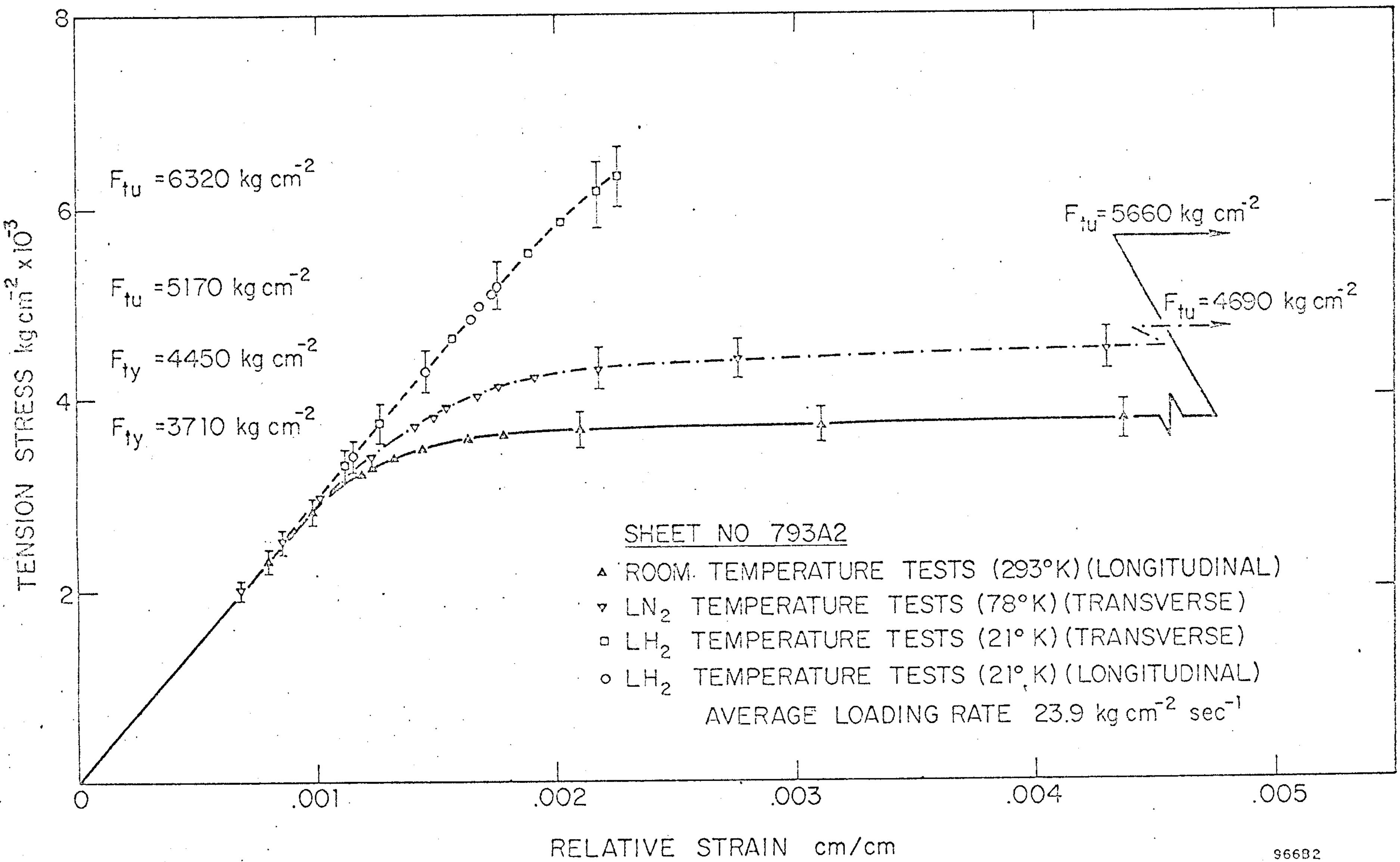
1. J. T. Milek, "Beryllium Mirrors of Cryogenic Temperatures," Hughes Aircraft Co., Report No. OPSR-3, 1967.

2. M. I. Jacobson, ASM Trans., 57 No. 2, 482 (June 1964).



8
6
4
2
0
TENSION STRESS kg cm^{-2} x 10^{-3}
F_{tu} = 6610 kg cm^{-2}
F_{tu} = 6020 kg cm^{-2}
F_{tu} = 5710 kg cm^{-2}
F_{ty} = 4970 kg cm^{-2}
F_{tu} = 6170 kg cm^{-2}
SHEET NO 466B2
ROOM TEMPERATURE TESTS (293°K) (TRANSVERSE)
LN_2 TEMPERATURE TESTS (78°K) (TRANSVERSE)
LH_2 TEMPERATURE TESTS (21°K) (TRANSVERSE)
LH_2 TEMPERATURE TESTS (21°K) (LONGITUDINAL)
AVERAGE LOADING RATE 24.5 kg cm^{-2} sec^{-1}
.001
.002
.003
.004
RELATIVE STRAIN cm/cm
96681

FIG. 1



8
6
4
2
0
TENSION STRESS kg cm^-2 x 10^3
F_tu =6320 kg cm^-2
F_tu =5170 kg cm^-2
F_ty =4450 kg cm^-2
F_ty =3710 kg cm^-2
F_tu = 5660 kg cm^-2
F_tu = 4690 kg cm^-2
SHEET NO 793A2
△ ROOM TEMPERATURE TESTS (293°K) (LONGITUDINAL)
▽ LN2 TEMPERATURE TESTS (78°K) (TRANSVERSE)
□ LH2 TEMPERATURE TESTS (21° K) (TRANSVERSE)
○ LH2 TEMPERATURE TESTS (21° K) (LONGITUDINAL)
AVERAGE LOADING RATE 23.9 kg cm^-2 sec^-1
.001
.002
.003
.004
.005
RELATIVE STRAIN cm/cm
96682

FIG. 2