THERMAL EXPANSION OF CRYOGENIC-GRADE GLASS-EPOXY LAMINATES

National Bureau of Standards

Ranney, M.A., & Clark, A.F. (1980). Thermal expansion of cryogenic-grade glass-epoxy laminates. In R.P. Reed (Ed.), *Materials studies for magnetic fusion energy applications at low temperatures - III*, (pp. 407-412). Boulder, CO: National Bureau of Standards.

THERMAL EXPANSION OF CRYOGENIC-GRADE GLASS-EPOXY LAMINATES

M. A. Ranney and A. F. Clark

ABSTRACT

Thermal expansion measurements for special grades of NEMA-type G-10 and G-11 glass-epoxy laminates were carried out in a quartz-tube dilatometer over a temperature range 4 to 300 K. It was found that expansions in the warp direction were comparable to those of the samples' reinforcement fabric, whereas expansions in the normal direction were characteristic of the samples' epoxy resins.

INTRODUCTION

Special grades of NEMA-type G-10 and G-11 glass-epoxy laminates (G-10CR and G-11CR) were measured for thermal expansion to investigate further their use in cryogenic properties.

These laminates are commercial products meeting current NEMA G-10 and G-11, MIL-P-18177C, and federal LP-509 specifications. G-10CR is a heat-activated, amine-catalyzed bisphenol A solid-type epoxy resin laminate reinforced with continuous-filament E-glass fabric, silane finished. G-11CR is an aromatic-amine hardened bisphenol A liquid-type epoxy resin laminate reinforced in the same manner.

Both laminates are woven glass cloth composites. The warp fibers are those which emerge from the loom, and fill fibers are those woven across them at right angles. Each composite has a yarn count of 17 $\pm$ 1 per cm (43 $\pm$ 3 per in) for warp and 12.6 $\pm$ 0.8 per cm (32 $\pm$ 2 per in) for fill. The composites' normal direction is perpendicular to the cloth ply plane.

Our measurements for G-10CR and G-11CR are in the warp and normal directions.

SAMPLE PREPARATION

For measurements in the normal direction, samples were prepared using eight pieces of each laminate, which were bonded end-to-end by a commercially available epoxy resin adhesive. This adhesive has special low expansion properties and was used to minimize our experimental error. The G-10CR sample dimensions were 6.5 mm x 6.5 mm x 19.92 mm, and the G-11CR sample dimensions were 6.5 mm x 6.5mm x 19.76 mm.

The samples for warp direction measurement were both directly machined to the dimensions 4.2 mm x 4.2 mm x 20.32 mm.

APPARATUS

Measurements were made in a quartz tube dilatometer [1], schematically shown in Figure 1. The differential contraction is transmitted to a room temperature mechanical dial gauge (sensitivity 0.5 μm) by concentric quartz tubes (labeled quartz support tube and quartz rider in Figure 1). All samples were kept vertical by a copper heat shield, which also inhibited thermal gradients from interfering with the measurement accuracy.

Samples were each cooled at a rate of 2.5 K min^{-1} from 300 to 4 K, and the temperature was determined by a chromel-constantan thermocouple attached directly to the samples at midpoint. The helium gas temperature and the sample temperature were assumed to be the same.

The apparatus was calibrated by measuring the thermal expansion of a polycrystalline OFHC copper bar. The difference between the average measured data and the standard reference material (SRM) data for OFHC copper [2] was used as an absolute correction factor. Measurement accuracy was estimated at $\pm$ 0.005%.

RESULTS

Figure 2 shows the relationship of the four samples tested (G-10CR warp and normal, G-11CR warp and normal), graphically depicted in terms of thermal expansion.* A computer curve fitting program was developed to fit the experimental data, [L(293) - L(T)]/L(293), and to approximate expansion coefficients, [1/L(293)](dL/dT) K^{-1}, from the data. The form of the function was

$$\frac{L(293) - L(T)}{L(293)} = a + \frac{T^4}{b + cT^2 + dT^3} . \qquad (1)$$

Table 1 summarizes the data for the four samples.

CONCLUSIONS

The data obtained indicate that thermal expansion in the warp direction is comparable to that of the composites' E-glass reinforcement fabric, while expansion in the normal direction is characteristic of the bisphenol A epoxy resin. Aside from the present study, only one other reference of G-10CR and G-11CR expansion data was located. These data on the same material, independently provided by the Los Alamos Scientific Laboratory, R. I. Schermer [3], gave the total contraction from 295 K to 75 K using a fixed-point apparatus. The Los Alamos data is found to be consistently ~10% greater in total contraction than the data in the present study, yet the difference is within the accuracy limits of the two sets of measurements.

---

*The SRM 736 Copper Standard is included as a scaling reference.

REFERENCES

1. A. F. Clark, Cryogenics 8, 282 (1968).
2. T. A. Hahn, J. Appl. Phys. 41, 5096 (1970).
3. M. B. Kasen, J. G. Hust, and H. M. Ledbetter, "Nonmetallics for Magnet Systems," in Materials Study for Magnetic Fusion Energy Applications at Low Temperatures-II, NBSIR 79-1609 (1979), p. 405.

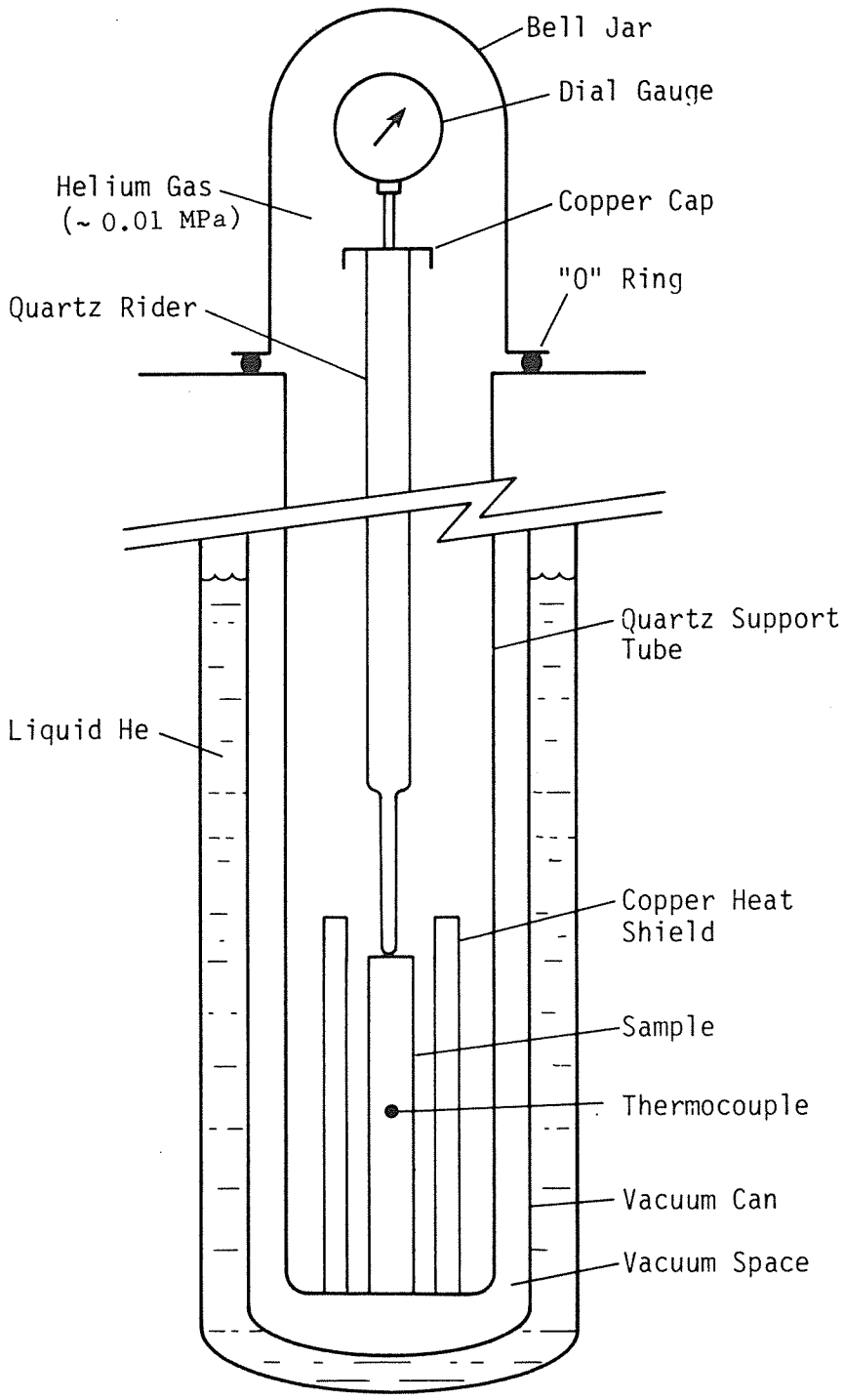

Figure 1. Schematic representation of quartz tube dilatometer.

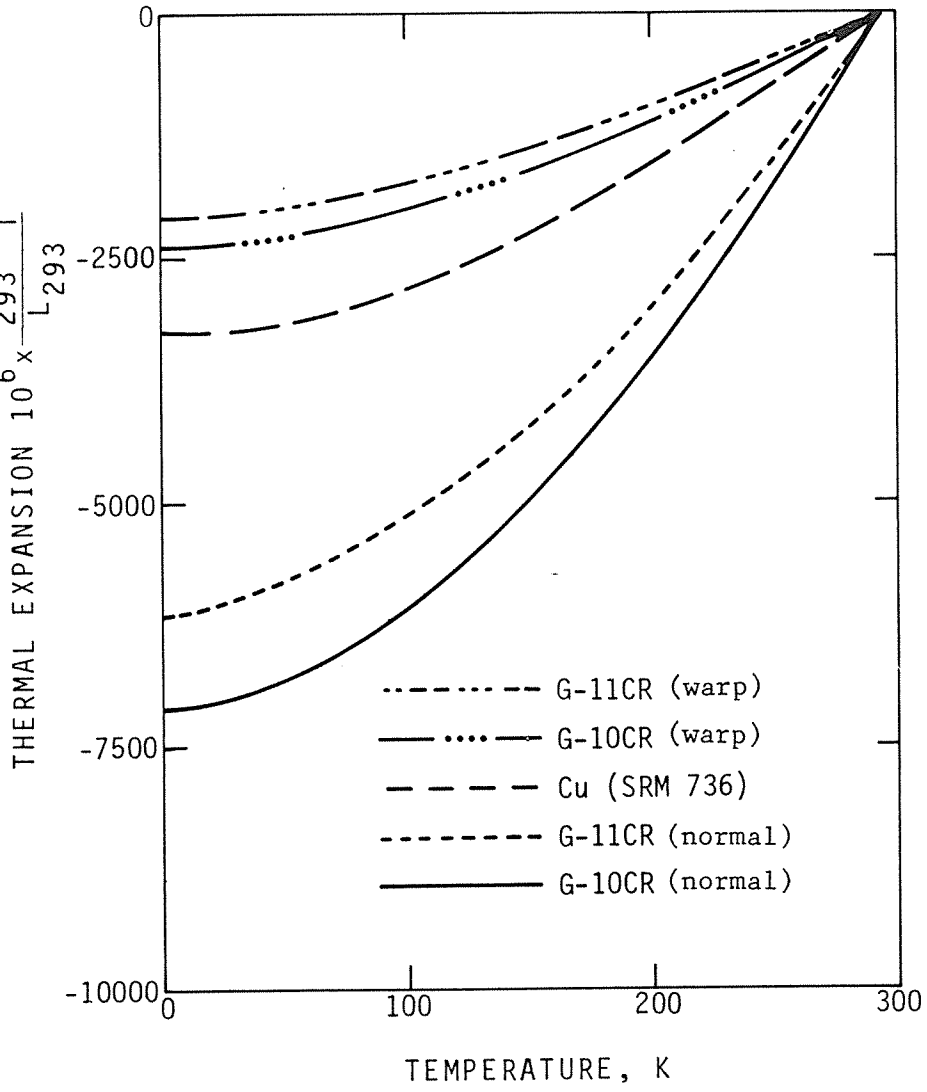

Figure 2. Thermal expansion of G-10CR and G-11CR in both warp and normal directions.

Table 1. THERMAL EXPANSION DATA FOR G-10CR and G-11CR

	G-10CR (warp)		G-11CR (warp)		G-10CR (normal)		G-11CR (normal)	
T,K	$10^6 \frac{L_{293}-L_T}{L_{293}}$	$\frac{10^8}{L_{293}} \cdot \frac{dL}{dT}$ K^{-1}	$10^6 \frac{L_{293}-L_T}{L_{293}}$	$\frac{10^8}{L_{293}} \cdot \frac{dL}{dT}$ K^{-1}	$10^6 \frac{L_{293}-L_T}{L_{293}}$	$\frac{10^8}{L_{293}} \cdot \frac{dL}{dT}$ K^{-1}	$10^6 \frac{L_{293}-L_T}{L_{293}}$	$\frac{10^8}{L_{293}} \cdot \frac{dL}{dT}$ K^{-1}
20	2409	267	2052	157	7055	599	6076	602
40	2337	448	2007	290	6900	978	5914	989
60	2234	574	1937	406	6670	1308	5690	1243
80	2109	664	1846	510	6379	1599	5422	1422
100	1970	733	1734	607	6031	1881	5122	1574
120	1817	793	1603	695	5627	2164	4791	1743
140	1652	853	1456	774	5166	2445	4422	1960
160	1476	918	1294	842	4649	2719	4004	2230
180	1285	986	1120	899	4079	2980	3528	2527
200	1081	1053	935	944	3458	3224	2994	2812
220	864	1111	743	979	2790	3452	2407	3048
240	637	1158	545	1004	2078	3661	1779	3222
260	402	1193	342	1022	1327	3855	1122	3334
273	246	1210	209	1030	818	3972	686	3380
280	160	1217	136	1034	538	4033	448	3398
293	0	1229	0	1040	0	4142	0	3421