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Short Communication

Thermal expansion and thermal conductivity of Torlon at low temperatures

G. Ventura [a,*], G. Bianchini [a], E. Gottardi [b], I. Peroni [a], A. Peruzzi [b]

[a] *Department of Physics, University of Florence, Via L. Pancaldo, 3/37, I-50127 Florence, Italy*
[b] *Department of Energetics, University of Florence, Florence, Italy*

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Abstract

We measured the expansion coefficient of Torlon 4203 (polyamide-imide) as a function of temperature between 4.2 and 295 K. The thermal expansion is lower than that of most polymers. The thermal conductivity k between 0.1 and 5 K was also measured: below 1 K, a quadratic dependence on temperature of k was found, as predicted by the tunnelling model, while the behaviour shown by our data above 1 K suggests the presence of a plateau. © 1999 Published by Elsevier Science Ltd. All rights reserved.

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1. Introduction

Torlon[1] (polyamide-imide) is a thermoplastic polymer which exhibits excellent mechanical properties and good chemical resistance. These characteristics enable Torlon to compete with metals and other engineering plastic resins in a growing number of automotive, aerospace and electronics applications.

Torlon is capable of performing throughout a wide temperature range. In particular, it retains its high strength at low temperatures, thus it is often used in cryogenic applications even if no data regarding its properties in this temperature range exist.

We measured the linear thermal expansion of Torlon 4203 in the 4.2–295 K temperature range and its thermal conductivity between 0.1 and 5 K.

2. Thermal expansion

Our sample was a cylinder 8.2 mm in diameter and 3 cm long. The optical setup for the interferometric measurement of the thermal expansion is shown in Fig. 1: in a folded Michelson interferometer, the two end-arm mirrors were fixed on each side of the sample, so that thermal expansion involved a variation in the difference of optical paths that was twice the sample length change. The interference fringes were counted by a photodetector (PD). A stabilised He–Ne laser was used (HP model 5501A).

The sample was mounted in good thermal contact with the cold plate of a ^{4}He dewar. A copper thermal shield was placed around the sample in order to ensure uniformity in the temperature of the cooled part of the experiment.

Measurements were performed by cooling the sample to 4.2 K and then recording the interference signal versus temperature during the sample heating. To ensure no time-lag existed between the temperature readings and the actual sample temperature, measurements with different heating time constants were performed: the same results were obtained.

The uncertainty of our expansion data was evaluated to be less than 5%. The relative thermal expansion $\Delta L/L$ vs. T is shown in Fig. 2. Curves for other materials are also reported for the sake of comparison: Torlon shows a linear thermal expansion lower than most polymers. Like Stycast 2850FT, Torlon thermal contraction closely matches those of some common metals (i.e. aluminium [1] or brass [2]).

Smoothed values for the thermal expansion of Torlon

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* Corresponding author. Tel.: + 39-55-412497; fax: + 39-55-412497

[1] Torlon is a registered trademark of Amoco Performance Products.

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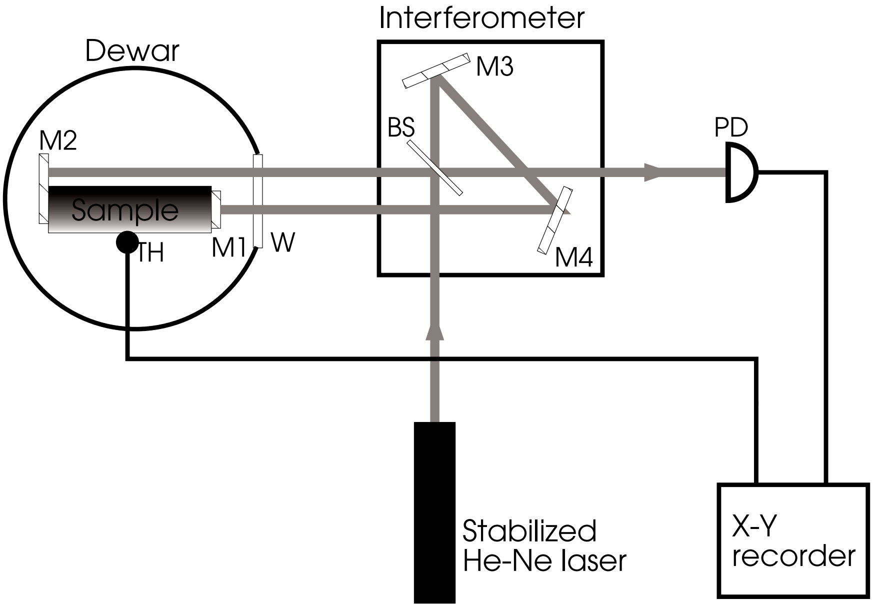

Fig. 1. Optical setup for the interferometric thermal expansion measurement (M1–M4 mirrors, BS beam splitter, PD photodetector, W window, TH thermometer).

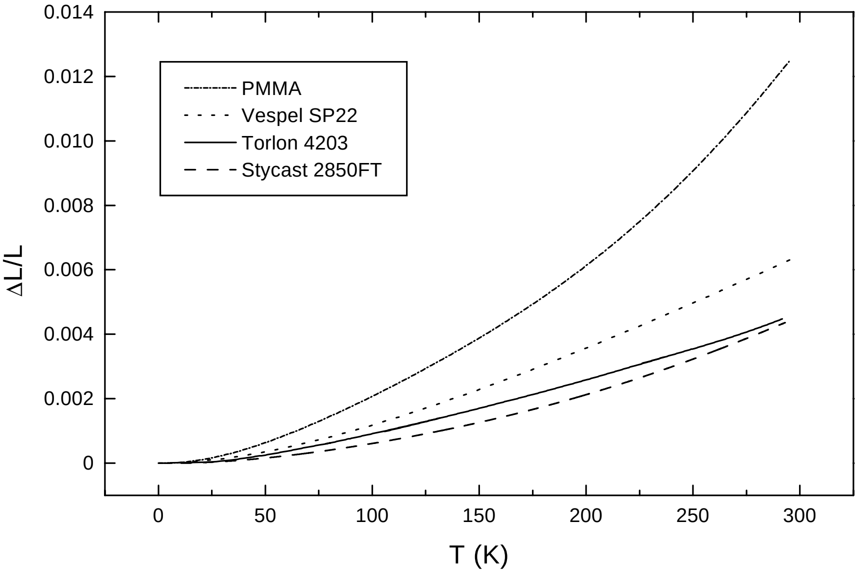

Fig. 2. Relative thermal expansion of PMMA [3], Vespel SP22 (polyimide) [2], Torlon 4203 and Stycast 2850FT [4].

relative to 4.2 K are reported in Table 1. The data are consistent with the thermal expansivity value (3.06×10^{-5} K^{-1} in the 250–400 K temperature range) supplied by the Torlon manufacturer.

3. Thermal conductivity

The sample was a cylinder with a geometrical factor $g = 0.106$ cm (see Fig. 3). The 'lower' end of the sample was fixed onto a copper holder in good thermal contact with the mixing chamber of a dilution refrigerator. A RuO_2 thermometer (R_l) monitored the temperature T_l of the holder. A small block of copper carrying another RuO_2 thermometer (R_u) and also a NiCr heater (H_u) was screwed onto the 'upper' end of the specimen. Four NbTi wires, 25 μm in diameter, were used to make the electrical connections. Their thermal resistance was about four orders of magnitude greater than that of the sample [5].

Thermal conductivity was measured by a steady state technique: the measurements below 1 K (above 1 K) were carried out with the mixing chamber maintained at a constant temperature $T_l \sim 70$ mK ($T_l \sim 300$ mK) by

Table 1
Smoothed values for the thermal expansion of Torlon relative to 4.2 K

T (K)	$\Delta L/L$ (%)	T (K)	$\Delta L/L$ (%)	T (K)	$\Delta L/L$ (%)	T (K)	$\Delta L/L$ (%)	T (K)	$\Delta L/L$ (%)
4.2	0	65	0.0421	125	0.127	185	0.229	245	0.344
10	0.000260	70	0.0485	130	0.135	190	0.239	250	0.353
15	0.000573	75	0.0547	135	0.144	195	0.248	255	0.363
20	0.00146	80	0.0609	140	0.152	200	0.257	260	0.373
25	0.00284	85	0.0682	145	0.160	205	0.266	265	0.384
30	0.00525	90	0.0751	150	0.169	210	0.276	270	0.394
35	0.00913	95	0.0825	155	0.177	215	0.285	275	0.406
40	0.0138	100	0.0900	160	0.186	220	0.296	280	0.417
45	0.0189	105	0.0971	165	0.195	225	0.305	285	0.429
50	0.0237	110	0.104	170	0.202	230	0.316	290	0.442
55	0.0295	115	0.113	175	0.212	235	0.325	295	0.454
60	0.0357	120	0.120	180	0.221	240	0.334		

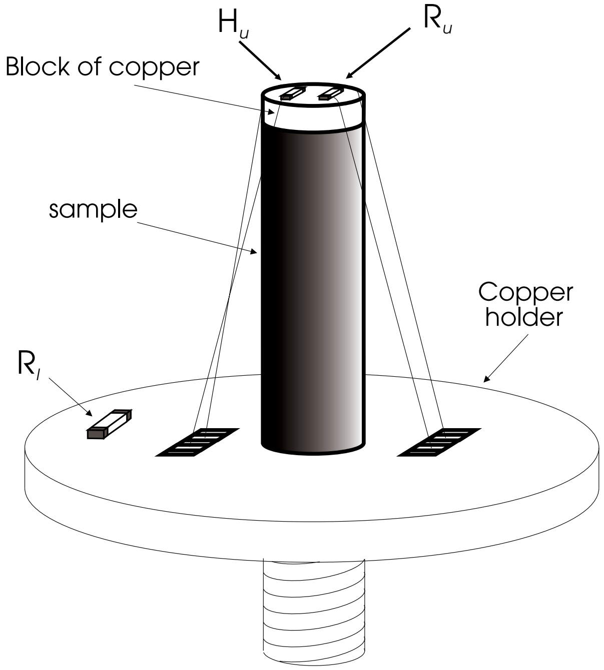

Fig. 3. Experimental assembly.

controlling the power dissipated in a heater glued to the copper holder. Electrical power P was supplied to H_u, and once the thermal equilibrium was reached, the temperature T_u was read by R_u. The heating power P was then changed, in order to obtain a set of data, shown in Fig. 4. The conductivity, obtained as the derivative of P/g, is shown in Fig. 5. The estimated error of k is less than 3%.

To test whether our results depended on the contact resistances, we repeated the experiment with a different g of the sample, obtaining the same values for k. Below 0.8 K, thermal conductivity can be represented by a typical power law $k = \alpha T^n$; the fit gave:

$$k = (6.13 \pm 0.07) \times 10^{-5} T^{2.18 \pm 0.01} \text{ W/cm K}$$

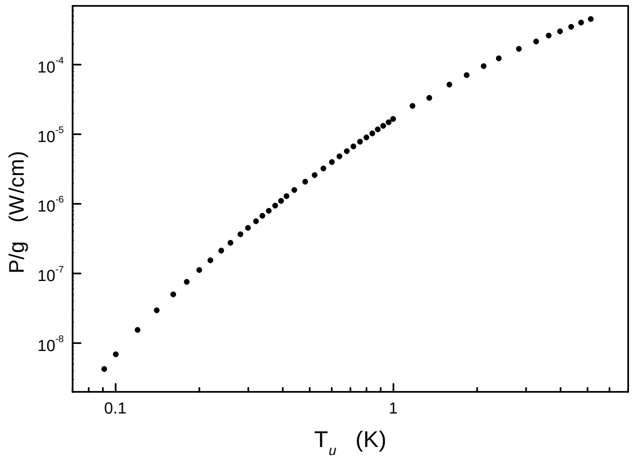

Fig. 4. Heating power applied to the sample.

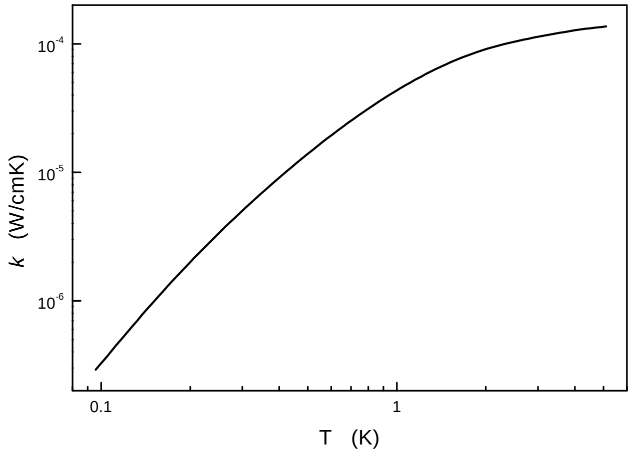

Fig. 5. Thermal conductivity of Torlon 4203.

This behaviour is in good agreement with the tunnelling model [6,7] which for polymers at $T < 1$ K predicts a quadratic temperature dependence of k, due to the resonant scattering of phonons by two level systems.

The decreasing of the slope of $k(T)$ at $T > 1$ K suggests the presence of a plateau, typical of almost all amorphous solids [8]. The beginning of the plateau just above 1 K has also been observed in the thermal conductivity of many other polymers, such as PS and PMMA [9].

4. Conclusions

The extremely low coefficient of linear thermal expansion gives Torlon 4203 excellent dimensional stability. Moreover, Torlon has a very low thermal conductivity: for instance, at 0.1 K, k is only a factor of four greater than that of graphite AGOT [10] (which is currently one of the best thermal insulators known). Torlon is also easily machined and is much stronger than most insulators. All these properties therefore make Torlon particularly suitable as construction material for low temperature apparatus.

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