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Technical Note

Long term elongation of Kevlar-49 single fiber at low temperature

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ABSTRACT

We have measured the rate of elongation of a loaded Kevlar-49 fiber as a function of time at 4.2 K. The result puts a worst case upper limit of 0.028% in the elongation rate $\Delta L/L$ for a 0.5 mm diameter fiber kept under a constant tension of 2.7 kg for 8 months. A value that is probably closer to reality is actually 0.004%. This result proves that Kevlar-49 can be safely used in cryogenic applications in which high mechanical stability under stress is required.

1. Introduction

Kevlar[1] (polyparaphenylene terephthalamide) is a commercial para-aramid synthetic fiber which is extensively used in cryogenic environments because of its excellent mechanical and thermal characteristics. In particular, the low thermal conductivity [1] and the high tensile strength [2] make it very suitable for the mechanical support of heavy components that must be thermally decoupled from the environment.

In case of high tension and long term operations (up to 10 years in our case), the high tensile strength is not by itself sufficient to guarantee good mechanical stability, even when the load is well below the yield strength of the material. Plastic materials are in fact known to suffer mechanical creep, a slow plastic permanent deformation, which depend on load, time, and temperature.

The result of creep is a slow permanent displacement of the load that might be larger than the mechanical tolerance of the system and therefore unacceptable. In this case, a careful characterization of the long term stability of the material is called for.

In this paper we report the measurement of the elongation as a function of time observed on a loaded Kevlar-49 fiber kept for several months at the temperature of 4.2 K. Although the main goal of our work was to verify the possibility of its employment in the construction of high performance suspension systems, we believe that the result has a more general interest in applications where Kevlar-49 is used for holding materials in cryogenic environments.

The suspension systems mentioned above are used to support the core of the CUORE [3–5] experiment, a cryogenic particle physics detector that is under construction at the Laboratori Nazionali del Gran Sasso in Italy.

CUOREs (Cryogenic Underground Observatory for Rare Events) will search for the neutrinoless double beta decay of ^{130}Te and other rare nuclear processes. The purpose of this search is to establish the true nature of the neutrino particle and to measure the neutrino mass. In particular, by using TeO_2 crystals operated as bolometers at a temperature of about 10 mK in a custom-designed cryostat, CUORE aims at reaching an unprecedented sensitivity of the order of 10^{26} y on the half life of ^{130}Te, which would also imply very stringent limits for $m_{\beta\beta}$, the effective neutrino Majorana mass [7].

Such a challenging sensitivity requires very demanding technical specifications on the design and on the construction of the CUORE detector. The experiment will have to operate more than one tonne of detector materials, made by 988 TeO_2 ultra-clean crystals of size $5 \times 5 \times 5\ cm^3$ and weighting 750 g, mechanical supports of the bolometers, radioactive shieldings made in copper and ultra-low radioactivity lead. Besides, the detectors must be kept in an extremely clean environment, carefully shielded from external radioactivity and decoupled from mechanical vibrations, which spoil the energy resolution of the bolometers.

These stringent and partially contradicting requirements make the design of the cryogenic system a real challenge. The large detector mass, the low working temperature, and the very low radioactivity requirements limit the amount and the type of materials that may be used in the construction of the cryostat, and particularly of the mechanical parts that must support the weight of the detector.

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[1] Kevlar is a registered trademark of the Dupont Corporation, Cortland, NY, USA.

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Due to their nice features, Kevlar-49 ropes were chosen for the construction of the CUORE suspension in the section between the 600 mK plate and the Mixing Chamber of the dilution refrigerator. Kevlar-49 ropes strongly reduce the thermal conductivity of the suspension, ensuring at the same time the required thermal insulation and mechanical stiffness. Kevlar-49 is also relatively clean from the point of view of radioactivity and is therefore very suitable for our purpose. The only unknown feature that must be checked before using it in the final design is the creep, and this work fills this gap.

In the following we describe the experimental setup and the results obtained.

2. Experimental setup

In order to measure the elongation of the Kevlar-49 cord under stress at low temperature, we designed and built a dedicated cylindrical capacitor (see Fig. 1).

The capacitance variation is proportional to the elongation of a Kevlar-49 fiber. The capacitance was measured using the commercial instrument NS2000 manufactured by Queensgate [8], a non contact capacitive displacement measuring system which operates by comparing the impedance of the sensing electrodes with a fixed internal reference capacitance $C_{ref} = 10$ pF.

The instrument guarantees the best accuracy and sensitivity when the capacity that must be measured is of the same order of magnitude of C_{ref}. We have therefore designed the cylindrical capacitor accordingly, taking into account the mechanical deformation from room temperature down to 4.2 K.

The capacitor is composed by an inner copper cylinder of radius R_1, covered by a dielectric layer $\Delta\epsilon$ of PTFE (Teflon) and enclosed by an outer copper cylinder with radius R_2 (see Fig. 1). The values of R_1 and R_2 and the Teflon thickness $\Delta\epsilon$ are chosen to leave a small gap g between the outer surface of the dielectric and the outer copper cylinder of radius R_2.

Mechanical construction constraints limit the geometrical parameters as follows: $R_2 \leqslant 5$ mm, $R_1 \geqslant 1$ mm and $g \sim 10$ μm. The small value of the gap is necessary to minimize the possibility of mis-alignment between the two cylindrical electrodes, potentially caused by the thermal contraction of the materials during the cooling down of the setup [9]. The Teflon dielectric layer is necessary to minimize the range of this displacement and avoid electrical shorts between the internal and external electrodes.

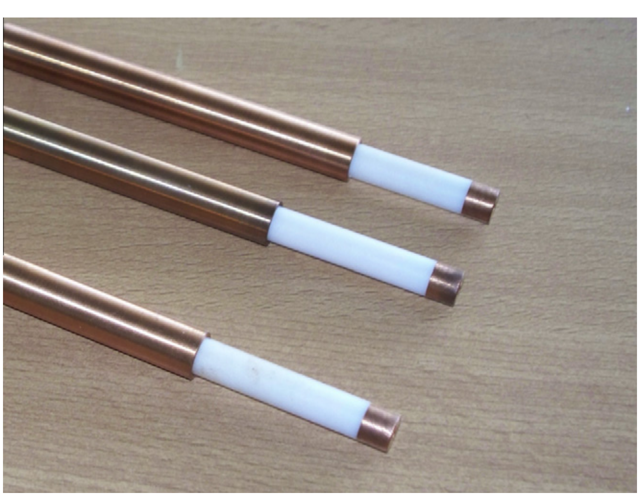

Fig. 1. The three capacitors realized for the low temperature characterization of the single Kevlar-49 fiber. The two cylindrical electrodes are made of copper, and are separated by a layer of PTFE.

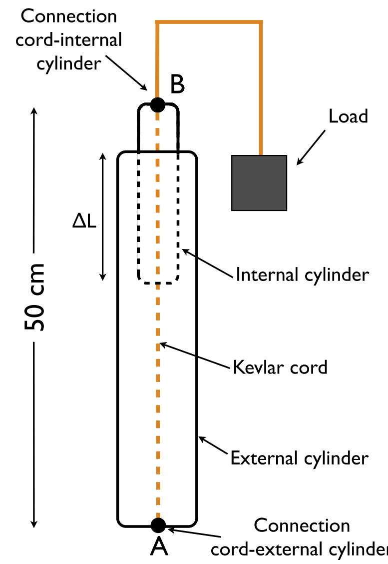

Fig. 2. Sketch (not in scale) of the measuring technique. The cord whose length is measured by the capacimeter is the dashed one. The other cord serves just the purpose of keeping the previous one under constant tension. See text for more details.

In order to obtain a work capacitance of the same order of magnitude of the reference capacitance C_{ref} of the instrument we have chosen the following parameters: $R_2 = 3$ mm, $R_1 = 1.7$ mm, $\Delta\epsilon = 1.29$ mm and $g = 10$ μm. For studying the reproducibility at various configurations, three identical capacitors, C1, C2 and C3, have been built. The capacitors are shown in Fig. 1. In order to asso-

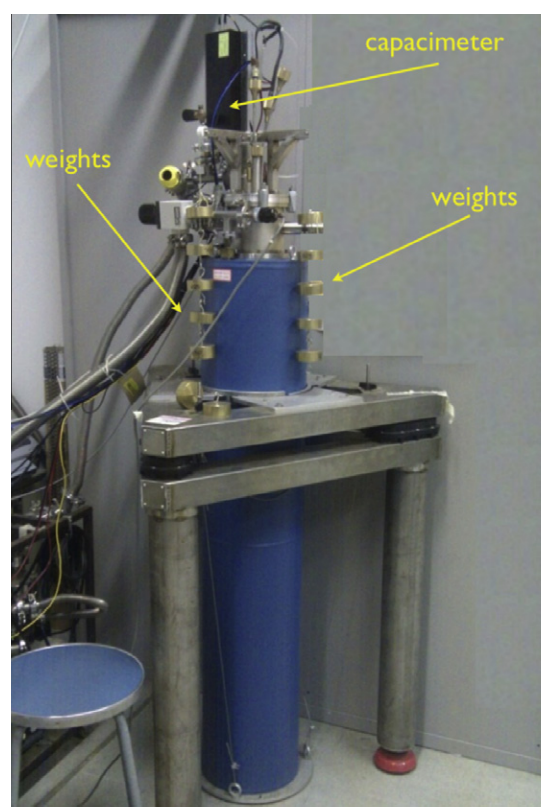

Fig. 3. Experimental setup for the measurement of the Kevlar-49 creep. The three capacitors are arranged inside the dewar. The capacimeter (black box on top) and the brass loads are indicated by arrows.