IL NUOVO CIMENTO **44 C** (2021) 148
DOI 10.1393/ncc/i2021-21148-8

COMMUNICATIONS: SIF Congress 2020

Compressive tests of a graphite used in devices for the production of radioactive beams

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received 19 January 2021

Summary. — SPES (Selective Production of Exotic Species) is an INFN project in advanced construction phase at Legnaro National Laboratories (Padua). The project is aimed at the construction of a facility for the production of radioactive ion beams, for physical and medical research. Due to the severe conditions that will be achieved during operation, owing to the high temperature and severe stresses, graphite is chosen for designing several devices. Experimental tests have been performed to assess the compressive strength of this material with temperature. The tests showed that as temperature increases, the compressive strength increases: at 2000 °C there was an average increase of 22% over its room temperature value. Moreover, as the density increases, the strength increases.

1. – Introduction

Graphite is used across a wide field of industries, thanks to high resistance at high temperature, low thermal expansion and high thermal conductivity. It is also used in some cutting edge fields, such as physical accelerators research facilities. A current example is given by the SPES project, presently in advanced construction phase at the Legnaro Laboratories of INFN, Italy [1, 2]. The project is aimed at the construction of a facility for the production of radioactive ion beams: a proton beam of 40 MeV energy and 200 μA current interacts with a $^{238}UC_x$ target, producing post accelerated beams of neutron-rich radioactive nuclei.

The increasing interest in the use of graphite as a high-temperature structural material is testified by the presence in the literature of numerous studies on the determination of high-temperature mechanical and thermal properties of this material. Even though many quantitative tensile test data are available [3, 4], only Green [5] and Gillin [6] presented experimental results regarding the high-temperature compressive strength. Moreover, the strength proved to be strictly dependent on the particular type of graphite. In the present work, the POCO EDM-3 isotropic ultrafine grain graphite used for the devices of SPES Project has been studied. The particular microstructure and thermal-mechanical properties of this type of graphite makes it suitable for high-temperature and high-vacuum applications [7].

2. – Materials and methods

2·1. *Testing equipment.* – The equipment designed for the experimental tests, shown in fig. 1, is housed inside an aluminium chamber, designed to work in vacuum.

The graphite specimen lies on the fixed punch and it is compressed by the movable punch. Tantalum end blocks are foreseen, in order to withstand the high temperatures reached during the tests. Heating is obtained by Joule effect, by means of tantalum foils, attached to copper clamps. The force is measured by means of an HBM-U9C 10 kN tension-compression load cell. The load is applied by using a manual handling.

2·2. *Testing conditions.* – To test the material, both cylindrical and hourglass specimens have been used (table I). In particular, the cylindrical geometries are characterized by a ratio of height to diameter (H/D) equal to two, according to testing standards [8]. The experimental tests have been performed at room temperature, at 1000 °C and at 2000 °C. Some tests were performed by interposing discs in different materials (silicon carbide and graphite) between the specimen and the punch. Moreover, specimens have been taken from two different lots, with different densities. Lot 1 presents a density equal to 1.67 g/cm^3, while for Lot 2 the density is equal to 1.72 g/cm^3.

2·3. *Testing procedure.* – Specimens have been carefully measured by means of an optical profilometer. Then, the specimen was placed on the tantalum end block of the fix punch. When a vacuum of 10^{-5} mbar was reached, to avoid oxidation caused by high temperatures, the sample was heated by Joule effect. An optical pyrometer checked the

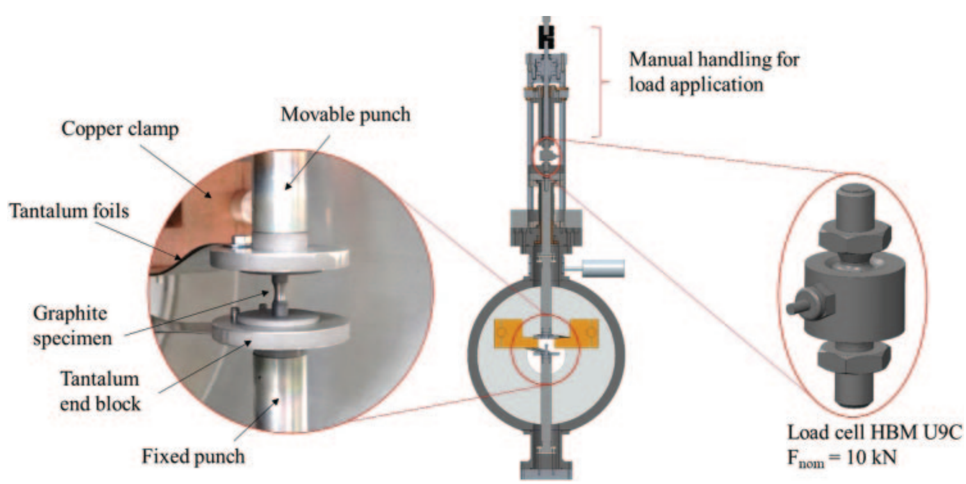
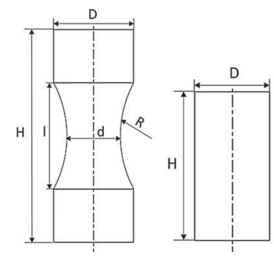


Fig. 1. – Experimental apparatus developed to apply the compressive forces for the tests.

TABLE I. – *Geometries and number of samples tested at room temperature (RT), 1000 °C and 2000 °C.*

Geometry	D [mm]	d [mm]	H [mm]	l [mm]	R [mm]	No. samples		
						RT	1000 °C	2000 °C
Hourglass I	6	4	16	8	8.5	12	4	7
Hourglass II	6	3	14	6	3.75	1	–	–
Cylindrical I	4	–	8	–	–	1	–	–
Cylindrical II	6	–	12	–	–	2	1	–
Cylindrical III	5	–	10	–	–	2	–	–



temperatures during the test. After the desired temperature was reached, the compressive test started, by applying slowly the load up to failure. The load cell allowed to obtain the compressive strength at failure.

3. – Results

Room temperature results have been first analyzed in order to identify the best geometry for the high-temperature tests. Strength values have been compared taking into account the density of the material and the contact material. Cylindrical specimens (fig. 2) showed higher strength for specimens with higher density (Lot 2). Contact material does not seem to influence the result.

Also hourglass specimens were tested at room temperature, interposing different contact materials. The results and the comparison with cylindrical geometries are reported in fig. 3. No influence of the contact material was observed for the hourglass geometries, while the influence of density on the strength is evident. Moreover, the hourglass specimens present higher resistance with respect to the cylindrical geometries. For this reason, the hourglass geometry was preferred for the high-temperature tests, performed at 1000 °C and 2000 °C. Figure 4 presents the average trend of the compressive strength with temperature, evaluated testing Hourglass I geometry. As temperature increases, also the strength increases. In particular, at 2000 °C a 22% average increase over the room temperature value was observed.

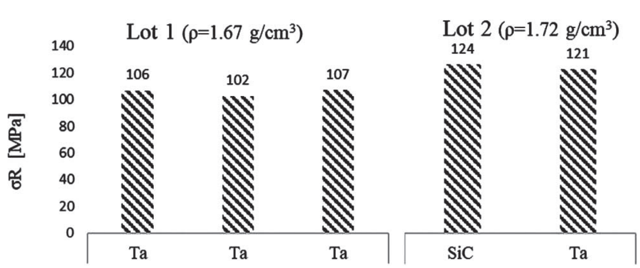


Fig. 2. – Strength data for all the cylindrical geometries at room temperature, obtained from Lot 1 and Lot 2, respectively.

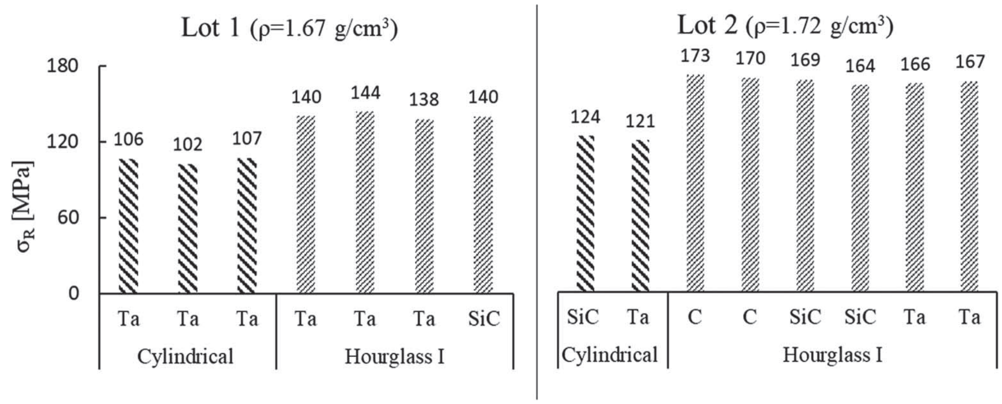


Fig. 3. – Compressive strength at room temperature for cylindrical and hourglass specimens, varying the contact material and the Lot.

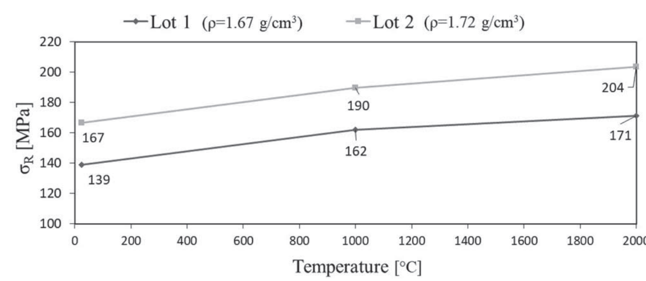


Fig. 4. – Average compressive strength with temperature in Hourglass I specimens, with lines as guides for the eye.

4. – Conclusions

High-temperature compressive tests on an isotropic ultrafine grain graphite, the POCO EDM-3, have been performed. The tests demonstrated that the compressive strength increases as the density and the temperature increase: at 2000 °C a 22% average increase of the compressive strength over its room temperature value was observed.

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