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Note

Electrical Resistance Anisotropy of a POCO AXM-5Q1 Graphite

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The electrical resistance of segments from a POCO AXM-5Q1 cylindrical graphite specimen, which was previously used for measurement of thermal diffusivity, was measured at 20°C. The objective of the measurements was to establish the existence and type of structural anisotropy that might affect the directional thermal transport properties of this material.

KEY WORDS: anisotropy; electrical resistance; graphite; thermal diffusivity.

1. INTRODUCTION

Because of its high refractoriness, desirable optical properties, ease of machining, and established fabrication methods, graphite appeared to be an attractive material for use as a thermal conductivity standard. Initial results from a round-robin cooperative program [1, 2] indicated that POCO AXM-5Q1 graphite[2] could be such a product. A batch of POCO graphite was acquired by the U.S. National Bureau of Standards (NBS) for additional measurements to establish its suitability as a standard reference material.

Subsequent measurements, however, revealed substantial variations in the physical properties of the NBS material. Taylor and Groot [3] found that the electrical and thermal transport properties vary not only from one rod specimen to another but also along any one rod. Moore and Graves [4] found that their thermal conductivity results were higher than those of other investigators. For example, the values obtained by Minges [2] were

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[2] Product of POCO Graphite Inc., Garland, Texas U.S.A.

12–13% lower than their own. On the other hand, the thermal diffusivity of the NBS material measured by Mirkovich [5] was lower than that determined by either Taylor and Groot [3] or Maglic [6]. The cause of these low values was attributed by Mirkovich to two principal factors: the anisotropy of graphite and the thermal diffusivity measuring method.

In a comprehensive publication Hust [7] reported an excellent correlation among electrical resistivity, thermal conductivity, and density, but he also indicated that substantial variations of these properties have been observed between some of the AXM-5Q1 rod specimens. The study by Hust was concerned primarily with interspecimen variations, whereas in this investigation variations within a single specimen were determined.

Because graphite is a scaly material, in the course of fabrication of graphite shapes (by extrusion, pressing, or even isostatic pressing), a certain amount of laminar structuring is unavoidable. The method of POCO graphite fabrication was not known when the thermal diffusivity and electrical resistance measurements were made. However, if the NBS material was originally prepared in the form of rods, then grain orientation, at and congruent to the surface, could be present.

The flash technique [8] was used by Maglic [6] and Taylor and Groot [3]. The specimens were disks, cut so that their flat surfaces were perpendicular to the main axis of the cylindrical samples. The heat flow in such a case would be parallel to the layering and the resulting thermal diffusivity could be higher than that of an amorphous material.

Mirkovich used a method based on radial symmetry [9, 10], where heat flows from the surface to the center of the cylinder. If the layering concentric with the surface existed and the heat flux was crossing it, then this heat flow barrier could account for the lower thermal diffusivity values.

The purpose of this investigation was to establish if variations in electrical resistance existed across the cross section of the cylindrical specimen used by Mirkovich.

2. EXPERIMENTAL, RESULTS, AND DISCUSSION

The specimen, a 25.4×25.4-mm cylinder, was glued to a plastic substrate with epoxy resin. By means of a diamond wafering blade the cylinder was cut into 60 bars, as shown in Fig. 1. The black dot on one of the top bars is the near-the-surface thermocouple hole. The center thermocouple hole was obliterated by the cutting. The bars were numbered as shown in Fig. 2.

After being removed from the substrate, most of the bars (some prisms near the surface had too small a cross-sectional area) were machined into square bars with 2.790 ± 0.0025-mm sides and 25.4 mm long. Twenty-four

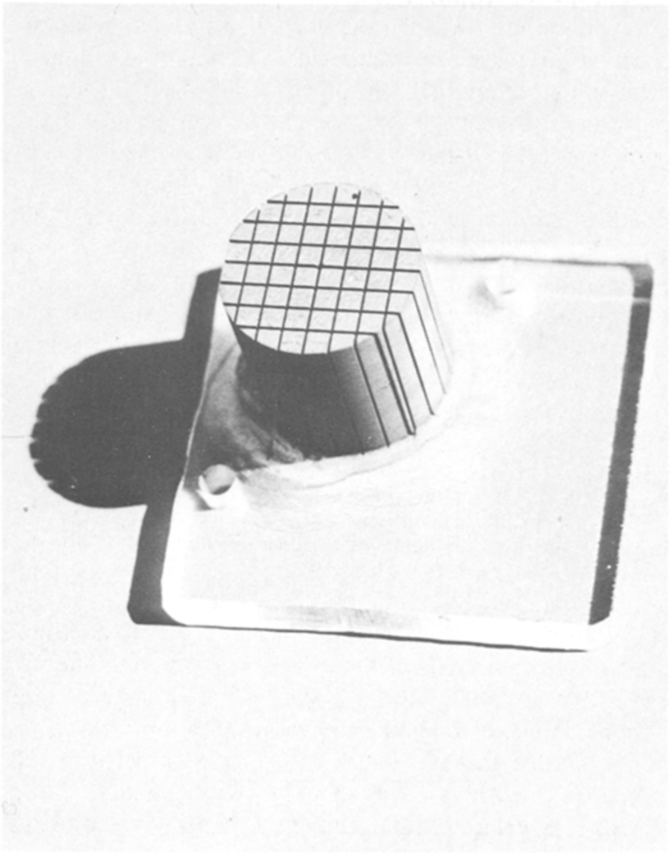

Fig. 1. POCO AXM-5Q1 graphite specimen mounted on plastic substrate and cut into square rods.

specimens were selected for the measurements. Their numbers and locations are shown in Fig. 2. For orientation purposes the thermocouple holes are also indicated. The near-the-surface thermocouple hole is shown on the bar next to the right of the bar 1. The central thermocouple hole is between bars 18, 19, 26, and 27.

Electrical resistance was measured at 20°C by the four-probe method. The voltage probes were approximately 1.3 cm apart, set equidistantly from the ends of the specimen. The measurements therefore pertain to the central half of the cylindrical specimen containing the plane in which thermal diffusivity measurements were made. The results are given in Table I. The average value for the 24 specimens is 1846 $\mu\Omega \cdot$cm. The last column in Table I shows the percentage deviation from the average value.

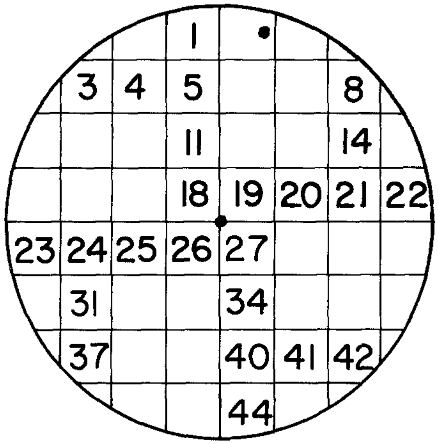

Fig. 2. Location of rod specimens used for measurement of electrical resistance. Black dots indicate positions of thermocouple holes.

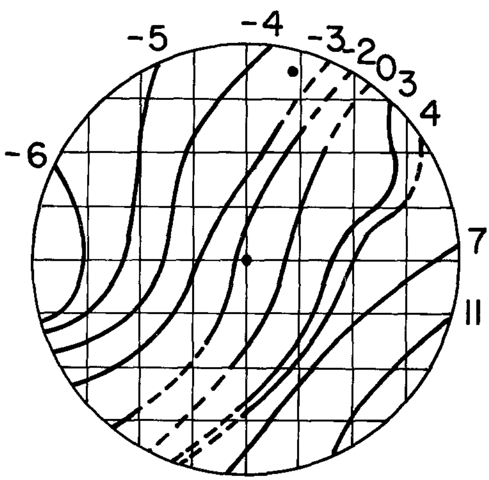

Fig. 3. Positions of lines of equal electrical resistance (as percentage of the average resistance) with respect to the thermocouple holes in the POCO AXM-5Q1 graphite cylinder. Dashed lines indicate uncertainty.

Table I. Electrical Resistivity (at 20°C) of Selected Rod Specimens from a POCO AXM-5Q1 Graphite Cylinder

No.	ρ ($\mu\Omega \cdot$ cm)	Deviation (%)[a]
1	1760	−4.67
3	1745	−5.45
4	1755	−4.93
5	1782	−3.44
8	1900	2.92
11	1783	−3.40
14	1897	2.76
18	1803	−2.30
19	1824	−1.20
20	1867	1.13
21	1921	4.06
22	1970	6.72
23	1723	−6.65
24	1754	−4.96
25	1777	−3.70
26	1807	−2.11
27	1840	−0.32
31	1777	−3.70
34	1873	1.46
37	1798	−2.59
40	1929	4.48
41	1983	7.40
42	2054	11.27
44	1980	7.24
Average	1846	

[a] Percentage deviation from the average value of 1846 $\mu\Omega \cdot$ cm.

Considering that the distance between any two specimen bars is small, the variation in the resistances in this material is rather substantial. For example, the distance between specimen 23 and specimen 42 is barely 2 cm, yet the difference in their resistances is almost 20%. On the basis of the percentage deviation from the average value in Table I, approximate lines of equal resistance were constructed in the diagram in Fig. 3.

Had the lines of equal resistance been concentric with the cylindrical surface, the grain orientation would be simple to deduce: in the proximity of the cylindrical surface the basal plane of the hexagonal graphite crystals would be predominantly parallel with the surface. The lines of equal resistance, however, indicate that the layering in this particular specimen is not concentric with the cylindrical surface. It is therefore possible to have more than one preferential grain orientation that will satisfy the electrical resistance results.

For example, in the low-electrical resistance area between specimen 23 and specimen 3 (Figs. 2 and 3) the predominant orientation of the basal planes of graphite tablets would be parallel with the axis of the cylinder. However, being in a vertical position the flat sides of tablets could stand either parallel or perpendicular to the radius of the cylinder (or in any other position in between). In the first instance the tablets' position would present the lowest resistance to radial heat flow, whereas in the second case the resistance would be the highest. On the other hand, in the area of the highest measured electrical resistance about specimen 42, the preferential orientation of the basal planes of the tablets would be perpendicular to the axis of the cylinder. The resistance to the radial heat flow in this section would be low. Finally, in the zone between the thermocouple holes, where the electrical resistance approaches the average value, either the graphite could have been isotropic or the predominant orientation of the graphite tablets could have been at 45° with respect to the cylinder axis (i.e., a position halfway between the low- and the high-resistance zones). In the second case, the orientation of the tablets with respect to the radius of the cylinder would have a wide choice, making it impossible to predict the resistance to the heat flow between the two thermocouple holes.

The results of electrical resistance measurements did not confirm the existence of grain orientation layering concentric with the surface of the cylindrical specimen, and therefore, the reasons for the comparatively low thermal diffusivity values cannot be established. However, the measurements reveal a considerable variation in the electrical resistance over relatively small distances. This indicates a significant material anisotropicity in the specimen, an undesirable characteristic for a standard reference material.

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