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Electrical Resistivity of Carbon-Carbon Composites

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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I. INTRODUCTION

X-ray diffraction (XRD) parameters have been shown to effectively monitor the progressive change in graphitic ordering with heat treatment in carbon-carbon composites. In addition, XRD parameters have been correlated with electrical resistivity and resistivity ratio. The resistivity ratio is the ratio of that property measured at the normal boiling point of LN_2 to the value at room temperature.[1,2] Electrical resistivity is especially useful for monitoring changes in graphitic ordering because it is relatively simple to measure.

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[1] G. S. Rellick and P. M. Adams, X-Ray Diffraction Studies of Carbon-Carbon Composites, TOR-0086(6645-01)-1, The Aerospace Corporation, El Segundo, Calif. (18 June 1986).

[2] A. D. Cull, Nondestructive Mechanical and Thermal Characterization of Five Involute, Low Risk, Carbon-Carbon Exit Cones, Southern Research Institute (April 1984).

II. EXPERIMENTAL PROCEDURE

The objectives of this procedure were to (1) devise a simple, reproducible method for measuring the electrical resistivity and the resistivity ratio of carbon-carbon composite billets; and (2) verify the method by correlating measurements on "Peacekeeper" exit cone specimens with previously published data.

A four-point method of measuring sample resistance was selected to overcome problems associated with lead and contact resistance (see Fig. 1). Because sample geometry could vary substantially, flexibility was maintained regarding allowable geometry.

During the experiment, the principal problem was how to attach the current and voltage probes to the sample. Several techniques were investigated. The most successful technique was to insert the lead wire into a small hole drilled in the specimen. Good electrical contact was established by coating the end of the wire with electrically conducting paint. Nonconductive epoxy was then used on the wire/sample junction so the junction would be strong enough for the measurement process (Fig. 2).

A schematic diagram of the circuit used in the resistivity measurement is shown in Fig. 3. The circuit had a controlled current power supply, an ammeter, and a high impedance voltmeter. The current through the sample was adjusted to a convenient value between 250 and 500 mA. The voltage drop resulting from resistance of the sample was then determined. The measurement was performed with the sample at room temperature. The measurement was then repeated after the sample was immersed in LN_2. The original room temperature measurement was reconfirmed after permitting the sample to return to room temperature.

To determine sample resistivity, the physical dimensions of the sample and the location of the voltage taps were used in conjunction with the measured sample resistance. The following relation was used

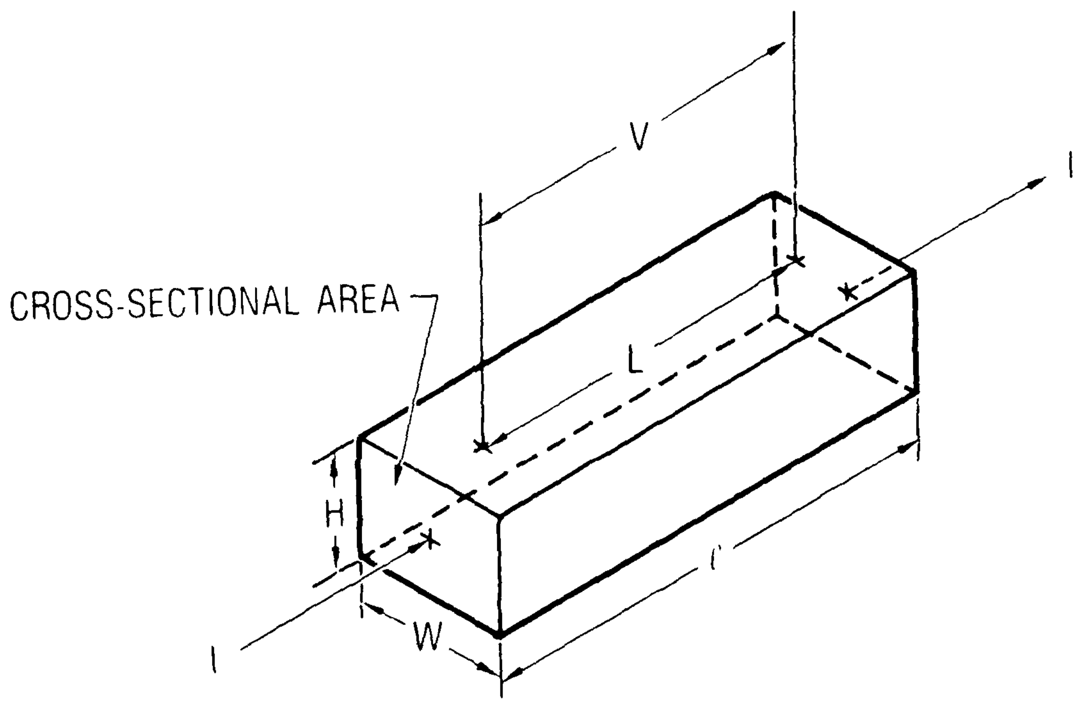

Fig. 1. Sample Geometry

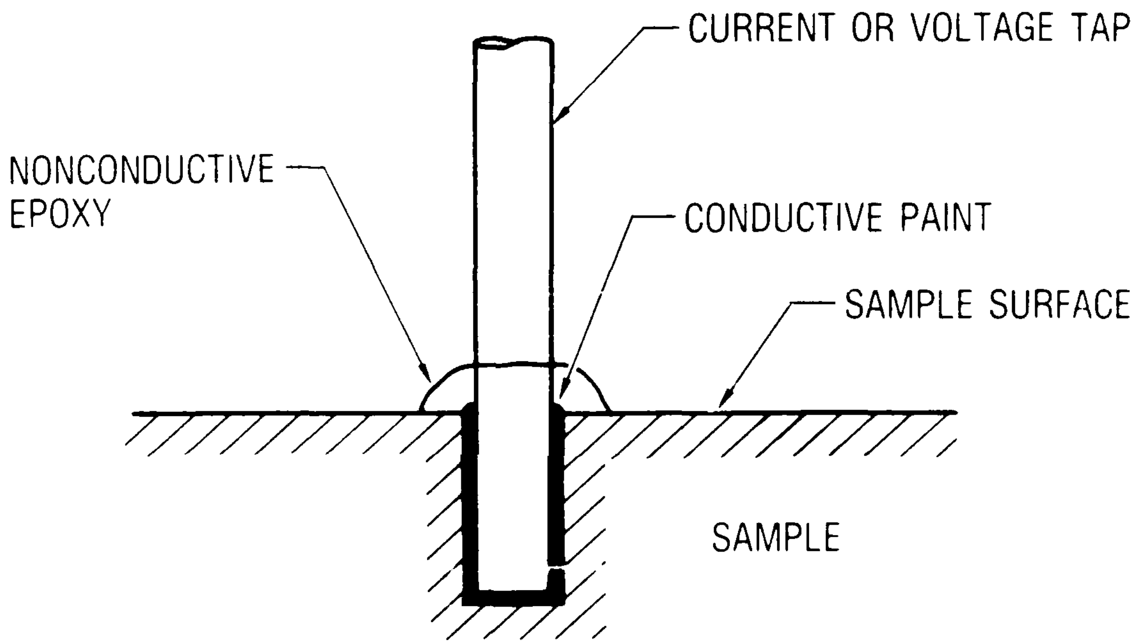

Fig. 2. Junction Construction

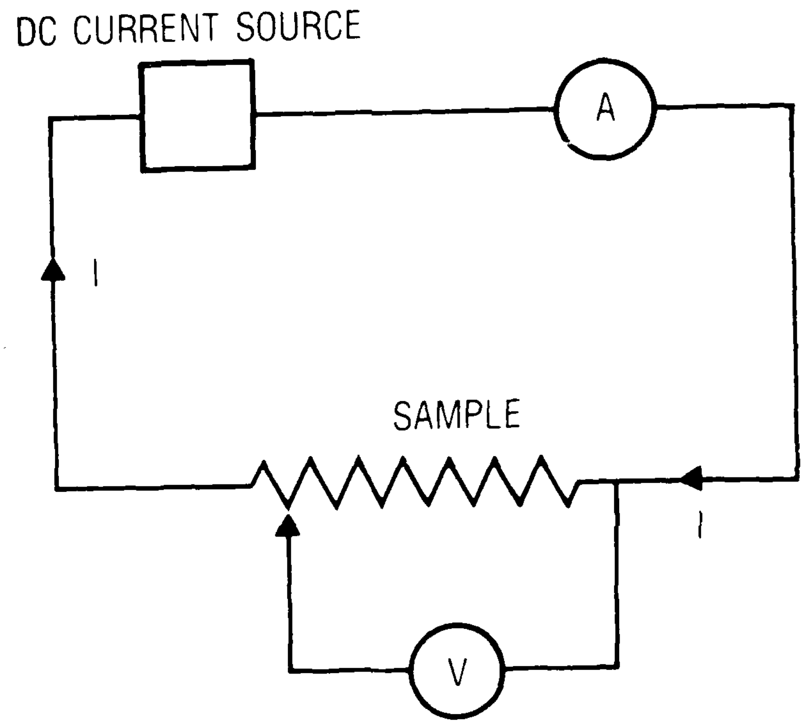

Fig. 3. Equivalent Measuring Circuit

$$\rho = A R/L \quad \text{ohm-cm}$$

where A is the cross-sectional area of the sample in the direction normal to the current flow in square centimeters, R is the resistance in ohms, and L is the distance between the voltage taps in centimeters.

The samples tested and the appropriate identifying and geometric parameters of the samples are listed in Table 1. The measured resistivity and resistivity ratio values are listed in Table 2.

Table 1. Samples

Sample No.	Sample ID	No. of Graphitic Cycles	Sample Height (cm)	Sample Width (cm)	Sample Length (cm)	Distance Between Voltage Taps (cm)
A	10042 SN 218-1	3	1.66	2.60	4.25	3.00
B	10042-013 SN 205	3	0.64	1.32	7.62	5.15
C	10042 SN 218-1	3	1.64	1.89	2.77	1.25
C1	10042 SN 218-1	3	0.85	1.62	1.86	1.20
D	10042 SN 218-1	3	0.35	0.90	---	4.50
F	10060 SN 125	1	0.30	0.60	---	5.00
G	10060 SN-3	2	0.30	0.35	---	5.20
H	10060 SN 126-1	1	0.40	1.00	---	4.70

Table 2. Resistivity of MX Exit Cone Samples

Sample No.	Date	Current Axis	ρ 300 K (μohm-cm)	ρ 77 K (μohm-cm)	ρ 77/ρ 300
A(3G)	10/10/86	Warp	5000	6200	1.22
A	9/18/86	Warp	5300	6300	1.19
A	9/18/86	Warp	5000	(5400)	(1.08)
A	9/17/86	Warp	5100	6300	1.23
A	9/15/86	Warp	5100	---	---
B(3G)	9/18/86	Fill	5500	6100	1.11
B	9/15/86	Fill	5500	---	---
C(3G)	9/19/86	Cross Ply	9200	---	---
C1	10/17/86	Cross Ply	7000	7200	1.03
D(3G)	10/17/86	Warp	4800	5400	1.11
F(1G)	11/7/86	Warp	5200	7500	1.42
G(2G)	11/7/86	Warp	2800	3700	1.33
H(1G)	11/7/86	Warp	5800	7700	1.32

III. CONCLUSIONS

The principal advantage of the method described is its simplicity: a reasonably precise estimate of the resistivity and the resistivity ratio can be obtained easily. However, one problem associated with the method is the possible loss of good electrical contact of one or more of the taps when immersing the sample at 77 K (normal boiling point of LN_2). This loss of contact can be avoided if the taps are carefully and firmly attached. A conductive epoxy might be used instead of the conductive paint.

To obtain good results, it is important to accurately measure the dimensions of the sample and the distance between the voltage taps, L (see Fig. 1). It is also important that the cross section of the sample be uniform along the distance L. A simple error analysis indicates that an uncertainty of 5% in each of the measured parameters--length, height, width, and resistance--results in an estimated error of 20% in the resistivity.

In Fig. 4, the resistivity values are plotted as resistivity ratio versus room temperature resistivity. The figure includes previously published data for similar exit cone samples.[1] The previously published data fall into a family of curves that can be associated with the number of graphitization cycles undergone by the sample during processing. The data of the present work are consistent with these results, at least to within the estimated accuracy described.

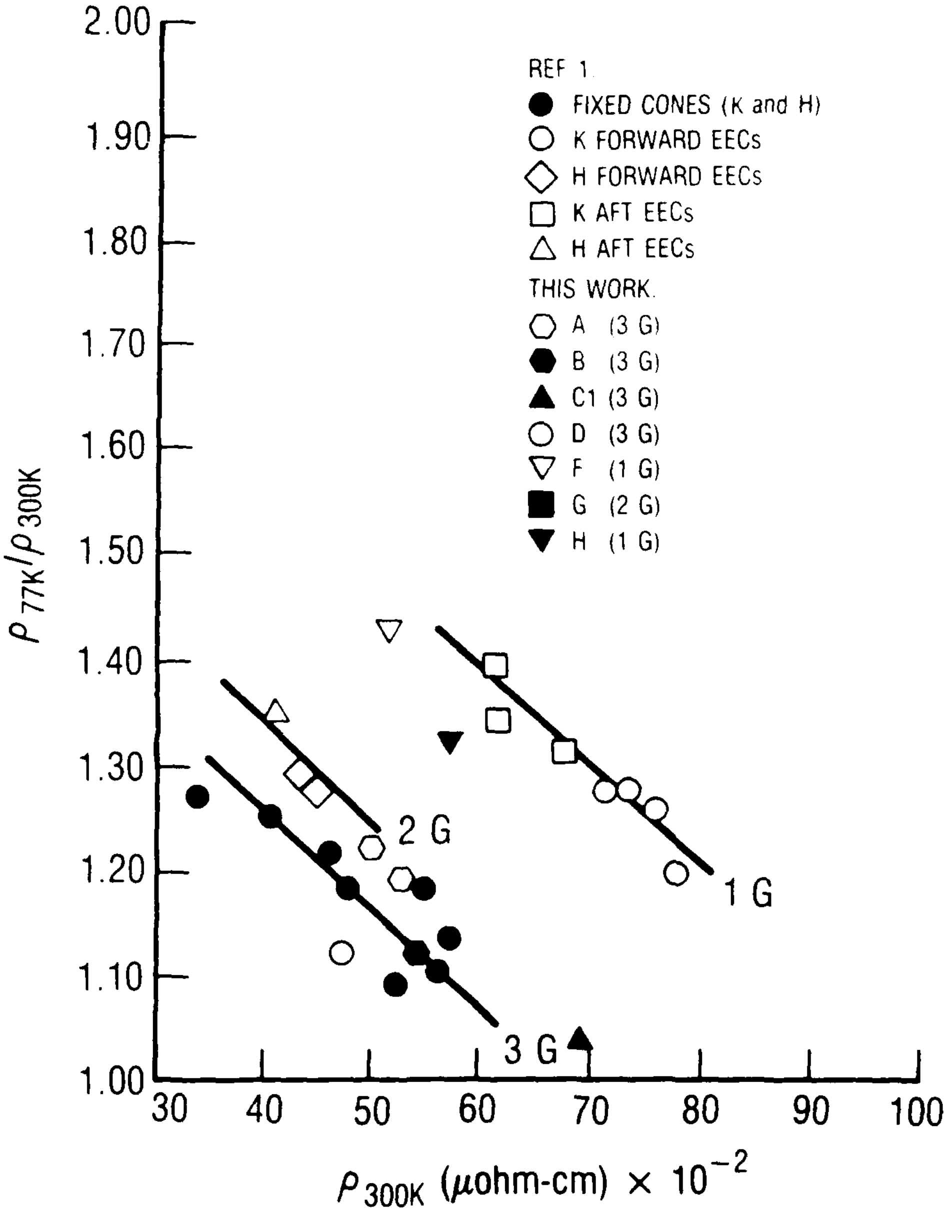

Fig. 4. Resistivity Ratio as a Function of Room Temperature Resistivity

LABORATORY OPERATIONS

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