Designation: C 611 – 98

An American National Standard

Standard Test Method for Electrical Resistivity of Manufactured Carbon and Graphite Articles at Room Temperature[1]

This standard is issued under the fixed designation C 611; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the electrical resistivity of manufactured carbon and graphite articles at room temperature.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definition:*

2.1.1 *resistivity*—the property of a material that determines its resistance to the flow of an electrical current. It is defined as the value of ρ, in milliohm metres, as follows:

$$\rho = (R{\cdot}A)/L$$

where:

R = resistance of a specimen of the material of uniform cross section, ohms,

A = uniform cross section, mm^2, and

L = distance between potential contacts, mm.

2.1.1.1 In cases where resistivity is requested in ohm-inches, multiply ρ in milliohm metres by 0.03937.

3. Significance and Use

3.1 This test method provides a means of determining the electrical resistivity of carbon or graphite specimens. The use of specimens that do not conform to the specimen size limitations described in the test method may result in an alteration of test method accuracy.

4. Apparatus

4.1 The means for applying current and potential terminals to the specimen is specified in 5.2.3.1. A typical specimen holder is shown in Fig. 1.

4.2 *Bridge, Potentiometer,* or *Suitable Digital Voltmeter,* with necessary accessories for making resistance measurements with a limit of error of less than 0.5 %. Fig. 2 schematically depicts two wiring diagrams that have been found satisfactory for this purpose.

4.3 The means for measuring the dimensions of the specimen should be adequate to determine its gage length and its mean area of cross section, each within 0.5 %.

5. Test Specimen

5.1 The test specimen may be in the form of a strip, rod, bar, or tube.

5.2 In order to determine the resistivity, each specimen shall conform to the following:

5.2.1 The cross-sectional area shall be uniform within 0.75 %. In general, the diameter of circular cross section, or the thickness and width of a strip specimen shall be determined by micrometer measurements, and a sufficient number of measurements shall be made to obtain a mean cross-sectional area to within 0.5 %. The test specimen shall be machined to yield planar and parallel end faces. These faces shall be perpendicular to the specimen length to within 0.001 mm/mm. All surfaces shall have a surface finish visually comparable to 0.8 µm (32 µin.) rms. Reasonable care should be exercised to assure that all edges are sharp and without chips or other flaws.

5.2.2 The test specimen shall show no defects observable with normal vision and shall be free of surface deposits.

5.2.3 The minimum ratio of specimen length to maximum cross-sectional dimension (width or diameter) shall be 6 : 1.

5.2.3.1 The gage length may be measured by any scale that will give an accuracy of ±0.5 % in the length measured. In the direction of the length of the specimen, the dimension of each potential contact shall be not more than 0.5 % of the distance between the potential contacts. The minimum distance between each potential contact and the adjacent current contact shall be the maximum cross-sectional dimension (width or diameter) of the specimen. If knife edges are used, they shall be parallel to each other and peripendicular to the longitudinal direction of the sample. The minimum ratio of gage length to maximum cross-sectional dimension (width or diameter) shall be 4 : 1.

5.2.4 No dimension shall be smaller than five times the length of the largest visible particle.

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.F on Manufactured Carbon and Graphite Products.

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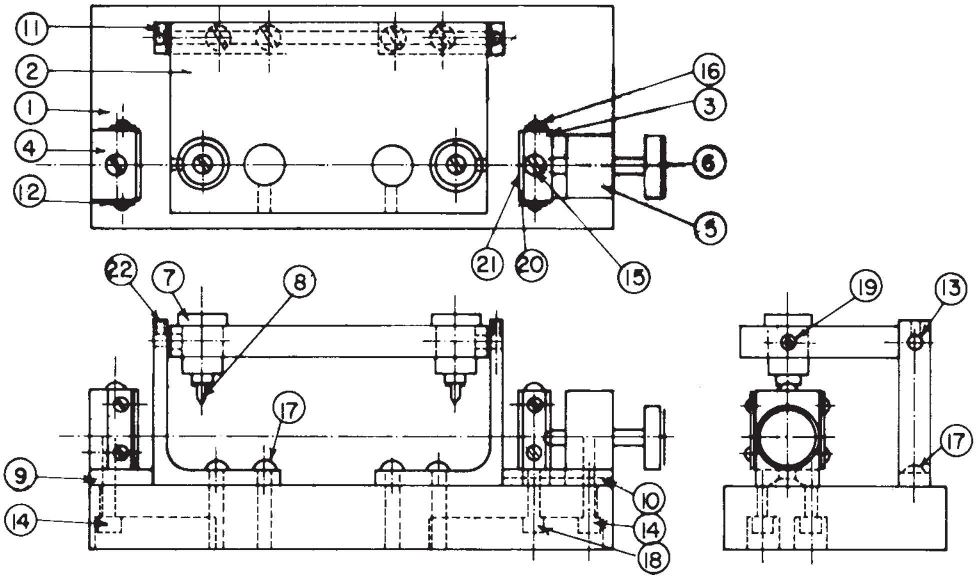


NOTE 1—Contacts for the voltage and current probes may be made through channels drilled in the brush holders (*7*) and the current blocks (*3* and *4*), respectively.

FIG. 1 Typical Test Apparatus

5.2.5 No joints or splices are permissible, unless this is the variable under study.

6. Conditioning

6.1 The specimen shall be dried for a minimum of 2 h at 110°C, cooled to room temperature in a desiccator, and stored in a desiccator until tested.

7. Procedure

7.1 *Resistance Measurement*—Measure resistance with instruments accurate to ±0.5 % or less (Note). To ensure a correct reading, the reference standard and the test specimen must be allowed to come to the same temperature as the surrounding medium.

NOTE 1—For resistance below 10 Ω, a Kelvin bridge method may be used, and for higher resistance, a Wheatstone bridge method may be used.

7.1.1 Clean the surface of the specimen at current and potential contact points to obtain good electrical contact. Mount the sample in the test apparatus, apply current, and measure the voltage. Take four measurements, on each side of a rectangular specimen, or at 90° (π/2 radians) apart on a round specimen. Reverse the current direction and take four measurements again. Remove the specimen from the test apparatus, turn it end for end, replace it in the apparatus, and repeat the measurements. The total of 16 measurements is recommended to minimize errors due to contact potential and forward and reverse currents. Average all individual values of measured resistance and use this value to calculate the resistivity.

7.2 *Heating of Specimen*—In all resistance measurements, the measuring current raises the temperature of the specimen above that of the surrounding medium. Therefore, take care to keep the magnitude of the current low, and the time short enough, so that changes in resistance cannot be detected. The measuring current shall be so small that the resistance of a specimen is not changed, thereby, as much as 0.1 %. This condition may be determined experimentally, or calculated from the power expended and the surface area of the specimen. A specimen heating check should be run after each group of samples. If resistance change exceeds 0.1 %, the sample should be cooled to ambient temperature and rerun at a lower measuring current.

7.3 A sample data collection work sheet that may be used for the testing is shown in Fig. 3.

8. Report

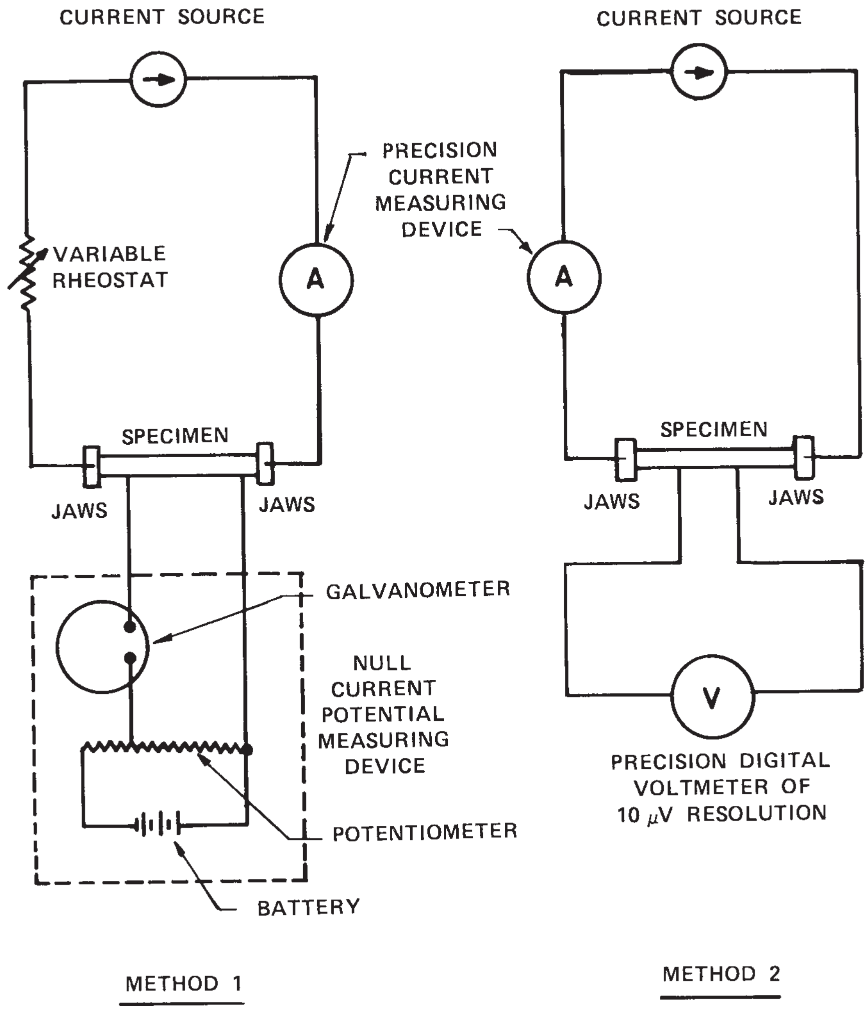
8.1 Report the following:

8.1.1 Identification and previous history of the test specimen.

8.1.2 Sample orientation.

8.1.3 Temperature of surrounding medium.

8.1.4 Dimensions of specimen used.



NOTE 1—Adjustable, regulated D-C power supply—line and load regulation to 0.1 % and ripple and noise ≤ 0.1 %.

FIG. 2 Typical Schematic for Resistivity Measurements

8.1.5 Method of measuring resistance, including gage length and probe location.

8.1.6 Value of resistance or potential plus the current readings.

8.1.7 Calculated value of resistivity.

9. Precision and Bias [2]

9.1 A round-robin test series was run to determine the precision and bias. The results of evaluating 20 test specimens of two different grades from 9 laboratories are as follows:

Within-Lab variability	0.75 %
Between-Lab variability	2.5 %

9.2 The within-lab variability is a combination of both test error and material variability since repetitious measurements were not made on single specimens within a laboratory. Material variability was, however, minimized by normalizing the results to values averaged from consistent results from five Laboratories. This yielded the estimate of a fairly small within-laboratory variability from 0.5 to 0.75 % which still includes a minor material variability.

9.3 Homogeneity of variance by the sensitive Barlett's test was not indicated, most likely, because of the very small within-laboratory variance and sensitivity to non-normality.

9.4 The between-Lab variability estimation was made on the measurement of the same specimen between Laboratories with the obvious exception of the results from laboratory A. The results still included some material variability as the resistivity varies to some extent along the length of the specimens.

9.5 The between–lab variability is fairly small and is probably a result of a minor lack of precision in the length measurement between voltage contacts on the specimen. This small variability could be further reduced by the use of a uniform standard specimen used to periodically check the resistivity measurement apparatus. The results were essentially unchanged over the range of 17 to 41 micro-ohm meters (700 to 1700 micro–ohm inches) in electrical resistivity.

[2] Supporting data giving complete results of the round–robin testing have been filed with ASTM International Headquarters.

Date ____________
Operator ____________

Sample ID ________________________________ Sample History ________________________________

L, gage length = ______________ mm I, applied current = ______________ amps T, ambient temperature = ______________ °C

1. *Cross-Sectional Area Determination, A:*

	Diameter, mm	or	Width, mm	Thickness, mm
1.	________		________	________
2.	________		________	________
3.	________		________	________
4.	________		________	________
5.	________		________	________
$\bar{X}$ =	________		________	________

Area for rounds:

$A = \bar{X}^2_{diameter}\,(\pi) \div 4 =$ ________ mm²

Area for rectangles:

$A = \bar{X}_{width}\,(\bar{X}_{thickness}) =$ ________ mm²

2. *Resistance Measurement, R:*

A. Ohmmeter Technique

Probe Position ________________________________

	Sample Position	*Forward Current*	*Reverse Current*
Sample Orientation 1	1	________ Ω	________ Ω
	2	________ Ω	________ Ω
	3	________ Ω	________ Ω
	4	________ Ω	________ Ω
Sample Orientation 2 (Note 3)	1	________ Ω	________ Ω
	2	________ Ω	________ Ω
	3	________ Ω	________ Ω
	4	________ Ω	________ Ω

$R_{\bar{x}}$ of all resistance measurements = ________ Ω

B. Voltmeter Technique

Probe Position ________________________________

	Sample Position	*Forward Current*	*Reverse Current*
Sample Orientation 1	1	________ mv	________ mv
	2	________ mv	________ mv
	3	________ mv	________ mv
	4	________ mv	________ mv
Sample Orientation 2 (Note 3)	1	________ mv	________ mv
	2	________ mv	________ mv
	3	________ mv	________ mv
	4	________ mv	________ mv

$V_{\bar{x}}$ of all voltage measurements = ________ mv

$R_{\bar{x}} = V_{\bar{x}} \div I =$ ________ Ω

C. Specimen Heating Check

$R_1 A - R_1 = \Delta R_1$ ________

3. *Resistivity, ρ, Calculation:*

$\rho = R_{\bar{x}}(A) \div L =$ ________ mΩ − M

NOTE 1—The sample history, ambient temperature, and probe position should be recorded for each sample on a separate sheet.

NOTE 2—A specimen heating check should be run after each group of samples. If resistance change exceeds 0.1 %, the sample should be cooled to ambient temperature and rerun at a lower measuring current.

NOTE 3—Remove the specimen from test apparatus, turn end for end and replace the specimen in the test apparatus.

FIG. 3 Electrical Resistivity Worksheet

9.6 In effect, the overall conclusion is that this test method will yield repeatable test results giving a good estimation of the electrical resistivity of a material as intended by the standard method of test.