Designation: A 342/A 342M – 99

Standard Test Methods for Permeability of Feebly Magnetic Materials[1]

This standard is issued under the fixed designation A 342/A 342M; 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 These test methods cover three procedures for determination of the permeability [relative permeability][2] of materials having a permeability not exceeding 4.0.

1.2 The test methods covered are as follows:

1.2.1 *Test Method 1* is suitable for materials with permeabilities between 1.0 and 4.0.

1.2.2 *Test Method 2* is suitable for measuring the permeability of paramagnetic materials having a permeability less than 1.05.

1.2.3 *Test Method 3* is a suitable means of measuring the permeability of a material as "less than" or "greater than" that of calibrated standard inserts designated for use in a Low-Mu Permeability Indicator.[3]

1.3 The values stated in either customary (cgs-emu and inch-pound) units or SI units are to be regarded separately as standard. Within this test method, the SI units are shown in brackets except for the sections concerning calculations where there are separate sections for the respective unit systems. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this specification.

1.4 *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. Referenced Documents

2.1 *ASTM Standards:*

A 341 Test Method for Direct Current Magnetic Properties of Materials Using dc Permeameters and the Ballistic Test Methods[4]

TEST METHOD NO. 1, FLUXMETRIC METHOD

3. Significance and Use of Test Method 1

3.1 This test method is suitable for specification acceptance, design purposes, service evaluation, regulatory statutes, manufacturing control, and research and development.

3.2 Because of the restrictions on the specimen shape and size, this test method is most often used to evaluate semifinished product before fabrication of parts.

4. Apparatus

4.1 *Power Supply*—A source of dc current for the electrical circuit shown in Fig. 1. Electronic power supplies are preferable although the use of storage batteries is permitted.

4.2 *Test Fixture*—A test fixture consisting of a magnetizing solenoid with a set of test coils mounted midway between the ends of the solenoid for measuring magnetic induction and an air flux balancing resistor, fluxmeter, and associated circuitry conforming to the following requirements:

4.2.1 *Magnetizing Solenoid*, C_1, having a minimum length of 30 cm [300 mm] and a ratio of length to equivalent diameter of four or more. The magnetizing winding shall be uniformly wound and be capable of producing a uniform field of at least 300 Oe [24 kA/m] over the length of the test specimen without overheating.

4.2.2 *Test Coil*, B_1, used for measuring induction, shall have a cross-sectional area not greater than ten times that of the test specimen. The test coil should have sufficient turns (>1000) to provide adequate resolution and should be no longer than 20 % of the test specimen length.

4.2.3 *Compensating Coil*, B'_1, of the same length, cross-sectional area, and number of turns as coil B_1 and connected to it in series opposition.

4.2.4 *Air Flux Compensating Resistor*, R'_B—This resistor is used in conjunction with coil B'_1 of Fig. 1 to help it

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[1] These test methods are under the jurisdiction of ASTM Committee A06 on Magnetic Properties and are the direct responsibility of Subcommittee A06.01 on Test Methods.

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[2] Test Methods 1 and 2 actually measure magnetic susceptibility. The permeability (μ) [relative permeability (μ_r)] is related to the susceptibility (κ) by the equations:

$$\mu = 1 + 4\pi\kappa \text{ (cgs-emu)}$$
$$\mu_r = 1 + \kappa \text{ (SI)}$$

The term permeability has been retained in these test methods because of its widespread commercial and technological usage.

[3] Low-Mu Permeability Indicator, manufactured by Severn Engineering Co., Inc., 555 Stage Rd., Suite 1A, Auburn, AL 36830, http://www.severnengineering.com, has been found suitable. Indicators can be returned for recalibration.

[4] *Annual Book of ASTM Standards*, Vol 03.04.

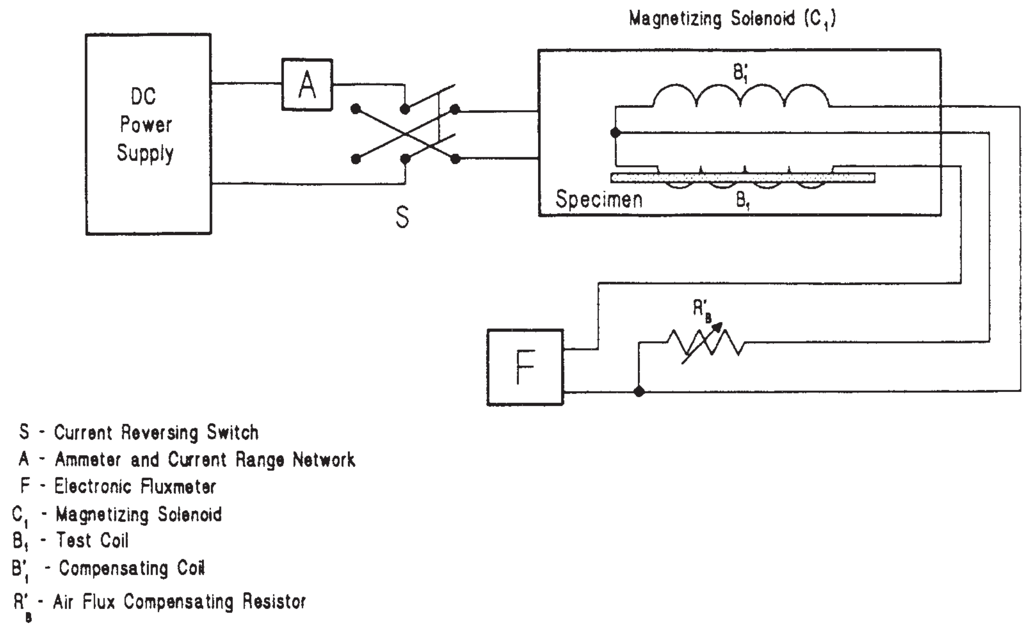

FIG. 1 Circuit Diagram for Method No. 1

compensate for the air flux enclosed by coil B_1 in order that the intrinsic induction may be measured directly.

4.2.5 *Electronic Fluxmeter, F*—used to measure magnetic induction. Alternatively, the magnetizing fixture may be connected to a dc hysteresigraph.

4.2.6 *Magnetic Field Strength Sensor (optional)*—if the magnetic field strength cannot be accurately determined from the magnetizing current, then either a Hall effect sensor or H-coil connected to the fluxmeter shall be used.

5. Test Specimens

5.1 The test specimens shall consist of straight bars, rods, wires, or strips of uniform cross section. Multiple pieces of the same test lot may be used to increase the specimen cross-sectional area when needed. The cross-sectional area shall be not less than 0.2 cm^2 [20 mm^2]. The length shall be not less than 10 cm [100 mm] and the ratio of length to diameter or equivalent diameter (that is, the diameter of a circle having an area equal to the cross-sectional area of the specimen) shall be as follows:

Permeability	Dimensional Ratio
Under 1.5	10 or greater
1.5 to 2.0, incl.	15 or greater
2.0 to 4.0	30 or greater

5.2 This test method can be used with smaller dimension-ratio test specimens when used for comparing to similar specimens for quality control purposes.

6. Procedure

6.1 Measure the thickness and width or diameter of the test specimens and calculate the cross-sectional area in square centimetres [square millimetres].

6.2 Before inserting the test specimen in the solenoid, obtain an exact balance to nullify the effect of air flux in coil B_1 by reversing the highest magnetizing current to be used in the test and adjusting the compensating resistor to obtain the minimum output from the flux sensing coils.

6.3 Place the test specimen in position in coil B_1, adjust the magnetic field strength to the desired test value, then reverse the magnetizing current and record the fluxmeter reading. Optionally, the B versus H curve can be recorded on a hysteresigraph.

7. Calculation (Customary Units)

7.1 Convert the fluxmeter reading to intrinsic induction B_i and calculate the permeability as follows:

$$\mu = 1 + \frac{B_i}{H} \tag{1}$$

where:
μ = permeability of the test specimen;
B_i = intrinsic induction of the test specimen, G; and
H = magnetic field strength, Oe.

8. Calculation (SI Units)

8.1 The output from the fluxmeter is the magnetic polarization J. The relative permeability is calculated as follows:

$$\mu_r = 1 + \frac{J}{\Gamma_m H} \tag{2}$$

where:
μ_r = relative permeability of the test specimen;
J = magnetic polarization, T;
Γ_m = $4\pi \times 10^{-7}$ H/m; and
H = magnetic field strength, A/m.

9. Precision and Bias of Test Method 1

9.1 The precision and bias of this test method have not been established by interlaboratory study.

9.2 The measured permeabilities will be less than their true values due to the demagnetizing field arising from the sample dimensional ratio. This leads not only to an overestimation of the magnetic field strength but also reduces the flux linkages in the *B*-coil. Provided the sample and coil dimensional ratios are as specified in 4.2.2 and 5.1, the largest negative error in $\mu - 1$ as a result of demagnetizing effects[5,6] will be −3 % for $\mu - 1 < 0.5$.

TEST METHOD NO. 2, PERMEABILITY OF PARAMAGNETIC MATERIALS

10. Significance and Use of Test Method 2

10.1 This test method is suitable for specification acceptance, design purposes, service evaluation, regulatory statutes, manufacturing control, and research and development.

10.2 Because of the restrictions on the specimen shape, size, and permeability, this test method is most often used to evaluate semifinished product before fabrication of parts.

11. Apparatus

11.1 *Power Supply*—A source of steady dc power such as a storage battery or a suitably regulated dc power supply.

11.2 *Permeameter*—A permeameter as shown in Fig. 2, consisting of an electromagnet and a balance conforming to the following requirements:

11.2.1 *Electromagnet*—The electromagnet shall have pole faces whose horizontal dimension is 3.8 cm [38 mm] and whose vertical dimension is 1.9 cm [19 mm]. The distance between the pole faces shall be 1.9 cm [19 mm]. The magnetizing winding shall be so wound as to produce a magnetic field strength of at least 1000 Oe [80 kA/m] between the pole pieces without overheating.

11.2.2 *Balance*—A balance capable of weighing up to 50 g with a sensitivity of 0.1 mg. Any magnetic material in the balance should be 12.7 cm [127 mm] or more above the electromagnet. The space surrounding the sample shall be closed by a shield of nonmagnetic material to protect the sample from air currents during measurements.

11.3 *Miscellaneous Current Control Equipment*, for the magnetizing circuit such as ammeter, rheostat, and reversing switch.

12. Test Specimens

12.1 The test specimens shall consist of straight bars, rods, wires, strips, or tubing of uniform cross section. The length of the specimen shall be not less than 6.6 cm [66 mm] and the width shall not exceed 1.27 cm [12.7 mm]. The minimum cross-sectional area shall be not less than 0.13 cm^2 [13 mm^2].

13. Procedure

13.1 Measure the thickness and width or diameter of the test specimens and calculate the cross-sectional area in square centimetres [square millimetres].

13.2 Suspend the specimen from the balance in such a manner that its lower end is within ±0.16 cm [±1.6 mm] of the center line of the air gap (Fig. 2) and weigh it with the magnetizing current off.

13.3 Turn on the magnetizing current and set it at such a value as to give a magnetic field strength 500 Oe [40 kA/m] along the center line of the air gap (Note 1). Reverse the current at least five times to nullify the effect of hysteresis in the electromagnet core. Then weigh the specimen with the current on.

NOTE 1—The field strength along the center line of the air gap may be determined by using a reference standard such as a saturated solution of nickel chloride of known permeability or a standard search coil and fluxmeter. If the coil is used its maximum diameter shall not exceed 0.32 cm [3.2 mm] and its axis shall be along the center line of the air gap when measuring the field by means of reversing the magnetizing current.

13.4 Repeat the procedure described in 13.3 with the magnetizing current adjusted to give a magnetic field strength of 1000 Oe [80 kA/m] along the center line of the air gap.

14. Calculations (Customary Units)

14.1 Calculate the permeability as follows:

$$\mu = 1 + \frac{8\pi F}{AH^2} \quad (3)$$

or:

$$\mu = 1 + \frac{24.65\Delta m}{AH^2} \quad (4)$$

where:

μ = permeability of the test specimen;
F = force acting on the specimen caused by the magnetic field, dynes;

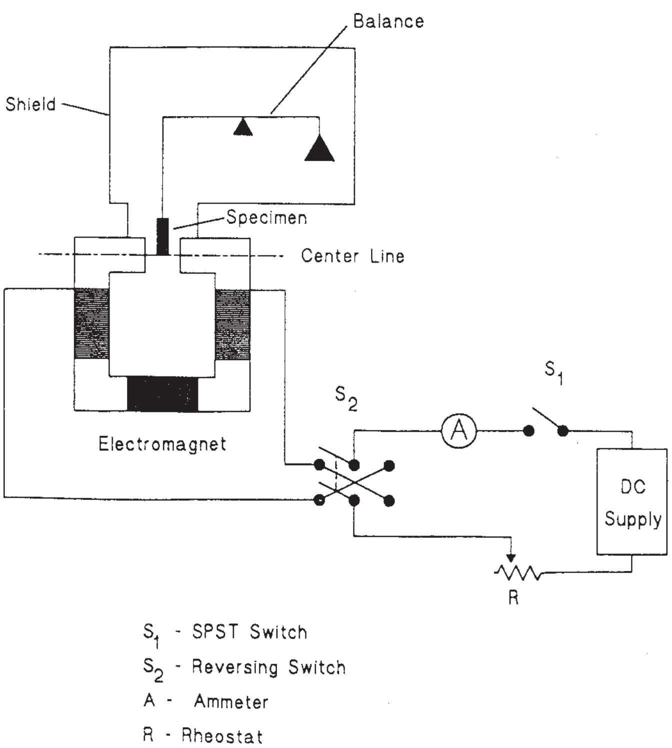

FIG. 2 Circuit Diagram for Method No. 2

[5] Chen, D.-X., and Li, B.-Z., "On the error of measurement of feebly magnetic material in regard to demagnetizing field," *Acta Metall. Sinica*, Vol. 19, pp. 217–224, Oct. 1983 (in Chinese).

[6] Chen, D.-X., Brug, J. A., and Goldfarb, R. B., "Demagnetizing Factors for Cylinders," *IEEE Trans. Magn.*, Vol. 27, 1991, pp. 3601–3619.

A = cross-sectional area of the specimen, cm^2;
H = magnetic field strength along the center line of the air gap at the time of weighing, Oe; and,
Δm = apparent change in mass, mg.

15. Calculations (SI Units)

15.1 Calculate the relative permeability as follows:

$$\mu_r = 1 + \frac{2F}{\Gamma_m A H^2} \tag{5}$$

or:

$$\mu_r = 1 + \frac{1.561 \times 10^7 \Delta m}{AH^2} \tag{6}$$

where:
μ_r = relative permeability of the test specimen;
F = force acting on the specimen caused by the magnetic field, N;
Γ_m = $4\pi \times 10^{-7}$ H/m;
A = cross-sectional area of the specimen, m^2;
H = magnetic field strength along the center line of the air gap at the time of weighing, A/m; and,
Δm = apparent change in mass, kg.

16. Precision and Bias of Test Method 2

16.1 The precision and bias of this test method has not been established by interlaboratory study. For specimens having a satisfactory degree of magnetic uniformity along their length, and tested at a definite temperature, it is believed the quantity ($\mu - 1$) should be accurate within ±8 % or ±0.0001, whichever is the greater.

16.2 If the values of the permeability obtained from the measurements prescribed in 13.3 and 13.4 do not agree within the limits of error stated in 16.1, this test method of measuring the permeability is not valid, because the permeability is not independent of field.

TEST METHOD NO. 3, LOW-MU PERMEABILITY INDICATOR METHOD OF TEST

17. Significance and Use of Test Method 3

17.1 The Low-Mu Permeability Indicator, schematically shown in Fig. 3, is suitable for determining if the permeability of low permeability materials (relative μ of 3.0 or less) is greater than or less than that of the standard insert employed at the time of the test.

17.2 The instrument is portable and suitable for use in the shop, field, and laboratory.

17.3 The instrument is suitable to test all forms and shapes including parts, provided a suitable flat surface is available on the specimen. The material under test is that which is at the surface and is against or is in immediate proximity to the permanent bar magnet.

17.4 This test method provides test values (generally stated as "permeability is less than") suitable for specification purposes.

18. Apparatus

18.1 *Permanent Bar Magnet*—The center of the permanent bar magnet is attached to an end of a movable arm having a fulcrum in the center and a counterbalance at the opposite end, thus permitting the permanent magnet to move in one plane in both directions.

18.2 The standard inserts are feebly magnetic materials of known permeability values as calibrated by the manufacturer of the indicator against their established standards.

19. Test Specimen

19.1 The test specimen or material to be tested is recommended to have a minimum area of 1 cm^2 [100 mm^2] and a minimum thickness of 0.3 cm [3 mm] (the specimen may be laminated). Test specimens having a volume in excess of the minimum value implied above may be in any form, shape, or condition (for example, castings, forgings, bars, weld beads, and so forth). The indicator may be placed on any location on the specimen to be tested provided that the surface is suitably flat and in full contact with the permanent bar magnet. The indicator is capable of detecting surface permeability differences, if present, of large objects.

20. Procedure

20.1 Screw into the top of the case a calibrated insert of known permeability. The permanent magnet is attached to the insert by a force dependent upon the insert's designated permeability value. Place the end of the permanent magnet projecting from the hole in the bottom of the indicator in

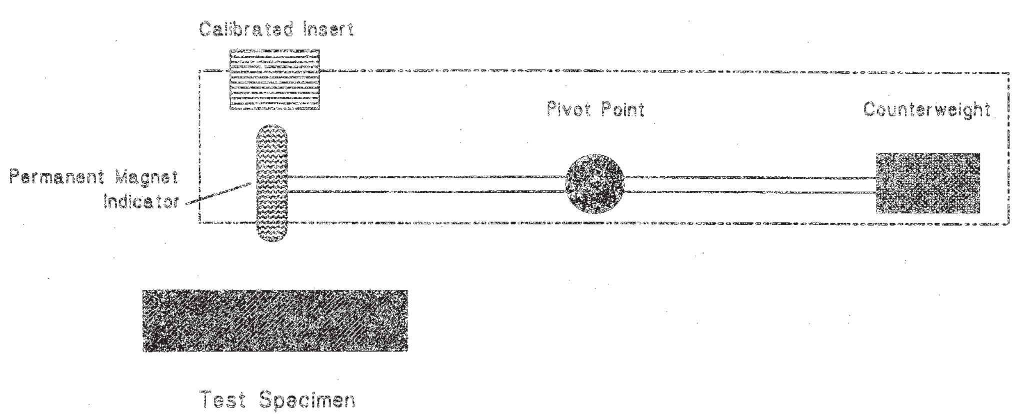

FIG. 3 Schematic Illustration of Low Permeability Indicator

contact with the material being tested. Move the indicator away in a direction normal to the contact surface. If the material being tested has a permeability higher than that of the insert, the permanent magnet will break contact first with the insert as the indicator is moved away. However, if the permeability of the material being tested is lower than that of the insert, the permanent magnet will break contact first with the test material as the indicator is moved away. By interchanging inserts, it is possible to bracket the permeability of the material under test.

21. Precision and Bias of Test Method 3

21.1 Indicators are available with calibrated inserts having relative permeabilities of 1.01, 1.02, 1.05, 1.10, 1.15, 1.2, 1.4, 1.6, 1.8, 2.0, 2.5 and 3.0.

21.2 The manufacturer of the Low-Mu Permeability Indicator determines the permeability of the calibrated inserts. The standards used in calibrating the inserts were measured by the National Institute of Standards and Technology using Test Method A 341. No significant changes were observed between 1952 and 1976. Measurements were made in a magnetic field of 100 Oe [8 kA/m] at 25°C.

21.3 Calibrated inserts have a bias of ±1 % or less at the low range and within ±5 % at the high range relative to the standards.

22. Keywords

22.1 paramagnetic; permeability; permeameter