INTERNATIONAL

Designation: A773/A773M – 01 (Reapproved 2009) A773/A773M – 14

Standard Test Method for dc Direct Current Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Low Coercivity Magnetic Materials Using Hysteresigraphs[1]

This standard is issued under the fixed designation A773/A773M; 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 provides dc hysteresigraph procedures (*B-H* loop methods) for the determination of basic magnetic properties of materials in the form of ring, spirally wound toroidal, link, double-lapped Epstein cores, or other standard shapes that may be cut, stamped, machined, or ground from cast, compacted, sintered, forged, or rolled materials. It includes tests for normal induction and hysteresis loop determination taken under conditions of continuous sweep magnetization. Rate of sweep may be varied, either manually or automatically at different portions of the curves during tracing. Total elapsed time for tracing a hysteresis loop is commonly 10 to 120 s per loop. measurement.

1.2 The equipment and procedures described in this test method are most suited for soft and semi-hard materials with intrinsic coercivity less than about 100 Oersteds [8 kA/M]. Materials with higher intrinsic coercivities should be tested according to Test Method A977/A977M.

1.3 The values stated in either SI units or inch-pound units and equations stated in customary (cgs-emu and inch-pound) or SI units are to be regarded separately as standard. Within this standard, SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformancenonconformance with thethis standard.

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:*[2]

A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials

A340 Terminology of Symbols and Definitions Relating to Magnetic Testing

A341/A341M Test Method for Direct Current Magnetic Properties of Materials Using D-C Permeameters and the Ballistic Test Methods

A343/A343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Test Frame

A596/A596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens

A977/A977M Test Method for Magnetic Properties of High-Coercivity Permanent Magnet Materials Using Hysteresigraphs

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *Other:*

IEC Publication 404-4:60404-4 Ed 2.2 – Part 4: Magnetic Materials—Part 4: Methods of Measurement of dcd.c. Magnetic Properties of Iron and Steel (1995)Magnetically Soft Materials (2008)[3]

3. Terminology

3.1 *Definitions*—The terms and symbols used in this test method are defined in Terminology A340.

[1] This test method is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.01 on Test Methods.
Current edition approved May 1, 2009Oct. 1, 2014. Published August 2009October 2014. Originally approved in 1980. Last previous edition approved in 20012009 as A773/A773M–01. –01 (2009). DOI: 10.1520/A0773_A0773M-01R09.10.1520/A0773_A0773M-14.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

4. Summary of Test Method

4.1 ~~As in making most magnetic measurements, a~~ A specimen is wound with ~~an exciting~~a magnetizing winding (the ~~primary)~~ primary winding) and a search ~~coil~~winding (the ~~secondary)~~ secondary winding) for measuring the change in flux. When ~~an exciting~~a magnetizing current, I, is applied to the primary winding, a magnetic field, H, is produced in the ~~coil, and this~~ coil. This in turn produces magnetic flux φ in the ~~specimen. In uniform specimens~~ specimen and the changing flux induces a voltage in the secondary winding which is integrated with respect to time using a fluxmeter. In specimens with uniform cross-sectional area that do not contain air gaps, such as ~~ring samples,~~ rings, all of the ~~exciting~~magnetizing current is used to magnetize the specimen, and H is proportional to I in accordance with the following equation:

$$H = KI \tag{1}$$

where:

H = magnetic field strength, Oe [A/m];
~~I = current in the exciting coil A; and~~
I = current in the magnetizing winding A; and
K = constant determined by the number of primary turns the magnetic path length of the specimen and system of units.

4.1.1 The magnetic flux may be determined by integration of the instantaneous electromotive force that is induced in the secondary ~~coil~~winding when the flux is increased or decreased by a varying H. The instantaneous voltage, e, is equal to:

$$e = -NK^{1}\frac{d\varphi}{dt} \tag{2}$$

$$e = -N\,K_1\frac{d\varphi}{dt} \tag{2}$$

or

$$\varphi = \frac{1}{K_1 N}\int edt$$

where:

dt = time differential,
~~N = number of turns, and~~
N = number of secondary turns,
~~K_1 = 10^{-8} for cgs-emu system, or $K_1 = 1$ for SI system.~~
K_1 = 10^{-8} for cgs-emu system, or $K_1 = 1$ for SI system, and
e = instantaneous voltage in the secondary winging, V.

The flux φ can be obtained if $\int edt$ can be determined. This can be accomplished by several means, as described in *ASTM STP 526*. (**1**) [4] The most common method uses an electronic integrator consisting of ~~a high-gain dc~~ an operational amplifier with ~~resistive-capacitive feedback. The relationship to ∫~~capacitive feedback. Some fluxmeters employ analog to digital ~~edt~~conversion ~~is:~~and digital integration techniques. The output voltage of the integrator is given by:

$$E = \frac{1}{RC}\int edt \tag{3}$$

where:

E = output voltage, V;
R = input resistance of the integrator in the secondary circuit, Ω; and
C = the feedback capacitance, F.

By combining the two equations:

$$\varphi = \frac{ERC}{K_1 N} \text{ or } E = \frac{\varphi N K_1}{RC} \tag{4}$$

~~If the voltage,~~The instantaneous value ~~E, is applied to the Y axis~~ of ~~an~~flux ~~X-Y~~is ~~recorder, the~~thus proportional ~~Y~~to ~~deflection of the pen is proportional to the flux, φ.~~the integrated voltage which can be recorded in various ways.

4.1.2 ~~Measurements~~Measurement of magnetic field strength and flux by the hysteresigraph method is illustrated in the block diagram of Fig. 1. The system consists of a magnetizing power source, ~~an exciting~~a magnetizing current controller, an electronic flux integrator, and a data recorder. As ~~exciting~~magnetizing current is applied to the ~~coil,~~ primary winding, a voltage proportional to I is produced across the ~~shunt~~ current measuring resistor which is connected in series with the primary ~~coil.~~winding. This voltage ~~determines~~ is proportional to the value of H.

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

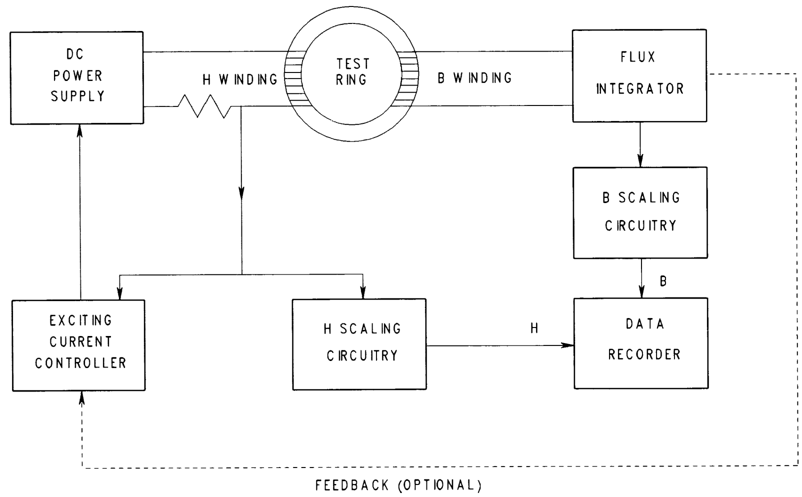

FIG. 1 Block Diagram of Ring Test Apparatus

4.1.3 In the testing of ~~hard magnetic materials, or~~ soft magnetic materials in the form of wire, bars or rods, or materials which cannot be sufficiently magnetized in ring form, or which are anisotropic, it is usually necessary to use a permeameter. This is shown in the block diagram of Fig. 2. When using permeameters, the value of *H* in the gap is generally not proportional to *I* that flows through the ~~exciting coil~~magnetizing winding of the yoke. In these cases, the value of *H* is determined by integration of the electromotive force that is induced in an *H* ~~coil~~ -coil (or Chattock potentiometer) or from the signal developed by a Hall probe which is placed near the specimen. When using an *H* ~~coil,~~ -coil, the determination of *H* is accomplished with an *H* integrator in exactly the same manner as that used to determine flux with the *B* integrator described in ~~3.1~~4.1. When using a Hall sensor, the *H* values are determined from the voltage output which is linearized to be proportional to *H*. ~~In some cases, the H versus I relationship may be sufficiently linear from 0 to the coercive field strength (H$_c$) of the material under test. In such cases, it is acceptable to determine the second quadrant of the hysteresis loop by determining H from the value of I in the exciting winding.~~

5. Significance and Use

5.1 ~~Hysteresigraph testing permits~~ Hysteresigraphs permit more rapid and efficient collection of normal induction and dc hysteresis (*B-H* loop) data as compared to the point by point ballistic Test Methods A341/A341M and A596/A596M. The ~~accuracy and precision of testing is comparable to the ballistic methods. Hysteresigraphs are particularly desirable for testing of semihard and hard magnetic materials where either the entire second quadrant (demagnetization curve) or entire hysteresis loop is of primary concern.~~high measurement point density offered by computer-automated systems is often required for computer aided design of electrical components such as transformers, motors, and relays.

5.2 Hysteresigraphs are particularly desirable for testing of semihard and hard magnetic materials, where either the entire second quadrant (demagnetization curve) or entire hysteresis loop is of primary concern. Test Method A977/A977M describes the special requirements for accurate measurement of hard (permanent magnet) materials.

5.3 Hysteresigraphs are not recommended for measurement of initial permeability of materials with high magnetic permeability such as nickel-iron, amorphous, and nanocrystalline materials due to errors associated with integrator drift; in these cases, Test Method A596/A596M is a more appropriate method.

5.4 Provided the test specimen is representative of the bulk sample or lot, this test method is well suited for design, specification acceptance, service evaluation, and research and development.

6. Interferences

6.1 Test methods using suitable ring-type specimens are the preferred methods for determining the basic magnetic properties of a material. When conducting tests on ring specimens, this test method covers a range of magnetic field strengths from about 0.01 Oe [0.8 A/m] up to about 1000 Oe [80 kA/m] or more depending on the specimen dimensions, number of primary turns, available magnetizing power, and the ability to remove heat generated in the primary winding. However, this test method has several important requirements. Unless ~~adequate~~the inside diameter to outside diameter ~~ratios are maintained in the test specimens, the~~ ratio or ring specimens is greater than 0.82, the magnetic field strength will be excessively nonuniform ~~throughout~~in the test material and the measured parameters cannot be represented as material properties. The basic quality of materials having ~~directional~~directionally sensitive properties cannot be tested satisfactorily with ~~punched rings or laminations. With them~~ ring specimens. With such materials it is necessary to use Epstein specimens cut with their lengths in the direction of specific interest

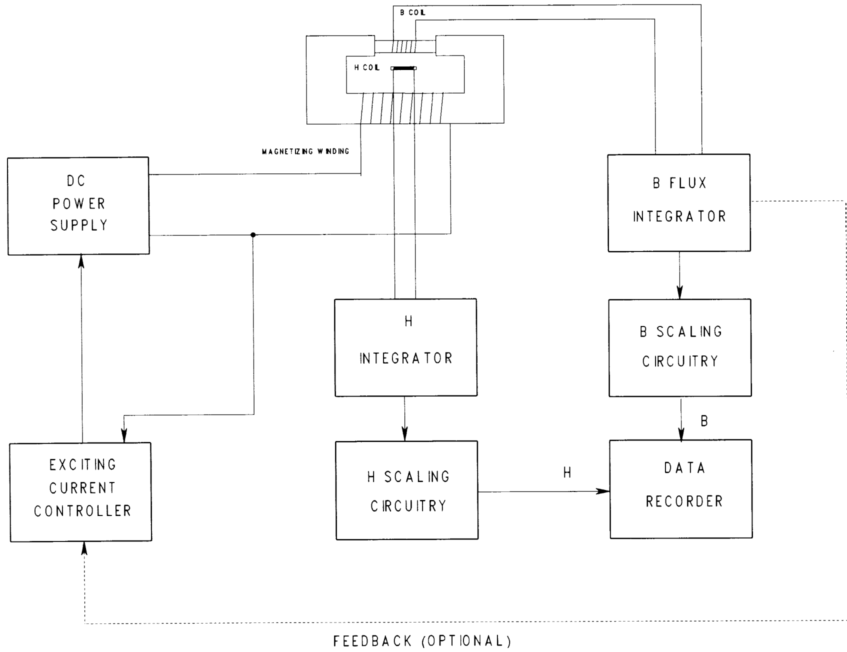

FIG. 2 Block Diagram of Permeator Test Apparatus

or to use long link-shaped[5] or spirally wound ~~core test specimens whose long dimensions are similarly oriented.~~ toroidal core test specimens. The acceptable minimum width of strip used in such test specimens ~~is also sensitive to~~ varies with the material under test. At present, it is ~~believed~~ recommended that the grain-oriented silicon steels should have a strip width of at least 3 cm [30 mm]. ~~Unless~~When ring specimens are large, it is difficult to provide sufficient magnetizing turns or current-carrying capacity to reach ~~high magnetic field strengths.~~ magnetic field strengths above about 1000 Oe [80 kA/m]. In general, magnetic materials tend to have nonuniform properties throughout the body of the test ~~specimens; for~~specimens. For this reason, uniformly distributed test windings and uniform specimen cross-sectional area are highly desirable to average nonuniform ~~behavior to a tolerable degree.~~behavior.

6.2 When conducting permeameter tests on bars, rods, and other appropriate specimens, this test method covers a range of magnetic field strengths from about 0.05 Oe [4 A/m] up to about 20 000 Oe [1600 kA/m] or more, depending on the specimen geometry and the particular permeameter (measuring fixture) that is used. In general, the lower limit of magnetic field strength is determined by the area-turns of the *H* coil (or the sensitivity of the Hall probe if it is used), the sensitivity of the integrator, and the sensitivities of the measuring and recording components. The upper ~~limitation~~limit in magnetic field strength is determined by the type of permeameter appropriate for the specimen, the power supply, and the heat generated in the yoke windings. Recommendations of the useful range of magnetic field strength for the various permeameters are shown in Table 1. ~~Other types may be used with appropriate precautions.~~

6.2.1 In general, permeameters do not ~~maintain~~produce a uniform magnetic field in either the axial or radial directions around the test specimen. The field gradients in both of these directions will differ in the various permeameters. Also the *H*~~-sensing~~-coils and *B*~~-sensing coils~~ -coils of the different permeameters are not identical in area, in turns, or in length or identically located. Although test specimens are prepared to have uniform physical cross section, they may still have undetected nonuniform magnetic properties radially or axially along the specimen length adjacent to the *H* or *B* coils. Some permeameters may also introduce clamping ~~strains~~stresses into the test specimen. For these reasons test results obtained on a test specimen with one type of permeameter may not compare closely with those obtained on the same specimen from another ~~type permeameter, and both may differ from more precise testing methods.~~permeameter type.

6.2.2 The limitation in the *B* measurement by this test method is determined by the number of ~~turns on~~secondary (*B* ~~the specimen, the cross-sectional area, the permeability, and the sensitivities of the~~) turns on the specimen, the specimen cross-sectional area, the permeability, ~~B integrator~~ and ~~X-Y~~the ~~recorder.~~ gain and drift of the fluxmeter and data recording device. In general, normal induction and hysteresis data may be determined from a flux linkage corresponding to 1000 Maxwell turns [10^{-5} Weber turns] to an upper ~~induction~~ magnetic flux density that corresponds to the intrinsic ~~saturation for most materials.~~saturation.

6.2.3 Some permeameters use compensation coils and require continual adjustment of the current flowing through these coils. This may not be compatible with ~~commercially available hysteresigraphs and can be a source of significant error.~~hysteresigraphs.

[5] Link-shaped specimens are defined in Practice A34/A34M.

TABLE 1 Permeameters Recommended for Use With Hysteresigraphs

NOTE 1—Other permeameters may be suitable for use with dc hysteresigraphs where appropriate modifications are made. Refer to Test Method A341/A341M for other permeameters.

Permeameter	Magnetic Field Strength Range		*H* Measurement Device
	Oe	kA/m	
Babbit (**2**, **3**)	40/100	3.2/8	current, *H* coil
Fahy Simplex (**4-6**)	0.1/300	0.008/24	*H* coil
Fahy Simplex Super H Adapter (**6**)	100/2500	8/200	*H* coil
IEC Type A	12/2500	1/200	*H* coil, Hall probe
IEC Type B	12/620	1/50	*H* coil
Isthmus (**6**, **7**)	100/20 000 +	8/1600 +	*H* coil, Hall probe

6.2.4 The magnetic test results, particularly for high permeability alloys such as nickel-iron alloys, may not exactly agree with test results obtained by the ballistic methods, Test Methods A341/A341M and A596/A596M. ~~This~~ For ring specimens, this is due to the influence of eddy ~~currents and~~ currents, the different nature of the magnetizing waveform between hysteresigraph and ballistic ~~testing.~~ testing, and possible disaccomodation. For testing using permeameters, residual magnetism of the yoke can be a significant source of error when measuring high permeability materials, especially when testing at low applied magnetic fields.

6.3 The standard Epstein frame as defined in A343/A343M has an assumed magnetic path length of 94 cm [0.94 m]. This may or may not be correct when conducting dc magnetic tests; however, the user of this test method should use this value for consistency of results.

7. Apparatus

7.1 The apparatus shall consist of as many of the components described in ~~6.2~~7.2 – ~~6.6~~7.8 as required to perform the tests.

7.1.1 All apparatus used in this test method shall be calibrated against known standards to ensure the accuracy limits given below.

7.2 *Balance or Scales:*

7.2.1 The balance or scales used to weigh the test specimen shall be capable of weighing to an accuracy of ~~0.2 %.~~ ±0.2 % of the measured value.

7.2.2 The micrometer or ~~dimensional measuring scales~~calipers, or both, used to determine specimen dimensions for calculation of cross-sectional area shall be capable of measuring to an accuracy of at least ~~0.1 %.~~ ±0.1 % of the measured value.

7.3 *Magnetizing Power Source*—The power source may range from ~~simple~~ batteries to ~~sophisticated~~ regulated, low-ripple, protected, programmable ~~types.~~ power supplies. It shall have sufficient capacity to produce the maximum currents required for magnetization of the specimen under test.

7.4 ~~*Exciting*~~*Magnetizing Current Controller*—Instantaneous value of magnetizing current, and its rate of change, may be controlled entirely manually by means of rheostats, potentiometers, shunts, reversing switches, and so forth; semiautomatically by means of variable-speed motors or sweep generators, and so forth; or entirely ~~automatic~~automatically by means of rate sensors, and so forth. In all cases, components shall be capable of carrying the required currents without overheating, and controls shall be of such design that the magnetizing current may be increased or decreased in a uniform ~~manner so that smooth traces are plotted on the~~ manner.~~X-Y recorder.~~

7.5 *B ~~or H~~ Integrator*—The ~~flux integrator(s) may be any of the types described in *ASTM STP 526B* (or other) and should have sufficient sensitivity, stability, linearity, and freedom from drift to ensure an accuracy of at least 0.5 % of full scale.~~integrator shall be an electronic integrator with a full-scale accuracy of ±0.5 % or better. The integrator shall have a calibration traceable to a national standards laboratory and should preferably have a calibration self-check capability.

7.6 *H Integrator (Optional)*—The *H* integrator shall be an electronic integrator with a full-scale accuracy of ±0.5 % or better. The integrator shall have a calibration traceable to a national standards laboratory and should preferably have a calibration self-check capability. This integrator is only required when testing using a permeameter and an inductive *H* sensor.

7.7 *Current Measuring Resistor*—When the magnetic field strength is to be determined from the magnetizing current, a non-inductive resistor with a low temperature coefficient of resistance shall be used. The resistor shall have a power rating capable of handling the largest currents capable of being produced by the power supply. Ideally, the resistor should be rated for two or more times the expected maximum power dissipation. The rated accuracy of the resistor shall be ±0.5 % or better.

7.8 *Data Recorder*—The *B* and *H* values can be recorded and displayed by either analog or digital *X-Y* chart recorders, dataloggers, or computers. The recording device shall be capable of resolving *B* or *H* values of ~~1 %~~±1 % of the full-scale value. For analog to digital converters, twelve-bit resolution or higher is desirable.

8. Test Specimens for Ring-Type Ring and Epstein Strip Measurements

8.1 The specificationsinformation in 7.28.2 – 7.88.9 covercovers the general case for specimens in which magnetic field strength is proportional to the excitingmagnetizing current, that is, $H = kI$.

8.2 When the test specimen represents a test lot of material, its selection sampling shall conform to the requirements of Practice A34/A34M or of an individual, unless superseded by a specification.

8.3 To qualify as a test specimen suitable for evaluation of material properties, the effective ratio of mean diameter to radial width shall be not less than 10 to 1 (or an inside diameter to outside diameter ratio not less than 0.82). When the test specimen has a smaller ratiosratio than the above requirements,requirement, the test data shouldshall not be represented as material properties but shouldshall be called core properties because of nonuniform flux and field distribution.

8.4 When link, oval-shaped, or rectangular test specimen forms are used, the requirements of 7.38.3 apply to the end or corner sections where flux crowding occurs. may occur. When straight-sided test specimens are very long relative to the length of the corner or end sections, they are suitable for basic material properties evaluation with relatively unoriented materials, provided the uncertainty in determination of true-pathtrue (effective) magnetic path length is less than 1 %±1 % of the total magnetic path length. When this uncertainty in magnetic path length (shortest or longest relative to the mean-path mean magnetic-path length) exceeds 1 %,±1 %, the test values shouldshall be reported as core properties and not basic material properties.

7.5 The test specimen may be constructed of solid, laminated, or strip materials and in any of the shapes described in 1.1.

8.5 Test specimen cores made from strip may be laminated, machined, spirally wound, or Epstein specimens (thespecimens. The method of selection for Epstein specimens is described in Annex A3 of Test Method A343/A343M).. When the material is to be tested half transverse and half longitudinal, the material shall be cut into Epstein strips or square laminations of adequateappropriate dimensional ratio.

8.6 Test specimens used for basic material evaluation shall be cut, machined, ground, slit, or otherwise formed to have a cross section that remains sufficiently uniform that its nonuniformity will not materially affect the accuracy of establishing and measuring induction, magnetic flux density, B, or magnetic field strength, H, in the test specimen. It is recommended that the cross-sectional not vary by more than ±1 % anywhere in the magnetic path. The possible effects of mechanical preparation on the magnetic properties must be considered prior to testing.

8.7 Laminated ring specimens or specimens of strain sensitive materials shall be enclosed by a nonmagnetic, nonconductive core box prior to applying the primary and secondary windings unless it has been established by prior testing that the test results are not materially affected. Air flux correction will typically be required when core boxes are used if testing is to be done at high magnetic field strengths.

8.8 For laminated ring and spirally wound cores, the specimen cross-sectional area shall be computed from the mass, magnetic path length, and density.[6] For Epstein specimens, the specimen cross-sectional area shall be computed from the mass, physical length, and density.

8.9 When required for material properties development, the test specimen shall have received a stress relief or other anneal heat treatment after specimen preparation. This anneal heat treatment is subject to agreement between manufacturer and purchaser.the producer and the user.

9. Test Specimens for Permeameter Measurements

9.1 The specificationsinformation in 8.29.2 – 9.98.11 covercovers the general case for specimens in which the magnetizing force that must be tested using a permeameter, and where the magnetic field strength is not proportional to exciting current and the specimen must be tested in conjunction with a suitable permeameter.the magnetizing current.

9.2 Where possible, test specimen cross-sectional area shall be directly measured using calipers or micrometers. If not possible because of cross-sectional shape or surface roughness, then the cross-sectional area shall be determined from the mass, length, and assumed density of theWhen the test specimen represents a test lot of material, sampling shall conform to the requirements of Practice A34/A34Mtest specimen., unless superseded by a specification.

9.3 Test specimens in bar form may be of round, square, or rectangular cross-sectional shape. cross-section. In some permeameters, the bar specimen may be a half round or any shape having a uniform cross-sectional area. Permeameters must have a good magnetic joint between the ends of the test specimen and the permeameter yoke or pole faces. Generally, to achieve a good magnetic joint, the test specimen must be of square or rectangular cross section and must be machined or ground to have straight and parallel surfaces. For permeameters using specimens butted to the pole tips, the specimen ends must be smooth and parallel.

[6] Densities of magnetic materials can be found in Practice A34/A34M.