Designation: A1054 – 16

Standard Specification for Sintered Ferrite Permanent Magnets[1]

This standard is issued under the fixed designation A1054; 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 specification covers technically important, commercially available, magnetically hard sintered ferrite permanent magnets.

1.2 Ferrite permanent magnets have residual induction B_r from 0.2 T (2000 G) up to about 0.5 T (5000 G) and intrinsic coercive field strength H_{cJ} from 160 kA/m (2000 Oe) up to about 400 kA/m (5000 Oe). Their specific magnetic hysteresis behavior (demagnetization curve) can be characterized using Test Method A977/A977M.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to customary (cgs-emu and inch-pound) units which are provided for information only and are not considered 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]

A340 Terminology of Symbols and Definitions Relating to Magnetic Testing

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

2.2 *Other Standards:*

MMPA Standard No. 0100-00 Standard Specifications for Permanent Magnet Materials[3]

IEC 60404-8-1 Magnetic Materials Part 8: Specifications for individual materials Section 1 – Standard specifications for magnetically hard materials[4]

3. Terminology

3.1 The terms and symbols used in this specification are defined in Terminology A340.

3.2 Terms that are not defined in Terminology A340 but are in common usage and used herein are as follows.

3.2.1 Recoil permeability, μ_{REC}, is the permeability corresponding to the slope of the recoil line. For reference, see incremental, relative, and reversible permeabilities as defined in Terminology A340. In practical use, this is the slope of the normal hysteresis loop in the second quadrant and in proximity to the B-axis. The value of recoil permeability is dimensionless. Note that in producers' product literature, recoil permeability is sometimes represented by the symbol μ_r, which is defined by Terminology A340 as relative permeability.

3.2.2 Magnetic characteristics change with temperature. Two key metrics of permanent magnet performance are residual induction, B_r, and intrinsic coercive field strength, H_{cJ}. The change in these characteristics over a defined and limited temperature range can be reversible, that is, non-destructive. This change is represented by values called reversible temperature coefficients. The symbol for reversible temperature coefficient of induction is $\alpha(B_r)$ and of (intrinsic) coercivity is $\alpha(H_{cJ})$. They are expressed in percent change per degree Celsius, %/°C, or the numerically equivalent percent per Kelvin, %/K. The change in magnetic characteristics is nonlinear so it is necessary to specify the temperature range over which the coefficient applies.

3.2.3 The maximum recommended working temperature of a permanent magnet, T_w, is a semi-arbitrary value sometimes assigned by magnet manufacturers to their products. T_w is not normative. See Appendix X3 for a more complete discussion.

4. Classification

4.1 The classification of ferrite permanent magnets is given in Tables 1 and 2, with cross-reference to MMPA Standard No. 0100-00 and IEC 60404-8-1 standards.

[1] This specification is under the jurisdiction of ASTM Committee A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.02 on Material Specifications.

Current edition approved Nov. 1, 2016. Published November 2016. Originally approved in 2007. Last previous addition approved in 2014 as A1054 – 14. DOI: 10.1520/A1054-16.

[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 The International Magnetics Association (IMA), 8 South Michigan Avenue, Suite 1000, Chicago, IL 60603.

[4] Available from IEC (International Electrotechnical Commission) Central Office 3, rue de Varembé, P.O. Box 131, CH - 1211, GENEVA 20 Switzerland.

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TABLE 1 Classification and Minimum Magnetic Property Requirements for Isotropic Sintered Ferrite Permanent Magnets

Material					Magnetic Properties				
ASTM Designation[A]	MMPA Brief Designation	Original MMPA Class	IEC Brief Designation	IEC Code Reference	Maximum Energy Product, $(BH)_{max}$ kJ/m ^{3} (MGOe)	Remanent Induction B_r, mT (gauss)	Normal Coercive Field Strength, H_{cB} kA/m (oersted)	Intrinsic Coercive Field Strength, H_{cJ} kA/m (oersted)	Relative Recoil Permeability, μ_{REC}
CE-I-01	1.03/3	Ceramic 1	...	S1-0-1	8.4 (1.05)	230 (2300)	148 (1860)	259 (3250)	1.2

[A] Designations are XX-Y-ZZZ where:

XX = material type (CE = ceramic ferrite),
Y = processing and orientation (I = isotropic (non-oriented), A = anisotropic (oriented)), and
ZZZ = numeric grade designation.

TABLE 2 Classification and Minimum Magnetic Property Requirements for Anisotropic Sintered Ferrite Permanent Magnets

Material					Magnetic Properties				
ASTM Designation[A]	MMPA Brief Designation	Original MMPA Class	IEC Brief Designation	IEC Code Reference	Maximum Energy Product, $(BH)_{max}$ kJ/m^3 (MGOe)	Remanent Induction B_r, mT (gauss)	Normal Coercive Field Strength, H_{cB} kA/m (oersted)	Intrinsic Coercive Field Strength, H_{cJ} kA/m (oersted)	Relative Recoil Permeability μ_{REC}
CE-A-02	...	Ceramic 2	...	...	14.3 (1.8)	290 (2900)	191 (2400)	239 (3000)	1.1
CE-A-05	3.4/2.5	Ceramic 5	Hard ferrite 26/18	S1-1-6	27.1 (3.40)	380 (3800)	191 (2400)	199 (2500)	1.1
CE-A-06	...	Ceramic 6	...	...	19.5 (2.45)	320 (3200)	225 (2820)	263 (3300)	1.1
CE-A-07	2.7/4.0	Ceramic 7	Hard ferrite 20/28	S1-1-2	21.9 (2.75)	340 (3400)	259 (3250)	318 (4000)	1.1
CE-A-08A	3.5/3.1	Ceramic 8A	Hard ferrite 25/12	S1-1-5	27.9 (3.50)	385 (3850)	235 (2950)	243 (3050)	1.1
CE-A-08B	...	Ceramic 8B	...	...	32.8 (4.12)	420 (4200)	232 (2913)	236 (2960)	1.1
CE-A-10	...	Ceramic 10	...	...	30.4 (3.82)	400 (4000)	280 (3510)	288 (3617)	1.1
CE-A-11	...	Ceramic 11	...	...	34.4 (4.32)	430 (4300)	200 (2512)	204 (2560)	1.1
CE-A-21	3.4/3.9	...	...	...	27.1 (3.40)	380 (3800)	271 (3400)	310 (3900)	1.1
CE-A-22	4.0/2.9	...	...	...	31.8 (4.00)	410 (4100)	223 (2800)	231 (2900)	1.1
CE-A-23	3.2/4.8	...	...	...	25.5 (3.20)	370 (3700)	279 (3500)	382 (4800)	1.1
CE-A-24	3.8/4.0	...	...	...	30.3 (3.80)	400 (4000)	290 (3560)	318 (4000)	1.1

[A] Designations are XX-Y-ZZZ where:

XX = material type (CE = ceramic ferrite),
Y = processing and orientation (I = isotropic (non-oriented), A = anisotropic (oriented)), and
ZZZ = numeric grade designation.

5. Ordering Information

5.1 Orders for parts conforming to this specification shall include the following information:

5.1.1 Reference to this standard and year of issue/revision.

5.1.2 Reference to an applicable part drawing.

5.1.3 Magnetic property requirements if they are more stringent than the minimum values listed in the tables.

5.1.4 Quantity required.

5.1.5 The required magnetization state of the provided material (unmagnetized, fully magnetized, magnetized and thermally stabilized, magnetized and partially demagnetized or "calibrated"). This information should appear on the part drawing whenever possible.

5.1.6 Certification of magnetic property evaluation.

5.1.7 Marking and packaging requirements.

5.1.8 Exceptions to this specification or special requirements such as plating, coating, or functional testing as mutually agreed upon by the producer and user.

6. Chemical Composition

6.1 The general chemical composition of ferrite magnets is $MO \cdot 6Fe_2O_3$ with M being barium, strontium (strontium preferred due to environmental issues), or some combination of the two. New ferrite grades may also include some rare earth elements and cobalt. Chemical compositions listed in the tables are typical and are not guaranteed.

7. Physical and Mechanical Properties

7.1 Typical thermal properties are listed in Appendix X1.

7.2 Typical physical properties are listed in Appendix X2.

7.3 Physical density values in Appendix X2 are given for information purposes only and are not guaranteed.

7.4 Strength testing of brittle materials such as ferrite permanent magnets is difficult, expensive, and time-consuming. Results can be widely distributed. Producers typically make these measurements at the onset of production and they are seldom repeated.

8. Magnetic Property Requirements

8.1 Magnetic properties are listed in Tables 1 and 2.

8.2 The values of essential magnetic properties listed in the table are specified minimum values at +20 ± 2 °C (+68 ± 4 °F), determined after magnetizing to saturation.

8.3 The specified values of magnetic properties are valid only for magnet test specimens with a uniform cross-section along the axis of magnetization. Properties for anisotropic (magnetically oriented) magnets are measured along the axis of preferred orientation.

8.4 Because of the nature of permanent magnet production, magnetic testing of each lot is strongly recommended, especially for applications where the magnet performance is closely specified. Such magnetic property evaluations shall be conducted in the manner described below. Where the magnet shape is not suitable for magnetic testing, a specimen shall be cut from the magnet using appropriate slicing and grinding techniques, paying attention to any magnetic orientation within the magnet.

8.4.1 The magnetic properties shall be determined in accordance with Test Method A977/A977M, or by using a suitable, mutually agreed upon magnetometric method.

8.4.2 When magnets are being purchased in the fully magnetized condition, the testing shall determine the magnetic properties from the as-received magnetization state, followed by magnetization to saturation and testing of the magnetic properties from the fully magnetized condition.

8.4.3 When magnets are being purchased in the unmagnetized condition or in an unknown state of magnetization, the test laboratory shall magnetize the test specimen(s) to saturation and measure the magnetic properties from the fully magnetized condition.

8.4.4 When magnets are being purchased in a calibrated, stabilized, or "knocked-down" condition, magnets should be handled with care to prevent exposure to externally applied fields. Refer to Appendix X3 for an explanation of these terms.

8.4.5 Other test methods may be utilized as agreed to between producer and user. Such tests may include the open circuit magnetic field strength Helmholtz test, field strength measurements in a defined magnetic circuit, or magnetic flux density measurements adjacent to the magnet surface.

9. Workmanship, Finish, and Appearance

9.1 Dimensions and tolerances shall be as specified on the magnet drawing and must be agreed upon between the producer and user.

9.2 Porosity and voids are common in sintered ferrite magnets and shall not in themselves constitute reason for rejection unless agreed upon between producer and user. Allowable defects shall be documented in writing as part of the ordering or contracting process.

9.3 Magnets shall be free of loose chips and surface residue which may interfere with assembly or proper device function.

9.4 Chips shall be acceptable if no more than 5 % of any surface identified as a magnetic pole surface is removed.

9.5 Cracks visible to the naked eye shall not be permitted unless otherwise agreed to by producer and user.

10. Sampling

10.1 A lot shall consist of parts of the same form and dimensions, produced from a single mixed powder batch or sintering run, or both, from an unchanged process, without discontinuity in production, and submitted for inspection at one time.

10.2 The producer and user shall agree upon a representative number of specimens for testing. Typically, a suitable number of parts, as mutually agreed upon between producer and user, shall be randomly selected from each lot. It is advisable to test a minimum of two parts from each lot, and more if there is reason to suspect that the magnetic properties are not uniform throughout the lot.

11. Rejection and Rehearing

11.1 Parts that fail to conform to the requirements of this specification shall be rejected. Rejection should be reported to the producer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the producer may make claim for a rehearing.

11.2 The disposition of rejected parts shall be subject to agreement between the user and the producer.

12. Certification

12.1 When specified in the purchase order or contract, the user shall be furnished certification that samples representing each lot have been either tested or inspected as directed in this specification and that the requirements have been met.

12.2 When specified in the purchase order or contract, a report of the test results shall include:

12.2.1 Grade of material.

12.2.2 Magnetic test results.

12.2.3 The results of any other tests stipulated in the purchase order or contract.

13. Packaging and Package Marking

13.1 Packaging shall be subject to agreement between the user and the producer.

13.2 Parts furnished under this specification shall be in a container identified by the name or symbol of the parts producer.

13.3 Magnetized parts shall be properly labeled as such for safe handling and shipping purposes.

13.3.1 Magnetized parts to be shipped via aircraft must be packaged in an appropriate manner to meet requirements for air shipment. These requirements may vary depending upon local, national, and international laws. It is the responsibility of the producer to ensure packaging meets all relevant regulations. This may require rearranging the parts within the shipping container, adding sheets of steel or other magnetically soft shielding material, or both, or other specialized packaging procedures as determined by regulation, carrier policy, or by agreement between producer and user, to reduce the magnetic field external to the shipping container below the required levels.

14. Keywords

14.1 ceramic magnet; coercive field strength; ferrite; ferrite magnet; hard ferrite; magnetic induction; magnetic properties; permanent magnet; sintered ceramic ferrite; sintered ferrite magnet

APPENDIXES

(Nonmandatory Information)

X1. TYPICAL THERMAL PROPERTIES OF FERRITE PERMANENT MAGNETS

Reversible temperature coefficient of residual induction	-0.2 %/°C
Reversible temperature coefficient of intrinsic coercive field strength	+0.2 to +0.5 %/°C
Curie temperature	450 °C
Maximum exposure temperature without structural change	800 °C

X2. TYPICAL PHYSICAL PROPERTIES OF FERRITE PERMANENT MAGNETS

Density	4.9 to 5.1 g/cm^3 (0.177 to 0.184 lb/in.^{3})
Coefficient of thermal expansion	
Perpendicular to magnetic orientation	10 ppm/°C
Parallel to magnetic orientation	14 ppm/°C
Thermal conductivity	2.93 J/m-sec°C (0.007 cal/cm-sec°C)
Electrical resistivity	10^4 ohm-m (10^6 ohm-cm)
Porosity	5 %
Modulus of elasticity	170×10^9 Pa (2.5×10^7 psi)
Poisson ratio	0.28
Compressive strength	900×10^6 Pa (130 000 psi)
Tensile strength	35×10^6 Pa (5000 psi)
Flexural strength	62×10^6 Pa (9000 psi)
Hardness	7 Mohs

X3. OTHER TERMINOLOGY

X3.1 Maximum Recommended Working Temperature

X3.1.1 The maximum recommended working temperature of a permanent magnet, T_w, is a semi-arbitrary value sometimes assigned by magnet manufacturers to their products. T_w is not normative. It is generally a function of the linearity of the normal hysteresis loop in the second quadrant at the specified temperature. In one interpretation, it is the maximum temperature at which the normal hysteresis loop is linear in the second quadrant. In a less demanding interpretation, the normal loop must be linear only to the maximum energy operating point on the normal hysteresis loop.

X3.1.2 The maximum working temperature is also an indication of the temperature a material can sustain without experiencing structural or metallurgical change which might adversely affect magnetic or mechanical properties.

X3.2 Magnetic Condition – Calibrated, Stabilized, Knocked Down

X3.2.1 It is often the case that a magnet can become partially demagnetized in handling, assembly, or in use. There are also three common adjustments to the magnetic output made to meet application requirements as follow.

X3.2.2 Magnets that are exposed to extreme temperatures may experience partial demagnetization. This can be minimized by pre-treating the magnets thermally in an oven at a temperature providing equivalent knock down to that experienced in use. To prevent partial demagnetization from exposure to magnetic fields, a demagnetizing field of predetermined field strength is applied to the magnet (an opposing or demagnetized field). Magnets treated by either method are said to be stabilized as subsequent exposure to the (*a*) defined temperature or (*b*) magnetic field will cause minimal-to-no additional demagnetization.

X3.2.3 In the event an application requires magnets to provide a specific magnetic field strength and within a narrow tolerance range, it may be necessary to treat the magnets, usually magnetically, to a reverse magnetic (knock down) field of a suitable magnitude. The intent of the reverse field is to knock down each magnet sufficiently to fall within a specific range of magnetic output. Stronger magnets may require a greater knock down field; weaker magnets may require a smaller knock down field. The result of treating the magnets is to reduce the variability of magnetic output within and among batches of magnets. In so doing all magnets will undergo some level of demagnetization. Magnets thus treated are said to be calibrated.

X3.2.4 In either of the above cases, the treated magnets will have experienced some level of knock down. Furthermore, there are times when magnets will require demagnetization in part or totally. Alnico and ferrite permanent magnets can be demagnetized with relative ease by exposure to a ringing AC field or by extracting the magnet from an AC field. Accomplishing this for neodymium iron boron and SmCo magnets is difficult due to their great resistance to demagnetization (high intrinsic coercive field strength). Neo magnets can be thermally treated above their Curie temperature, 310 to 350 °C or higher depending upon composition, to demagnetize them. SmCo magnets can also be demagnetized by treatment above their Curie temperature of ~825 °C, but exposure to such a high temperature may require a controlled thermal treatment to fully restore magnetic properties. In any event, when a magnet has been partially or totally demagnetized it is said to have been knocked down.

X3.3 Historical Abbreviations

X3.3.1 Several alternative abbreviations of magnetic properties are or have been in general use. *Residual induction* is without confusion shown as "Br." However, *normal coercive field strength* is variously shown as Hc, Hcb, bHc, and H_{cB}. *Intrinsic coercive field strength* is shown as Hci, iHc, jHc, or H_{cJ}. The consensus CGS terms are Br, Hc, and Hci, while SI abbreviations are B_r, H_{cB}, and H_{cJ}. The modifying letters are often, for convenience, not subscripted.

X3.3.2 Origin of "*i*" in the abbreviation is a priori referring to the "intrinsic" (B-H versus H) characteristic while the absence of "*i*" refers to the normal (B versus H) characteristic. The intrinsic characteristics and curve is increasingly referred to as polarization with abbreviation "*J*." Abbreviations used within this standard conform to Terminology A340. ASTM standards are *living documents* and it is recommended to refer to the most recent version.

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