Designation: A1070 – 16

Standard Specification for Cast and Sintered Alnico Permanent Magnets[1]

This standard is issued under the fixed designation A1070; 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, cast and sintered permanent magnets known commonly as Alnico.

1.2 Alnico magnets have approximate magnetic properties of residual magnetic induction, B_r, from 0.52 T (5200 G) to 1.35 T (13500 G) and coercivity, H_{cB}, from 38 kA/m (475 Oe) to 175 kA/m (2200 Oe). Their specific magnetic hysteresis behavior (demagnetization curves) 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, except as noted in 3.2.

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, $\mu_{(rec)}$, 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 characteristic 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 for (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 changes in magnetic characteristics are non-linear so it is necessary to specify the temperature range over which the coefficient applies.

3.2.3 The maximum recommended working temperature, T_w, of a permanent magnet 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 Alnico permanent magnets is given in Table 1, and Appendix X1, Table X1.1, with cross-reference to MMPA Standard No. 0100-00 and IEC 60404-8-1.

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[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.

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[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] MMPA Standard No. 0100-00 is now available from the Permanent Magnet Division of the SMAA (www.smma.org). It was previously available from The International Magnetics Association (IMA). The IMA had been the successor to the MMPA and both organizations no longer exist.

[4] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st Floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

TABLE 1 Alnico Magnets: Minimum Magnetic Property Requirements[A]

NOTE 1—"..." indicates that there is no known published data.

ASTM Designation[B]	Chemical Composition[C]					Maximum Energy Product $(BH)_{max}$		Residual Induction B_r		Coercive Field Strength H_{cB}		Intrinsic Coercive Field Strength H_{cJ}	
	Al	Ni	Co	Cu	Ti	kJ/m^3	(MGOe)	mT	(G)	kA/m	(Oe)	kA/m	(Oe)
CAST ISOTROPIC ALNICO													
AL-CI-9/47	...	...	...	...	...	9.0	(1.1)	550	(5500)	44.0	(553)	47.0	(591)
AL-CI-10/38	12	25	...	3	...	9.7	(1.2)	665	(6650)	36.3	(456)	37.8	(475)
AL-CI-12/55	...	...	...	...	...	11.6	(1.5)	630	(6300)	52.0	(653)	55.0	(691)
AL-CI-12/44	10	19	13	3	...	12.2	(1.5)	713	(7125)	42.3	(532)	43.8	(551)
AL-CI-17/86	...	...	...	...	...	17.0	(2.1)	580	(5800)	80.0	(1005)	86.0	(1081)
CAST ANISOTROPIC ALNICO													
AL-CA-28/61	8	16	24	3	1	27.9	(3.5)	998	(9975)	59.0	(741)	60.5	(760)
AL-CA-36/148	...	...	...	...	...	36.0	(4.5)	700	(7000)	140.0	(1759)	148.0	(1860)
AL-CA-37/49	...	...	...	...	...	37.0	(4.6)	1180	(11 800)	48.0	(603)	49.0	(616)
AL-CA-38/112	...	...	...	...	...	38.0	(4.8)	800	(8000)	110.0	(1382)	112.0	(1407)
AL-CA-36/164	8	14	38	3	8	35.8	(4.5)	684	(6840)	143.6	(1805)	164.1	(2062)
AL-CA-38/141	7	15	35	4	5	38.0	(4.8)	779	(7790)	124.7	(1568)	140.6	(1767)
AL-CA-39/49	8	14	24	3	...	39.4	(5.0)	1216	(12 160)	48.4	(608)	48.8	(613)
AL-CA-44/53	...	...	...	...	...	44.0	(5.5)	1200	(12 000)	52.0	(653)	53.0	(666)
AL-CA-47/51	8	14	24	3	...	46.6	(5.9)	1264	(12 635)	50.7	(637)	51.0	(641)
AL-CA-58/53	...	...	...	...	...	58.0	(7.3)	1300	(13 000)	52.0	(653)	53.0	(666)
AL-CA-54/56	8	14	24	3	...	53.7	(6.8)	1283	(12 825)	55.9	(703)	56.3	(708)
AL-CA-60/112	...	...	...	...	...	60.0	(7.5)	900	(9000)	110.0	(1382)	112.0	(1407)
AL-CA-65/115	7	15	35	4	5	64.5	(8.1)	1007	(10 070)	113.4	(1425)	114.5	(1439)
AL-CA-72/120	...	...	...	...	...	72.0	(9.0)	1050	(10 500)	118.0	(1483)	120.0	(1508)
SINTERED ISOTROPIC ALNICO													
AL-SI-9/47	...	...	...	...	...	9.0	(1.1)	550	(5500)	44.0	(553)	47.0	(591)
AL-SI-12/55	...	...	...	...	...	11.6	(1.5)	630	(6300)	52.0	(653)	55.0	(691)
AL-SI-11/43	10	19	13	3	...	10.7	(1.4)	675	(6745)	41.6	(523)	43.1	(542)
AL-SI-17/86	...	...	...	...	...	17.0	(2.1)	580	(5800)	80.0	(1005)	86.0	(1081)
SINTERED ANISOTROPIC ALNICO													
AL-SA-21/62	8	15	24	3	1	20.8	(2.6)	893	(8930)	59.7	(751)	62.0	(779)
AL-SA-26/58	...	...	...	...	...	26.0	(3.3)	900	(9000)	56.0	(704)	58.0	(729)
AL-SA-28/48	8	14	24	3	...	27.9	(3.5)	1036	(10 355)	46.9	(589)	47.6	(599)
AL-SA-31/111	...	...	...	...	...	31.0	(3.9)	760	(7600)	107.0	(1345)	111.0	(1395)
AL-SA-29/128	7	15	35	4	5	28.6	(3.6)	703	(7030)	113.4	(1425)	127.8	(1606)
AL-SA-33/150	...	...	...	...	...	33.0	(4.1)	650	(6500)	135.0	(1696)	150.0	(1885)
AL-SA-34/48	...	...	...	...	...	34.0	(4.3)	1120	(11 200)	47.0	(591)	48.0	(603)
AL-SA-32/153	7	14	38	3	8	32.2	(4.1)	637	(6365)	136.1	(1710)	152.7	(1919)

[A] Magnetic properties are minimum for +20 ± 2 °C (+68 ± 4 °F) and for a fully magnetized specimen.

[B] ASTM Designations are of the form *MM-TT-XX/YY* where:

MM = material (AL = Alnico),
TT = type of processing and orientation (CI = cast isotropic (non-oriented), CA = cast anisotropic (oriented), SI = sintered isotropic (non-oriented), SA = sintered anisotropic (oriented)),
XX = energy product in k/J/m^3 rounded to the nearest integer, and
YY = intrinsic coercivity in kA/m rounded to the nearest integer.

[C] Composition are representative and approximate and are non-mandatory information. The numbers presented here are weight percent.

5. Ordering Information

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

5.1.1 Reference to this specification 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 then partially demagnetized—see Appendix X3 for an explanation of terms). 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 Alnico magnets is aluminum, nickel, and cobalt with selected transition metals and minor constituents and the balance of the composition being iron. Approximate chemical compositions for each grade are listed in Table 1 and are typical but not mandatory.

7. Physical and Mechanical Properties

7.1 Typical thermal and physical properties are listed in Appendix X2, Table X2.1.

7.2 Physical density values are given for information purposes only and are not mandatory.

7.3 Alnico magnets are used for their magnetic characteristics. The end-use application should not rely on them for structural purposes due to low tensile and flexural strength. These materials are brittle and can chip or break easily. Magnetic properties may also be affected by physical stress.

8. Magnetic Property Requirements

8.1 Magnetic properties are listed in Table 1.

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 in closed magnetic circuit.

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 in the same orientation as the received specimens' indicated direction of magnetization and measure the magnetic properties from this 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. During testing using Test Method A977/A977M and to avoid changing the magnetization state of the material prior to test, the measurement should proceed in the second quadrant only without attempting to saturate the magnet specimen.

8.4.5 Other test methods may be utilized as agreed to between producer and user. Such tests may include open circuit magnetization Helmholtz test (refer to Appendix X3), field strength measurements in a defined magnetic circuit or magnetic flux density measurements adjacent to the magnet surface.

8.4.6 Due to the ease with which the magnetic field of Alnico magnets can be affected, the producer and user should agree on methods to prevent unintended changes from occurring. These preventive measures may include the use of keepers across the magnet poles, spacing within packaging to prevent like poles from affecting each other, or other agreed-to methods.

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 Alnico magnets and shall not in themselves constitute reason for rejection unless agreed upon between producer and user. Allowable defects shall be defined and 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 10 % of any surface identified as a magnetic pole surface is removed unless otherwise agreed to by producer and user.

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

10. Sampling

10.1 Unless otherwise agreed to between producer and user, a lot shall consist of parts of the same form and dimensions, produced from a single furnace melt (cast Alnico) or mixed powder batch or sintering run (sintered Alnico), and 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 promptly and in writing. In case of dissatisfaction with the results of the test, the producer may make a claim for a rehearing.

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

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 producer and the user.

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 applicable 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 (*1*) rearranging the parts within the shipping container, or (*2*) 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 Alnico magnet; cast Alnico magnet; coercive field strength; magnetic flux density; magnetic properties; maximum energy product; permanent magnet; residual induction; sintered Alnico magnet

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION

X1.1 See Table X1.1.

TABLE X1.1 Alnico Magnets: Classification and Grade Cross Reference

NOTE 1—"..." indicates that there is no known published data.

ASTM	MMPA		IEC	
ASTM Designation[A]	Original MMPA Classification	MMPA Brief Designation	IEC Brief Designation	IEC Code Number
CAST ISOTROPIC ALNICO				
AL-CI-9/47	...	...	Alnico 9/5	R1-0-1
AL-CI-10/38	Alnico 3	1.35/0.50	...	...
AL-CI-12/55	...	...	Alnico 12/6	R1-0-2
AL-CI-12/44	Alnico 2	1.7/0.58	...	...
AL-CI-17/86	...	...	Alnico 17/9	R1-0-3
CAST ANISOTROPIC ALNICO				
AL-CA-28/61	Alnico 6	3.9/0.80	...	...
AL-CA-36/148	...	...	Alnico 36/15	R1-1-5
AL-CA-37/49	...	...	Alnico 37/5	R1-1-1
AL-CA-38/112	...	...	Alnico 38/11	R1-1-2
AL-CA-36/164	Alnico 8HC	5.0/2.2	...	...
AL-CA-38/141	Alnico 8	5.3/1.9	...	...
AL-CA-39/49	Alnico 5	5.5/0.64	...	...
AL-CA-44/53	...	...	Alnico 44/5	R1-1-3
AL-CA-47/51	Alnico 5DG	6.5/0.67	...	...
AL-CA-58/53	...	...	Alnico 58/5	R1-1-6
AL-CA-54/46	Alnico 5-7	7.5/0.74	...	...
AL-CA-60/112	...	...	Alnico 60/11	R1-1-4
AL-CA-65/115	Alnico 9	9.0/1.5	...	...
AL-CA-72/120	...	...	Alnico 72/12	R1-1-7
SINTERED ISOTROPIC ALNICO				
AL-SI-9/47	...	...	Alnico 9/5	R1-0-1
AL-SI-12/55	...	...	Alnico 12/6	R1-0-2
AL-SI-11/43	Alnico 2	1.5/0.57	...	...
AL-SI-17/86	...	...	Alnico 17/9	R1-0-3
SINTERED ANISOTROPIC ALNICO				
AL-SA-21/62	Alnico 6	2.9/0.82	...	...
AL-SA-26/58	...	...	Alnico 26/6	R1-1-11
AL-SA-28/48	Alnico 5	3.9/0.63	...	...
AL-SA-31/111	...	...	Alnico 31/11	R1-1-12
AL-SA-29/128	Alnico 8	4.0/1.7	...	...
AL-SA-33/150	...	...	Alnico 33/15	R1-1-13
AL-SA-34/48	...	...	Alnico 34/5	R1-1-10
AL-SA-32/153	Alnico 8HC	4.5/2.0	...	...

[A] The ASTM designation conforms to the requirements of this specification. MMPA and IEC designations are included for reference only. ASTM designations are of the form *MM-TT-XX/YY* where:

MM = material (AL = Alnico),
TT = type of processing and orientation (CI = cast isotropic (non-oriented), CA = cast anisotropic (oriented), SI = sintered isotropic (non-oriented), SA = sintered anisotropic (oriented)),
XX = energy product in kJ/m^3 rounded to the nearest integer, and
YY = intrinsic coercivity in kA/m rounded to the nearest integer.

X2. TYPICAL THERMAL, ELECTRICAL, AND MECHANICAL PROPERTIES

X2.1 See Table X2.1.

TABLE X2.1 Alnico Magnets: Typical Thermal and Physical Properties

NOTE 1—"..." indicates that there is no known published data.

ASTM Designation[A]	α (B_r)%/°C[B] %/°C	α (H_{cJ})[B] %/°C	Recoil Permeability[C] $\mu_{(rec)}$	T_c[D] °C	T_w[E] °C	Density g/cm³ (lb/in.³)	Tensile Strength MPa (ksi)	Transverse Rupture MPa (ksi)	Hardness HRC	Thermal Expansion ×10⁻⁶/°C	Resistivity $10^{-6}\Omega \cdot m$
CAST ANISOTROPIC ALNICO											
AL-CI-9/47	–0.02	...	7	750	550	6.80 (0.245)	...	...	...	...	...
AL-CI-10/38	–0.04	–0.04	7	760	450	6.90 (0.249)	83 (12)	152 (22)	45	13.0	0.60
AL-CI-12/55	–0.02	...	7.5	...	550	7.00 (0.253)	...	...	...	...	...
AL-CI-12/44	–0.03	–0.02	7	810	450	7.10 (0.256)	21 (3)	50 (7.2)	45	12.4	0.65
AL-CI-17/86	–0.02	...	7.5	...	550	7.10 (0.256)	...	...	...	...	...
CAST ANISOTROPIC ALNICO											
AL-CA-28/61	–0.02	+0.03	4.2	875	500	7.40 (0.267)	159 (23)	310 (45)	...	11.4	0.50
AL-CA-36/148	–0.02	...	2	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-37/49	–0.02	...	4	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-38/112	–0.02	...	2	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-36/164	–0.025	–0.01	2	860	550	7.30 (0.263)	69 (10)	207 (30)	50	11.0	0.50
AL-CA-38/141	–0.025	–0.01	2	860	500	7.20 (0.260)	69 (10)	207 (30)	50	11.0	0.50
AL-CA-39/49	–0.02	+0.01	2.2	890	500	7.30 (0.263)	37 (5.4)	69 (10)	50	11.3	0.47
AL-CA-44/53	–0.02	...	3	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-47/51	–0.02	+0.01	2	890	500	7.30 (0.263)	36 (5.2)	69 (10)	50	11.3	0.47
AL-CA-58/53	–0.02	...	3	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-54/56	–0.02	+0.01	2	890	500	7.30 (0.263)	34 (5.0)	55 (8)	50	11.3	0.47
AL-CA-60/112	–0.02	...	2	...	550	7.30 (0.263)	...	...	...	...	...
AL-CA-65/115	–0.025	...	1.5	860	500	7.30 (0.263)	48 (7.0)	55 (8)	50	11.0	0.50
AL-CA-72/120	–0.02	–0.01	2	...	550	7.30 (0.263)	...	...	...	...	...
SINTERED ISOTROPIC ALNICO											
AL-SI-9/47	–0.02	...	7	750	550	6.80 (0.245)	...	...	...	...	...
AL-SI-12/55	–0.02	...	7.5	...	550	7.00 (0.253)	...	...	...	...	...
AL-SI-11/43	...	...	6	810	450	6.80 (0.245)	448 (65)	483 (70)	45	12.4	0.68
AL-SI-17/86	–0.02	...	7.5	...	550	7.10 (0.256)	...	...	...	...	...
SINTERED ANISOTROPIC ALNICO											
AL-SA-21/62	...	...	4	860	540	6.90 (0.249)	379 (55)	689 (100)	45	11.4	0.54
AL-SA-26/58	–0.02	...	4.5	...	550	7.10 (0.256)	...	...	...	...	...
AL-SA-28/48	...	...	4	860	540	6.90 (0.249)	345 (50)	379 (55)	45	11.3	0.50
AL-SA-31/111	–0.02	...	3	...	550	7.10 (0.256)	...	...	...	...	...
AL-SA-29/128	...	...	2	860	540	7.00 (0.253)	345 (50)	379 (55)	45	11.0	0.54
AL-SA-33/150	–0.02	...	2	...	550	7.10 (0.256)	...	...	...	...	...
AL-SA-34/48	–0.02	...	4	...	550	7.30 (0.263)	...	...	...	...	...
AL-SA-32/153	...	...	2	860	540	7.00 (0.253)	345 (50)	379 (55)	45	11.0	0.54

[A] Designations are *MM-TT-XX/YY* where:

MM = material (AL = Alnico),
TT = type of processing and orientation (CI = cast isotropic (non-oriented), CA = cast anisotropic (oriented), SI = sintered isotropic (non-oriented), SA = sintered anisotropic (oriented)),
XX = energy product in kJ/m³ rounded to the nearest integer,
YY = intrinsic coercivity in kA/m rounded to the nearest integer.

[B] α (B_r) is the reversible temperature coefficient of induction and α (H_{cJ}) is the reversible temperature coefficient of (intrinsic) coercivity.

[C] Recoil permeability is nonmandatory and approximate, based upon IEC specification IEC 60404-8-1 and manufacturer information. 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.

[D] T_c = Curie temperature. Curie temperature is most commonly reported in °C as shown in the table.

[E] T_w = maximum recommended working temperature. Working temperature is most commonly reported in °C as shown in the table. See Appendix X3.

X3. OTHER TERMINOLOGY

X3.1 Helmholtz Measurement

X3.1.1 An identical pair of solenoid coils connected electrically in series and separated by a distance determined by the diameter of the coils creates a region within it of uniform magnetic field either as generated by a current in the coils or by moving a magnet into or out of the uniform region to produce a voltage across the coil. This effect was quantified and defined by Hermann von Helmholtz and the coil (the pair of coils) thus constructed is referred to using his name, Helmholtz coil, and the measurement of a magnet's open circuit magnetization is a Helmholtz measurement.

X3.1.2 In the common form of the test, a Helmholtz coil is connected to the input of an integrating fluxmeter. A magnet is then inserted into the center of the coil, the fluxmeter is zeroed, the magnet is extracted (along the axis of the coil) to a distance sufficient so that additional changes to the fluxmeter output are immeasurable, and the fluxmeter output is recorded. An alternative extraction method is to remove the magnet from the side of the coil pair producing the same measurable flux output. A frequently used alternative is to rotate the magnet on axis within the coil producing an output twice as great as simple extraction. This larger value may be used as-is for comparative readings or divided by two for computation of magnetic moment.

X3.1.3 Advantages of the Helmholtz measurement method include that it is a non-destructive test and that it is relatively easy and fast to perform. It is commonly used to measure magnets after stabilization or calibration treatment. When the volume of the magnet is known, the fluxmeter output can provide a measure of the magnet's open circuit intrinsic induction, often symbolized by B_{di}. In addition to calibration of the integrating fluxmeter, the Helmholtz coil must be "calibrated," that is, a coil constant needs to be established to permit accurate output.

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.

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 demagnetizing field). Magnets treated by either method are said to be **stabilized** as exposure in the application to the defined (*a*) temperatures or (*b*) fields 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 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 will require a greater knock down field; weaker magnets will 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 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 Neo 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, typically between 310 to 350 °C depending upon composition. SmCo can also be demagnetized by treatment above the 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 Maximum Recommended Working Temperature, T_w

X3.3.1 The maximum recommended working temperature of a permanent magnet 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. As the normal curve of Alnico is not linear, the maximum working temperature is determined by the second limiting criterion as follows.

X3.3.2 The maximum working temperature is an indication of the temperature a material can sustain without experiencing structural or metallurgical change which might adversely affect magnetic or mechanical properties.

X4. SYMBOLS

X4.1 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, H_{cB}. *Intrinsic coercive field strength*, although not usually used with Alnico magnet properties, is shown as Hci, iHc, jHc, or H_{cJ}. The CGS terms appear settled on Br, Hc, and Hci while SI abbreviations are B_r, H_{cB}, and H_{cJ}. The modifying letters are often, for convenience, not subscripted.

X4.2 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 characteristic and curve is increasingly referred to as polarization with abbreviation "*J*."

X4.3 Abbreviations used within this specification conform to Terminology A340. ASTM standards are *living documents* and it is recommended to refer to the most recent version.