Designation: A1102 – 16

Standard Specification for Sintered Samarium Cobalt (SmCo) Permanent Magnets[1]

This standard is issued under the fixed designation A1102; 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 (fully dense) permanent magnets commonly known as samarium cobalt. These materials are available in two general composition families abbreviated "SmCo 1:5" and "SmCo 2:17." The numbers indicate the approximate atomic ratio of samarium to the sum of other constituents. (Refer to Appendix X3 for additional composition information.)

1.2 Samarium cobalt magnets have approximate magnetic properties of residual magnetic induction, B_r, from 0.78 T (7800 G) to 1.18 T (11 800 G) and intrinsic coercivity, H_{cJ}, typically greater than 800 kA/m (10 000 Oe). Special grades and isotropic (un-aligned) magnets can have properties outside these ranges (see Appendix X4). 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, unless otherwise noted, 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, $\mu_{(rec)}$, 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 these characteristics over a defined and limited temperature range can be reversible, that is, nondestructive. 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.

[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] Available from the Permanent Magnet Division of the SMMA (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 (MMPA and IMA) 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.

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 X6 for a more complete discussion.

4. Classification

4.1 The classification of samarium cobalt permanent magnets is given in Table 1 and in Table X1.1 with cross-reference to MMPA Standard No. 0100-00 and IEC 60404-8-1.

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). 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 Samarium cobalt magnets should be specified primarily by magnetic performance. Chemical composition can have an influence on both magnetic and physical characteristics but should only be specified when other options are insufficient to meet user requirements. Agreement on composition must be mutually arrived at by producer and user.

TABLE 1 Samarium Cobalt Permanent Magnets: Minimum Magnetic Property Requirements[A]

ASTM Designation[B]	Maximum Energy Product $(BH)_{max}$		Residual Induction B_r		Coercive Field Strength H_{cB}		Intrinsic Coercive Field Strength H_{cJ}	
	kJ/m³	(MGOe)	mT	(G)	kA/m	(Oe)	kA/m	(Oe)
ANISOTROPIC SmCo 1:5								
S1-SA-115/1436	115	(14.4)	789	(7885)	567	(7125)	1436	(18050)
S1-SA-120/1600	120	(15.1)	800	(8000)	620	(7791)	1600	(20106)
S1-SA-129/2268	129	(16.2)	827	(8265)	643	(8075)	2268	(28500)
S1-SA-140/1200	140	(17.6)	920	(9200)	660	(8294)	1200	(15080)
S1-SA-143/2268	143	(18.0)	855	(8550)	665	(8360)	2268	(28500)
S1-SA-150/700	150	(18.8)	900	(9000)	600	(7540)	700	(8796)
S1-SA-160/1200	160	(20.1)	920	(9200)	660	(8294)	1200	(15080)
S1-SA-170/700	170	(21.4)	930	(9300)	600	(7540)	700	(8796)
S1-SA-179/1134	179	(22.5)	998	(9975)	722	(9073)	1134	(14250)
ANISOTROPIC SmCo 2:17								
S2-SA-140/1000	140	(17.6)	900	(9000)	620	(7791)	1000	(12566)
S2-SA-160/700	160	(20.1)	940	(9400)	600	(7540)	700	(8796)
S2-SA-172/529	172	(21.6)	950	(9500)	454	(5700)	529	(6650)
S2-SA-172/1966	172	(21.6)	950	(9500)	703	(8835)	1966	(24700)
S2-SA-180/1000	180	(22.6)	1000	(10000)	680	(8545)	1000	(12566)
S2-SA-180/1500	180	(22.6)	1000	(10000)	660	(8294)	1500	(18850)
S2-SA-186/756	186	(23.4)	998	(9975)	680	(8550)	756	(9500)
S2-SA-186/1966	186	(23.4)	1017	(10165)	737	(9263)	1966	(24700)
S2-SA-200/700	200	(25.1)	1050	(10500)	600	(7540)	700	(8796)
S2-SA-200/1500	200	(25.1)	1050	(10500)	700	(8796)	1500	(18850)
S2-SA-201/529	201	(25.2)	1036	(10355)	491	(6175)	529	(6650)
S2-SA-201/1966	201	(25.2)	1045	(10450)	779	(9785)	1966	(24700)
S2-SA-215/756	215	(27.0)	1045	(10450)	718	(9025)	756	(9500)
S2-SA-215/1512	215	(27.0)	1045	(10450)	779	(9785)	1512	(19000)
S2-SA-215/1814	215	(27.0)	1045	(10450)	779	(9785)	1814	(22800)
S2-SA-215/2268	215	(27.0)	1045	(10450)	779	(9785)	2268	(28500)
S2-SA-220/756	220	(27.6)	1088	(10878)	718	(9025)	756	(9500)
S2-SA-220/1500	220	(27.6)	1100	(11000)	600	(7540)	1500	(18850)
S2-SA-220/1890	220	(27.6)	1088	(10878)	801	(10070)	1890	(23750)
S2-SA-230/756	230	(28.9)	1107	(11068)	718	(9025)	756	(9500)
S2-SA-230/1134	230	(28.9)	1107	(11068)	824	(10355)	1134	(14250)
S2-SA-230/1512	230	(28.9)	1107	(11068)	824	(10355)	1512	(19000)
S2-SA-230/1890	230	(28.9)	1107	(11068)	824	(10355)	1890	(23750)
S2-SA-236/756	236	(29.7)	1112	(11115)	718	(9025)	756	(9500)
S2-SA-236/1134	236	(29.7)	1112	(11115)	832	(10450)	1134	(14250)
S2-SA-236/1512	236	(29.7)	1112	(11115)	832	(10450)	1512	(19000)

[A] Magnetic properties at 20 °C (68 °F).
[B] The ASTM designation conforms to the requirements of this specification and is of the form *MM-TT-XX/YY* where:

MM = material (S1 = samarium cobalt 1:5; S2 = samarium cobalt 2:17),
TT = type of processing and orientation (S = sintered; I = isotropic (non-oriented), A = anisotropic (oriented)),
XX = energy product in kJ/m³ rounded to the nearest integer, and
YY = intrinsic coercivity in kA/m rounded to the nearest integer.

6.2 The general chemical constituents of samarium cobalt 1:5 magnets are samarium and cobalt. Samarium cobalt 2:17 magnets contain samarium, cobalt, iron, copper, and zirconium. Approximate chemical compositions are listed in Table X3.1 and are typical but not mandatory.

6.3 In some grades of samarium cobalt 1:5, praseodymium is used to substitute for a portion of the samarium to increase maximum energy product (see Table X3.1 and Appendix X4). In either the 1:5 or 2:17 grades, substitution of a portion of samarium by gadolinium (or a combination of gadolinium and dysprosium) will result in "temperature-stable" grades, those which exhibit less change in flux output as a function of temperature. These are generally made to customer specification and are not considered standard grades.

7. Physical and Mechanical Properties

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

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

7.3 Samarium cobalt 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.

7.4 Strength testing of brittle materials such as samarium cobalt is difficult, expensive, and time-consuming and there may be considerable scatter in the measured values. 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 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 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 specimen's 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 X6 for an explanation of these terms. During testing using Test Method A977/A977M, 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 the open circuit magnetic field strength Helmholtz test, field strength measurements in a defined magnetic circuit, or magnetic field strength 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 producer and user.

9.2 Though porosity and voids are uncommon in samarium cobalt magnets, their appearance shall not in themselves constitute reason for rejection unless agreed upon between producer and user. Allowable amounts of porosity and voids shall be documented in writing and included as part of the ordering or contracting process.

9.3 Magnets shall be free of adhered magnetic particles 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.

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, 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, at a minimum, include:

12.2.1 Grade of material.

12.2.2 Lot or batch number.

12.2.3 Magnetic test results.

12.2.4 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 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 coercive field strength; magnetic field strength; magnetic flux density; magnetic properties; maximum energy product; permanent magnet; residual induction; samarium cobalt magnet; sintered rare earth magnet

APPENDIXES

(Nonmandatory Information)

X1. CLASSIFICATION

X1.1 See Table X1.1.

TABLE X1.1 Samarium Cobalt Permanent Magnets: Classification and Grade Cross Reference

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

ASTM	MMPA	IEC	
ASTM Designation[A]	MMPA Brief Designation	IEC Brief Designation	IEC Code Number
SINTERED ANISOTROPIC SmCo 1:5			
S1-SA-115/1436	16/19	...	...
S1-SA-120/1600	...	$RECo_5$ 120/160	R5-1-5
S1-SA-129/2268	18/30	...	...
S1-SA-140/1200	20/16	$RECo_5$ 140/120	R5-1-1
S1-SA-143/2268	20/30	...	...
S1-SA-150/700	...	$RECo_5$ 150/70	R5-1-3
S1-SA-160/1200	22/16	$RECo_5$ 160/120	R5-1-2
S1-SA-170/700	...	$RECo_5$ 170/70	R5-1-4
S1-SA-179/1134	...	...	...
SINTERED ANISOTROPIC SmCo 2:17			
S2-SA-140/1000	...	RE_2Co_{17} 140/100	R5-1-10
S2-SA-160/700	...	RE_2Co_{17} 160/700	R5-1-11
S2-SA-172/529	24/7	...	...
S2-SA-172/1966	24/26	...	...
S2-SA-180/1000	...	RE_2Co_{17} 180/100	R5-1-12
S2-SA-180/1500	...	RE_2Co_{17} 180/150	R5-1-15
S2-SA-186/756	26/10	...	...
S2-SA-186/1966	26/26	...	...
S2-SA-200/700	...	RE_2Co_{17} 200/70	R5-1-13
S2-SA-200/1500	...	RE_2Co_{17} 200/150	R5-1-16
S2-SA-201/529	28/7	...	...
S2-SA-201/1966	28/26	...	...
S2-SA-215/756	...	...	...
S2-SA-215/1512	...	...	...
S2-SA-215/1814	30/24	...	...
S2-SA-215/2268	...	...	...
S2-SA-220/756	...	...	...
S2-SA-220/1500	...	...	...
S2-SA-220/1890	...	...	...
S2-SA-230/756	...	...	...
S2-SA-230/1134	...	...	...
S2-SA-230/1512	...	...	...
S2-SA-230/1890	...	...	...
S2-SA-236/756	...	...	...
S2-SA-236/1134	...	...	...
S2-SA-236/1512	...	...	...

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

MM = material (S1 = samarium cobalt 1:5; S2 = samarium cobalt 2:17),
TT = type of processing and orientation (S = sintered; I = isotropic (non-oriented), A = 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 Samarium Cobalt Permanent Magnets: Typical Thermal, Electrical, and Mechanical Properties[A]

Property	Symbol	Orient.[B]	Units	SmCo 1:5	SmCo 2:17
THERMAL, ELECTRICAL, AND MISCELLANEOUS PROPERTIES					
Recoil Permeability[C]	$\mu_{(rec)}$		(none)	1.05	1.08
Reversible Temperature Coefficient of Induction (B_r)[D]	α (B_r)	//	%/°C	–0.04	–0.035
Reversible Temperature Coefficient of Coercivity (H_{cJ})[D]	α (H_{cJ})	$\perp$	%/°C	–0.30	–0.25
Coefficient of Thermal Expansion[E]		//	10^{-6}/°C	4 to 10	8 to 12
		$\perp$	10^{-6}/°C	10 to 16	10 to 14
Curie Temperature	T_c		°C	750	825
Maximum Recommended Working Temperature[F]	T_w		°C	250	350
Specific Heat	*C*		J/(kg•K)	300 to 500	300 to 500
Thermal Conductivity	*k*		W/(m•K)	5 to 15	5 to 15
Resistivity	ρ		$10^{-6}\Omega$•m	0.4 to 0.7	0.6 to 0.9
PHYSICAL AND MECHANICAL PROPERTIES					
Density			g/cm^3	8.3 to 8.5	8.3 to 8.4
Tensile Strength (Ultimate Tensile Strength)			MPa	30 to 41	35 to 50
Bending (Flexural) Strength			MPa	90 to 180	80 to 150
Compressive Strength			MPa	600 to 1100	400 to 900
Young's Modulus (Modulus of Elasticity)	*E*		GPa	100 to 160	117 to 200
Hardness (Vicker's Hardness)			Hv	500 to 700	550 to 750

[A]Thermal properties are moderately variable from one producer to another. Values shown in the table are typical and should be confirmed with the producer. Mechanical property testing of brittle materials is difficult and is rarely performed. The values in this table are typical.
[B]Orientation is either parallel (axial, //) or perpendicular (transverse, $\perp$) to the easy axis of magnetization (the direction of magnetization within the magnet). Some properties are dependent upon this direction and are measured in both orientations. Other measurements may not be affected by direction of magnetization and are reported in one, usually unspecified axis.
[C]Recoil permeability is nonmandatory and approximate. Values presented here are based upon manufacturer information and IEC 60404-8-1. In the CGS system, recoil permeability is without units though often interpreted to be Gauss/Oersted. Recoil permeability, $\mu_{(rec)}$, is sometimes called relative permeability or relative recoil permeability. For further explanation refer to Terminology A340.
[D]Temperature coefficients represent the average rate of change in magnetic property as a function of change in temperature. The values shown here are approximate for the temperature range of 20 to 150 °C (68 to 302 °F). Samarium cobalt magnets are often used at temperatures above 150 °C (302 °F). The user is advised to refer to producer specifications for performance at other temperatures.
[E]Values shown for the coefficient of thermal expansion are from 20 to 120 °C (68 to 248 °F).
[F]T_w = Maximum recommended working temperature as determined and published by the magnet manufacturer. See Appendix X6 for additional information.

X3. COMPOSITION OF SAMARIUM COBALT

X3.1 The entire family of SmCo magnets is often referred to as RE-Co magnets, where RE stands for rare earth. SmCo 1:5 was the first material discovered and commercialized. It was followed a few years later by SmCo 2:17. SmCo magnet compositions are named using the following and similar formats:

SmCo 1:5—$SmCo_5$-or- (Sm,Pr,Gd) Co_5
SmCo 2:17—$Sm_2(Co,Fe,Cu,Zr)_{17}$-or- $Sm(Co_aFe_bCu_cZr_d)_z$

X3.2 Substitution for samarium by other rare earth elements provides for adjustment of magnetic properties as illustrated in Fig. X3.1.[5] The referenced documents are very informative and thorough. Producers and users are encouraged to read them for a greater understanding of SmCo magnets.

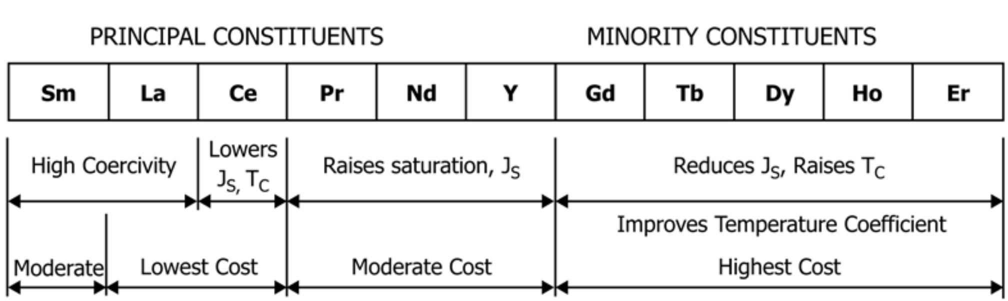

FIG. X3.1 Principal and Minority Constituents in SmCo Permanent Magnets

[5] Adapted from K. J. Strnat, *J. of Magnetism and Magn. Mater.* Vol 7, 1978, p. 351; K. J. Strnat, R. M. W. Strnat, *J. of Magnetism and Magn. Mater.* Vol 100, 1991, pp. 38-56, Elsevier.

TABLE X3.1 Samarium Cobalt Permanent Magnet Typical Compositions[A]

Magnet Grade Type	Sm	Pr	Gd	Co	Fe	Cu[B]	Zr[B]	Comments
SmCo 1:5, Standard	37			63				Standard grade.
SmCo 1:5, High Energy	22	15		63				Standard grades are limited to about 175 kJ/m^3 (22 MGOe); substitution of up to 15 weight percent Pr permits increase in maximum energy product up to 199 kJ/m^3 (25 MGOe).
SmCo 1:5, Temperature Stabilized	22 to 37		0 to 15	63				Gadolinium is substituted for samarium; content is adjusted to meet specific application requirements.
SmCo 2:17, Standard	25			51	16	5	3	Standard grades represent an excellent compromise between high maximum energy product and high temperature capability.
SmCo 2:17, High Energy	25			47	20	5	3	High energy grades are achieved by substituting iron for some of the cobalt; increased iron content makes thermal processing more difficult.
SmCo 2:17, High Temperature	25			55 to 62	5 to 12	5	3	Higher temperature grades are achieved by reducing iron and raising the cobalt content; maximum energy products are concomitantly lower.

[A]Compositions are nonmandatory information, are approximate, and are based on published information. Numbers in the table are weight percents.
[B]Copper and zirconium are modifying elements. Exact composition varies by manufacturer and by percentages of the other elements. Values presented here are for standard grades and are only crudely approximate for nonstandard grades.

X4. NONSTANDARD GRADES OF SAMARIUM COBALT

X4.1 Temperature Stable Grades

X4.1.1 Substitution of a portion of the samarium in either SmCo 1:5 or 2:17 by either gadolinium or a combination of gadolinium and dysprosium results in a more temperature-stable material. That is, the B_r (and magnetic field) of the magnet does not change as rapidly with changes in temperature as for the standard grades. The trade-off is that room temperature B_r and energy product are reduced from the standard grades. Rather than offering specific grades, manufacturers tailor properties to meet customer requirements.

X4.2 High Temperature and High Energy Product (2:17) Grades

X4.2.1 Early in the discovery and use of samarium cobalt 2:17 magnets (1970–1973) it was recognized there is a trade-off between high energy output and high temperature capability. High values of energy product are achieved by substituting greater amounts of iron for cobalt. For example, by increasing the weight percent iron from 15 to 16 %, the standard range, to 18 to 20 %, the energy product can be increased from 223 to as high as 263 kJ/m^3 (from 28 to 33 MGOe or higher). However, as iron is increased, the manufacturing process becomes more sensitive and other properties, notably H_{cJ}, are compromised. Although iron contents up to 30 weight percent have been researched, the practical limit appears to be ~20 %.

X4.2.2 Conversely, by reducing the iron content below the 15 to 16 % standard range with corresponding increase in cobalt content, the Curie temperature is increased and the material is made capable of performing at temperatures above 350 °C (662 °F). A practical low limit for the amount of iron is ~5 % by weight resulting in compositions capable of operating above 500 °C (932 °F).

X4.3 High Energy Product Samarium Cobalt (1:5)

X4.3.1 Samarium cobalt 1:5 has routinely been manufactured with energy product up to 175 kJ/m^3 (22 MGOe). To achieve higher energy output, such as 199 kJ/m^3 (25 MGOe), praseodymium is added at up to 15 % by weight, substituting for samarium. This is a very effective method but results in a product with increased chemical reactivity, thus reducing appropriate applications and often requiring corrosion protection similar to that for neodymium-iron-boron. This “destabilization” was noted early in the material’s development and written about by Karl Strnat and his associates at the University of Dayton.[6]

X4.4 Low Temperature Performance

X4.4.1 Samarium cobalt can be utilized at temperatures as low as near absolute zero. However, manufacturer’s published data seldom offers performance information for temperatures below 20 °C (68 °F). Users are advised to request such low temperature performance information directly from the producer.

X4.5 Isotropic Magnetic Grades

X4.5.1 The great majority of samarium cobalt is manufactured with magnetic grains aligned parallel to each other to create what is called an anisotropic (oriented) magnet. This alignment provides the largest energy product, but only in the specific direction of alignment. It is sometimes desirable to magnetize a finished magnet with an arrangement of poles that are not possible from a pre-oriented structure. In this case, during manufacture, the grains are left randomly oriented and

[6] *Ferromagnetic Materials*, Vol 4, Edited by E. P. Wohlfarth and K. H. J. Buschow, Elsevier Science Publishers B.V., 1988

the finished product is called isotropic (un-oriented). No isotropic published properties have been identified for commercial product, and the user is encouraged to enquire directly of the producer.

X5. THERMAL AND MECHANICAL PROPERTIES

X5.1 Thermal Properties

X5.1.1 Residual induction, B_r, and intrinsic coercivity, H_{cJ}, vary with change in temperature. Once a magnet has experienced all temperatures within the specified range, further exposure causes a reversible change in the magnetic parameters and these are called the reversible temperature coefficients of induction and of coercivity. The change in magnetic properties is nonlinear. The reversible temperature coefficients represent the average change within the specified temperature range. The temperature range must be specified for the values to be relevant. Reversible temperature coefficients as presented here are typical and for the range 20 to 150 °C (68 to 302 °F). Producers' published coefficients are frequently rounded to two or even one significant digit. This rounding can create large errors in calculating the magnetic characteristics. Consult the producer to confirm these values and for coefficients for other temperature ranges.

X5.1.2 Coefficients of thermal expansion as presented in Table X2.1 are approximate for the temperature range 20 to 120 °C (68 to 248 °F). Because of the variability in temperature range reported for commercial product, grade of material, and specific formulation properties, a broad range of values are shown in the table.

X5.2 Mechanical Properties

X5.2.1 Samarium cobalt is a brittle material. Brittle materials are difficult to test for mechanical properties and testing can yield a wide spread of property values. Furthermore, magnetic properties will change as a result of the magnet being subjected to stress. Magnets are not recommended to be part of the structural system and should be protected from stress to the greatest extent possible.

X6. OTHER TERMINOLOGY

X6.1 Maximum Recommended Working Temperature

X6.1.1 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.

X6.1.2 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.

X6.2 Magnetic Condition – Calibrated, Stabilized, Knocked Down

X6.2.1 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 follows.

X6.2.2 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 knockdown 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 subsequent exposure to the defined (*a*) temperature or (*b*) magnetic field will cause minimal-to-no additional demagnetization.

X6.2.3 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 (knockdown) 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 knockdown field; weaker magnets may require a smaller knockdown 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.

X6.2.4 In either of the above cases, the treated magnets will have experienced some level of knockdown. 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, 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.

X7. SYMBOLS

X7.1 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* 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.

X7.2 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*."

X7.3 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.