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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of International Trade and Industry through deliberations at Japanese Industrial Standards Committee in accordance with the Industrial Standardization Law. Consequently **JIS C 2502 : 1989** is replaced with **JIS C 2502 : 1998**.

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Materials for permanent magnet

Introduction This Japanese Industrial Standard is prepared based on **IEC 60404-8-1** Revision draft (68/149/CD), *Magnetic materials—Part 8 : Specifications for individual materials—Section One—Standard specifications for magnetically hard materials* distributed for suggestions in 1996, without any change in the technical contents.

However, specifications not stated in the corresponding International Standard are added and such portions are underlined with dots.

1 Scope This Japanese Industrial Standard specifies minimum values and nominal values of basic magnetic characteristics and dimensional tolerances of industrially important magnetically hard materials (permanent magnets). The densities and chemical compositions of the materials are given as informative references, and some physical and mechanical data of the magnetic materials are shown for the purpose of comparison as informative references.

Remarks : The International Standard corresponding to this Standard is given below.

IEC 60404-8-1 Revision draft (68/149/CD) : 1996 *Magnetic materials—Part 8 : Specifications for individual materials—Section One—Standard specifications for magnetically hard materials*

2 Normative references The following standards contain provisions which, through reference in this Standard, constitute provisions of this Standard. If the indication of the year of coming into effect is given to these referred standards, only the edition of indicated year constitutes the provision of this Standard but the revision and amendment made thereafter are not applied. The normative references without the indication of the year of coming into effect apply limiting only to the most recent edition (including the amendment).

JIS C 2501 *Methods of test for permanent magnet*

Remarks : **IEC 60404-5** : 1993, *Magnetic materials—Part 5 : Permanent magnet (magnetically hard) materials—Methods of measurement of magnetic properties* is identical with the above standard.

IEC 60404-1 : 1979 *Magnetic materials—Part 1 : Classification*

IEC 60050 (121) : 1978 *International Electrotechnical Vocabulary (IEV)—Chapter 121 : Electromagnetism*

IEC 60050 (221) : 1990 *International Electrotechnical Vocabulary (IEV)—Chapter 221 : Magnetic materials and components*

Informative reference : The above **IEC** numbers are based on the new numbering system of **IEC** which came into force in January 1, 1997. The standard published before the said date is changed to a number equal to the traditional number plus 60000. This is the change in the numbering system only and the contents remain as they are.

3 Types of materials and their applications Magnetically hard materials, also designated as permanent magnetic materials are classified in IEC Standard **60404-1** : Magnetic Materials, Part 1 : Classification in Clauses R (Magnetically hard alloys), S (Magnetically hard ceramics) and U (Bonded magnets).

Permanent magnets have a coercivity of magnetic polarization ≥ 1 kA/m. After being magnetized to saturation they have a material dependent specific magnetic energy, which can be used in static and dynamic magnetic circuit applications. Permanent magnetic materials are used in many areas of daily life. They perform coupling, modulating, or regulating functions in equipment and devices based on electromagnetic principles, for example in measuring instruments, motors, generators and loud-speakers. Magnetic materials are indispensable in office equipment and computer hardware, automobiles, entertainment electronics, communication techniques, household appliances and medical instruments, as well as in mechanical engineering as holding devices, clamping plates, etc.

Further possible and typical applications for the commercially available permanent magnetic materials are described in Sections R, S and U of IEC **60404-1**.

4 Classification Compared to the preceding edition of IEC **60404-8-1** (1986) this revised edition uses a new classification of the permanent magnetic materials for technical applications. This classification is given in Table 1. The materials are regrouped according to their metallurgical relationships. (For orientation purposes column 2 of Table 1 shows the old classification.)

Table 1 Classification of magnetically hard materials

Group	Principal constituents	First part of code number (Revised standard) This edition	Old code numbers (First edition 1986)
Magnetically hard alloys (R)	Aluminium-nickel-cobalt-iron-titanium alloys	R1	R1
	Chromium-iron-cobalt alloys	R2	R6
	Cobalt-iron-vanadium-chromium alloys	R3	R3
	Rare earth-cobalt alloys	R4	R5
	Neodymium-iron-boron alloys	R5	R7
	NN (Space mark)	R6	
	NN (Space mark)	R7	
	Platinum-cobalt alloys	deleted	R2
	Copper-nickel-iron alloys	deleted	R4
Magnetically hard ceramics (S)	Magnetically hard ferrites ($MO \cdot nFe_2O_3$; M=Ba and/or Sr, $n=4.5$ to 6.5)	S1	S1
Bonded hard magnetic materials (U)	Bonded aluminium-nickel-cobalt-iron-titanium magnets	U1	R1-2 R1-3
	Bonded rare earth-cobalt magnets	U2	R5-3
	Bonded neodymium-iron-boron magnets	U3	
	Bonded hard ferrites	U4	S1-2 S1-3
	NN (Space mark)	U5	
	NN (Space mark)	U6	

4.1 Principal magnetic properties The permanent magnetic materials are identified by the principal magnetic properties given in Table 2.

Table 2 Principal magnetic properties

Magnetic properties	Symbol	Unit	Term number of IEC publications 60050 (221) and 60050 (121)	
Maximum value of (BH) product	$(BH)_{\max}$	kJ/m^3	221-04-05	—
Remanence	B_r	mT	221-02-38	121-02-43
Coercivity relating to the flux density	H_{cB}	kA/m	221-02-36	—
Coercivity relating to the polarization	H_{cJ}	kA/m	221-02-36	—

Minimum values and nominal values at room temperatures of magnetic properties, determined after magnetization to saturation, are given in Tables 4 to 12.

The specified values of magnetic properties are valid only for magnets having a cross section invariable along the axis of magnetization, with a volume from 1 cm^3 to 200 cm^3 and with dimensions in three directions of the coordinate axes of at least 5 mm. For anisotropic materials they are valid only along preferred axial direction.

- Remarks 1 For more details of size limits for measurements, see 5 of JIS C 2501.
- 2 For reasons connected with the manufacturing methods, smaller values of the magnetic properties may be obtained if the dimensional conditions mentioned above are not satisfied.

4.2 Additional magnetic properties (see Table 3)

Table 3 Additional magnetic properties

Magnetic properties	Symbol	Unit	Term number of IEC publications 60050 (221) and 60050 (121)	
Recoil permeability	μ_{rec}	—	221-03-16	—
Temperature coefficient of the remanence [it corresponds to the temperature coefficient of the magnetic saturation $\alpha(J_s)$]	$\alpha(B_r)$	%/K	—	—
Temperature coefficient of the coercivity of magnetic polarization	$\alpha(H_{cJ})$	%/K	—	—
Curie temperature or Curie point	T_c	K	—	121-02-32

The values given in Tables 4 to 12 are typical minimum values. They are mean values published in the literature and are given as an indication only and are not guaranteed. The temperature range for the temperature coefficients in the tables is generally from 273 K to 373 K, but this does not preclude the use of these materials outside this temperature range. The magnetic field strength necessary for magnetizing magnetically hard materials to magnetic saturation is defined in 4.2 of JIS C 2501.

Table 4 Magnetic properties, Curie temperature, maximum service temperatures and densities of AlNiCo magnets

Material			Manufacturing method		Magnetic properties							Curie temperature	Max. service temperature	Density ρ
Brief designation	(1)	Code number			Max. BH product	Remanence	Coercivity	(Intrinsic) coercivity	Relative recoil permeability	Temperature coefficient of $B_r^{(2)}$	Temperature coefficient of $H_{ci}^{(2)}$			
					$(BH)_{max}$ kJ/m ³	B_r mT	H_{cb} kA/m	H_{ci} kA/m	μ_{rec}	$\alpha(B_r)$ %/K	$\alpha(H_{ci})$ %/K	K	K	$\times 10^3$ kg/m ³
AlNiCo														
					Min- imum value	Nomi- nal value ⁽³⁾	Min- imum value	Nomi- nal value ⁽³⁾	Min- imum value	Nomi- nal value ⁽³⁾	Min- imum value	Typical values		
AlNiCo 9/5	i	R1-0-1	Cast or sintered		9	13	550	600	44	52	47	55	7	6.8
AlNiCo 12/6	i	R1-0-2			11.6	15.6	630	680	52	60	55	63	7.5	7.0
AlNiCo 17/9	i	R1-0-3			17	21	580	630	80	88	86	94	7.5	7.1
AlNiCo 37/5	a	R1-1-1	Cast		37	41	1 180	1 230	48	56	49	57	4	7.3
AlNiCo 38/11	a	R1-1-2			38	42	800	850	110	118	112	120	2	7.3
AlNiCo 44/5	a	R1-1-3			44	48	1 200	1 250	52	60	53	61	3	7.3
AlNiCo 60/11	a	R1-1-4			60	64	900	950	110	118	112	120	2	7.3
AlNiCo 36/15	a	R1-1-5			36	40	700	750	140	148	148	156	2	7.3
AlNiCo 58/5	a	R1-1-6			58	62	1 300	1 350	52	60	53	61	3	7.3
AlNiCo 72/12	a	R1-1-7			72	76	1 050	1 100	118	126	120	128	2	7.3
AlNiCo 34/5	a	R1-1-10	Sintered		34	38	1 120	1 170	47	55	48	56	4	7.1
AlNiCo 26/6	a	R1-1-11			26	30	900	950	56	64	58	66	4.5	7.1
AlNiCo 31/11	a	R1-1-12			31	35	760	810	107	115	111	119	3	7.1
AlNiCo 33/15	a	R1-1-13			33	37	650	700	135	143	150	158	2	7.1

Notes (1) i = isotropic; a = anisotropic

(2) Values at 273 K to 373 K

(3) This is not specified value but shows the central value in characteristic change.

Table 5 Magnetic properties, Curie temperature, maximum service temperatures and densities of CrFeCo and FeCoVCr magnets

Material			Manu- facturing method	Magnetic properties							Curie tempera- ture	Max. service tempera- ture	Density ρ $\times 10^3$ kg/m ³					
Brief designation	(1)	Code number		Max. BH product (BH) _{max} kJ/m ³	Remanence B_r mT	Coercivity H_{ch} kA/m	(Intrinsic) coercivity H_{ci} kA/m	Relative recoil per- meability μ_{rec}	Tempera- ture coef- ficient of B_r (2) $\alpha(B_r)$ %/K	Tempera- ture coef- ficient of H_{ci} (2) $\alpha(H_{ci})$ %/K								
									Typical values									
CrFeCo/FeCoVCr				Mini- mum value	Nomi- nal value(3)	Mini- mum value	Nomi- nal value(3)	Mini- mum value	Nomi- nal value(3)									
CrFeCo 12/4	i	R2-0-1	Cast or sintered	12	16	800	850	40	44	42	46	6	-0.05	-0.04	893 to 913	773	7.6	
CrFeCo 10/3	i	R2-0-2		10	14	850	900	27	31	29	33	6	-0.03					7.6
CrFeCo 28/5	a	R2-1-1		28	32	1 000	1 050	45	49	46	50	3.5					7.6	
CrFeCo 30/4	a	R2-1-2		30	34	1 150	1 200	40	44	41	45	3.5					7.6	
CrFeCo 35/5	a	R2-1-3		35	39	1 050	1 100	50	54	51	55	3.5					7.6	
CrFeCo 44/5	a	R2-1-4	44	48	1 300	1 350	44	48	45	49	2.5					7.7		
FeCoVCr 11/2	a	R3-1-1	Cast	11	15	800	850	24	28	24	28	5	-0.01	-0	993	773	8.1	

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Table 6 Magnetic properties, Curie temperature, maximum service temperatures and densities of RECo magnets

Material			Magnetic properties							Curie temperature	Max. service temperature	Density
Brief designation	(1)	Code number (4)	Manu- facturing method	Max. BH product (BH) _{max} kJ/m ³	Remanence B _r mT	Coercivity H _{cb} kA/m	(Intrinsic) coercivity H _{ci} kA/m	Relative recoil per- meability μ _{rec}	Tempera- ture coef- ficient of B _r (2) %/K	Tempera- ture coef- ficient of H _{ci} (2) %/K	K	× 10 ³ kg/m ³
RECo				Mini- mum value	Nomi- nal value(3)	Mini- mum value	Nomi- nal value(3)	Mini- mum value	Typical values			
RECo 140/120	a	R4-1-1	Sintered	140	860	600	1 200	1 360	1.05	-0.04	993	8.3
RECo 160/120	a	R4-1-2		160	920	660	1 200	1 360	1.05			
RECo 150/70	a	R4-1-3		150	900	600	700	860	1.05			
RECo 170/70	a	R4-1-4		170	930	600	700	860	1.05			
RECo 140/100	a	R4-1-10		140	900	620	1 000	1 160	1.1	-0.03	1 093	8.4
RECo 160/70	a	R4-1-11		160	940	600	700	860	1.1			
RECo 180/100	a	R4-1-12		180	1 000	680	1 000	1 160	1.1			
RECo 200/70	a	R4-1-13		200	1 050	600	700	860	1.1			
RECo 220/70	a	R4-1-14		220	1 100	600	700	860	1.1			
RECo 180/150	a	R4-1-15		180	1 000	660	1 500	1 660	1.1			
RECo 200/150	a	R4-1-16		200	1 050	700	1 500	1 660	1.1			

Note (4) R4-1-x : x = 1 to 9 RECo₅; R4-1-x : x = 10 to 19 RE₂Co₁₇

Table 7 Magnetic properties, Curie temperature, maximum service temperatures and densities of REFe magnets

Material			Manu- facturing method	Magnetic properties								Curie tempera- ture	Max. service tempera- ture	Density ρ kg/m ³				
Brief designation	(1) Code number			Max. BH product (BH) _{max} kJ/m ³	Remanence B_r mT	Coercivity H_{CB} kA/m		(Intrinsic) coercivity H_{ci} kA/m	Relative recoil per- meability μ_{rec}	Tempera- ture coef- ficient of B_r (2) $\alpha(B_r)$ %/K	Tempera- ture coef- ficient of H_{CB} (2) $\alpha(H_{ci})$ %/K							
						Mini- mum value	Nomi- nal value(3)								Mini- mum value	Nomi- nal value(2)	Mini- mum value	Nomi- nal value(3)
REFe				Typical values														
REFe 170/190	a	R5-1-1	Sintered	170	186	980	1 030	700	730	1 900	2 060	1.05	-0.10 to -0.12	-0.45 to -0.60	583	Depend- ing on working point and coercivity	7.5	
REFe 210/130	a	R5-1-2		210	226	1 060	1 110	790	820	1 300	1 460							1 460
REFe 250/120	a	R5-1-3		250	266	1 130	1 180	840	900	1 200	1 360							1 360
REFe 290/80	a	R5-1-4		290	306	1 230	1 280	700	920	800	960							960
REFe 200/190	a	R5-1-5		200	216	1 060	1 110	760	840	1 900	2 060							2 060
REFe 240/180	a	R5-1-6		240	256	1 160	1 210	840	920	1 800	1 960							1 960
REFe 280/120	a	R5-1-7		280	296	1 240	1 290	900	980	1 200	1 360							1 360
REFe 320/88	a	R5-1-8		320	336	1 310	1 360	800	1 000	880	1 040							1 040
REFe 210/240	a	R5-1-9		210	226	1 060	1 110	760	840	2 400	2 560							2 560
REFe 240/200	a	R5-1-10		240	256	1 160	1 210	840	920	2 000	2 160							2 160
REFe 310/130	a	R5-1-11		310	326	1 300	1 350	900	1 020	1 300	1 460							1 460
REFe 320/90	a	R5-1-12		320	336	1 310	1 360	800	1 020	900	1 060							1 060
REFe 250/240	a	R5-1-13		250	266	1 200	1 250	830	950	2 400	2 560							2 560
REFe 260/200	a	R5-1-14		260	276	1 210	1 260	840	960	2 000	2 160							2 160
REFe 340/130	a	R5-1-15		340	356	1 330	1 380	920	1 050	1 300	1 460							1 460
REFe 360/90	a	R5-1-16		360	376	1 350	1 400	800	1 020	900	1 060							1 060