KOERZIT™ S

Sintered AlNiCo

Koerzit is the KOLEKTOR MAGNET TECHNOLOGY GmbH tradename for sintered permanent magnets based on AlNi and AlNiCo alloys. Koerzit magnets are made by powder metallurgy. KOLEKTOR MAGNET TECHNOLOGY GmbH produces isotropic and anisotropic Koerzit magnets offering a wide range of magnetic values depending on composition and the process parameters used during manufacture. The high-remanence and coercivity values of Koerzit 500 S with values of 1200 mT and 50 kA/m respectively is complemented by the high-coercivity grades Koerzit 450 and Koerzit 1800 with remanence values of around 880 and 740 mT respectively and coercivity values of 120 and 160 kA/m respectively. Of the isotropic AlNiCo grades, Koerzit 260 delivers the highest remanence and coercivity with 650 mT and 115 kA/m respectively.

Low-coercivity isotropic Koerzit magnets are also produced for use as hysteresis materials in motors and couplings.

Common to all Koerzit magnets is the low temperature dependence of their magnetic properties. They can be used at ambient temperatures of up to 500°C without microstructural damage.

ALLOYS AND METALLURGICAL RELATIONSHIPS

Koerzit magnets are multi-component alloys made from the elements aluminum, nickel, cobalt and iron. In addition to these main components, whose concentrations vary over a wide range according to grade, the alloys may contain copper, niobium and titanium. Table 1 gives an overview of the composition spectrum of Koerzit magnets.

To create a better understanding of the magnetic properties and manufacturing methods, some of the metallurgical relationships of the underlying AlNi/AlNiCo alloy system first need to be explained. The system exhibits a series of temperature-dependent phase regions, which through careful temperature control have to be targeted, avoided or passed through at a certain speed in order to develop and optimize the required magnetic values.

Table 1: Alloy Compositions (Weight %)

Al	Ni	Co	Cu	Nb	Ti	Fe
6 - 13	13 - 18	0 - 42	2 - 6	0 - 3	0 - 9	Balance

The temperature range over which these phases extend is between 1300 and 500°C. A body-centered cubic high-temperature phase (α' phase) at temperatures above 1200°C is followed between 1200 and 900°C by a mixture of body-centered and face-centered cubic phases ($\alpha + \gamma$ phase). Since the γ phase is unfavorable for the development of the magnetic values, this temperature range has to be passed through quickly during magnet production to prevent γ phase from developing. Below 900°C the supersaturated high-temperature α phase and α‘ phase. The α‘ precipitations have an α stick-shape structure. This spontaneous process is known as spinodal decomposition. Both the γ and α' phases are body-centered cubic but they differ in composition. The zones of the Fe of FeCo-rich α‘ phase are embedded in the NiAl-rich matrix of the α phase. Due to their different compositions, the Fe and FeCo-rich phase zones are strongly magnetic, while the NiAl-rich matrix is weakly magnetic or non-magnetic.

The temperature thresholds of the above-mentioned phases change with the composition of the AlNiCo alloys. This has to be taken into account in manufacture in developing the grade-specific magnetic values. The magnetic values of the Koerzit materials are closely and critically linked to the formation of the ($\alpha + \alpha'$) structure. As well as alloy composition, therefore the course and duration of heat treatment are of decisive importance in developing the magnetic values. To achieve high coercivities the α' precipitations must form magnetic single-domain particles having pronounced shape anisotropy, i.e. they must be as long as possible and small in diameter. These finely dispersed precipitations measure a few 10 nm across but can be 10 to 15 times greater in length. For reasons of shape anisotropy the preferred direction of magnetization is parallel to the longitudinal axis of the precipitations.

In the case of Koerzit grades with cobalt contents above approx. 23 weight percent the curie temperature Tc of the strongly magnetic α' phase lies in the spinodal decomposition range of the high-temperature α phase (800-900°C). Under the influence of a magnetic field during phase decomposition the stick-like highly magnetic precipitations align themselves parallel to the direction of the field. This produces anisotropic Koerzit magnets with high values of flux density and maximum energy product.

After spinodal treatment the magnets are given a final tempering treatment in the 500-1300°C range which via diffusion processes results in further compositional shifts between the ($\alpha + \alpha'$) phases. This increases the coercivity of the Koerzit magnets.

FIGURE 1

SHAPING

Shape and dimensional accuracy are of major importance in permanent magnet applications. Koerzit magnets are hard and brittle and can generally only be machined by grinding. Direct shaping to close tolerances is therefore extremely important.

Sintered magnets have relatively smooth surfaces and even small parts meet close tolerances. Table 2 gives the tolerances specified for sintered magnets in DIN 17410. Closer tolerances than those indicated can only be achieved by grinding. Edge chipping during grinding cannot be avoided owing to the brittleness and susceptibility to fracture of these materials, particularly the titanium-containing grades of Koerzit 260, Koerzit 450 and Koerzit 1800. However this does not detract from magnetic performance. Despite the advances made in grinding, tolerances should be decided on a case-by-case basis taking magnetic requirements and cost factors into account. Wherever possible the magnetic circuit should be designed so that only the magnet’s pole faces have to be machined.

Small holes and slots can also be introduced in the compacts prior to sintering but these should not run perpendicular to the direction of pressing.

Testing of tolerances and mechanical properties of Koerzit magnets is carried out on the basis of DIN 17410, ISO 2859-1 and ISO 3951. Fig. 1 and 2 shows a selection of typical Koerzit magnets.

MATERIAL PROPERTIES

The magnetic properties of Koerzit magnets at room temperature are summarized in the Koerzit S Data table. As well as the KOLEKTOR MAGNET TECHNOLOGY GmbH grade names the table includes the materials’ names under DIN 17410. The number before the oblique is the (BH)max value in kJ/m³, that after 1/10 of the HcJ value in kA/m. As the DIN numbers are minimum values, the table also includes typical magnetic values.

The minimum room-temperature values specified in DIN 17410 apply only to permanent magnets having a constant cross section along the magnetization axis, a volume of between 1 and 200 cm³ and width, height and depth dimensions of at least 8mm. Most Koerzit magnets have volumes between .01 and 50 cm³ The values in the Koerzit S Data table are based on these volumes and on weight, height and depth dimensions of at least 4 mm. For manufacturing reasons, smaller magnets may have values below those stated. Magnetic properties are measured in accordance with DIN 17410, DIN 50470, DIN 50472, and ISO 3951.

It is generally advisable to exchange magnetic samples and agree on a simple measuring technique suitable for production testing.

Table 2: Admissible Tolerances on As-Sintered AlNiCo Magnets (Values in mm)

Nominal Dimension		Sintered Alloys Containing 1% Ti		Sintered Alloys Containing 4% Ti	
Over	Up To	Perpendicular to pressing Dir. ±	In Pressing Direction ±	Perpendicular to pressing Dir. ±	In Pressing Direction ±
0	4	0.15	0.20	0.20	0.25
4	6	0.20	0.25	0.25	0.30
6	8	0.20	0.25	0.25	0.30
8	10	0.20	0.30	0.30	0.35
10	13	0.25	0.30	0.30	0.35
13	16	0.25	0.35	0.35	0.45
16	20	0.30	0.35	0.40	0.45
20	25	0.30	0.40	0.45	0.55
25	30	0.35	0.45	0.50	0.60
30	35	0.40	0.50	0.55	0.70
35	40	0.45	0.55	0.65	0.75
40	45	0.50	0.60	0.70	0.85
45	50	0.50	0.65	0.75	0.90

Finally, the table gives indicative values for recoil permeability (µp), material density (g/cm³) and required magnetizing field strength (Hs).

Diagrams 1 and 2 show the dependence of magnetic flux density B on the demagnetizing field -H. Diagram 1 contains the curves for isotropic Koerzit magnets, diagram 2 for anisotropic ones. To make it easy to find the maximum energy product (BH)max the diagrams contain families of curves for constant (BH) values. In addition, the slopes of load lines are indicated by the B/-µ°H values.

KOLEKTOR MAGNET TECHNOLOGY GmbH Products Physical & Mechanical Properties table (in Section 1) shows physical and mechanical properties of Koerzit magnets. The values vary depending on alloy composition and are given as guidance only.

Throughout their production as well as in the finished product Koerzit magnets display a high degree of brittleness. This results in wide variations in strength values. Koerzit magnets should not be subjected to heavy mechanical loading.

Table 2 gives the tolerances specified in DIN 17410 for sintered AlNiCo magnets. The dimensional tolerances shown also include the shape variations typical of sintered magnets. As a result of differing green densities, shrinkage during sintering may cause slight deformations on the magnet's surface.

FIGURE 2

CHEMICAL STABILITY

The corrosion behavior of Koerzit magnets depends on their composition and the conditions under which they are used, e.g. temperature. In general, owing to their high nickel and cobalt contents Koerzit magnets behave similarly to corresponding high-alloy steels.

Koerzit magnets are unstable in all inorganic acids, in seawater and in strongly alkaline solutions. They display limited resistance to most organic acids and concentrations below 10%. Koerzit is not attacked to a detectable degree by organic solvents, alcohols, oils or gasoline.

TEMPERATURE BEHAVIOR AND AGING

The magnetic values of Koerzit magnets can change under the effect of external fields and as a function of temperature and time. The changes may be reversible or irreversible. Irreversible magnetization losses can be caused by microstructural changes or may be the result of spontaneous reversals of magnetization of individual domains due to natural aging or temperature effects.

Microstructural aging caused by high temperatures is not a factor with Koerzit magnets. Up to the admissible operating temperatures of 500°C the phases responsible for magnetism are stable, i.e. no microstructural changes occur. Only at temperatures above 500°C do irreversible magnetic losses occur which are not recoverable by remagnetization.

Natural aging follows a logarithmic time law. It increases with increasing magnet load and decreasing coercivity. The natural aging of today's permanent magnets is generally very minor. Even in the worst case of a heavily loaded Koerzit magnet with low coercivity the flux loss only amounts to a few per mil over a period of several months and a few percent over many years.

The process of natural aging can be brought forward by subjecting the magnet to an alternating magnetic field of decreasing amplitude or by thermal cycling to induce losses on the order of 2-5%. These measures can also offset unavoidable variations in the magnetic values of volume-produced magnets. They also have the effect of bringing forward the irreversible polarization losses, which permanent magnets can undergo as a result of temperature effects, or opposing magnetic fields. However, the losses must be adapted to the envisaged operating temperatures and expected opposing fields.

The irreversible magnetization losses caused by natural or artificial aging can be recovered by remagnetization.

Alongside the irreversible loses, reversible changes in magnetization also occur. These reversible changes cannot be avoided or brought forward. They result from the material-specific temperature dependence of saturation polarization and coercivity. The reversible magnetization changes are described by the temperature coefficients of saturation polarization TC(Js) and intrinsic coercivity TC(HcJ). For all Koerzit grades TC(Js) = - 0.02%/K in the 0 to 100°C temperature range.

The temperature coefficient of intrinsic coercivity HcJ is also very low in Koerzit magnets, ranging from +0.03 to -0.07%/K depending on alloy composition and heat treatment. As a rule this temperature dependence can be neglected, as it does not cause any change in flux density in the magnet's operating range.

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Product 1)	$(BH)_{max}$ kJ/m³ typ.	$(BH)_{max}$ kJ/m³ min	$(BH)_{max}$ MGOe typ.	$(BH)_{max}$ MGOe min.	Br mT typ.	Br mT min.	Br G typ.	Br G min.	H_{cB} kA/m typ.	H_{cB} kA/m min.	H_{cB} Oe typ.	H_{cB} Oe min.	Intrinsic Coercivity H_{cJ} kA/m typ.	Intrinsic Coercivity H_{cJ} kA/m min.	Intrinsic Coercivity H_{cJ} Oe typ.	Intrinsic Coercivity H_{cJ} Oe min.	Relative Permeability typ.	Density g/cm³ typ.	Required Magnetic Field kA/m min.	Temperature Coefficient of Br, α (20-100 °C) %/K typ.	Temperature Coefficient of HcJ, β (20-100 °C) %/K typ.	Maximum Operating Temperature °C
Koerzit S 130 (9/5) i	10.3	8.8	1.3	1.1	550	520	5500	5200	57	54	716	679	54	51	679	641	3.5-4.5	6.9	240	−0.02	+.03 to -.07	500
Koerzit S 160 (12/6) i	13.5	11.9	1.7	1.5	650	610	6500	6100	60	57	754	716	57	53	716	666	4.0-5.5	7.0	240	−0.02	+.03 to -.07	500
Koerzit S 260 (19/11) i	22.3	19.1	2.8	2.4	640	590	6400	5900	114	107	1433	1345	105	100	1319	1257	2.5-4.4	7.3	400	−0.02	+.03 to -.07	500
Koerzit S 190 (15/6) a	16.7	15.1	2.1	1.9	750	700	7500	7000	62	57	779	716	60	56	754	704	4.0-5.5	7.0	240	−0.02	+.03 to -.07	500
Koerzit S 400 (28/6) a	31.8	27.9	4.0	3.5	1100	1000	11000	10000	65	61	817	767	64	60	804	754	3.5-5.0	7.3	320	−0.02	+.03 to -.07	500
Koerzit S 450 (39/12) a	43.8	37.4	5.5	4.7	880	850	8800	8500	119	115	1495	1445	115	111	1445	1395	3.0-4.5	7.3	500	−0.02	+.03 to -.07	500
Koerzit S 500 (37/5) a	41.4	39.0	5.2	4.9	1240	1180	12400	11800	51	48	641	603	51	48	641	603	2.0-4.0	7.3	240	−0.02	+.03 to -.07	500
Koerzit S 1800 (39/15) a	43.8	39.0	5.5	4.9	740	740	7400	7000	160	151	2011	1898	150	142	1885	1784	1.5-2.5	7.2	750	−0.02	+.03 to -.07	500

i = Isotropic
a = Anisotropic

1) Required Magnetic Field — Values are dependent on size, shape and characteristics of the magnetizing pulse
2) Maximum Operating Temperature is contingent upon the entire magnetic circuit. Consult your KOLEKTOR MAGNET TECHNOLOGY GmbH representative for application specific recommendations.

Chart 1: Demagnetization curves B(H) of Isotropic KOERZIT (AlNiCo) magnets

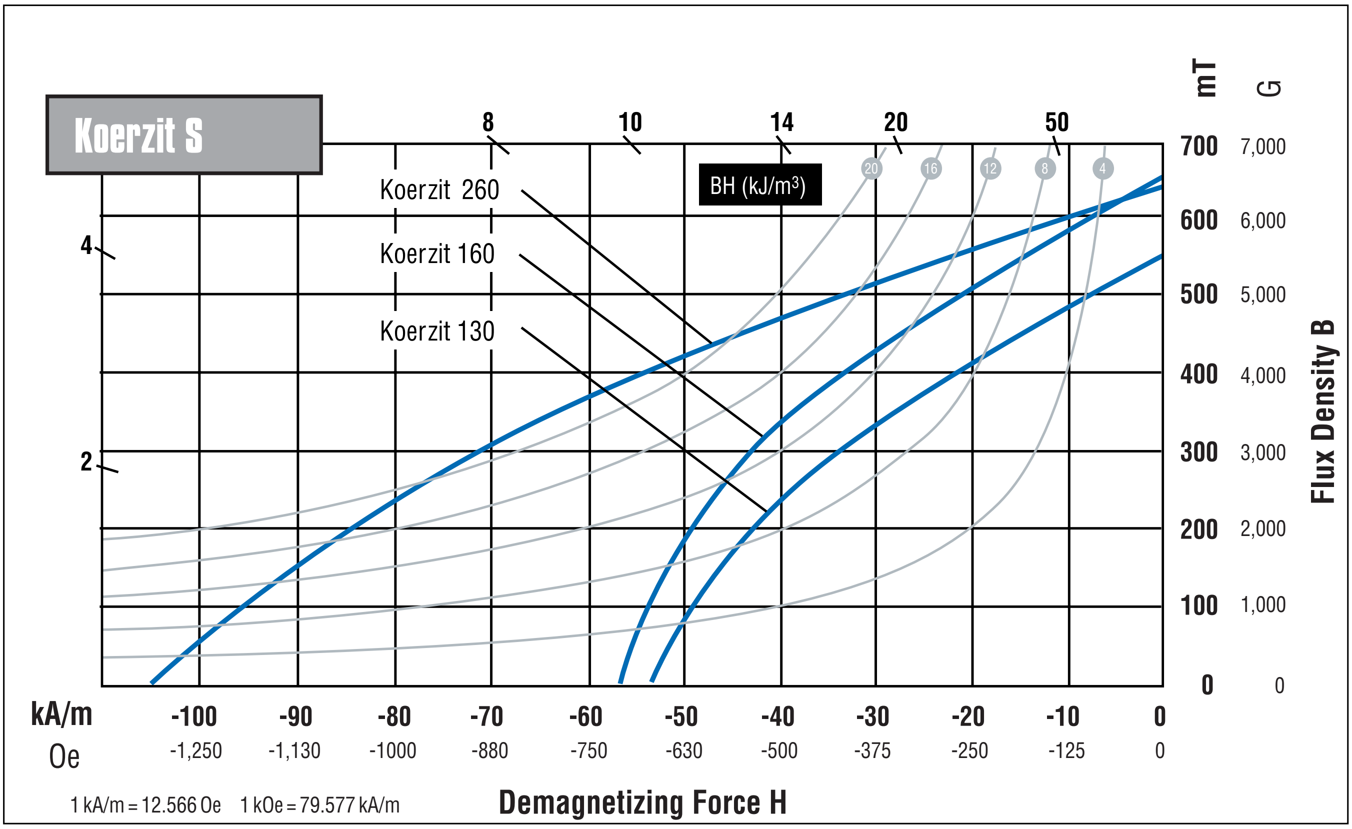

Chart 2: Demagnetization curves B(H) of Anisotropic KOERZIT (AlNiCo) magnets