

Review

Progress and Prospect of Sm-Fe-N Magnets

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Abstract

High-performance but expensive neodymium-iron-boron (Nd-Fe-B) magnets are widely used in automotive and electrical applications. Prospective candidates for rare-earth-free magnets include Fe-based magnets such as $L1_0$ -FeNi and α'' -Fe₁₆N₂ phase. However, these rare-earth-free magnets cannot replace Nd-Fe-B magnets due to their lower coercivity. Thus, the development of Sm-based magnets, using the relatively abundant rare-earth element Sm, has become a focus of attention. A promising, cheaper alternative with excellent magnetic properties is the Samarium-iron-nitride (Sm-Fe-N) magnet. This paper describes the production and magnetic properties of Sm-Fe-N powders with Th₂Zn₁₇ and TbCu₇ phases. The production process and magnetic properties of Sm-Fe-N bonded magnets prepared from the powders are also described. Current approaches for producing Sm-Fe-N sintered magnets are included.

Keywords: permanent magnet; rare-earth compound; samarium-iron-nitride

1. Introduction

The industrial use of high-performance Nd-Fe-B magnets is expanding rapidly in automotive, industrial, and electrical applications [1–3]. The high demand for Nd-Fe-B magnets has raised concerns over their price and the availability of rare earth elements. These severe concerns have led to the study of alternative permanent magnets, which contain fewer or no rare-earth elements.

2. Materials

Prospective candidates for rare-earth-free magnets include manganese-based and iron-based magnets. Mn-based magnets are already produced commercially [4]. Mn-based magnets, such as Mn-Bi magnets with a low-temperature phase and Mn-Ga magnets with a D0₂₂ phase, have gained attention [5–14]. The advantage of the Mn-based magnets is their high anisotropy constant, which indicates high coercivity [15–21]. However, a problem with Mn-based magnets is their relatively low saturation magnetization, which prevents the creation of high-performance Mn-based magnets [22].

2.1. Rare-Earth-Free Iron-Based Magnets

High-performance Nd-Fe-B magnets are composed of the Nd₂Fe₁₄B phase, which has a large saturation magnetization ($4\pi M_s$), a high anisotropy constant (K_1), and a high Curie temperature (T_c) [23]. Table 1 compares these magnetic properties of $L1_0$ -FeNi and α'' -Fe₁₆N₂ phases with those of the Nd₂Fe₁₄B phase [24,25]. Table 1 compares these magnetic properties of $L1_0$ -FeNi and α'' -Fe₁₆N₂ phases with those of the Nd₂Fe₁₄B phase.



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Table 1. Intrinsic magnetic properties of L1₀-FeNi and α'' -Fe₁₆N₂.

Phase	Saturation Magnetization $4\pi M_s$ (T)	Anisotropy Constant K_1 (MJm ^{−3})	Curie Temperature T_c (K)
Nd ₂ Fe ₁₄ B	1.61	4.3	588
L1 ₀ -FeNi	1.6	1.0	773
α'' -Fe ₁₆ N ₂	2.4	1.0	810

The L1₀-FeNi phase (tetrataenite) is found in iron meteorites [26]. This phase has a face-centered tetragonal (fct) structure, characterized by high saturation magnetization and a high Curie temperature [27,28]. Although the anisotropic constant of the L1₀-FeNi phase is smaller than that of the Nd₂Fe₁₄B phase, it is high enough to be a permanent magnet. Thus, the L1₀-FeNi phase is an ideal alternative for Nd-Fe-B magnets. Since the L1₀-FeNi phase forms naturally at an extremely slow cooling rate of 1 K/10⁶ years in iron meteorites, it cannot be easily obtained by conventional solidification techniques. Recently, a new method for its production, named the NITE (nitrogen insertion and topotactic extraction) method, has been developed [29]. The method involves two steps: first, the nitriding of the FeNi phase to form the FeNiN phase, and then the denitriding of the FeNiN phase to the L1₀-FeNi phase. The obtained L1₀-FeNi powder possesses a high saturation magnetization of 1.45 T and a coercivity of 140 kA/m [30].

Among rare-earth-free magnets, the α'' -Fe₁₆N₂ phase is the most promising candidate, since the nitrogenation of Fe can prepare it. The α'' -Fe₁₆N₂ phase has a body-centered tetragonal (bct) structure with an extremely high saturation magnetization, significantly higher than that of the Nd₂Fe₁₄B phase [31]. The anisotropy constant of the α'' -Fe₁₆N₂ phase is smaller than that of the Nd₂Fe₁₄B phase but is comparable to that of the L1₀-FeNi phase. Its Curie temperature is higher than that of the Nd₂Fe₁₄B phase [32]. Thus, the α'' -Fe₁₆N₂ phase is also an ideal alternative for Nd-Fe-B magnets. Although this high saturation magnetization was first reported in 1972 [33], it was not confirmed until the α'' -Fe₁₆N₂ phase with a high saturation magnetization was reproduced in 1991 [34]. The α'' -Fe₁₆N₂ phase is metastable and thus cannot be obtained by conventional techniques. It is formed by the following reaction: nitrogenation (α -Fe phase $\rightarrow$ γ -FeN phase), quenching (γ -FeN phase $\rightarrow$ α' -FeN phase), and long tempering (α' -FeN phase $\rightarrow$ α'' -Fe₁₆N₂ phase) [35]. However, it is not possible to obtain pure α'' -Fe₁₆N₂ phase in this way because the solubility of N in the γ -FeN phase is less than the required concentration (12.5 at %). Thus, studies of the α'' -Fe₁₆N₂ phase have used various thin-film processing techniques [36–39]. α'' -Fe₁₆N₂ powders have been produced by chemical synthesis [40,41]. Powder was produced by a reduction in nano-sized α -Fe₂O₃ powders, followed by nitriding. It had a high saturation magnetization of 2.18 T at 5 K and a magnetocrystalline anisotropy constant of 0.96 MJm^{−3} [40]. Powder prepared by chemical synthesis exhibited a high saturation magnetization of 1.57 T, along with a coercivity of 208 kA/m [42]. The problem with Fe-based magnets is the relatively low coercivity. Although Fe-based magnets cannot replace Nd-Fe-B magnets, they can serve as gap magnets, making them suitable substitutes for Nd-Fe-B magnets in certain applications that do not require high coercivity [43]. Therefore, the development of new permanent magnets with high coercivity but without costly rare-earth elements has become a research focus.

2.2. Sm-Based Magnets

Although some rare-earth-free magnets exhibit high saturation magnetization, their performance is expected to be inferior to that of Nd-Fe-B magnets due to their lower coercivity. Therefore, the development of permanent magnets using rare-earth elements

is crucial. In practice, Nd-Fe-B magnets are not suitable for motors due to their lower coercivity; instead, Nd-Dy-Fe-B magnets, which incorporate Dy to enhance coercivity, are used. The primary issue with the rare-earth market is the extremely short supply of Dy [44]. Despite their name, rare-earth elements are not rare: cerium (Ce), lanthanum (La), neodymium (Nd), and yttrium (Y) are actually more common in Earth's crust than lead. The rare-earth elements are defined as a group of 17 elements with similar chemical properties, making it difficult to separate them from one another chemically. So, because it is not easy to obtain a particular rare-earth element directly from its ores, various rare-earth elements are simultaneously obtained by refining ores. Currently, there is an enormous surplus of Ce, Y, and Sm in the rare-earth market [45].

Thus, the development of Sm-based magnets, using the relatively abundant rare-earth element Sm, has become a focus of attention. Studies on Sm-based magnets have focused on SmFe₁₂ and Sm₂Fe₁₇N₃ [46–48]. Both compounds have magnetocrystalline anisotropies and saturation magnetizations comparable to those of the Nd₂Fe₁₄B phase (Table 2).

Table 2. Intrinsic magnetic properties of SmFe₁₂ and Sm₂Fe₁₇N₃.

Phase	Saturation Magnetization $4\pi M_s$ (T)	Anisotropy Constant K_1 (MJm ^{−3})	Curie Temperature T_c (K)
Nd ₂ Fe ₁₄ B	1.61	4.3	588
SmFe ₁₂	1.64	3.8	555
Sm ₂ Fe ₁₇ N ₃	1.54	8.6	749

The SmFe₁₂ phase has a tetragonal structure (ThMn₁₂-type) with a high saturation magnetization comparable to that of the Nd₂Fe₁₄B phase [48,49]. Although its anisotropy constant and Curie temperature are slightly smaller than those of the Nd₂Fe₁₄B phase, they are high enough to make it permanently magnetic. As the SmFe₁₂ phase is metastable, its formation is difficult, and only SmFe₁₂ sputtered films have been reported [50,51]. As a result of intensive research on the SmFe₁₂ phase, the substitution of small amounts of Ti for Fe in the SmFe₁₂ phase stabilized the SmFe₁₂ phase as the Sm(Fe,Ti)₁₂ phase [52–55].

Although the substitution of the non-magnetic Ti for Fe in the SmFe₁₂ phase, as the SmFe₁₁Ti phase, leads to a slight increase in the anisotropy constant and Curie temperature, it significantly decreases the saturation magnetization (Table 3). Further work is underway to improve the magnetic properties of the SmFe₁₂-based phase [56,57].

Table 3. Intrinsic magnetic properties of SmFe₁₂ and SmFe₁₁Ti.

Phase	Saturation Magnetization $4\pi M_s$ (T)	Anisotropy Constant K_1 (MJm ^{−3})	Curie Temperature T_c (K)
SmFe ₁₂	1.64	3.8	555
SmFe ₁₁ Ti	1.21	4.0	590

Up to now, the Sm₂Fe₁₇N₃ phase has been the most promising candidate, since its saturation magnetization is comparable to that of the Nd₂Fe₁₄B phase [46]. In addition, its anisotropy constant and Curie temperature are higher than those of the Nd₂Fe₁₄B phase. The details of the Sm₂Fe₁₇N₃ phase are discussed in the following section.

3. Sm-Fe-N Magnets

Two types of Sm-Fe-N phases have been produced: the Sm₂Fe₁₇N₃ phase and the SmFe₇N phase [46,58–63]. The Sm₂Fe₁₇N₃ phase is obtained by the nitrogenation of Sm-Fe

powder with the $\text{Th}_2\text{Zn}_{17}$ phase, while the SmFe_7N phase is obtained by the nitrogeneration of Sm-Fe melt-spun ribbon with the TbCu_7 phase. The basic difference between the two phases is the crystal structure: the $\text{Th}_2\text{Zn}_{17}$ phase is rhombohedral, and the TbCu_7 phase is hexagonal (Figure 1).

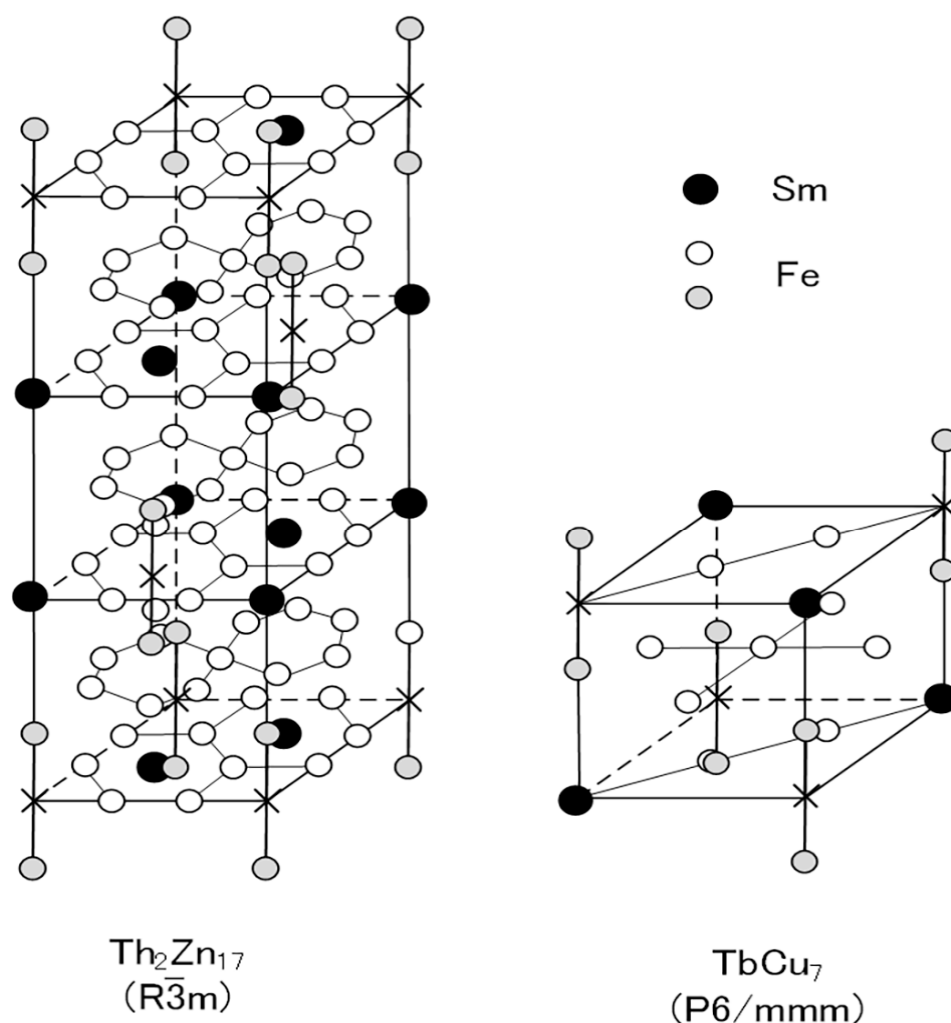


Figure 1. Schematic diagrams of $\text{Th}_2\text{Zn}_{17}$ (rhombohedral: $R\bar{3}m$) and TbCu_7 (hexagonal: $P6/mmm$) structures. In the Sm-Fe-N magnets, N atoms occupy interstitial sites in the Sm plane of the $\text{Th}_2\text{Zn}_{17}$ and TbCu_7 structures [64].

3.1. Sm-Fe-N Powder

In the production of the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder (Figure 2), the starting materials are Sm_2O_3 and Fe powders. $\text{Sm}_2\text{Fe}_{17}$ powder is obtained by the reduction–diffusion (RD) process, during which the Sm_2O_3 powder is reduced to Sm metal by Ca, and the Sm diffuses into the Fe powder to form $\text{Sm}_2\text{Fe}_{17}$ powder. The product is washed and rinsed to remove the CaO formed during the RD process. After the nitrogeneration of the $\text{Sm}_2\text{Fe}_{17}$ powder, the resultant $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ powder is pulverized finely [65–67]. It consists of the $\text{Th}_2\text{Zn}_{17}$ phase (Figure 3a), with an average particle size of about 3 μm (Figure 4a).

Another RD process is used to obtain fine $\text{Sm}_2\text{Fe}_{17}$ powder without pulverization [68–70]. In this process, a sulfuric acid solution containing Sm^{3+} , Fe^{2+} , and SO_4^{2-} , is used as a starting material. Sm-Fe hydroxide is first obtained by co-precipitation from the sulfuric acid solution, and then pyrolysis of it forms Sm-Fe oxide. Mixtures of fine $\text{Sm}_2\text{Fe}_{17}$ and CaO powders are produced from the Sm-Fe oxide by the RD process. After the nitrogeneration of the mixtures, the CaO is removed from the fine $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ powder by washing with water.

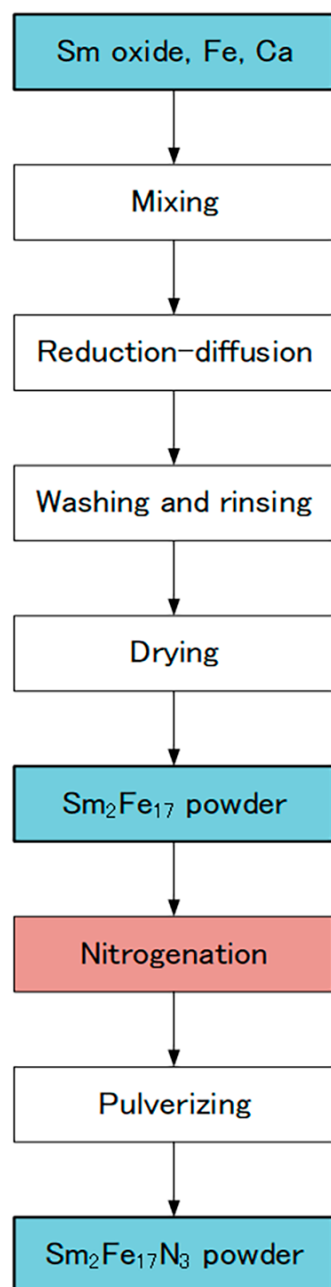
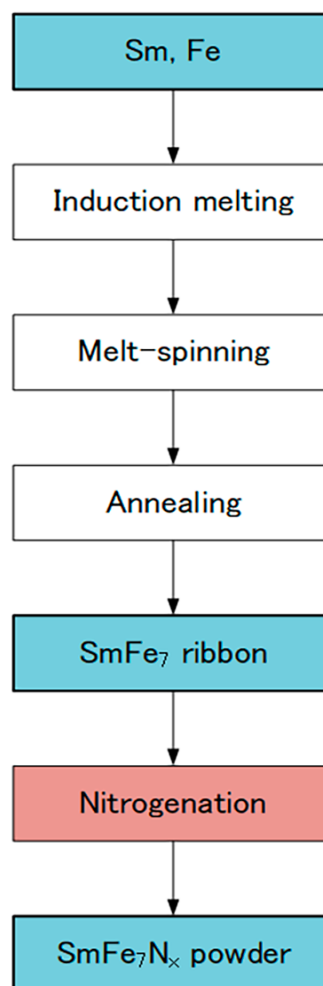
(a) $\text{Th}_2\text{Zn}_{17}$ -type(b) TbCu_7 -type

Figure 2. Production flows of (a) $\text{Th}_2\text{Zn}_{17}$ -type and (b) TbCu_7 -type Sm-Fe-N powders.

In the production of the TbCu_7 -type Sm-Fe-N powder, the starting materials are Sm and Fe metals [62,71]. The powder is prepared through rapid solidification processing, typically using the melt-spinning technique. The Sm and Fe metals are induction melted, and the resultant SmFe_7 alloy is rapidly solidified into SmFe_7 ribbon by melt-spinning. Annealing and subsequent nitrogenation of the SmFe_7 ribbon produces the SmFe_7N_x ribbon, which is then crushed into a coarse powder. It consists of the TbCu_7 phase (Figure 3b), with an average particle size of about 20 μm (Figure 4b).

The hysteresis loops of the $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe-N powders are shown in Figure 5. The hysteresis loops of the $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe powders, before nitrogenation, are also shown in Figure 5 for comparison. The loops are evaluated under the applied magnetic field of 2 MA/m after the powders are embedded in

paraffin. Since the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powders are anisotropic, they were magnetically aligned before being embedded in paraffin for evaluation under an applied magnetic field of 2 MA/m. The narrow hysteresis loops of the Sm-Fe powders (before nitrogenation) indicate that their coercivity values are small. However, the Sm-Fe-N powders have wide hysteresis loops with high coercivity. This confirms that the nitrogenation of the TbCu_7 -type and $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe powders significantly increased coercivity.

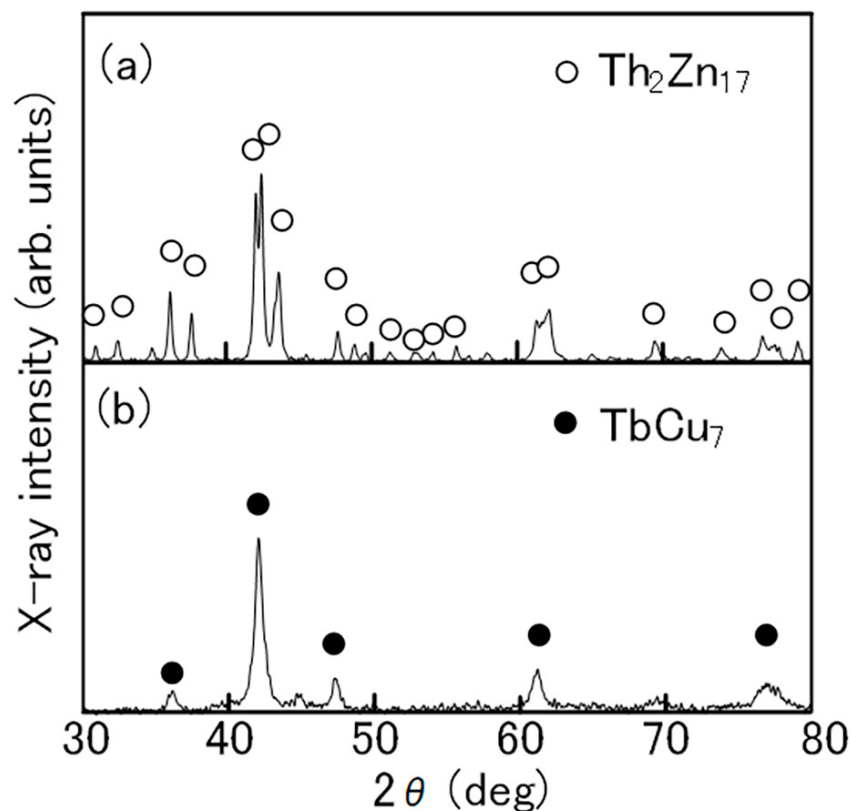


Figure 3. X-ray diffraction patterns of (a) $\text{Th}_2\text{Zn}_{17}$ -type and (b) TbCu_7 -type Sm-Fe-N powders [64].

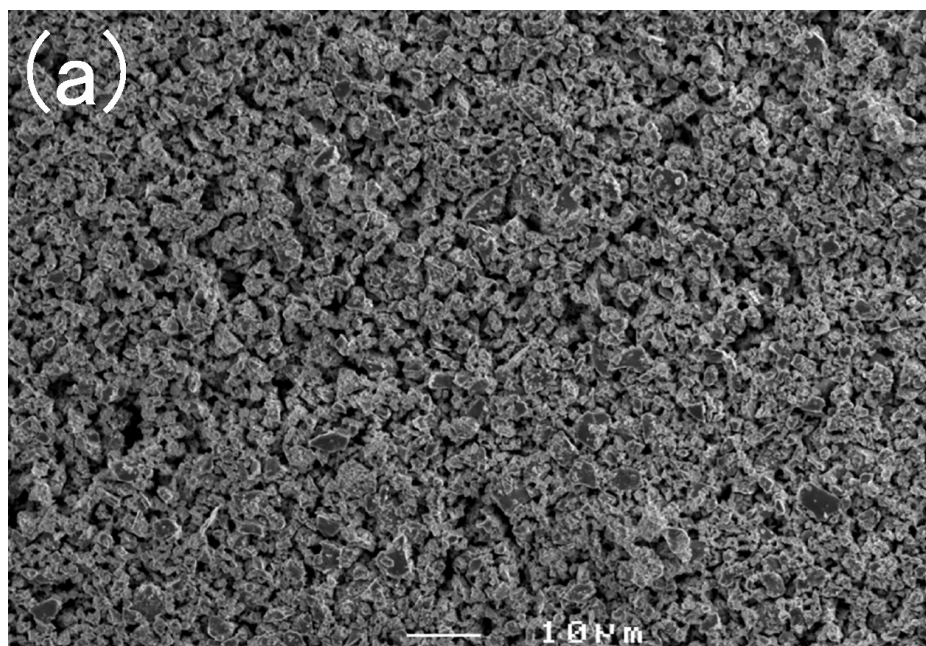


Figure 4. Cont.

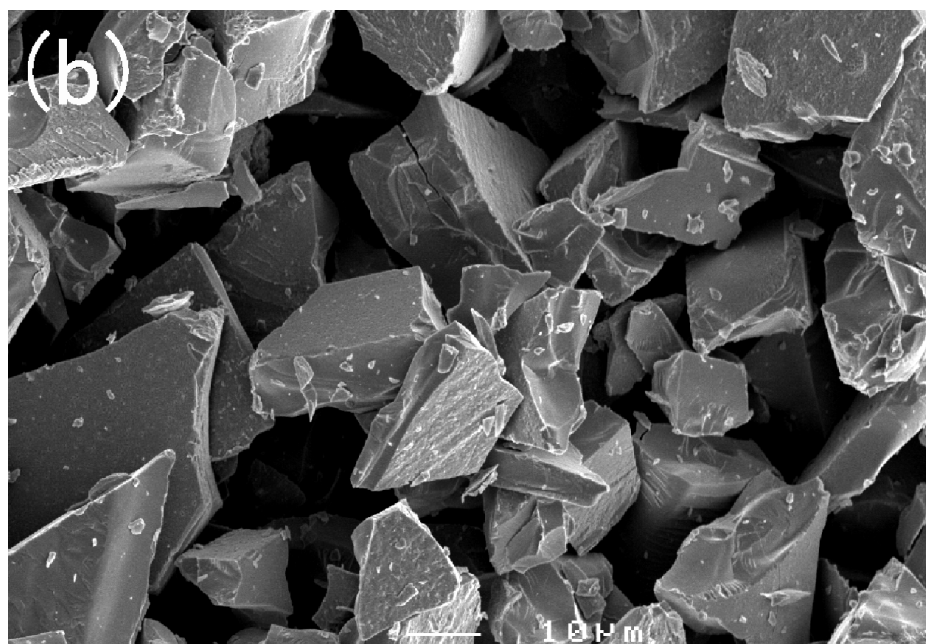


Figure 4. External appearances of (a) $\text{Th}_2\text{Zn}_{17}$ -type and (b) TbCu_7 -type Sm-Fe-N powders [64].

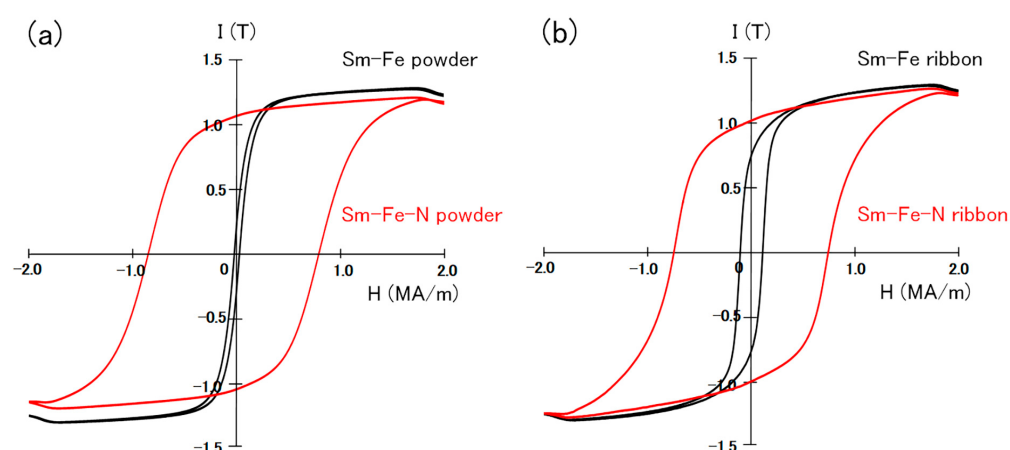


Figure 5. Hysteresis loops of (a) $\text{Th}_2\text{Zn}_{17}$ -type and (b) TbCu_7 -type Sm-Fe-N powders, measured under an applied magnetic field of 2 MA/m after the powders were embedded in paraffin [64].

The thermomagnetic curve of the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder clearly shows the Curie temperature (T_c) of the Sm-Fe-N phase (Figure 6a). That of the TbCu_7 -type Sm-Fe-N powder is almost the same (Figure 6b). The increase in magnetization at high temperatures above 800 K is noted in the thermomagnetic curve of the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder. The observed increase in the thermomagnetic curve is due to the formation of the ferromagnetic phase during the thermomagnetic measurement. The Curie temperature of the ferromagnetic phase is near 1050 K, corresponding to the Curie temperature of the α -Fe phase. The increase is also noted in the thermomagnetic curve of the TbCu_7 -type Sm-Fe-N powder. It is believed that the α -Fe phase is formed by the decomposition of the $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe-N phases at high temperatures [72].

The magnetic properties of the $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe-N powders are summarized in Table 4. The $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder is commercially prepared by the RD process, while the TbCu_7 -type Sm-Fe-N powder is commercially prepared by melt-spinning. Since the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder is prepared from the Sm oxide, the production of the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder is less costly than that of the TbCu_7 -type Sm-Fe-N powder. Both $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe-N powders show excellent

magnetic properties: high remanence magnetization, high intrinsic coercivity, and high Curie temperature. Since the $\text{Th}_2\text{Zn}_{17}$ -type Sm-Fe-N powder is anisotropic, it has a higher remanence value than the TbCu_7 -type Sm-Fe-N powder.

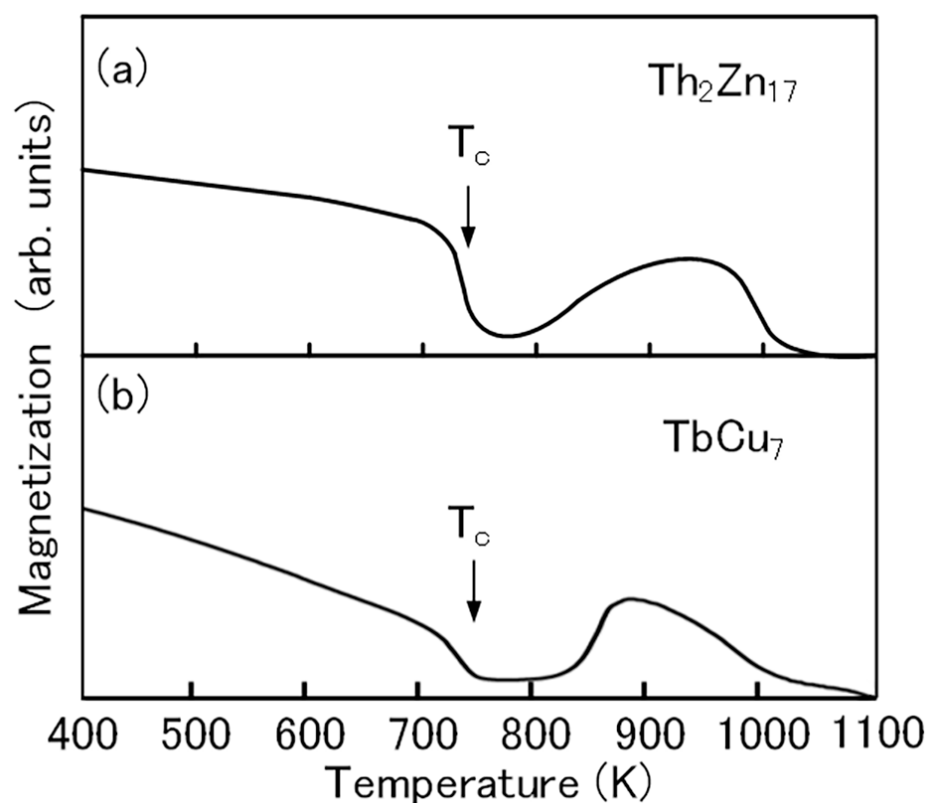


Figure 6. Thermomagnetic curves of (a) $\text{Th}_2\text{Zn}_{17}$ -type and (b) TbCu_7 -type Sm-Fe-N powders [64].

Table 4. Magnetic properties of $\text{Th}_2\text{Zn}_{17}$ -type and TbCu_7 -type Sm-Fe-N powders.

Sm-Fe-N Powder (Production)	Remanence Magnetization I_r (T)	Intrinsic Coercivity H_{ci} (kA/m)	Curie Temperature T_c (K)
$\text{Th}_2\text{Zn}_{17}$ -type (RD process)	1.08	840	740
TbCu_7 -type (melt-spinning)	1.02	756	740

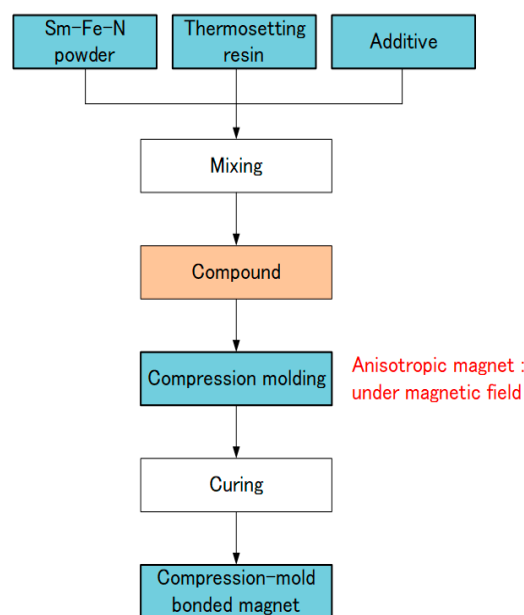
In recent years, studies have focused on improving the magnetic properties, especially the coercivity, of Sm-Fe-N powder [73–76]. It has been reported that Sm-Fe-N powder produced by a polymerized-complex reduction–diffusion process had a high coercivity of 1.84 MA/m [73] and fine Sm-Fe-N powder made by a surfactant-assisted grinding method had a high coercivity of 1.4 MA/m [74]. Since the oxidation of Sm-Fe-N powder reduces the coercivity, Sm-Fe-N powder with a low oxygen content has high coercivity [75,76]. Such high-performance Sm-Fe-N powder will be available soon.

3.2. Sm-Fe-N Bonded Magnets

Magnets are either bonded or sintered. Bonded magnets are widely used as permanent magnets. The first application of Sm-Fe-N powder is in bonded magnets [65,66], which are suitable for mass production owing to their complex shapes and precise sizes, all of which can be achieved without machining.

Sm-Fe-N bonded magnets are usually produced by compression molding or injection molding. In compression molding, Sm-Fe-N powder, thermosetting resin, and an additive are mixed (Figure 7). The typical thermosetting resin is epoxy, and the additive is a coupling agent. The compound is compression-molded and then cured. In injection molding, Sm-Fe-N powder, thermoplastic resin, and an additive are kneaded together. The typical resin is polyamide (PA). The compound is then injection-molded. A magnetic field is applied during both molding processes when producing anisotropic bonded magnets.

(a) Compression molding



(b) Injection molding

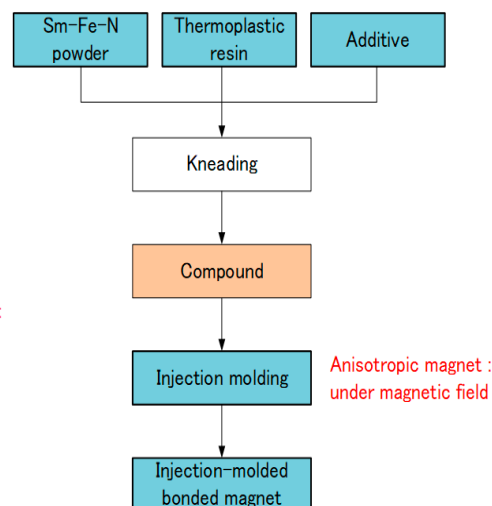


Figure 7. Production of Sm-Fe-N bonded magnets: (a) compression molding; (b) injection molding.

The magnetic properties of a bonded magnet are determined mainly by the volume fraction and the magnetic properties of the Sm-Fe-N powder. Both anisotropic and isotropic Sm-Fe-N bonded magnets are available from Japanese and Chinese manufacturers. Their typical magnetic properties are listed in Table 5.

Table 5. Magnetic properties of Sm-Fe-N bonded magnets.

Manufacturer	Powder	Resin	Magnetic Properties
Sumitomo Metal Mining Co., Ltd. (Tokyo, Japan)	Th ₂ Zn ₁₇ -type Sm-Fe-N powder	PA12 (anisotropic)	B _r = 0.80 (T) H _{cj} = 800 (kA/m) (BH) _{max} = 115 (kJ/m ³)
Nichia Corporation (Tokushima, Japan)	Th ₂ Zn ₁₇ -type Sm-Fe-N powder	PA12 (anisotropic)	B _r = 0.78 (T) H _{cj} = 870 (kA/m) (BH) _{max} = 112 (kJ/m ³)
Daido Electronics Co., Ltd. (Gifu, Japan)	TbCu ₇ -type Sm-Fe-N powder	Epoxy (isotropic)	B _r = 0.785 (T) H _{cj} = 735 (kA/m) (BH) _{max} = 105 (kJ/m ³)
Hangzhou Chase Technology (Hangzhou, China)	Th ₂ Zn ₁₇ -type Sm-Fe-N powder	PA11/PA12 (anisotropic)	B _r = 0.836 (T) H _{cj} = 569 (kA/m) (BH) _{max} = 86.8 (kJ/m ³)

As well as thermosetting or thermoplastic resin, metals and alloys have been tested as the adhesive in Sm-Fe-N bonded magnets. Among low-melting-point metals, zinc proved

to be a good metal adhesive [77–80]. Since then, metal-bonded Sm-Fe-N magnets have been intensively studied (Table 6). Recently, high-performance metal-bonded Sm-Fe-N magnets with a $(BH)_{\max}$ of 206 (kJ/m³) have been achieved [80].

Table 6. Development of metal-bonded Sm-Fe-N magnets.

Adhesive	B _r (T)	H _{cj} (kA/m)	(BH) _{max} (kJ/m ³)	Ref.
Zn	–	454	206	[76,78–80]
Sm-Cu	–	824	–	[81]
Sm-Fe-Cu-Al	–	~ 1000	–	[82]
Cu	–	760	–	[83]

3.3. Sm-Fe-N Sintered Magnets

As Sm-Fe-N bonded magnets consist of Sm-Fe-N powder and a substantial amount of nonmagnetic binders, their magnetic properties are inferior to those of the fully dense, sintered Sm-Fe-N magnets. Thus, several efforts have been made to produce Sm-Fe-N sintered magnets.

In the Nd-Fe-B sintered magnets, Nd-Fe-B powder is cold-pressed into a compact and then sintered and subsequently annealed at high temperature [25] (Figure 8). However, the same procedure cannot be applied to the Sm-Fe-N sintered magnets, because the Sm-Fe-N phase decomposes into the α -Fe and SmN phases during sintering [72]. Thus, a SmFeN sintered magnet has yet to be realized.

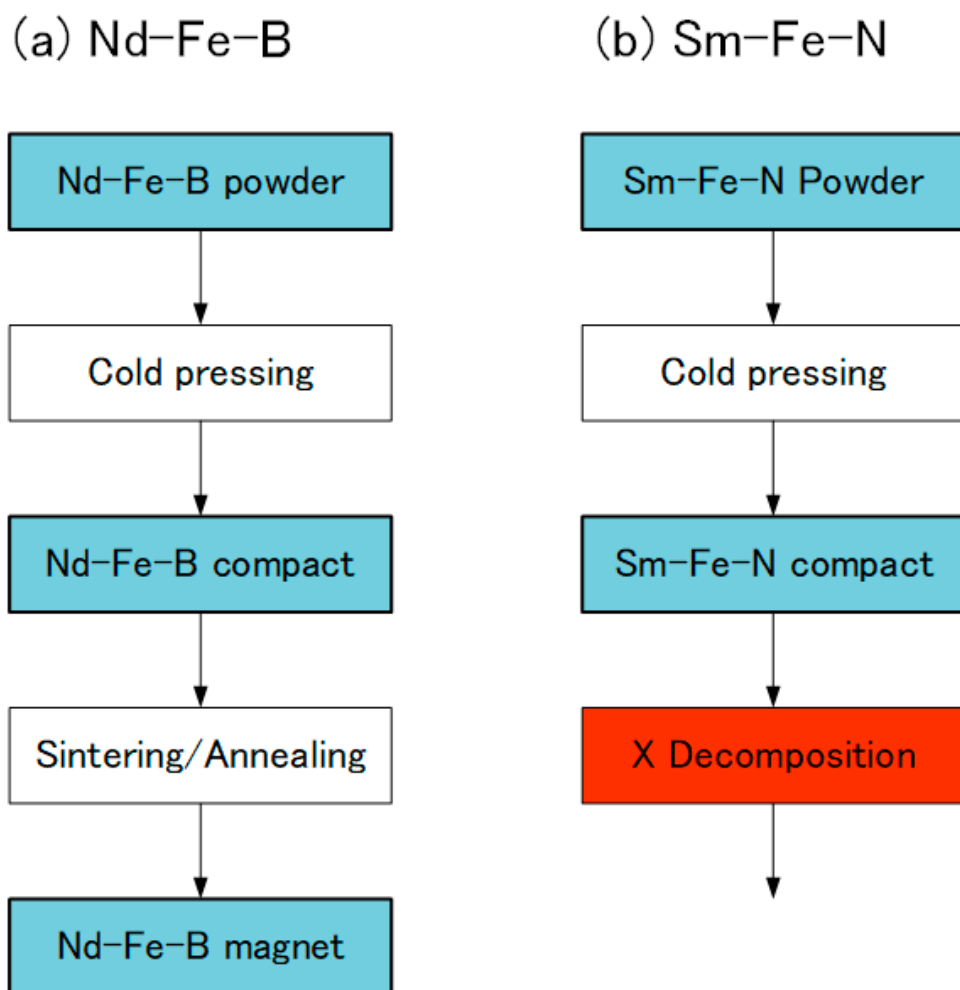


Figure 8. Production of (a) Nd-Fe-B and (b) Sm-Fe-N magnets.

Figure 9 presents current approaches to the production of Sm-Fe-N magnets. Novel production techniques, such as cold pressing and low-temperature sintering, have been employed to prevent the decomposition of the Sm-Fe-N phase. In cold pressing, the Sm-Fe-N powder is consolidated into bulk magnets at room temperature. In low-temperature sintering, the powder is sintered at temperatures lower than its decomposition temperature.

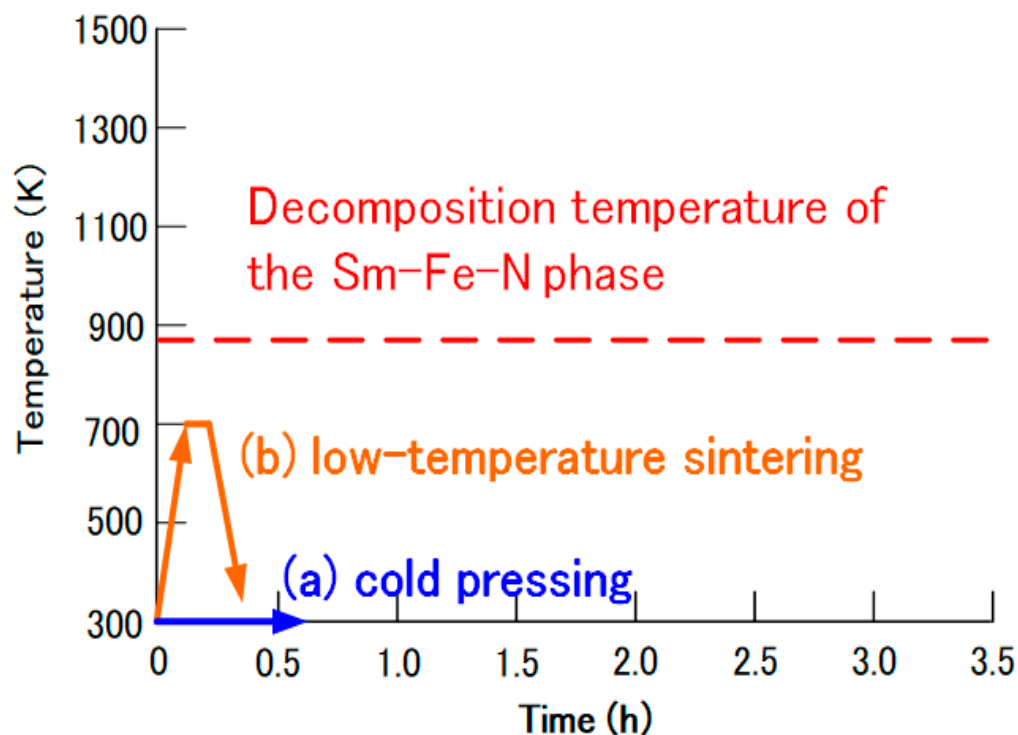


Figure 9. Approaches to the production of Sm-Fe-N magnets: (a) cold pressing and (b) low-temperature sintering.

Table 7 describes the production of the Sm-Fe-N sintered magnets. In cold pressing, Sm-Fe-N magnets have been produced by dynamic compaction [84,85] or by the compression shearing method [86]. In the dynamic compaction, Sm-Fe-N powders have been consolidated into bulk materials at room temperature by a shock wave, produced by an explosion [84] or a gun method [85]. On the other hand, Sm-Fe-N powders have been consolidated into bulk materials at room temperature by the application of the shear stress to the powder in the compression shearing method. Cold-pressing techniques have yielded high-density Sm-Fe-N magnets. However, these nonconventional techniques cannot be applied to the mass production of Sm-Fe-N magnets.

Table 7. Techniques used in the production of Sm-Fe-N sintered magnets.

Approach	Method	Ref.
cold pressing	Dynamic compaction	[84,85]
	Compression shearing method	[86]
low-temperature sintering	High-pressure compaction	[87]
	Hot isostatic pressing (HIP)	[88]
	Spark plasma sintering (SPS)	[89–91]
	Hot rolling	[92]

Sm-Fe-N magnets have been obtained by low-temperature sintering techniques, such as high-pressure compaction [87], hot isostatic pressing (HIP) [88], spark plasma sintering

(SPS) [89–91], and hot rolling, a new consolidation technique [92]. High-density Sm-Fe-N magnets have been produced by applying a high pressure of 1.2 GPa at a low temperature of 673 K for 60 s in the high-pressure compaction [87], and those have been produced by applying an isostatic pressure of 200 MPa at a low temperature of 723 K for 0.5 h in the HIP process [88]. Those have also been produced by applying a pressure of 100 MPa at a low temperature of 673–773 K for 300 s in the SPS process [89–91]. The mass production of Sm-Fe-N magnets has good prospects with such advances in manufacturing techniques.

4. Conclusions

In this paper, the magnetic properties of several compounds, L_{10} -FeNi, α'' -Fe₁₆N₂, SmFe₁₂, SmFe₁₁Ti, and Sm₂Fe₁₇N₃ phases are compared. The Sm₂Fe₁₇N₃ phase is revealed as the most promising candidate for the manufacture of Nd-Fe-B magnets. There are two types of Sm-Fe-N magnets: produced from Th₂Zn₁₇-type and TbCu₇-type Sm-Fe-N powders. The former is produced by the nitriding of Sm₂Fe₁₇ powder prepared by reduction-diffusion. The latter is produced by the nitriding of SmFe₇ powder prepared by melt spinning. Both Sm-Fe-N powders are successfully processed into bonded magnets with excellent magnetic properties. Despite numerous studies, the production of Sm-Fe-N sintered magnets is still in development. Several new studies have been made for the Sm-Fe-N magnets [93–95].

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