Phase formation and magnetic properties of (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ melt-spun ribbons

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Abstract
Phase formation and magnetic properties of (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ (x = 0.1–0.8) alloys were investigated experimentally by x-ray diffraction (XRD) and vibrating sample magnetometer (VSM). The phase structure analysis reveals that the as-cast (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ alloys were made of 2:14:1 phase with tetragonal Nd$_2$Fe$_14$B-tpyped structure, REFe$_2$ and α-Fe phases, while the melt-spun ribbons are composed of 2:14:1 phase and α-Fe Phase. Based on the magnetic measurements, the remanence ($B_r$), the coercivity ($H_c$), the maximum magnetic energy product ((BH)$_{max}$) and the Curie temperatures ($T_c$) of (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ ribbons reduces gradually with increasing Y substitution. The relatively high coercivity (6.75 kOe) of (Nd$_{0.4}$Y$_{0.6}$)$_{14}$Fe$_{80}$B$_6$ ribbon with high Y substitution was achieved, which indicates that good magnetic properties of Nd–Y–Fe–B ribbons would be obtained through the design of alloy composition and phase formation.

1. Introduction
Nd–Fe–B magnets have been widely used in many industrial applications such as medical equipment, electronic information, energy transportation and automobile industry [1–4]. Generally, the magnetic performance of Nd–Fe–B magnets was improved through the addition of low high abundant and expensive rare earth metals Dy and Tb [5–8]. With the increasing demand of Nd–Fe–B magnets in the modern electronic industry, the over-consumption of rare earth metals Dy and Tb would result in the unbalanced utilization of rare earth metals. Considering the comprehensive utilization of rare earth metals and the reduction of the costs of magnets, high abundant and cheap rare earth metals La, Ce and Y would be used effectively in the production of Nd–Fe–B magnets [9–15]. Therefore, the integrated utilization of rare earth metals in Nd–Fe–B magnets is a promising way to achieve the sustainable development of Nd–Fe–B magnets. However, magnetic properties of Nd–Fe–B magnets with La, Ce and Y would be deteriorated unavoidably because intrinsic magnetic properties of La$_2$Fe$_{14}$B, Ce$_2$Fe$_{14}$B and Y$_2$Fe$_{14}$B phases are inferior to those of Nd$_2$Fe$_{14}$B, Dy$_2$Fe$_{14}$B and Tb$_2$Fe$_{14}$B phases [16].

Recently, magnetic properties of Nd–Fe–B alloys substituted by Y were investigated in the literature [17–24]. Chen et al. [17] reported that Nd$_{9.3}$Y$_{0.7}$Fe$_{74.5}$Ti$_{5}$Zr$_{1}$B$_{15}$ melt-spinning ribbons exhibit good magnetic properties ($J_s = 0.78$ T, $H_s = 923.4$ kA m$^{-1}$, (BH)$_{max} = 98.5$ kJ m$^{-3}$). Zheng et al. [18] reported magnetic properties of (Nd$_{9.3}$Y$_{0.7}$)$_{14.5}$Fe$_{80}$B$_6$Co$_{20}$Al$_1$Cu$_{0.5}$ melt-spinning ribbons. It was found that the remanence and the coercivity ($H_c$) of the ribbons decrease from 0.80 to 0.71 T and 1400 to 809 kA m$^{-1}$, respectively, when Y content increases from $x = 0$ to $x = 0.4$. Liu et al. [21] found that the temperature coefficients of the remanence and the coercivity of [Nd$_{0.8}$Dy$_{0.2}$]$_{14}$Fe$_{80}$B$_6$ alloys in the temperature range of 273–393 K were enhanced from $-0.979$/K and $-0.397$/K to $-0.088$/K and $-0.394$/K, respectively. Fan et al. [22] obtained better coercivity (9.73 kOe) in Y substituted Nd–Ce–Fe–B magnets with the core–shell microstructure. It indicates that Y substitution is a
feasible way to maintain good magnetic properties of Nd–Fe–B magnets at high temperature and reduce their costs [23]. Although microstructure and magnetic properties of Nd–Fe–B magnets substituted by Y and with different fabrication technologies (e.g. double-main-phase method, dual-alloy method and grain boundary diffusion method) were investigated in the literature [17–24], the mechanism of the improvement of magnetic properties of Y-substituted Nd–Fe–B magnets need to be elucidated further. According to the experimental results reported by Tang et al [25], the phase constitution greatly affects the crystalline texture and magnetic properties of Y-substituted Nd–Fe–B ribbons. It is necessary to further understand the relationship between phase formation, phase structure and magnetic properties of Nd–Fe–B alloys with Y substitution. Therfore, phase formation, phase structure and magnetic properties of (Nd1−xYx)14Fe80B6 ribbons were studied experimentally in this work.

2. Experiment

(Nd1−xYx)14Fe80B6 (x = 0.1–0.8) alloys were fabricated by arc-melting technology using Nd, Y, Fe and B metals (purity, 99.99%). Alloy samples were melted in pure argon for more than four times to ensure their composition uniformity. The melt-spun ribbons were obtained that alloy samples were melted by induction and then sprayed onto the surface of the copper wheel with the rotational speed of 26 m s−1.

The phase structure of as-cast alloys and melt-spun ribbons were examined by x-ray diffractometer (XRD, PLXcel 3D) with Cu Kα radiation (λ = 1.5406 Å, 45 kV, 40 mA, step = 0.013) in the 2θ range of 20° to 90°. The lattice parameters and phase volume fraction were obtained by the rietvled refinement of Fullprof program. Magnetic properties of the ribbons were measured by vibrating sample magnetometer (VSM, Lakeshore, 7400 740H) at room temperature. Thermogravimetric experiments were performed to determine the Curie temperatures of the ribbons using thermal analysis (DTA, TA Instruments, SDT/Q-600) at heating rate of 20 K min−1 under a constant magnetic field.

3. Results and discussion

3.1. Phase formation

Figure 1 shows the Rietveld refinements of XRD powder patterns of (Nd1−xYx)14Fe80B6 (x = 0.1–0.8) as-cast alloys. The red points are the experimental data and the solid lines represent the calculated results. The green vertical bars indicate the bragg positions of 2:14:1 phase, α-Fe and REFe2 phases. The blue lines show the differences between the experimental data and the calculated results. The calculated patterns agree well with the experimental data. The diffraction peaks of (Nd1−xYx)14Fe80B6 (x = 0.1–0.3) as-cast alloys display the structure characteristics of 2:14:1 phase with tetragonal Nd2Fe14B-typed structure (space group P42/mnm) named as (NdY)2Fe14B phase and α-Fe phase (space group Im 3 m). Nevertheless, the diffraction peaks of (Nd1−xYx)14Fe80B6 (x = 0.5–0.8) as-cast alloys show that REFe2 phase (space group Fd 3 m) was formed and α-Fe phase was disappeared, except for (NdY)2Fe14B phase. Table 1 summarizes the crystal structure parameters.
and volume fractions of (NdY)$_2$Fe$_{14}$B, $\alpha$-Fe and REFe$_2$ phases in (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ as-cast alloys. It indicates that lattice parameters and cell volumes of (NdY)$_2$Fe$_{14}$B phase in (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ as-cast alloys decrease linearly with increasing Y substitution, while the formation of $\alpha$-Fe phase could be inhibited due to the formation of REFe$_2$ phase.

Figure 2. Rietveld refinements of XRD powder patterns of (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ (x = 0.1–0.8) melt-spun ribbons. (a) x = 0.1–0.3; (b) x = 0.4–0.8.

Figure 3. Lattice parameters and cell volumes of 2:14:1 phase in (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ (x = 0.1–0.8) melt-spun ribbons.

| Sample alloys | Lattice parameters (NdY)$_2$Fe$_{14}$B | Volume fraction | | |
|---------------|-------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|               | a (Å) | c (Å) | c/a | Cell volume (Å$^3$) | $\alpha$-Fe a (Å) | REFe$_2$ a (Å) | (NdY)$_2$Fe$_{14}$B | $\alpha$-Fe (%) | REFe$_2$ (%) | Rwp |
| x = 0.1       | 8.782(2) | 12.170(1) | 1.386 | 938.64(6) | 2.862(8) | — | 97.13 | 2.87 | — | 14.6 |
| x = 0.2       | 8.779(6) | 12.148(7) | 1.383 | 936.43(7) | 2.863(2) | — | 98.25 | 1.75 | — | 17.3 |
| x = 0.3       | 8.775(2) | 12.146(1) | 1.384 | 935.30(5) | 2.862(4) | — | 98.66 | 1.34 | — | 14.9 |
| x = 0.4       | 8.775(8) | 12.138(2) | 1.383 | 934.82(5) | — | — | 100 | — | — | 14.6 |
| x = 0.5       | 8.773(0) | 12.126(7) | 1.382 | 933.33(5) | — | 7.357(1) | 96.66 | — | 3.34 | 11.4 |
| x = 0.6       | 8.768(7) | 12.108(2) | 1.381 | 930.99(7) | — | 7.354(2) | 92.21 | — | 7.79 | 12.9 |
| x = 0.8       | 8.761(3) | 12.071(5) | 1.378 | 927.91(5) | — | 7.327(3) | 88.51 | — | 11.49 | 12.7 |

Table 1. Lattice parameters and volume fractions of identified phases in (Nd$_{1-x}$Y$_x$)$_{14}$Fe$_{80}$B$_6$ (x = 0.1–0.8) as-cast alloys by Rietveld refinements.
Melt-spun ribbons a

Table 2. Lattice parameters and volume fractions of identified phases in (Nd1−xYx)14Fe80B6 melt-spun ribbons by Rietveld refinements.

| Melt-spun ribbons | Lattice parameters | Volume fraction |
|-------------------|--------------------|-----------------|
|                   | (NdY)2Fe14B        | α-Fe (%)        |
|                   | a (Å) | c (Å) | c/a  | Cell volume (Å³) | α-Fe (%) | R_p   |
| x = 0.1           | 8.792(6) | 12.169(3) | 1.384 | 940.80(3) | 2.866(3) | 96.15 | 3.85 | 15.1 |
| x = 0.2           | 8.784(5) | 12.145(2) | 1.382 | 937.29(1) | 2.868(2) | 97.38 | 2.62 | 13.6 |
| x = 0.3           | 8.779(5) | 12.139(6) | 1.383 | 936.00(9) | 2.866(7) | 97.65 | 2.35 | 17.9 |
| x = 0.4           | 8.775(5) | 12.127(2) | 1.382 | 934.79(6) | — | 100 | — | 15.6 |
| x = 0.5           | 8.770(4) | 12.106(5) | 1.381 | 932.28(6) | — | 100 | — | 12.8 |
| x = 0.6           | 8.763(2) | 12.093(7) | 1.380 | 930.07(4) | — | 100 | — | 11.2 |
| x = 0.8           | 8.753(3) | 12.071(5) | 1.379 | 924.91(5) | — | 100 | — | 16.2 |

Figure 2 is the Rietveld refinements of XRD powder patterns of (Nd1−xYx)14Fe80B6 melt-spun ribbons. As can be seen, the calculated patterns agree well with the experimental results. The diffraction peaks of REFe2 phase were not found in (Nd1−xYx)14Fe80B6 melt-spun ribbons, while the diffraction peak of α-Fe phase was weak gradually with increasing Y substitution. Compared with the standard diffraction patterns of Nd2Fe14B and Y2Fe14B phases, the diffraction peaks of (NdY)2Fe14B phase in (Nd1−xYx)14Fe80B6 melt-spun ribbons shift slightly to higher 2θ values with increasing Y substitution. On the basis of the Rietveld refinements, table 2 summarizes the crystal structure parameters including the lattice parameters and cell volumes of (NdY)2Fe14B melt-spun ribbons as shown in figure 3. According to the Rietveld refinements, Nd and Y atoms occupy two (4g, 4f) positions in the tetragonal Nd2Fe14B-type structure, while Fe atoms are located at five sites (4c, 4e, 8j, 16k1, 16k2) and B atoms occupy one (4g) sublattice. The increase of Y substitution results in the decrease of the lattice parameters and cell volumes of (NdY)2Fe14B main phase in (Nd1−xYx)14Fe80B6 melt-spun ribbons because of smaller Y atoms enter into the structure lattice of Nd2Fe14B to replace Nd atoms.

3.2. Magnetic properties

Figure 4 is the magnetization curves of (Nd1−xYx)14Fe80B6 melt-spun ribbons. Table 3 summarizes the magnetic properties including the remanence (B_r), the coercivity (H_c), and the maximum magnetic energy product ((BH)_{max}) of (Nd1−xYx)14Fe80B6 melt-spun ribbons. The B_r and H_c of the ribbons was determined directly from the magnetization curves (M-H curves), while the (BH)_{max} of the ribbons was obtained from the area of the largest rectangle inscribed in the second quadrant of B-H curves transformed from M-H curves. As shown in table 3, it seems that high coercivity (6.75 kOe) of the ribbon with x = 0.6 is still achieved even if higher Y substitution. The remanence (B_r) and the coercivity (H_c) of the ribbon with x = 0.1 are 9.53 kGs and 11.56 kOe, respectively, while those of the ribbon with x = 0.8 are 5.32 kGs and 4.43 kOe. With increasing Y substitution,
The remanence ($B_r$) and the coercivity ($H_{cj}$) of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons decrease gradually. It could result from the magnetic dilution effect due to lower magnetocrystalline anisotropy field and lower saturation remanence of $Y_2Fe_{14}B$ phase compared with those of $Nd_2Fe_{14}B$ phase when Nd atoms are replaced by Y atoms in the lattice of $Nd_2Fe_{14}B$ phase, which was confirmed by XRD results of the ribbons in figure 2. On the other hand, the $(BH)_{max}$ of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons decreases monotonically with increasing Y substitution. The $(BH)_{max}$ of the ribbon with $x = 0.1$ is 17.72 MGOe, while that of the ribbon with $x = 0.8$ is only 5.37 MGOe.

In order to understand better the magnetization behavior of the melt-spun ribbons, the measured initial magnetization curves and their first derivative of the initial magnetization curves of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons were shown in figures 5(a) and 5(b), respectively. The magnetization process of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ($x = 0.1–0.8$) ribbons is controlled by nucleation and pinning domain wall. As can be seen, two kinds of collective magnetic reversal were found in the first derivative of the initial magnetization curves. The first one is that the value of $dM/dH$ decline rapidly in the magnetic field range of 0–3.5 kOe, indicating that the magnetization process of the ribbons at the beginning is controlled by nucleation. The second one is a step-type magnetization process in the figure 5(c).

### Table 3. Magnetic properties of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ melt-spun ribbons.

| Melt-spun ribbons $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ | $T_c$ (K) | $B_r$ (kGs) | $H_{cj}$ (kOe) | $(BH)_{max}$ (MGOe) | $M_r$ (emu g$^{-1}$) | Remanent ratio ($M_r/M_s$) |
|-----------------------------------------------|-----------|------------|----------------|---------------------|----------------------|------------------------|
| $x = 0.1$                                      | 576.0     | 9.53       | 11.56          | 17.72               | 93.11                | 0.758                  |
| $x = 0.2$                                      | 575.2     | 8.84       | 10.76          | 14.08               | 83.33                | 0.780                  |
| $x = 0.3$                                      | 573.8     | 6.83       | 9.34           | 9.64                | 70.28                | 0.785                  |
| $x = 0.4$                                      | 567.1     | 6.89       | 9.04           | 10.10               | 70.25                | 0.764                  |
| $x = 0.5$                                      | 570.4     | 6.32       | 7.01           | 7.80                | 62.07                | 0.731                  |
| $x = 0.6$                                      | 564.6     | 5.72       | 6.75           | 7.45                | 57.63                | 0.716                  |
| $x = 0.8$                                      | 563.5     | 5.32       | 4.43           | 5.37                | 51.50                | 0.641                  |

The remanence ($B_r$) and the coercivity ($H_{cj}$) of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons decrease gradually. It could result from the magnetic dilution effect due to lower magnetocrystalline anisotropy field and lower saturation remanence of $Y_2Fe_{14}B$ phase compared with those of $Nd_2Fe_{14}B$ phase when Nd atoms are replaced by Y atoms in the lattice of $Nd_2Fe_{14}B$ phase, which was confirmed by XRD results of the ribbons in figure 2. On the other hand, the $(BH)_{max}$ of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons decreases monotonically with increasing Y substitution. The $(BH)_{max}$ of the ribbon with $x = 0.1$ is 17.72 MGOe, while that of the ribbon with $x = 0.8$ is only 5.37 MGOe.

In order to understand better the magnetization behavior of the melt-spun ribbons, the measured initial magnetization curves and their first derivative of the initial magnetization curves of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ribbons were shown in figures 5(a) and 5(b), respectively. The magnetization process of $(Nd_{1-x}Y_x)_{14}Fe_{80}B_6$ ($x = 0.1–0.3$) ribbons is controlled by nucleation and pinning domain wall. As can be seen, two kinds of collective magnetic reversal were found in the first derivative of the initial magnetization curves. The first one is that the value of $dM/dH$ decline rapidly in the magnetic field range of 0–3.5 kOe, indicating that the magnetization process of the ribbons at the beginning is controlled by nucleation. The second one is a step-type magnetization process in the
magnetic field range of 3.5–20 kOe, indicating that the magnetization process is controlled by pinning domain wall. Emura et al [26] pointed out that the demagnetization process of Nd–Fe–B nanocomposite magnets would include the nucleation process in the soft magnetic phase and the domain wall displacement process from the soft magnetic phase to the hard magnetic phase through the grain boundary. Meanwhile, the exchange coupling pinning field of the displacement of the irreversible domain walls across the grain boundary is larger than the nucleation field of the soft magnetic phase, which results in that the coercivity of the magnet should be determined by the exchange coupling pinning field. Therefore, the local nucleation in the ribbons with \( x = 0.1 - 0.3 \) is caused from a small amount of \( \alpha \)-Fe phase remaining in the ribbons (seen in figure 2(a)), while the domain wall pinning between grains determines ultimately the magnetization reversal of hard magnetic phase grains. On the other hand, the first derivative of the initial magnetization curves in figure 5(b) presents a typically uniform domain wall pinning behavior in \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) (seen in figure 2(b)). In addition, the strength of the pinning field gradually decreases with increasing \( Y \) substitution because of the lower magnetocrystalline anisotropy field of \( \text{Y}_2\text{Fe}_{14}\text{B} \) phase [16].

In figure 5(c), the demagnetization curves of \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) in the second quadrant are relatively smooth, which is typical single-phase hard magnetic behavior, indicating that the microstructure in the ribbons is well crystallized. However, the kinks were found in the demagnetization curves of the \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) (\( x = 0.1 - 0.3 \) ribbons, indicating the existence of soft magnetic phase and uneven region in the ribbons. Fidler et al [27] used TEM to analyze Nd–Fe–B magnet and found Fe-rich precipitation in the uneven region of the microstructure of the magnet. The exchange coupling effect between the soft magnetic phase and the \( \text{Nd}_2\text{Fe}_{14}\text{B} \) main phase resulted in the kink of the demagnetization curve, which is evident for the existence of soft magnetic nucleation center in the reverse magnetic domains. It can be seen from table 3 that the remanent ratios \( (M_r/M_s) \) in \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) melt-spun ribbons is greater than 0.5, indicating the existence of intergranular exchange coupling in the melt-spun ribbons [28]. The remanent ratios of the ribbons increase from 0.758 to 0.780 when \( Y \) substitution from 0.1 to 0.3, which suggests that the intergranular exchange coupling increases gradually in the ribbons. There is a exchange coupling between \( \alpha \)-Fe soft magnetic phase and adjacent \( \text{Nd}_2\text{Fe}_{14}\text{B} \) hard magnetic main phase, resulting in obvious kinks in the demagnetization curves. The remanent ratios of the ribbons decrease from 0.780 to 0.641 when \( Y \) substitution from 0.3 to 0.8, which suggests that the intergranular exchange coupling reduces gradually in the ribbons and thus these kinks disappear.

Thermogravimetric measurements of \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) melt-spun ribbons were carried out to determine their Curie temperatures \( (T_C) \) by thermal analysis under a constant magnetic field. As shown in figure 6(a), the thermogravimetric curves of \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) ribbons present a sudden weight change with increasing temperature, resulting from the occurrence of magnetic transition from ferromagnetic state to paramagnetic state. The minimum temperatures of the derivative thermogravimetric curves \( (dT/dT) \) in figure 6(b) were determined to be the Curie temperatures \( (T_C) \) of the ribbons as given in table 2. The Curie temperature \( (T_C) \) of the ribbon with \( x = 0.1 \) is 576.0 K, while that of the ribbon with \( x = 0.8 \) is 563.5 K. It is evident that the Curie temperatures \( (T_C) \) of \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) ribbons (except for the ribbon with \( x = 0.5 \)) decreases gradually with increasing \( Y \) substitution, resulting from the lower Curie temperature of \( \text{Y}_2\text{Fe}_{14}\text{B} \) phase (565 K) due to the replacement of Nd atoms by smaller Y atoms in the lattice of 2:14:1 phase.

Figure 6. Thermogravimetric curves (a) and derivative thermogravimetric curves (b) of \( (\text{Nd}_{1-x}\text{Y}_x)_{14}\text{Fe}_{80}\text{B}_6 \) (\( x = 0.1 - 0.8 \)) melt-spun ribbons under a constant magnetic field during heating process.

![Figure 6](image-url)
4. Conclusions

Phase formation and magnetic properties of (Nd\textsubscript{1−x}Y\textsubscript{x})\textsubscript{14}Fe\textsubscript{80}B\textsubscript{6} (x = 0.1−0.8) melt-spun ribbons were studied experimentally. The phase structure analysis by XRD shows that (Nd\textsubscript{1−x}Y\textsubscript{x})\textsubscript{14}Fe\textsubscript{80}B\textsubscript{6} as-cast alloys are composed of 2:14:1 phase with tetragonal Nd\textsubscript{2}Fe\textsubscript{14}B\textsubscript{8}-type structure (space group P4\textsubscript{2}/mmn) as well as α-Fe phase (space group Im 3 m) and/or REFe\textsubscript{2} phase (space group Fd 3 m), while the melt-spin ribbons are composed of 2:14:1 phase and α-Fe phase. With increasing Y substitution, the formation of α-Fe phase in the ribbons was inhibited due to the formation of REFe\textsubscript{2} phase. Rietveld refinement results suggest that Y atoms enter into the structure lattice of Nd\textsubscript{2}Fe\textsubscript{14}B phase to replace Nd atoms in the ribbons. According to magnetic measurements, the remanence (B\textsubscript{r}), the coercivity (H\textsubscript{c}), the maximum magnetic energy product ([BH]\textsubscript{max}) and the Curie temperatures (T\textsubscript{c}) of the ribbons reduce gradually with increasing Y substitution. It was achieved that the coercivity of (Nd\textsubscript{0.4}Y\textsubscript{0.6})\textsubscript{14}Fe\textsubscript{80}B\textsubscript{6} ribbon with high Y substitution is relatively high to be 6.75 kOe.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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