Article

Optimum Soft Magnetic Properties of the FeSiBNbCu Alloy Achieved by Heat Treatment and Tailoring B/Si Ratio

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Abstract: To increase the saturation magnetization ($M_s$) of commercially available soft magnetic Finemet alloys to the level comparable to that of Si-steel and Fe-based nanocrystalline alloys such as Nanoperm, Nanomet, the B or Si content in combination with annealing heat treatment was tailored. The ribbons of $Fe_{95−x}Si_xB_{11}Nb_3Cu_1$ ($x = 11, 12, 13$) and $Fe_{87−x}Si_xB_{9}Nb_3Cu_1$ ($x = 6, 8, 10$) were prepared by melt-spinning and annealed at different temperatures to develop nanocrystalline microstructure optimizing the soft magnetic properties. The magnetic properties of the as-spun and annealed ribbons were measured using a vibrating sample magnetometer and AC B-H loop tracer to acquire $M_s$ of above 1.4 T in all as-spun ribbons. Among the alloys, $Fe_{84}Si_1B_{11}Nb_3Cu_1$ annealed at 545 °C showed the highest $M_s$ of 2 T, which exceeds that of the conventional Finemet and other Fe-based nanocrystalline alloys.

Keywords: annealing; amorphous; soft magnetic properties; ferromagnet

1. Introduction

Due to their superior soft magnetic properties, magnetic materials such as Si-steel have been widely used to produce actuators, sensors, transformer cores, or electric motors [1,2]. Recently, attention has been paid to low core loss ($P_{cv}$) due to the increasing demand on energy efficiency [3]. Fe-based soft magnetic or nanocrystalline alloys could be a strong candidate for the emerging engineering technologies thanks to their potential for low $P_{cv}$ and sufficient mechanical properties [4–6]. However, the saturation magnetization ($M_s$) of these materials is relatively lower than that of Si-steels [4]. Therefore, improving the soft magnetic properties of the alloys to keep $P_{cv}$ low and, at the same time, to increase $M_s$ to the level exceeding that of Si-steel is required for the development of next-generation soft magnetic materials.

Finemet alloys are based on Fe-Si-B-Nb-Cu, which are derived from the conventional Fe-Si-B system with a minor addition of Cu and Nb [7]. High soft magnetic properties in these alloys are originated from the precipitation of nanocrystalline α-Fe dispersed in an amorphous matrix [8–11]. Although the overall magnetic properties of Finemet were considered innovatory when it was first produced by Yoshizawa et.al in 1988 [10], currently, there are some competing nanocrystalline alloys that have remarkable soft magnetic properties including Nanoperm, Hitperm, or Nanomet. These alloys show very high saturation magnetization flux density ($B_s$) above 1.5 T higher than that of Finemet which is 1.23 T [12–15]. However, the Finemet-based alloys are still attractive as soft magnetic materials because of the potential for further improvement including excellent magnetic permeability.
We modified the atomic concentration of B or Si in the Finemet-based alloy system in exchange with 
XRD patterns for the as-spun ribbons with variation of Si and B content. The patterns of ribbons with 
various temperatures (T) was determined using XRD where Cu-Kα radiation (D8 Advance, Bruker, Germany). The Ms was measured with 
a vibrating sample magnetometer (VSM) at room temperature under the in-plane applied magnetic 
field ranging from 0.1 A/m. The values of Ms were measured by di 
Magnetic properties although the latter case induced higher Hc [7,17]. Therefore, effect of B and Si 
content variation in connection with the Fe content on the soft magnetic properties would be of interest in 
the further optimization of the Finemet-based alloy system. In this study, we focused on increasing 
the value of saturation magnetization Ms while maintaining low Pcv by varying the B or Si contents. 
We modified the atomic concentration of B or Si in the Finemet-based alloy system in exchange with 
Fe content. In addition, in order to further optimize soft magnetic properties, annealing treatment at 
various temperatures (T_a) was applied.

2. Materials and Methods

Multicomponent ingots with the compositions of Fe_{95-x}Si_{x}B_{5}Nb_{3}Cu_{1} (x = 11, 12, 13) and Fe_{87-x}Si_{x}B_{3}Nb_{3}Cu_{1} (x = 6, 8, 10) were prepared by arc melting under Ti-gettered argon atmosphere and 
remelted at least four times for homogeneity. Amorphous ribbons were produced by using melt-spinner in 
an argon atmosphere with a wheel speed of 56.3 m/s. The width and thickness of ribbons were 
2 mm and 20–30 µm, respectively. As-spun ribbons were annealed in a vertical furnace at various 
temperatures for 60 min under an argon atmosphere. The cooling rate that can be achieved in this 
method was of order 0.67 °C/s. The structural properties of as-spin ribbons were identified by X-ray 
diffraction (XRD) with Cu-Kα radiation (D8 Advance, Bruker, Germany). The Ms was measured with 
a helium pycnometer (AccuPyc II, Micromeritics). The Mm and Pcv were measured by using 
an AC B-H loop tracer. The values of Mm were measured under the maximum applied filed (Hm) of 
800 A/m, and the values of Pcv were measured under a frequency (f) of 100 kHz and the Hm of 0.1 A/m. 
For annealing, a temperature above the crystallization temperature (Tc) of the as-spun amorphous 
ribbons was chosen for each specimen. Tc was measured by differential scanning calorimetry (DSC) at 
a heating rate of 0.34 °C/s.

3. Results and Discussion

The atomic structure of as-spun Fe_{95-x}Si_{x}B_{5}Nb_{3}Cu_{1} (x = 11, 12, 13) and Fe_{87-x}Si_{x}B_{3}Nb_{3}Cu_{1} (x = 
6, 8, 10) ribbons was determined using XRD where Cu-Kα radiation was used. Figure 1 shows the 
XRD patterns for the as-spun ribbons with variation of Si and B content. The patterns of ribbons with 
different B contents (upper 3 patterns in Figure 1) consist of broad halos without any sharp diffraction 
peaks corresponding to crystalline phases, indicating that the structure is fully amorphous for the 
alloys considered here. However, the as-spun ribbons of Fe_{81}Si_{6}B_{9}Nb_{3}Cu_{1} and Fe_{78}Si_{9}B_{2}Nb_{3}Cu_{1} (4th 
and 5th patterns from the top of the Figure 1, respectively) have obvious crystalline peaks in the 2θ 
range of 40–50°. This suggests that the ribbons are partially crystallized. The alloys Fe_{95-x}Si_{x}B_{5}Nb_{3}Cu_{1} 
(x = 11, 12, 13) and Fe_{79}Si_{10}B_{9}Nb_{3}Cu_{1} (x = 10, y = 9) maintain amorphous phase in as-spun state 
suggesting their good glass-forming ability (GFA).

The hysteresis loops for Fe_{95-x}Si_{x}B_{5}Nb_{3}Cu_{1} (x = 11, 12, 13) and Fe_{87-x}Si_{x}B_{3}Nb_{3}Cu_{1} (x = 6, 8, 10) 
of the as-spun ribbons are shown in Figure 2. All specimens exhibit high soft magnetic properties with 
a high Ms about of 1.4–1.5 T. The measured Ms for all as-spun ribbons are summarized in Table 1.
because of the accompanying increase in Fe content [18].

The XRD patterns of the Fe\(_{95-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 11, 12, 13) and Fe\(_{87-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 6, 8, 10) as-spun ribbons.

Hysteresis loops of the as-spun Fe\(_{95-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 11, 12, 13) and Fe\(_{87-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 6, 8, 10).

Table 1. Summary of density (\(\rho\)), saturation magnetization (\(M_s\)) of the Fe\(_{95-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 11, 12, 13) and Fe\(_{87-x}\)Si\(_x\)B\(_x\)Nb\(_3\)Cu\(_1\) (x = 6, 8, 10) alloys.

| Alloy             | \(\rho\) (g/cm\(^3\)) | \(M_s\) (emu/g) | \(M_s\) (T) |
|-------------------|-------------------------|----------------|-------------|
| Fe\(_{84}\)Si\(_1\)B\(_{11}\)Nb\(_3\)Cu\(_1\) | 7.41                    | 165.4          | 1.54        |
| Fe\(_{83}\)Si\(_1\)B\(_{12}\)Nb\(_3\)Cu\(_1\) | 7.38                    | 163.5          | 1.52        |
| Fe\(_{82}\)Si\(_1\)B\(_{13}\)Nb\(_3\)Cu\(_1\) | 7.34                    | 163.5          | 1.51        |
| Fe\(_{81}\)Si\(_1\)B\(_{14}\)Nb\(_3\)Cu\(_1\) | 7.03                    | 175.3          | 1.55        |
| Fe\(_{79}\)Si\(_1\)B\(_{15}\)Nb\(_3\)Cu\(_1\) | 6.86                    | 172.4          | 1.49        |
| Fe\(_{77}\)Si\(_1\)B\(_{16}\)Nb\(_3\)Cu\(_1\) | 6.69                    | 166.7          | 1.40        |

As can be seen in Table 1, with decrease in the Si or B content, the values of \(M_s\) increase mainly because of the accompanying increase in Fe content [18].
For the optimum conditions of formation, the dependence of the onset crystallization on temperature and Cu content is noteworthy [19]. It was determined by DSC. The DSC curves, which indicate the crystallization behavior of the amorphous ribbons with different B or Si content, are shown in Figure 3a,b and compared with Finemet as a reference (placed on top of both Figure 3a,b with composition of Fe73.5Si13.5B5Nb3Cu1). The exothermic peaks are observed for all ribbons, which suggest the crystallization reaction of the as-spun alloys. The $T_x$ values are increased from 394 to 422 °C and from 425 to 475 °C along with an increase in the B content from 11 to 13 at.% and the Si content from 6 to 10 at.%, respectively. For the Fe-based amorphous alloys that are mostly intended for the soft magnetic applications, the first crystalline phase precipitating at the lowest temperature is likely to be $\alpha$-iron, which dominantly contributes to the high magnetization. Therefore, for commercial nanocrystalline alloys, the suitable $T_a$ is usually in the range between the end of the first crystallization and the start of the second crystallization to effectively control the volume fraction, precipitate size, and distribution of the $\alpha$-iron [20]. Based on the acquired $T_x$ values, the annealing temperatures ($T_a$) were determined. For obtaining the nanocrystalline state, each as-spun ribbon was annealed under argon atmosphere at various $T_a$ covering a wide range. Four different annealing temperatures for each alloy were applied: the lowest $T_a$ is near the onset temperature $T_x$ with three more annealing conditions of higher temperature [19]. The values of $T_a$ and $T_x$ are listed in Table 2.

![Figure 3](image1.jpg)

**Figure 3.** The DSC patterns of (a) the Fe$_{95-x}$Si$_x$B$_3$Nb$_3$Cu$_1$ ($x = 11, 12, 13$) and (b) the Fe$_{97-x}$Si$_x$B$_9$Nb$_3$Cu$_1$ ($x = 6, 8, 10$) as-spun ribbons with Finemet ($x = 13.5, y = 9$).

**Table 2.** Crystallization temperature ($T_x$), annealing temperature, and compositions of the Fe$_{95-x}$Si$_x$B$_3$Nb$_3$Cu$_1$ ($x = 11, 12, 13$) and Fe$_{97-x}$Si$_x$B$_9$Nb$_3$Cu$_1$ ($x = 6, 8, 10$).

| Composition (at.%) Fe$_{96-x}$Si$_x$B$_y$Nb$_3$Cu$_1$ | $T_x$ (°C) | Annealing Temperature (°C), 1 h |
|-------------------------------------------------|-----------|---------------------------------|
| $x = 1, y = 11$                                 | 394       | 395 445 495 545 545            |
| $x = 1, y = 12$                                 | 406       | 410 460 510 560                |
| $x = 1, y = 13$                                 | 422       | 420 470 520 570                |
| $x = 6, y = 9$                                  | 425       | 425 475 525 575               |
| $x = 8, y = 9$                                  | 452       | 450 450 550 600               |
| $x = 10, y = 9$                                 | 475       | 480 530 580 630               |

After cooling down to room temperature, the annealed ribbons were measured again by VSM. Figure 4 depicts the hysteresis loops for the Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$ alloy, for their as-spun state and after annealing treatment at 395, 445, 495 and 545 °C for 60 min. The Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$ alloy has been selected since this alloy shows the highest values of $M_s$ among the annealed alloys with different element atomic ratio. In addition, Figure 5a,b shows the variation of $M_s$ and $H_c$ of the Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$ along with $T_a$. The graphs show the trend that the tendencies of $M_s$ and $H_c$ are opposite. As can be seen in Figure 5, there is a correlation between $M_s$ and $T_a$. $M_s$ considerably increased with an increase
of $T_a$. Furthermore, $M_s$ decreased at $T_a = 445 \, ^\circ C$, then reached the maximum value of 2.06 T at 545 \, ^\circ C$. Based on the DSC patterns in Figure 3, we propose that structural reordering, eventually leading to crystallization, begins at annealing temperatures of around 394 \, ^\circ C. The alloy becomes magnetically harder after annealing in the temperature range between 395 and 445 \, ^\circ C compared with either its relaxed amorphous state or the nanostructured state after crystallization [21].

Due to the precipitation, $H_s$ would act as pinning centers for the domain wall displacements, thereby increasing $H_c$ [22]. Through the annealing treatment, the residual stress was removed, and it resulted in the structural relaxation. Harder after annealing in the temperature range between 395 and 445 \, ^\circ C compared with either its

For Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$, $T_a = 545 \, ^\circ C$, the $M_s$ is 2.06 T, which is the highest value of all the considered alloys. Moreover, the lowest $H_s$ measured at 1 kHz is 114.52 A/m when $T_a = 545 \, ^\circ C$ at which the highest $M_s$ is exhibited. The highest $H_c$ measured at a 1 kHz is 301.88 A/m at $T_a = 445 \, ^\circ C$. This change in magnetic behavior with $T_a$ containing both Cu and Nb can be interpreted based on the report that observed similar cases [21]. The latter magnetic hardening appears to be a consequence of the appearance of Cu-enriched clusters, which form even before the $T_x$. Simultaneously with Cu precipitation, $\alpha$-Fe grains start to nucleate. Both the Cu-enriched clusters and the $\alpha$-FeSi nanocrystals would act as pinning centers for the domain wall displacements, thereby increasing $H_s$ [22]. Through the annealing treatment, the residual stress was removed, and it resulted in the structural relaxation. Therefore, the $H_c$ were considerably reduced due to the reduced free volume and the nucleated clusters [22,23]. As a result, the Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$ represented the excellent soft magnetic properties such as high $M_s$ and low $H_c$ at $T_a = 545 \, ^\circ C$. The detailed magnetic properties such as $M_s$ and $H_c$ of

![Figure 4. Hysteresis loops of the annealed Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$.](image)

![Figure 5. Variation of (a) $M_s$ and (b) $H_c$ values measured at 1, 10, and 20 kHz in the annealed ribbons of Fe$_{84}$Si$_1$B$_{11}$Nb$_3$Cu$_1$ with increasing $T_a$.](image)
the Fe₈₄Si₁₁Nb₃Cu₁ ribbons are summarized in Table 3. The annealed Fe₈₄Si₁₁Nb₃Cu₁ ribbons exhibit a very high \( M_r > 200 \text{ emu/g} \) (1.8 T) at all \( T_a \). These values are considered very high, which are higher than that of Finemet or Fe-based nanocrystalline alloys of \( \simeq 1.5 \text{ T} \) [7,13–15]. The \( H_c \) values of the annealed Fe₈₄Si₁₁Nb₃Cu₁ significantly decreased from 272.96 to 114.52 at 1 kHz, from 329.01 to 157.18 at 10 kHz, and from 357.94 to 184.83 at 20 kHz along with increasing \( T_a \).

In Figure 6, the annealing temperature dependence of \( \mu_r \) and \( P_{cv} \) of the Fe₈₄Si₁₁Nb₃Cu₁ alloy are shown. The graph shows a trend that the tendencies of \( H_c \) and \( P_{cv} \) are similar. In addition, the values of \( \mu_r \) increase with increasing \( T_a \). The smallest value of \( P_{cv} \) \( \simeq 406 \text{ mW/cm}^3 \) and the highest value of \( \mu_r \) \( \simeq 1340 \) are present in Fe₈₄Si₁₁Nb₃Cu₁ annealed at 545 °C at the f of 1 kHz. These values of \( \mu_r \) and \( P_{cv} \) are superior soft magnetic properties compared to the conventional value of Finemet (\( \mu_r \) \( \simeq 10^3 \), \( P_{cv} \) \( \simeq 300 \text{ kW/m}^3 \) at the f of 1 kHz) [14]. Annealing at a higher temperature leads to an increase in the number density of nanocrystals. However, if the \( T_a \) is as high as the second crystallization temperature, the overall properties such as \( \mu_r \) and \( P_{cv} \) deteriorate due to the formation of other compounds, for instance, iron boride phases such as Fe₃B (tetragonal structure) and Fe₂₃B₆ (fcc structure) [24]. The \( \mu_r \) and \( P_{cv} \) values of all specimens are compared in Table 4. Overall, the alloys show similar tendencies with Fe₈₄Si₁₁Nb₃Cu₁. The annealed Fe₇₉Si₁₀B₉Nb₃Cu₁ exhibits the highest \( \mu_r \), and the annealed Fe₇₀Si₁₀B₉Nb₃Cu₁ exhibits the lowest \( P_{cv} \) \( \simeq 100 \text{ mW/cm}^3 \) at the f of 1 kHz. Although there is no obvious correlation between \( P_{cv} \) and \( T_a \), the \( P_{cv} \) values of the alloys with variation of Si ratio is relatively lower than that of the alloys with variation of B ratio.

![Figure 6](image-url)  
**Figure 6.** Variation of (a) \( \mu_r \) and (b) \( P_{cv} \) values measured at 1, 10 and 20 kHz in the annealed ribbons of Fe₈₄Si₁₁Nb₃Cu₁ with increasing \( T_a \).

| Alloy               | \( T_a \) (°C) | \( M_r \) (emu/g) | \( M_s \) (T) | \( H_c \) (A/m) 1 kHz | \( H_c \) (A/m) 10 kHz | \( H_c \) (A/m) 20 kHz |
|---------------------|---------------|------------------|---------------|-----------------------|-----------------------|-----------------------|
| as-spun             |               |                  |               |                       |                       |                       |
| Fe₈₄Si₁₁Nb₃Cu₁      | 395 °C        | 209.1            | 1.95          | 272.96                | 329.01                | 357.94                |
|                     | 445 °C        | 203.0            | 1.89          | 301.88                | 368.93                | 404.38                |
|                     | 495 °C        | 214.1            | 1.99          | 207.43                | 278.92                | 318.82                |
|                     | 545 °C        | 221.3            | 2.06          | 114.52                | 157.18                | 184.83                |
Table 4. $\mu_r$ and $P_{cv}$ values of the $Fe_{95-x}Si_1B_xNb_3Cu_1$ ($x = 11, 12, 13$) and $Fe_{87-x}Si_1B_9Nb_3Cu_1$ ($x = 6, 8, 10$) according to $T_a$.

| Alloy               | $T_a$ (°C) | $\mu_r$ | $P_{cv}$ (mW/cm$^2$) |
|---------------------|------------|---------|----------------------|
|                     | 1 (kHz)    | 10      | 20                   | 1       | 10      | 20                   |
| $Fe_{84}Si_1B_{11}Nb_3Cu_1$ | 395 | 650.0   | 645.99              | 645.21  | 519.32  | 5920.7               | 12,820 |
|                     | 445 | 885.5   | 850.67              | 851.63  | 702.14  | 8527.9               | 18,890 |
|                     | 495 | 1025.7  | 1024.40             | 1025.2  | 532.2   | 7166.7               | 16,530 |
|                     | 545 | 1347.2  | 1340.60             | 1344.9  | 406.18  | 5846.5               | 13,120 |
| $Fe_{83}Si_1B_{12}Nb_3Cu_1$ | 410 | 768.2   | 752.59              | 748.36  | 1012.8  | 10,900               | 22,680 |
|                     | 460 | 917.7   | 915.59              | 916.2   | 631.01  | 7970.1               | 17,890 |
|                     | 510 | 1014.8  | 1014.20             | 1017.4  | 761.18  | 9636.9               | 21,780 |
|                     | 560 | 1302.7  | 1299.40             | 1302.4  | 246.83  | 7175.9               | 9273.9 |
| $Fe_{82}Si_1B_{13}Nb_3Cu_1$ | 420 | 914.1   | 907.56              | 905.83  | 733.91  | 8639.4               | 19,130 |
|                     | 470 | 741.0   | 736.20              | 735.99  | 707.47  | 8142.7               | 17,600 |
|                     | 520 | 1030.2  | 1021.40             | 1017.6  | 542.97  | 7193.8               | 16,280 |
|                     | 570 | 1347.2  | 1340.60             | 1344.9  | 406.18  | 5846.5               | 13,120 |
| $Fe_{81}Si_1B_9Nb_3Cu_1$ | 425 | 658.9   | 655.32              | 656.33  | 226.53  | 3027.5               | 7110.6 |
|                     | 475 | 758.1   | 754.24              | 756.5   | 240.97  | 3523.6               | 8359 |
|                     | 525 | 812.6   | 810.18              | 812.94  | 281.05  | 3864.1               | 9154.5 |
|                     | 575 | 887.5   | 885.09              | 889.47  | 200.91  | 3475.5               | 8684.9 |
| $Fe_{79}Si_1B_10Nb_3Cu_1$ | 450 | 780.0   | 775.56              | 777.49  | 72.164  | 1819.9               | 4913.1 |
|                     | 500 | 882.3   | 880.42              | 883.41  | 125.85  | 3039.3               | 8035.8 |
|                     | 550 | 1068.2  | 1069.00             | 1074.8  | 94.186  | 2482.6               | 6899.5 |
|                     | 600 | 915.5   | 913.35              | 917.54  | 100.42  | 2176.3               | 5906.9 |
| $Fe_{77}Si_1B_9Nb_3Cu_1$ | 480 | 792.6   | 791.90              | 792.9   | 76.789  | 1921.8               | 5130.5 |
|                     | 530 | 901.2   | 902.98              | 907.13  | 76.215  | 1872.4               | 5099.9 |
|                     | 580 | 1061.4  | 1058.60             | 1062.4  | 141.42  | 3418.4               | 8784.9 |
|                     | 630 | 1091.1  | 1089.10             | 1094.7  | 321.02  | 4714.4               | 11,250 |

4. Conclusions

In this study, soft magnetic properties of $Fe_{95-x}Si_1B_xNb_3Cu_1$ ($x = 11, 12, 13$) and $Fe_{87-x}Si_1B_9Nb_3Cu_1$ ($x = 6, 8, 10$) alloys were investigated by tailoring B or Si content ratio. All alloys were annealed at the various $T_a$ in order to achieve the precipitation of nanocrystalline $\alpha$-Fe phase and to optimize the soft magnetic properties.

The X-ray diffraction patterns of the as-spun alloys with variation of Si and B content reveal an amorphous structure except for $Fe_{81}Si_1B_9Nb_3Cu_1$ and $Fe_{79}Si_1B_9Nb_3Cu_1$, which are partially crystalline. As-spun $Fe_{95-x}Si_1B_xNb_3Cu_1$ ($x = 11, 12, 13$) alloys can maintain amorphous phase because of the high glass-forming ability of B.

In addition, the values of $M_s$, $H_c$, $\mu_r$ and $P_{cv}$ were investigated. Annealed $Fe_{84}Si_1B_{11}Nb_3Cu_1$ exhibits excellent $M_s$ values above 1.8 T at the various annealing temperatures, $T_a$ and when the $T_a$ is 545 °C, the $M_s$ value reaches maximum of about 2 T, which is higher than that of Finemet or Fe-based nanocrystalline alloys of about 1.5 T with the low $H_c$ value less than 120 A/m. Moreover, the values of $\mu_r$ and $P_{cv}$ are superior soft magnetic properties compared to the conventional value of Finemet.

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