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24-CHROMIUM FERRITIC STEEL MAGNETIC PROPERTIES

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ABSTRACT

24-CHROMIUM FERRITIC STEEL MAGNETIC PROPERTIES. A 24-chromium ferritic stainless steel had been made by foundry methods. The purpose of this investigation is to investigate the magnetic behavior of this ferritic sample, as one of the divvy of its characteristics. Some of supporting data used to prove that the material sample was ferritic type and followed by hysteresis curve obtained from the experiment. By Vibrating Sample Magnetometer (VSM) equipment, it is found that the ferritic steel has the saturation induction around of 150 emu g^{-1}, with the coercive force H_c is close to 3 x 10^{-4} T and the remanent induction B_r is close to 1.1 x 10^{-3} emu g^{-1} meanwhile by permagraph equipment the saturation induction around of 3.13 kG, and the coercive force H_{cB} is equal to 0.005 kOe and the remanent induction B_r is 0.23 kG with the dissipasion energy BH_{max} zero, explains that the ferritic stainless steel has a relative good magnetic behavior with relative high magnetization at the relative weak external magnetic field and can be demagnetized easily, appropriate to soft magnetic materials.

Kata kunci: Ferritic, Steel, Magnetic, Remanent induction, Coercive forte

ABSTRAK

SIFAT MAGNETIK BAJA FERITIK 24-KROMIUM. Telah dibuat baja feritik 24-kromium dengan metode pengecoran. Tujuan investigasi ini untuk mengetahui perilaku magnet sampel baja feritik ini yang merupakan bagian dari karakteristik baja ini. Sebagian data dukung digunakan untuk membuktikan bahwa sampel yang digunakan adalah jenis feritik dan kurva histerisis yang diperoleh dari percobaan. Dengan alat *Vibrating Sample Magnetometer* (*VSM*), diperoleh bahwa feritik ini memiliki induksi saturasi sekitar 150 emu g^{-1}, dengan gaya koersif Hc mendekati 3 x 10^{-4} T dan induksi remanen sekitar 1,1 x 10^{-3} emu g^{-1} sedangkan dengan alat permagraf nilai induksi saturasinya sekitar 3.13 kG, dan gaya koersif H_{cB} 0.005 kOe dan induksi remanen Br 0,23 kG dengan energi desipasi BH_{max} nol menunjukkan bahwa baja feritik ini memiliki perilaku magnet yang relatif baik dengan magnetisasi yang tinggi pada medan magnet eksternal yang relatif lemah dan dapat didemagnetisasi dengan mudah, cocok untuk bahan magnet lunak.

Keywords: Feritik, Baja, Magnetik, Induksi Saturasi, Gaya koersif

INTRODUCTION

A 24-chromium ferritic stainless steel had been made by foundry methods utilizing the local mining products as starting materials [1-3]. The purpose of the ferritic sample synthesis is to investigate magnetic behavior of very high chromium ferritic steel and the potential used for many applications [4]. High chromium content of ferritic steel is proposed because of its high corrosion resistant characteristic in various corrosive environment. According to magnetic behavior classification, ferritic stainless steels are classified as ferromagnetic and because they are easy to magnetize and demagnetize, they are called soft magnetic materials [5]. They have been used as soft magnetic components in such devices as electromagnets, transformer, inductor cores operating up to high a.c. frequencies, pole pieces and return paths. Although their magnetic properties are not generally as good as conventional soft magnetic alloys, they are successfully used for magnetic

Tabel 1. Chemical composition of the sample.

Element	Cr	Mn	Si	C	Ti	Al	P	S
Quantity(%)	23.711	0.821	2.02	0.258	0.006	0.007	0.022	0.014

components which must withstand corrosive environments. As such, they offer a cost-effective alternative to plated iron and silicon-iron components. In addition, the relatively high electrical resistivity of ferritic stainless steels has resulted in superior AC performance. The ferritic stainless steels have soft magnetic properties: high magnetic permeability, low coercive force H_c, and low residual induction Br, which depend on alloy chemistry [5, 6]. In particular, impurities such as carbon, sulfur, and non-metallic inclusions, and stresses are present in the material because of cold working; with increasing amounts of impurities and stress, the magnetic permeability decreases and the coercive force H_c increases, so the behavior is less magnetically soft. Hence, optimum magnetic performance is obtained with high-purity alloys and well-annealed [7, 8]. When heated, ferromagnetic materials become paramagnetic at a temperature known as the (ferromagnetic) Curie point [9]. So it can be said that in many ferromagnetic materials the magnetic properties depend greatly on the effect of impurity, previous history state of strain, size, perfection and orientation of crystals, and temperature [3, 8, 9, 10]. The condition of the sample composition according to the measurement result by Optical Emission Spectroscopy (OES) methods in Bandung Manufacture Poly-technique [1] is tabulated in Table-1.

THEORETICAL BACKGROUND

When a material is in a magnetic field H^i with the magnetization (or dipole moment per unit volume) M^i, the magnetic induction in the material B^i is given by

$$B^i = \mu_o(H^i + M^i) = \mu_o\mu_r H^i = \mu H^i \quad \text{.................... (1)}$$

where $\mu_o = 4\pi \times 10^{-7} \frac{\text{T m}}{\text{A}}$ is free space permeability, μ_r is the material relative permeability (= 1 for vacuum), a dimensionless quantity, and the *i* superscript is vectors contravariant index. The relative permeability is a measure of the intensity of the induced magnetic field. Hence

$$\mu_r = 1 + \frac{M^i}{H^i} = 1 + \chi \quad \text{.............................. (2)}$$

where χ is magnetic susceptibility. H^i, M^i and B^i are vectors; the unit of B^i is tesla or $\frac{\text{weber}}{\text{m}^2}$, while H^i and M^i have the same units of $\frac{\text{A}}{\text{m}}$. To guarantee the validity of equation (1), it is more save if the relation formula in equation (1) is written in the form of

$$B^i = \mu^{ij} H_j \quad \text{... (3)}$$

where now the material permeability is in the tensor form, to hold if the magnetic induction (B^i) direction is different from the external magnetic (H_j) direction, where j-subscript in H_j magnitude is covariance index. This is particularly in connection with the magnetic domain and the magnetic domain wall which can turn the magnetic induction direction.

The energy is dissipated when the hysteresis loop is traversed in the counterclockwise direction and the work done by the loop area

$$P = \frac{1}{\mu_o} \oint \vec{H}.d\vec{B} \quad \text{.. (4)}$$

and the loop integral values in equation (4) is proportional to the area found within the B-H hysteresis curve.

EXPERIMENT

This section explains about the procedure of material measurement by vibrating sample magnetometer in the ferritic sample magnetic properties investigation in the laboratory; the explanation involving other measurement data, including the micro structure and the X-ray diffraction data which were carried out before was reported elsewhere [1].

Sample preparation

First the ferritic stainless steel bulk was sliced into several thin pieces of steel by a disc blade apparatus. Then the thin pieces of steel were again cut into smaller slices, but this time perpendicular to the first slice in such a manner that now the maximum areal dimension of around 2 x 2 mm^2 was obtained. Finally the samples were weighed in a high-precission balance scales and the samples mass was found to be equal or less than 60 mg; but it is better if the mass is around of 40 mg. The final form of the sample is cubic grain with the 1 x 1 mm^3 size and around of 60 mg maximum weight.

Hysteresis Measurement

The instrument employed in the hysteresis measurement is the Vibrating Sample Magnetometer (VSM), manufactured by the German Oxford Enterprise Co.

A piece of steel sample with the specified mass and dimension mentioned above was inserted into the VSM sample holder and the measurement was then carried out at the following measurement conditions, the measurement temperature is 296 K, the vibration frequency was 55 Hz, with an external magnetic field varied in the range of 0 – 1 T. The result is plotted to be BH hysteresis curve.

Another hysteresis measurement was carried out by the permagraph equipment in the Electronics and Telecommunication Research Center, Indonesian Science Institute (PPET-LIPI) in Bandung

RESULT AND DISCUSSION

In order to confirm that the synthesized 24-chromium ferritic stainless steel sample is of the ferritic type, first the sample optical microgram will be shown followed by the x-ray diffraction patterns. The sample microgram with the magnification of 100 is shown in Figure 1, and depicts the ferritic type material grains, where the grain boundaries are found to consist of irregular spasmodic arch path fragments and this is the typical ferritic type material grain boundaries. Meanwhile it is common knowledge that the austenitic type grain boundaries consist of straight line fragments.

The X-ray intensity pattern of the sample was recorded with an automated Shimadzu X-ray difractometer using Cu Kα radiation by measuring the diffraction angle (2θ) between 40° and 120° using the step-scan method with an increment of 0.05° with the time counting 10 seconds. It is easily observed from the X-ray patterns that the characteristic signature peaks, i.e. 110, 200, 211, 220, 310, are clearly identifiable in the samples as shown in Figure 1. These diffraction peaks of the foundry synthesized F1 ferritic steel are in excellent agreement with those reported in literature therefore confirms the BCC model of the sample's crystal structure and immediately confirms the ferritic characteristic structure of the sample.

The measurement result from VSM equipment is shown in Figure 3, that depicts the the ferritic stainless steel B-H or hysteresis curve. In this picture the top part curve line is shown to be almost paralel to and also to overlap with the bottom part curve line. From the curve it is also visible that the value of the saturation induction reached is relative high, around of 150 emu g^{-1} that if converted [11], it is equal to around 1.5 T at magnetic field H^i strength of around of 1 Am^{-1}. Therefore by

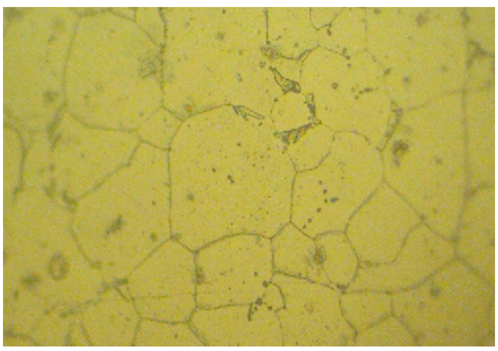

Figure 1. The 24-chromium ferritic type stainless steel micro structure, 100 x magnification

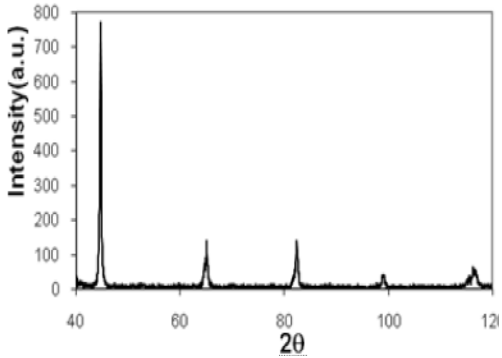

Figure 2. X-ray diffraction pattern of the 24-chromium ferritic type stainless steel

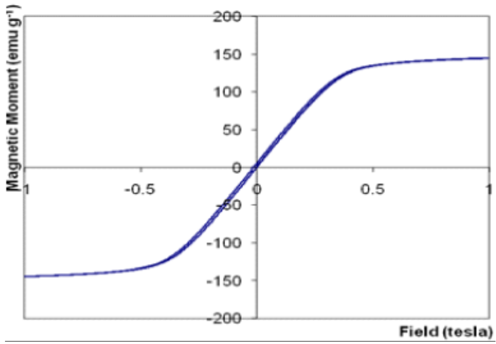

Figure 3. Hysteresis curve of the 24-chromium ferritic stainless steel found by VSM equipment

equation (1) and the conversion factor it could be calculated that the material's relative permeability μ_r is 11.9366 x 10^5 $m^3 kg^{-1}$, meanwhile the material's magnetic suseptibility χ is around minus one as estimated from this value. From the curve it is also visible that the *coercive force* H_c is close to the origin point, as is the *remanent induction*, B_r, and from the experiment data value both . of the coercive force $H_c \cong -3 \times 10^{-4}$ T and the remanent induction value $B_r \cong 1.1 \times 10^{-3}$ emu g^{-1} respectively. These results also can be looked at Table 2, where the units were converted to Gauss (G) and Oerstedt (Oe), and it could be said that both of the coercive force H_c and the remanent induction value B_r respectively are very small. From this point of view it could be immediately corroborated that the area bounded by the curve lines is very thin or very small, and is almost invisible, so that the work done by the loop integral which is related to the dissipation energy is also practically close to zero, and this result is suittable with the result of permagraph measurements (Table 3) where the value of BH_{max} is equal to zero (0 MGOe). Therefore from this point of view it could be argued that the ferritic stainless steel sample is both easily magnetizable and demagnetizable in a relatively weak external magnetic field.

Table 2. Parameter values from VSM measurement result

B_r (kG)	H_{cB} (μOe)	H_{max} (kOe)	χ(k emu g^{-1} Oe^{-1})
0.11	3.8	0.00004	95

Meanwhile, the B-H curve from permagraph measurement result is shown in Figure 4. The red curve is external magnetic used, meanwhile the blue one is the internal respons induction from material (sample). Beside this curve it is also attached the some parameters values of the measurement as shown in Table 2 meanwhile Table 3 below shows the magnetic field strength (H) versus the magnetic polarization (J), and averagely it is appear that the curve is very thin and it is consistent with the that of VSM measurement result and the Table 3 and Table 4 elucidate this.

From Table 3 can be looked that the remanen induction magnet B_r is equal to 0.23 kG, a relative small value, and the induction coercivitas force (H_{cB}) is equal to 0.005 kOe, meanwhile the polarization coercivitas force (H_{cJ}) is equal to 0.007 kOe, the value that is very small. Meanwhile another magnitude parameters can be looked from Table 2; here B_a symbol is the magnetic flux, meanwhile the H_a symbol is the field strong at the maximum dessipation energy.

From Table 4 also can be looked that the magnetic polarization component (J) is equal to zero, and it is mean that there is no polarization contribution to the material magnetic respons.

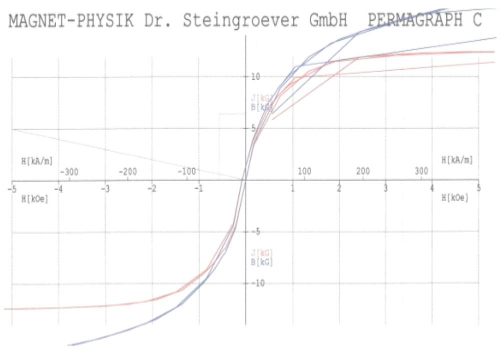

Figure 4. Hysteresis curve of the 24-chromium ferritic stainless steel by permagraph measurements. The red curve is external magnetic, meanwhile the blue one is the internal respons induction

Table 3. Parameters values from the permagraph measurement result

1	2	3	4
B_r (kG)	H_{cB} (kOe)	H_{cJ} (kOe)	BH_{max} (MGOe)
0.23	0.005	0.007	0.00

5	6	7
Ha (kOe)	Ba(kG)	H_{max} (kOe)
0.560	3.13	14.065

Table 4. H-J measurements result values, where J is the magnetic polarization

H (kOe)	-20	-40	-60	-80	-100	-120	-140
J (kG)	0.0	0.0	0.0	0.0	0.00	0.00	0.0

Table 5. Some H_c value of standard feritic stainless steels

No.	Materials	Coersive Force, Hc	
		Oe	A m^{-1}
1	AISI-430F	2	160
2	AISI-430FR	2	160
3	AISI-446	4.5	360
4	24-chromium ferritic SS sample (VSM)	0.4	32
5	24-chromium ferritic SS sapmle (Permagraph)	5	400

Especially for coersive force H_c, this parameter can be compared to the literatur for some data of standard ferritic stainless steels [12] that can be looked at Table-5 below. Due to lack of data, another magnetic parameter magnitudes as well as B_r not found yet. So from Table-5, it is found that the coersive force magnitude of the 24-chromium ferritic stainless steels is still has small value close to the some standard ferritic materials, and has better value for measurement with VSM instrument.

Although the sampel form in experiment by VSM and the permagraph is different, but the curve form that is very thin resulted by both of experiment is still consistent, with relative high magnetic moment; both of experiment results show that the energy dissipation is very small close to zero, so that the material magnetic properties is suitable to soft magnetic properties.

CONCLUSION

From the experimental results and the discussion above it can be concluded that the the 24-chromium ferritic stainless steel has a relative good soft magnetic properties; it can become very strongly magnetized in a relative weak external field and simultaneously could also easily be demagnetized, and by the very thin curve form, it is mean that the energy dissipation is very small, close to zero. The measurement from both apparatus, VSM and also permagraph gives the consistence results. Conclusively, this material is appropriate to be used as a soft magnetic material and hence it can be used as a substitute for conventional soft magnetic materials.

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