**Tsugunori KANADA[1], Yukihito KIDO[1], Akifumi KUTSUKAKE[1], Tetsu IKEDA[1], Masato ENOKIZONO[2]**

Oita Prefectural Organization for Industry Creation (1), Oita University (2)

# Magnetic properties of soft magnetic materials under tensile and compressive stress

***Abstract**. The measurement is carried under the tensile and compressive stresses on non-oriented electrical steel sheets and amorphous sheet, 100×500mm. They are measured by stress load type SST. The results of magnetic power loss and magnetization curve on NO steel sheet in case of no stress, tensile stress 15MPa and compressive stress 15MPa are shown. It is clear that the effect of tensile stress is not so remarkable, though compressive stress affects the magnetic properties greatly. Three types of amorphous sheet, as cast, annealed and annealed in magnetic field were measured.*

***Streszczenie.** Przeprowadzono badania wpływu naprężeń na właściwości b lach niezorientowanych SiFe oraz amorficznych. Wykorzystano urządzenie typu SST – próbka miała rozmiary 100 x 500 mm. Badano straty mocy i krzywą magnesowania. (**Właściwości magnetyczne materiałów magnetycznie miękkich poddanych naprężeniom**)*

**Keywords:** tensile and compressive stress, SST, iron loss and magnetization curve
Słowa kluczowe: naprężenia mechaniczne, materiały magnetycznie miękkie.

## Introduction

It is important to know the magnetic properties under applied stresses, because the building factor (the ratio between the properties of the constructed material which is affected by the stress and original one) should be considered. In this case, a single sheet tester (SST) type is convenient and conventional as one of the measurement devices. For the measurement of the field strength, one method is to measure the magnetizing current from the shunt resistor, as it is made with the Epstein tester, and another method is to measure it directly by using the H-coil [1]. The magnetizing current method is simple and comparatively easy but the effective magnetic path should be considered. Contrary in case of the H-coil method, the precise magnetic field is obtained but the measurement system is complicated. In this paper we present the results of the studies of the material properties using the H coil method.

## Stress load type SST and materials

The measurement is carried under the tensile and compressive stresses on NO (non-oriented) electrical steel sheets and amorphous sheet. The NO sheet has the dimensions of 100×500×0.35 mm and the amorphous sheet has 100×500×0.024 mm. About NO steel sheet, L (RD) specimen of the sheet was measured. The three types of amorphous materials; as cast, annealed, and annealed in a magnetic field are investigated, too. All specimens measured are shown in Table.1. They are measured by the stress load type SST. This is manufactured according to a fundamental structure regulated in Japanese Industrial Standard, JIS C 2556 [1], and in addition it has a tensile and compressive stress application function. This is composed of a yoke unit, a coil unit, a stress load unit, and others. The picture is shown in Fig.1. And the dimensions of the coil unit and the yoke unit are shown in Fig.2. This is known as a vertical double yoke type.

The cut model of coil unit which is composed of a B coil, two H coils, and an excitation coil is shown in Fig. 3. The exciting coil is composed of PPS (polyphenylene sulfide) frame and PAI (polyamide) copper wire( $\phi$ 0.8 mm) which is wound in six layers(485 turns per layer). The B coil is composed of PPS frame and UEW (polyurethane) copper wire ( $\phi$ 0.1 mm) which is wound 20 turns in one layer. The H coil is composed of glass epoxy frame : 90 mm×140 mm×1 mm and UEW cupper wire ( $\phi$ 0.04 mm) which is wound 1666 turns in one layer.

The measurement is carried out at the center part (100 mm length) of the specimen. It has a uniform magnetic field strength distribution.

The measurement conditions are as follows. The exciting frequency is 50 Hz. The measured magnetic flux density amplitude with uncertainty lower than 0.05 % and sinusoidal waveform within 0.5% in relation to standard value. The measurement is carried out from 0.1 to 1.7 T every 0.1 T in order to keep the conditions.

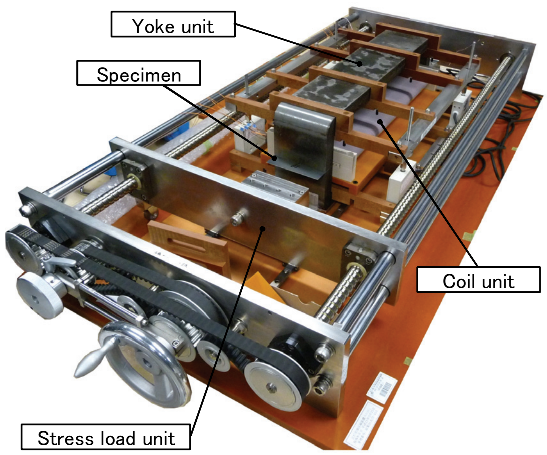



Fig.1. Photograph of stress load type SST (100 mm type). A stress is applied by moving the stress load unit plate back and forth using the manual handle shown at the front side

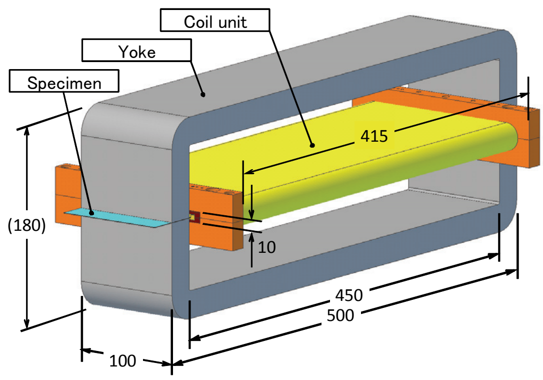



Fig.2. Dimension of coil unit and yoke unit (mm). The yoke is made of oriented electomagnetic steel sheet,23ZDKH90 which has high peameabilty and low iron loss

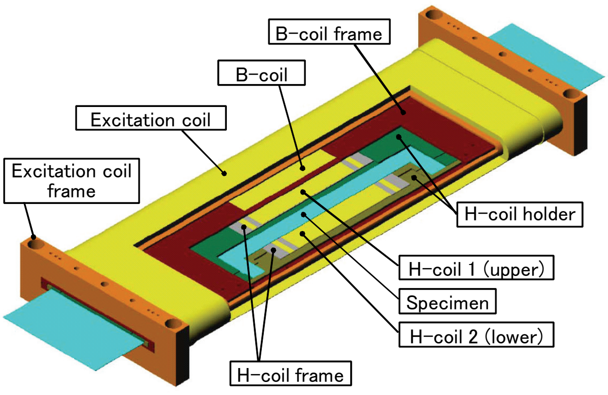



Fig.3 Cut model of the coil unit and frame

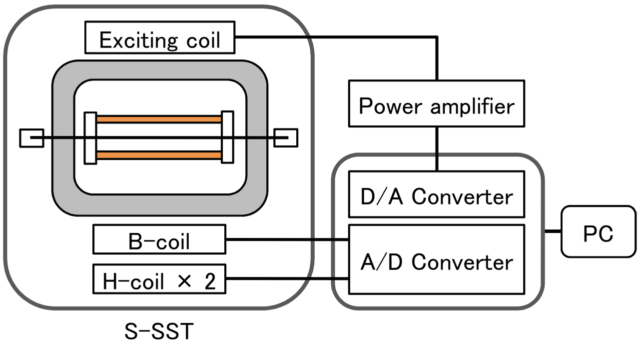



Fig.4 Stress load type SST measurement system

Table.1 Measured specimen

| specimen | Dimensions(mm) | specification |
|---|---|---|
| No-oriented | 100×500×0.35 | L(RD) |
| Amorphous | 100×500×0.024 | As cast, Annealed, Annealed in magnetic field |

**H coil**

H coil should be considered on the design and related materials. As the winding frame, three materials, ceramic (silicon nitride), glass epoxy resin and Bakelite were compared concerning price, strength and coefficient of thermal expansion. Finally, glass epoxy is selected as the optimum.

One H coil is placed on the upper side and one on the lower side of the specimen sheet respectively. Both are placed as near as possible to the sheet.
The applied field strength is decided as the average of the two shown as below.

(1) $$H_{Hcoil} = (H_1+H_2)/2 \text{ (A/m)}$$

Here, $H_1$ is the field strength of the upper coil and $H_2$ is the one of the lower coil (Fig.2). H coil 1 has the area-turn of 0.16642 ($m^2$・turn), and H coil 2 has 0.16020 ($m^2$・turn).

**Experimental results on NO steel sheet(L type)**

The tensile and compressive type SST is developed in our laboratory. This SST is applied for the specimen and amorphous specimen. The SST is composed of a coil unit, a yoke unit and a tensile and compressive unit. The results of iron loss and magnetization curve in case of no stress, tensile stress 15MPa and compressive stress 15MPa are shown in Fig.1 - Fig.4.

From the Figs, it is clear that both the tension and the compression deteriorate the magnetic properties. The effect of tensile stress is not so remarkable, though the compressive stress affects the magnetic property greatly as shown. In another measurement on C (TD) specimen, we have observed that tensile stress of 10 MPa causes an increase in magnetization whilst compression remains unchanged. It is known that a tensile stress induces a decrease of magnetization once but then increases with increased stress magnitude [2, 3].

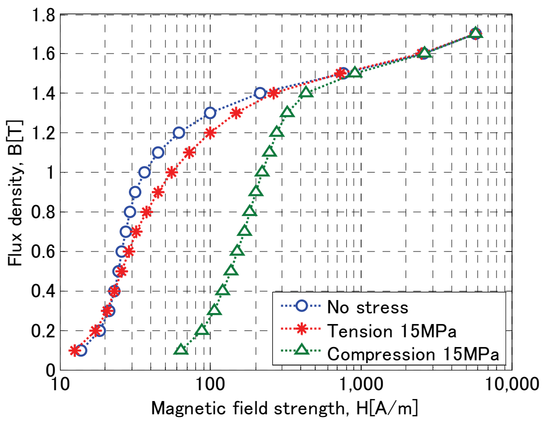



Fig.5 Magnetization of NO steel sheet under tensile and compressive stress

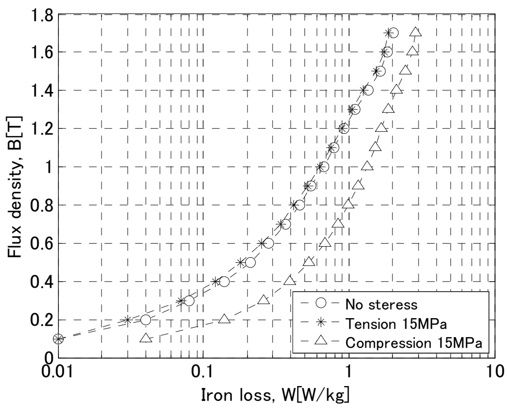



Fig.6 Iron loss of NO steel sheet under tensile and compressive stress

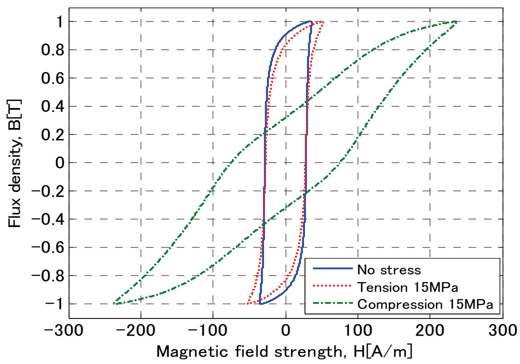



Fig.7 B-H curve of NO steel sheet under tensile and compressive stress (1.0T)

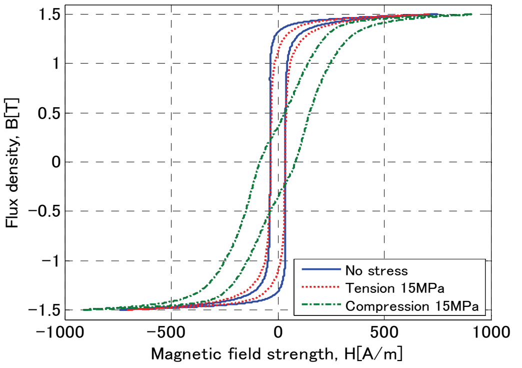


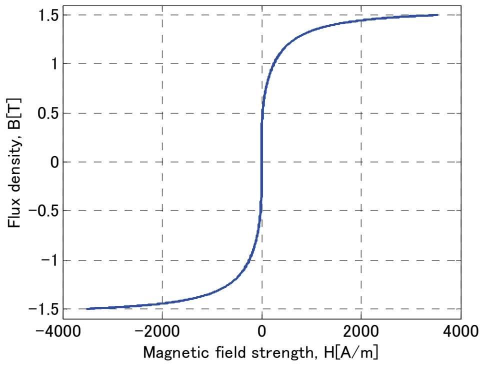

Fig.8 B-H curve of NO steel sheet under tensile and compressive stress (1.5T)

**Experimental results on amorphous sheet**

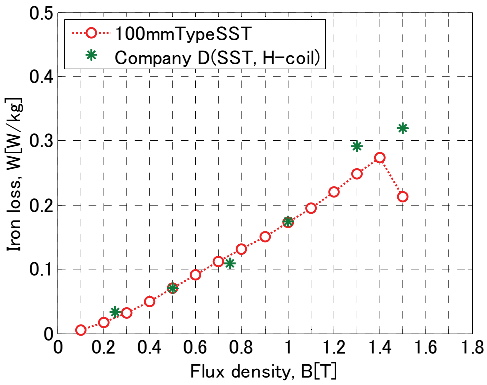
The amorphous sheet types, as cast, annealed and annealed in a magnetic field were measured using the same system for the NO-oriented sheet.The results are shown in Fig.9,10,11.

In comparison of B-H curve of Fig.9(a), Fig.10(a) Fig.11(a), It is clear that the magnetization increases more abruptly from Fig.9 (a) to Fig.11(a) by looking at the horizontal axis. Especially remarkable is the annealing effect in magnetic field.

As shown in Flux density vs. Iron loss curve, the iron loss decreases from Fig.9(b) to Fig.11(b) reflecting their magnetization curve. They are summarized in Fig.12 (a),(b). So the specimen annealed in the magnetic field has the least loss.

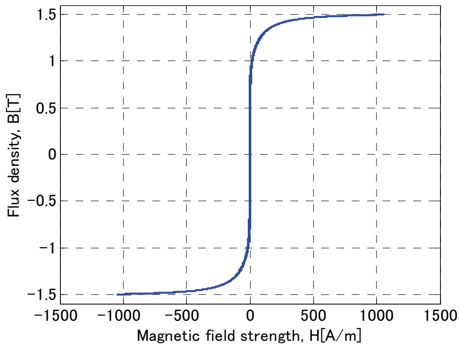



(a)B-H curve

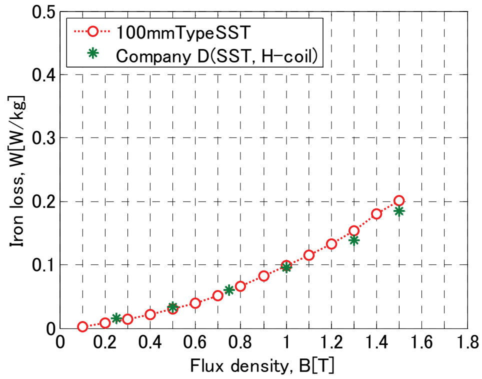



(b)Flux density vs. Iron loss

Fig.9 Amorphous specimen(as cast)

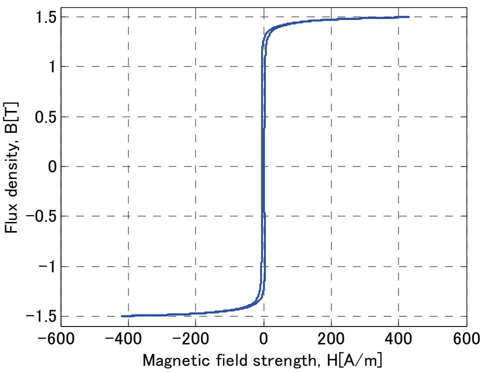



(a)B-H curve

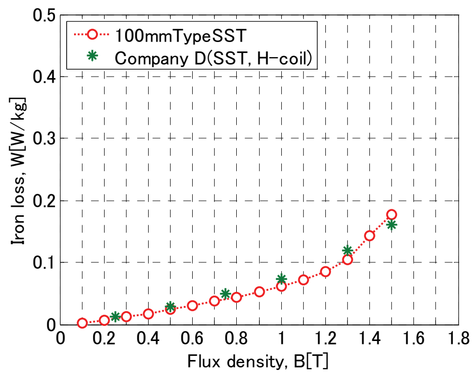



(b)B-H curve

Fig. 10 Amorphous specimen(annealed)

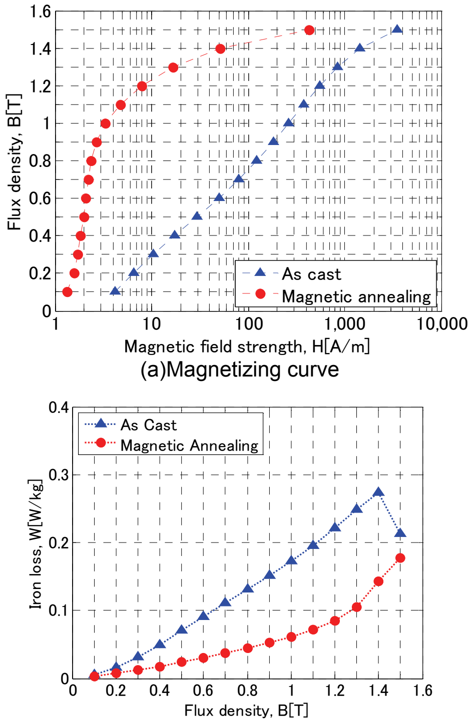



(a)B-H curve




(b)Flux density vs. Iron loss

Fig.11 Amorphous specimen(annealed in magnetic field)



(a)Magnetizing curve

(b)Iron loss

Fig.12 Comparison of as cast and magnetic annealing of amorphous specimen

The curves are shown together with commercial company data for reference. Mostly they show a similar curve. But in the case of Fig.9 (b), the cast specimen, in the high flux density range the two values separate and the measured value shows a smaller increase and sudden drop at 1.7T. It is possible that the tendency is caused by the phase difference between B and H peculiar in high flux density. This is now in consideration in relation to the difference of the impedance between the two coils. In next time, we will be able to report.

The result of the measurement under tensile stress on an amorphous specimen will be reported soon. Compression seems difficult to measure because of its thinness.

## Conclusions

・Compressive stress affects the magnetic properties of NO electrical sheet more strongly than tensile stress.

・The best magnetic properties of the amorphous specimen are realized in the case of annealing in magnetic field.

・ Magnetic power loss of as cast amorphous specimen decreases suddenly at 1.7T. The reason is under consideration.

*Acknowledgment*

*This work was supported by a grant from "Prefectural Collaboration of Regional Entities for the Advancement of Technological Excellence, JST".*

## REFERENCES

[1] Japanese Industrial Standard, Method of measurement of the magnetic properties of magnetic steel sheet and strip by means of a single sheet tester, C 2556 (1996)

[2] A. J. Moses, Effects of stress on the magnetic properties of grain-oriented silicon iron magnetized in various directions, *IEEE Trans. Mag.*, Vol.MAG-17,No.6,2872-2874(1981)

[3] A.J.Moses, Effects of Applied Stress on the Magnetic Properties of High Permeability Silicon-Iron, *IEEE Transactions on Magnetics*, Vol. 15, No. 6, pp.1575-1579, (1979)

***Author**: Tsugunori Kanada, Yukihito Kido, Akifumi Kutsukake,Tetsu Ikeda, Oita Prefectural Organization for Industry Creation, 17-20 Higashikasuga Oita 870-0037, Japan, E-mail: kanada.tugunori@topaz.plala.or.jp, Masato Enokizono, Oita university, 700 Ooaza dannoharu Oita 870-1192, Japan, E-mail:enoki@cc.oita-u.ac.jp*