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Non-Destructive Detectability of Phase Transformation and Stress-damaged State of Ferromagnetic Shape Memory Fe-Pd Alloy for Health-monitoring

Teiko Okazaki, Yasubumi Furuya, Mark Spearing* and N. W. Hagood*[1]

Faculty of Science and Technology, Hirosaki University, Hirosaki 036-8561, Japan
Fax: 81-172-39-3553, e-mail: teiko28@cc.hirosaki-u.ac.jp
*Faculty of Engineer., M I T, Boston, MA 02139-4307,USA
*[1] At present: President, Continuum Control Corp., USA

We studied that the possibility to detect the phase transformation with martensites by heating or cooling and stress-loading in ferromagnetic shape memory Fe-Pd alloy ribbons by using magnetic Barkhausen noise (BHN). BHN is caused by the irregular interactions between magnetic domain and thermally activated martensite twins during magnetization. Based on the experimental results from BHN measurements for both thermoelastic and stress-induced martensite phase transformations in Fe-Pd ribbons, BHN method seems a useful technique to non-destructive evaluation of martensite phase transformation and stress-induced internal damages of ferromagnetic shape memory alloy, which is used as the filler of our proposing " Smart Composite Board".

Keywords: Ferromagnetic shape memory alloy, Nondestructive evaluation, Barkhausen noise, Internal damage, Phase transformation

1. INTRODUCTION

The concept of design for "Smart Composite Board" which can combine the non - destructive magnetic inspection and shape recovery function in the material itself was formerly proposed by the authors [1]. In general, shape memory alloy has the feature of thermoelastic martensite phase transformation i.e., shape memory effect as well as stress-induced martensite phase transformation, where the microstructure changes from stable austenite (A) phase at higher temperature into martensite (M) phase with many twins at lower temperature or stress-loading. Magnetic Barkhausen noise (MBHN) will be caused by the pinning movements of magnetic domain walls with irregular interactions between magnetic domain and thermally activated martensite twins during magnetization of ferromagnetic alloy. Based on the background of the features of microstructure change of FSMAs and non-destructive sensing technique of MBHN[2], in the present study, as a first step to realize the concept of " Smart Composite Board ", we try to survey the possibility to detect the phase transformation with microscopic martensites twin by heating as well as stress - loading in ferromagnetic shape memory Fe-30at%Pd alloy thin foil [3],[4] by using MBHN sensor. We found that MBHN method is a useful technique for non-destructive evaluation of phase transformation and stress - induced internal damages of ferromagnetic shape memory alloy which is used as the filler of our proposing "Smart Composite Board".

2. EXPERIMENTAL PROCEDURES

BHN measurement was done at each temperature of Fe-29.6at%Pd, Fe-30.2at%Pd alloys foil (50 mm long, 5 mm wide, 70 μm thick) [5]. The testing temperature of specimen was maintained constant at BHN measurement by using the electric temperature controller. Foil type specimen was magnetized at the strength of $\pm 1.5\times10^{-2}$ Tesla through the contact-type senor by using the alternative current($\pm$2V, $\pm$1A) from the bi-polar power supply by amplifying the basic AC signals (i.e. sine wave, 3Hz) from pulse generator(NF, FG-161). The local changes of magnetic leakage flux can be detected as the induced voltage through the small pick-up sensor at the center part of contact-type sensor (i.e. permalloy head whose size is 1mm long and 0.5mm wide). The picked-up irregular voltage is amplified by x100 magnification(NF, LI-75A), then filtered (1kHz-Thru) to disappear the low frequency from magnetizing AC signal by using wide band filer(NF, FV-628A) and then the filtered BHN signals are analysed by using FFT machine(Iwatsu,SM-2701)[5].

3. RESULTS AND DISCUSSION

The detected MBHN signals are thought to consist mainly of the following three factors. One is BHN (1) from the most coarse grain boundary of Fe-Pd alloy, next, (2) from the relative coarse, lens-type martensite twins boundary of stable b.c.c structure in the grains at lower temperature, the third, (3) from the very fine, feather-type martensite twins of f.c.t structure which will cause the magnetically induced magnetostriction.

3.1 BHN power voltage and spectrum

Analysis of MBHN signals is discussed by dividing the frequency range based on the above-mentioned idea.

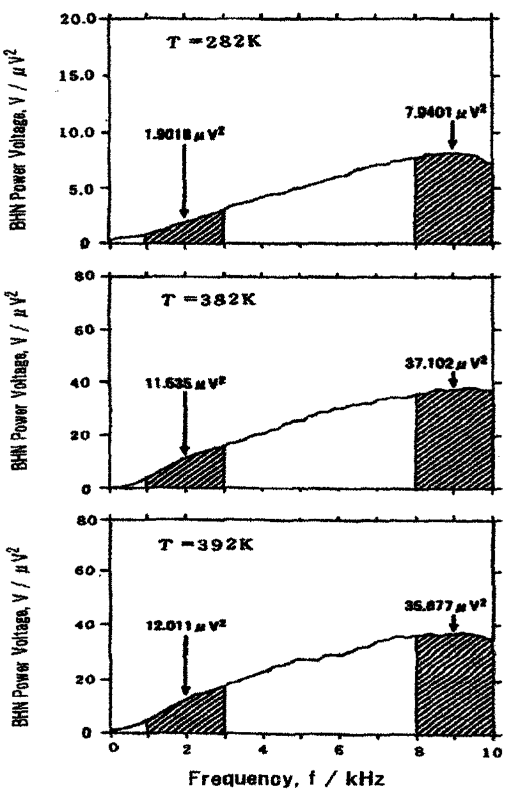

Fig.1 The measured spectrum (BHN power voltage vs. frequency) and shadowed parts mean the lower frequency MBHN range(1kHz-3kHz) and higher frequency MBHN range (8kHz-10khz) respectively.

Figure1 shows one example of the measured spectrum (BHN voltage vs. frequency) and shadowed parts mean the lower frequency MBHN range(1kHz-3kHz) and higher frequency MBHN range (8kHz-10khz) respectively.

Figure 2 shows the depencency of the normalized BHN power voltage for lower frequency range(f=1~3kHz), higher frequency range(f=8~10kHz) and the magnetostriction ε on the temperature. The vertical axis (Y-axis) means normalized BHN power voltage at the value of R.T.(273K), and horizontal axis(X-axis) means heating temperature. The BHN voltage in higher frequency range (8kHz-10kHz) increased gradually with increase of temperature from R.T.(293K) and saturated at the temperature range from 353K to 383K, and then it decreased with inceasing temperature over 383K. On the other hand, BHN voltage in lower frequency range (1kHz-3kHz) also increased more higher level, but it saturated at the temperature from 393K to 423K which is more high temperature than in the case of higher frequency range(8kHz-10kHz). The increase of BHN signals in lower frequency range(1kHz-3kHz) is thought to be resulted from the increase of intense pulse outbreaks of BHN mainly from the pinning of domain wall at each grain boundary(spacing distance: 5~10μm) of matrix Fe-Pd alloy. As for the MBHN in the intermediate frequency range(3kHz -8kHz), it seems to be resulted from pinning between considerably large, lens-type b.c.c. martensite (spacing distance:0.5-3μm) which does not disappear by heating from R.T.(273K) to 423K. The most high frequency range (8kHz-10khz) of MBHN is thought to be resulted from very fine feather-type f.c.t. martensite (spacing distance:~0.3μm) which is easy to be activated and move and finally disappears with increasing temperature from A_s (393K) to A_f(423K) point of this alloy. The tendency of the change of higher frequency MBHN is similar to that magnetostriction (ε) which seems to be related with the magnetically induced martensite twins movements [3]. The inclination of decrease of MBHN voltage above As, Af points thought to be caused by the decreasing potentiality for magnetization toward Curie point of this ferromagnetic alloy.

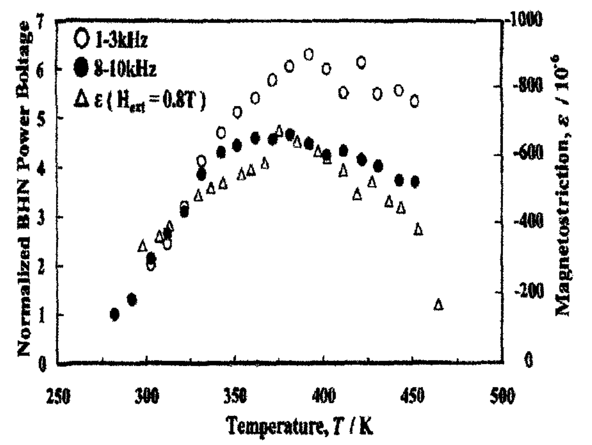

Fig.2 Dependency of the normalized BHN power voltage for lower frequency range(f=1~3kHz), higher frequency range(f=8~10kHz) and the magnetostriction of Fe-29.6at%Pd alloy on the temperature.

3.2 BHN envelop and peak voltage

Next, we pay our attention to the changes of envelop of MBHN peak voltage on the relationship between MBHN pulse and time.

Figure 3 shows the examples of the envelopes from averaged and smoothed BHN peak voltage with increasing temperature in two materials, pure iron (αFe) and ferromagnetic Fe-29.6at%Pd with martensitic transformation. In the case of Fe-29.6at%Pd alloy, two peaks on the envelop can be seen and the former peak did not change ,but, latter peak disappeared with increasing temperature, on the other hand, in pure iron, the envelop of MBHN did not change.

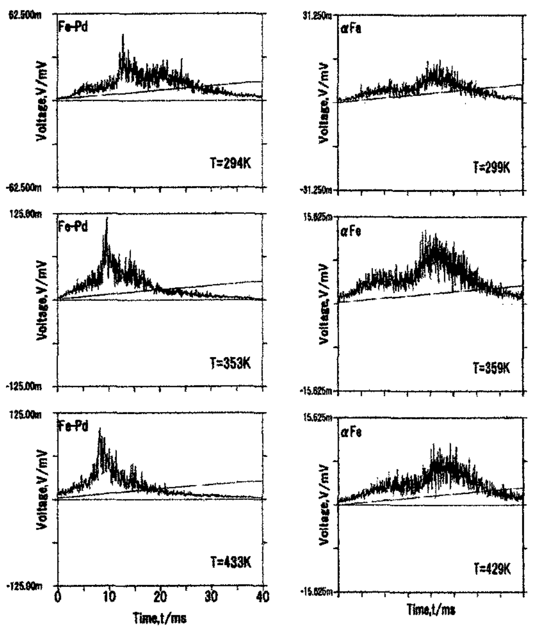

Fig. 3 The envelopes from averaged and smoothed BHN peak voltage with increasing temperature in two materials, pure iron (αFe) and ferromagnetic Fe-29.6at%Pd with martensitic transformation.

Figure 4 shows the dependency of the normalized BHN peak-voltage at maximum value during magnetization process on the temperature for Fe-29.6at%Pd, pure αFe and pure Ni. In pure iron and pure Ni with no phase transformation in this testing temperature range, MBHN scarcely changed, on the other hand, Fe-29.6at%Pd alloy

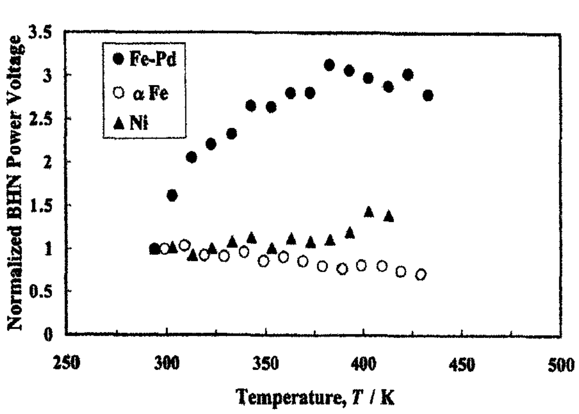

Fig. 4 Dependency of the normalized BHN peak-voltage during magnetization process on the temperature for Fe-29.6at%Pd, pure αFe and pure Ni.

showed the increase of MBHN voltage due to the intense and dynamic interactions between thermally activated martensite twins and the grains and many kinds of defects in the matrix below inverse martensite phase transformation temperature(A_f=423K) and then their MBHN voltage peaks decreased by the affect to approaching Curie points of their alloys. From this result, it can be concluded that MBHN can detect the thermoelastic martensite phase transformation of ferromagnetic Fe-29.6at%Pd alloy.

3.3 BHN changes by cyclic loadings

Martensitic transformation with formation of twin boundaries is also caused by stress-inducing mechanism instead of thermoelastic mechanism, therefore , in this study, we investigated the detectability of stress-induced martensite and internal damage after cyclic loading by using Fe-30.2at%Pd foil sample. In this alloy composition, the test specimen is in stable austenite at room temperature because its inverse transformation temperature (A_f=283 K) is below R.T.(293 K) by increasing Pd content.

Figure 5 shows the dependence of BHN power voltage on loading and unloading process. The samples were re-heated up to 90 ℃ after each test to diminish the loading history completely and to start from the same level of BHN. First, BHN voltage gradually increased with depending on increasing applied stress(σ) and then very much over σ=50MPa. After BHN peak value at σ=70-100MPa , it gradually decreased in the unloading process.

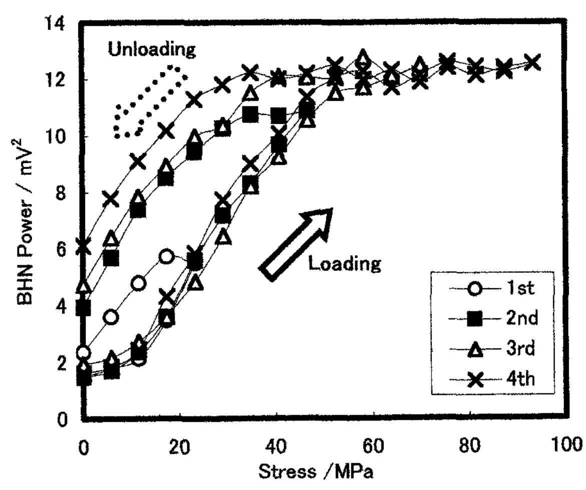

Fig. 5 Dependence of BHN power voltage of Fe-30.2at%Pd alloy on loading and unloading process in the case of diminishing the loading history completely and to start from the same level of BHN.

BHN increased monotonically with increasing loading stress and then, it decreased with unloading, however BHN showed large hysteresis between loading and unloading passes. After diminishing the martensite twins by heating above A_f temperature, the correlations between the BHN voltage and loading stress were examined one by one.

The hysteresis range of BHN voltage is apt to increase with increasing maximum loading stresses probably because of the residual internal damage such as irreversible martensite twins, dislocation and so forth . In the Fig. 5 MBHN voltage value at the starting point of σ=0 increased from 20% to 200% depending on applied load level.

From the experimental results of this study on the dynamic interactions between martensite twins and magnetic domains during ferromagnetic shape memory alloy, it can be concluded that MBHN method seems a useful technique to non-destructive evaluation of phase transformation and stress-induced internal damages of ferromagnetic shape memory alloy which is used as the filler of our proposing "Smart Composite Board".

4. CONCLUSION

The authors formerly proposed an advanced idea for passive health-monitoring of smart composite board by combining ferromagnetic shape memory alloy and magnetic nondestructive Barkhausen noise analysis method. First, we studied the possibility to detect the phase transformation with martensites twins in ferromagnetic shape memory Fe-29.6at%Pd alloy thin foil by using magnetic Barkhausen noise (MBHN) sensor. MBHN is thought to be caused by the irregular interactions between magnetic domain and activated martensite twins during magnetization. The detectability of phase transformation depending on temperature as well as internal damage i.e. stress-induced martensites depending on applied stresses in Fe-30.2at%Pd alloy by MBHN method were studied.

MBHN method is found to be a useful technique to non-destructive evaluation of phase transformation and internal damage .i.e. stress-induced martensite of ferromagenetic SMAs.

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