THE EFFECT OF MECHANICAL STRESS ON BARKHAUSEN NOISES FROM HEAT-TREATED NICKEL PLATES

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Abstract

The effect of mechanical stress on Barkhausen noise from pure nickel plates is reported for as-rolled plate and plates which are annealed at various temperatures up to 1000 K. The data are compared with Vickers hardness and SEM images. The Barkhausen noise energy detected has been found generally to decrease rapidly with nominal stress except a case of a plate annealed at around 400 K. The larger the annealing temperature, the larger the rate of decrease was observed. Overall features are explained qualitatively by a model in which tensile stress pull out the Barkhausen jumps from an observable condition and annealing makes the number of pinning sites small.

1. Introduction

When varying magnetic field is applied to a ferromagnetic material, the magnetization shows discontinuous change due to discontinuous domain wall motion which induces magnetic Barkhausen noise in a pickup coil. The magnetic Barkhausen noise measurements have been reported and discussed in relation to heat treatment, grain size, strain, and hardness [1]. However, still a mechanism of the generation of the Barkhausen noise has not been well understood and the measurements are not established as a popular method for non-destructive test (NDT). It has been known that mechanical stress applied to a ferromagnetic material has an effect on the Barkhausen noise from the material [2]. It was found that the Barkhausen noise amplitude increases with increasing tensile stress [2]. On the other hand, the stress response of rms value of Barkhausen noise for steel concrete reinforcement cables was investigated and it was found that the rms value steadily decrease as a function of tensile stress up to a level of 1000 MPa [3]. In view of these somewhat conflicting results, it was decided to do experimental study on nickel specimen which is a simple and fundamental ferromagnet. The effect of mechanical stress on Barkhausen noises from rolled thin plates of nickel is reported. The effect has also examined for the plates which are annealed at various temperatures. Experimental studies on Barkhausen noise energy, magnetic properties such as permeability and hardness for heat-treated, thin plates of pure nickel were reported [4]. Pure nickel has a simple phase diagram which consists of only fcc phase and the pinning centers of magnetic domain wall are expected to be simpler compared with cases of iron, steel or permalloy. Temperature dependence of the Barkhausen noise energy down to very low temperature of 5 K was also reported [4].

2. Experimental Results

2.1 Effect of Stress to Rolled Nickel Plate

Nickel plates which were prepared by rolling with a thickness of 0.20 mm supplied by the Nilaco Corporation with a purity of 99.7 %, a specific weight of 8.90 and Vickers hardness of about 250 was used as a starting specimen. The shape and size of the specimen for test is shown in Fig.1. A stress is applied using a stepping motor and a ball-screw motion controller. The stress is measured using a load cell unit. The output voltage from the load cell is amplified by an amplifier and transferred to 16-bit AD board built in a PC.

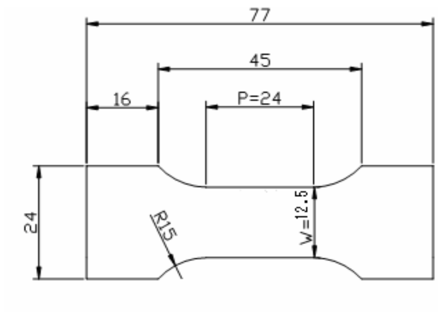

Figure 1*: The shape and size of a test piece.*

A pair of magnetizing coils with 450 turns and a detecting coil with 400 turns were directly wound over the specimen to observe Barkhausen noise only from the sample itself [4]. The load of the detecting coil was 10 kΩ.The magnetic field was swept from -0.02 T to 0.02 T (=200 Oe) in sinusoidal wave form with a frequency of 0.5 Hz. The Barkhausen noise voltage was amplified by a low-noise preamplifier followed by a band-pass filter with a frequency range from 1 kHz to 100 kHz, and transferred to 16-bit AD board built in an another PC.

A typical graph of stress versus strain for the stating specimen of the nickel plate is shown in Fig.2. The Young's modulus, the tensile strength and the proof stress of 0.2% of the sample are obtained to be 62.6 GPa, 620 MPa and 606 MPa, respectively.

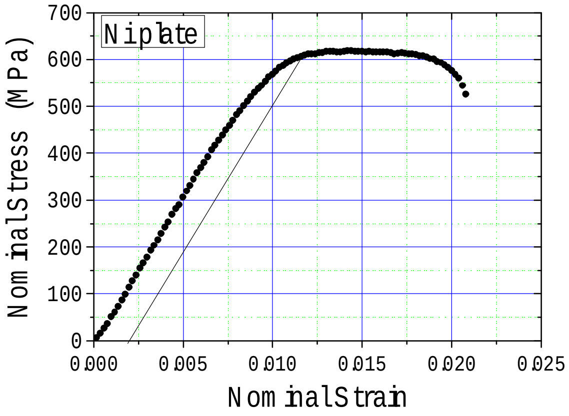

Figure 2*: A result of a tension test for a rolled nickel plate.*

One-shot voltage profiles for Barkhausen noise at various stress levels from a rolled nickel plate from the same batch as the plate in Fig.2 are shown in Fig.3. The coil current which is proportional to the applied magnetic field is also shown. This voltage profile is different in every run because the Barkhausen noise is essentially a noise, and root-mean-square (rms) voltage profiles averaged over 400 times are shown in Fig.4. The Barkhausen noise voltage is found to decrease with increasing tensile strength in this sample. The peak position of the noise burst is simultaneously delayed on the time axis, indicating an increase in coercive force. These behaviors are similar to behaviors observed in steel concrete reinforcement cables in ref.3.

A parameter, the Barkhausen noise energy (BNE), which is defined as the total electric energy integrated over a single sweep of externally applied field for a 10 kΩ resistance load on a detecting coil, is proposed in ref.4.

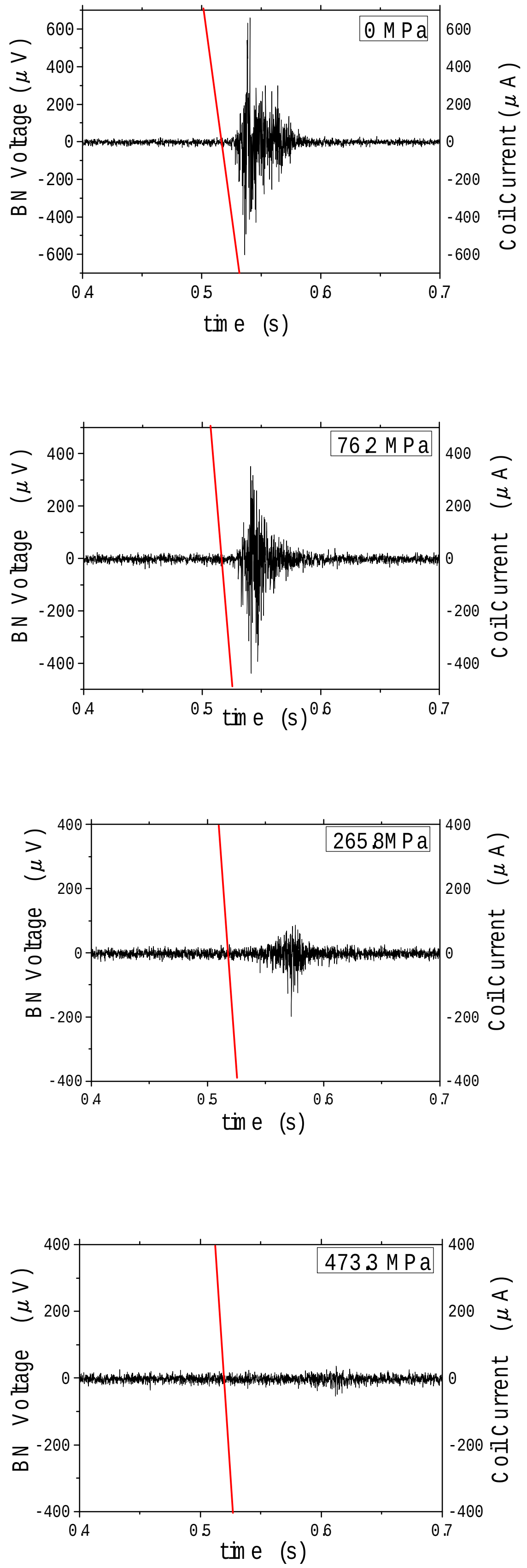

Figure 3*: Barkhausen noise profiles at various tensile stresses for the nickel plate. The coil current is also shown.*

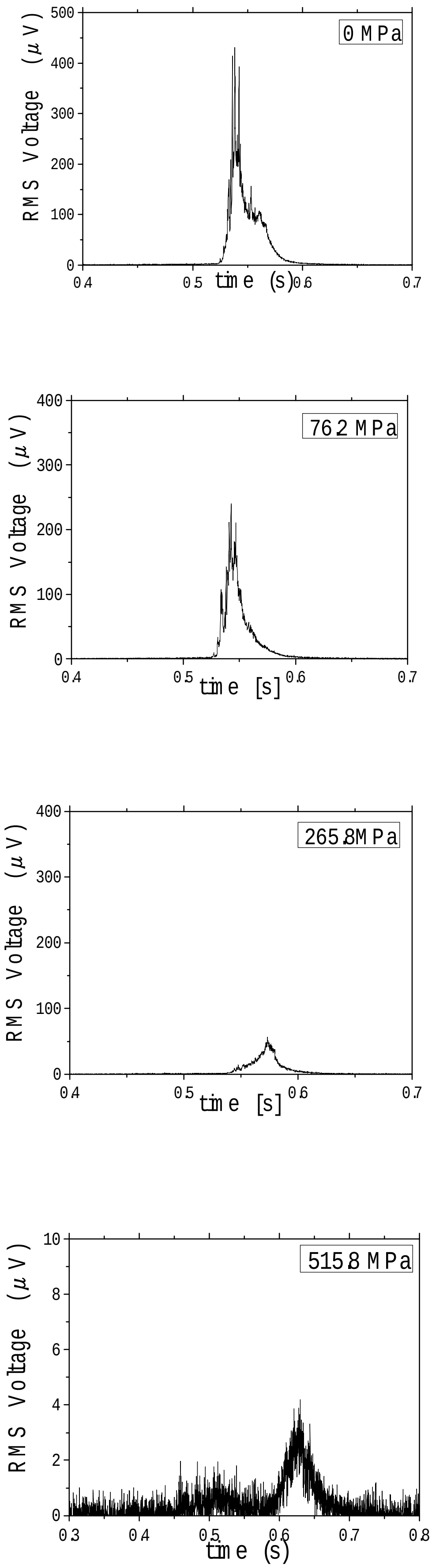

Figure 4*: Rms Barkhausen noise profiles at various tensile stresses for the nickel plate.*

The magnitude of BNE is shown in Fig.5 as a function of nominal stress for the rolled nickel plate. The BNE is observed to be a rapidly decreasing function of applied stress.

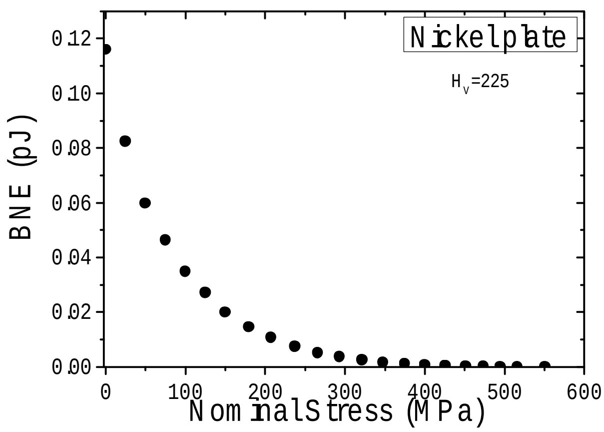

Figure 5*: BNE versus nominal stress for a rolled nickel plate (see text).*

2.2 Effect of Stress to Annealed Nickel Plates

The rolled nickel plate as received is cut in the shape of Fig.1 and annealed at 400, 500, 600, 800 and 1000 K for 30 minutes in a temperature-controlled furnace and cooled slowly down to room temperature in the furnace. The Vickers hardness H_V of the nickel plate annealed is shown in Fig.6. By the annealing, the hardness increases at first followed by a gradual decrease with increasing temperature of the heat treatment

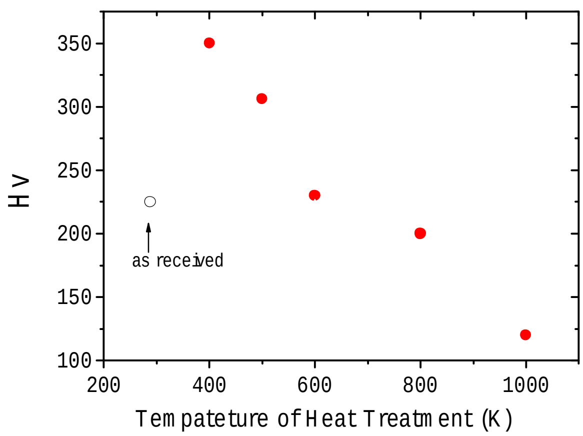

Figure 6*: Vickers hardness of annealed nickel plate.*

The magnitude of BNE of annealed specimen of nickel plate without tensile stress is shown as a function of temperature of the heat treatment in Fig.7. This behavior is qualitatively similar to that of hardness in Fig.6.

Each annealed specimen was given a constant stress step by step, rms Barkhausen noise profile was measured in each step, and the magnitude of the BNE was calculated. The result is shown in Fig. 7. The Barkhausen noise energy has been found generally to decrease rapidly with nominal stress except a case of a plate annealed at around 400 K, which shows a slight increase in a small stress range followed by rapid decrease in larger stress range. The larger the annealing temperature, the larger the rate of decrease is observed.

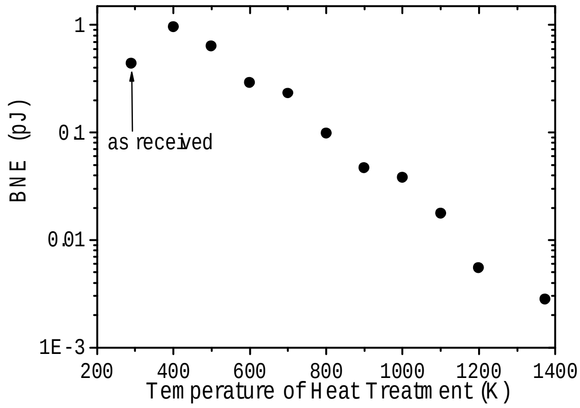

Figure 6*: BNE of annealed nickel plate as a function of temperature of annealing.*

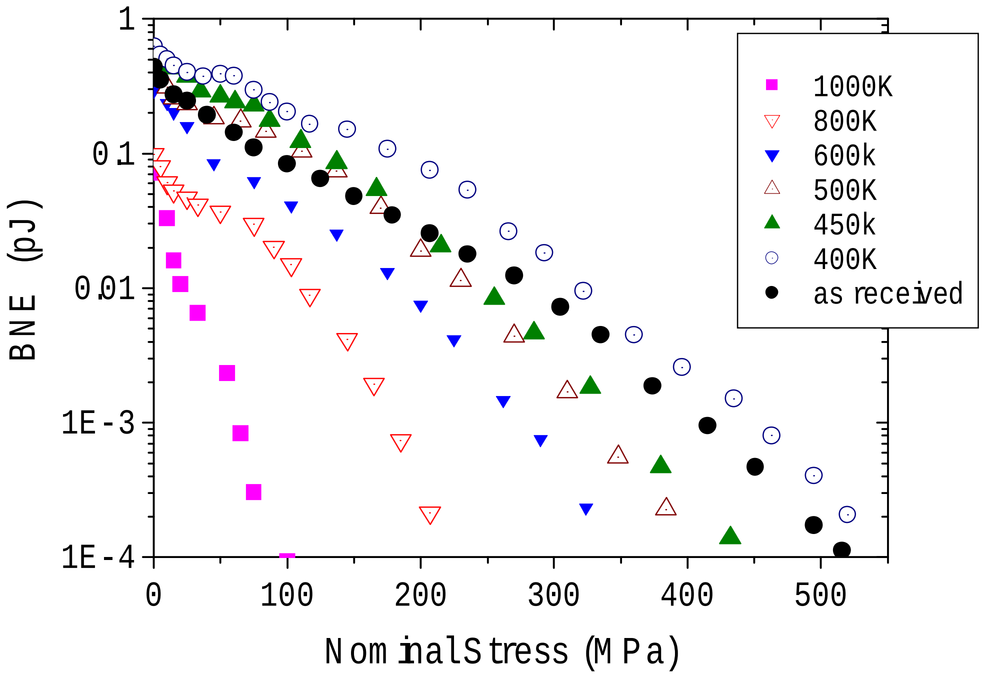

Figure 7*: Stress dependence of the Barkhausen noise energy (BNE) for nickel plates annealed at different temperatures.*

This result is somewhat similar to the case of steel concrete reinforcement cables in ref. 3, but the rate of the decrease is larger in the present case, where the BNE decreased in more than three orders of magnitude. On the other hand, this result shows clear contrast to reported results for XC10 French steel etc. in which Barkhausen noise voltage integrated increased with stress [2].

2.3 SEM images

The microstructure of the surface of the nickel plate was observed using a SEM mode of an EPMA apparatus (JOEL JXA-8900R) with an operating voltage of 20 kV. Surface images of the rolled nickel plate as received are shown in Fig.8 before and after the tension test. Surface images of the nickel plates annealed at 400, 600 and 1000 K are shown in Figs. 9-11. Elongated microstructures before tension tests are seen in Figs. 8-10, while isotropic microstructure with a smaller size is seen in Fig.11 (left), where the annealing temperature is above the recrystallization temperature of the nickel.

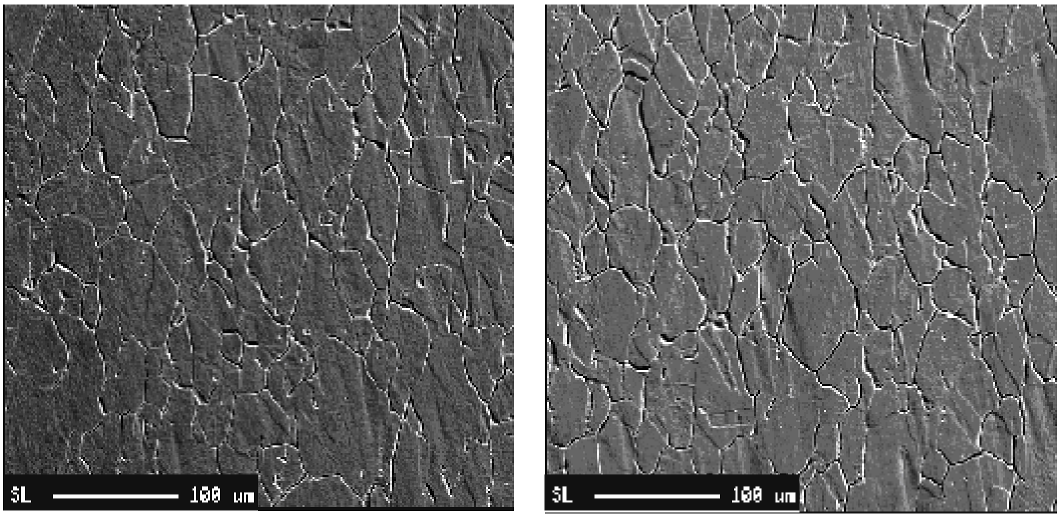

Figure 8*: Surface images of the rolled nickel plate as received before tension test (left) and after (right).*

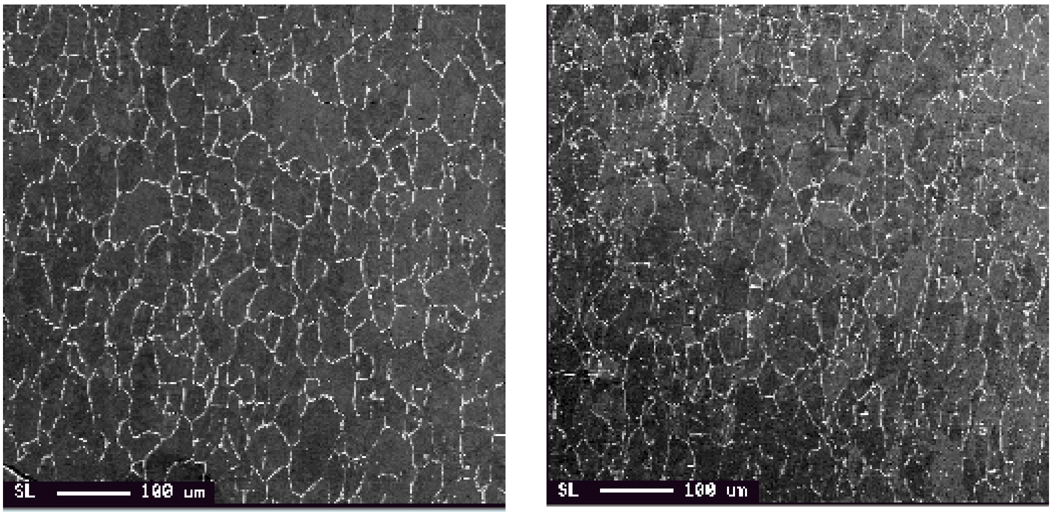

Figure 9*: Surface images of the nickel plate annealed at 400 K before tension test (left) and after (right).*

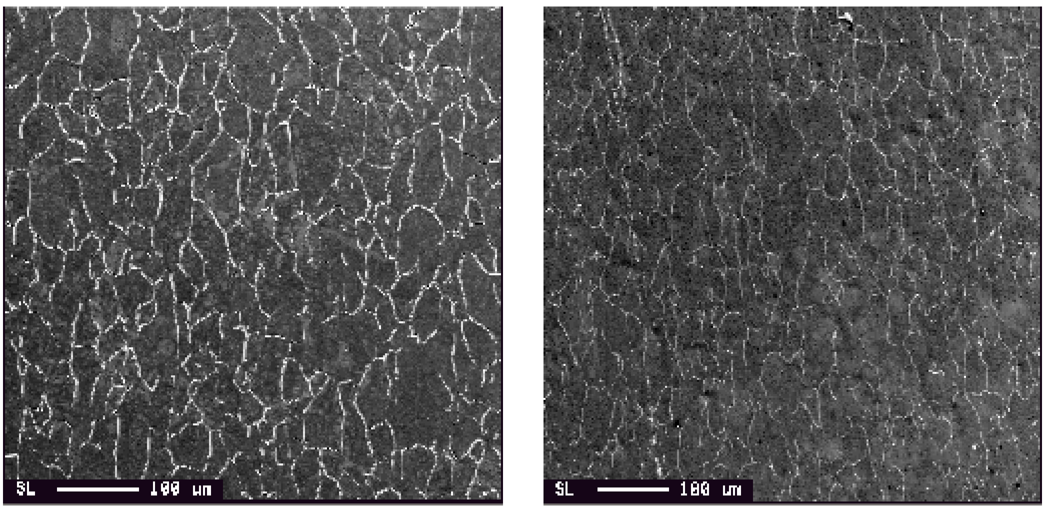

Figure 10*: Surface images of the nickel plate annealed at 600 K before tension test (left) and after (right).*

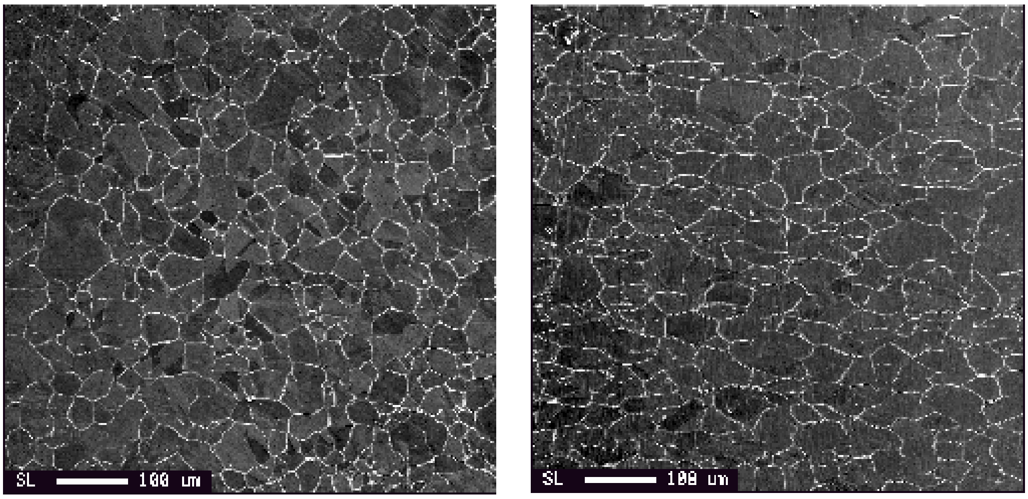

Figure 11*: Surface images of the nickel plate annealed at 1000 K before tension test (left) and after (right).*

The microstructures in Figs. 8-10 do not change appreciably by the tension test, while the microstructure in the nickel plate annealed at 1000 K in Fig.11 shows elongated structure along the direction of stress (horizontal direction in this picture).

3. Discussion

The experimental results which are described in the preceding section are interpreted qualitatively in our new points of view as follows. The effect of tensile stress to the nickel plates has been found generally to decrease the Barkhausen noise energy rapidly except the case of the plate annealed at around 400 K. With increasing the tensile stress, the peak position of the noise burst is simultaneously delayed on the time axis, indicating an increase in coercive force. This means specimen becomes magnetically harder with increasing tensile stress. The magnetization process spreads beyond the swept applied field range of ($\pm$0.02 T) in the experiment. Pinning potentials of domain walls in the sample probably become deep and the probability of the depinning process becomes less within the small magnetic field range. Furthermore, the receiving system for the Barkhausen noise detects noise voltage with a restricted frequency range from 1 kHz to 100 kHz. The slower magnetization change in magnetically harder material may bring a shift of the frequency components of the Barkhausen noise energy to lower frequency components less than the minimum frequency of the detection. These phenomena may happen heterogeneously in a specimen. A microscopic domain which sustain more stress than other domain does may have pinning sites with larger pinning potentials. The Barkhausen noise from such a domain cannot be detected. These seem to be the origin of the decrease of the Barkhausen noise energy with increasing stress.

On the other hand, the Barkhausen noise energy from rolled nickel plate was found to decrease with the increase of annealing temperature [4]. The annealing makes the material both mechanically and magnetically soft, especially when the annealing temperature is higher than the recrystallization temperature of about 1000 K [4]. This behavior is naturally explained by a decrease in number of pinning sites or defects. Magnetic domain walls have a tendency to move smoother with less Barkhausen noise due to annealing. This behavior is also seen in Fig. 6 and 7 except the case of the plate annealed at around 400 K.

Thus, the Barkhausen noise energy is influenced by both number of pinning sites and the depths of the pinning potentials. The Barkhausen noise is difficult to be observed both in magnetically very hard material in which number of pinning sites is large but the distribution in the depth of pinning potential is not appropriate for the observation of Barkhausen noise, and in magnetically very soft material in which number of pinning sites is small and domain walls move smoothly. It is to be stressed that there exists the preferable condition for the observation of the Barkhausen noise.

Considering the above condition, the properties of the Barkhausen noise from the rolled nickel plate annealed at 400 K is interpreted as follows. The rolled nickel plate as received becomes harder by the annealing at 400K as seen in Fig.6. The annealing seems to recover torn microstructure due to rolling, and that makes many pinning sites which makes appropriate Barkhausen jumps to be observed and Barkhausen noise energy larger as seen in Fig.6. Those pinning sites seem to help the delay of decrease in Barkhausen noise energy with increased tensile stress seen in Fig.7.

The SEM pictures of the microstructures of the surface of the rolled nickel plates which was annealed at several temperatures were taken before and after tensile tests and the changes due to annealing and tensile stress is observed, but close relation between the microstructure and the Barkhausen noise was not identified.

4. Summary

The effect of mechanical stress on Barkhausen noise from pure nickel plates is studied for as-rolled plate and plates which are annealed at various temperatures up to 1000 K. The Barkhausen noise energy detected has been found generally to decrease rapidly with nominal stress except a case of a plate annealed at around 400 K. The larger the annealing temperature, the larger the rate of decrease was observed. Overall features are explained qualitatively by the model in which tensile stress pull out the Barkhausen jumps from an observable condition and annealing makes the number of pinning sites small. It is stressed that there exists the preferable condition for the observation of the Barkhausen noise.

5. References

[1] See, for a review, O. Sundstrom and K. Torronen, "The Use of Barkhausen Noise Analysis in Nondestructive Testing", Materials Evaluation **37,** 51-56, 1979, D.C. Jiles, "Review of magnetic methods for nondestructive evaluation", NDT International **21**, 311-319, 1988.

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