Effect of Strain by Mechanical Punching on Nonoriented Si–Fe Electrical Sheets for a Nine-Slot Motor Core

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Domain observation has been done to investigate the effect of strain due to a punching process on the magnetization process of a nine-slot core for 12-pole small brushless dc motor by using the Kerr microscopy technique. Stripe domain structures oriented to a transverse direction are observed at the edge of a tooth of the core without stress relief annealing. Due to the domain configuration, permeability near the punched edge of the motor core is reduced. A stress relief annealing at 700 °C for 2 h can relive the punching stress.

Index Terms—**Magnetic domain observation, nonoriented Si–Fe electrical sheet, punching process, stress relief annealing.**

I. Introduction

NONORIENTED Si–Fe electrical sheets are widely used for motor cores because of their isotropic properties. It is well known that mechanical punching of motor cores induces significant plastic and elastic deformation in the electrical sheets and influences driving characteristics of electrical motors. Therefore, knowledge about the relation between residual strain and magnetic properties is important for designers of electrical motors. However, little has been reported about the magnetization process of mechanically shaped Si–Fe electrical sheets [1], [2]. This paper is intended to explore the effect of the punched stress on the domain structure of Si–Fe sheets in a form of nine-slot motor core by a Kerr microscopy.

II. Experiment

A nonoriented 3% Si–Fe sheet provided by Nippon Steel Co. was punched to motor core shape for a 12-pole small brushless dc motor using a nine-slot core, as shown in Fig. 1. The diameters of outside and inside are 20.2 and 8.2 mm, respectively. The thickness of the specimen is 0.35 mm. The width of a tooth is 1.6 mm. The specimen was polished for a domain observation after the punching. A Kerr microscope is used to view magnetic domains of the sheet before stress relief annealing. The specimen was then annealed in a vacuum of 3.7×10^{-3} Pa at 700 °C for 2 h to avoid the mechanical stress. Magnetic domain observation was done at the same point before and after the stress relief annealing. The magnetization process was observed at the edge and center of the tooth of the punched core applying a dc field along the rolling direction.

III. Results and Discussion

Fig. 2 shows a cross-sectional photograph of punched core at an edge of a tooth. A shear drop by the punching process

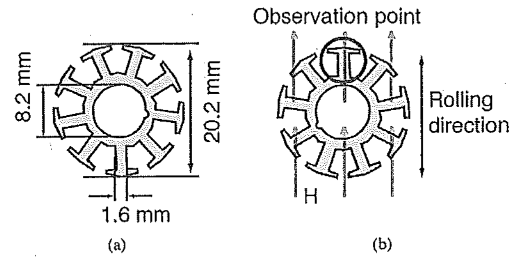

Fig. 1. Schematic view of the punched motor core.

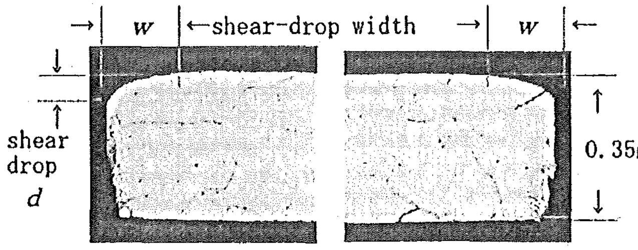

Fig. 2. Cross-sectional photograph of a punched motor core at a tooth.

can be seen at the top surface. The photograph indicates that the averaged grain size is about 0.2 mm, and the specimen has a few grains in the normal direction.

Fig. 3 shows the domain patterns at the tooth of the punched core at the remanent state before annealing. The bright and dark domains have magnetizations pointing in upward and downward directions, respectively. It is seen that almost all the grains near the edge exhibit stripe domain configurations running in the transverse to the rolling direction. It is noted that the direction of the magnetization in the stripe domains is transverse to the stripe and parallel to the rolling direction due to the Kerr contrast. The domain structure indicates that the magnetizations in the dark and bright domains are heading-on each other at the surface. On the other hand, grains at the center of the tooth exhibit complicated domain patterns and stripe domains parallel to the rolling direction. Few heading-on domain structures are

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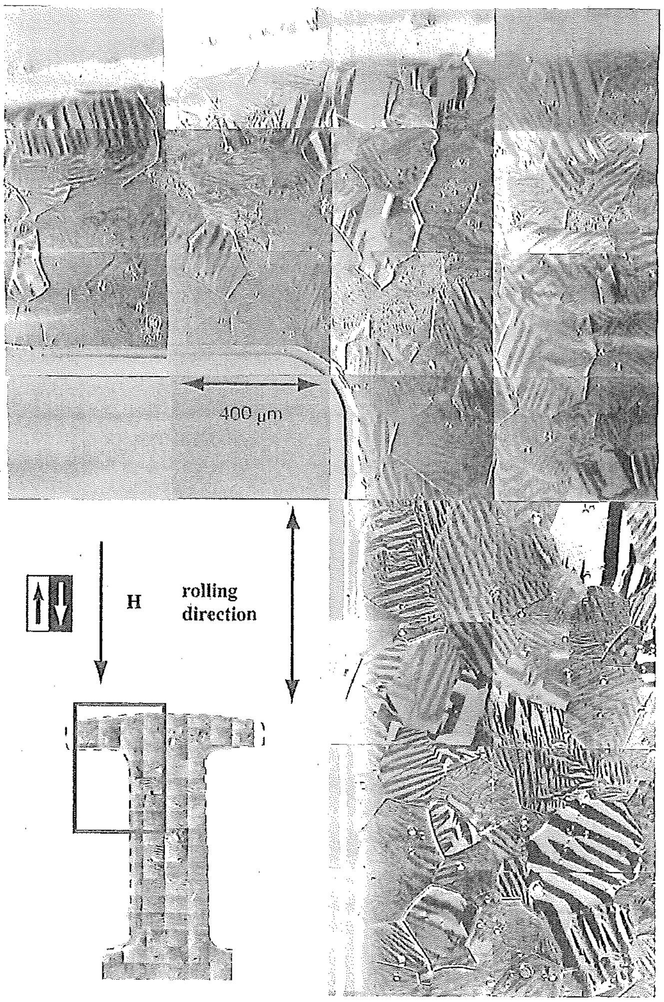

Fig. 3. Domain image at the tooth of the punched motor core before annealing.

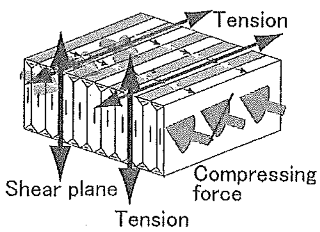

Fig. 4. Model of domain structure at punched area.

observed at the center. These domain structures observed at the center of the tooth are similar to that of nonoriented Si–Fe electrical sheets as rolled [3]–[5]. The change in the domain structures near the edge indicates that the punching process induces stress and changes the domain structure near the edge of the specimen.

Fig. 4 shows a schematic model of the stress distribution and domain configuration. Shear stress caused by punching at the edge turns the magnetization along the normal direction inside the sheet. The normal component of the magnetization increases the magnetostatic energy at the surface. Therefore, the stripe domain configuration observed at the surface must reflect the

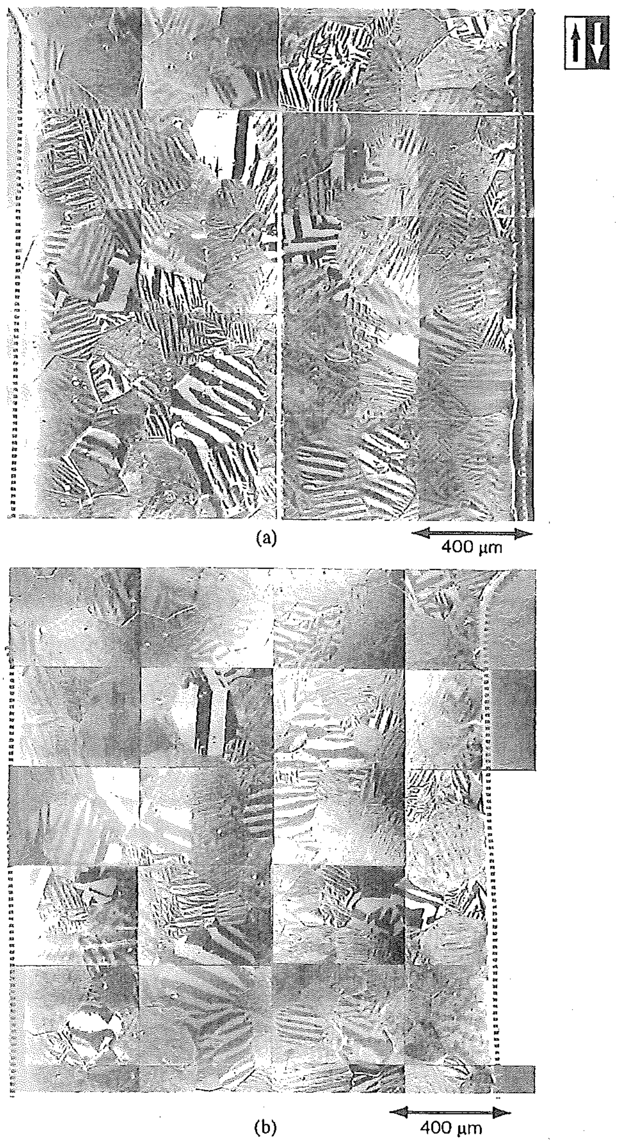

Fig. 5. Domain patterns before and after stress relief annealing.

closure domain structure underneath the surface to decrease the magnetostatic energy. The normal component of the magnetization would generate the increase in eddy current loss and result in the increasing anomaly factor [3]–[5]. The stripe domain structure can be seen from the edge to the inside of 0.2 mm that is comparable to the thickness of the specimen.

Fig. 5 shows the domain patterns before and after stress relief annealing at a remanent state. It was found that some stripe domain patterns along the transverse direction changed to the stripe domains along the rolling direction near the edge of the core after the annealing. Increasing in the width of the stripe is also observed at some grains. It seems that the change in the domain structure is caused by stress relief due to the annealing.

Fig. 6 shows the domain images on applying an ac field before and after annealing. To observe a magnetization process, a change in the domain pattern is extracted by subtracting the reference domain pattern using an image processor [6], [7], as shown in Fig. 7. The reference image is the domain pattern at

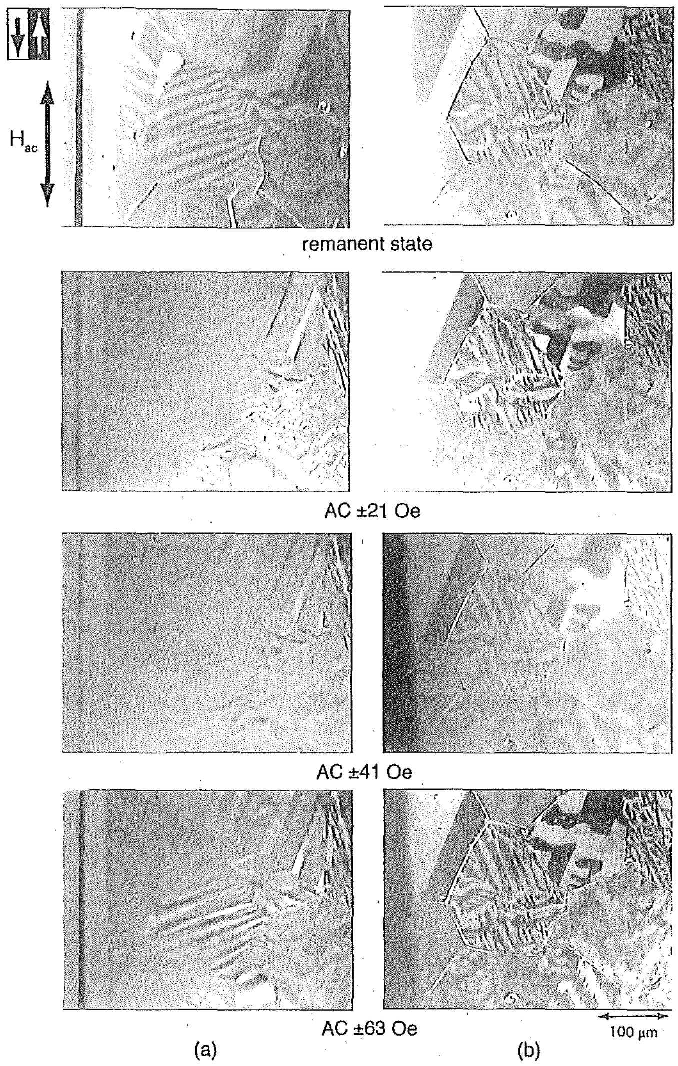

Fig. 6. Magnetization process at the edge of the core.

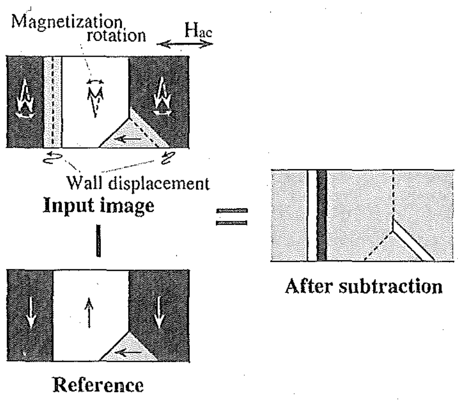

Fig. 7. Schematic of domain subtraction by an image processor.

a remanent state, and 128 subtracting images are integrated at each 1/30 s to enhance the domain contrast due to the Kerr effect signal. Before the annealing, wall displacement is hardly observed under the applied field of ±41 Oe, as shown in Fig. 6(a). When the field reaches ±63 Oe, wall displacement occurs. On the other hand, applying field of ±21 Oe produces easily wall displacement after the annealing, as shown in Fig. 6(b). It was found that the shear stress reduces an in-plane permeability, and the annealing at 700 °C for 2 h can relieve the punching stress.

IV. Conclusion

In the present work a magnetic domain of a punched nonoriented Si–Fe sheet in a form of a nine-slot motor core has been observed with a Kerr microscope. Results have indicated that the shear stress by the punching process changes domain structure and reduces an in-plane permeability near the edge of the core. It is noted that the length of the area influenced by the stress is comparable to the thickness of the sheet from the edge. Moreover, the annealing at 700 °C for 2 h can relieve the punching stress. The data would allow us to ease the design of motor cores.

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