Pulsed neutron imaging of the temperature, structure, magnetic field, and elemental identification of a practical product

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1. Visualisation of residual strain in induction-hardened gears studied by neutron Bragg-edge transmission (BET) imaging

1.1 Introduction

In recent years, induction hardening is used to introduce harder layers, such as martensite phase in the gear surface to increase the fatigue strength. Usually significant compressive residual stress is developed at the gear surface, which helps to resist crack initiation and bending fatigue. The newly developed two-dimensional (2D) time-of-flight (TOF) BET imaging method is a very effective tool for revealing elastic strain and microstructure in engineering materials. We applied this technique to investigate residual strain distribution in induction-hardened gears.

1.2 Experiment

We performed the BET imaging experiment at RADEN at J-PARC. Two kinds of gears, sample 1 and sample 2, were measured. In addition, sample 2 was remeasured after the bending fatigue test. An MPC-type detector with a 55 × 55 μm^2 pixel and a total area of 28 × 28 mm^2 was used to obtain the transmission spectra. The lattice plane spacing, d_{110}, and the Bragg-edge broadening, $\Delta\sigma_{110}$, were obtained two-dimensionally by the single-edge fitting using RITS code. Then, the residual strain was calculated by $\varepsilon_{110} = \frac{d_{110} - d_0}{d_0}$, where d_0 is the corresponding stress-free reference lattice spacing. Here we deduced d_0 for the ferrite and martensite phases by assuming the linear proportional relationship between the martensite phase fraction in the sample and the Vickers hardness, which is replaceable with the obtained $\Delta\sigma_{110}$.

1.3 Results

Figure 1 (a) shows the 2D maps of the obtained residual strain ε_{110} of the gears before fatigue test. The ε_{110} changes from compressive in the hardened area to near zero in the non-hardened area for both samples as shown in Figure 1(b). The distribution of ε_{110} in the two samples is obviously different due to different induction hardening methods. The distribution of ε_{110} for the sample 2 before and after fatigue test showed little difference.

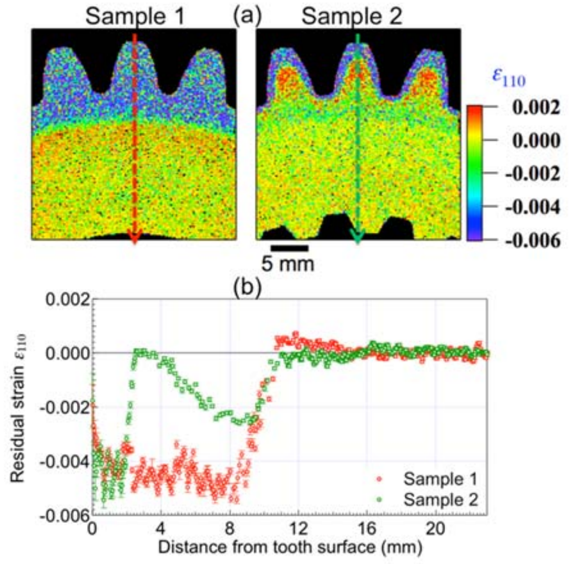

Figure 1. (a) 2D maps of the ferrite 110 residual strain, and (b) 1D plot of the residual strain from tooth surface to the inside as marked in the 2D maps.

1.4 Conclusion

Compressive residual strains are observed in the gear tooth surface area in the 2D BET-imaging maps. The effect of fatigue test is hardly observable for present sample 2. All the results are consistent with those determined by the XRD analysis.

2. Observation of a leaked magnetic field from a model electric transformer using pulsed polarized neutron imaging

2.1 Introduction

Observation of magnetic fields emanating from electromagnetic devices gives important information on not only their soundness but also their energy loss under operating conditions. Pulsed polarized neutron imaging (PNI) is suitable method for direct observation of such magnetic fields because it enables us to visualize the field distributions in both massive objects and free space with a large field of view up to several square centimeters. In this study, we attempted to visualize leaked magnetic field from a small electric transformer using PNI technique.

2.2 Experiment

PNI experiment was performed at BL22 RADEN of MLF. The object was a small electric transformer consisting of a step-lap rectangular core and 2 coils wound at both sides of the core (Figure 2). A 50.15-Hz AC voltage was applied to the primary windings during the imaging experiment. The temporal change of the wavelength-resolved polarization distribution image was obtained by means of an AC field imaging technique developed in our previous study.

2.3 Results

Leaked field from the core and the primary windings were observed as a deterioration of the polarization degree around the transformer in the polarization distribution image (Figure 3). The phase at maximum leaked field intensity was about 0.7 π radians, which was slightly delayed from the peak of the applied AC voltage at 0.5 π radians. Next, we visualized the distribution of the field strength integrated along the neutron flight path by analyzing the wavelength dependence of the polarization degree point by point. As a result, the leaked field from the gap of the step-lap could be clearly observed (Figure 4).

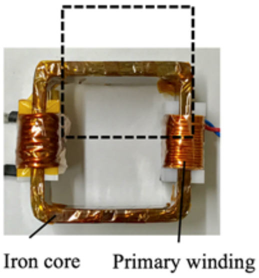

Figure 2. Photograph of the model electric transformer. Dashed square indicates field-of view of the PNI measurement.

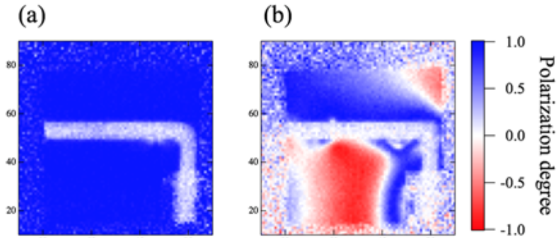

Figure 3. Polarization distribution images (λ =2.5 Å) at AC phase of (a) 0.1 π radians and (b) 0.7 π radians.

2.4 Conclusion

Leaked magnetic field from an AC voltage applied electric transformer was successfully observed by PNI. The relationship between the leaked field distribution and eddy current loss in the iron core will be studied by comparing the experimentally obtained field distribution image and that expected by computational simulation.

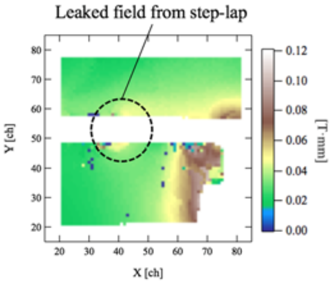

Figure 4. Distribution image of integrated field strength (AC Phase = 0.7 π) obtained by analyzing wavelength dependence of polarization image.