Elastic and plastic strain effects on eddy current response of carbon steel

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Introduction

Shot peening causes plastic deformation in a peened surface and induced a compressive residual stress. The compressive residual stress of the surface can increase a fatigue life of components. Therefore, monitoring the residual stress and/or plastic strain distribution in a peened layer of the component is important to guarantee its fatigue life. However, the induced residual stress is typically difficult to measure or predict. Presently, X-ray diffraction (XRD) is the widely used method that is able to measure the residual stress of the peened components. However, it is difficult for XRD to measure the residual stress distribution in the peened layer without a destructive method. The eddy current (EC) testing has the potential to measure the residual stress and plastic strain distribution induced by the shot peening because the electrical conductivity of metals is affected by both stress and plastic strain. Consequently, effects of stress and plastic strain on the EC response must be revealed for establishing EC testing to determine the residual stress and plastic strain distribution of the peened components.[1] Morozov et al.[1] conducted the EC measurements and revealed the dependence of the electrical conductivity on stress for aluminum alloys to establish a cheap indicator of the state of residual stress in metals and alloys. However, they did not investigate on steel materials. Dahia et al.[2] developed a methodology for the modelling of stress detection using the EC technique. They applied the method to the Iron-Cobalt alloy and concluded that the uniaxial tensile stress could be detected. However, their investigation was only within the elastic region.

Objectives

This study revealed the respective effects of stress and plastic strain on the change of EC response (coil impedance) using the mild steel for obtaining the fundamental data to establish the non-destructive EC technique to measure the residual stress induced by the shot peening.

Methodology

This study chose the mild steel that shows the clear upper-yield stress as the testing material, as shown in Figure 1. The round specimen of Φ15 mm diameter and of 250 mm length was used in this study. The specimen was annealed at 600 ℃ in order to release the residual stress induced by machining the specimen before the measurement of the coil impedance. Figure 1 shows the measurement apparatus used in this study. The specimen was stretched within the encircling coil using the tensile testing machine, as shown in the figure. The tensile strain of the specimen was measured by the strain gage during stretching. This study conducted two types of the testing to reveal the respective effects of the stress and plastic strain on the coil impedance. First, measurements were conducted every 50 MPa in the elastic region for evaluating only the effect of the stress on the coil impedance. After yielding, in the plastic region, the measurements were conducted at 283 MPa, 308 MPa, and 363 MPa. The coil impedances were measured for each stress state. The range of excitation frequency was from 5 KHz to 8 MHz. By investigating the measurements in the elastic region, only the effect of the applied stress can be evaluated. The measured relative variations of coil impedance with respect to the unstressed state was described by the following equation.

$$Z(X\ MPa)/Z(0\ MPa) \tag{1}$$

Second, another sample was plastically deformed by tensile loading up to 10% with step of 1%. The measurements of coil impedance were conducted at each plastic strain after removing the load to evaluate only the effect of the plastic strain on the coil impedance. The measured relative variations of coil impedance with respect to no plastic strain state was described by the following equation.

$$Z(\varepsilon_p\ X\%)/Z(\varepsilon_p\ 0\%) \tag{2}$$

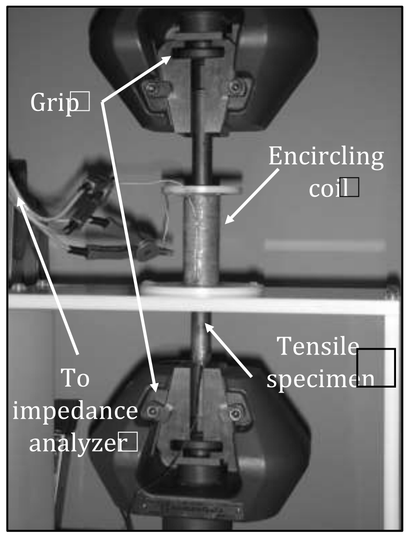

Figure 1 Experimental apparatus used in this study.

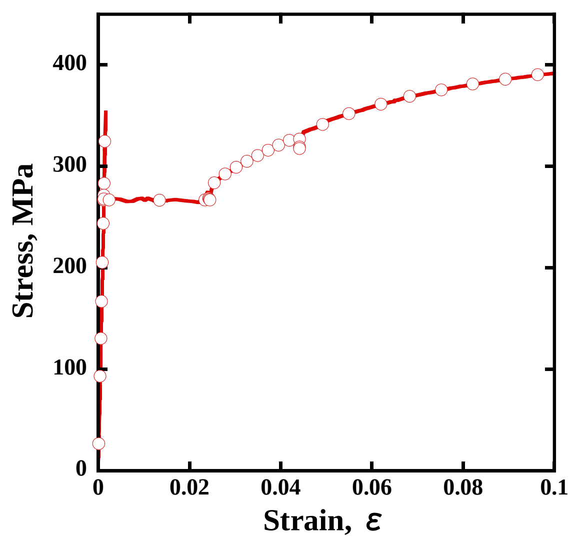

Figure 2 Stress-strain curve of the mild steel used in this study.

Results and analysis

Figure 3 represents the change of coil impedance during loading at 5902 Hz. At the elastic region, impedance of coil showed the non-monotonic behaviour and the knee at low stress. When the stress reached the yield stress, the coil impedance showed the discontinuous behaviour and became lower than that of the initial state, as shown in Figure 3. The further loading caused the reduction of the coil impedance after yielding. Figure 4 showed the effect of the plastic strain on the coil impedance at 5902 Hz. The figure showed that initial yielding had the drastic effect of decreasing the coil impedance and that the further increase in the plastic strain amount reduced the coil impedance. The result of Figure 4 indicates that the discontinuous behaviour at the yield stress and the reduction of the coil impedance after yielding in the Figure 3 were mainly due to the effect of the plastic strain. The obtained results show that the coil impedance was sensitive to not only the applied stress, but also the plastic strain. Therefore, strategies were required for separating the plastic strain and residual stress effects to establish the measurement technique for residual stress distribution induced by the shot peening.

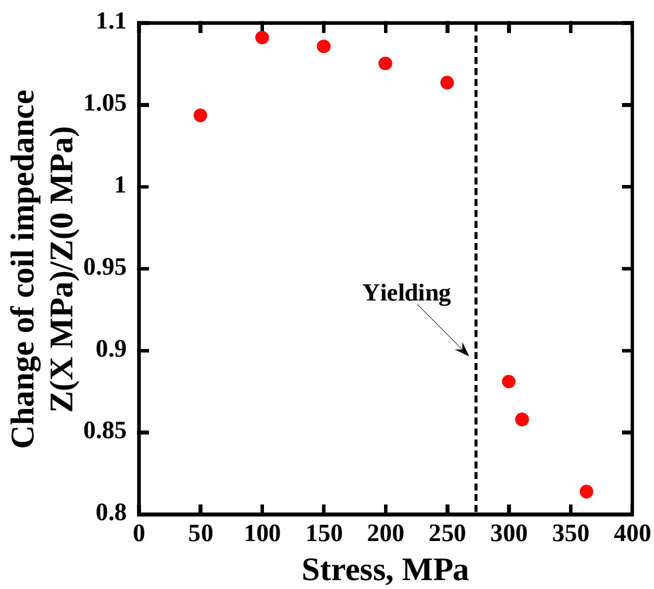

Figure 3 Coil impedance measurement result of 5902 Hz during loading the specimen.

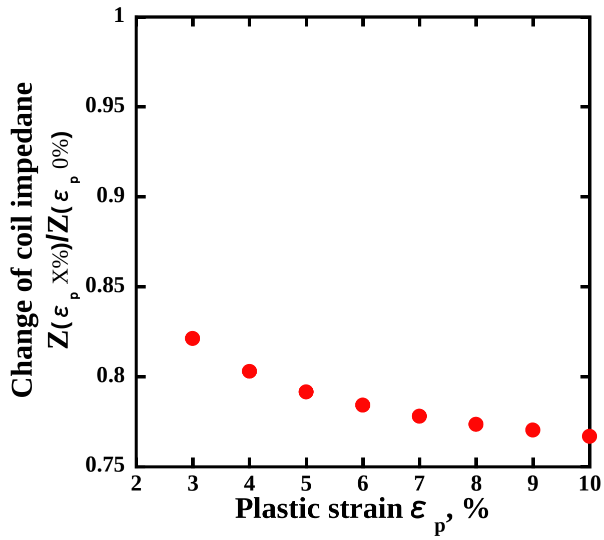

Figure 4 Effect of amount of the plastic strain on the coil impedance at 5902 Hz.

Conclusions

This study investigated the respective effects of the plastic strain and the stress on the EC measurement on the mild steel. At the elastic region, impedance of coil showed the non-monotonic behaviour and the knee at low stress. When the specimen reached the yield stress, the coil impedance showed the discontinuous behaviour. Further loading caused the reduction of the coil impedance. By investigating the effect of the plastic strain on the coil impedance, this study showed that the changes of coil impedance at and after yielding were attributed mainly to the effect of the plastic strain. Therefore, further work should be conducted to separate the plastic strain and the residual stress.

References

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