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Eddy Current Characterization of Magnetic Treatment of Materials

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I. INTRODUCTION

Magnetic field processes are thought to improve material mechanical properties[1] such as stress relief, wear resistance, and fatigue strength[2], thus increasing service life of machine tools such as drills, taps, end mills, gear hobs, etc. Although most results have been positive, some contradictory results have also been reported. Many material evaluation techniques such as positron annihilation, fractographic analysis, secondary-ion mass spectroscopy, magneto-mechanical acoustic emission and x-ray diffraction have been used to characterize the effect of magnetic treatment on materials. No conclusive results have been obtained and the basic effects of magnetic field processes[3] on materials are yet to be fully understood.

Electromagnetic testing methods[4-9] are commonly used for evaluating the electromagnetic properties of materials. Eddy current NDE techniques[6-9], which are sensitive to induced changes in a material's electromagnetic properties, are particularly well suited for this investigation. We have applied the impedance measuring technique to study the effect of magnetic treatment of Nickel 200 specimens. The specimens were subjected to various mechanical and magnetic processes such as annealing, magnetic field, applied strain, shot peening, and magnetic field after shot peening. Eddy current coil impedance was then measured after each mechanical and magnetic treatment process. Experimental results have exhibited a functional relationship between coil impedance and specimens subjected to the processes. It can be clearly seen that magnetic treatment did induce changes in the electromagnetic properties of the materials tested.

The fundamental effects of magnetic field processes on materials are complicated. Eddy current tests confirmed the change in material electromagnetic properties induced by a magnetic field and improved the understanding of the magnetic treatment on materials. However, the exact mechanism of magnetic treatment in relation to service life extension of machine tools remains indeterminate.

II. EXPERIMENTAL PROCEDURE

Sample preparations and processes

The material used for the study was Nickel 200 alloy for its magnetic properties. Nickel 200 is commercially pure wrought nickel (plus cobalt) with limited contents of iron, manganese, silicon, copper, carbon and sulfur. The raw stock Nickel 200 was first rolled to approximately 0.065"

(0.165 cm) thick and subsequently cut to 3.5" (8.90 cm) long by 0.5" (1.27 cm) wide strips. All specimen strips were annealed and stress relieved at 900°C for 1/2 hour in a vacuum chamber purged with argon gas. The annealing process was in accordance with American Society for Metals (ASM) annealing methods for nickel and nickel alloy[10].

The eddy current coil impedance were measured on the annealed specimens to establish the baseline data. Impedance measurements were also made after subjecting these annealed specimens to various engineering processes. The engineering processes were (1) strain, (2) magnetic field, (3) shot peening, and (4) magnetic field after shot peening. Surface tensile strain was exerted on the specimen by a standard four-point bending fixture. The applied surface strains were monitored by electrical resistance strain gauges placed on the specimens. A FluxaTron U102 machine was used for the magnetic treatment of the specimens. The machine produces a peak magnetic field amplitude of 120 Gauss, with the on-off cycle frequency as a function of the magnetic treatment intensity as shown in Figure 1. Peening specimens were prepared by glass-bead shot peening with 0.005N, 0.008N, 0.010N and 0.012N intensity. The peening intensity unit N, represents the arc height of a 3.0" (7.62 cm) by 0.75" (1.90 cm) by 0.03" (0.076 cm) Almen test strip. One third of the area of each specimen was masked from shot peening to provide normalized comparison. Peening/Magnetic treatment specimens were the magnetically-treated peened specimens, after performing the eddy current measurements.

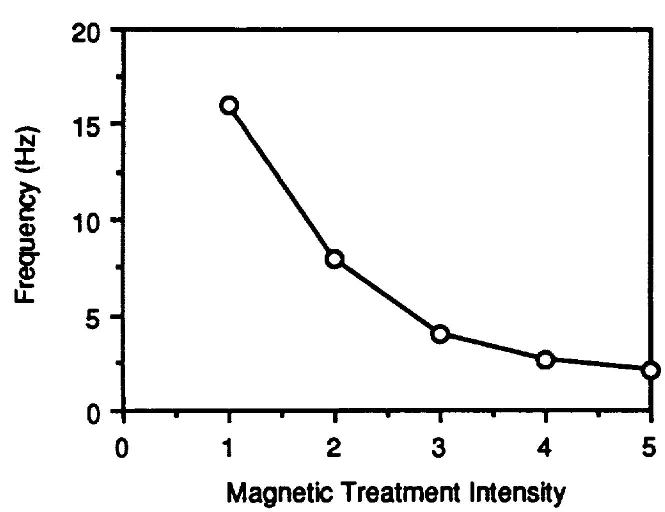

Figure 1. ON-off cycle frequency characteristics of the FluxaTron U102 as a function of magnetization intensity.

Laboratory setup and impedance measurements

The impedance measuring apparatus is a typical eddy current test setup. Figure 2 is a block diagram of the configuration of the eddy current impedance measuring system. An IBM-PC compatible computer was used as the system controller for instrument control, data acquisition, processing, analysis and storage. A Hewlett-Packard 4284A precision LCR meter was the eddy current instrument used for impedance measurements. The sensing coil of a Nortec 100 kHz absolute pencil probe was connected to HP 4284A as the sensor. The reference coil was left unconnected. Two components of the coil impedance, namely resistance and reactance, were time averaged and acquired by the host computer through an IEEE 488 interface bus.

For contact eddy current tests, the probe coil impedance is a function of electrical conductivity σ, and magnetic permeability μ, of the material, i.e. $Z = Z(\sigma,\mu)$. Engineering processes such as annealing, magnetic field, strain, peening, magnetic field after peening, etc. will induce changes in σ and μ. The impedance Z is a complex quantity and can be expressed as $Z = R + j X_L$, where R is the resistance and X_L is the inductive reactance. With the equipment arranged as in Figure 2, coil impedance measurements can be acquired either in an amplitude $/Z/$ and phase θ mode, or in R and X_L mode. We selected to monitor and analyze the relative changes of coil resistance $R(\sigma,\mu)$ and reactance $X_L(\sigma,\mu)$ with respect to annealed conditions as the principle of the study.

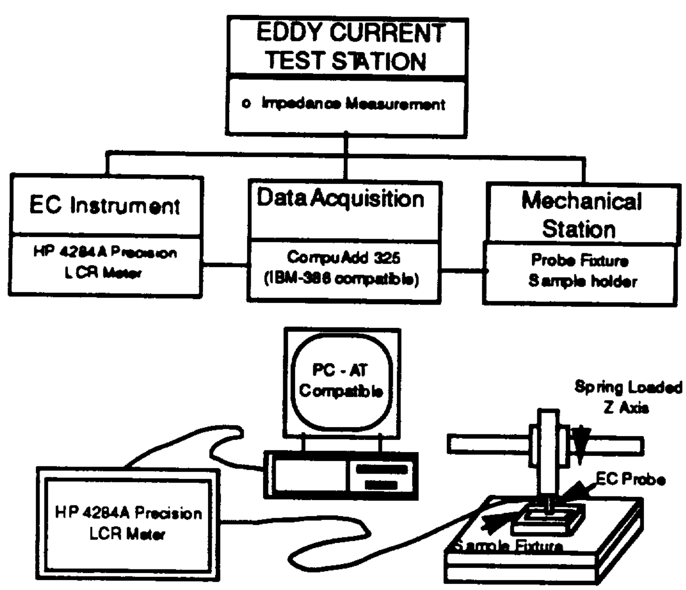

Figure 2. Block diagram of the eddy current measuring system.

Laboratory experiments were performed at ambient conditions. Except for the strain test specimens, all Nickel 200 test pieces were housed in a specimen holder and placed under a spring loaded Z-axis eddy current probe assembly. The spring loaded mechanism was used to maintain constant probe pressure with respect to the specimen and to ensure the reliability and repeatability of the measurements. Resistance and reactance data were taken at pre-determined sampling points. The coil resistance and reactance measurements were normalized to the readings of the annealed condition at the same location on the specimen.

The acquired coil resistance and reactance data of all test specimens for each of the designed experiments were archived and compared to evaluate the effect of each engineering process on the material's electromagnetic properties. The results from the experiments are summarized in the next section.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 is a plot of normalized coil impedance change as a function of applied strain. The experimental value of Young's modulus from stress-strain tests is E = 184.6 GPa. The maximum applied stress exerted by the four-point bending method was about 0.078 MPa compared to a referenced yield strength of 207 MPa for annealed Nickel 200. Eddy current - strain tests verified previous findings. Figure 4 is a plot of normalized coil impedance change as a function of magnetic field intensity for annealed specimens. There is no significant effect of magnetic treatment on annealed specimens. Experimental results also showed that there is a negligible effect between the number of magnetic treatment cycles and impedance changes.

The results of normalized coil impedance change as a function of peening intensity is shown in Figure 5. The data show that shot peening does induce a higher percentage of change in resistance and reactance. However, the lack of functional dependence between the impedance and peening intensity may be due to the limited skin depth of the test setup. Figure 6 is a plot of the normalized coil impedance change as a function of peening intensity followed by magnetic treatments. The magnetic treatment does reduce the normalized coil resistance and reactance from 7.5% to 0.24% and -6.26% to 0.065%, respectively as shown in Figure 6. The magnetic field process drastically reduced the dependence of coil reactance with respect to peening intensity. However, the resistance data displayed a linear functional relationship with respect to peening intensity. The process demonstrated the equivalent of 2.1 micro strain or 0.4 MPa of stress relief.

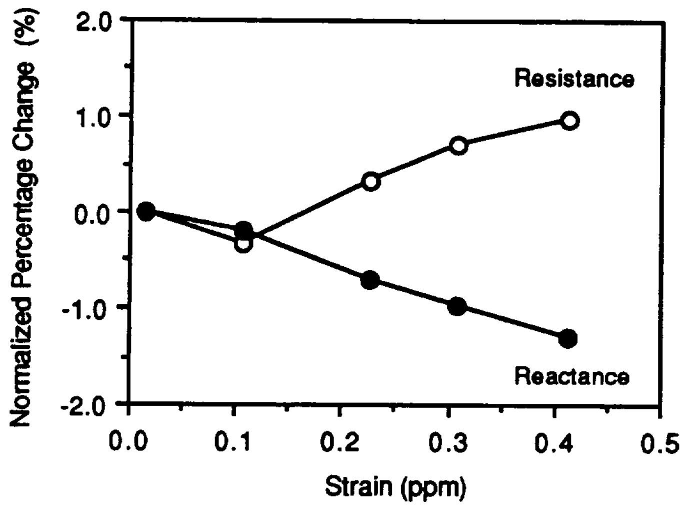

Figure 3. Normalized coil impedance (resistance and reactance) change as a function of applied strain for annealed Nickel 200 specimens.

IV. CONCLUSION

We have conducted an experimental study using eddy current impedance measurements to characterize the effect of magnetic treatment and other engineering processes. The results have demonstrated that the eddy current method is capable of monitoring changes in electromagnetic properties induced by various engineering processes on the material tested.

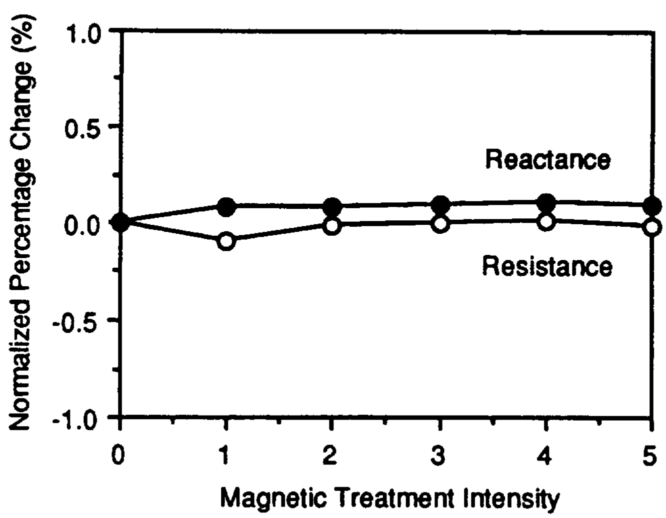

Figure 4. Normalized coil impedance (resistance and reactance) change as a function of magnetic treatment intensity.

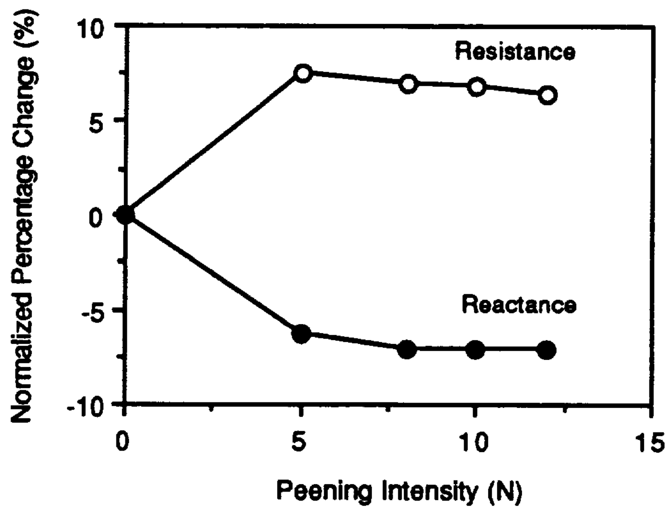

Figure 5. Normalized coil impedance (resistance and reactance) change as a function of glass shot peening intensity.

Magnetic treatment has little or no effect on annealed specimens as expected. The analysis showed that magnetic treatment reduced normalized impedance changes induced by the shot peening process. The data can be viewed as evidence of stress relief by magnetic treatment. The stress relief may contribute to the extension of machine tool service life.

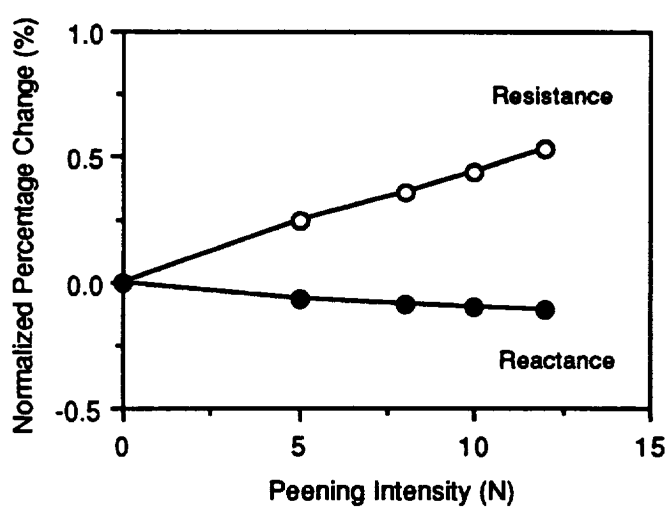

Figure 6. Normalized coil impedance (resistance and reactance) change as a function of shot peening intensity following magnetic treatment.

However, the eddy current impedance measuring method only measures gross material property changes. The effect of a magnetic field on a material's electromagnetic properties and its influence on the mechanical behavior of the material may be more complicated than that observed with the eddy current method. Further fundamental studies are necessary to fully understand the exact mechanism of the magnetic field processing effect in relation to machine tool service life.

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