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Benjamin Ducharne

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Magnetic incremental permeability using direct electrical contacts for a robust and directional characterization of ferromagnetic steel surface treatments

TENE DEFFO Yves Armand¹, DUCHARNE Benjamin²

Faculty of Eng. and Tech., Univ. of Buea, Buea P.O. Box 63, Cameroon.

ELyTMaX IRL3757, CNRS, Univ. Lyon, INSA Lyon, UCB Lyon 1, Tohoku Univ., Sendai, Japan.

Abstract

Magnetic incremental permeability (MIP) method is an efficient Non-Destructive Testing (NDT) method for characterizing metallurgical treatments (carburization, shoot-peening). Still, the conventional experimental setup is limited by inherent properties mostly due to the flat coil Eddy Current Testing (ECT) sensor (lift-off, etc.). In this study, direct electrical contacts derived from the magnetic needle probe (MNP) stand in place of the conventional sensor. This alternative “MNP-MIP” method provides directional measurement and solves multiple issues of the current process as applied to material surface treatment inspection.

1 Introduction

MI) is an efficient NDT method for an indirect characterization of steel surface treatments (carburizing, nitriding, peening, etc.) [1] [2]. It was implemented in the 3MA® (Micromagnetic Multiparametric Microstructure and stress Analyzer) industrial controller designed by IZFP Fraunhofer. Even if 3MA® and, more specifically, MIP have received many positive reviews, it also faces limitations and criticisms from both the academic and industrial worlds. Quasi-systematic ones come from the ECT flat coil sensor: 1) The sensitivity of the results appears to be highly dependent on the lift-off and, indirectly, the tested specimen surface quality. 2) the sensor directivity [3], which differs from the low-frequency magnetization field forbidding access to directional properties like anisotropy of the magnetic response and of the targeted property. This work addressed these issues by opting for a different sensor. We took inspiration from the so-called the magnetic needle probe (MNP) method [4] and used a pair of needles electrically connected with the surface of the specimen under test. The needle probes were supplied from the LCR meter, and the equivalent impedance was monitored along with the low-frequency magnetization process, similarly to the flat coil, for an accurate characterization of the surface treatment.

2 Experimental conditions and specimen preparation

The experimental validation of the needle probes derived MIP sensor was carried out on a series of 16NiCrMo13 martensitic stainless-steel specimens subjected to different levels of surface mechanical case hardening by carburizing process. Fig. 1(left) depicts the magnetic characterization setup made up of two U-shaped FeSi 3 wt.% yokes and two 2000 turns excitation coils. The specimens were divided into four groups. The first group, called “control group,” was kept untreated; the other groups were submitted to incremental carburization processes leading to the hardness levels and measured from 1 kg load Vickers hardness tests. The hardness threshold defining the case depth (h) was set to 580 HV and the surface hardness VH_{surf} defined at 100 μ m case depth (table). Results and discussion

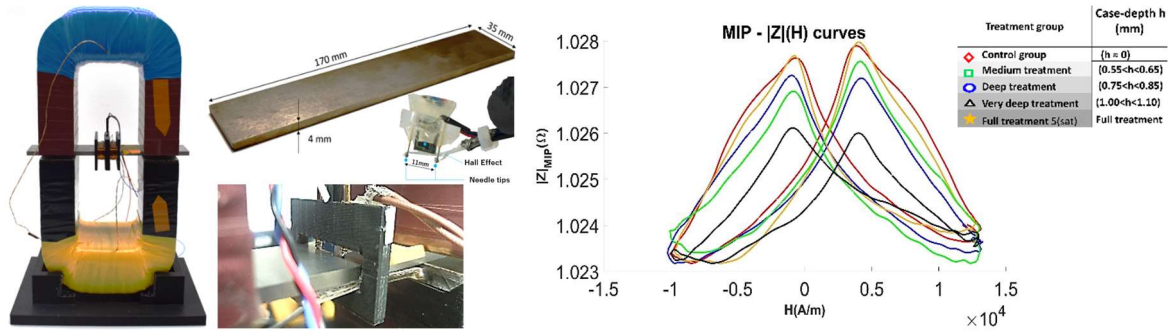


Figure 1: Experimental setup and specimen dimensions (left); MIP magnetic signatures for different carburization levels and surface hardness (right).

3 Results and discussion

The proposed “MNP-MIP” method was used to investigate the surface hardness due to carburization treatment. Fig. 1(left) depicts the MIP magnetic signatures for different carburization levels with a 50 kHz alternative contribution. This limits the thickness of the scanned area to a few 100 μm below the specimen surface, equal to the electromagnetic skin effect depth under MIP. Hence, correlating the MIP indicators ($\Delta|Z|_{\text{Mean}}$ and $\Delta\theta_{\text{Mean}}$) and the mean case depth per treatment level with the measured surface hardness at $h=100\mu\text{m}$ proves the sensitivity of the “MNP-MIP” method for surface and near surface treatment inspection (see Fig. 2).

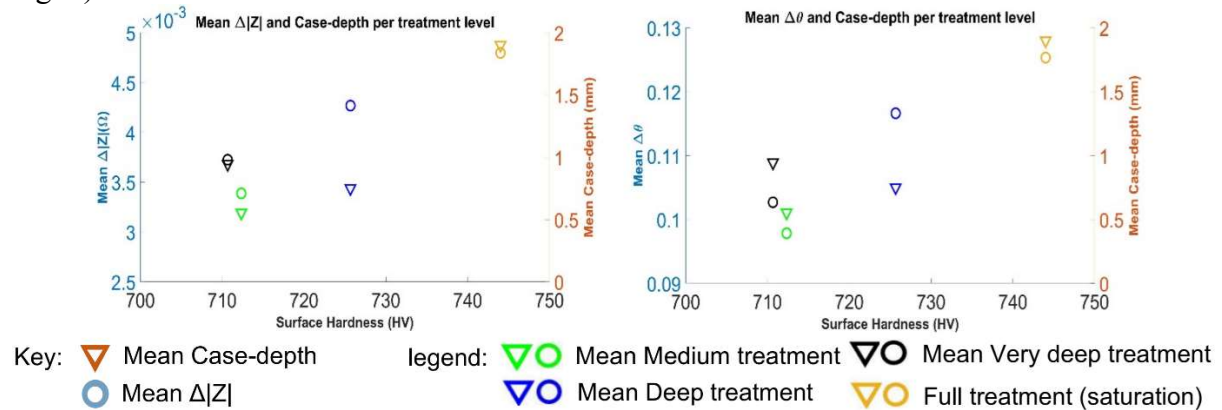


Figure 2: MIP indicators and case depth correlation with respect to the surface hardness $VH_{surf}, \Delta|Z|_{\text{Mean}}$ (left) and $\Delta|Z|_{\text{Mean}}$ (right).

4 Conclusion

This study presented a robust and directional electrical contact MIP sensor for surface treatment evaluation. A series of plaque-shaped specimens treated with different carburization levels and pre-characterized case depth were tested by the proposed “MNP-MIP” method.

References

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