QUANTITATIVE HARDENING-DEPTH-MEASUREMENTS UP TO 4 mm BY MEANS OF MICRO-MAGNETIC MICROSTRUCTURE MULTIPARAMETER ANALYSIS (3MA)

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INTRODUCTION

Micromagnetic techniques since years have been used to characterize the microstructure and to analyse residual stress states in magnetizable materials, i.e. steels [1,2]. Applying a dynamic sinusoidal magnetization in the frequency range 50 mHz ≤ f ≤ 110 Hz with field strength maxima up to 150 A/cm irreversible (magnetic Barkhausen noise) and reversible (incremental permeability) micromagnetic processes (Bloch-wall-jumps, rotations) give independent nd-quantities together with a derived coercivity. The question arises as to whether these techniques can be adapted for the characterization of surface-hardened materials for the estimation of the hardening depth.

BARKHAUSEN NOISE AND INCREMENTAL PERMEABILITY AT HARDENED SURFACE LAYERS

During dynamic magnetization of the material Barkhausen events (Fig.1) occur, which result in a local change of the magnetization. Micro-pulsed-eddy-currents are induced, which diffuse in the bulk volume. The diffusion-length is mainly determined by the frequency spectrum of the pulse, the electrical conductivity and the magnetic incremental permeability of the material at which the latter is a function of the magnetization state (eddy current damping). An inductive sensor (pick-up air coil, core coil, tape recorder head) at the surface will receive the pulsed signal as a voltage pulse as far as the Barkhausen event was excited within the directivity pattern of the sensor. Barkhausen events excited at larger distances from the surface will result in voltage pulses with lower frequency content than near surface events. Changing the analysing frequency \( f_A \) of a band pass filter from high to low, \( f_A \) gives a weighted characterization of the Barkhausen noise from near surface regions up to larger depths. In addition, hardened near-surface structures in steel have martensitic microstructures. They can be distinguished magnetically from the bulk (unhardened) material by the coercivity which is near two times the coercivity of the bulk volume, i.e. martensitic structure is magnetically much harder than ferritic, pearlitic, bainitic and anneled martensitic structures. Furthermore the frequency content in the Barkhausen noise of martensitic structures is much higher than the one of the other microstructures. Both facts improve the possibilities to separate both microstructure influences in the measured Barkhausen-profiles \( M(H) \) as function of the magnetic field strength.
Fig. 1. Magnetic Barkhausen noise and incremental permeability, basic principles at hardened surfaces.

Fig. 2 gives an example for an inductive hardened steel 34 CR 4 (hardening depth 1.07 mm) where the analysing frequency $f_A$ is tuned from 50 kHz down to 1 kHz. In the upper profile the peak-distance of the two symmetric maxima (50 kHz profile) corresponds to two times the coercivity of the hardened martensitic layer. Decreasing the analysing frequency (5 kHz profile, in the middle) two additional peaks can be observed corresponding to the magnetic soft bulk volume. The effect is further enhanced for $f_A$=1 kHz. Using an analysing frequency in the lower range so that both microstructure influences can be separated in the profiles, the ratio of the amplitude maxima $M_{\text{maxsurf}}/M_{\text{maxbulk}}$ can be calibrated in hardening depths estimated by metallography- or microhardness-analysis as references. Fig. 3 shows our state of the art for 4 different steel grades (34 CR 4, 42 CRMo 4, CK 45, 20 MoCr 4) and the cast iron GTS 55. It seemed that more or less the steels follow an unique straight line, whereas the cast iron microstructure has a different behaviour. Nevertheless the results should be confirmed by a larger ensemble of specimens to obtain better statistical results.

Using an eddy current coil instead of a passive Barkhausen sensor the coil impedance change as function of the magnetization is a function of the incremental permeability $\mu_A$. The interaction volume is determined by the coil directivity pattern but mainly by the eddy current frequency $f_A$ and the alternating field amplitude $\Delta H$ of the coil. As far as $\Delta H$ is small related to the coercivity of the material to be inspected, the magnetization processes are reversible. Fig. 4 shows the application at inductive hardened surfaces of the cast iron GTS 55. The eddy current coil was driven by an alternating current $\Delta I=1A$ with a frequency.
Fig. 2. Barkhausen profiles of a 1.07 mm inductive hardened surface for different analysing frequencies \( f_A \).

Fig. 3. Barkhausen noise, calibration curves for hardening depth inspection.
The magnetizing frequency was 0.8 Hz. The eddy current coil was a transformer pick-up air coil with inner diameter 4 mm, outer diameter 9 mm, 100 windings (transmitter coil), 2000 windings (receiver coil) and a wire thickness of 22 μm, the resonance frequency was 146 kHz.

Comparable to the Barkhausen noise profiles now μA-profiles are obtained which allow the separation of the microstructures (hard/soft) in the profiles. As function of the increasing hardening depth (0.5 mm - 3 mm) the peaks of the bulk volume (small peak-separation) disappear. Fig.5 shows the result of a calibration with metallography as reference. The ratio of the peak-amplitudes μA(Hcbulk)/μA(Hcsurf.) gives a resolution in hardening depth-values up to 2 mm depth.

Fig. 4. Incremental permeability profiles for different hardened surface layers.

CONCLUSION

First results to the quantitative hardening-depth-measurements at steel- and cast iron surfaces were discussed using micromagnetic 3MA-techniques. Whereas the incremental permeability has a detectability up to 2 mm hardening depth, magnetic Barkhausen noise can be applied up to 4 mm hardening depth.
material: cast iron GTS-55/I

Fig. 5. Incremental permeability, calibration curve for hardening depth inspection.

REFERENCES


2. E. Schneider, I. Altpeter, W.A. Theiner, ibid., p. 115