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Self-magnetic-leakage field detection using magneto-optical sensor technique

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Abstract. Measurement of spontaneous magnetic stray field signals has been reported to be a promising tool for capturing macro-scale information of deformation states, defects and stress concentration zones in a material structure. This paper offers a new method for self-magnetic leakage field detection using a magneto-optical (MO) hand-held microscope. Its sensor has a dynamic field range between ±0.05 and ±2 kA/m and a lateral optical resolution of approx. 10 μm. We examined flat tensile test specimens of metastable austenitic steel AISI 304. Static tensile tests were repeatedly interrupted at various predetermined states of strain and the magnetic information was measured by the MO system. Comparative measurements using a high-precision magnetic field GMR-sensor, verify the outstanding capability of the MO microscope regarding spatial resolution of magnetic fields.

1. Introduction

The self-magnetic-leakage field (SMLF) detection is based on the assumption of "naturally" emerging magnetic fields in the presence of so-called stress concentration zones [1]. In contrast to traditional magnetic flux leakages testing, the samples are not intentionally magnetized by an external magnetic field [2]. It is assumed, that the distribution of the SMLF highlights areas of potentially pre-cracked and fatigued material zones. In addition, relation was reported between the SMLF and residual stress [3], hardness [4] and elastic/plastic deformation states [5]. Thus the SMLF detection could be a convenient method for evaluating areas of potential crack initiation. It is still to be clarified, whether these results will be confirmed using higher spatial resolution measuring techniques. In this study, the influence of martensitic phase transformation on the SMLF is the reference for comparison of a magneto-optical (MO) and a giant magneto resistance (GMR) high resolution measurement technique.

2. Methods

Flat tensile test specimens with narrows were cut from a sheet of metastable austenitic steel AISI 304 with a thickness of 3 mm. The total length of the specimen was 115 mm and the width was 7 mm at the narrowed section. Before and after the predetermined states of strain, we carried out the SMLF

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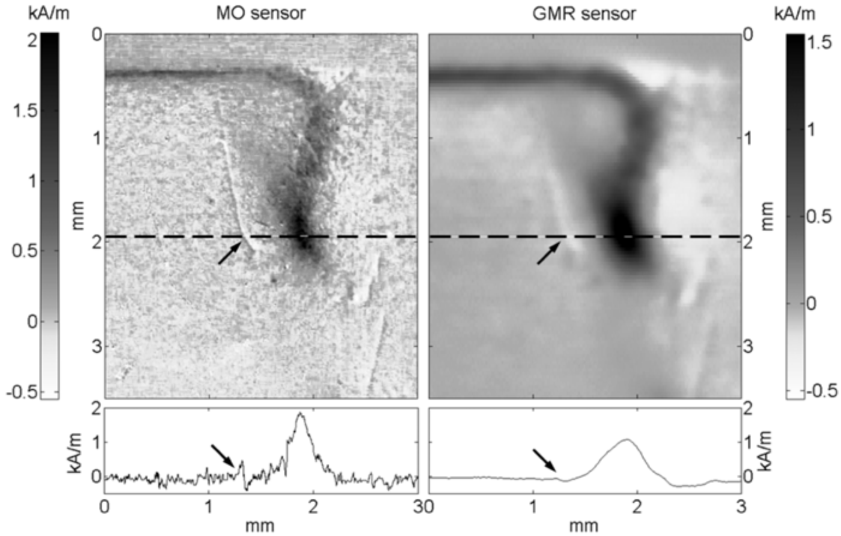

Figure 1. a) MO measurement of the middle section of specimen-4; b) multi-line GMR measurement of the same location; underneath each plot: the distribution of the SMLF along the dashed line. Arrows mark the location of the SNR evaluation. (Images were enhanced for publication purposes.)

measurements using MO and GMR technique. The principle of MO method is based on Faraday-effect. Its sensor coating works in direct contact with the specimen and magnetic fields are transformed into an intensity distribution. The sensor has a dynamic field range between ± 0.05 and ± 2 kA/m. Its size is $8 \times 8\,\text{mm}^2$. The lateral resolution of the microscope is on the order of $10\,\mu$m. As an alternative, we used a GMR sensor optimized for NDT applications with an active area of $25 \times 15\,\mu\text{m}^2$ and a dynamic field range between ± 3 kA/m.

3. Results and discussion

Usually SMLF detection is performed by relatively bulky magnetic inspection sensors providing a lateral resolution of about a few millimetres. Our approach shows that MO and GMR can provide a very high degree of information in which even very small magnetic variations can be detected in terms of field strength and spatial resolution. The performance ability of both methods using the example of a magnetic inclusion is presented in Fig. 1. The arrows mark the signal-to-noise ratios (SNR) for the same location, which are 11 dB for the MO sensor and 18 dB for the GMR technique, respectively.

The MO technique is direct, quick and obtains high-resolution 2D images. In contrast, the GMR multi-line measurements are more time-consuming and the results have a lower spatial resolution, caused by the size of the GMR's sensing area and a necessarily slight sensor lift off. Its high field sensitivity maintains an advantage. Even though it is not proved yet that this high degree of information can be transferred into a more reliable interpretation of SMLF results, we state that the MO and GMR sensor technique are feasible instruments for high resolution magnetic field detection.

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