INVESTIGATION OF THE MAGNETIZING YOKE’S INFLUENCE IN MAGNETIC ADAPTIVE TESTING

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Influence of the magnetizing yoke on the calculated magnetic descriptors of Magnetic Adaptive Testing was studied by measuring cold rolled austenitic stainless steel samples. It was found that the material and shape of the magnetizing yoke has no influence on the relative values of the descriptors, evaluated by Magnetic Adaptive Testing technique.

Keywords: Nondestructive testing, Magnetic Adaptive Testing, Ferromagnetic material, Magnetization curves

1 INTRODUCTION

Magnetic measurements are frequently used for characterization of changes in structure of ferromagnetic materials, because their magnetization processes are closely related to the microstructure of the materials. This fact also makes magnetic measurements an evident candidate for non-destructive testing, for detection and characterization of any modification and/or defects in materials and in products manufactured from such materials [1,2]. An alternative, sensitive and experimentally friendly approach to this topic, the Magnetic Adaptive Testing (MAT) method was considered recently [3]. This method is based on magnetic minor loops measurement and introduces general magnetic descriptors to diverse variations of non-magnetic properties of ferromagnetic materials, optimally adapted to the just investigated property and material.

In the present work MAT is applied on cold rolled austenitic steel samples. The influence of the material, size and shape of the magnetizing yoke on quality and sensitivity of the magnetic descriptors of MAT is studied.

2 EXPERIMENTAL

Titanium stabilized austenitic stainless steel, 18/8 type, is investigated. Stripe-shaped specimens, 20 mm wide and 60 mm long, were cut from the original 7.4 mm thick stainless steel plate. The specimens were annealed at 1100°C for 1 hour. Then they were quenched in water in order to prevent any carbide precipitation, and to achieve homogeneous austenitic structure as the starting material structure. The metallographic average grain size of the stainless steel specimens was 25 μm. The as-prepared stainless steel specimens were cold-rolled at room temperature to different strain, ε. As it was already discussed in more detailed way in [4], the originally paramagnetic austenite specimens became more and more ferromagnetic, as a consequence of the applied cold-rolling. The austenitic stainless steels are paramagnetic in the annealed, fully austenitic condition, and the only magnetic phase, which can be induced (e.g. by cold-rolling) in the low carbon austenitic stainless steels, is the bcc α'-martensite, which is highly ferromagnetic. This process can be followed easily by magnetic measurements.

A specially designed Permeameter [5] with a magnetizing yoke was applied for measurement of families of minor loops of the magnetic circuit differential permeability. The block-scheme of the device and the sketch of the yoke with a sample can be seen in Fig. 1. Two different (both in size, shape and material) yokes were used: one of them was made of soft ferrite, the other one is of laminated Fe-Si. The ferrite yoke, made of M2TN-B type soft ferrite material, was 16 mm long, 11 mm high, and the cross section of its legs was 5x6 mm. The iron yoke was made of a C-shaped laminated Fe-Si core and the corresponding size was 27, 26 and 8x10 mm, respectively.

![Fig. 1. Block-scheme of the Permeameter and sketch of the yoke](image)

The magnetizing coil wound on the yoke gets a triangular waveform current with step-wise increasing amplitudes and with a fixed slope magnitude in all the triangles. This produces time-variation of the effective field, \( h_a(t) \), in the magnetizing circuit and a signal is induced in the pick-up coil. As long as \( h_a(t) \) sweeps linearly with time, the voltage signal \( U(h_a,h_b) \), in the pick-up coil is proportional to the differential permeability, \( \mu(h_a,h_b) \), of the magnetic circuit

\[
\mu(h_a,h_b) = \text{const} \cdot U(h_a,h_b) = \text{const} \cdot \frac{\partial h_a}{\partial h_b} \cdot \frac{\partial h_b}{\partial h_a}
\]
The Permeometer works under full control of a PC computer, which sends the steering information to the function generator, and collects the measured data. An input-output data acquisition card accomplishes the measurement. The computer registers data-files for each measured family of the minor “permeability” loops, corresponding to each measured sample. They contain detailed information about all the pre-selected parameters of the voltage signal induced in the pick-up coil. The step of the magnetic circuit effective field amplification and interpolates the experimental data into a regular square grid of elements, \( \mu_i = \mu(h_{ai}, h_{bj}) \), of a \( \mu \)-matrix with a pre-selected field-step. The consecutive series of \( \mu \)-matrices, each taken for one sample with a value of the plastic strain, of the consecutive series of the more-and-more deformed material, describes the magnetic reflection of the material plastic deformation.

The matrices are processed by a matrix-evaluation program, which normalizes them by a chosen reference matrix, and arranges all the mutually corresponding elements \( \mu_i \) of all the evaluated \( \mu \)-matrices into a \( \mu(\epsilon) \) table. Each \( \mu(\epsilon) \)-column of the table numerically represents one \( \mu(\epsilon) \)-degradation function of the material.

The way of optimization of parameters obtained from the evaluated matrices is discussed in [6]. It is described how the most sensitive and at the same time the most reliable degradation functions can be picked up from the large data pool. The optimal \( \mu(\epsilon) \)-degradation functions of the investigated samples were determined according to this procedure. In all cases the measurement and the corresponding evaluation were made for both types of yokes. The most sensitive \( \mu(\epsilon) \)-degradation functions of the whole sample series are shown in Fig. 3, for each of the yokes, as a function of the strain.

![Fig. 3. The most sensitive \( \mu \)-degradation functions for the ferrite and iron yokes as functions of the plastic strain](image)

3 RESULTS

The induced signals in the pick-up coil, measured on the same piece of sample are shown in Fig. 2, for the ferrite and for the iron yoke. It is seen that the signals are rather different. This reflects the different behaviour of the whole magnetic circuit (yoke-air gap-sample).

![Fig. 2. The induced signals obtained on the same sample by using the ferrite and iron yokes](image)

The experimental raw data are processed by a data-evaluation program, which divides the originally continuous data of each measured sample into a family of individual permeability half-loops. Then the family, either of the top half-loops or the bottom half-loops or their average is chosen for next processing. The program filters experimental noise and interpolates the experimental data into a regular square grid of elements, \( \mu_i = \mu(h_{ai}, h_{bj}) \), of a \( \mu \)-matrix with a pre-selected field-step. The consecutive series of \( \mu \)-matrices, each taken for one sample with a value of the plastic strain, of the consecutive series of the more-and-more deformed material, describes the magnetic reflection of the material plastic deformation.

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4 DISCUSSION

Magnetic measurements were carried out with the aid of two different magnetic yokes. The consecutive series of \( \mu \)-matrices describe the magnetic reflection of the material modification very well. As it was proved in previous works [3,4,6], by applying the Magnetic Adaptive Testing method, the relatively small difference between the magnetic characteristics of the investigated sample series can be determined much more sensitively, than by the conventional methods.

Another advantageous and independent outcome of the tested method is the confirmation, that without magnetic saturation of the samples, measuring a series of minor loops
and performing MAT method on the obtained data-pool, reliable and sensitive parameters can be determined. Moreover, the relative measurement can be done with a ferromagnetic yoke attached to the sample, and the yoke does not even have to be large and very special. The method does not give absolute values of the traditional magnetic quantities, because of the non-uniform magnetic circuit and of the not-reached magnetic saturation, but evidently it is able to serve as a powerful tool for comparative measurements, and for detection of changes, which occur in structure of the inspected samples during their lifetime or during a period of their heavy-duty service.

Even if quality of the magnetic contact between the samples and the yoke was assumed to be stable, the magnetic circuits were certainly non-uniform and the magnetic values obtained from each measurement were rather effective magnetic parameters of the circuit than real magnetic parameters of the samples.

As can be seen in Fig. 3, independently of the applied yoke very similar dependences were found between the plastic strain and the optimum magnetic descriptors. This fact shows that by application of MAT really the samples’ characteristics are determined, and the remaining part of the magnetic circuit – if kept constant at each measurement – has no basic influence on the relative value of the calculated quantities. The feature of the magnetic circuit has an influence on the absolute value of the measured signal, but considering that the whole measurement is relative, and only the results, measured at the same conditions are compared, this fact has no influence on applicability of the method. Consequently it can be concluded that any of the investigated yokes is suitable for sensitive and reliable measurements.

5 CONCLUSION

The influence of the applied magnetizing yoke was investigated on the nondestructive magnetic characterization of cold rolled austenitic stainless steel samples when Magnetic Adaptive Testing method was used. It was found that exactly the same relationship with very similar sensitivity was obtained, regardless on the actual type of yoke.

The obtained results are considered to be very important, because if different relative dependencies within the same sample series would have been experienced by application of different yokes, the reliability and applicability of the whole MAT would be questionable.

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