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Influence of magnetizing current speed in magnetic adaptive testing

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Influence of changing rate of magnetizing current in magnetic adaptive testing was studied. Sensitivity of magnetic descriptors, which characterize the samples degradation, was found to depend on this speed. Low speed results in a better sensitivity, but the effect depends on permeability of the investigated specimens. Recommendation was made for the optimal choice of the applied speed of the magnetizing current.

Keywords: magnetic NDE, magnetic adaptive testing

1 Introduction

Changes in structure of ferromagnetic materials are frequently characterized with the help of magnetic measurements, because magnetization processes of ferromagnetic materials are strongly related to their microstructure. This fact also makes it possible to use magnetic measurements for non-destructive testing, i.e. for detection and characterization of modifications and defects in ferromagnetic construction materials and in industrial details made of them, see *eg* [1]. For a long time the structural properties of ferromagnetic materials have been successfully investigated by the traditional magnetic hysteresis methods. These methods are simply based on correlations between the material structural variations and behavior of the traditional macroscopic parameters of major hysteresis loops. An alternative, more sensitive method of such a measurement, has recently been considered in [2,3] based on analysis of families of minor hysteresis loops. The method, called Magnetic Adaptive Testing (MAT) introduces general magnetic descriptors. These magnetic descriptors are compared with the independently measured non-magnetic parameters of samples, which are generally used for characterization of material, but their measurement is frequently either destructive or at least complicated. The purpose of MAT is to adapt optimally the magnetic descriptors to the non-magnetic properties of the material. The method is very suitable for sensitive nondestructive characterization of structural changes in ferromagnetic materials. When influence of the sample shape [4] and influence of different ways of the sample magnetization were studied [5], it was found that their impact on applicability of the method is very low or even zero.

In one of our recent works another important experimental condition, namely speed of the samples magnetization, was analyzed. It is well known that in every inductive method the speed of change of the applied magnetic field has a great influence on the detected signal. The question is, how this speed qualitatively modifies the magnetic descriptors, which are used for characterization of the structural changes of the materials. In our previous paper [6] this problem was already studied and it was found that the sensitivity of the top-responsive degradation functions drops down significantly with increasing field-slope. In that paper a rather detailed description of the dependence of the signal and of the NDT sensitivity on the speed of magnetization of the low carbon, well defined ring samples, distorted by a uniaxial tension in the direction along the diameter of the ring was given. In the present work we investigate how the speed of magnetization change influences the evaluated magnetic parameters of samples having rather different magnetic behavior. The magnetizing currents speed dependence of MAT descriptors of the two different materials is also compared and analyzed.

2 Experimental

The investigated samples were titanium stabilized austenitic stainless steel, 18/8 type. 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. The as-prepared stainless steel specimens were cold-rolled at room temperature down to about 60% strain. The originally paramagnetic austenite specimens became more and more ferromagnetic, as a consequence of the applied cold-rolling. The stainless steels in the annealed, fully austenitic condition, are paramagnetic, and the only ferromagnetic phase, which can be induced (*eg* by cold-rolling) in the low carbon austenitic stainless steels, is the bcc α' -martensite. The conversion

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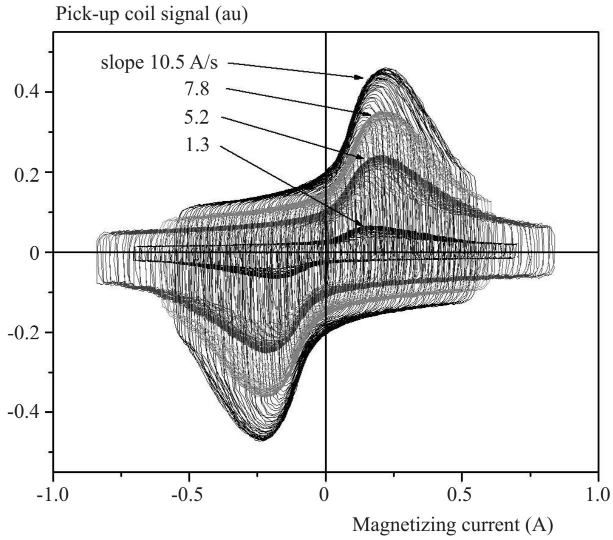

Fig. 1. Measured signal of the pick-up coil as a function of magnetizing current for different speeds of magnetization, in the case of the most ferromagnetic piece of samples

of austenite to martensite can be easily followed by magnetic measurements. The ferrite content of samples was determined by a Ferromaster device. Good correlation was found between MAT parameters and ferrite content.

A specially designed Permeameter [7] was applied for measurement of families of minor loops differential permeability of the magnetic circuit. The magnetization of the sample was carried out by 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 in the magnetizing circuit and a signal is induced in the pick-up coil. The magnetizing current rate of change varied between 0.7 and 38 A/s. The plate shape austenitic stainless steel samples were magnetized by a yoke. It was made of a C-shaped laminated Fe-Si core. It was 27 mm long, 26 mm high and the cross section of legs was 8×10 mm. The exciting coil and the pick-up coil were directly wound on the yoke.

3 Results

The signals induced in the pick-up coil, (measured on the most ferromagnetic one from the series) are shown in Fig. 1, as an illustration, for four different speeds of the magnetizing current. It is seen, how the measured signal is modified if the speed of the magnetizing current is changed.

The way of optimization of parameters obtained from the measured permeability curves is discussed in [5]. Fig. 2 shows the result of evaluation. It can be seen, how the optimal MAT parameter depends on the plastic deformation. The measurement and evaluation were performed at different speeds of the magnetizing current for the same series of samples, and this speed is used as a parameter in Fig. 2. All the degradation functions in Fig. 2 were normalized by the corresponding values of the first piece (the least ferromagnetic) of the investigated series of samples.

The influence of the speed of magnetizing current on magnetic descriptors is seen even better if the modification of degradation functions versus the speed is directly shown, as made in Fig. 3. Here, the optimal MAT descriptor values are given for the most ferromagnetic cold rolled austenitic stainless steel sample. The result is very similar to other samples of the series, which are not shown here, however. To make a comparison between the behaviour of materials having different magnetic properties, this Figure shows also the corresponding speed dependence of plastically deformed steel, which was studied in [6]. For proper comparison, all magnetic parameters in Fig. 3 are normalized by the corresponding value of the sample, measured by the highest speed of magnetization.

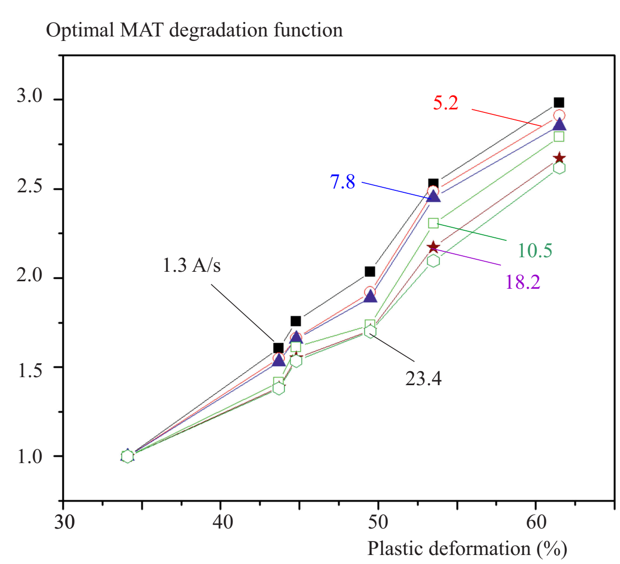

Fig. 2. The optimal descriptors, determined for the series of the cold rolled austenitic stainless steel plates, at different speeds of the magnetizing current

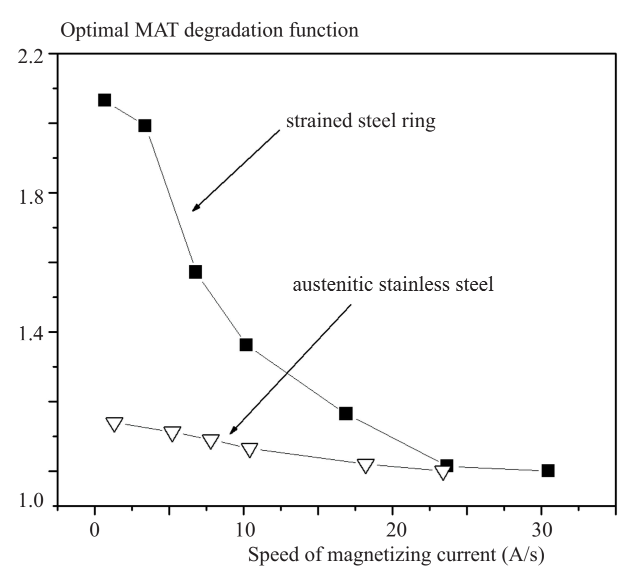

Fig. 3. Optimal MAT descriptors of the austenitic stainless steel and of a plastically deformed steel of ref.[6] as functions of the speed of magnetizing current

4 Discussion

It is seen very well, that the speed of magnetizing current has a great influence on the measured signal (Fig 1) regardless of the actual sample series. Both the maximal value of the induced voltage and the shape of the curves are modified. The signal to noise ratio also increases with increasing speed of the magnetizing current. This phenomenon is well known in all methods where inductivity is measured. Based on these considerations, and taking into account only value of the measured signal and of the signal-to-noise ratio, one can imagine that the higher the speed of magnetization, the more effective the measurement is. However, as it is shown in Fig. 3, the increasing speed of magnetization results in decreasing sensitivity of the measurement. Sensitivity in this case means, how sensitively we can distinguish between the members of sample series having different material degradation. This difference characterizes the structural modifications in the material, which is caused in the present case by mechanical distortion, but in other cases it can be due to any other effect, i.e. thermal treatment, neutron irradiation, etc. The final purpose of MAT is to follow these processes, so an optimal solution between the sensitively measured signal, and the sensitively evaluated magnetic descriptors should be found.

Figure 3 tells us also, that in spite of the significant difference in the measured permeability curves (see Fig. 1), where the top value of permeability is 8 times larger in the high speed case, than in the low speed case), the optimally chosen MAT descriptors, which characterize the structural changes in the material decrease only by 12% for the stainless steel samples, if the lowest and highest speed magnetization is considered. This is in contrast to our previous experience (see [6]), where plastically deformed steel was measured and the most sensitive MAT parameters decreased by 50%. In both cases dependence of sensitivity of MAT descriptors were observed on the applied speed of magnetizing current, but the scale of steep dependence is different. This is illustrated in Fig. 3, where the speed dependence of the most sensitive MAT descriptors is compared with each other for the two different materials. The main reason of different quantitative behavior of the two materials could be in the different values of their permeability. If permeability is low, the effect of slope dependence is much less emphasized.

5 Conclusions

The influence of the speed of magnetizing current during Magnetic Adaptive Testing was investigated. It was found that signal/noise ratio significantly depends on the speed. The higher the speed the larger the measured signal is, as expected in any inductive measurement. However, if we want to make large enough difference between samples, having different mechanical distortion, low speed measurement results in larger sensitivity. The optimum speed of the magnetizing field/current is not a general parameter, it depends on the actual conditions of the measurement. The observed speed-sensitivity depends on the actual value of permeability. In highly ferromagnetic steel significant speed dependence was found. In less ferromagnetic austenitic stainless steel the sensitivity is also experienced, but it is much less.

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