

Nondestructive inspection of plastic deformation in commercial carbon steels using magnetic Barkhausen noise

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Recibido el 12 de octubre de 2007; aceptado el 9 de agosto de 2008

The present work shows measurements of the Magnetic Barkhausen Noise (MBN) in commercial AISI/SAE 1045 and ASTM 36 steel deformed samples. The correlation between the MBN root mean square, Barkhausen signal profile and MBN power spectrum with the plastic deformation is established. The results show that the power spectral density of the Barkhausen signal is more effective as nondestructive evaluator than root mean square of Barkhausen signal. The outcomes also suggest the presence of unbalanced tensions between the surface and the bulk of sample due to the presence of plastic deformation.

Keywords: Magnetic Barkhausen noise; defects; plastic deformation; plain steels.

Se mide el Ruido de Barkhausen Magnético (MBN) en muestras comerciales de acero deformado AISI/SAE 1045 y ASTM 36. La establece relación entre la raíz cuadrática media de MBN, señal de contorno Barkhausen y la potencia espectral MBN con la deformación plástica. Los resultados muestran que la potencia de la densidad espectral de la señal Barkhausen es mas efectiva como evaluador no destructivo que la raiz cuadrática media de la señal Barkhause. Los resultados hacen pensar la existencia de tensiones desequilibradas entre la superficie y el volumen de muestra debido a la presencia de deformación plástica.

Descriptores: Ruido magnético Barkhausen; defectos; deformaciones plásticas; aceros planos.

PACS: 64.60 Lx; 75.60Ej

1. Introduction

The Magnetic Barkhausen Noise (MBN) is sensible to many microstructural features. That is the reason for which this effect can be used to evaluate some of these parameters, such as the carbon content [1-3], grain size [4,5], and plastic deformation in the material [6-10]. In particular, it has been shown that some parameters of the MBN such as the root mean square and the MBN profile depends on the plastic deformation [6-9]. However, the use of this and other parameters of the MBN, in order to evaluate the plastic deformation, is still unsolved.

In general, the plastic deformation in commercial carbon steels produces a decrease of the MBN signal [6,7]. Previous works, Stefanita *et al.* [7], have studied the evolution of the MBN parameters with the applied tension from elastic deformation to the plastic deformation condition. Additionally, Baldev *et al.* [8] have shown the influence of the plastic deformation on the MBN profile. These works reveal that:

- The applied tension (below the elastic limit) changes the magnetic domain arrangement due to the magneto-elastic effect [7].
- On the other hand, the plastic deformation influence on the magnetic properties of sample is due to two mechanisms:
 - (i) the increase of the number microstructural defects on the lattice in form of dislocation tangles.
 - (ii) the formation of a crystallographic texture with the development of a new easy magnetization axis, which occur at high deformation levels (higher than 10 %) [8].

The complexity of the aforementioned mechanisms is the cause for which it is difficult to find a MBN nondestructive evaluator for the plastic deformation. The present work is undertaken to establish the advantages of the power spectrum as a nondestructive evaluator of the plastic deformation.

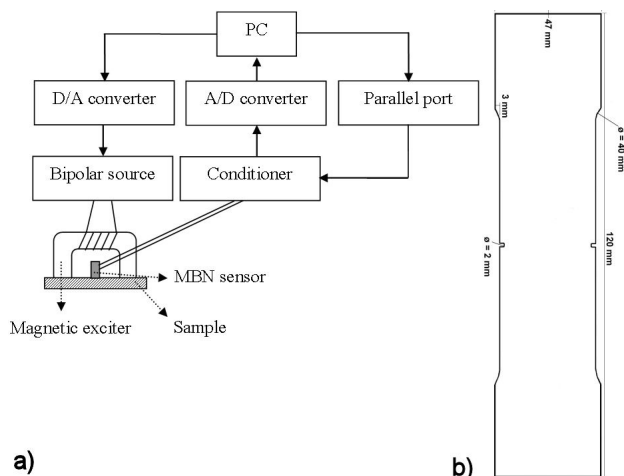


FIGURE 1. Experimental setup.

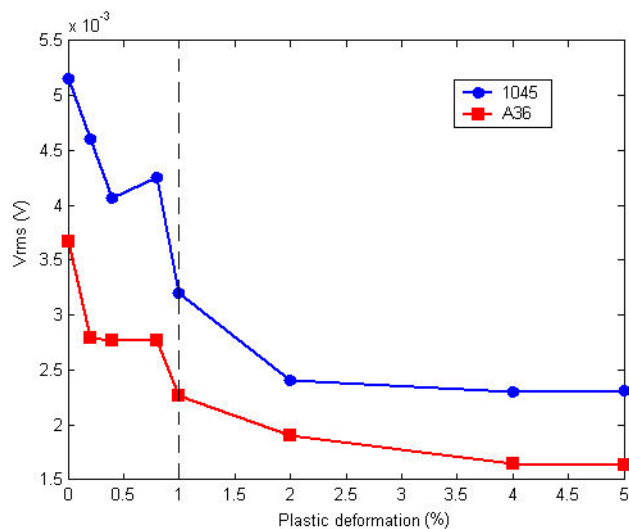


FIGURE 2. Dependence of Vrms of MBN on the plastic deformation in AISI/SAE 1045 and ASTM A36.

2. Experimental setup and materials

The measurement system is schematically shown in Fig. 1. A Personal Computer (PC) with a data acquisition device (with A/D, D/A and D/D channels) supplies a sinusoidal wave of 1 Hz, which is amplified by a bipolar source Kepco BOP20-20D that feeds the magnetic circuit in order to magnetize the sample using a magnetic field of $\pm 2.13 \times 10^4$ A/m, producing magnetic saturation in the samples. The MBN sensor output is amplified and band pass filtered (1 - 100 kHz). The MBN signals were visualized using a digital oscilloscope and a data acquisition device performed the digital acquisition with a sampling frequency of 200 kHz. A commercial magnetic head, placed on the sample surface, detects the magnetic signals induced by the domain wall motion.

The levels of plastic deformations are: 0, 0.2, 0.5, 1, 2, 4, 5%. The mechanical tensions were applied through a hydraulic tensile machine. The plastic deformation of the sam-

ple has been made along the longitudinal direction, which coincides with the direction of the applied magnetic field. Figure 1b shows the samples dimensions and shape.

For all the experimental measurements, the used samples (120 mm \times 47 mm \times 1.2 mm) were made of commercial ASTM 36 steel and AISI/SAE 1045. In order to obtain a statistical validation of the results 3 samples for each deformation condition and ten measurements for each experimental condition in each sample have been used, which is sufficient to obtain values inside the 95% of confidence. The residual tensions were reduced using a normalization heat treatment (700°C, 1 hour).

3. Results and discussions

Figure 2 shows the dependence of Vrms root mean square voltage of MBN on the plastic deformation (0 - 5 %) in the AISI/SAE 1045 and ASTM A36 steel samples.

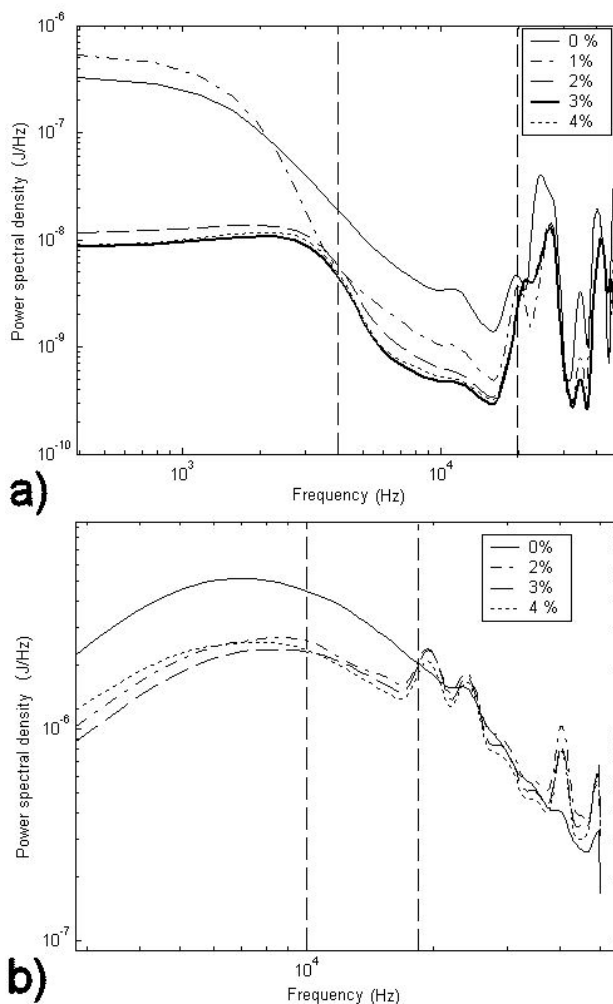


FIGURE 3. Power spectral density for different plastic deformation in a) AISI/SAE 1045, b) ASTM A36 steel samples. The power spectral density inside the dashed line presents a clear dependence with the plastic deformation.

It can be seen from this Fig. 2 that the V_{rms} decrease with the plastic deformation in almost all the range, from 0 to 5% deformation. However, it also can be seen from figure that the V_{rms} increases at 0.8% deformation. This phenomenon has been reported previously [6,7,9]. Nevertheless, the explanation of this fact is still unclear. This process has been attributed to the presence of local tensions at the grain boundary that increase the 90° domain wall movement [11]. However, this anomaly may be also attributed to the unbalanced tension between the surface and the bulk of the material [12]. According to Moorthy *et al.* [12] these tensions appear as a results of the shift between the surface layer of the material and the bulk due to the deformation process. The presence of unbalanced tensions could “help” the domain wall movement through the magneto-elastic effect increasing the MBN signal. This unbalanced tension can be studied using the power spectral density (PSD) of the MBN signal.

It can be seen from these curves that the dependence of the PSD for very high and very low frequencies on the plastic deformation is not clear. However, Fig. 3 shows that, for mean frequencies, the PSD always decreases with the plastic deformation. In the case of the AISI/SAE 1045 samples the same correlation was found. This fact has been attributed to the unbalanced tension between surface and the bulk [8] of the sample. Since, the value PSD depends on the penetration depth of the MBN signal which is inversely proportional to

the frequency. The high component corresponds to the upper surface of the sample, the lower frequency to the bulk of the sample and the mean frequency is below the sample surface. Thus, the value of the central region of the PDS can be used as nondestructive evaluator of the plastic deformation of the sample.

It can be also notice from Fig. 3 that the frequency band for the steel ASTM A36 is different from the steel AISI/SAE 1045. This phenomenon can be attributed to difference in some physical, chemical and microstructural features between these steels samples. These divergences in some parameters such as the carbon content and young modulus produce a different plastic deformation distribution. Thus the depth of the region, where shift between layers is produced, is not the same for both materials and the MBN frequency response will be also shifted.

4. Conclusions

The V_{rms} of the MBN generally decreases with the plastic deformation. However, this dependence for deformation values between 0.8 - 1% is not present. Nevertheless, the PSD for mean frequencies decreases with plastic deformation for all the range of plastic deformation. That is the reason for with this parameter may be proposed as a nondestructive evaluator of the plastic deformation.

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