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NONDESTRUCTIVE EVALUATION OF RESIDUAL STRESSES IN WELDED STRUCTURES

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ABSTRACT

A initial study about the use of the magnetic Barkhausen noise analysis as a nondestructive testing method for residual stresses determination in welded structures is presented in this paper. The test system calibration, the measurements of residual stresses and the results obtained are discussed.

Keywords: residual stresses, Barkhausen noise, nondestructive examination.

I. INTRODUCTION

Residual stresses are the stresses present in a material which is free from an external load or temperature gradients. They have strong influence on the in-service behavior of structural components and, depending on their nature, magnitude and distribution, they can contribute for increasing the component expected life or for its premature failure. Residual stresses are superimposed upon loading stresses and can promote the failure of the component by overloading. By other hand, failure can occur if the material or component is placed in a corrosive environment, by a stress corrosion process.

Generally, all of the manufacturing processes of structural components introduce residual stresses in the final products and several destructive and nondestructive methods are used to determine their value and nature. A recent method, based on the magnetic Barkhausen noise analysis have been used for this purpose. In nuclear industry, Barkhausen noise analysis have been used for residual stresses measurements in Steam Generators [1-3].

Barkhausen effect results from discontinuous changes on magnetization due to the interactions occurring between domain walls and pinning sites present into a ferromagnetic material, during the magnetization process. Domain walls motion is affected by the presence of structural discontinuities and mechanical stresses, which actuate as pinning sites to their movement, that occur in jumps, from one pinning site to the another [4]. For materials with positive magnetostriction Barkhausen noise increases under influence of tension stresses and diminishes for compression stresses [5]. This behaviour permits to perform measurements of the stress level in ferromagnetic materials after a specific calibration. For stresses measurements, calibration is carried out in standard conditions and consists in generating a known stress state in a sample of the same material to be tested and recording the magnetic Barkhausen (MBN) noise referent to it. This procedure is repeated for different stress values and a curve relating stress level and MBN amplitude is plotted and used for posterior evaluations.

II. EXPERIMENTAL METHODOLOGY

Instrumentation. MBN measurements were performed using a Barkhausen noise analysis equipment and an uniaxial probe, as we see in Fig. 1.

This equipment allows to control test parameters such as the excitation magnetic field amplitude and frequency and the analysis frequency. The probe incorporates a yoke, to exciting the material with a variable magnetic field and a pick-up coil, to detect the resulting magnetic Barkhausen noise. The material can be excited using a variable magnetic field with frequencies of 10 Hz or 100 Hz and the corresponding magnetic Barkhausen noise can be detected from depths of 0.05, 0.10, 0.20, 0.40 and 0.80 mm.

Measurements of strains during the test system calibration were performed with a PL-10-11 strain gage (TML). Residual stress measurements, using the Hole-

Drilling Strain Gage Method [6] were performed using a FRS-2-11 rosette (TML).

Figure 1. Magnetic Barkhausen Noise Analysis Equipment.

Materials. Welded plates of ASTM A 515 steel and SAC 50 steel were used in the experiments. The calibration test specimens and welded test specimens of ASTM A 515 were obtained from a 1000 mm x 1000 mm x 6,35 mm plate. The welded specimen of USI-SAC 50 was obtained from a 1000 mm x 500 mm x 12,7 mm plate. ASTM A 515 steel is a structural material for pressure vessels which operates at intermediate and high temperatures. USI - SAC 50 steel is a structural low-alloy steel that presents a high resistance to atmospheric corrosion allied to a good weldability.

Test Specimens. The experiments were conducted in two steps. The first one consisted in performing measurements of Barkhausen noise emissions in the USI-SAC 50 plates, before and after the welding. In this step, only qualitative results were obtained and a specific calibration for this material was not done. The second step consisted in determining the value of the residual stresses in the ASTM A 515 plates after the welding, using the Barkhausen noise measurements and the Hole-Drilling Strain Gage Method. In a specific location of the specimen, measurements of Barkhausen noise emissions were performed, in directions parallel and perpendicular to the weld seam. After this, in the same place, measurements of residual stresses using the Hole-Drilling Strain-Gage Method were carried out, in order to compare with the ones obtained by Barkhausen noise measurements. The material surface at the place selected to fix the rosette for the residual stresses measurements was prepared according to the conventional techniques of strain gage technology.

Calibration Samples. Magnetic Barkhausen noise amplitude is strongly dependent on the direction of the measurements. Thus, for the quantitative stress measurements performed in the ASTM A 515 welded specimen, two samples with the shape of a constant stress beam, as we see in Fig. 2, were prepared, to allow the test system calibration. The beams were machined from a plate of the tested material and their axes are coincident with the directions parallel and perpendicular to the rolling direction of the material, determined from metallographic examination and Barkhausen noise measurements [7]. They were identified as constant stress beams A and B respectively. The posterior measurements in other plates or components must be done in the same directions. After machining, the beams were submitted to a heat treatment for stress relieving and instrumented with strain-gages, oriented parallel to the beams axis. Surface preparation procedures for strain gage installation were similar to those used for rosette installation.

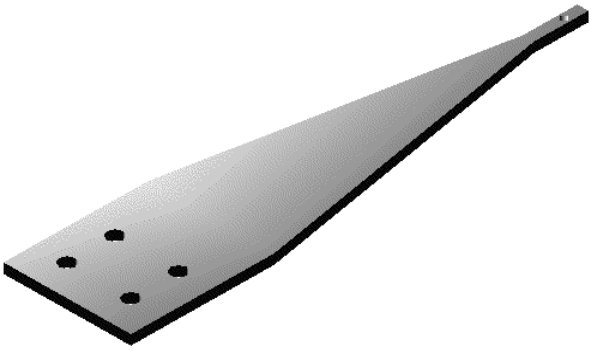

Figure 2. Constant Stress Beam Used in the Test System Calibration – ASTM A 515 Steel.

Test System Calibration. After instrumented, the beams were assembled in a special device as we see in Fig. 3. The Barkhausen probe was placed on the beams surface and parallel to the beam axis.

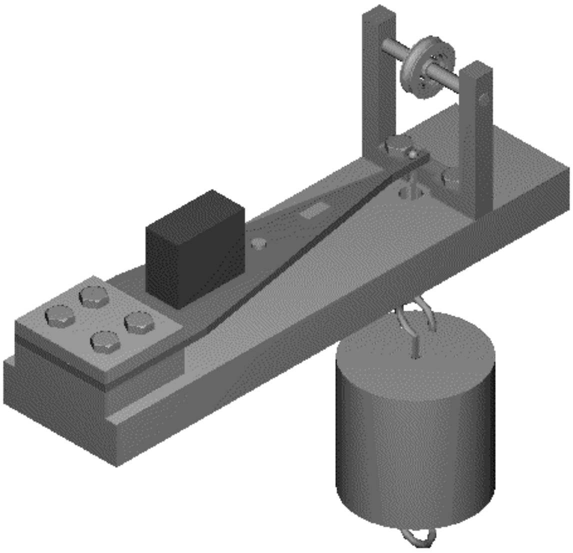

Figure 3. Device for Uniaxial Calibration of the Test System.

The loads were applied at the extremity of the beams, using a dead load system, generating tension and compression stresses at the beams surface. To each applied

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load, the corresponding strains and Barkhausen noise rms values were recorded and curves relating stress level and Barkhausen noise rms values were plotted, as we see in. Fig. 4 and Fig. 5.

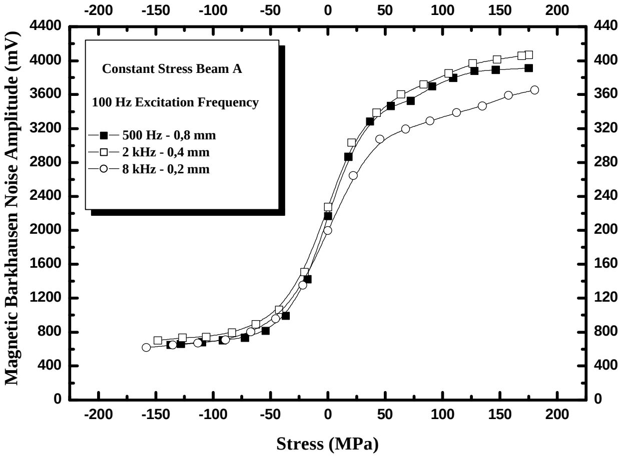

Figure 4. Calibration Curve for the Constant Stress Beam A.

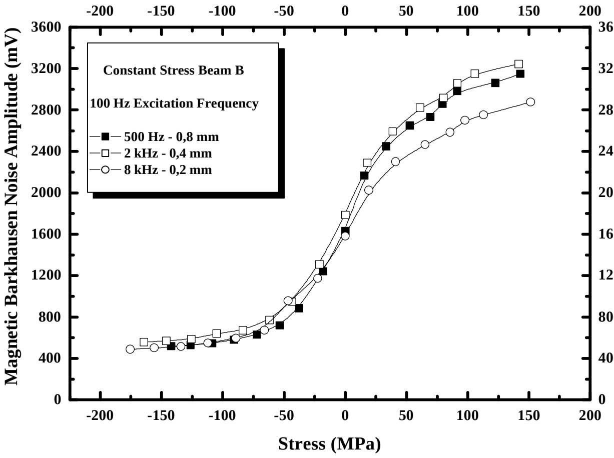

Figure 5. Calibration Curve for the Constant Stress Beam B.

These curves correspond to the calibration curves for the constant stress beams A and B and, consequently, to the directions parallel and perpendicular to the rolling direction of the material.

Residual Stresses Measurements. MBN measurements in the USI-SAC 50 steel were performed in the directions parallel to the weld seam, corresponding to the direction parallel to the rolling direction of the material and the results obtained indicate a change in the stresses profile before and after the welding, as we can see in Fig. 6.

MBN measurements in the ASTM A 515 welded specimen were performed in the directions parallel and perpendicular to the welding seam, in a specific location of the sample.

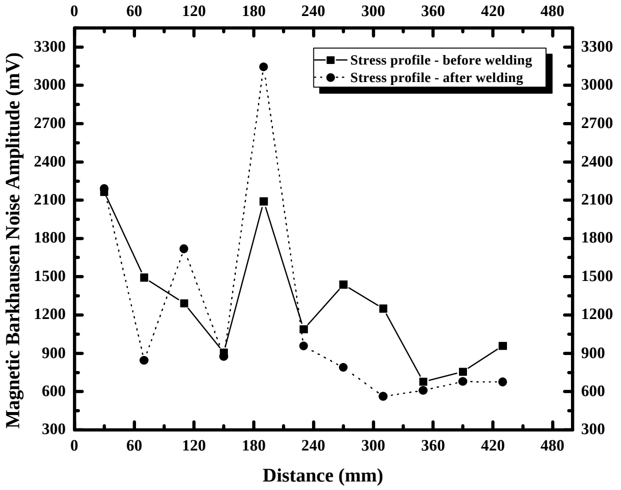

Figure 6. Stress Profile for the USI-SAC 50 Steel.

The values obtained were compared with those of the calibration curves and the value of the stresses based on MBN were determined. After this, a rosette used for residual stresses measurements was installed at the same place, with the elements 1 and 3 positioned in the directions parallel and perpendicular to the weld seam respectively. The value and directions of the principal stresses were determined by the Hole-Drilling Strain Gage Method. The results obtained from the two test methods can be seen in Fig. 7.

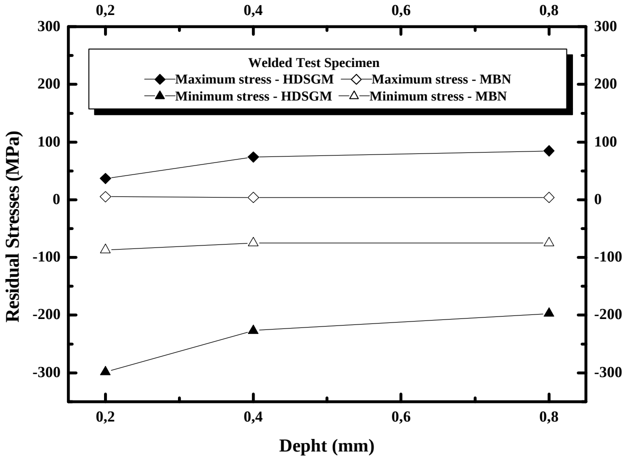

Figure 7. Residual Stresses Measurements Results.

III. DISCUSSION OF THE RESULTS

The calibration curves obtained from the constant stress beams A and B are shown in Figures 4 and 5. In these curves, we can observe two distinct regions, with different behavior. For low values of the tension and compression stresses, the relation between the MBN rms value and stress magnitude is approximately linear. After a certain level, the changes induced in the MBN value due to stress increasing, diminish until a point where a saturation occurs. For the material tested and the experimental set-up used, these points are 50% of the yield strength for tension stresses and compression stresses. The rms values of MBN obtained for the constant stress beam A are higher than the ones for the constant stress beam B. This behavior was expected because the axis of the beam A, coincident with the measurement direction, is parallel to the material rolling direction.

For the welded sample, the principal residual stresses determined by the Hole-Drilling strain-gage method occurred in the directions of the elements 1 and 3 of the residual stress rosette. The measurements of MBN in these directions indicated that this test method was sensitive to the changes in the material stress state but have limitations for high values of compression stresses. The MBN measurements indicate stresses values smaller than those obtained by the Hole-Drilling Strain-Gage Method for the principal stresses.

IV. CONCLUSIONS

The MBN measurements were sensitive to the stress changes occurred in the tested material. However, the results obtained for residual stresses measurements by this test method indicate stress levels smaller than the values obtained by the Hole-Drilling Strain-Gage Method. To obtain more conclusive results about the possibilities and restrictions to the use of this test method as a tool for quantitative residual stresses determination in structural materials it is necessary to perform more detailed experiments, with specimens submitted to different residual stresses levels and calibration conditions. The next step in this research will be the test system calibration under a biaxial stress state.

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