DAMAGE ASSESSMENT OF AISI 8620 STEEL SUBMITTED TO AXIAL FATIGUE

Tanius Rodrigues Mansur
Centro de Desenvolvimento da Tecnologia Nuclear – CDTN/CNEN – CP 941 – CEP 30123-970 – Belo Horizonte, MG, Brasil.
tanius@cdtn.br

Ernani Sales Palma
Pontifical Catholic University of Minas Gerais – PUC Minas – Belo Horizonte, MG, Brasil.
palma@pucminas.br

Silvério Ferreira da Silva Júnior
Centro de Desenvolvimento da Tecnologia Nuclear – CDTN/CNEN – CP 941 – CEP 30123-970 – Belo Horizonte, MG, Brasil.
silvasf@cdtn.br

***Abstract.**.Defining a variable to damage characterization is a complex problem, involving microscopic and macroscopic characteristics of the material. Two categories of test methods are used for this purpose, classified as direct and indirect methods. Optical microscopy, measurements of porosity and X-ray diffraction are examples of techniques considered as direct methods for damage evaluation. Measurements of the changes occurring in the elasticity module and microhardness of the material, as well as the magnetic Barkhausen noise are examples of indirect methods. In this paper, a study of damage evolution in specimens of AISI 8620 steel is performed by measurements of the changes occurring in the elasticity module, microhardness and magnetic Barkhausen emissions. The results obtained from these three methods are discussed.*

***Keywords**: fatigue damage, failure, damage assessment*

1. Introduction

The damage creation event in metals represents the creation of surface or volumetric discontinuities, microcracks and cavities respectively (Lamaitre and Chaboche, 1985). A material is considered free of damage (a virgin material), in the absence of microcracks and cavities at microscopic scale ($10^{-3} – 10^{-2}$ mm) in its body. A final stage of damage is the rupture of the material. Damage is defined as:

$$D = \frac{A_D}{A} \tag{1}$$

where D is the damage, A is the area of the transversal section of the considered volume element and A_D is the area of all defects present in transversal section A.

The methods used for quantitative damage evaluation are classified as direct and indirect methods. The direct methods allows evaluating the damaged area A_D. Measurements of the micro-defects density by microscopy, porosity by changes in the density and x-ray diffraction are examples of direct methods. The indirect methods are those where the damage evaluation is done from the measurements of the changing occurring in the physical and mechanical properties of the material, caused by the damage level induced in it.

The indirect methods can be destructive (Elasticity Module Changes Measurements Method, Ultrasonic Testing) or non-destructive (Microhardness and Electrical Potential Changes Measurements Methods, Barkhausen Noise Analysis) methods. In this paper, the experiments are performed by measurements of the changes occurring in the elasticity module, microhardness and magnetic Barkhausen emissions of specimens AISI 8620 steel.

2. Quantitative indirect methods for damage evaluation

2.1. Method of the elasticity module changes measurement

In the strain equivalency hypothesis (Lemaitre and Chaboche, 1985), the strain behavior of a damaged material can be described by the same laws applied to a non-damaged material, replacing the value of the stress by the effective stress. Thus, the equivalent strain is determined by:

$$\varepsilon_{eq} = \frac{\overline{\sigma}}{E} = \frac{\sigma}{(1-D)\times E} = \frac{\sigma}{\overline{E}} \tag{2}$$

and,

$$\overline{E} = E \times (1 - D) \tag{3}$$

where ε_{eq} is the equivalent strain, $\overline{\sigma}$ is the effective stress, σ is the applied stress, E is the elasticity module of the non-damaged material and $\overline{E}$ is the elasticity module of the damaged material. From Eq. (3), the damage equation can be written as:

$$D = 1 - \frac{\overline{E}}{E} \tag{4}$$

This method requires a high precision in the strain measurements. It is used mainly in the situations where the damage is uniformly distributed into the materials volume to be measured. For high cycle fatigue, where the damage is localized, this method is not adequate.

2.2. Method of microhardness changes measurement

Microhardness is a non destructive test method used for damage assessment of materials (Lemaitre et al, 1987). From the concepts of effective stress and equivalence of strains (Lemaitre e Chaboche, 1985) the microhardness of a damaged material can be obtained by:

$$H = K \times (R + \sigma_y) \times (1 - D) \tag{5}$$

Consequently, the microhardness for a non-damaged material can be obtained by:

$$H^* = K \times (\sigma_y + R) \tag{6}$$

In these equations, H is the microhardness of a damaged material, H* is the microhardness of a non-damaged material, σ_y is the upper yield limit, R is the mechanical hardening variable and D is the damage. From equations (5) and (6), the damage equation can be written as:

$$D = 1 - \frac{H}{H^*} \tag{7}$$

2.3. Method of Magnetic Barkhausen Noise Measurements

Magnetic Barkhausen noise is generated into a ferromagnetic material during the magnetisation process. It results from the interactions occurring between magnetic domains walls and structural discontinuities present in the materials microstructure (DHAR, 1992). The presence of structural discontinuities into the material, such as precipitates, inclusions, cracks and voids, acts as pinning sites to the domain walls motion which occur in a discontinuous way and promotes discontinuous changes in the magnetic flow (SIPAHI, 1994). These changes induce electrical signals in a coil placed in the material surface. The sum of all signals induced in the coil are called Barkhausen noise.

Dislocations, microcracks and voids genarated during the fatigue process act as pinning sites for domain walls, during their motion in the magnetization process, promoting changes in magnetic properties of the material and affecting the magnetic Barkhausen noise characteristics. This aspect of the fatigue process allows the quantitative damage evaluation from Barkhausen noise measurements.

3. Experimental methodology

The experimental set-up used for fatigue testing of the AISI 8620 steel specimens can be observed in Fig. 1.

Figure 1. Experimental set-up used for the axial fatigue testing of the AISI 8620 steel specimens..

3.1. Elasticity module measurements method

Three sets of fatigue specimens, submitted to axial fatigue loadings, were used for elasticity module measurements. For all specimens, the minimum applied stress was 30 MPa. The maximum applied stresses were 427 MPa (05 specimens), 485 MPa (07 specimens) and 580 MPa (08 specimens). Each specimen was submitted to a unique number of cycles. The strain gages used for strain measurements were installed in the central region of the specimens and after the fatigue loadings. The results obtained are shown in Figs. 2, 3 and 4. The first point in the graphics refers to the damage of a non stressed specimen.

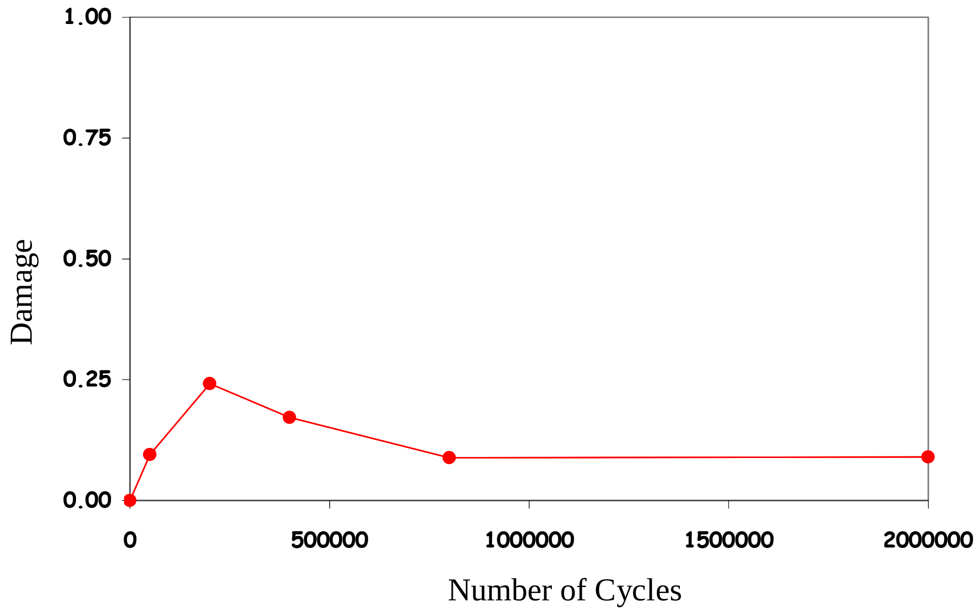

Figure 2. Damage determined from elasticity module changes method for SAE 8620 steel submitted to an axial fatigue loadings with applied stress of 427 MPa.

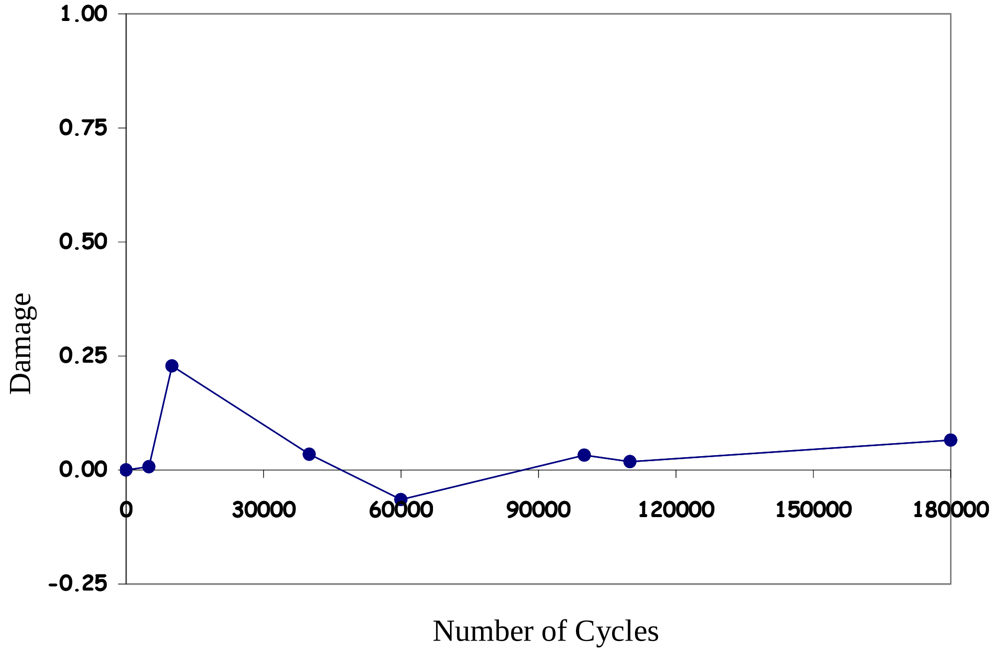

Figure 3. Damage determined from elasticity module changes method for SAE 8620 steel submitted to an axial fatigue loadings with applied stress 485 MPa.

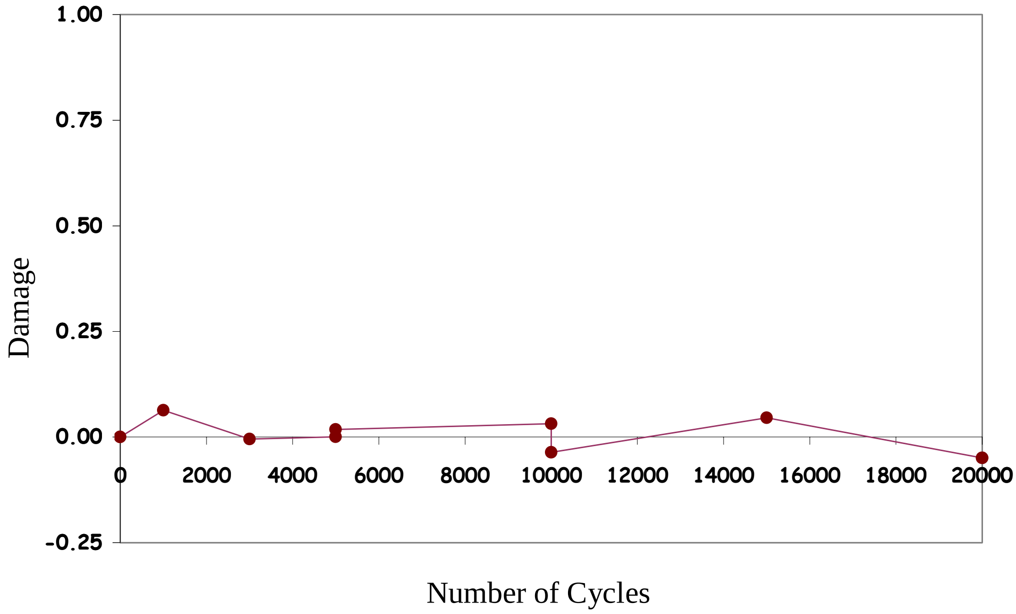

Figure 4. Damage determined from elasticity module changes method for SAE 8620 steel submitted to an axial fatigue loadings with applied stress 580 MPa.

3.2. Microhardness changes measurement method

The objective of determining damage by using the method of microhardness changes is verifying the proposal presented by Lemaitre, Dufailly e Billardon, considered one of the most promising theories for damage determination (Lemaitre e Dufailly, 1987).

Two sets of fatigue specimens (05 specimens each), submitted to axial fatigue loadings, were used for measurements of the microhardness changes. Measurements were performed after the fatigue failure of the specimens, in their transversal section. The results obtained are shown in Fig. 5.

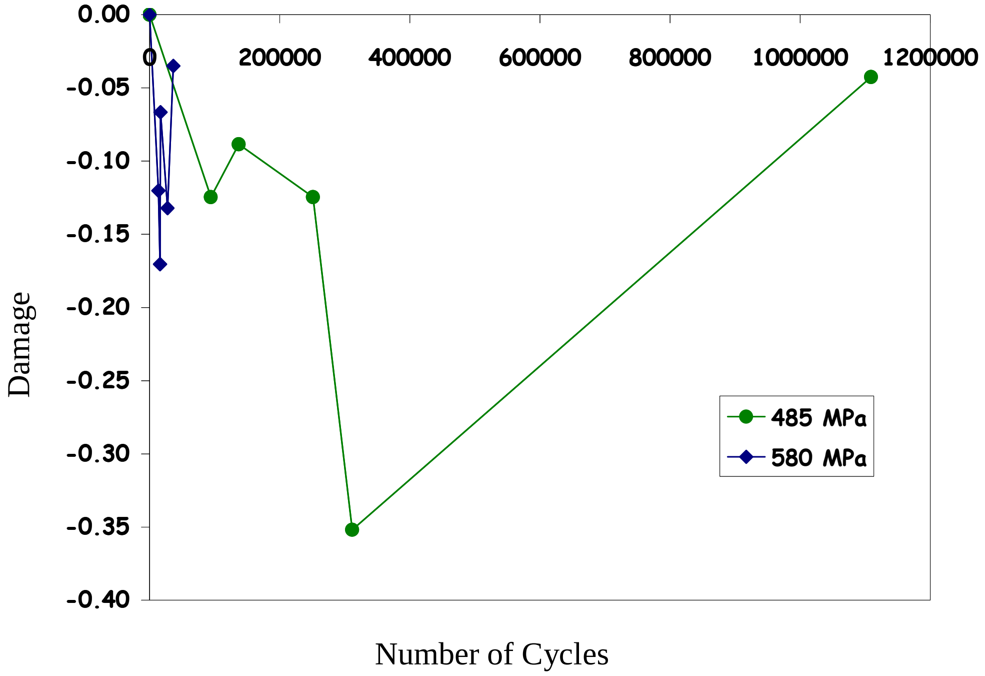

Figure 5. Damage determined from microhardness changes measurements method for SAE 8620 steel submitted to an axial fatigue loadings with applied stresses of 485 and 580 MPa.

3.1. Barkhausen noise measurements method

The fatigue tests of the specimens used for Barkhausen noise measurements were performed with five levels of the maximum stresses: 250 MPA and 259 MPa (loading frequency of 60 Hz), 427 MPa, 485 MPa and 580 MPa (loading frequency of 40 Hz). The measurements of Barkhausen noise were performed in the central region of the specimens. The results obtained are shown in Fig. 6.

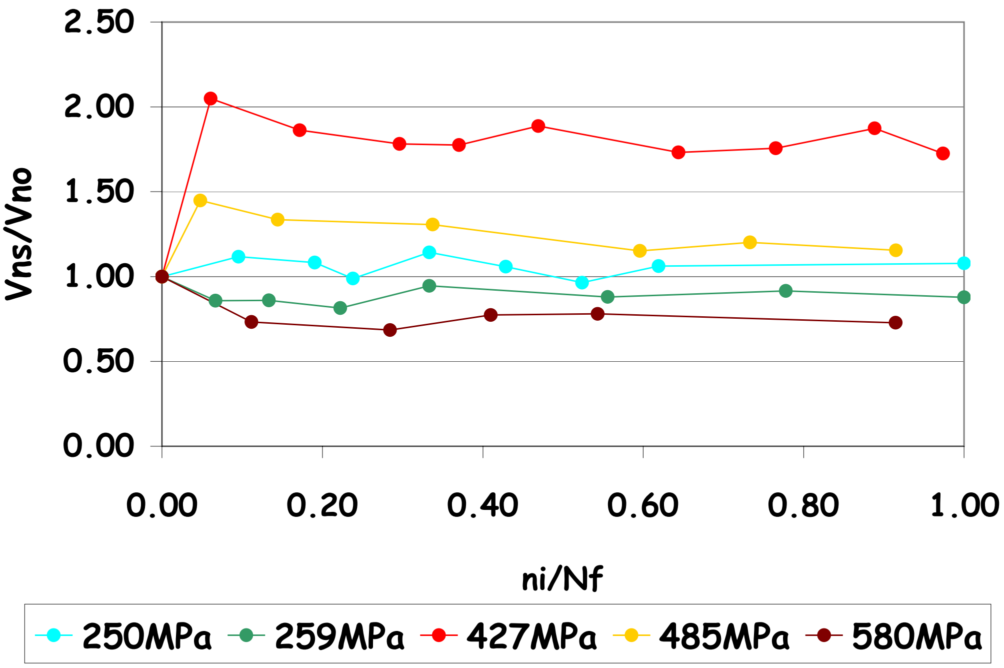

Figure 6. Damage determined from Barkhausen noise measurements method for SAE 8620 steel submitted to an axial fatigue loadings.

4. Discussion of the results

An increasing in the RMS value of the magnetic Barkhausen noise is observed in the initial stage of damage nucleation. After this, the magnetic Barkhausen noise decreases until that the fracture of the material occurs This behavior can be observed in Fig. 5, for the specimens submitted to axial fatigue with maximum stresses of 427 MPa and 485 MPa, above of the yield limit of the material (376±17 MPa). For the specimens submitted to a maximum stress of 580 MPa, near the strength limit of the material (607±32 MPa), the results obtained suggest the non applicability of this method for damage determination at this level of stress.

The results obtained from the Elasticity Module Changes Measurement Method, proposed by Lemaitre e Dufailly, a change in the elasticity module with the number of cycles could be verified, but none trends are observed. When the applied stress is below the fatigue limit of the material (194±5 MPa), the damage obtained from this method is insignificant. The analysis of the Figs. 2, 3 and 4 suggests a dependence between the applied stress and the number of cycles.

By the microhardness changes measurement method, the values obtained for the damage according to the proposition of Lemaitre et al (1987), using Equation 5, produces negative results. Thus, this proposition was not verified with the tests performed in this paper.

5. Conclusions

The magnetic Barkhausen noise is not adequate for damage measurements when the value of the stress applied to the specimens is near to the strength limit of the original material. It is necessary to define a region of damage nucleation and propagation in the specimens, in order to increase the Barkhausen test system resolution and to improve the quality of the data obtained.

Although the Elasticity Module of the original material be sensitive to the number of cycles in a fatigue testing, the proposal of Lemaitre e Duffaily for damage measurements using the elasticity module changes was not verified.

According to the results obtained, the microhardness changes measurement method was not adequate for damage measurements.

6. References

Chaboche, J. L., 1988, “Continuum damage mechanics: part I - general concepts”, Journal of Applied Mechanics. March 1988, vol. 55/59.

Dhar, A., Jagadish C., Atherton, D. L., 1992, “Using the Barkhausen Effect to determine the Easy Axis of Magnetization in Steels”, Materials Evaluation, pp. 1139-1141.

Lemaitre, J.; Chaboche, J. L., 1985, “Mécanique des Matériaux Solides**”,** Bordas, Paris.

Lemaitre, J.; Dufaily, J., 1987, “Damage Measurements”, Engineering Fracture Mechanics, vol. 28, nº 5/6, pp. 643-661.

Sipahi, L. B., 1994, “Overview of Applications of Micromagnetic Barkhausen Emissions as a Noninvasive Materials Characterization Technique”, Journal of Applied Physics, v.75, n.10, p.6978-6980.

7. Responsibility notice

The authors are the only responsible for the printed material included in this paper.