CONSIDERATIONS ON THE EFFECT OF PLASTIC DEFORMATION OVER THE MAGNETIC BEHAVIOR OF SOFT FERROMAGNETIC ALLOY FE-3%SI NO

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Abstract: The paper synthetically presents the results obtained over the degradation of magnetic properties of soft ferromagnetic sheets Fe-3%Si NO required mechanically in plastic deformation area. Chronologically, the evolution of magnetic behavior was considered from two complementary approaches: after plastic deformation and, recently, during a uniaxial traction/pull. The analyze of the behavior refers firstly to the structure of dislocation and, secondly, to the level of internal tensions generated during cold hammering..

Keywords: soft ferromagnetic, magneto-mechanic, internal tensions, plastic deformations

1. INTRODUCTION

The electric characteristic of the ferromagnetic material are sensitive at the mechanical require and metallurgical treatment. For example, the making of the sheets of the electric engine could cause a very important increase, up to three times upon the lost of power (Hubert and Hug, 1995;Ossard et al.,1999). Also, the measuring of the electromagnetic properties represents an interesting technique of the nondestructive control over the metallic structures, supplying pieces of information about the state of internal tensions, the level of cold hammering ,the microstructure. Our objective is to build an experimental device, that allows making electromagnetic measures <<in situ>>,during a mechanical requirement, in order to collect relevant pieces of information regarding the interaction between the mechanic and magnetic behavior of this materials.

2. MECHANICAL BEHAVIOR

The analyzed alloy,Fe-3%Si not-orientated, has a crystallographic and cubical structure with a centered volume. Therefore, the mechanical properties are characteristic for this category. The monoaxial traction curve is a typical curve with Luders's bearing and it has a length that depends on experimental conditions. Cold hammeringul (characterized by a cold hammering coefficient $\theta = d\sigma / d\varepsilon_p$) shows three stages, each one is associated with a distinct manner of deformation (Weertman et al.,1992) (fig. 1).

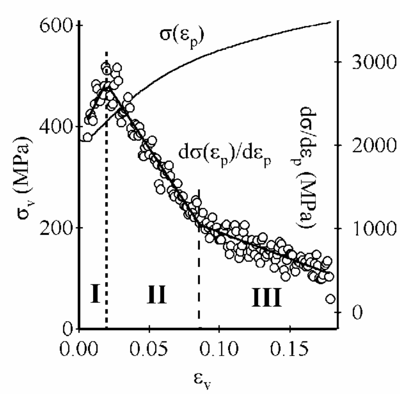

Fig. 1: The traction curve (depending on the plastic deformation and the cold hammering coefficient for the alloy Fe-3%Si and the deformation speed around 1,33.10^{-3}s^{-1} (Hubert,1998).

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The microstructural analysis of the dislocations with the help of an Electronic Microscope give emphasize to two main transitions : the <<amas>> forming with a dislocation for 3-4% plastic deformation and the appearance of a banded structure of high density with dislocation of approximately 9%(Hubert,1998).

The evolution of internal macroscopic X tension (a measure of cinematic cold hammering) according to the Lemaitre-Chaboche model (Lemaitre et al., 1998), can be emphasized in successive tries of loading-unloading in monoaxial traction. The internal tension can be decomposed in two components: (relation 1)

$$X = X_{intra} + X_{inter} \quad (1)$$

where X_{intra} and X_{inter} are the internal tension intragranular and intergranular. Through quantitative determination in electronic microscopy, one could reach the value of Xintra tension that develops progressively inside of a crystalline grain while the formation of the heterogenic structure of dislocation. One can draw the conclusion of the X_{inter} component's evolution.

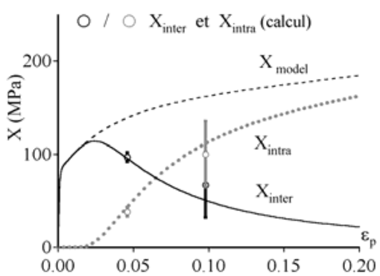

Fig.2: The schematic representation of the global internal tension X and X_{intra} si X_{inter} parts, alloy Fe-3%Si (Hubert,1998).

Figure 2 shows the appearance of an important internal tension that has an intergranular nature even from the beginning of the plasticity. As the dislocations organize themselves in bands, the intergranular internal tensions become prevailing. The phenomenon evolves towards the equilibrium between the increasing the density of the dislocation bands and the annulment of the dislocations that have opposite sign. This leads to a saturation of the internal global tension for the high values of the plastic deformation.

3. THE EFFECT OF PLASTIC DEFORMATION ON THE MAGNETIC PROPERTIES

3.1 Colinar measurements

The measurements have been done upon the traction epruvete that were plastically deformed and then unloaded, in a mechanically required way. The magnetic properties perceptibly wear down from the beginning of the plastic deformation (fig.3). The degradation is marked for the smaller values of the amplitude of the excitation magnetic field H_m, the domain is characterized by the magnetic Bloch walls that can be reversible and irreversible. The phenomenon becomes progressively dim for high values of the magnetic fields (fig. 4), when the material reaches the magnetic saturation and the magnetization is made thought the rotation of the magnetic moments.

3.2 <<Crossing >> measurements

Magnetic measurements have been made over the plastically deformed sample perpendicular on the direction of the mechanical requirement in order to emphasize a possible anisotropys of the magnetic behavior inducted by the plastic deformation. We can see in fig. 5 a more obvious degradation of the material when the measurement is made in the same way as the requirement. The degradation is smaller when the requirement is perpendicular on the direction of the measurement. This phenomenon remains true regardless the initial direction of the mechanical distress.

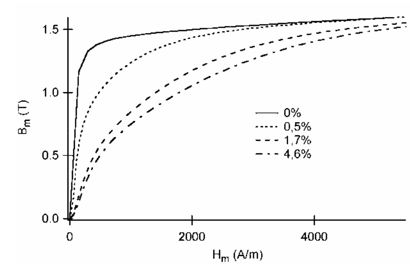

Fig.3: The normal magnetization curves of one alloy Fe-3%Si NO for some different values of the plastic deformation.

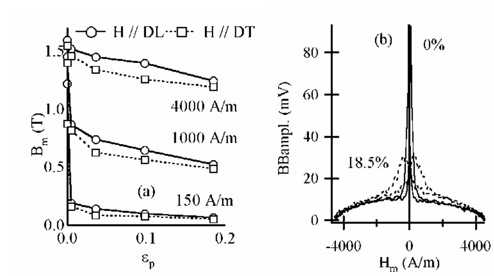

Fig. 4 : a) The B_m magnetisation for different values of the excitation field, measurements in the rolling direction of the Dlsheet and in the cross section direction DT [6] b) Barkhausen noise measured at 0.2 Hz for the alloy Fe-3%Si NO (Hug and Iordache,2000)

3.3 Hypothesis

The previous results (fig. 3,4,5) show that the plastic deformation generates a powerful degradation of the magnetic behavior of the analyzed alloy; the phenomenon was observed in previous studies (Neurath,1956 ;Szpunaet al.,1984) and also for other materials. Generally, this degradation seems to be caused by the appearance and the development of the dislocation's structure caused by the cold hammering; this dislocations become points of ancraj for the Bloch walls, hindering the magnetization of the material (Seegeraet al., 1964; Kronmüller, 1972) the same time, so far it has been accepted that the plastic deformations, unlike the elastic ones, have an scalar influence on the magnetic behavior (Sablik and Jiles, 1993). But, the results of the <<crossing>>

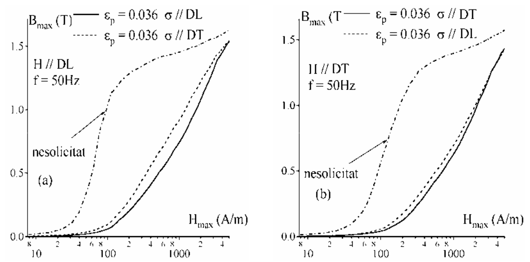

Fig.5: The magnetization curves of the alloy Fe-3%Si NO measured in the rolling direction and in the cross section direction(b) for a plastic deformation around 3,6%, the solicitation parallel with the measurement direction and in a perpendicular direction. Comparison with the not out of shape state.

Measurements (fig.5) emphasized a lightly tensorial character of the plasticity .The plastic domain is characterized by the existence of some important internal tension that have elastic nature in the metallic matrix of the material. That's why we can assume that anisotropy of the magnetic behavior in the plate plan is a consequence of the heterogenic distribution of this internal tensions.

4. MAGNETICAL MEASUREMENTS <<IN SITU>> DURING THE UNIAXIAL TRACTION/PULL

4.1 The experimental device

The ensemble of the previous results was obtained by characterizing the unloaded samples, after the remove of the mechanical requirement. So, we have built an experimental device (*Hug and Iordache, 2000)* which allows us to accomplish the measurements during the requirement for uniaxial traction. A general chart of the device is being presented in fig.6.

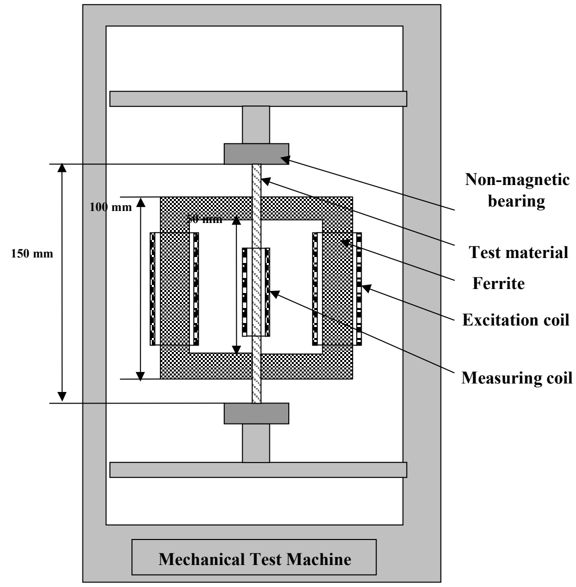

Fig.6: The general scheme of the magnetic characterization device during a uniaxial traction solicitation

The device consists of measuring banc which represents adjustment according to the international standard IEC404-3, 1992, the magnetic characteristics are being performed on a test specimen required in tractiune uniaxiala with the help of a machine that is used for mechanical attempts. The running principle can be understood form the chart of the supplying and acquisition of the system of data (fig.7).

The supplying block gives a sinusoidal current i(t) in the excitation primary winding arranged on a ironed core.This current is in fact a magnetic filed that closes-up in test specimen through the help of the ferrite.The variation of the magnetic stream, according to Farraday's law, induces in the secondary winding that surrounds the test specimen with a tension u(t) directly proportional with this variation.The primary current and the inducted tension are caught and processed from an informational point of view allowing the estimation of the magnetic values.

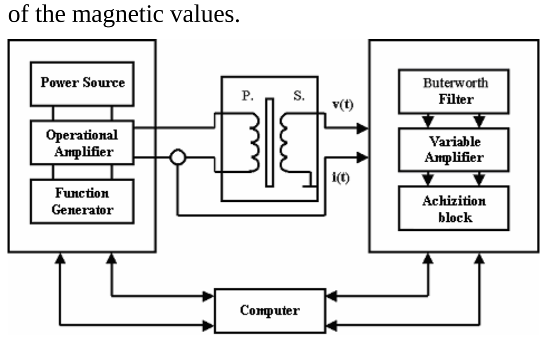

Fig.7: The block-scheme of the supplying and acquisition of the data's system.

The magnetic field is estimated according to Amper's theorem with relation no.3:

$$(2)\ \ H(t) = \frac{N}{L_m} i(t)$$

where N is number of coils the primary winding and L_m is the actual conventional length of the magnetic circuit(equivalent with the internal length of the ferrite)

Considering, from a point of view, the difference between the section of the secondary winding and the section of the test specimen and from another point of view, the variation of the test specimen of the section during the mechanical requirement and so we estimate the magnetic induction B in test specimen:

$$(3)\ \ B(t) = \frac{1+\varepsilon}{S_0}\left[\frac{1}{n}\int_T u(t)dt - \mu_0 H(t)\left(S_{bs} - \frac{S_0}{1+\varepsilon}\right)\right]$$

where ε is the conventional deformation of the sample , S_0 its inita l section and a number of coil of the secondary winding and S_{bs} ,the section of the secondary winding .

Finally, the total lost of energy P are estimated :

$$(4)\ \ P_t = \oint HdB = \frac{1+\varepsilon}{nS_0}\int_T H(t)u(t)dt$$

4.2 The magnetic characteristic

The tests, with an excitation frequency of 50 Hz, have been made on an test specimen from an alloy Fe-3%Si non-oriented, with a width of 0.35mm,required in uniaxial traction at values of the tension σ smaller and then bigger than the resilience limit σ_e. The analyzed points are presented in the chart from fig. 8.After characterizing the initial state (1), we have made measurements under the elastic load (2), under the plastic load (3) and in a proper state of unloading.(4) We should mention that the measurements under load in plastic domain had been accomplished after the mechanical stabilization, so, after the relaxation of the viscous component of the maximum tension. This manner of characterization was inspirited by Makar and Tanner's studies and pearlitic construction steel (Makar and Tanner,1998).

In fig. 9 we present the evolution of the parameters B_{max}^{1000} (the maximum value of the magnetic induction B_{max} for an excitation of 1000A/m) and P_{1T} (the losses of energy estimated fore a maximum induction level of 1Tesla) as well as for the measuring under the load that for the measuring in an unloaded proper state, depending on the real value of the tension barred by the test specimen.

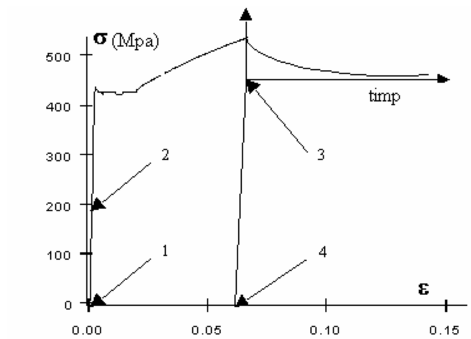

Fig.8: The scheme of magnetic characterization points of the test specimen during a loading-unloading solicitation in uniaxial traction

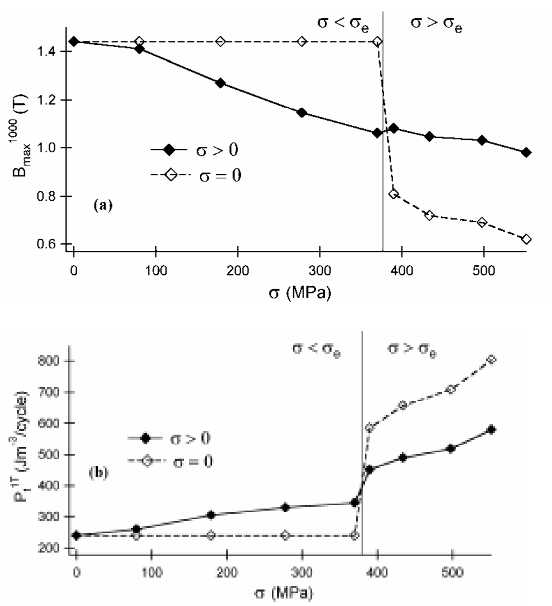

Fig.9: The evolution of the maximum induction B_{max} at 1000 A/m (a) and total losses of energy P_t at IT (b) for a test specimen Fe-3%Si NO during a loading-unloading solicitation in uniaxial traction (magnetic excitation frequency 50 Hz)

Regarding the measurements under load, one can observe that B_{max}^{1000} decreases almost linearly depending on the applied tension, the overcoming of the elasticity limit is not to be seen by using the magnetization curve of the material. On the other hand, the beginning of plasticity can be observed following the evolution of the total losses P_t. The leap of values of the energy losses that corresponds to the transition into the plastic domain is obvious in fig.9b.

The results obtained after the elimination of the request show that the magnetic properties are reversible in the elastic area and then they strongly wear down, starting with the smallest value of the plastic deformation. We also take into account the wear down, much more emphasized, of the material in an unloaded state in the plastic area then under the mechanic load.

5. CONCLUSION AND PERSPECTIVES

The experimental results presented show that the deterioration of the magnetic characteristic due to plasticity is made thought typical mechanisms, that take action especially over the losses of energy. The maximum value of induction that translates the capacity of the material to respond to a magnetic excitation, seems to be influenced only by the level of the mechanical tension applied, no matter whether we speak about plastic or elastic domain.

At the same time, it’s important to distinguish, from a magnetic point of view, between the state of mechanical distress and the unloaded state .The effect of the internal tensions that are characteristic to plasticity is much more emphasized when it comes to unrequested test specimens plastically deformed. The study of magneto-mechanic is now being made for other materials with distinct magnetically restrictive properties, such as the alloy Fe-Ni, also Ni, Co and simple Fe. We hope to obtain these pieces of complementary information regarding these coupling having as pragmatic final aim the harmless control of the metallic structures by electromagnetic measurements.

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