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Residual Stress Analysis in the Stainless Steel by Micro Magnetic Methods

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Abstract

The control by eddy current, Barkhausen noise (BN), hysteresis loop is a very much used technique in the nondestructive evaluation of materials.
These processes find a significant application in mechanical and metallurgical determination of materials parameters. The object of this work is to carry out an analysis of the residual stresses undergone by a material by the methods of non destructive testing by eddy currents (CF), Barkhausen noise (BN), Hysteresis loop. Different stainless steel samples were subjected to constraints (Tensile) with various procedures (time, load...).
Measurements by the magnetic techniques were taken in the critical zone. The analysis of the results will be compared with the results obtained by the traditional methods (X-rays diffraction...) in order to determine a relation between the non-destructive tests and destructive and the possibility to evaluating micro structural material and thus the critical components by the nondestructive methods.

Keywords: NDT, residual stress, eddy current, Barkhausen noise (BN), Hysteresis loop.

Introduction:

The electromagnetic properties of steels depend on their composition, their microstructures and applied stress.
It is thus natural to try to use the electric and magnetic parameters materials to evaluate their microstructures. The experiments carried out showed broad possibilities of analysis by the methods of non destructive testing (NDT), one using the electric and magnetic processes of the evolution of the various metallurgical characteristics.
It would be interest to use the latter to characterize materials and to determine the evaluation of the residual stresses which are creating by the application of the mechanical requests. The internal stresses can cause imperfection, degradation of the machine elements. This is why they are studied much out of metallurgy.
These solicitation influences will be evaluated by the methods of the eddy currents (CF), Barkhausen noise (BN) and it hysteresis loop which is a recent technique and it is very used in this field. The information contained in the received signal makes it possible to determine several parameters as the material analysis is the objectif. The interpretation of the signal is most delicate and difficult in the direction or it is always difficult to connect the signal to a mechanical or metallurgical event
.

Physical Approach.

The interaction between the constraint and the magnetic microstructure comes from the magneto elasticity phenomenon of ferromagnetic materials with positive magnetostriction [1-2]. Let us recall that this property is the opposite phenomenon of magnetostriction. In the case of iron, material with positive magnetostriction, the application of a tensile stress will favour the longitudinal magnetic fields, leading to an additional elongation of the sample. In this case, the transverse fields disappear. We notice that the stress measurement by the Barkhausen technique is directional. The initial morphology of the magnetic microstructure is conditioned by its past, constraint…

Magnetizing process is then mainly made up of wall movements of 180° and the material has a softer magnetic behavior. The privileged fields are perpendicular to the direction of the constraint and the magnetic field. The process of magnetizing is then more complex, with movements of walls of 90° and 180° [3-4].These two sensitivities are interesting because they allow to consider many applications in fields as varied as the effort measurement in the cables or the control depth and the surface heat treatments qualities [5-8] ... But this duality can often prove to be awkward because, in many applications, it is difficult, if not impossible, to conclude if the variations observed are micro structural or related to the internal constraints in particular [9-10]. Magnetic Barkhausen noise is an inherently random phenomenon, so only the average properties are reproducible. The curve fit makes use of many data points, whereas direct measurement depends only of small point numbers, and is therefore more sensitive to random fluctuations. The height is a measure of maximum Barkhausen activity, and is related to the steepness of the hysteresis loop. The width measures the range over which the MBN is spread, and is also related to the hysteresis loop steepness.

Many authors [11-15] have shown that it is possible to use BN to characterize traction or compression stress. Pasley [16] was one of the first to use BN to quantify stress measurements. He studied the evolution of the BN amplitudes as a function of to the stress level on a test tube. For a traction load, Pasley observed an increase in the BN amplitude in the elastic domain, followed by a zone of saturation when moving into the plastic domain. For a compression load, he detected the reduction of the BN amplitude in the elastic domain. Langman [17] studied the stress influence on the hysteresis loop shape on annealed condition mild steel. He showed that the hysteresis loop narrows when the measurement of the field parallels the applied stress, and becomes larger, though with a smaller amplitude, when the measurement of the field is perpendicular to the stress. Other studies have been done to determine stress using the BN level of pieces tempered at different temperatures and having different degrees of hardness [6-7], also on materials with different micro-structures [18].

Experimental Approach

The parts carried out were subjected to a definite experimental procedure in order to obtain different mechanical modification in material. We have chosen the Z 15 CN 16-02 stainless steel type for our study**.** A physicochemical analysis was carried out to find out the steel nuance used.The dimension samples are 300x40x2 mm3. They were taken on the same sheet for the same structure.

The test-specimens were cut out and were machined in conformity with the French standard NF A03-160. These test-specimens were subjected to tensile stresses. In order to be in strong solicitation case in the critical zones, we have taken two charges:

- A load higher than the elastic limit (state 1) correspondent to the F1.
- A load close to the rupture limit (state 2) correspondent to the F2.

These forces were applied during one hour. Measurements by probes with eddy current, by electromagnet (BN, Hysteresis loop) were taken every 05 minutes. Acquisition systems were located on the critical zone level.
The data acquisitions were done by a PC connected by an interface IEEE 488. Optimum condition works were taken in consideration in order to avoid systematic or experimental errors.

1- Sample subjected to a force F_1 during one hour with measurements by eddy current every 05 minutes by two probes.
2- Another steel sample subjected to a force F_2 during one hour with measurements by eddy current every 05 minutes too.
3- Another sample subjected to the method said »continue" witch consists in applying the force F_1 during one hour, than discharge to 0, and than applied the force F_2 during another hour. Acquisitions were carried out during each load, every 05 minutes.
In eddy current control it is necessary to carry out the characterization of the probe according to the case studied. Study feasibility depends strongly on the probe used and the material treated. In this work, we will quote the impedance diagram only, because it summarizes in itself the stability of the probe used. Moreover it enables us to determine the optimal frequency allowing a maximum energy exchange between the probe and material and a satisfactory penetration depth.
As the stainless steel used was ferromagnetic, we used two other techniques to measure the appearance of the constraints in material. Barkhausen Noise and hysteresis loop. . The signal collected is amplified and filtered. Acquisitions were carried out by a numerical oscilloscope which allows the signals digitalization.
The comparison was done between the NDE results and X-rays diffraction. A diffractometer " X PERT PRO MPD " of the Philips company was used. The data acquisition was done on the PC, using software carried out in graphic programming language.

Results and Interpretation

The results treatment obtained by eddy currents on the stainless steel samples shows the oscillations with a 55,8 ohm amplitude peak at 25 minutes for the load F_1.
A stability of the impedance with low oscillation is perceived beyond 15 minutes around 53,8 ohm. For the load F2, contrary to the load F1 we observe the impedance decrease but the oscillations are more significant and the high amplitude (figures 1-2).
That is explained by the electromagnetic movements, which are more significant in this case. The load applied F2 causes movements in the microstructure which is reflected on the conductibility of materials. That can be explained only by the size of the grains which undergoes the material by these solicitations and thus an agitation microstructural.
The electromagnetic movements are random and the internal stresses sudden by the solicitations answering differently from a sample another without differentiating in the content. We notice that the peak shifted at 30 minutes for the same load. Stability is perceived beyond this time. By the internal stresses undergoes by the traction solicitation .Stainless steel produces a microstructural movements which is accompanied by electromagnetic movements and consequently by the impedances oscillations.
The stainless steel is ferromagnetic. The analysis methods of the microstructures are generally done by BN or the loop hysteresis. The FFT analysis obtained of the BN shows for the charge F_1 according to time (Figure 3) the number of oscillations is important with high amplitude located between t = 10-20 minutes .After t=20 minute we have a fall important of amplitude and a stability around 150mv. That implies that the magnetic domain

penning is variable according to the charge time. This pinning generally is made on the level grain boundaries. It's maximum for t = 15minute. For a F_2 load, the first observation is the decrease in the amplitude of the FFT compared to F_1 load.

For F_2 and t>¨10 minutes, a fall of this amplitude is to be noted with very stable oscillations around 81 mV (figure 4). For the continuous case, in the F1 charge, the same observation is verified. The results are not repetitive, the amplitudes are not the same ones but the signal shape is identical.We notice that the oscillations for the case continues are more significant but the amplitude variation according to the charge time is weak. F2 load application in the case continues provokes a decrease of the FFT amplitude.we observe a fall of oscillation number according to the load time (Figures 5-6).That is explained by electromagnetic movements and thus microstructural movements. A significant reduction in the oscillation number between F_2 and F1 shows that specimen tends to stabilization and thus the magnetic aspect of material tends towards saturation.

In conclusion to this analysis on the FFT according to the load time, we notice that the amplitudes of penning are significant and fluctuate. That is explained by the presence of the constraint which modifies the magnetic movement and thus the grain boundaries in a random way. The amplitude of peak is more important in the F1 charge application. That implies the presence of the constraints within the microstructure of material .

For the peak number, generally it informs us on the state micro structural. We will consider only the peaks of amplitude higher than 50% of the maximum amplitude or we suppose that the influence is significant on the microstructural state and can be quantified.

The F_2 load results show that the peak number is constant until 20 minutes of load. After this time, the peak number increase and the amplitude is more significant (Figure 7-8).

That indicates us that the number of peaks found by the BN study is always in relation with the events number which occur in the aspect microstructural or nonstructural in the material subjected to the external constraint.

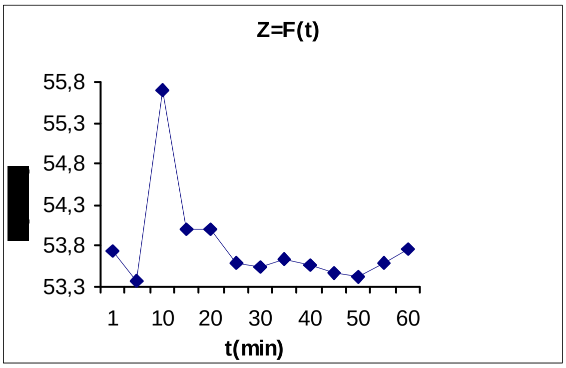


Figure 1: Impedance according to the load time of F1=26KN

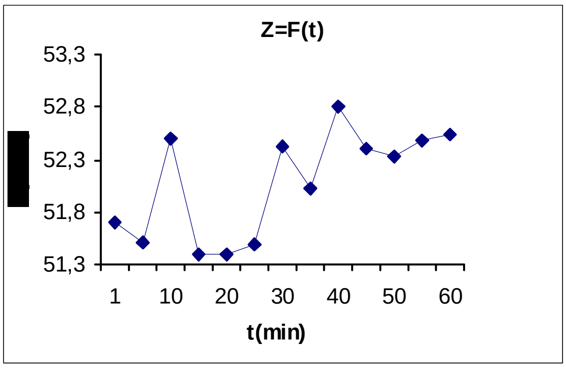


Figure 2 : Impedance according to the load time of F1=27,5KN

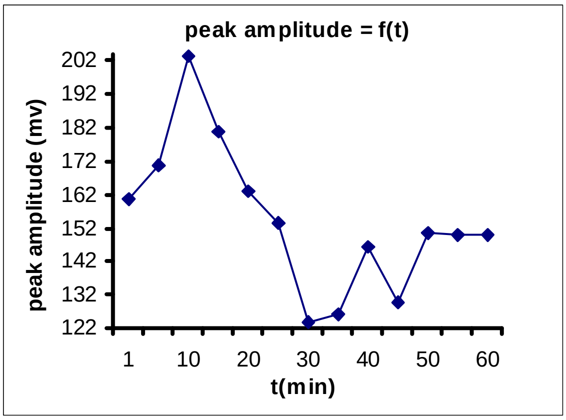


Figure 3 : Amplitude of the principal peak of the FFT according to the load time of F_1=26KN

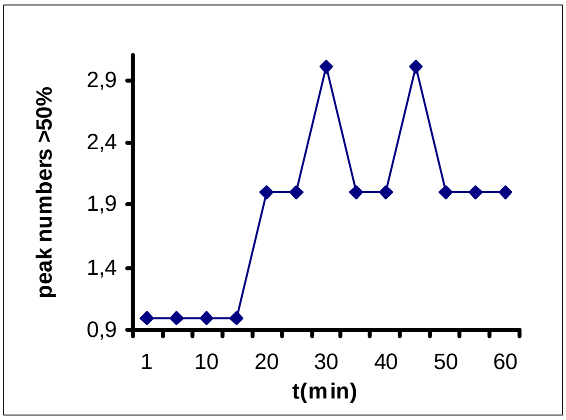


Figure4 : Numbers Peak of FFT(> 50%) according to the load time of F_1=26KN

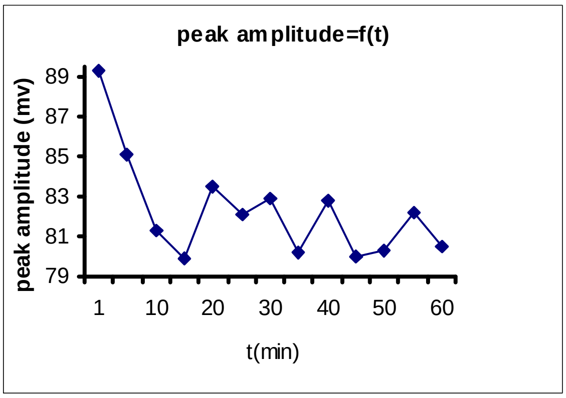


Figure 5 : Amplitude of the principal peak of the FFT according to the load time of F_2=27,5KN

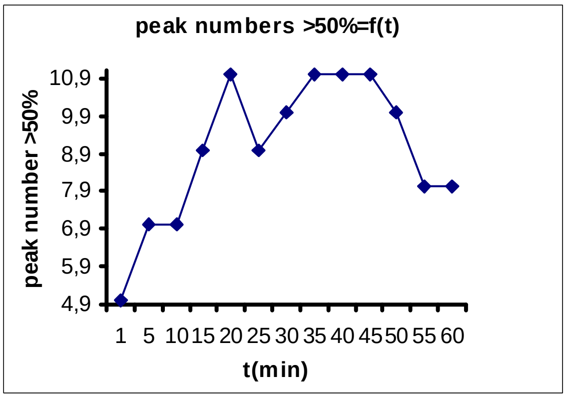


Figure 6 : Numbers peak of FFT(>50%) according to the time of load F_2=27,5KN

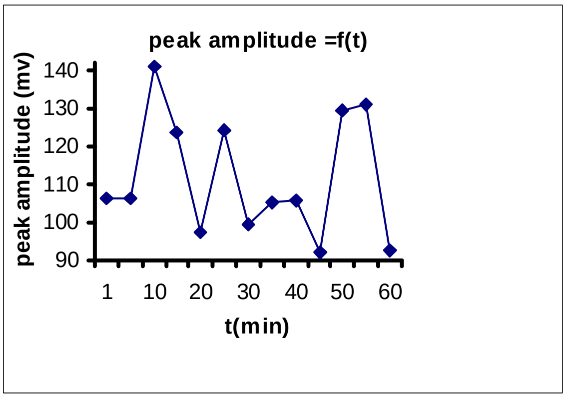


Figure 7 : Amplitude of principal peak of the FFT according to the time of load F_1=26KN « continuous»

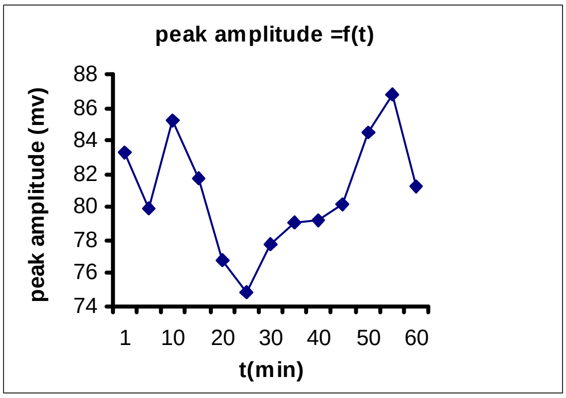


Figure 8 : Amplitude of principal peak of the FFT according to the time of load F_2=27,5KN« continuous »

For the load continues, a comparison between the two curves obtained (Figures 9-10) shows that the number of peak is more significant for a load F_2 and thus the number of event are more significant.
In conclusion on the peak number, we notice that for a load on verge of rupture the number of event increases and thus the number of constraint increases.
With regard to the principal peak position, results obtained shows that for a load F_1 according to the load time shifts slightly towards the right (figure 11). For a load F2, this shift is more visible (figure 12). The curves obtained in the figure 11 and 12 show the shift between the F1and F2 charges
The comparison between the F1 and F2 load, in the case continues, show this shift. The solicited specimen by F_2 force shifts the peak principal towards the right (Figures13-14).).
The influence of the load time on material by the constraints applied is shown by the graphs (figure(11-13). Indeed to take notice that the amplitude changes according to the charge time, moreover the width at peak half is different according to solicitation time.
This analysis is very significant in the possibility to determine the structure life time. «Prediction life material ».The results obtained by the hysteresis loop treatment give estimation on thehe results obtained, we note that for F1 load the material loses its capacities to store magnetic energy , and for the loa magnetic behavior of material. Indeed the analysis

quoted previously is confirmed in the sense that the fields coercitive Hc, remanence Br or the

rength modifies Hc, Br, Bs (figures 14-17). This variation of Hc and Br can be caused only by the internal solicitation.
In conclusion on the continues test, according to td F2 the material loses its remanence and tends to become " non ferromagnetic ".
In order to check the results obtained by Non Destructive methods, we carried out tests of x-ray diffraction. We notice from the results obtained by x-rays diffraction on the samples subjected to a charge F_1 according to time in the case of F1 alone and F1 continue is different and depend on the constraint created randomly. Indeed the same remark is obtained by x diffraction for samples subject to F1 charge and tested by eddy current testing, BN or hysteresis loop, methods .This important observation is obtained by the non destructive testing methods. The answer of measurement by NDT methods or by X diffraction depend enormously of the residual constraint. The spectrum lines obtained by diffractions for the samples subjected to the same load are different (figure 18). The residual stresses are random behavior and then the results obtained by diffraction or by NDT methods are not necessarily repetitive.

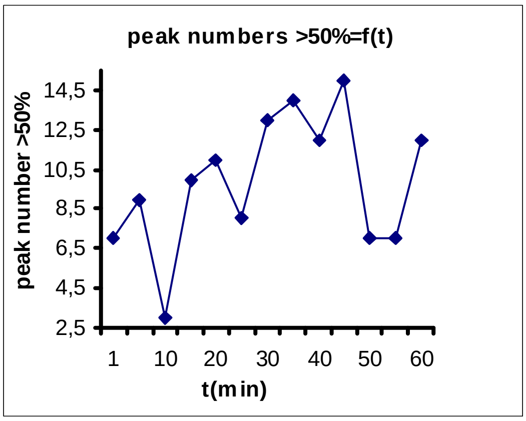


Figure09 : Numbers peak of FFT (>50%) according to load time of F_1=26KN« continuous»

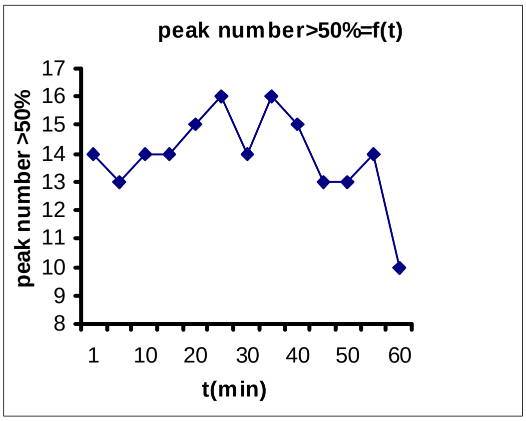
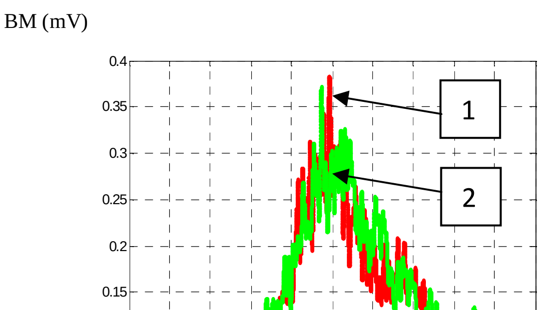
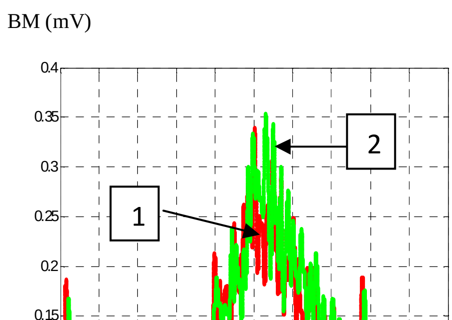


Figure10 :Numbers peak of FFT (>50%) according to the load time F_2=27,5KN« continuous »





The X diffraction analysis shows that lines variation position in the 2è indicates that residual stresses exist in material. This result is significant because it shows that the existence of the residual stress can be determined and thus quantified after , indeed the same shifts of the peak principal towards the right according to the applied load is noticed. The second remark is that the amplitude increases if the load F_1 or F_2 or the continuous test is applied (Figure 19) The same results are obtained by non destructive testing methods. Indeed, we noticed the shift of the principal position of the peak when it subjected to loads F_1, F_2 or continuous. Moreover analyses by NDT make it possible to check in real time the evolution of the maximum amplitude peak according to the load time.

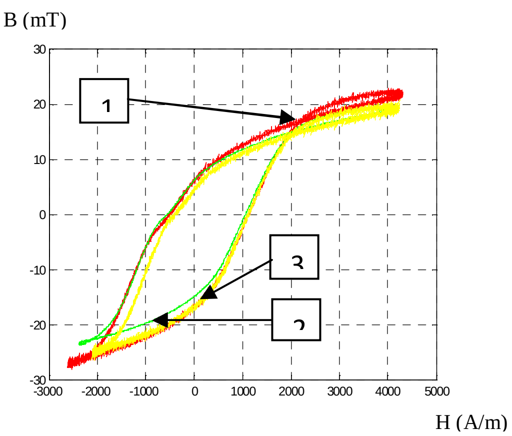


Figure15: Hysteresis loop at t=1,10 and

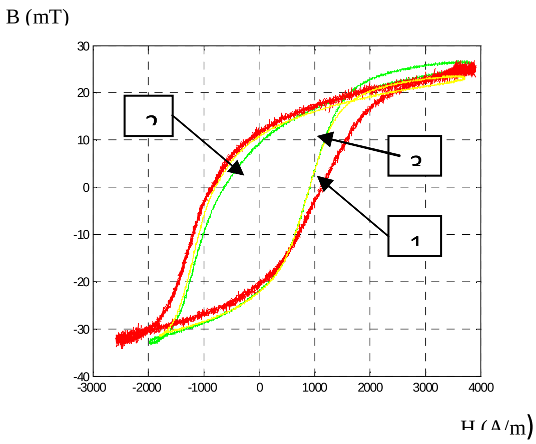


Figure 16 : Hysteresis loop at t= 1,10

Conclusion

The investigation in this field being very competitive, The NDT techniques as the eddy currents (ET), the Barkhausen Noise (BN) and the loop hysteresis can give by their sensitivities a significant place to solve complex mechanical and metallurgical problems in industry and the aerospace in particular.

The simplicity of these techniques and the various advantages which they offer in the determination of the intrinsic properties of materials allow the evaluation of material.

Analysis NDT results confirm that the oscillations obtained by eddy current, BN, hysteresis loop are due to constraints in the material in the real-time caused by the tensile stress.

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The coercitive force Hc, the remanence induction Br, and the saturation Bs determine the microstructural or nanostructural state which exists in the material level caused by the external charge in real-time. Results obtained by NDT was confirmed by X diffraction.

The same manner as x-diffraction, the NDT techniques shows fluctuations on the peaks amplitudes created by internal stress caused by the uniaxial stress.

The most significant result is in addition to the shift of peak obtained by X-rays diffraction or by BN according the load time, coercitif, remanence, saturation and the the width with middle height of the BN according to the charge time explain clearly that the samples are in unstable states by the constraint presence .This constraint would be quantified in the future and allows the installation prediction life analysis.

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