Mechanical Stress Analysis by Eddy Current Method

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Abstract: A lot of progress is made in the last decade concerning the theoretical and practical aspects of eddy current testing. In addition to the defect characterization, actual studies deal with the metallurgical evaluation of materials. Surface examination allows the prediction of the material strength and consequently its life time.
In order to obtain various microstructures and to modify the mechanical and metallurgical characteristics of materials, samples such as aluminum or steels have been submitted for mechanical stress.
We have shown in this work that all microstructure modifications of the samples were detected and can be quantified by eddy current impedance measurement.
The impedance analysis by eddy current will be correlated with the microstructure changes observed in the material because of aging, fatigue.

Introduction

The good mastership of working stresses level in mechanical components and structures is an important factor in engineering industries. Evaluation and monitoring of the stress state of these elements is a time consuming job, beside it involves quite tedious work.

The characterization of microstructures, mechanical properties, deformation, damage initiation and growth by Non-Destructive Evaluation (NDE) techniques is assuming a vital role in various industries because of the growing awareness of the benefits that can be derived by using NDE techniques for assessing the performance of various components. Fracture mechanics based analysis of component integrity requires quantitatively characterization of microstructure defects as well as stresses.

Any alteration in the microstructure, which reduces the life or performance, should be predicted sufficiently in advance in order to ensure safe, reliable and economic operation of the components. This prediction is possible with NDE techniques, when it is realised that the interaction of the non-destructive probing medium with the material depends on the sub structural / micro structural features such as point defects, dislocations, voids, micro and macro cracks, secondary phases, texture and residual stress. The stress plays a very important role with respect to the different material properties.

Physical approach

Various non-destructive techniques are available for the measurement of either applied stresses or residual stresses. The non-destructive test method based eddy current is sensible to changes in micro structural characteristics and the stress state of the material and can be used to evaluate these materials characteristics.

The eddy current method [1,2] allows to evaluate the state of stress in the ferromagnetic material. The given method is used for determining own stress as well as that formed in effect of outside load. The study by Dybiec et al. [1] used the eddy current method to evaluate the state of stress in ferromagnetic material.. A notable change in the magnetic characteristics occurs as early as at small values of strain degree.

It is known that during plastic deformation defects of metal continuity are generated (e.g. microspores, micro cracks, vacancies, etc). The defects are observed as early as at early stages of plastic deformation. The formation of discontinuities is accompanied by partial relaxation of elastic energy [1], which leads to changes in the magneto-elastic energy of material in the regions adjacent to the defects. This phenomenon is likely to affect the magnetic and electric parameters of materials.

Experimental Procedure

Merlin machine of traction is used for evaluating the solicitation degree of material in the specific zone of the specimen. The effect of traction strain and accumulated damage on magnetic properties was studied on standard specimen subjected to elongation. The correlations obtained make it possible to evaluate the traction strain and current damage of metal, as well as to estimate the residual lifetime of an article under traction.

The said equipment is characterized by the high sensitivity of indication measurements regarding changes occurring in the material structure. The software allows to command the load tensile continually or by step. The probe of eddy currents is placed in the zone of the rupture that is predetermined by a preliminary test. . At each load, we have located five points impedance or phase measures in the rupture zone. (figure1).

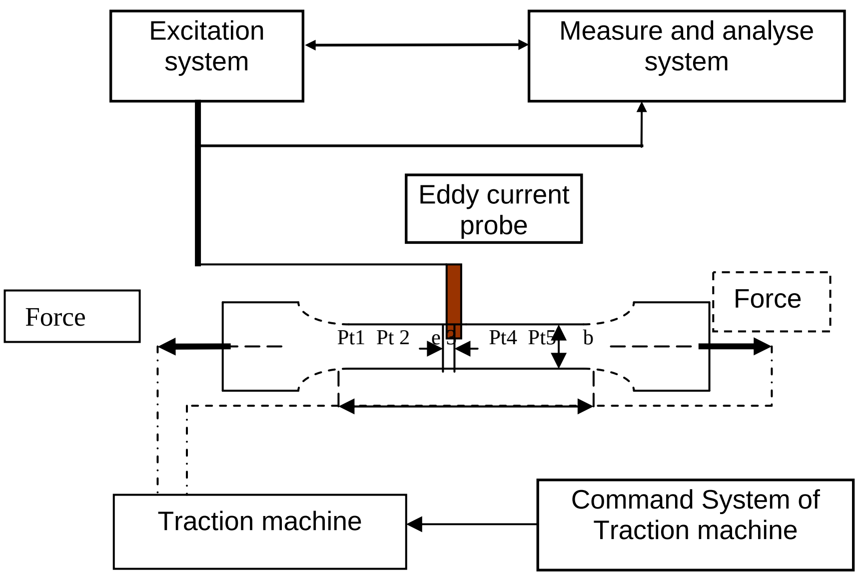


Figure1: Synoptic of measure system (Traction and eddy current)

Measure conditions

Some recommendations have been required for the measure precision

- The determination of the rupture load
- The load step is 3KN for the aluminium 2024 with the 3 min of maintain time
- The load step is 8KN in the elastic zone and 3KN in the plastic zone for the steel 304L with 2min of maintain time

At each charge step, we have measured the impedance and the phase of eddy current in the five point chooses.

Results and Interpretation

With an aim of finding a relation between the magnetic parameters, electric and mechanics of materials subjected to constraints. We chose an experimental approach which consists in subjecting the sample to traction while taking measurements of the phase and the impedance in several point of the specimen.

The curve presents a stage which corresponds to the transition zone.
The same result is obtained for all the points chosen on the sample (figure1), which indicates that the structure presents a priori the same electric and magnetic modification when the sample is submitted to the traction. This remark is observed for all curves representing the impedance according the deformation, the constraint or the elongation(figure 2at 7)..
This result is obtained for the phase according the deformation, the constraint or the elongation (figure 12at 17).
The curve representing the impedance according to the load shows two zones of transitions. Indeed we notice that the trajectory undergoes two jumps, one is located at 9-10 kN and correspond to an impedance of 23.82Öhm, the other is located at 22-24 KN and correspond to an impedance of 23.78 Ohm.

This jump is observed for all the curves representing the impedance according to the deformation, the elongation, the constraint and the load. Table 1 gives the two points of transition.

Alum	Z(ohm)	A%	D(mm)	P(kn)
Jump1	23.82	2.22	4.82	9-10
Jum2	23.78	4.5	5.2	22

Table1

This significant remark is observed for the representation of the phase according to the various mechanical parameters.
The two jumps are observed for phases table 2 gives the values of the deformation, elongation, the constraint and the load for the two points of transitions

Alum	Ph(degre)	A%	D(mm)	P(kn)
Jump1	35.32	2.22	4.82	9
Jum2	35.45	4.5	5.2	22

Table2

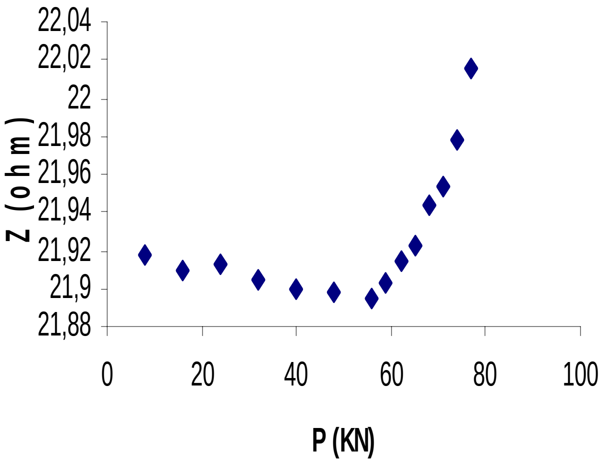


Figure2: impedance according the charge for steel

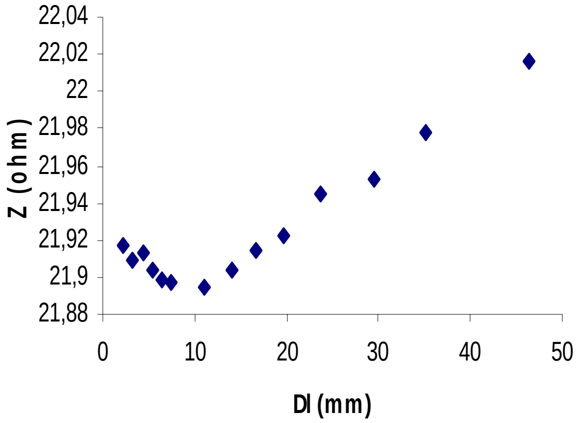


Figure3: impedance according the elongation for steel

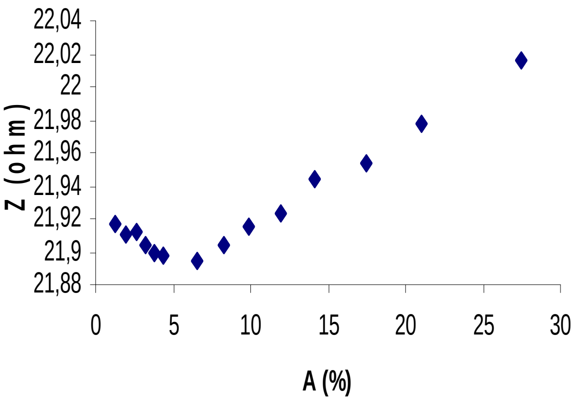


Figure4: impedance according the deformation for steel

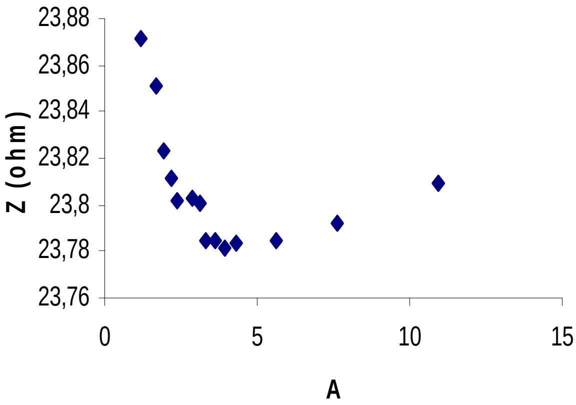


Figure5: impedance according the deformation for aluminum

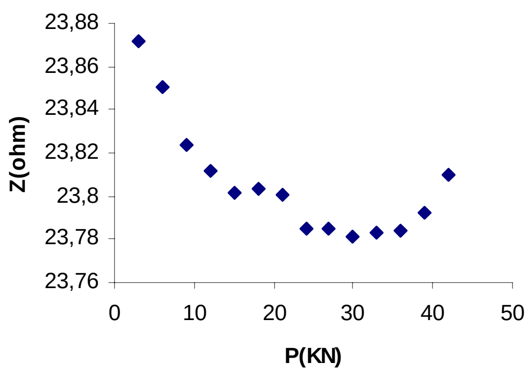


Figure:6 Impedance according the charge for aluminum

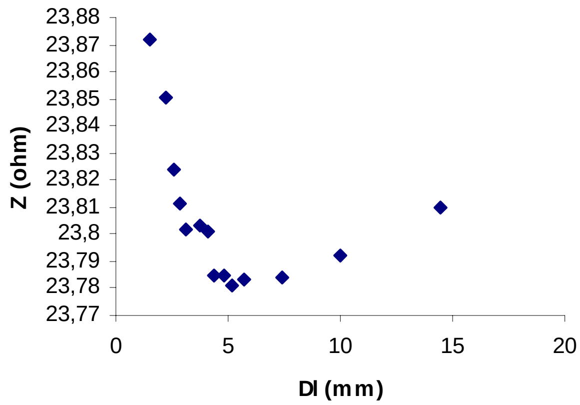


Figure:7 impedance according the elongation for aluminum

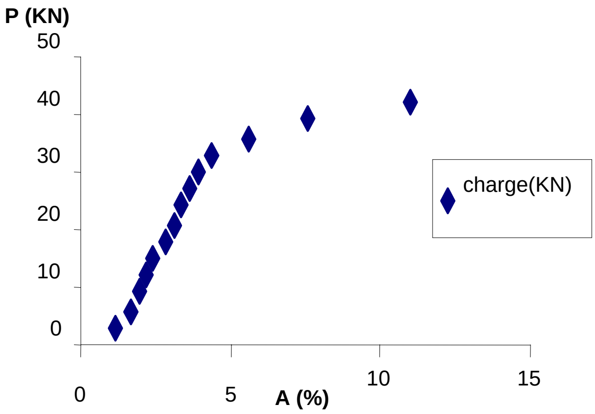


Figure:8 Charge according to the deformation for aluminum

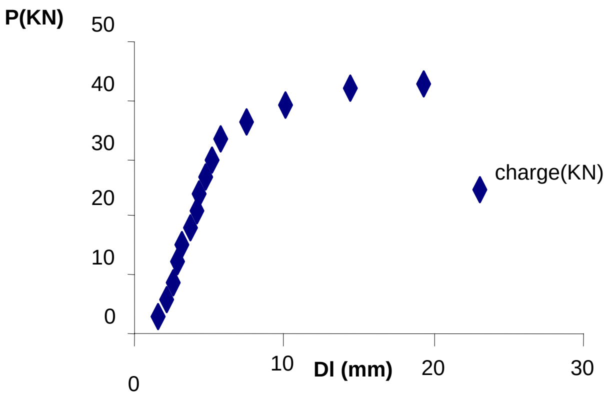
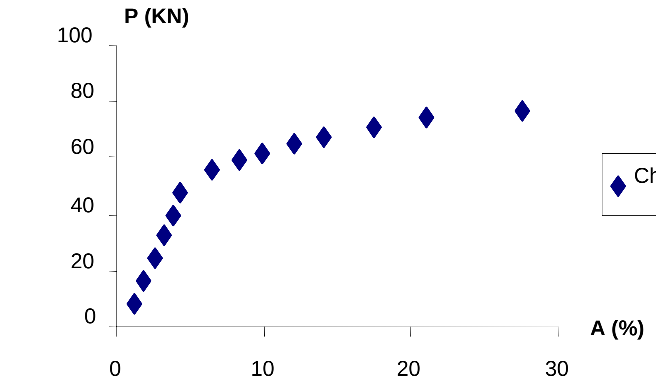


Figure:9 Charge according to the elongation for aluminum



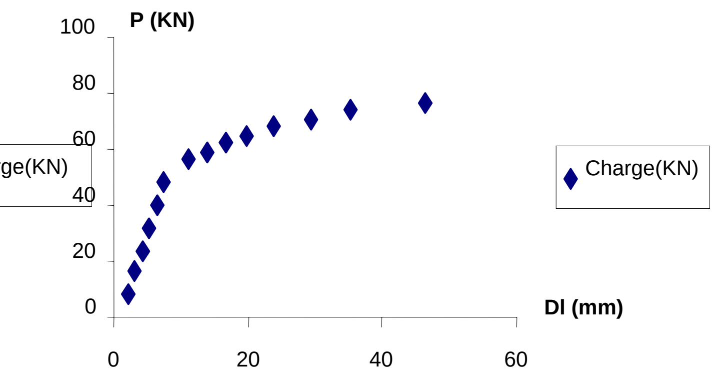


Figure 10: The charge according the deformation for the steel figure11: The charge according the elongation for the steel

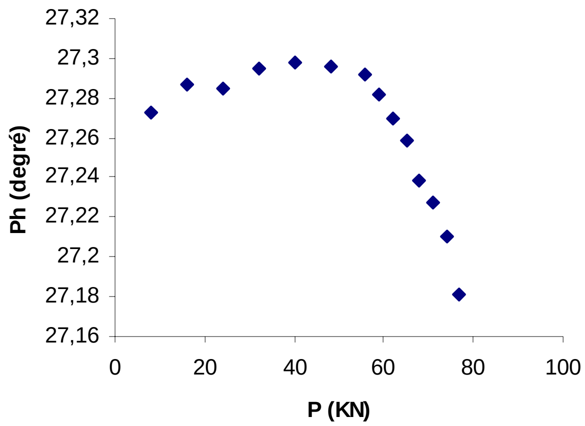


Figure:12 Phase according the charge for steel

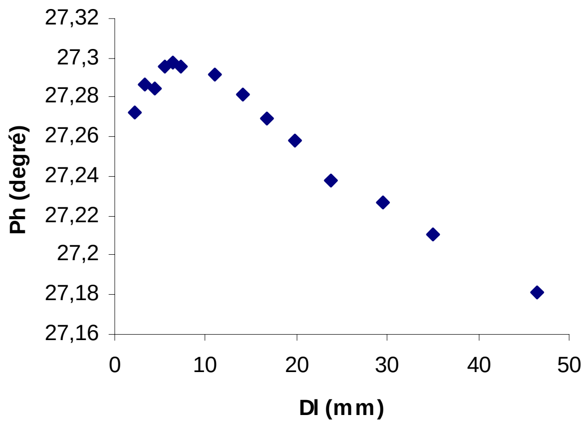


Figure:13 Phase according the elongation for steel

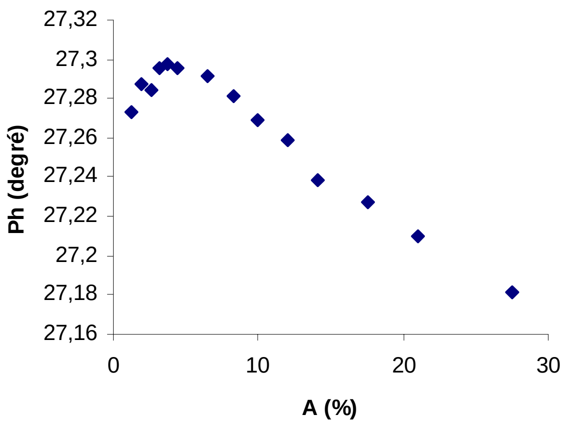


Figure14: Phase according the deformation for steel

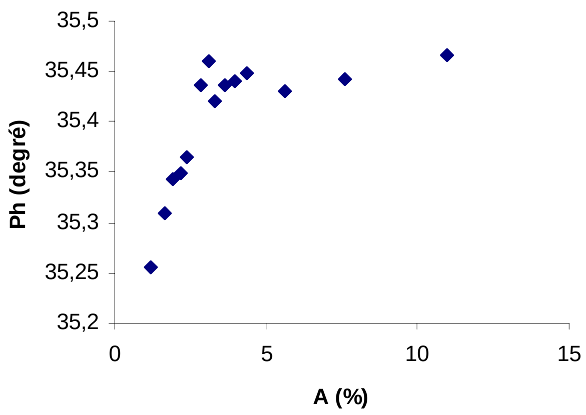


Figure15: Phase according the deformation for aluminum

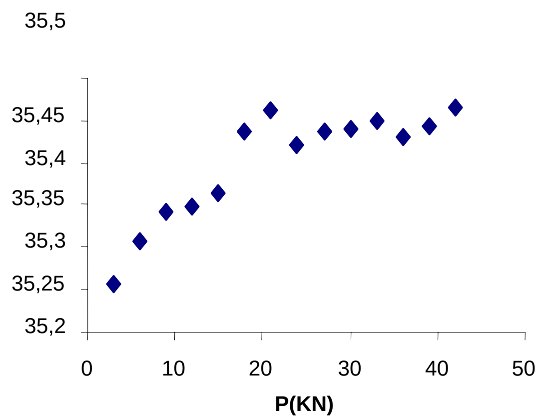


Figure:16 Phase according the charge for aluminum

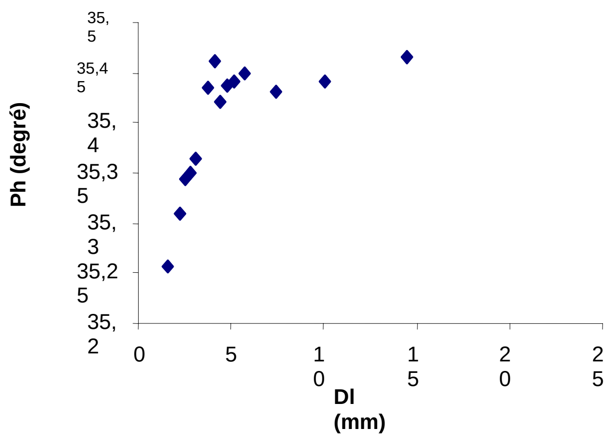


Figure: 17Phase according the elongation for aluminum

We notice that for the austenitic steel, the curve representing the impedance according to the load shows two zone of transition (figure 2-4) .In the second jump the trajectory of the curve change the direction. , table 3-4 gives the values of the impedance and the phase according the deformation, elongation, the constraint and the load for the two points of transitions
(figure 12-14) . The comparison between table 1 and 3 and table 2 and 4 gives results differently between an austenitic steel and aluminium and allow to know the materials behaviour under constraint. The value of the impedance or the phase is different between the first and the second jump

Acier(z=f( ))	Z(ohm)	A%	D(mm)	P(kn)
Jump1	21.910	2.41	4	18
Jum2	21.885	5-6	9	55-58

Table 3

Acier(ph=f( ))	Ph(degr)	A%	D(mm)	P(kn)
Jump1	27.285	2.4	4	18
Jum2	27.300	5	8-9	55-58

Table4

These resulted are confirmed by mechanical measurements where the jumps are observed (figure 8-9). (table5)
The impedance curve of austenitic steel allows to see also two jumps. This result of mechanical measurements shows only the second jump (figure 10-11) (table6).

Alum PH=f( )	P(kN)	A%	D(mm)
Jum1	9	2.2	4
Jump2	25	4.5	5-6

Table5

AcierPH=f( )	P(kN)	A%	D(mm)
Jum	55	5	9

Table6

These results are significant in the determination of the elastic limit and the plasticity of material. For aluminium, the first jump corresponds to the limit elastic and the second jump corresponds to the limit of resistance very useful for the determination of the endurance for the fatigue. Whereas for steel we noticed two jump and which corresponds to the elastic limit and the start of the plasticity. We remark also in the steel that the impedance increase and the phase decrease after the second jump corresponding to the start of the plasticity. Also the steel acquires a magnetization by the tensile stress applied.
For the aluminium, we notice in the curve (figure 5to7 and 15 to17), the impedance and the phase have a relation with the young modulus. This remark is very important because we can measure the mechanics parameters only by the impedance and phase measure. Also the start of the plasticity is represented by a change of the trajectory direction.

Conclusion

Lifetime extension of components in technical applications is a general task with economical benefits. NDT/NDE has developed first attempts for materials characterization taking into account damage assessment as part of the in service inspection. We have showed in this work the relation between eddy currents measurements and the mechanical parameters.
The curve representing the impedance or the phase according to the elongation or the deformation follow a well determined trajectory where the elastic limit and the start of the plasticity of the material is determined by the impedance or the phase measure. For the Aluminium the relation between the phase and the charge according to the elongation have the same trajectory shape as the mechanical curve.
The curve of the phase is closer to the proportionality in the elastic zone and it is possible to determine the young modulus.
This work shows that we can determine the material behaviour submitted to a constraint by eddy current measure analysis. We will found the elastic limit or the start of plasticity by the impedance measure. In the aluminium also, it is possible in the future to calculate the young modulus by the phase analysis.
These results are very significant for the determining the mechanical parameters and it is useful for using in the In Service Inspection.

References

[1] Dybiec, C., Wlodarczyk, S. and Dybiec, M., " Measurement of Own Stress Using the Eddy Current Method", ECNDT, Vol. 3 December 1998

[2] C.Dybiec and all “Determining Residual Austenite Wiith Eddy Current Method”,ECNDT Vol3 Decembre 1998

[3] Baldev Raj ,V.Moorthy,T.Jayakumar and K.Bhanu Sankara Rao,”Assessmentof Microstructures and Mechanical behaviour of Metallic Materials Through Non Destructive Characterisation”International Materials Reviews October 2003,Vol 48 ,N°5