NEW NONDESTRUCTIVE TESTING METHOD FOR AGEING EVALUATION OF AIRCRAFT STRUCTURE

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The lifetime management is became the new -safe and economical- method of operating aircraft structures. The successful life management is based on enhanced monitoring and data acquisition. The monitoring should include the time dependent material degradation.

Sophisticated periodic inspection procedures for defect detection and evaluation of the obtained results are already widely used. On the other hand the material ageing data generally given only by laboratory tests.

Nowadays a new way to use NDT methods seems to have increasing possibilities: the non-destructive evaluation of the material properties.

The most prospective NDT (nondestructive testing) methods for evaluation of material degradation are the measurement of magnetic and acoustic properties.

One of the most promising magnetic testing method for evaluation of fatigue and thermal ageing of ferromagnetic materials is the Barkhausen noise measurement. In varying magnetic field a discontinuous change of the magnetic moment can be measured. This change can be correlated with the material degradation.

The aim of this work is to study how these new NDT method can be include into the life management of the aircraft structures. Preliminary results obtained on artificially thermal aged CrMoV and CrMoNi alloyed steels shows acceptable correlation between the Barkhausen measurement and material toughness degradation.

Introduction

Structural integrity of engineering structures should be maintained during operational lifetime. Although a significant part of the production and operational costs is used for quality assurance of some of these structures, as nuclear and aeronautical systems, further efforts have been taken to prevent the possibility of catastrophic failures.

Methods enhancing the safety level are extremely. The rapid development of the non-destructive testing (NDT) methods enhanced the degree of reliability of the heavily loaded parts of the aircraft structures.

Until now non-destructive testing has been applied to inspections it has mainly been used for defect detection. For example: ultrasonic, magnetic, eddy current, X-ray, visual checking methods are widely and successfully used to detect production defects, and to discover cracks which have occurred during service.

Nowadays a new way to use NDT methods seems to have increasing possibilities: the non-destructive evaluation of the material properties.

The aircraft industry makes extensive efforts to ensure the structural integrity of aircraft, with special attention to older aircraft. Nowadays the operational lifetime of these aircraft is much longer than the original projected life. The use of new materials such as maraging steel increase the lifetime together with changing of the mechanical and physical material properties At the same time the potential for fatigue failure is increasing.

Based on above explanations, new methods are needed for low cost life evaluation. The new methods should be feasible and applicable during inspection, without impairing the serviceability of the object being investigated. [1]

Theoretical Basis

Some important material properties are defined by destructive testing such as yield strength and ultimate tensile strength. These properties can be correlated with microstructure and their changing can be measured by nondestructive testing. Literature reported that magnetic parameters of the materials could be related with mechanical properties, such as hardness, fatigue, grain size, precipitates, etc. [2, 3, 4, 5] These results initiated the study introduced below.

Ferromagnetic materials are divided into regions called domains. The domains are subgrain size regions in saturated magnetisation state. However the domain somatory of the ferromagnetic material can be aleatory oriented resulting in unmagnetized material at macroscopic level.

The domain regions are originated by many uncompensated spins, they are aligned parallely and in one direction by interatomic forces, giving a magnetic momentum vector. From one domain passing to another adjacent, the atomic momentum vector, m_0, rotates gradually from one up to the new direction. This region, between the two domains, is called domain wall. The ferromagnetic materials magnetisation is related to the changing of the domain configuration.

Increasing magnetic field results in two different processes associated with the domain configuration:

1- In weak (debile) magnetic field - only the domain walls are moving to increase the volume of the favourably oriented domain volume.,

2- Application of an intensive magnetic field causes intensive wall movement and finally the domain rotates into the field direction.

Structural defects cause pinning of the moving domain walls . [4, 6, 7]

When the ferromagnetic force acting over the domain is greater than the pinning force, the domain liberates itself from the obstacle and it goes to other pinning sites.

The magnetic flux density versus intensity of magnetic field applied is a non-linear step function. These steps of the function caused by jumps of domains are called Barkhausen effect, and the signal caused by this effect is the magnetic Barkhausen noise or emission (MBN/MBE), and it can be detected by magnetic coils. The jumps of the domains also result acoustic noise in the material. This acoustic noise can also be correlated with material properties. This is called acoustic Barkhausen emission or noise (ABN/ABE), and it can be detected by piezoelectric sensors.

Ageing is caused by the increasing number of structural defects such as precipitates, dislocations. Since these affect the movement of the domain walls the Barkhausen noise may be used to determine the change of the structural properties and the variation of the microstructure.[3, 5, 6, 8]

In case of MBE measurement different parameters of the noise (e.g. frequency, intensity) can be evaluated and correlated with the material degradation caused by fatigue, corrosion, creep, thermal ageing etc.[9, 10]

<u>Study of Ageing by Barkhausen Noise Measurement</u>

Based on the results published in the above cited literature we started to study the effect of one of the characteristic time dependent material degradation mechanisms: the thermal ageing. Thermal ageing is a typical long duration degradation mechanism which occurs in steel structures serving in the temperature range 300-700 °C.

During thermal ageing a group of the alloying and pollution elements are diffunding from the grain matrix to the grain boundary. The material structure in the enriched zone at the grain boundary may include segregation (typically carbides) or a highly enriched very thin layer (Phosphorus enriched thin layer is a typical and dangerous example). Both types of grain boundary ageing mechanisms are reducing the ductility, sometimes together with the reduction of strength and hardness. The brittle grain boundary phase is the location of the crack initiation, and causes intergranular crack propagation. The absorbed energy for crack propagation is low in this region, and this leads to a brittle fracture.

During the thermal ageing the atoms of the interstitial alloying elements are leaving the grain matrix reducing the stresses in the lattice, therefore causing the softening of the matrix. Since threshold energy necessary for movement of the domains depends on the atomic stress level, it is decreased by the softening and the MBN value is increased.

High strength CrMoV and CrMoNi steel which is widely used in the power and aircraft industry has been selected for the first study. The chemical analysis of the studied steel is given in TABLE 1.

Element	C %	Si %	Mn %	Ni %	Cr %	Mo %	V %	P %
Cr-Mo-V steel	0.30	0.3	0.8	0.39	1.19	1.42	0.25	0.02
Cr-Mo-Ni steel	0.18	0.2	1.4	0.84	0.12	0.5	0.002	0.02

TABLE 1 - Chemical analysis of the tested steels.

Computer controlled STRESSTEST 20 type equipment was used for measurement and for data acquisition. The peak value of the noise amplitude (ABS), and the average root mean square voltage (RMS) were measured in the function of the magnetisation force. 10 and 100 Hz alternating current was used together with 2 different filter frequencies. In every case 20 different magnetisation levels were used, which means that during every test series 160 individual measurements were performed

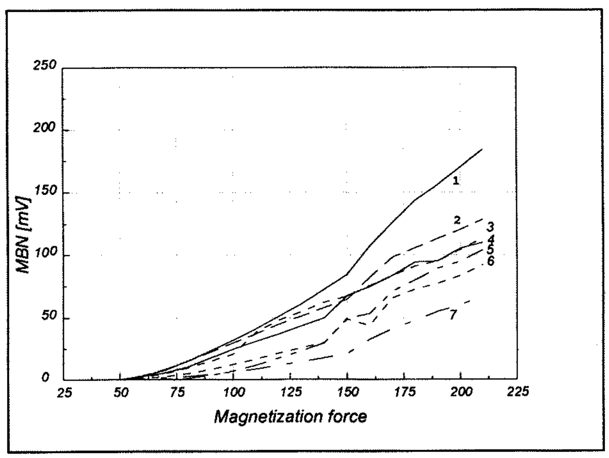

FIGURE 1 - Barkhausen Results Measured on Differently Aged Steel.

The result of every series of Barkhausen measurements is a sinus or tangent hyperbolic curve in the function of magnetisation force. The absolute peak value of the Barkhausen signal (ABS), the rate mean widths of the signal (RMS) belonging to a certain magnetisation level, the ABS/RMS ratio or the maximum slope of the curve, were calculated and evaluated.

As typical results ABS values measured in the function of the magnetization force are shown on FIGURE 1. The curves measured on differentally aged samples are numbered as 1-7.

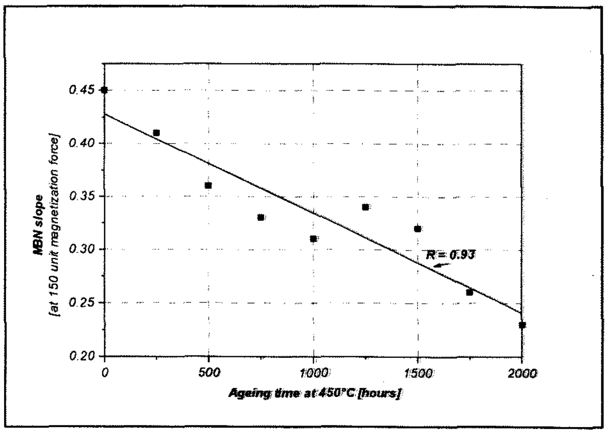

FIGURE 2 - Correlation Between MBN Slope and Ageing Time.

The legend number is the number of the sample (n). Every sample has been thermally aged for (n-1)×250 hours, at 560 °C.

Several attempts were made to select the best characteristic values for evaluation of the Barkhausen measurements. Finally the slope of the ABS curves in the range of magnetisation force level values between 100-150 was chosen. FIGURE 2 shows the correlation between the noise slope and the ageing time.

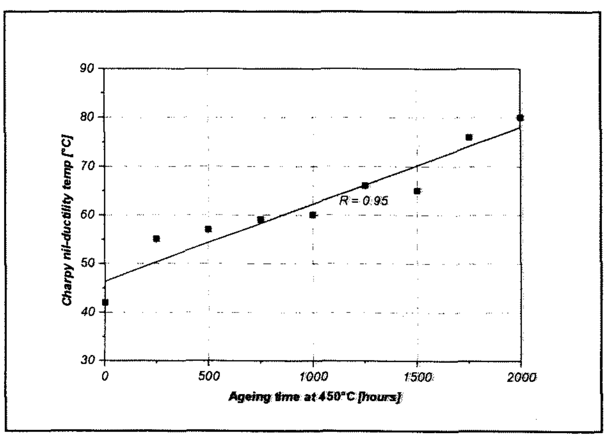

FIGURE 3 - Correlation Among MBN Slope and Nil-Ductility Temperature

FIGURE 3 shows the correlation between nil ductility transition temperature NDT, measured by Charpy impact testing and MBN values.

More study is needed to decide, whether this correlation is a direct one, or in the selected thermal ageing case the correlation between the hardness and NDT is reflected in the results.

To get a better picture thick forged steel block of CrMo steel was tested. During the forging process the deformation rate and the cooling rate is varying in the function of distance from the surface.

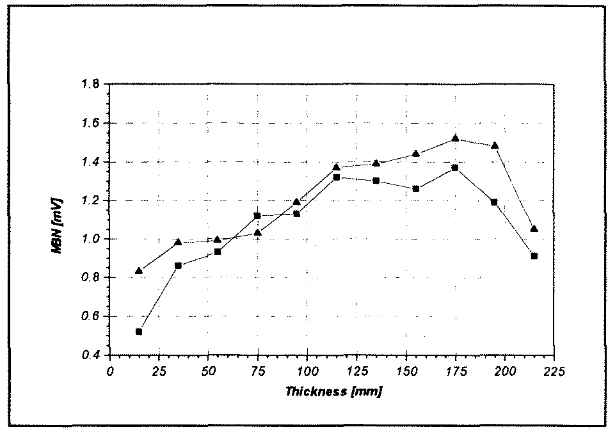

FIGURE 4 - MBN Values in the Function of the Cross Section of JRQ Steel Block.

This causes similar changes in the microstructure. In the middle the steel the grains are less deformed, the cooling rate is smaller than on the surface, so most of the impurities could diffuse to the grain boundary and cause segregation MBN measurements were performed perpendicularly to the surface. The results are shown on FIGURE 4.

The hardness measurements performed on the same material show slight variations, it can be observed on FIGURE 5, although not enough to explain the relatively great changes in the MBN values. This seems to verify the correlation between the NDT temperature and the measured MBN values, see FIGURE 6.

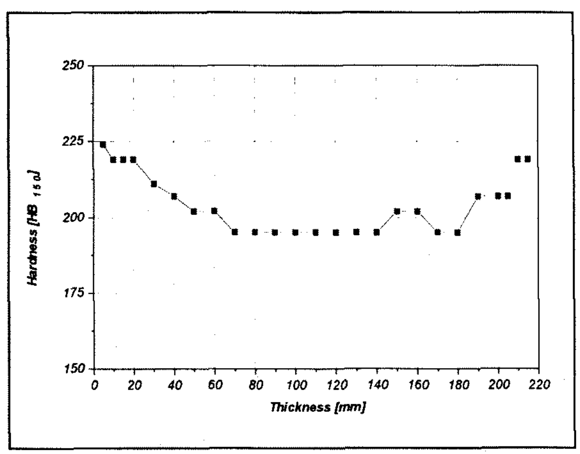

FIGURE 5 - Hardness Testing Results in the Function of the Cross-Section of Cromo Steel Block

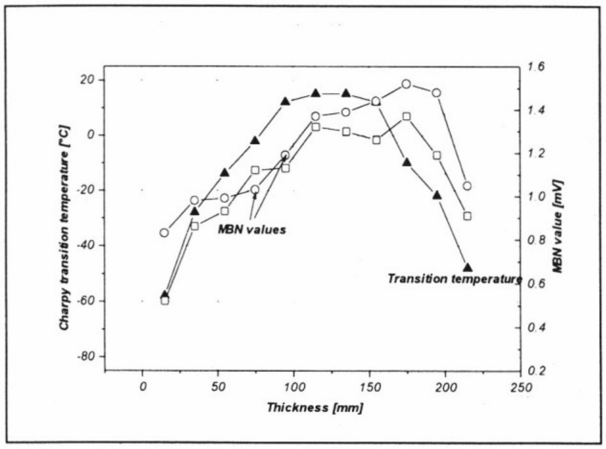

FIGURE 6 - Comparison of MBN Values and Charpy Nil-Ductility Temperature (68J Criteria), Distribution in Cross Section of Cromo Steel Block.

Testing of Aircraft Spare Parts

The results shown in the previous parts of this paper verify the use of the magnetic Barkhausen method for evaluation of the remaining lifetime of the aircraft spare parts.

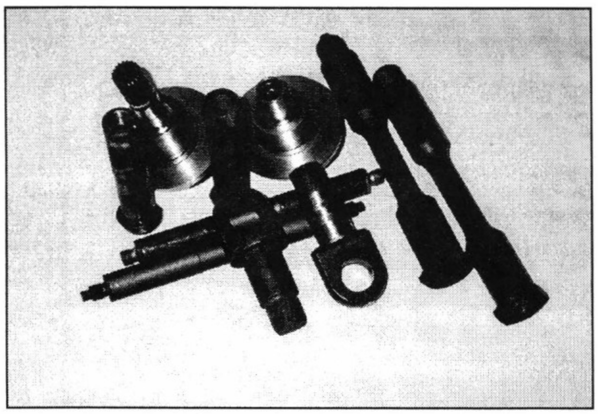

FIGURE 7 - Aircraft Spare Parts Prepared for Barkhausen Testing.

Some typical spare parts of fighter planes and helicopters, on which crack initiation wasfound after service were provided for testing by the repair and maintenance company, it are show on FIGURE 7. Attempts were made to measure MBN level on these spare parts and to compare the results with the noise level obtained on new spare parts.

A significant difference between the values measured on the used and new spare parts was found in several cases. A systematic study has been started to evaluate the differences.

Specimens cut form original steels and particles will be fatigue tested, and at every stage of the fatigue test MBN will be measured. A catalogue of samples for comparison (etalons) including metallography tests - will be prepared for site test purposes.

Discussion

The magnetic Barkhausen measurements are sensitive to the residual stresses, grain size change, microcracks and diffusion caused changes in the grain matrix. These changes affect the residual life of ageing structures. The magnetic Barkhausen test can be used for evaluating the residual lifetime of aircraft spare parts, if the results are compared with the results measured on steel samples properly aged in a laboratory.

Acknowledgements

The author of this paper wish to thank for the support of the Danubian Aircraft Company, the Aeronautical Institute of Technical University of Budapest, Atomic Energy Research Institute, AEKI/KFKI and Metallelektro Co. in Budapest, Hungary .

References

1. Pirfo B., S. *A review of nondestructive testing applied for inspections of aircraft.* XIII National Congress of Nondestructive testing, XIII CONAEND, Belo Horizonte, Brazil, September 1994.
2. Hill,R., Geng, R.S., Cowking, A. and Mackersie, J.W. *The effect of Nickel hardness and grain size on acoustic and electromagnetic Barkhausen emission.* NDT & International vol.23, n.2, April 1990.
3. Govindaraju, M.R., Strom, A., Jiles, D.C., Biner, S.B. and Chen Z.J. *Evaluation of fatigue damage in steel structural components by magnetoelastic Barkhausen signal analysis.* J. Appl. Phys. 73 (10), 15 May 1993
4. Ranjan, R., Jiles, D.C., Buck, O. and Thompson, R.B. *Grain size measurement using magnetic and acoustic Barkhausen noise.* J. Appl. Phys. 61 (8), 15 April 1987.
5. Ranjan, R., Buck, O. and Thompson, R.B. *A study on the effect of dislocations on the magnetic properties of nickel using magnetic NDE methods.* J. Appl. Phys. 61 (8), 3196, 15 April 1987.
6. Reitz, John R., J. Milford, F. And Christy W.R. *Foundations of Electromagnetic Theory*, Addison-Wesley (1980) pp.218-229.
7. Kittel, C. *Introduction to Solid State Physics* John WILEY & Sons (1976) pp.445-483.
8. Durin, G., Beatrice, C. and Bertotti, G. *Microstructural study of amorphous magnetic materials through the Barkhausen effect*, IEEE transactions on magnetics, 30 92), 464, 1994. .
9. Morgner W.; *Fundamentals of non-destructive materials characterisation.* NDT & E International, vol. 27, n. 5, pp. 263-268, 1994.
10. Pozsgay G., Imre L.; *Stress Examination of Bridges Using Barkhausen Noise Measurement.* Proc Int. Conf. 6th E.C.N.D.T. vol.1. pp. 297-301, Nice 1994.