Application of NDT Procedures for Identification of Fatigue Life Stages of AlMg Alloys

Petr LISKUTIN [1], Pavel MAZAL [1], Jaroslav FIALA [2], Frantisek VLASIC [1]

[1]Brno University of Technology; Brno, Czech Republic,
Phone: +420 54114 3229, e-mail: mazal@fme.vutbr.cz
[2]University of West Bohemia, Plzen, Czech Republic. e-mail: fialaj@ntc.zcu.cz

Abstract

This paper describes some basic exposures of Al and Mg alloys (EN AW 6082, EN AW 7075, and AZ 91) behaviour change during high cycle fatigue loading which were detected using some NDT methods. Changes of loading frequency and acoustic emission signal were used for identification of different stages of fatigue process. However it is very difficult to exactly specify the reason of AE signal change or the loading frequency. That is why the X-ray diffraction analysis of the structure method was used. This method can further clarify some processes in the loaded material.

Keywords: acoustic emission (AE); fatigue properties; loading frequency; X-ray diffraction

1. Introduction

Al and Mg alloys present a very important group of construction materials, which are used thank to its specific properties in many different applications mostly in transportation – for example in aircraft, train and automobile industries. In many cases, products made of these materials have to meet very high requirements; that is why it is necessary to obtain detailed information about their mechanical properties [1, 2, 3].

An important group of degradation processes of construction parts is connected with mechanical and especially cyclic mechanical loading. The process of cyclic degradation of properties of AlMg alloys differs in some ways from standard principles relatively well known at iron alloys. For example damaging of AlMg alloys proceeds even with loading amplitudes that correspond to app. 10^7 load cycles (standard threshold of fatigue of common materials) and therefore reliable determination of fatigue threshold is very difficult.

A considerable problem of AlMg alloys (whose semi-products are fabricated by forcing -through method) is non-homogeneity of structure and its significant differences in different directions – so called structure directivity (Fig.1). This directive non-homogeneity can influence some mechanical properties and consequently the properties of individual real parts can differ [4]. Also the propagation of the fatigue crack is relatively complicated (Fig.2). One of the projects that are currently being solved in Eco-centre for Applied Research of Non-ferrous Metals of the Brno University of Technology is identification and quantification of these changes and determination of their influence mainly on fatigue properties of materials.

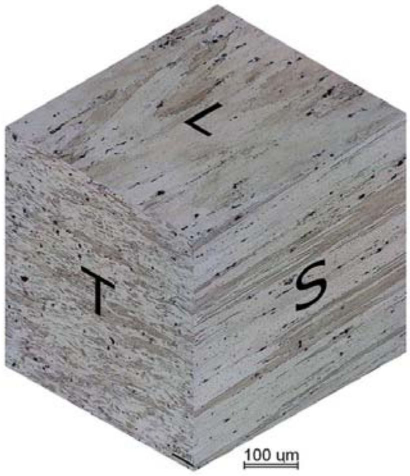


Figure 1. 3D representation of structure non-homogeneity in directions L, S, and T (mater. EN-AW-7072).

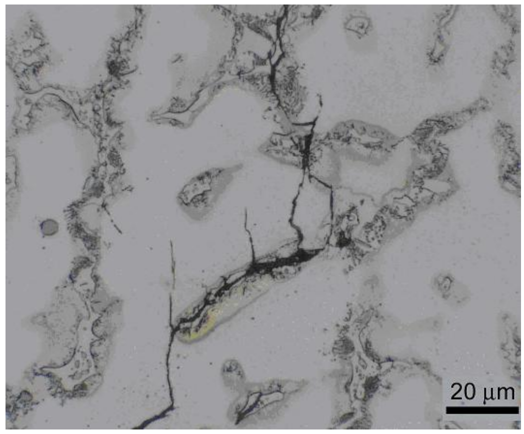


Figure2. Surface microstructure of the Mg alloy AZ 91 with fatigue crack branching.

As the tests of Al and Mg alloys in high cyclic area are very time-consuming, it is necessary to use resonance fatigue loading machines. These machines provide rather restricted set of information about the course of cyclic damage. For this reason, we have tried to broaden the range of available information, using some additional NDT procedures.

Non-destructive evaluation is provided in three main steps:

a) Preliminary loading frequency evaluation during the tests on electro-resonance machines
b) Continuous sensing and evaluation of acoustic emission signal
c) Use of X-ray diffraction for detailed evaluation of selected samples

2. Material and experimental apparatus

The results presented in this paper were received on Al alloy EN-AW-6082/T6 (medium strength alloy with excellent corrosion resistance), EN-AW-7072 (high strength alloys widely used in aerospace structures) and Mg alloy AZ 91 prepared by squeeze casting technology (pressure 50 and 150 MPa). The composition of used materials complied with appropriate standards.

The fatigue tests were performed on fatigue testing machines Cracktronic 160 and 70 (RUMUL AG comp.); these dynamic testing machines work on the principle of electromagnetic resonance and operate at their natural frequencies. Samples (Fig.3) were loaded by four point bending. Specimens with machined notches were stressed with a bending moment, which is composed of a dynamic and a static part. Between the grips there is a constant bending moment (Fig.4). The electromagnet is integrated in a closed loop system and the machine can be controlled either by the bending moment or by the oscillating angle.

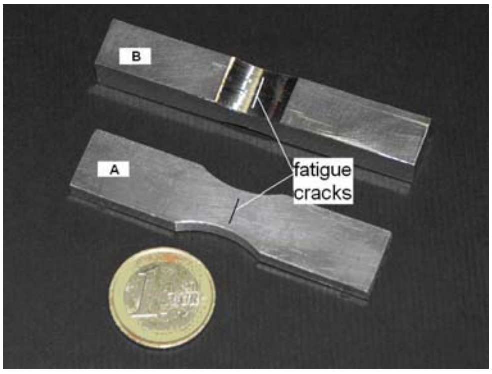


Figure 3. Specimens used for tests presented in this paper.

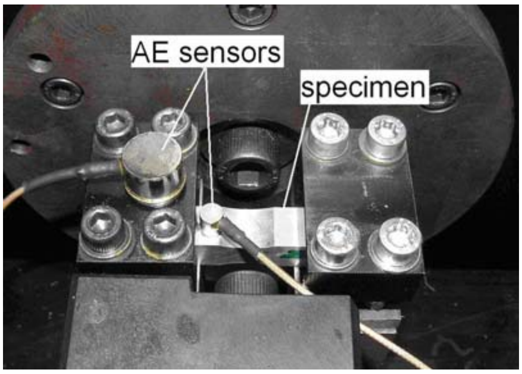


Figure 4. The clamping part of Cracktronic 160 machine with a specimen and two AE sensors.

Acoustic emission method - four and two-channel AE systems Dakel Xedo© were used for presented experiments. Measuring channel units of these equipments were, for the purposes of measuring of AE parameters, fitted with piezo-ceramic sensors of type Midi and standard (magnetic) – Fig.4, the signal of which was sent into analyser and processed by PC. The information from data files were subsequently processed by software DaeShow©, which enables all basic procedures of evaluation – ring down counts, AE burst rate, summation of AE counts, RMS etc. The possibility to divide measured signals into up to 16 pre-adjustable levels (with independent detection thresholds) provides very useful results.

Some specimens were subjected to the “interrupted loading” - after fixed number of loading cycles the tests were stopped and specimens were handed over to the West Bohemia University in Pilsen for X-ray diffraction analysis of structure of the surface (wavelength dispersive X-ray fluorescence spectrometer AXS Bruker S4 Explorer).

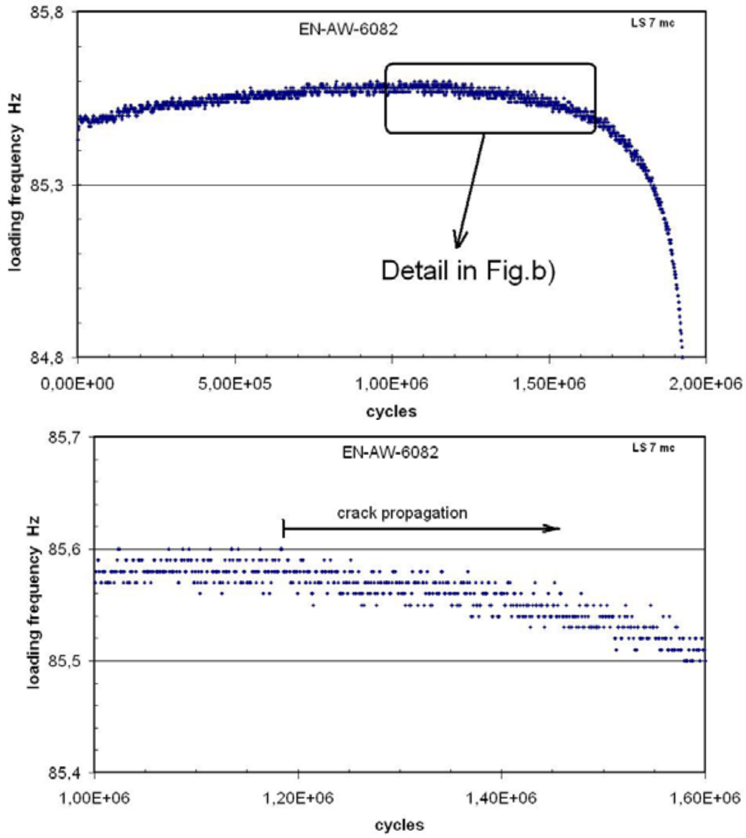
3. Examples of experimental results

3.1 Loading frequency changes

The electro-resonance fatigue machines work with loading frequency corresponding with the resonance of the whole loading system and in case that the rigidity of the sample is changed (in case of fatigue crack spreading) this frequency is decreased. It means that it is possible to estimate the length of the phase of fatigue crack spreading and the tendency of the material towards cyclic strengthening or softening in the initial part of loading.

Fig. 5a depicts the typical shape of the curve of frequency dependence on cycle count (for a given strain amplitude). In more detailed image of the area of the beginning of decrease of the frequency (Fig. 5b) it is possible to relatively exactly identify the beginning of steady decrease of loading frequency and therefore also sample rigidity in consequence of main fatigue crack propagation.

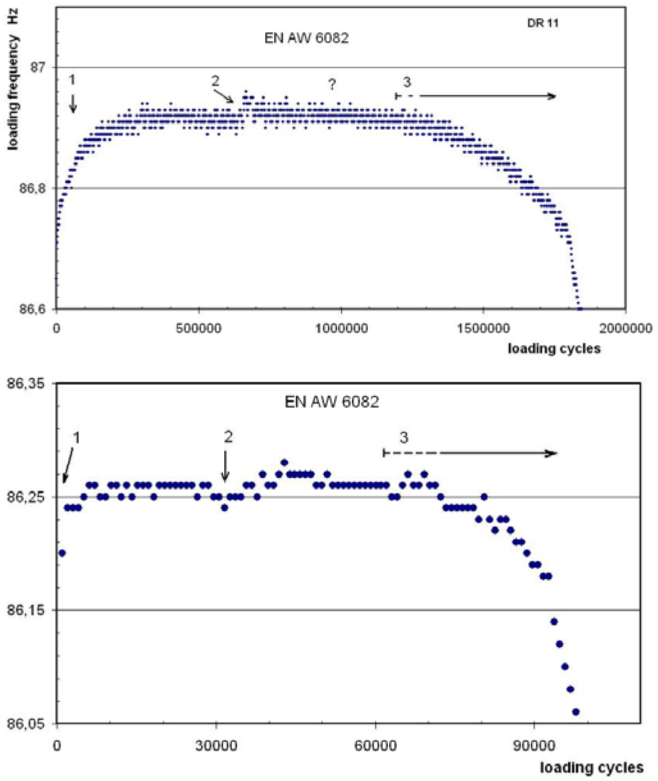
After detailed analyses of further frequency curves, in many cases areas of significant frequency discontinuity were found (Fig. 6a, b). Structural changes are probably appearing in these places, but it is not possible to identify them using common methods.



a)

b)

Figure 5. a) overall view of the whole frequency curve (EN-AW-6082), b) detail of the beginning of steady decrease of sample rigidity



a)

b)

Figure 6. Examples of frequency curves discontinuity of EN-AW-6082 alloy with different durability of samples: a) app $1{,}9.10^6$ cycles, b) app $1{,}0.10^5$ cycles.

3.2 Acoustic emission method

Acoustic emission method seems to be a very valuable tool for evaluation of damage degree. This method enables monitoring of changes of damage processes directly in the course of loading cycle, which is its big advantage, compared with other identification methods. It is however very difficult to identify the exact fundamental of the source of AE signal changes.

Despite that, the analysis of AE from Al and Mg alloys samples offers interesting results. Fig. 7 depicts an example of record of oversight count over predefined threshold of AE signal, which corresponds to record of frequency curve change on Fig. 6b. It can be clearly seen that changes of AE signal correspond very closely to changes in loading frequency, and so the AE signal confirms the existence of structural changes during the period of damage cumulation (Ind. 2). Very obvious is the rise of AE activity in consequence of main fatigue crack propagation (Ind. 3) and also in the initial stage of cyclic hardening (Ind. 1).

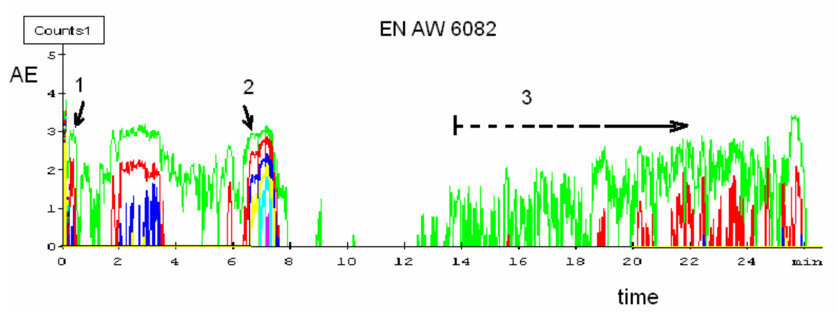


Figure 7. Plot of AE signal for the specimen from the Fig. 6b. Indication 1 – cyclic hardening, 2 – microstructure change, 3 – main crack propagation.

The results of more advanced processing of AE signal are depicted in Fig. 8. It captures the overall AE activity during the first 8 minutes of sample loading from Fig. 6b and 7 and also changes of selected parameters of AE events – amplitude history, event duration history and rise time history. Using these parameters and by analysis of frequency characteristics of individual events, it is possible to create an approximate image of AE signal sources.

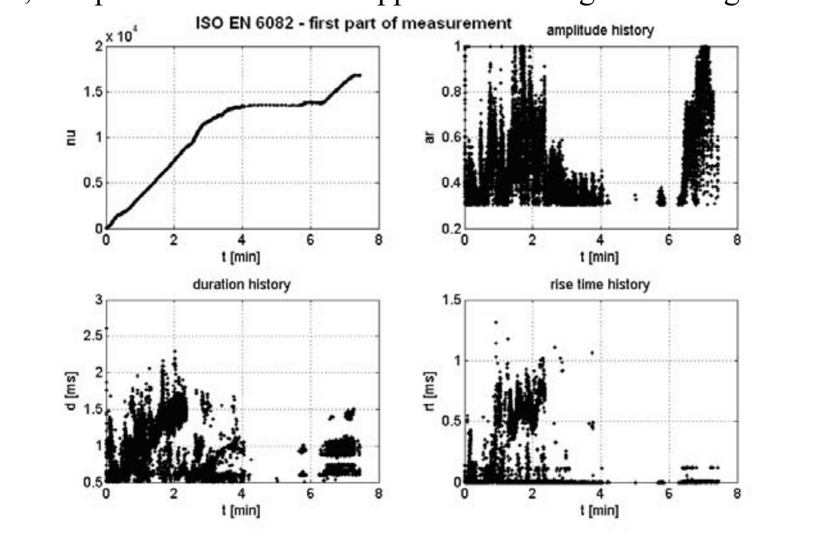


Figure 8. Detail of AE signal parameters changes during the first 8 minutes of loading (cumulative number, relative amplitude history, events duration and rise time history) [6].

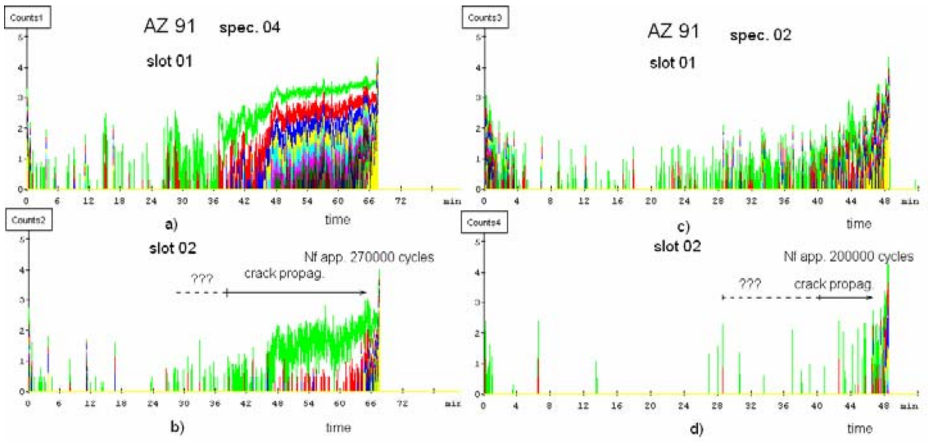
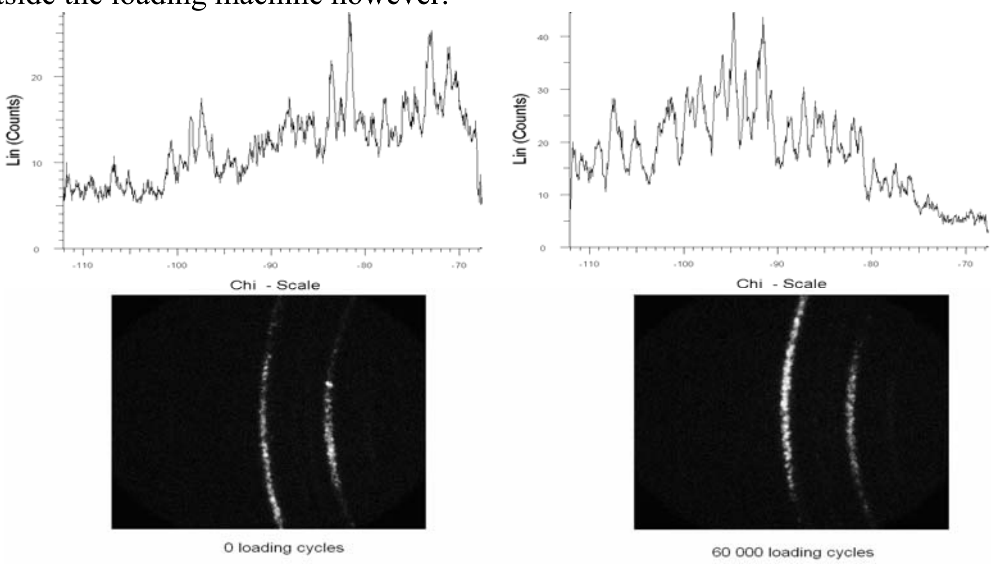


Figure 9. Plot of AE signal activity during fatigue loading of Mg alloy AZ 91.

Fig. 9 shows examples of AE activity records during fatigue loading of Mg alloy MZ 91. From these records it is again possible to determine approximate length of the main crack propagation stage. Correct setting of parameters of sensing framework, eventually suitable placement of sensor is however very important. Records b) and d) were obtained with lower amplification of AE signal.

3.3 X-ray diffraction analysis

X-ray diffraction analysis of loaded samples structure is based on the knowledge that in case of loading of wrought materials the redistribution of deformation strengthening occurs, which is caused by re-arrangement of dislocations. Details about this regrouping can be obtained by X-ray diffraction and by electron microscopy. These detailed analyses have to be done outside the loading machine however.



a) b)

Figure 10 Exemple of X-ray diffraction analysis: a) test specimen in the initial state - azimuthal profile of the (200) aluminium diffraction line on the left side of the diffraction pattern, b) results of the same test specimen after 60 000 loading cycles [7].

By X-ray examination of the aluminium alloy under study, we have found that its microstructure, as characterized by the proportion R of the large CSR´s (mosaic blocks, structural cells) greater than 10 μm, does change much under repeated stress [7]. In the first stage of loading (up to 6000 cycles), the CSR´s due to the introduced plastic strain disintegrate. As a result of this, the boundary surface of the cell aggregate extends, and, consequently, its energy finally increases enough to initiate its coarsening. The energy necessary to activate the growing of the larger blocks at the expense of the smaller ones is supplied by further cycling (over 6000 cycles). But, during this growth, paracrystalline distortions emerge, which gradually accumulate in the interior of the widening cells, raising thus their volume energy. After 60000 cycles, the energy increases to such degree that the blocks begin disintegrate anew. Due to this disintegration, the paracrystalline distortions relax and the alloy energy drops.

4. Conclusions

The undertaken experiments have proven that detailed analysis of loading frequency change allow for approximate determination of periods, where the character changes of the material damage process occur. It is possible to reliably determine whether softening or hardening of the tested material occurs and it is possible to determine the length of this period for different levels of loading amplitude. It is also possible to approximately identify the length of the period of main crack propagation. The exact beginning of interconnection of short cracks and appearing of main crack cannot unfortunately be unambiguously defined on the basis of these analyses.

The measuring of damage progress by acoustic emission method is significantly more exacting on experimental technique, but it provides much more detailed information about the instants of damage character changes. AE method application proved a possibility of the basic identification of individual stages of fatigue processes of AlMg alloys on electro-resonance fatigue testing machines. The technology of acoustic emission enables monitoring of the state in the whole loaded volume of the material and it could enable monitoring of cracks that spread under the surface of the specimen.

The fact that every measuring is unique is still a great problem for repeatable application of AE method. This is caused by very difficult ensuring absolutely identical conditions of every measuring (often long-lasting). Before all, various materials differ significantly in their “acoustic activity” and its character. The possibility of mutual comparison of results strongly depends on used sensors, on the way they are fastened to the sample, on the contact medium between the surface of the material and the sensor, etc. The shape of the samples and the distance between the sensor and the place of monitored defect play an important role, too.

Beyond these restrictive factors, the method of acoustic emission has its indisputable justification for the identification of fatigue degradation stage. It is necessary to work out standard procedures, including rules for setting parameters of AE analyser, location of sensors, and, of course, the way of evaluation of acquired signal. Extensive experimental work is necessary to work out general procedures of evaluation. Searching for congenial parameters and their fitting into the evaluation programmes will require considerable effort. For qualified estimate of real sources of acoustic emission in material, it is necessary to make use of much more demanding signal processing, using suitable mathematics methods. It is necessary to take off characteristic shapes of events in individual stages of damage and to provide detailed frequency analysis.

The AE method application proved a possibility of basic identification of individual stages of fatigue processes in tested AlMg alloy. This method can further enrich knowledge about individual stages of fatigue damage. It is however not possible to expect from AE method the exact identification of AE sources. That is possible only by connecting AE with further laboratory procedures capable of identification of processes in material substructure (e.g. with X-ray diffraction analysis) [7]. These commonly gained experiences will contribute to identification of processes, which take place in AlMg alloys even in loads which correspond to very high lifetimes and which are very difficult to identify by common material testing procedures.

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