LABORATORY- AND PRODUCTION-SCALE USE OF A METHOD OF ACOUSTIC EMISSION

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LABORATÓRNA A VÝROBNÁ SCHÉMA POUŽITIA METÓDY AKUSTICKEJ EMISIE

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Abstrakt

V príspevku sú ukázané dva spôsoby praktickej implementácie AE - metódy. Prvý spôsob je monitorovanie kvality materiálov pomocou AE merania v priebehu laboratórneho výskumu, ktorý sa nazýva " Monitoring kvality materiálov " (použitý počas mechanických, koróznych a iných testov), druhý je AE - monitoring výroby materiálov a AE - monitoring pracovných podmienok technologického zariadenia, ktorý sa nazýva "Technologický monitoring". Výsledky štúdia mechanizmov a kinetík lomov kovových materiálov (dvojfázové ocele, binárne a multikomponentné Zr zliatiny, multivákuové supravodiče a kompozitné drôty) sú analyzované. Kvantitatívna lomová analýza je založená na meraniach akustických impulzných vrcholov amplitúd pomocou nerezonančných senzorov pre lineárne meranie akustických posunutí a meraní parametrov trhliny. Vyvinutá metóda absolútnej kalibrácie AE zariadenia bola kontrolovaná pomocou skúšok rôznych typov materiálov a merania parametrov trhliny v lomoch. Kalibračné závislosti pre kvantitatívne merania sú ukázané tiež. Možnosti AE pre kvalitatívnu analýzu a pre charakterizovanie materiálov v procese mechanických a iných testov a v procese tlakového namáhania s pomocou vývoja experimentálnych computerizovaných AE systémov sú demonštrované tiež.

Abstract

Two ways of practical implementation of AE-method are shown. The first way it is monitoring of quality of materials with the help of AE measurements during laboratory research, which is called «Quality monitoring of materials» (used during mechanical, corrosion and other tests), the second it is AE-monitoring of processing of materials and AE-monitoring of work conditions of technological equipment, which is called «Technological monitoring». The results of a study of the mechanism and kinetics of metallic material fracture (dual phase steels, binary and multicomponental zirconium alloys, multifilamentary superconductors and composition wires) are given. The quantity fracture analysis is based on measurements of acoustic impulse peak (maximum) amplitudes by non-resonance sensors for linear measurement of acoustic shifts and crack parameters measurement. The developed methods of absolute calibration of AE equipment were checked by testing various types of materials and crack parameter measurements in laps and fractures. The calibration dependencies for quantity measurements are shown. The possibilities of AE for quality analysis and for characterizing of materials in the process of mechanical and other tests and in the process of pressure processing with the help of a developed experimental computerized AE system are demonstrated.

Key words: acoustic emission, material fracture, crack parameters, measurement.

1. Experimental Procedure

AE-Devices for " Quality monitoring of materials " and "Technological Monitoring"

1. *Small Size Systems for AE-Measurements* -The objectives of laboratory AE-measurements of fracture are comparisons of events in structure with generated AE signals. The peculiarity of an AE signal, generated by a microcrack, is a low level of a signal - which can be compared with the noise level of receiving amplifying devices.

In the program for developing AE quantitative measurements was used a method, based on implementation of nonresonance damped piezoelectric elements [1]. In that case the sensor from the opposite side to the tested sample is damped by acoustic trap, which absorbs an acoustic wave, passing through the piezoelectric element. This leads to increase of time resolution of devices and allows the detection of the formation of inside cracks with the help of AE, to calibrate equipment for crack size measurements and to make quantitative analysis of kinetics of damage accumulation in deformed material.

In a specially developed wide band piezoelectric converter for broadening the band of linear transformation the AE piezoelectric element is damped by a conic acoustic trap. Amplitude-frequency characteristic of a sensor is linear on the level of 3 dB in frequency band not less than 20 MHz. The design of the sensor allows to the registration of a signal directly from the working part of the tested sample. The acoustic sensor contacts the sample through the oil layer. The developed small size device for AE-signals registration in dynamic range is shown on Fig.1.

Fig.1 Schematic of acoustic emission facility and test schemes

Time resolution of impulses is determined by the frequency limit of a detector, which for a high speed recorder is f_{max} = 150 Hz. Peak (maximum) AE impulse amplitude U_p is expressed in dB ($V_p = 20 \cdot \lg(U_p/U_n)$) in relation to average noise impulse amplitude (U_n), which is determined for each sample after the second loading, the first stage of test, in a zone of Kaizer effect.

Microprocessor Detectors of AE-Signal - Microprocessor detectors of AE-signals (MDS) were developed for registration, transformation, preliminary processing and recording of results of quantitative analysis of deformation fracture and process kinetics.

2. *Multichannel Computerized System "Test AE" Type* - The"Test AE" type system, allows measuring, processing and archiving of AE signals [2]. Such an information measuring system is designed by a module principle. AE-signals are detected by a processor. Preamplifying and the filtration of signals is carried out by analogue, connected to a multichannel module of AE signals numbering. This module is on an interface board, which is mounted in an IBM PC. Data input is fulfilled by a 16-channel digital module. Numbering of signals is fulfilled by a 12-digit analogue-to-digital converter. Maximum beat frequency is up to 20 MHz; for preliminary digital processing of signals a RISK-processor is mounted in the interface board.

Interface of a system for processing of signals is based on technology of virtual (image) devices, such as Labview software, which is used for realization of algorithms of information processing and data archiving.

3. *AE Devices for Monitoring of Pressure Processing of Materials* -High sensitivity of AE radiation allows the implementation AE method in conditions of high background noise for monitoring pressure processing of metals, for example, drawing of a wire made of composite materials.

The following problems were solved when the set of devices was developed:

1) Detection of acoustic signals directly in a zone of minimum distance from deformation zone, in conditions of high deformation rate, high temperature and vapor of technological liquids.

2) Extraction of legitimate acoustic signals from the deformation zone of the background of technological noise of the loading unit and industrial noise. Block-schema of AE device is shown in Fig.2.

Fig.2 Information and measurement unit for drawing AE-control of composite superconductors

The information measuring device has 16 channels. The AE-detecting block consists of a measuring cell with 2-12 piezoelectric sensors (3), connected to them are small size preamplifiers (4) and electronic devices of preliminary processing of AE signals (5). The amplification is 60 dB in a frequency band of 0,1 to 20 MHz with time resolution 10^{-4} s. The complex and measurements are controlled by 12 channels with the help of a "Test-AE" computerized system.

2. Results and Discussion

AE Monitoring of Materials

Assessment of Ductility Margin of Materials-The AE method was widely used by the authors to assess the ductility margin in mechanical tests for tension and bend of high manganese steels and Zr alloys (Zr-1Nb, Zr-2,5Nb, Zr-1,3Sn-1Nb-0,4Fe;) in different structure conditions [2, 3, 4]. The joint analysis of strain and AE diagrams demonstrates the interrelationship between the ductility determining route of plastic flow stability loss and the mode of AE. Figures 3 and 4 illustrate the AE upon the plastic flow stability loss due to a "geometric loss of strength" by the Zr-alloy where they are of the uniform plastic strain and the level of AE does not exceed the level of a noise. The figure illustrates the earlier loss of flow stability due to the formation of an "internal" neck induced by microcracks initiating structure defects (aggregates of coarse particles, brittle secondary phase, etc.).

FIG.3 Diagrams of strain and AE upon tension Zr-1.3Sn-1Nb-.4Fe samples containing fine particle (a); and aggregates of coarse particles (b)

FIG.4 Diagrams of strain and AE upon tension of hydrogenated Zr-2.5Nb samples containing fine (a) and coarse (b) hydrides

Here, before a load drop into the to test several strong AE impulses are recorded due to microcrack openings which are corroborated by the metallographic and fractographic analyses of samples. Thus, the structure determined differences in the way the flow stability and the deformability of materials are lost are unambiguously revealed in the joint analysis of the deformation and AE diagrams. This allows the application of AE measurements for monitoring the alloy quality in the standard mechanical tests [5].

Analysis of Crack Resistance of Coats - In the tests for static and dynamic crack resistances of carburized layers the measurements of AE together with metallographic and microfractographic analyses made it possible to determine differences in the structure mechanisms and the kinetics of a fracture over the layer depth (Fig.5). The feasibility is shown using AE to measure individual crack ramps and predict the depth of a crack penetration into a layer. Mechanism and kinetics of fracture of electrolytic chrome coatings on multifilamentary superconducting wire have been investigated with the AE method when developing superconductors for the ITER magnetic system. The objective in this work is to assess the structure and the strength of 3 types of chrome coatings, different in view of their production technologies, for choice of the best coating quality. Resistance of layers to cracking characteristics of chrome electrolytic precipitates were determined using the AE measurements at the wire specimen tension.

Fig.5 Diagrams of strain, AE (a) and forecast of a crack length on AE (b) in carburized steel

Assessment of propensity to SCC of Zr tubes. The method of Acoustic Emission was applied for an assessment of propensity to Stress Corrosion Cracking (SCC) of Zr tubes (Fig.6) [6]. The technique based on the local corrosion area with AE detecting near the zone of an aggressive medium. The direct comparisons of the AE-diagrams and the results of the metallographic and fractographic analyses in express SCC tests of various alloys tubes made it possible to pick out unambiguously informative parameters that describe the process kinetics at different stages of SCC. In this case on the AE diagrams two stages - T1 (time of a beginning of destruction of an oxide film) and T2 (time of a beginning of active corrosion destruction, when pittings and microcracks are formed) were fixed which were accepted as parameters assessing propensity to SCC of zirconium alloys (Fig.7).

Fig.6 Block diagram of SCC testing with AE measurements

Fig.7 Typical AE diagrams of SCC testing of Zr-1Nb alloy

Technological Monitoring

AE Analysis of Material Damageability in Operations Composite Superconductor Twisting. The technological ductility of composite superconductors is limited by a crack formation at the drawhole-die interface.

The AE diagrams of twisting superconductors of different designs reveal three distinctive stages that differ in the acoustic radiation power (Fig.8). The first stage is distinguished by an increase in the AE power upon transition to the plastic deformation of a superconductor. The second stage corresponds to a uniform deformation and is described by AE with small amplitude of signals. The duration of this stage depends on the ductility margin of a superconductor. Upon going to the third stage one observes a raise in the power and a broadening of the amplitude spectrum of acoustic signals that accompany the formation and evolution of defects, i.e., cracks.

Crack Measurement by Acoustic Emission. To analyze the fracture processes by the AE signals are to be quantitatively compared to the events that generated them. For this purpose one is to provide and calibrate the single-valued linear relation "crack increment-acoustic signal amplitude-amplitude of recorded electric signal". The linear dependences "amplitude-crack size" corroborated for different materials are shown on fig.9.

Fig.8 Acoustic emission during twisting of composite conductor

FIG.9 Structural calibration of AE-equipment at measurement of crack sizes

Internal cracks: manganese dual phase steels (a); Zr - 2,5Nb alloy containing hydrides (b)

3. Conclusion

The quality level of materials can be determined only by complex analysis of AE measurements data and comparison of these data with standard mechanical tests.

The basis of the program for developing AE quantitative methods is formed by procedures and instruments that are based on the notion of the linear relation between the maximum peak amplitude of the acoustic field and the elastic energy of the AE source at the rate of the AE source evolution close to the sound velocity. The developed system of AE quality monitoring allows the conductance of a complex analysis of mechanical characteristics and the results of AE measurements. This allows a unique scientific and technological information to be obtained.

The quantity fracture analysis is based on measurements of acoustic impulse peak (maximum) amplitudes by non-resonance sensors for linear measurement of acoustic shifts and crack parameter measurements. The developed methods of absolute calibration of AE equipment were checked by testing various types of materials and crack parameter measurements in laps and fractures. The calibration dependencies for quantity measurements are shown. The possibilities of AE for quality analysis and for characterizing of materials in the process of various mechanical tests and in the process of pressure processing with the help of developed experimental computerized Test-AE system are demonstrated. The high sensitivity of the test-AE system provides a new level of quality monitoring of materials.

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