Some Statistical Parameters of Acoustic Emission Signals in Porous Iron under Static Loading

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Abstract Acoustic Emission (AE) method is based on detection of ultrasonic signal due to the process of plastic deformation and fracturing of a loaded material. In this paper two characteristics of the AE signal, distributions of time intervals between successive pulses and amplitude distributions of these pulses were obtained. Samples were made of the porous iron with a porosity in the range P=0.05-0.25. This class of materials can be considered as a model to study the influence of geometry of the inhomogeneous medium and percolation effects (due to changing of porosity) on the processes of deformation and fracture, and therefore the behavior of the various parameters of acoustic emission. Registered signals were broadband in a range of frequencies from 100 to 800 kHz. Consideration of amplitude distributions of AE signals showed that it is possible to identify two groups of AE pulses - low-amplitude and high-amplitude in the recorded signals. The first group corresponds to the plastic deformation of the compact sites of the material, and the latter one is usually generated by large plastic shears and crack propagation. It was showed that they have scaling with exponents vary with changes in porosity. Obtained distributions can be perceived as indirect evidence of self-organized processes occurring in porous metallic materials.

Keywords acoustic emission, plastic deformation, amplitude distribution, fracture

1. Introduction

Acoustic emission (AE) method is successfully used for nondestructive testing purposes. It is well developed for homogeneous metallic materials. New types of materials such as sintered powder metals or composites with high degree of heterogeneity have many potential mechanisms of ultrasonic emission. Therefore it is very important to understand how and when these mechanisms activate, and to be able to estimate their parameters.

Usually only some basic characteristics of acoustic emission process are used for AE diagnostics [1]. These characteristics are kinetic, such as rate or AE event count, and energy (energy of AE signal and energy of discrete events). But AE process in heterogeneous material is a complex phenomenon, with many mechanisms interacting with each other. Not without reason there are many synergetic and/or fractal theories of plastic deformation and fracturing of materials. For this kind of processes some new integral parameters of AE signal can be introduced.

In this paper two of such complex or integral parameters of AE were considered. First is well known. It is an amplitude distribution of AE signal. In heterogeneous materials this parameter has complex behavior. It is closely associated with second parameter - distribution of time intervals between successive AE events.

2. Materials and samples

As an example of material with highly heterogeneous structure porous metals were used. They can be considered as heterophase media with ultimately different properties of the two phases (solid framework and pores) [2].

Samples for acoustic emission tests were made of an iron powder obtained by spraying in air

(PZhRV2 grade). They were prepared by pressing to a preset porosity followed by sintering at 1500 K for 2.5 h in vacuum. The samples had the standard shape for tensile tests with a rectangular working part of 3X3 mm cross section. Their porosity varied within P=0.05-0.25. During static loading of these samples AE signals were recorded, and thereafter were digitally processed [3]. First, digital band-pass filtering with cutoff frequencies 100 and 800 kHz was done. Events with amplitudes under preassigned threshold (~0.2 V) were not taken into succeeding calculations.

3. Amplitude distributions

Amplitude distributions for extracted events were calculated. An example of such distribution is presented on Fig.1. Logarithmic scale was used. We can see two amplitude ranges. Dependence of amplitude rate in these ranges can be written as $n(u) \sim u^{-h}$, where h is an exponent coefficient. Amplitude of AE events is closely related to the size of the AE sources. Of course, inhomogeneity of material, reflection of acoustic waves on sample surfaces can change amplitudes of AE events, but qualitative dependence of amplitude distributions cannot be changed dramatically. So we see that there were two groups of AE events. First group of events with low amplitudes can be attributed to plastic deformation of material. From [4] we know that such type of deformation cause AE emission with frequent and low bursts. Second group of events with high amplitudes is related to nucleation and propagation of microcracks, originated from the pores [2, 4]. There’s an amplitude threshold between two groups. This threshold didn’t change for every sample in our setting. So we can use it for discrimination of AE events with different mechanisms.

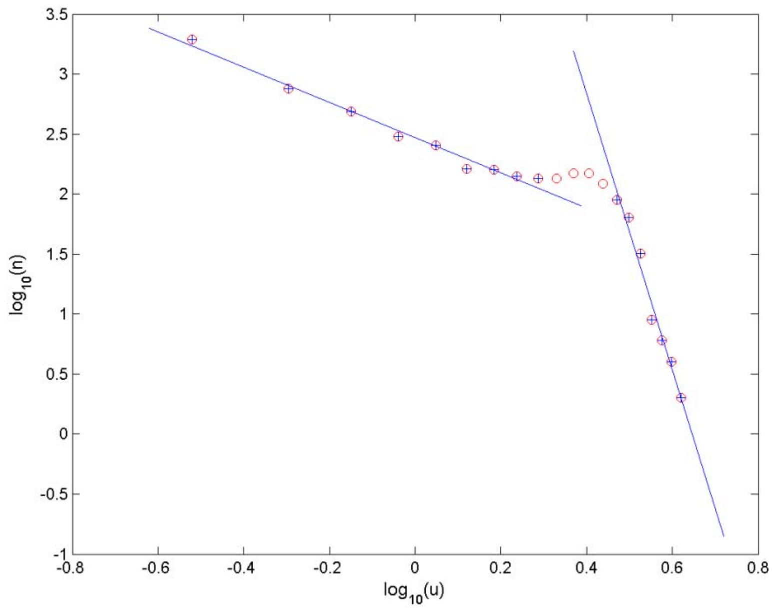

Figure 1. An example of amplitude distribution (P=0.09).

On Fig.2 the values of exponent coefficients for different samples were showed. The exponent coefficient of high amplitude events were changed for different values of porosity, while the other group of events had the same coefficients regardless of porosity. As we can see, for samples with porosity near percolation threshold (P~0.1 for porous iron [2, 5]) there was a large spread of coefficients for high amplitude AE events. It can be explained by the fact, that the structure of porous space varies from sample to sample and scale range of AE sources varies greatly respectively. For some samples isolated pores were prevailed, and for others pores form “infinite” clusters [5]. Plastic flow in compact regions of porous metal doesn’t change and therefore there’s no dependence of low amplitude coefficients on porosity.

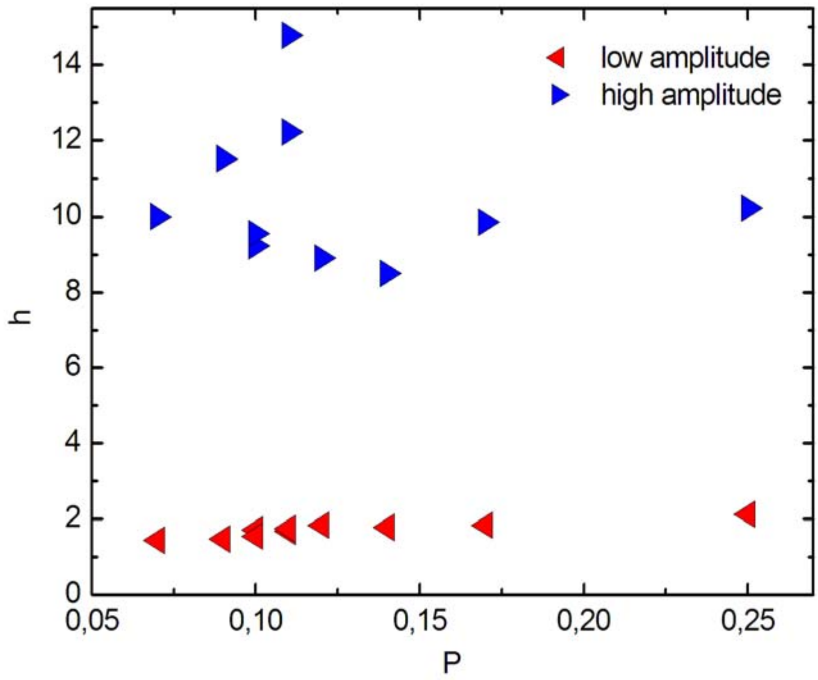

Figure 2. Exponent values of amplitude distributions for different porosities.

4. Distributions of time intervals between AE events

The next step of our work was calculation of distributions of time intervals. This parameter has a great advantage over other AE parameters, because it does not depend on peculiarities of acoustic wave propagation. Time intervals between registered AE bursts and corresponding AE events in media are the same. Also time intervals between AE events give more information about kinetic characteristics of AE process than usual parameters such as AE event count. There is only one difficulty in applying this parameter. Time distribution for all AE events takes into account all the processes that are responsible for the emission of acoustic waves. The structure of such distribution can be too intricate. To overcome this difficulty the following approach had been proposed.

All AE events had been divided into two groups according to the amplitude. Time intervals were calculated not for successive events but for successive events in one group. Fig.3 illustrates this idea. For low amplitude events with $U_{discr} < U < U_{threshold}$, where $U_{threshold}$ corresponds to amplitude threshold between "low" and "high" groups and U_{discr} was a preassigned threshold above, a distribution $w_{low}(\Delta t^{low})$ was calculated. And for high amplitude AE events with $U_{threshold} < U$ a distribution $w_{high}(\Delta t^{high})$ was obtained. These distributions had the same scaling form:

$$w_{low}(\Delta t^{low}) \sim (\Delta t^{low})^{-a_{low}} , \quad (1)$$

$$w_{high}(\Delta t^{high}) \sim (\Delta t^{high})^{-a_{high}} \quad (2)$$

Values of exponents a_{low} and a_{high} are showed in Fig.4. As we see from this figure, all exponents for low and high amplitude events were in two "bands" or value intervals.

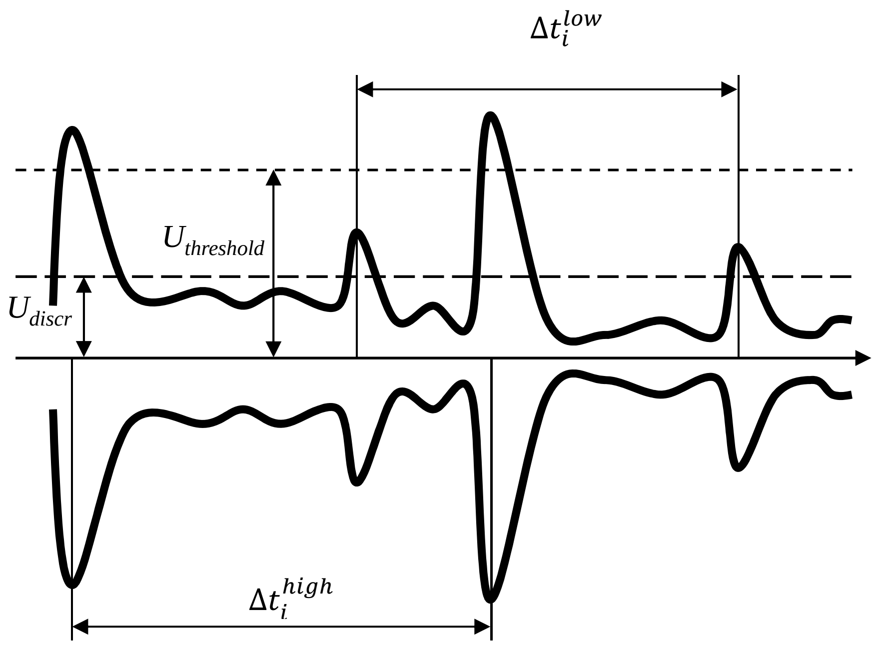

Figure 3. Explanation of the method of finding time interval distributions.

A theoretical approach for the self-organization of defects in material [6, 7] can be used to understand these experimental results. Low amplitude events strongly correlated with each other. Their exponents had higher values than for high amplitude events. Therefore "low" events and sources of acoustic emission in compact sites of porous material respectively were strongly correlated with each other. On the contrary, in the case of high amplitudes, correlation of events was weaker. The ensembles of microcracks emit acoustic waves synchronous and relatively independent of each other.

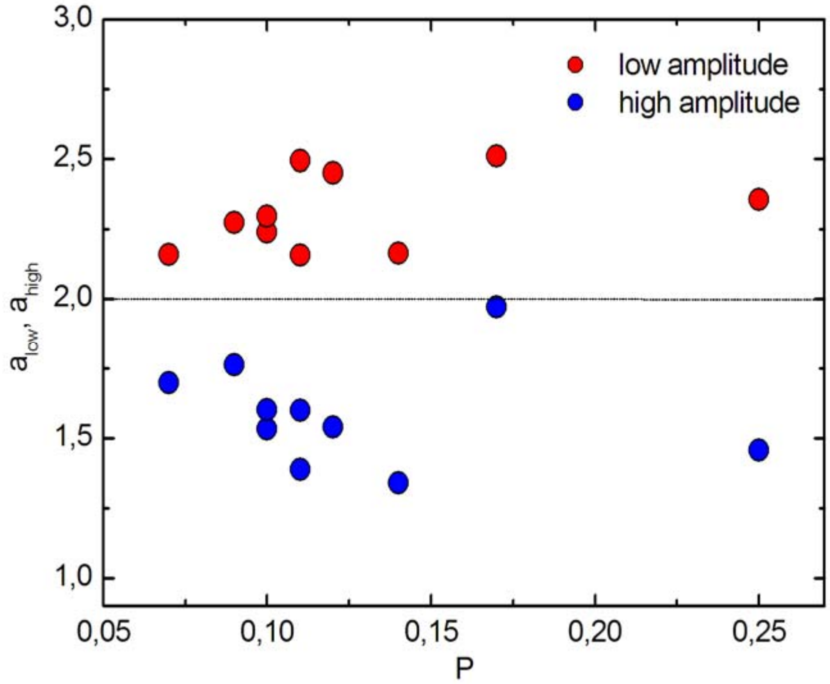

Figure 4. Exponent values of time intervals distributions for different porosities

5. Conclusion

The modified method of AE signal processing based on separate estimation of AE parameters for different groups of events was proposed. It was shown, that for the acoustic emission in porous metallic materials two groups of events and respectively two groups of AE sources can be identified. The first group was characterized by low amplitudes and the second had high amplitudes. They had different behavior of exponents for amplitude and time interval distributions. Proposed approach can be used for the development of nondestructive testing methods applied to inhomogeneous materials.

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