Application of acoustic emission for monitoring of deformation behavior of lead

D. S. Salita, and V. V. Polyakov

Citation: AIP Conference Proceedings **2051**, 020263 (2018); doi: 10.1063/1.5083506
View online: https://doi.org/10.1063/1.5083506
View Table of Contents: http://aip.scitation.org/toc/apc/2051/1
Published by the American Institute of Physics

Application of Acoustic Emission for Monitoring of Deformation Behavior of Lead

D. S. Salita[a)] and V. V. Polyakov[b)]

Altai State University, Barnaul, 656049 Russia

[a)] d.s.salita@gmail.com
[b)] Corresponding author: pvv@asu.ru

Abstract. In this paper, a study on the application of acoustic emission for monitoring of deformation behavior of lead under static tension has been conducted. It is found out that characteristics of acoustic emission signals change significantly along with the changes of strain-hardening stages. It corresponds to changes of dominant physical mechanisms of deformation under loading. Acoustic emission characteristics and their dependence on the strain-hardening stages are analyzed with the principal component analysis. The registered signals are split into small blocks where each block corresponds to the respectful part of the loading curve. A set of informative parameters related to energy and frequency characteristics of the registered signals describes the acoustic emission for each block. The performed processing provides the relation between the acoustic emission and the strain-hardening stages. The obtained results can be used in the acoustic emission study of stages of plastic deformation processes in materials and be helpful for identification of their deformation behavior.

INTRODUCTION

A study of acoustic emission signals during mechanical loading of material provides essential information about physical mechanisms of plastic deformation. Some peculiar features of acoustic emission in lead which is characterized by extremely low melting temperature and high plastic behavior have a considerable interest [1]. Thus, the same processes that occurred in other metallic materials at high temperatures can be researched at room temperatures. However, interpretation of experimental data presents certain difficulties due to the complexity of the mentioned processes and simultaneous effects of different mechanisms and sources of acoustic emission [2, 3]. An effective approach to solve this problem is the application of mathematical processing methods based on projection methods of multidimensional analysis of data [4–6]. This paper examines the relation between acoustic emission and strain-hardening stages of lead (as an example) using the principal component analysis (PCA) processing.

MEASURING EQUIPMENT

Experiments are conducted with samples of commercially-pure lead. The samples were produced by fusion casting with subsequent machining. All samples used for static tension tests are of standard shape with gauge section of 50x10x5 mm. Granular structure of the samples is shown in Fig. 1.

A material testing machine is utilized for loading with a constant rate of extension. The imposed load (used to calculate the value of true stress σ) and extension (used to calculate the value of true (logarithmic) strain ε) are registered during the testing. The strain-hardening coefficient is calculated using those values as follows [7]

$$K = \frac{\mathrm{d}\sigma}{\mathrm{d}\varepsilon}.$$

Acoustic emission signals are measured simultaneously with the mechanical characteristics by the automatic test system. The signals within the range from 50 Hz up to 500 kHz are registered with the sampling frequency of 2.5 MHz. Informative parameters measured for the signals are root mean square (RMS) values of acoustic emission stress U and a total number of impulses N.

Proceedings of the Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures
AIP Conf. Proc. 2051, 020263-1–020263-4; https://doi.org/10.1063/1.5083506
Published by AIP Publishing. 978-0-7354-1777-9/$30.00

FIGURE 1. Microstructure of lead sample. ×500

A typical result of mechanical tests is shown in the Fig. 2. There are the stress–strain curve σ(ε) and the influence curve *K*(ε). Boundaries of the strain-hardening stages are identified according to the changes of the strain-hardening coefficient *K*(ε). These changes are located at places where the curve is bent or where the curve changes its slope so that they can be found visually.

As it is demonstrated in the Fig. 2, four strain hardening stages can be identified: linear stage I, two parabolic stages II and III where *K*(ε) behaves differently, and destruction stage IV accompanied by necking and disruption of a sample.

A typical dependence of the RMS values of acoustic emission stress U on the strain ε is shown in the Fig. 3. The oscillatory curve describes the acoustic emission behavior, and an increase of strain causes significant changes in the behavior of the dependence *U*(ε). The values of *U*(ε) are significant by their magnitude at the stage I. The most prolonged stage II is accompanied by the significant decrease of the values of *U*(ε). Apparently, deformation processes at this stage are characterized by the movement of dislocation flows that are beyond the boundary and grain-boundary phenomena. Acoustic emission signal behavior can be explained by changes of the contribution of grain boundary sliding to the deformation processes of samples. According to [1], this contribution is dominant at the initial stages of plastic deformation and tends to decrease with the increase of ε. Additional peaks of acoustic emission can be found at the stage III that precedes the further disruption. These peaks can be related to the beginning of the cracking process at the grain boundaries. Acoustic emission signals are quickly dropped at the final stage IV.

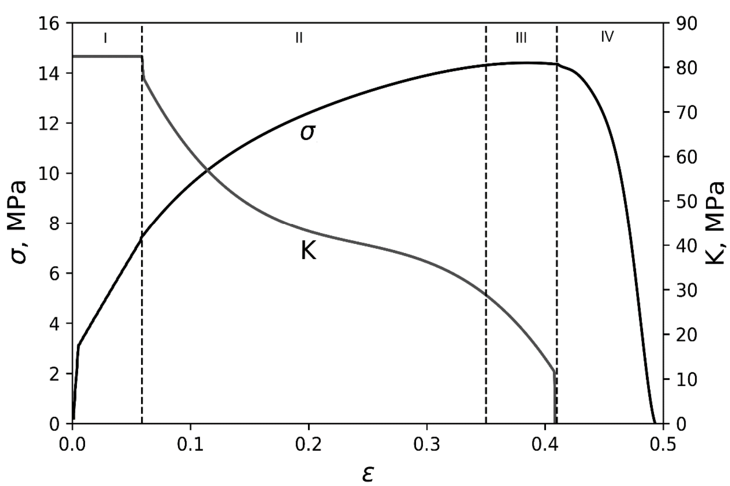

FIGURE 2. Strain-hardening of lead. I, II, III, IV—strain-hardening stages

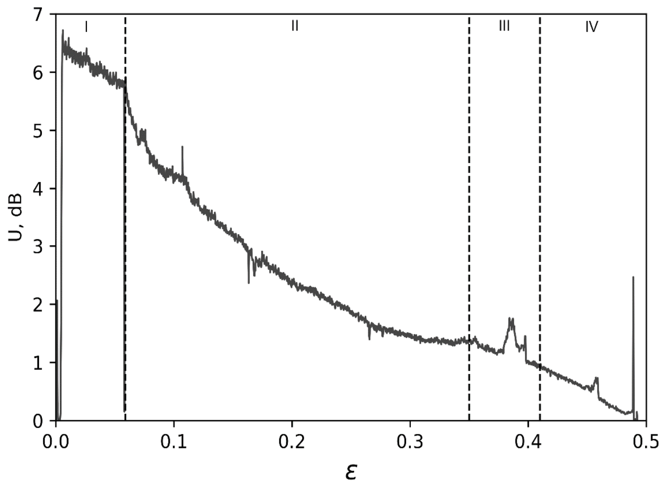

FIGURE 3. Acoustic emission upon loading of lead. I, II, III, IV—strain-hardening stages

The influence of grain structure on acoustic emission is also investigated. Samples with different grain structure with different temperature and time of recrystallization have been used. Analysis of σ(ε) dependencies reveals that samples with fine-grain structure have higher mechanical characteristics, such as tensile strength and maximum strain. Measured parameter $U(\varepsilon)$ of acoustic emission signals tends to be dependent to the structure of samples. Maximums of $U(\varepsilon)$ are expressed weaker and dropped quicker for samples with fine-grain structures. This can be explained by the different contribution of grain boundary sliding to acoustic emission for samples with different structures. A density of triple junctions of grain boundaries is relatively high in samples with fine-grain structures, and these triple junctions are the main barriers that block the movements of grain boundary dislocations. Since the movements are obstructed, acoustic emission signals demonstrate weak maximums. Samples with coarse-grain structure have a low density of triple junctions of grain boundaries and, therefore, the grain boundary sliding and movements of grain boundary dislocations rates are higher and more intense. It results in significantly stronger maximums of acoustic emission measured parameter $U(\varepsilon)$. It can be said that acoustic emission behaves the same way as it behaves in cases when porosity of samples changes. In the samples used in this study, pores are located at triple junctions of grain boundaries, and it makes the movements of grain boundary dislocations easy. Thus, acoustic emission in porous materials becomes stronger when porosity becomes higher.

APPLICATION OF PRINCIPAL COMPONENT ANALYSIS

As it is shown in the Fig. 3, acoustic emission signals are related to deformation processes occurred in the material during its loading. The relation between the characteristics of those signals and the strain-hardening stages is established by application of PCA [8]. The sequence of registered signals is split into separate blocks with a duration of ~1 s, where each block corresponds to the respectful part of the stress–strain curve σ(ε). To describe the acoustic emission signal, the feature vector of informative parameters related to energy and frequency properties of the signal is used as input data for the PCA processing method [9]. The feature vector consists of the following parameters:

– RMS value of stress U,
– maximum value U_m,
– peak factor $U_p = U_m / \bar{U}$ ($\bar{U}$ —average value for each block),
– form factor $U_f = \bar{U} / U$,
– total number of impulses N.

This feature vector provides coordinates for a point in a multidimensional space of principal components. Points related to blocks with similar physical characteristics are located close to each other and assembled into clusters. Further, for illustrative purposes, the input data are treated as geometrical projections on a coordinate plane of the first and the second principal components PC1 and PC2. Processing results are presented in the Fig.4.

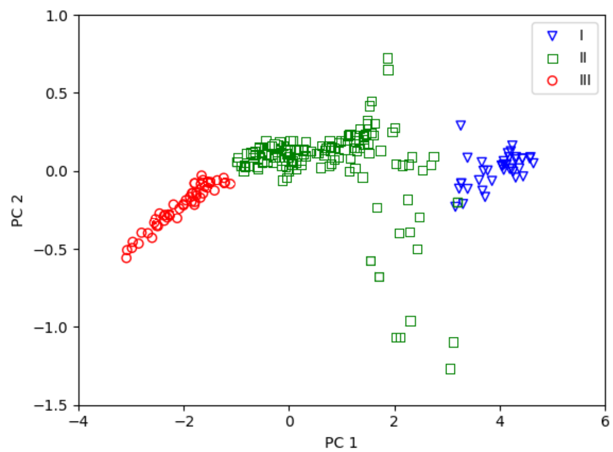

FIGURE 4. Projection of acoustic-emission signal's characteristics on the plane of first principle component. I, II, III—strain-hardening stages

Points marked as I, II, and III are related to different blocks of strain-hardening stages I, II, and III correspondingly.

According to the Fig. 4, all points are assembled into three clusters corresponding to three stages of strain hardening. Placement of points indicates the change of the dominant mechanism of plastic deformation when the stages are changed. It results in changes in energy and frequency characteristics of acoustic emission signals. Thus, the proposed processing approach reveals latent structures and establishes quantitative relations between strain-hardening stages and characteristics of the acoustic emission signals.

CONCLUSION

This paper presents the study of acoustic emission in lead under static tension. Dependence of characteristics of acoustic emission signals is revealed, and qualitative changes of acoustic emission caused by transitions from one strain-hardening stage to another due to an evolution of the dominant mechanism of plastic deformation are described. The PCA is used to establish quantitative relations between strain-hardening stages and characteristics of the acoustic emission signal with reliable clustering of the signal characteristics according to the stages mentioned above.

The proposed approach can be used in studying deformation processes in lead-based materials and in monitoring of deformation behavior of materials.

ACKNOWLEDGMENTS

This research is partially supported by the RFBR grant No. 17-08-00914.

REFERENCES

1. T. F. Elsukova, E. M. Novoselova, V. V. Karavaeva, and G. V. Angelova, Phys. Mesomech. **3**(5), 87 (2000).
2. M. M. Krishtal and D. L. Merson, Phys. Met. Metallogr. **81**(1), 156–162 (1996).
3. D. B. B. Ferreira, R. R. Da Silva, J. M. A. Rebello, and M. H. S. Siqueira, Insight **46**(5), 282–289 (2004).
4. K. H. Esbensen, *Multivariate Data Analysis—In Practice* (CAMO Process AS, Oslo, 2002).
5. A. Sophian, G. Y. Tian, D. Taylor, and J. Rudlin, NDT E Int. **36**, 37–41 (2003).
6. A. V. Egorov, S. V. Kucheryavskiy, and V. V. Polyakov, Chemometrics Intelligent Labor. Syst. **160**, 8–12 (2017).
7. S. A. Barannikova, V. I. Danilov, and L. B. Zuev, Tech. Phys. **74**(10), 52–56 (2004).
8. A. A. Lependin, V. V. Polyakov, and D. S. Salita, Tech. Phys. Lett. **41**(5), 411–413 (2015).
9. V. V. Polyakov and A. V. Egorov, Russ. J. Nondestruct. Test. **51**, 631–636 (2015).