Power law distributions and multifractality of acoustic emission spectra during intermittent plastic deformation

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Acoustic emission (AE) refers to high frequency transient elastic waves generated due to deformation of material. AE is reported in a large variety of systems ranging from geological to laboratory scales. In the context of plastic deformation of metals and alloys, AE studies have been carried out on metals and alloys for over five decades. Correlations have been established between the nature of the AE signals and dislocation sources in variety of deformation conditions. In the case of the Portevin-Le Chatelier (PLC) effect, a specific type of spatio-temporal plastic deformation instability, studies have established that the AE signals follow a power law distribution for the static type C, partially propagating type B and fully propagating type A bands. The existence of multifractality of AE signals for the three types of bands have been reported [1]. However, there has been little progress in constructing models that explain the nature of acoustic emission and it's statistical and dynamical features.

The major obstacle is the inability to bridge the widely differing time scales corresponding to the AE signal (MHz) and applied strain rate ($\sim 10^{-5}s^{-1}$). Recently, we developed a general framework for calculating AE signals during any kind plastic deformation [2, 3]. The dissipated acoustic energy is represented by the Rayleigh-dissipation function which is the square of the gradient of elastic strain rate. Then, the amplitude of the AE signals is proportional to the square of the local strain rate that depends on the number of dislocations involved in the plastic instability. The origin of different types of AE signals during the PLC instability is explained by employing the Ananthakrishna model for the PLC effect. The nature of the AE spectrum associated with these three different types of serrations are distinct. Our results show that for the type C bands where the serrations are large, acoustic emission pattern consists of well separated burst type AE signals. With the increase of strain rate, these burst type of AE signals merge to form nearly continuous signals with overriding bursts for the continuously propagating type A bands.

The purpose of the paper is to verify if the model AE spectrum for the three types of serrations follow a power law distribution and also to verify the multifractality of the AE signals seen in experiments. A multifractal is an interwoven structure of infinitely many fractals. It describes the statistical properties of singular measures associated with the nonuniform distribution in terms of their singularity spectrum or their corresponding generalized dimensions [4]. Using the formalism developed in Ref. [2, 3], we first calculate the AE spectra corresponding to the three types of serrations and show that the AE spectrum for the three types of serrations follow a power law distribution with an exponent whose value increases with increasing strain rate. The exponent value is smallest for the large amplitude nearly regular type C serrations increasing to the highest value of 2.5 for the low amplitude type A serrations. Fig. 1(a) shows plots of $ln\, D(\Delta R_{AE})$ versus $ln\, \Delta R_{AE}$ for the three strain rates. The calculated the multifractal spectra corresponding to the AE spectra for the three types of serrations using the direct method proposed by Chhabra *et al.,* [5] are shown in Fig. 1(b). These results are consistent with the experiments [1].

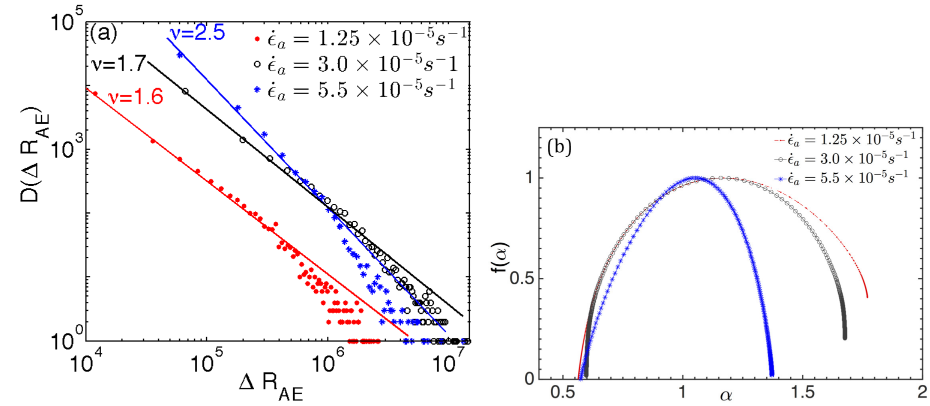

Figure 1: (a) Log-log plots of $ln\, D(\Delta R_{AE})$ versus $ln\, \Delta R_{AE}$ for $\dot{\epsilon}_a = 1.25, 3.0$ and $5.5 \times 10^{-5}s^{-1}$ and (b) the corresponding $f(\alpha)$ spectra.

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