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## The intermittency of plasticity in an Al3%Mg alloy

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Abstract: Statistics of acoustic emission accompanying plastic deformation and of stress serrations caused by the Portevin-Le Chatelier effect are studied during tension of an Al3%Mg alloy at room temperature. Power-law distributions of acoustic emission reflecting self-organization of dislocations and intermittency of plastic flow are found, irrespective of the strain rate, both before and after the critical strain for the onset of the serrated flow. In contrast, several regimes including both power-law and peaked distributions are observed at the macroscopic scale of stress serrations, depending on the applied strain rate.

### 1. Introduction

Recent studies of jerky flow in dilute alloys, also referred to as the Portevin–Le Chatelier (PLC) effect, proved that it is often characterized by scale invariance through power law distributions of jerks reflecting self-organization of the dislocation ensembles (see review [1] and references therein). Statistical and dynamical analyses of serrated stress-time series revealed such complex nonlinear phenomena as self-organized criticality (SOC) [2] and chaotic dynamics [3]. Independently, power-law statistics were found for bursts of acoustic emission (AE) and local strain rate recorded during deformation of pure crystalline solids [4, 5], which bears evidence to an intermittent, avalanche-like character of the macroscopically homogeneous plastic “flow”, albeit at sizes of the local strain-rate jumps much smaller than during jerky flow. These observations suggest that self-organization phenomena are of a general nature in dislocation ensembles, and may become apparent at various plastic event scales [6].

Due to huge collective effects resulting in the macroscopic stress serrations, the PLC effect presents a distinct advantage for the investigation of self-organization of dislocation ensembles. Indeed, simultaneous application of the traditional stress-time recording techniques and of more sensitive methods, such as AE or local extensometry, allows for studying deformation processes in a large range of event scales. Moreover, the existence of a critical strain for the occurrence of jerky flow offers an opportunity to study collective effects both during the seemingly smooth flow below the critical strain and the unstable regime beyond it. Hence a comparative study of intermittent plasticity in dilute alloys and in pure solids can be documented.

To our knowledge, the statistical study of the PLC effect over such diverse event scales has not been performed so far. In the present work we report on the statistical analysis of AE accompanying plastic deformation of an AlMg alloy – a classical material exhibiting the PLC effect – and compare the AE statistics with that of stress serrations.

## 2. Experimental technique

Tensile specimens with a gauge part  $25 \times 6.8 \times 2.5 \text{ mm}^3$  in size were cut from a polycrystalline cold-rolled sheet of Al3%Mg alloy, annealed at  $400^\circ\text{C}$  during 2 h, and quenched into water. Uniaxial tensile tests were conducted at room temperature with constant crosshead velocity corresponding to the initial imposed strain rate  $\dot{\epsilon}_a$  from  $2 \times 10^{-5} \text{ s}^{-1}$  to  $6 \times 10^{-3} \text{ s}^{-1}$ . The data acquisition rate was chosen in a range from 2 Hz to 500 Hz, depending on the strain rate.

AE was recorded during tensile tests by a computer-controlled LOCAN 320 system. The piezoelectric transducer was attached to the surface just above the deforming part of the sample with the aid of grease. The total gain and the threshold voltage for the identification of the starting point of an AE event were respectively 80 dB and 27db.

## 3. Macroscopic behavior

Figure 1 shows examples of stress-strain curves observed at three different strain rates. Together with local extensometry measurements presented elsewhere, these data show that the studied alloy exhibits the well-known types of the PLC behavior. Type *A* regime is observed at high strain rates. It is characterized by irregular stress fluctuations associated with deformation bands propagating quasi-continuously along the tensile axis. At lower strain rates, these irregular deformation curves are replaced by more regular oscillations of type *B* (see also Fig. 3) which result from static deformation bands sequentially nucleated ahead of each other. Such correlated nucleation is conventionally referred to as “hopping propagation”. Further decrease in strain rate leads to sharp type *C* serrations, which are usually attributed to randomly nucleated bands, although the analysis of the serrations bears evidence to some correlation [7]. It can also be seen from Fig. 1 that the macroscopic stress jumps occur after some critical strain  $\epsilon_{cr}$  exhibiting strain rate dependence.

The statistical behavior of the stress serrations in the investigated alloy is also consistent with literature data [1]. Scale-free power-law distributions are found for the amplitude of type *A* serrations, in agreement with the SOC hypothesis for type *A* behavior. In the case of type *B* curves, the histograms are characterized by large peaks with irregular shape reflecting the occurrence of characteristic scales. Two distinct scales of stress drops, leading to essentially bimodal distributions (cf. [8]), are distinguished for type *C*: the sequence of deep drops is accompanied by serrations with essentially lower amplitudes, usually preceding them. The latter are generally considered as stochastic fluctuations and disregarded in the theories of the PLC effect

An unexpected feature is observed for these small-scale drops. By calculating the distributions separately for the two kinds of events (Fig. 2), we found power-law statistics at small scale, which proves the nonrandom nature of the small serrations. The power-law exponent  $\alpha$  varies roughly between 1 and 1.5, similar to  $\alpha$ -values determined for type *A* serrations. It should be noted that small drops with the same amplitude also occur before the critical strain for type *C* instability, indicating that plasticity is strongly heterogeneous at this scale all over the deformation curve. This conclusion is also confirmed by the observation of stress undulations before the critical strain for type *B* instability.

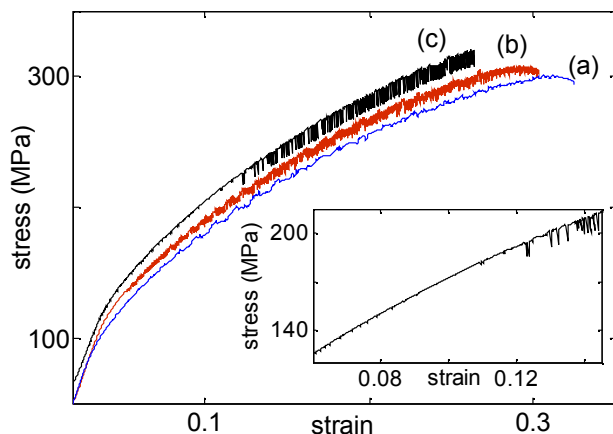


Figure 1. True stress-true strain curves recorded at room temperature and various strain rates: (a)  $6 \times 10^{-3} \text{ s}^{-1}$ , type *A* behavior; (b)  $2 \times 10^{-4} \text{ s}^{-1}$ , type *B*; (c)  $2 \times 10^{-5} \text{ s}^{-1}$ , type *C*.

Inset: Portion of a stress-strain curve at  $2 \times 10^{-5} \text{ s}^{-1}$ , which displays small-amplitude stress drops before the onset of the macroscopic instability.

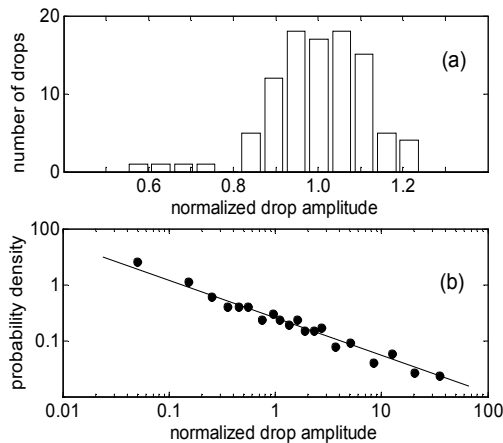


Figure 2. Distribution of the amplitudes of (a) large stress drops and (b) low-amplitude serrations for  $\dot{\epsilon}_a = 2 \times 10^{-5} \text{ s}^{-1}$ .

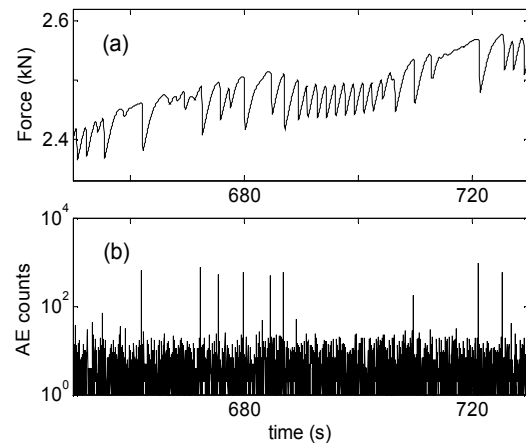


Figure 3. Synchronous records of (a) the deformation curve and (b) AE counts;  $\dot{\epsilon}_a = 2 \times 10^{-4} \text{ s}^{-1}$ .

#### 4. Acoustic emission

Figure 3 represents synchronous records of a type *B* deformation curve and the concomitant AE count. Such behavior is typical of the PLC effect and suggests distinguishing “continuous” vs. burst-like AE components [9]. The continuous AE also consists of discrete bursts but owes its name to its random-like appearance, so that it is customarily attributed to uncorrelated motion of dislocation pile-ups. This kind of AE is observed from the beginning of plastic deformation. Bursts in the AE count rate and event duration are noticed for some type *B* stress drops only (Fig. 3). They accompany almost every deep stress drop of type *C*, but are hardly discernible during type *A* serrations. Note that the amplitude of the AE events practically does not display any increase at the instant of the stress drops. Thus, the bursts in AE count rate and duration are likely due to overlapping of numerous AE events.

As justified in Ref. [10], a physically based measure of the plastic activity in the sample is provided by the AE energy which can be evaluated as  $E \sim A^2$ , where  $A$  is the amplitude of the acoustic events. Statistical analysis of this quantity reveals unexpected behavior. Namely, the calculated distributions are found to obey power laws in all deformation conditions. This result refutes the hypothesis of randomness and seems to be a generic property of the intermittency of plastic flow. The power-law exponent  $\alpha_{\text{AE}}$  depends on strain rate and generally changes in the course of deformation. However, as shown in Fig. 4, it is possible to determine time intervals during which it remains statistically invariant within some least square error. In Fig. 4, such intervals are designated by rectangles, the height of which displays the respective error.

During unstable flow,  $\alpha_{\text{AE}}$  usually takes on rather high values, ranging roughly from 2 to more than 3. Close values of  $\alpha_{\text{AE}}$  are observed for various specimens in type *A* regime (Fig. 4a), whereas it noticeably changes with deformation, and from sample to sample, at lower strain rates, particularly, in type *B* regime (Figs. 4b). This observation agrees with conclusions on the variable sensitivity of the dislocation dynamics to the microstructure in various deformation conditions, drawn in Ref. [11] from the analysis of stress serrations. It is worthy of notice that  $\alpha_{\text{AE}}$  typically takes on lower values below  $\epsilon_{\text{ct}}$ . In particular, it appears to be less than 2 for type *A* instability, thus approaching the value of 1.5-1.6 reported for smoothly deforming pure materials [4, 5, 10].

#### 5. Conclusions

The statistical analysis of both stress serrations and AE signals during deformation of a dynamically strain ageing alloy reveals a complex multiscale behavior of dislocation ensembles. The following major conclusions can be made.

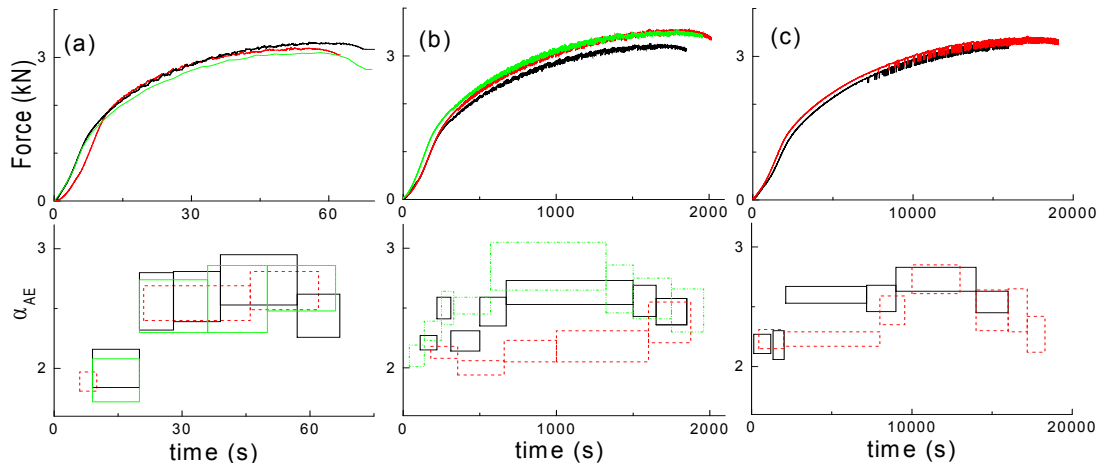


Figure 4. Force vs. time curves and variation of the power-law index  $\alpha_{AE}$  for the AE energy distribution. (a)  $\dot{\epsilon}_a = 6 \times 10^{-3} \text{ s}^{-1}$ ; (b)  $\dot{\epsilon}_a = 2 \times 10^{-4} \text{ s}^{-1}$ ; (c)  $\dot{\epsilon}_a = 2 \times 10^{-5} \text{ s}^{-1}$ .

(1) A persistent scale invariance feature, as reflected by power laws, is found for the statistical distributions of AE energy. The power-law statistics is also observed for low-amplitude stress serrations, corresponding to an intermediate scale between AE and macroscopic stress drops. These observations bear evidence to an inherently intermittent nature of plastic flow associated with an avalanche-like dislocation dynamics. At the same time, the power law is not universal in the present experiments, in contrast to a situation often met in pure crystals [5, 6], but its slope depends on the deformation conditions. Understanding these variations requires further investigation of the role of the dislocation aging, grain boundaries, as well as of the effect of the finite time resolution leading to overlapping of the AE events.

(2) The power-law statistics of the AE confirms the hypothesis of SOC-like behavior in the conditions of type *A* instability, which was previously based on the observation of the power-law statistics of stress serrations [1], whereas it differs from the peaked distributions characterizing type *B* and type *C* stress drops. Thus, distinct statistics coexist in this case: whereas the power-law distributions and scale-free behavior uncovered by AE monitoring correspond to the motion of dislocation groups, the peaked histograms reveal the existence of characteristic scales at the macroscopic scale of the deformation curve. The latter behavior may occur through synchronization of dislocation groups, a process reminiscent of the collective synchronization of coupled oscillators [12].

## References

- [1] Kubin L P, Fressengeas C, Ananthakrishna G, 2002 *Dislocations in solids*, vol **11**, Nabarro F.R.N, Duesbery M S, Editors 101
- [2] Bak P, Tang C, Wiesenfeld K 1988 *Phys. Rev. A* **38** 364
- [3] Abarbanel H D I, Brown R, Sidorowich J J and Tsimring L Sh 1993 *Rev. Mod. Phys.* **65** 1331
- [4] Miguel M C, Vespignani A, Zapperi S, Weiss J and Grasso J R 2001 *Nature*, **410** 667
- [5] Weiss J, Richeton T, Louchet F, Chmelik F, Dobron P, Entemeyer D, Lebyodkin M, Lebedkina T, Fressengeas C and McDonald R J 2007 *Phys.Rev. B* **76** 224110
- [6] Zaiser M 2006 *Advances in Physics* **55**, 185
- [7] Lebyodkin M A and Lebedkina T A 2008 *Phys. Rev. E* **77** 26111
- [8] Lebedkina T A and Lebyodkin M A 2008 *Acta Mater.* **56** 5567
- [9] Chmelik F, Ziegenbein A, Neuhäuser H and Lukáč P 2002 *Mater. Sci. Eng. A* **324** 200
- [10] Weiss J, Grasso J R, Miguel M C, Vespignani A and Zapperi S 2001 *Mater. Sci. Eng. A* **309** 360
- [11] Bharathi M S, Lebyodkin M A, Ananthakrishna G, Fressengeas C, Kubin L P 2002 *Acta Mater.* **50** 2813
- [12] Strogatz S H 2000 *Physica D* **143**, 1