ARCHIVES OF ACOUSTICS
18, 3, 473–480 (1993)

ACOUSTIC EMISSION DEPENDENCE ON GRAIN SIZE IN COPPER

A. PAWEŁEK, Z. JASIEŃSKI, S. PILECKI AND W. BOCHNIAK

Aleksander Krupkowski Institute of Metal Research
Polish Acadmy of Sciences
(30-059 Kraków, ul. Reymonta 25)

Institute of Fundamental Technological Research
Polish Academy of Sciences
(00-049 Warszawa, ul. Świętokrzyska 21)

1. Introduction

The technique of acoustic emission (AE) is still currently applied to the investigations of the plastic deformation of metals and alloys (e.g. [1, 2]). One of the controversial problems is the explanation of the influence of grain size on the acoustic emission (AE) activity [3, 4]. Some of the experimental results indicate that AE increases with diminishing grain size; however, there are cases where an increase of AE has been observed with increasing grain size. WADLEY et al. [3] suggested that a reduction in grain size and, consequently, diminishing of the area of the individual dislocations slips should lead to a reduction in AE activity. The controversy lies in the fact that on the other hand, Gillis [4] suggested that if two polycrystals differing only in grain size d, becom deformed to the same value of strain, ε, ($\varepsilon = b\rho_m L = \text{const}$, b — the Burgers vector, ρ_m — mobile dislocation density, $L \cong d$ — mean free path of dislocation), then more dislocation segments must be activated in a smaller grain, hence the AE activity in a greater grain should be smaller.

Recently [5], it has been suggested that the problem may be considered on the basis of the concept of AE where the origins of AE sources during plastic deformation are considered mainly as the results of dislocation annihilation processes which are accompanied by the operation of the dislocation sources (e.g. Frank – Read type). In this paper we present, qualitatively, that the experimentally observed AE activity in technically pure polycrystalline copper is greater in the material of a smaller grain size than in that of greater one, and that this result may be quite well explained on the basis of the dislocation annihilation concept of AE sources. Moreover, using the same concept of AE, some suggestions about the possibility of the inverse dependence of AE on the grain size has also been briefly discussed.

2. Experiments and results

Three kinds of plane specimens of standard sizes (100 mm × 10 mm × 1 mm) were performed. Each of them was annealed for 45 min in air: the first at 400°C, the second at 600°C and the third one at 850°C. This way we obtained the samples of three different grain size, arbitrarily referred hereafter to as small, average and large grained material, respectively. The specimens were deformed at room temperature using the standard testing machine of INSTRON type. Tensile tests were carried out at constant strain rate $\dot{\varepsilon} = 1.5 \times 10^{-4}\,s^{-1}$ and the AE parameter $\Delta N/\Delta t$, i.e., the number ΔN of AE enevents detected in a time interval Δt, was measured simultaneously. The AE impulses

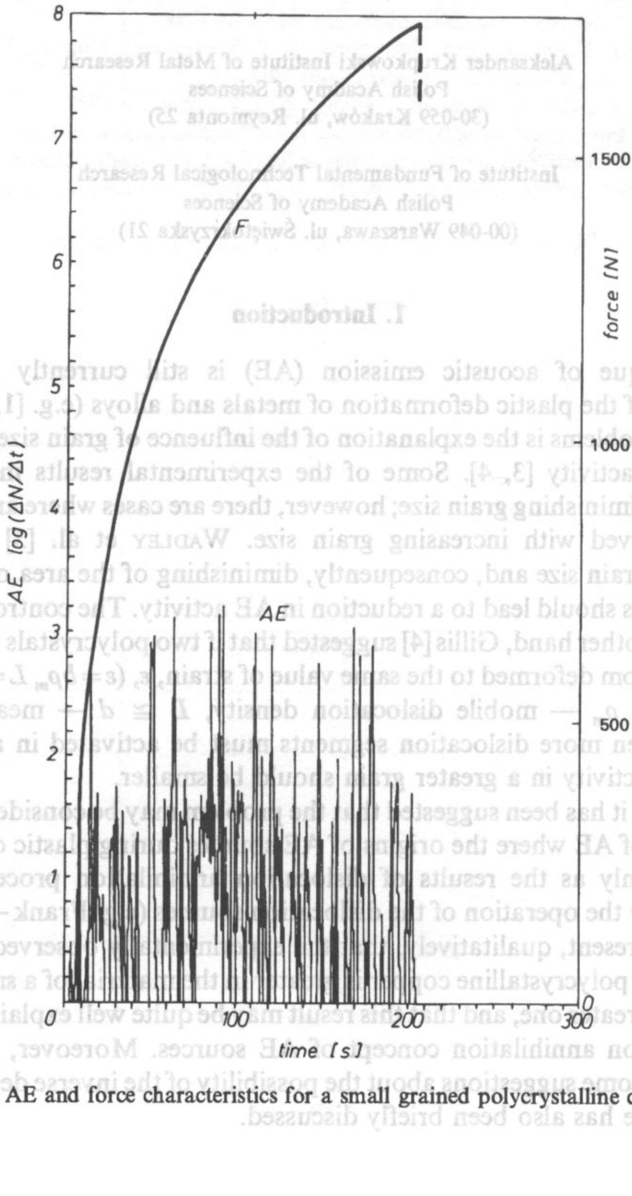

Fig. 1. AE and force characteristics for a small grained polycrystalline copper.

were detected by using the broad-band (from 50 kHz to 600 kHz) piezoelectric sensor in $\Delta t = 1$ s time intervals. The threshold voltage of the discriminator was 0.73 V and the total amplification including the preamplifier was 94 dB; for more details about the AE apparatus see [6].

Figures 1 to 3 show the behaviour of both AE activity and tensile force during the deformation of the samples of small, average and large grain size, respectively. Comparing these figures we can state that the AE activity is greater in the sample of smaller grain and that this fact seems to be correlated with the plasticity feature, i.e., the total elongation of the sample of greater grain is also smaller than of the sample of smaller grain. However, on the other hand, we realize that this correlation may be of

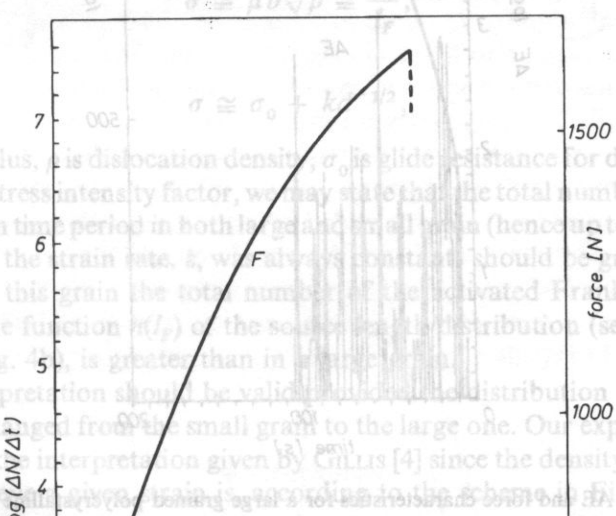

Fig. 2. AE and force characteristics for a polycrystalline copper of intermediate grain size.

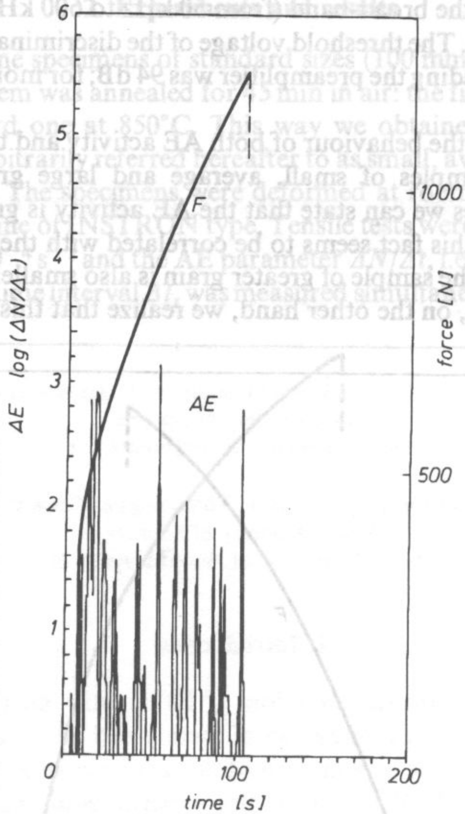

Fig. 3. AE and force characteristics for a large grained polycrystalline copper.

virtual and incidental character but, nevertheless, we should like to discuss this problem also on the basis of the dislocation annihilation concept of AE source.

3. Discussion

We would like to show here that the presented observations of AE dependence on the grain size in technically pure polycrystalline copper may be satisfactorily explained on the basis of the dislocation annihilation concept of the sources of AE during plastic deformation. This concept is based on both experimental results obtained by Boiko et al. [7, 8, 9] and the theoretical results of calculations carried out by Natsik et al. [10, 11] and this way it was developed and extended to the case of plastic deformation of metals (see for details [12, 13, 14, 15]). The essence of this concept is the fact that the AE events are induced mainly by the processes of dislocation segment annihilation occurring during the operation of the Frank-Read sources each time when dislocation loops are released from the source (for a detailed description of this mechanism (see [16, 17]) [The concept includes also the possibility of the annihilation processes occurring during the escape of dislocation from the specimen to its free surface we do not exclude either that some contribution to the detected AE pulses may originate by other dislocation processes related, for example to the non-stationary movement of dislocations].

In order to explain the AE dependence on the grain size, it is very reasonable to assume that the length, l_{AE} of the dislocation segments, the annihilation of which induces the AE events, and which is required for the closing of the dislocation loop (see Fig. 4a), is proportional to the length, l_F, of the dislocation segment being potentially the Frank–Read source, i.e., $l_{AE} = \alpha l_F$, where α is a factor independent of the grain size.

Using well-known relations for plastic flow stress [20]

$$\sigma \cong \mu b \sqrt{\rho} \cong \frac{\mu b}{l_F}, \tag{1}$$

and [21]

$$\sigma \cong \sigma_0 + k d^{-1/2}, \tag{2}$$

μ is a shear modulus, ρ is dislocation density, σ_0 is glide resistance for dislocations, and k is microscopic stress intensity factor, we may state that the total number of AE events detected in a given time period in both large and small grain (hence up to the same value of strain, ε, since the strain rate, $\dot{\varepsilon}$, was always constant) should be greater in a small grain because in this grain the total number of the activated Frank-Read sources, determined by the function $n(l_F)$ of the source length distribution (see the schematic illustration in Fig. 4b), is greater than in a large grain.

Such an interpretation should be valid provided the distribution function $n(l_F)$ is not drastically changed from the small grain to the large one. Our explanation is then convergent with the interpretation given by GILLIS [4] since the density of dislocations activated to achieve a given strain is, according to the scheme in Fig. 4b, equal to

$$\rho_1 = \int_{l_{F_1}}^{\infty} n(l_F)\, dl_F, \tag{3}$$

and thus in the small grain it is greater than the corresponding density

$$\rho_2 = \int_{l_{F_2}}^{\infty} n(l_F)\, dl_F, \tag{4}$$

in the large grain. However, our explanation is more general since the one given by GILLIS [4] is valid under the assumption that the mean free path of dislocation is equal to the average size of the grain which is not always satisfied, particularly in very large grained materials.

On the other hand, if the distribution function $n(l_F)$ were drastically different in both grains, then our interpretation would give the possibility of an occurrence of the inversed AE dependence on the grain size. Such a situation is shown schematically in Fig. 4c, where the density of dislocations activated is, of course, greater in a smaller grain but it is possible that the number $n(l_F)$ of dislocation segments activated as

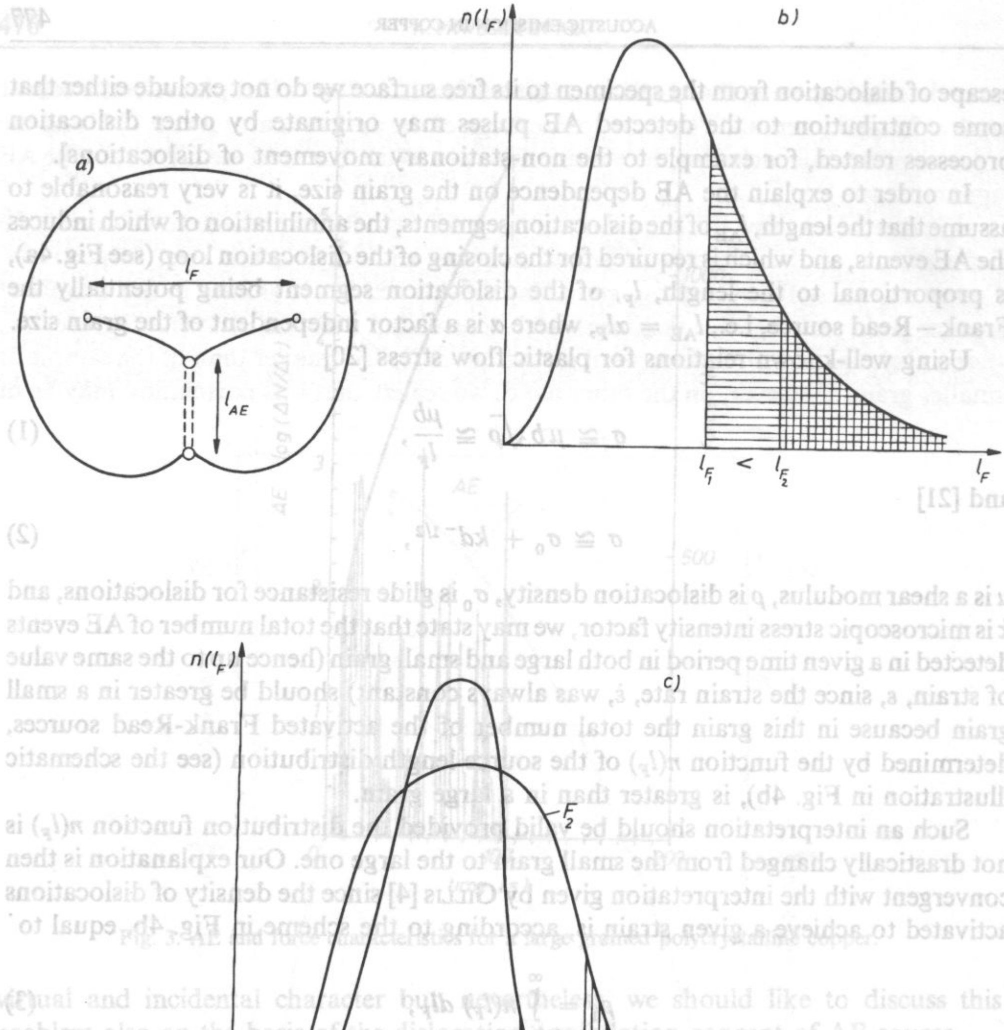

Fig. 4. A schematic illustration of the dislocation annihilation process during the operation of a Frank – Read source (a); (b) — the case when the function of source length distribution is the same for different grain sizes, and (c) — the case when this function is drastically changed from the one grain (F_1) to another (F_2).

Frank – Read sources — and so the total number $n(l_{AE})$ of AE events — is greater in a large grain than in a smaller one.

Now we discuss briefly the possible correlation of AE to the plasticity feature, i.e., to the total elongation of the sample up to the fracture. The fact that the strain localization, leading to the fracture, occurs faster in a large grain in pure polycrystalline metals than in a small one (e.g. [18]) has been experimentally stated. There are two reasons for this. First, the size of the local "geometric defect" formed at a free surface of a large grained specimen (e.g. due to the operation of two slip systems at least) is deeper than the size of such a "geometric effect" formed at the same time in a small grained specimen; hence in the former case the tendency to necking and fracture is faster. Second, the number of adjacent grains belonging to a given grain in a large grained sample is smaller than the number of grains surroundings a given grain in a small grained sample, and thus the changes in grain orientations caused by their rotation as well as the possibility for slip transfer from one grain to another are easier in the large grained material. Then also a „transcrystallographic" slip, if required for macroscopic strain localization, may occur in an easy way. One can see that the dislocation processes responsible for AE and for total elongation are, in fact different in nature, and the correlation between AE behaviour and this plasticity feature seems to be rather virtual and incidental, though we do not exclude that the inverse dependence of AE on the grain size (reported, e.g. in [4]) may be related to the inverse dependence of total elongation on the grain size i.e. the faster tendency to strain localization in a small grained material, evidenced in some alloys of low stacking fault energy, e.g. in [19].

4. Conclusions

The general conclusion from the experimental observations presented here of AE dependence on the grain size can probably be that this dependence may be explained qualitatively on the basis of the dislocation annihilation concept of AE sources. Other considerations about the inverse dependence of AE on grain size as well as the statement on a probable lack of the correlation between the AE and the total elongation are only of predictional character and they must be experimentally verified in further investigations.

References

[1] S. Pilecki, Archiwum Akustyki, **21**, 109 (1986).
[2] A. Polakovič, P. Minor, H. Hyross, Z. Jasieński, A. Litwora and A. Piątkowski, Kovové Materialy, **24**, 114 (1986).
[3] H.N.G. Wadley, G.B. Scruby and J.H. Speake, Int. Metals Review, 249, 41 (1980).
[4] P.P. Gillis, Acoustic Emission. ASTM Spec. Tech. Publ., 505, 20 (1972).
[5] A. Pawełek, W. Bochniak, H. Dybiec, and W. Stryjewski, Archives of Metallurgy, **33**, 645 (1988).
[6] W. Stryjewski, G. Zapalski and A. Pawełek, Archives of Metallurgy, **33**, 485 (1988).

[7] V.S. Boiko, R.I. Garber, L.F. Krivenko and S.S. Krivulya, Fiz. Tverd. Tela, **15**, 321 (1973).
[8] V.S. Boiko, R.I. Garber, and L.F. Krivenko, Fiz. Tverd. Tela, **16**, 1233 (1974).
[9] V.S. Boiko, R.I. Garber, V.F. Kivshik and L.F. Krivenko, ZhETF, **71**, 708 (1976).
[10] V.D. Natsik and K.A. Chishko, Fiz. Tverd. Tela, **14**, 3126 (1972).
[11] V.D. Natsik and A.N. Burkhanov, Fiz. Tverd. Tela, **14**, 12896 (1972).
[12] A. Pawełek, W. Stryjewski, W. Bochniak, H. Dybiec, Phys. Stat. Sol. (a), **90**, 531 (1985).
[13] A. Pawełek, H. Dybiec, W. Bochniak and W. Stryjewski, Archives of Metallurgy, **34**, 239 (1989).
[14] A. Pawełek, W. Stryjewski, H. Dybiec and W. Bochniak, Archives of Acoustics **15**, 211 (1990).
[15] A. Pawełek and S. Pilecki, Archives of Metallurgy in press.
[16] A. Pawełek, Archives of Acoustics, **18**, 166 (1993)
[17] A. Pawełek, J. Appl. Phys. **63**, 5320 (1989).
[18] Z. Jasieński, A. Piątkowski, A. Litwora and H. Paul, Spr. IPM PAN, CPBP 02.07, temat 5.1, zadanie 5.1.13, 1990.
[19] Z. Jasieński and A. Litwora, Spr. wew. IPM PAN 1988.
[20] A.H. Cottrell, *The Mechanical properties of matter*, Wiley, New York, 1964.
[21] N.J. Petch, Phil. Mag., 1, 866 (1956).

Received February 4, 1992