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BRIEF NOTES

ACOUSTIC EMISSION DURING NONHOMOGENEOUS TENSILE DEFORMATION OF ARMCO-IRON

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Measurements of acoustic emission count rates and RMS value in the ARMCO-iron have been carried out in tensile loading. Specimens of the ARMCO-iron have been used in two stands: annealed or pre-rolled and cut in parallel or perpendicular direction. Experimental results have been discussed in the light of possibility of dislocation proliferation and annihilation as well as their accelerated and decelerated movement.

1. Introduction

There is not any great number of works dealing with the correlation between nonhomogeneous deformation — mainly such types as Lüders bands, Portevin-LeChatelier bands and shear bands — and its influence on the behaviour of acoustic emission (AE) activity. The first most important observation of AE during Lüders deformation was made by FISHER and LALLY [1]. They observed that during tensile deformation of 0.1% carbon steel, a peak of AE activity occurred near the upper yield point and afterwards, i.e., in the region of Lüders bands propagation this activity rapidly decreased and remained at a nearly constant level after which it again decreased monotonically with increasing strain hardening. The authors suggested that such AE behaviour resulted from the fast collective movement of a great number of dislocations however, they did not discuss any particular mechanism of direct reasons of AE. A similar observation of a strong increase of the AE activity during the nucleation of a Lüders band in the region of the upper yield point in Fe-Si alloys was carried out by TANDOM and TANGRI [2], who related this fact to the observed dislocation pile-ups, the presence of which they explained by the operation of the dislocation sources in the grain boundaries. Another behaviour of AE activity in the region of the Lüders plateau, discussed in details in Sect. 3 of this paper, was recently reported in [3] where the AE sources are related, also in a general way, to dislocation movement, to the overcoming of obstacles by dislocations as well as to the slip bands nucleation and propagation.

On the other hand, the examinations of another type of nonhomogeneous deformation by the AE method, i.e., that related to the Portevin-LeChatelier effect, are so far slightly more advanced [4–8]. One of the first studies, reported in the literature available, was that by PASCUAL [4], who noticed that each local peak of the flow strain is accompanied by an increase of the AE activity. A similar observation was made by CACERES and BERTORELLO [6]. In both papers the phenomenon is explained generally in the same way, as a result of the multiplication of dislocations, but also no particular mechanism is discussed there.

Furthermore, to our knowledge there are no reports in the literature available concerned with the studies of the nucleation and propagation of shear bands by the AE method. Many recent experimental data (e.g., [9–11]) on the SB formation and propagation in polycrystals, suggest strongly that the collective, highly dynamic properties of moving dislocations are responsible for this phenomenon. There are simultaneously synchronized in space and time, and successively organized from micro- through meso- up to macroscopic well-defined objects. Moreover, this propagation often occurs across many grains by a "non-crystallographic" way, i.e., without change in the primary direction of propagation. Hence we suppose that the specific behaviour of AE activity should be then observed. Therefore the main aim of this paper is to report on the AE behaviour during tensile deformation of pre-rolled polycrystalline ARMCO iron where shear bands nucleation and propagation are visible even with the naked eye, and to explain a particular type of AE behaviour during tensile deformation of annealed polycrystalline ARMCO iron in the region of the Lüders plateau.

2. Experiments and results

A. AE in annealed ARMCO iron

The cylindrical samples for measuring AE parameters were cut from ARMCO iron containing 2% C, rolled rods of a 20–30 mm diameter. The final specimens of 65 mm in length and 12 mm in diameter were annealed at 950° C for 1 hour in the vacuum and then furnace cooled to room temperature. The tensile tests were carried out at strain rate $\dot{\varepsilon} = 2.8 \times 10^{-4}\ s^{-1}$ using the testing machine of the ZWICK-10T type. AE characteristics were meassured by applying the Structural Integrity Monitoring System SIMS device, developed by the TRODYNE Company (USA), which contains an analog and digital system for the conversion of electric signals. The following AE parameters were measured: AE count rate in unit time base equal to 0.3 s and the RMS (root mean square), i.e., the effective value of an electric signal. These magnitudes were recorded by total amplification equal to 98 dB (including that from the preamplifier) and at the discriminator threshold equal to 0.25 V. The applied piezoelectric transducer of resonant frequency 200 kHz was made from PP type ceramics produced in Poland or Germany (see also [3]).

Figure 1 shows both mechanical and AE characteristics during the tensile deformation of annealed ARMCO iron. A specific type of AE behaviour is seen in the Lüders plateau region. The AE count rate has (Fig. 1a), as usual, the peak at the yield point; however, in the Lüders region it is not nearly constant at a considerably low level — as it was observed in most cases so far (see, e.g. [1, 12]) — but varies nearly periodically reaching at maxima values even higher than at the yield point. This is clearly visible in Fig. 1b where the

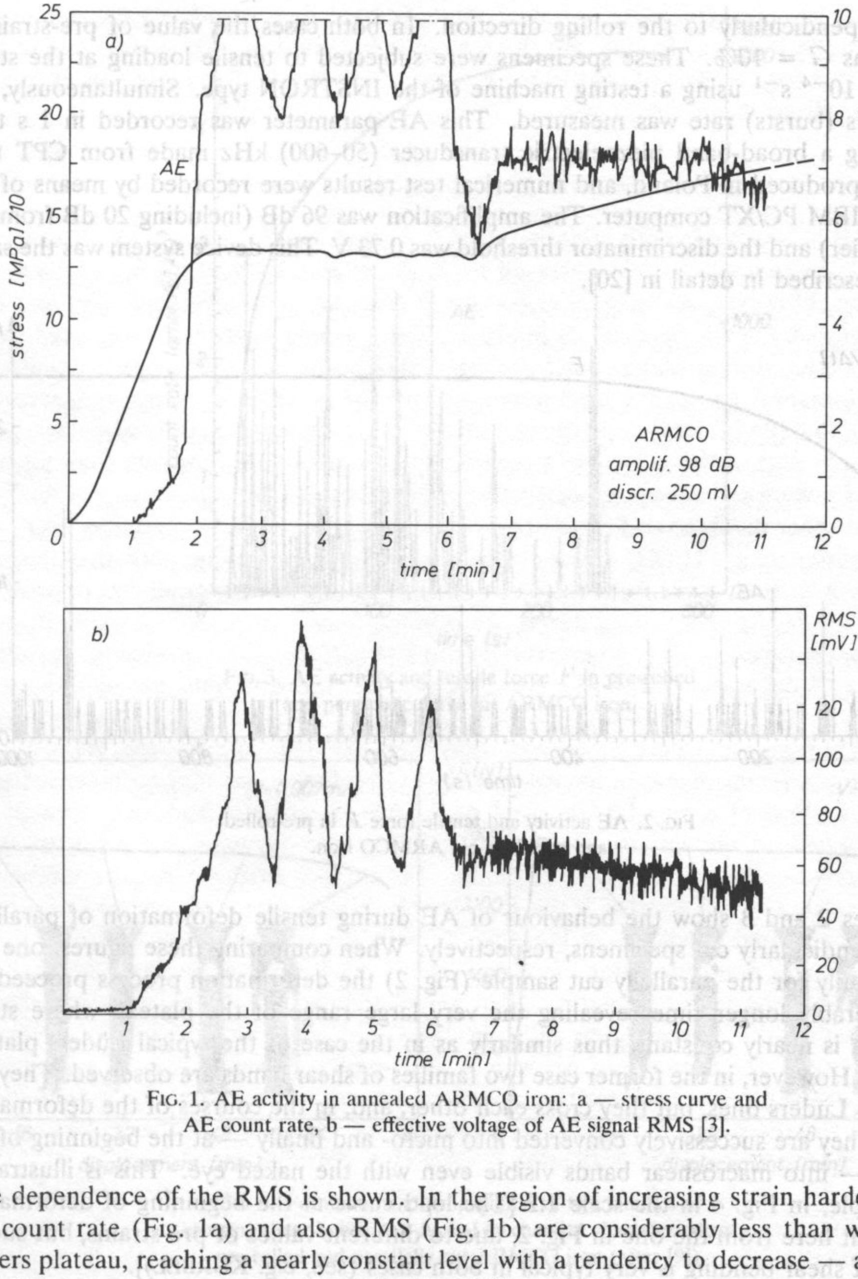

FIG. 1. AE activity in annealed ARMCO iron: a — stress curve and AE count rate, b — effective voltage of AE signal RMS [3].

time dependence of the RMS is shown. In the region of increasing strain hardening the AE count rate (Fig. 1a) and also RMS (Fig. 1b) are considerably less than within the Lüders plateau, reaching a nearly constant level with a tendency to decrease — according to earlier observations reported, e.g., in [1, 2, 12].

B. AE in pre-rolled ARMCO iron

Planar samples of size 80 mm × 12 mm × 1 mm were made from the rolled sheet of 2% C ARMCO iron. Two kinds of specimens were made: one cut parallelly and the other perpendicularly to the rolling direction. In both cases the value of pre-strain in rolling was $G = 10\%$. These specimens were subjected to tensile loading at the strain rate $\dot{\varepsilon} = 10^{-4}\ \mathrm{s}^{-1}$ using a testing machine of the INSTRON type. Simultaneously, the AE events (bursts) rate was measured. This AE parameter was recorded in 1 s time base using a broad-band piezoelectric transducer (50–600) kHz made from CPT type ceramics produced in Poland, and numerical test results were recorded by means of the standard IBM PC/XT computer. The amplification was 96 dB (including 20 dB from the preamplifier) and the discriminator threshold was 0.73 V. This device system was the same as that described in detail in [20].

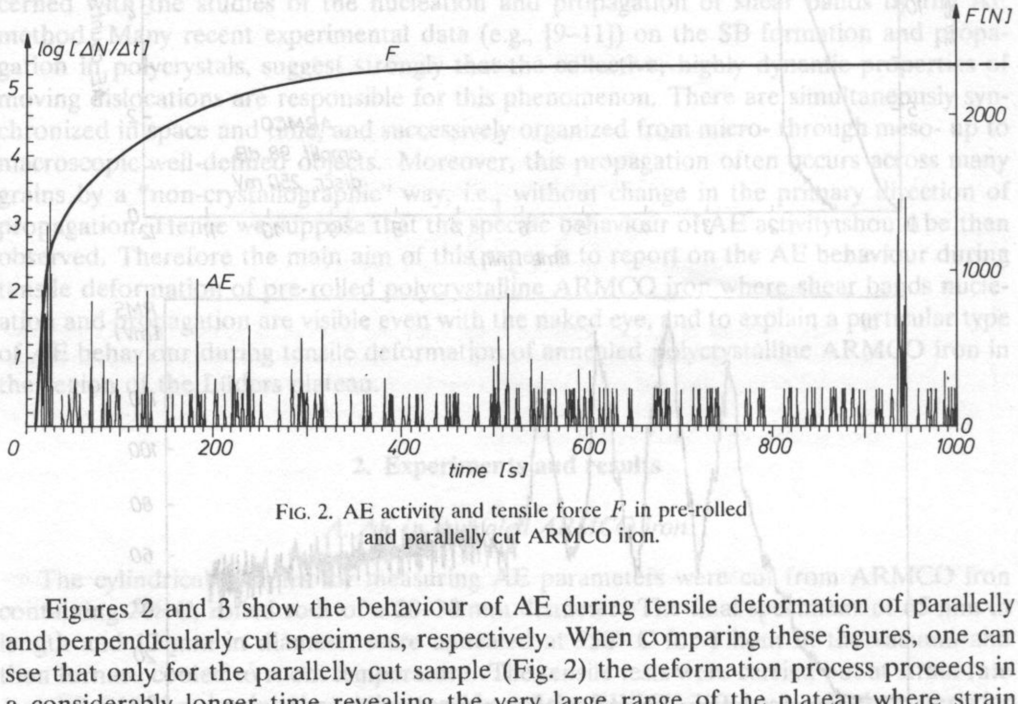

FIG. 2. AE activity and tensile force F in pre-rolled and parallelly cut ARMCO iron.

Figures 2 and 3 show the behaviour of AE during tensile deformation of parallelly and perpendicularly cut specimens, respectively. When comparing these figures, one can see that only for the parallelly cut sample (Fig. 2) the deformation process proceeds in a considerably longer time revealing the very large range of the plateau where strain hardening is nearly constant, thus similarly as in the case of the typical Lüders plateau (Fig. 1a). However, in the former case two families of shear bands are observed. They are similar to Lüders ones, but they cross each other, and, in the courses of the deformation process, they are successively converted into micro- and finally — at the beginning of the necking — into macroshear bands visible even with the naked eye. This is illustrated, for example, in Fig. 4 in the scale 1:2 [The load curve at the beginning of deformation is different here from the one in Fig. 2, due to different values of pre-strains, but such a picture of shear bending is very typical in both cases (see, e.g. KORBEL)].

Now, we make a general comparison between the AE behaviour within the typical Lüders plateau in the annealed sample (Fig. 1a) and the AE behaviour in the parallelly cut sample (Fig. 2). One can see, apart from the region of the yield point where AE activity is very high in both cases, that in the latter case the AE varies incidentally reaching very high and sharp local maxima, whereas in the typical Lüders case these maxima are very smooth and they proceed rather in a more regular way. A more precise comparison is,

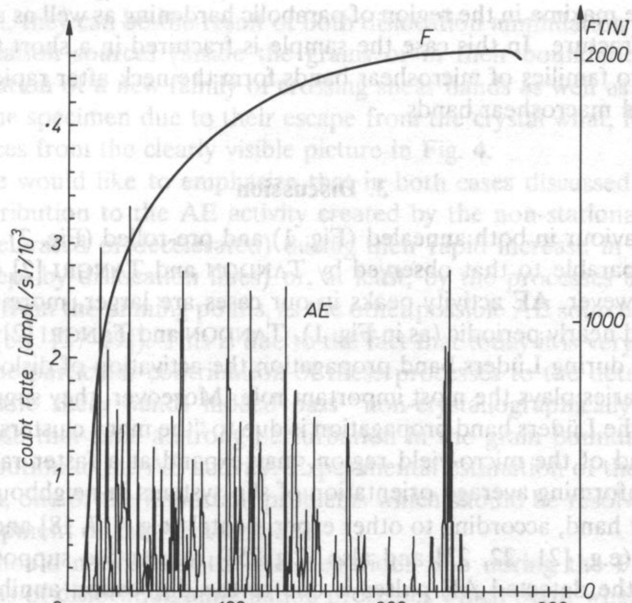

FIG. 3. AE activity and tensile force F in pre-rolled and perpendicularly cut ARMCO iron.

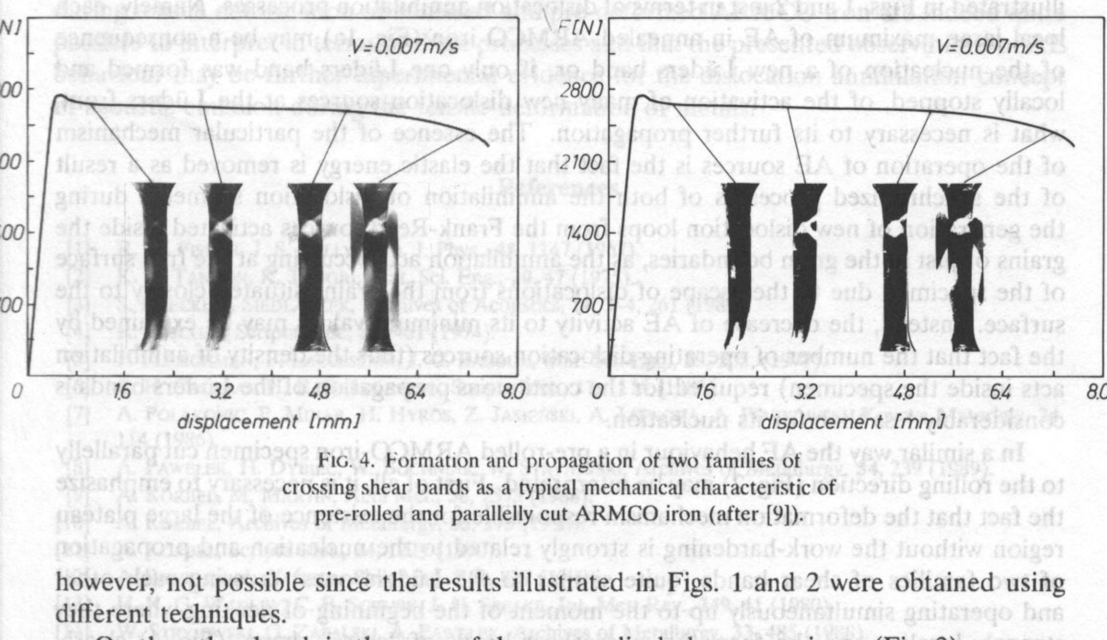

FIG. 4. Formation and propagation of two families of crossing shear bands as a typical mechanical characteristic of pre-rolled and parallelly cut ARMCO iron (after [9]).

however, not possible since the results illustrated in Figs. 1 and 2 were obtained using different techniques.

On the other hand, in the case of the perpendicularly cut specimen (Fig. 3), one can see that the plasticity is considerably smaller and the deformation process without of very large region of constant strain hardening. AE activity is also high at the yield point and shows a few large maxima in the region of parabolic hardening as well as a sharp maximum just before the fracture. In this case the sample is fractured in a short time period after yielding since two families of microshear bands form the neck after rapid conversion into strongly localized macroshear bands.

3. Discussion

The AE behaviour in both annealed (Fig. 1) and pre-rolled (Fig. 2) ARMCO iron is, in general, comparable to that observed by TANDON and TANGRI [2] in polycrystalline silicon iron. However, AE activity peaks in our cases are larger, more visible, and even more regular and nearly periodic (as in Fig. 1). TANDON and TANGRI [2] suggested that in the AE creation during Lüders band propagation the activation of dislocation sources in the grain boundaries plays the most important role. Moreover, they suggested, according to [15, 16], that the Lüders band propagation is due to "the many clusters of yielded grains which, at the end of the micro-yield region, may expand at a faster rate than all other because of a conforming average orientation of slip systems in neighbouring grains".

On the other hand, according to other experimental (e.g. [17, 18] and also [8, 19–20]) and theoretical (e.g. [21, 22, 23] and also [24, 25]) results, we suppose that the main contribution to the detected AE pulses is due to the dislocation annihilation processes occurring inside the crystal, e.g., during the closing of dislocation loops emitted from the Frank-Read sources, as well as occurring at the free surface of the specimen, e.g., during the escape of dislocations from the crystal interior (i.e., the annihilation of dislocations with their virtual images). We would like to show that it is possible to explain results illustrated in Figs. 1 and 2 just in terms of dislocation annihilation processes. Namely, each local large maximum of AE in annealed ARMCO iron (Fig. 1a) may be a consequence of the nucleation of a new Lüders band or, if only one Lüders band was formed and locally stopped, of the activation of many new dislocation sources at the Lüders front, what is necessary to its further propagation. The essence of the particular mechanism of the operation of AE sources is the fact that the elastic energy is removed as a result of the synchronized processes of both the annihilation of dislocation segments during the generation of new dislocation loops from the Frank-Read sources activated inside the grains or just in the grain boundaries, as the annihilation acts occurring at the free surface of the specimen due to the escape of dislocations from the grains situated closely to the surface. Instead, the decrease of AE activity to its minimum values may be explained by the fact that the number of operating dislocation sources (thus the density of annihilation acts inside the specimen) required for the continuous propagation of the Lüders bands is considerably less than for its nucleation.

In a similar way the AE behaviour in a pre-rolled ARMCO-iron specimen cut parallelly to the rolling direction (Fig. 2) may be interpreted. First of all, it is necessary to emphasize the fact that the deformation mechanism responsible for the existence of the large plateau region without the work-hardening is strongly related to the nucleation and propagation of two families of shear bands (quite similar to the Lüders ones) crossing each other and operating simultaneously up to the moment of the beginning of necking where they strongly localize and the form the macroshear bands of "cross" shape, (Fig. 4) clearly visible. Hence we suppose that the more or less regular sharp peaks of AE activity appearing in the course of the deformation process may be also explained similarly as the previous case, i.e., they can be the result of both dislocation annihilation events occurring when new dislocation sources (inside the grains or in their boundaries) are activated during the nucleation of a new family of crossing shear bands as well as occurring at the free surface of the specimen due to their escape from the crystal what, for example, may be directly deduces from the clearly visible picture in Fig. 4.

Moreover, we would like to emphasize that in both cases discussed here we cannot exclude the contribution to the AE activity created by the non-stationary movement of dislocations (accelerated or decelerated) during their rapid increase in the rate of their density (area swept by dislocation lines) or, at least, by the processes of their breaking and/or breakway from the pinning points, as the other possible AE sources often discussed in the literature (e.g. [27–29]). This is due to the fact that today it is very difficult to state experimentally the particular contribution of these processes to the detected AE pulses. Furthermore, if the shear bands indeed pass "non-crystallographically" through many grains, we suppose that such a strong perturbation in the grain boundaries should also give some contribution to the AE activity. Experimental estimation of these contributions is, in our opinion, one of the important problems which should be resolved in the course of further development of the AE technique.

Finally, we should notice that the AE behaviour also during the PL effect may be explained in terms of dislocation annihilation processes which occur when the dislocation sources previously locked by solute atoms are operated again (or operated as quite new sources), what was mentioned earlier in [8, 20, 30]. Hence we are strongly convinced that the main contribution to the detected AE pulses is due to the dislocation annihilation processes. And we believe that the observations presented here of the peaks of AE activity during tensile deformation of annealed and pre-deformed ARMCO iron are indeed quite possible to interpret in terms of these processes and that the presented observations of AE behaviour may be further experimental evidence for the dislocation annihilation concept of acoustic emission during the tensile deformation of metals.

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