JOURNAL OF MATERIALS SCIENCE 18 (1983) 1015–1020

On the origin of the first peak of acoustic emission in 7075 aluminium alloy*

R. WELLS
Division of Materials Science and Engineering, Department of Mechanical Engineering, University of California, Davis, CA 95616, USA

M. A. HAMSTAD
Department of Mechanical Engineering, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550, USA

A. K. MUKHERJEE
Division of Materials Science and Engineering, Department of Mechanical Engineering, University of California, Davis, CA 95616, USA

The origin of acoustic emission (AE) in 7075 aluminium alloy was investigated in tension and compression tests. It is suggested that the first peak associated with the root-mean-square (rms) AE plot against time (or strain) is due to the unpinning of dislocation segments from solute atom clusters and is not due to the fracture of particles. Alteration in the value of the AE first peak and also in electrical resistivity values due to heat treatment of this alloy support the proposed origin of the AE first peak near yield.

1. Introduction

Acoustic emission (AE) is defined as the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized source or sources within a material, or alternatively as the transient elastic wave so generated [1]. The objective of this study was to isolate the source of AE in 7075 aluminium alloy prior to and during the onset of plastic strain. The 7075 alloy in the T6 and T651 tempers has been the subject of numerous AE studies [2–9]. The precipitation hardenable 7075 alloy has a nominal composition (in wt%) of 5.6 Zn, 2.5 Mg, 1.6 Cu, 0.23 Cr and the rest aluminium. For the T6 temper, the alloy is solution treated at 490° C, quenched and aged at 120° C for 24h. The T651 temper has the same solution treatment and ageing treatment. The significant difference lies in the fact that in T651 temper, the alloy is stress-relieved by stretching to produce a permanent set of 1.5 to 3% subsequent to solution heat treatment and prior to any precipitation heat treatment. Tensile and compression tests have shown that two peaks in AE (measured as either root-mean-square (rms) voltage or count rate) are generated by the T6 tempered material (Fig. 1). The maximum in the first peak was found to correspond to the onset of plastic deformation, while the second peak maximum occurred at strains of between 1 and 3% [4, 8].

Carpenter and Higgins [4] have shown that the increasing AE count rate during the first peak is

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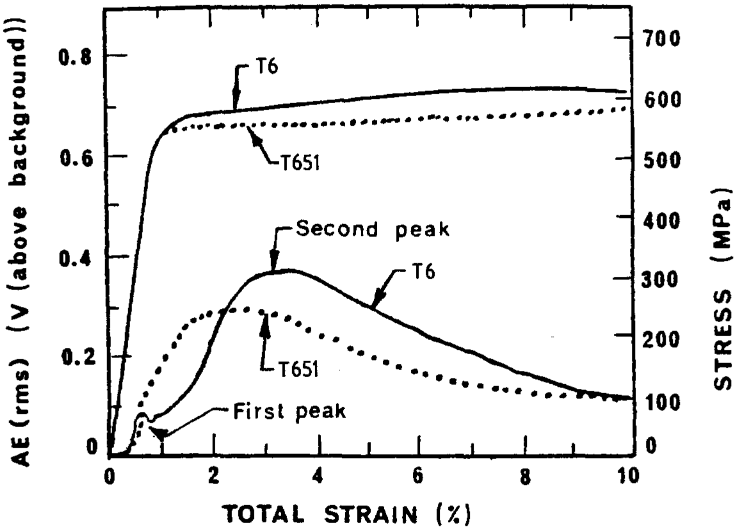


Figure 1 Acoustic emission and stress as a function of strain for 7075-T6 and T651 aluminium tested in tension.

coincident with an increase in dislocation damping (Fig. 2). Because dislocation damping increases rapidly with increasing free length of dislocation segments and is only linearly dependent upon their density, Carpenter and Higgins postulated that the initial AE peak was caused by dislocation segments breaking away from the weaker pinning points.

In an AE study of an age hardened AlCuZnMg alloy, Schmitt-Thomas *et al.* [10] observed dual AE peaks similar to those observed for 7075-T6. They also observed that the first peak maximum coincided with the onset of plastic deformation and the second peak occurred in the strain hardening region. Schmitt-Thomas *et al.* [10] found that the first peak rms voltage and energy associated with acoustic events increased with decreasing ageing time in the under-age range and with increasing ageing time in the over-age range. At the optimum age (maximum strength) condition, both the peak height as measured by rms voltage and the energy of the AE events was minimized for the first peak. The opposite trend was observed in the behaviour of the second peak. The first peak was attributed to dislocation breakaway from unspecified "obstructions", while the second peak was associated with both particles fracture and micro-cracking at matrix–spherical particle interfaces.

The microstructure of 7075-T6 is such that one can expect AE both from fracture of particles and from dislocation related sources. The possible dislocation related sources can be further divided into multiplication (i.e., the operation of fast dislocation sources) and unpinning. The dislocations being considered here can be pinned by other dislocations, intermetallic inclusions, ageing precipitates, solute atoms and vacancies.

The general approach of this study was to isolate the active AE source by a process of elimination. To this end, an ageing study similar in concept to the Schmitt-Thomas *et al.* [10] study was performed. As an independent measure of ageing, resistivity measurements were performed on 7075 in aged conditions matching those used in the AE tests. Since the characteristics of the aged structure and particularly that for solute atom clusters will figure in the correlation with AE results, a few pertinent points regarding the ageing of this alloy are outlined here.

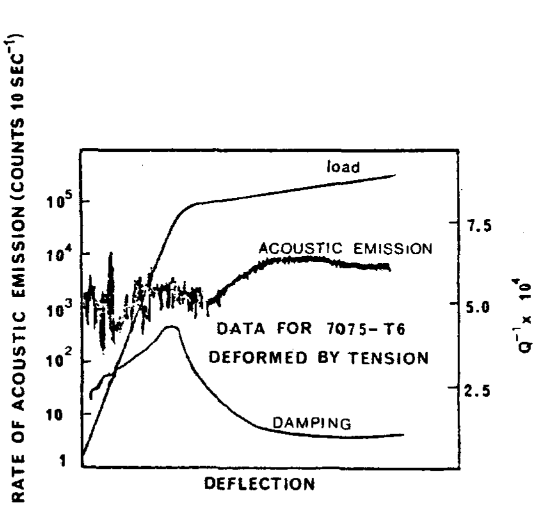


Figure 2 Data showing the rate of acoustic emission and the dislocation damping as a function of deflection for a 7075-T6 aluminium alloy deformed in tension.

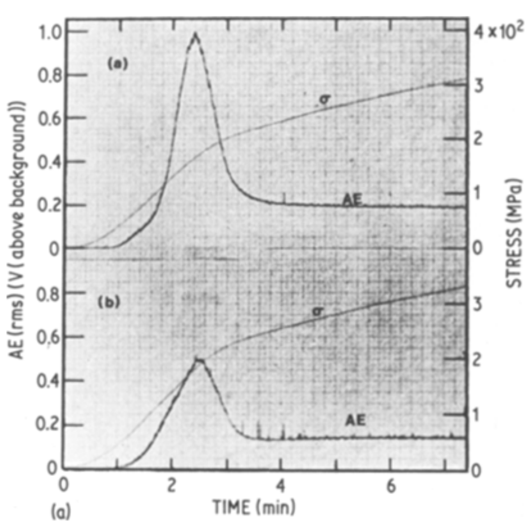
Four stages are usually present during the progressive ageing of 7075 aluminium alloy: (a) super-saturated solid solution, (b) Guinier–Preston zones, (c) η' transition phase, and (d) η($MgZn_2$) (stable precipitate). The supersaturated solution is usually assumed to contain a random dispersion of magnesium atoms, zinc atoms, and vacancies. However, electron microscope studies [11–13] indicate that precipitates are nucleated at grain boundaries during quenching in AlMgZn alloys, suggesting that the distribution of solute atoms may not be entirely random. Additionally, Auger spectroscopy has confirmed the existence of magnesium and zinc segregation to the grain boundary in a quenched Al–5.5 wt% Zn–2.5 wt% Mg alloy. In addition to ageing precipitates, numerous other second phase, intermetallic compounds are also present. These intermetallics are unaffected by solution treatment and subsequent ageing treatments [12–18].

The ability of 7075 and other AlMgZn alloys to age at room temperature has been attributed to unusually high solute diffusion caused by the high flux of excess vacancies [11]. There is evidence that the high mobility of the solute species is caused by Mg-vacancy and Zn-vacancy pairing [19–22]. Thus, the diffusion of solute atoms and the initial growth of precipitates may occur by the migration of solute–vacancy clusters which continuously collect solute as they move through the matrix in a manner proposed by Hart [23] for precipitation in dilute AlCu alloys. While the existence of clusters in AlMgZn alloys was theorized from resistivity effects [20, 21, 24], it is only recently that neutron scattering [25], bright field transmission electron microscopy [26], and weak beam TEM [27] investigations have provided corroborating evidence. The latter indicates that clusters are heterogeneously nucleated on dislocations.

2. Experimental details

Test specimens were prepared from a single plate of commercial grade 7075 aluminium. This plate was strained exactly 3% prior to ageing to the T6 temper. Standard pin-type tensile specimens having an approximate gauge length of 3.50 cm and cross-sectional dimensions of 1.24 cm x 0.65 cm were used for the AE tests. Resistivity specimens were prepared in the shape of bars having dimensions of 7.8 cm x 1.24 cm x 0.65 cm. Tensile and resistivity specimens were given identical heat treatments consisting of resolution treatment at 471 ± 3° C for 2 h in argon, followed by an ice-water quench and isothermal ageing in a carefully controlled (± 0.5° C) oil bath. All specimens were stored at approximately − 20° C prior to testing.

Tensile/AE tests were performed at a constant



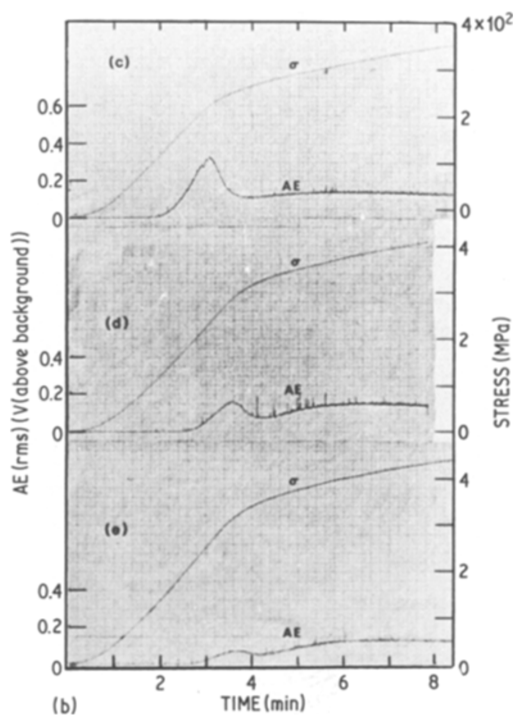


Figure 3 (a) Acoustic emission and stress as a function of time for 7075 (3% T651) Aluminium (a) resolution treated and quenched, and (b) aged at 40° C for 15 min (background noise is 0.2 V). (b) Acoustic emission and stress as a function of time for 7075 (3% T651) aluminium aged for 15 min at (c) 60° C, (d) 90° C, and (e) 120° C.

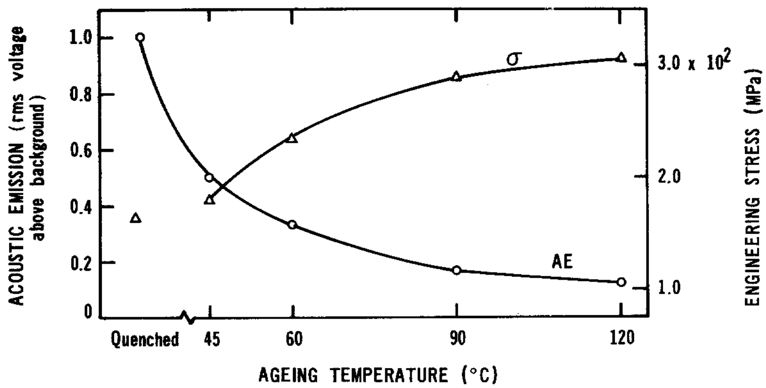


Figure 4 First maximum AE (rms) and stress at AE maximum as a function of ageing temperature isothermally aged for 15 min.

crosshead speed of 0.05 cm min^{-1} in a Model TT-D Instron tester. AE was monitored with an AET Corp. System (Model 201) at a total gain of 96 dB and frequency range of 100 to 250 kHz. Resistivity measurements were made at room temperature with a Model 2781 Honneywell potentiometer. A detailed description of this experimental procedure can be found in [28].

3. Results

The results of tensile AE tests on specimens in the "as-quenched" condition and after ageing at 40, 60, 90, and 120°C for 15 min are shown in Figs. 3a and b. Note that the first peak height is greatest in the solution treated specimen and decreases with increasing ageing temperature. Values of the acoustic emission, in rms volts above the background and the stress corresponding to the first AE peak, are plotted as a function of ageing temperature in Fig. 4. The stress at the first AE maximum steadily increased with increasing ageing temperature, whereas the magnitude of the AE (rms) decreased.

Results of AE tests on specimens that were solution treated and quenched and subsequently aged at 120° C for 15 min and 1 h indicate that the first peak height also decreases with increasing ageing time at a fixed ageing temperature (see Fig. 5). For purposes of comparison, AE from an "as-received" specimen in the T651 (aged 24 h at 120° C) temper is included in Fig. 5.

The effect of prior thermal treatment on the

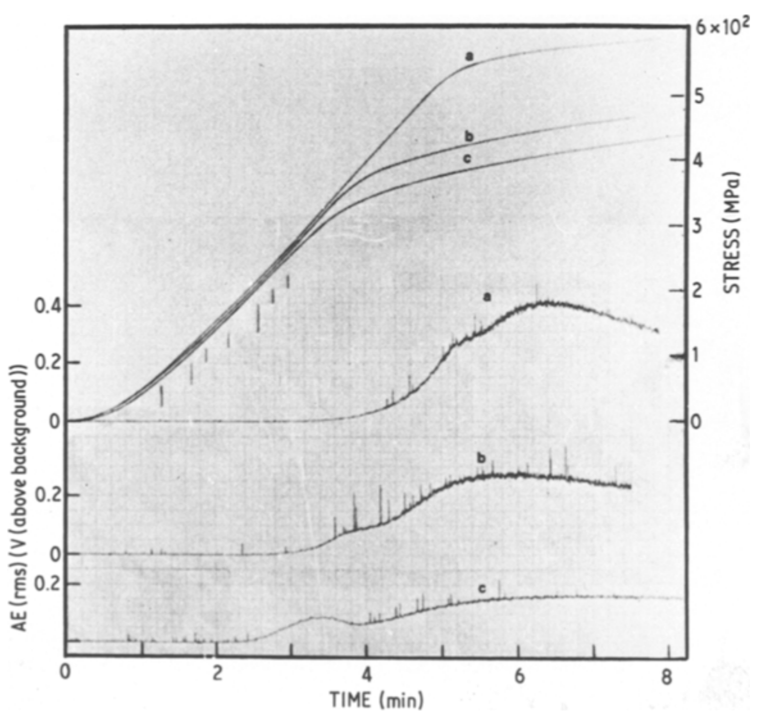


Figure 5 Acoustic emission and stress as a function of time for 7075 (3% T651) aluminium (a) "as-received" and after resolution, ice water quenched, and ageing at 120° C for (b) 1 h, and (c) 15 min.

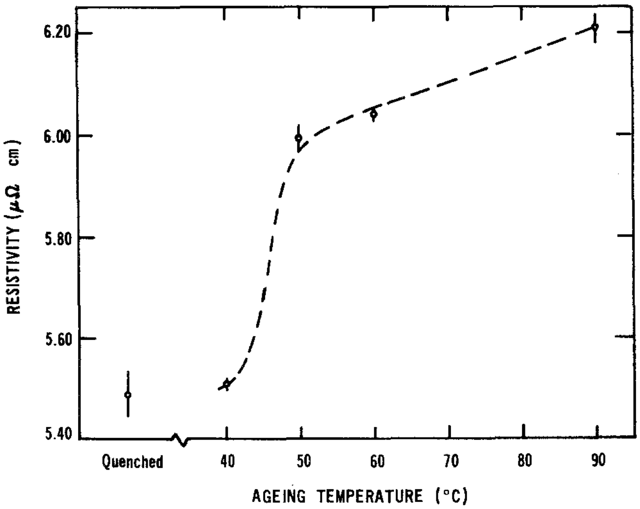


Figure 6 Resistivity against ageing temperature isothermally aged for 15 min.

AE in compression tests was investigated in a separate series of experiments. One set of specimens was heat treated to standard T6 temper. (These specimens were never prestretched to T651 temper in their prehistory.) The other set of specimens were of T651 temper to begin with. They were resolution treated, rapidly quenched, and then aged to T6 temper. The AE first peak in compression from these two sets of specimens was essentially identical. Thus, the effects of prestretching during the T651 temper on AE is completely reversible.

In another series of tests, specimens of T651 temper were resolution treated, rapidly quenched, and stored in dry ice until tested in compression at room temperature. This supersaturated solid solution specimen (i.e. "0" temper) exhibited a large first peak in rms values that was very similar to the corresponding peak (Fig. 3a, curve a) in a resolution treated and quenched specimen tested in tension. Thus, the operation of the source of AE first peak in the present work is unaffected by tension or compression stress state.

The results of resistivity measurements on specimens in the solution treated, "as-quenched" state, and after ageing for 15 min at 40, 50, 60 and 90° C are plotted as a function of temperature in Fig. 6. Resistivity was found to increase with increasing temperature over the 40 to 90° C range, with the value for the "as-quenched" state being the lowest.

4. Discussion

These results indicate the following:

(a) particle fracture is not the dominant AE source near yield since the AE peak height decreased as the stress at maximum emission increased because of ageing. If particle fracture was the AE source, an increase in stress should result in an increase in the intensity and number of fractures and, therefore, AE;

(b) first peak emission is probably not caused by dislocation multiplication since detectable emission consistantly precedes the onset of macroplastic deformation and, concommitantly, the activation of fast dislocation sources [29]. Thus, these results seem to indicate that dislocation unpinning is the most likely source of emission. Such dislocation escape from pinning points has also been cited as a probable cause for AE in an Al–13 wt % Mg solid solution alloy [30].

The fact that the first peak is large and remains so in resolution treated and quenched specimens, regardless of whether the test is in tension or compression, attests to the conclusion that the first peak is associated with dislocation motion and not with particle fracture and/or decohesion.

Implied in considering unpinning as a source of AE is the assumption that AE can result from the rapid movement of dislocations through small distances prior to macroscopic yielding. Since the rms voltage is a function of the energy released by the AE events, AE (rms) is a qualitative measure of the total energy released. This energy, in turn, is related to the amplitude of elastic waves. In the case of unpinning events, this amplitude of elastic waves. In the case of unpinning events, this amplitude is dependent on the dislocation segment participitating in the process. It is the decrease in the dislocation segment length that produces the observed large alteration in the AE signal (first peak) with heat treatment.

Resistivity measurements support the contention that solute clusters form during low temperature ageing treatments. For AlMgZn alloys, this anomalous rise in sensitivity has been attributed to: (a) the formation of clusters of a critical size (0.5 to 1.0 nm) and, alternatively, (b) the formation of strain fields at coherent zones [31]. Mott [32] suggested that zones of the same dimensions as the wave-length of conduction electrons will cause a critical scattering of these electrons.

If it is assumed that resistivity reflects the amount of clustering then the increase in resistivity over the 40 to 90° C range measured supports the theory that solute clusters (probably in the form of solute–vacancy complexes due to diffusion considerations) or possibly solute–vacancy pairs are the pinning constituents which give rise to the first peak AE. The decline in AE with increased ageing temperature infers that increased cluster density decreases emission. This is consistent with emission by unpinning since an increase in the cluster density would cause a decrease in the average segment length of dislocations and therefore decrease the AE response.

5. Conclusions

The origin of AE in 7075 aluminium alloy was investigated in both tension and compression tests. The AE associated with the first peak (near yield) seems to arise from unpinning events of dislocation segments from solute atom clusters. The results indicate that fracture of intermetallic particles is not the dominant AE source near yield.

It is suggested that AE energy as measured by rms values is related to the length of dislocation segments participating in the unpinning process. The alternation in this average value of dislocation segment length with heat treatment produces the observed large alteration in the AE (rms) values associated with the first peak. Electrical resistivity measurements also support the proposed origin of the AE first peak in this alloy.

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Received 10 February
and accepted 31 August 1982