ACOUSTIC EMISSION AND MECHANICAL PROPERTIES OF ALUMINIUM ALLOYS DURING AGEING

E.A. Esmail*, M.N. Abouelwafa and A. Shokry**

*Department of Engineering Mathematics and Physics,

**Department of Mechanical Engineering,

Faculty of Engineering, Alexandria University, Alexandria, Egypt.

ABSTRACT

The acoustic emission energy during material straining for aluminium alloys is studied. Results of the tests which were performed during ageing period show that the acoustic emission decreases with ageing time. Moreover, acoustic emission energy is directly proportional to the number of unstable solute atoms in the alloy and inversely proportional to the ageing time. Acoustic emission energy during tension test, which was performed after steady state conditions is achieved (at the end of the ageing time), has been studied. Relations between acoustic emission energy, mechanical energy, percentage of elongation and the applied stress on the specimen are suggested. Relations between acoustic emission and mechanical properties are suggested.

INTRODUCTION

Acoustic emission (AE) is defined as the stress or pressure waves generated during dynamic processes in materials.

Acoustic emission techniques are utilized in studies related to material research, material characterization and evaluation, nondestructive testing and structural evaluation.

In the field of material research considerable work has been conducted on polycrystalline tensile specimens [1-3] and on single crystals [4,5]. Studies also have been made on composite materials [6,7].

In engineering applications steel is the most widely used material and the most important but for aeronautical engineering, the first priority is to light metals and alloys. Aluminium alloys have wide applications in aircrafts and space vehicles. Research units related to aeronautical and space equipment pay attention to aluminium alloys in that field, so it is important to have enough information about them.

Heat treatable aluminium alloys belong to systems with limited solubility in the solid state. These alloys are heat treated to develop optimum properties. They find widespread applications in engineering industries. The most typical heat-treatable ones are duralumins (based on the Al-cu-Mg system).

Due to the practical importance and its wide use in the design of aircrafts and space vehicles, duralumin alloy 2024-T3 is used for the present study. This study deals with the acoustic emission characteristics and its relation to the mechanical properties during ageing. Natural ageing (at 20° C) is considered since duralumin 2024-T3 is used in aircraft structure repair. The alloy for this application is quenched and used at room temperature to maintain sufficient ductility. This makes it suitable to form different shapes in wings and bodies. These sections get hard during natural ageing.

EXPERIMENTAL TECHNIQUE

1- *Specimen Preparation*

Test specimens used are made from 2024-T3 Alclad with the following chemical composition:

Alloy	Nominal composition (%)						
	Si	Cu	Mn	Mg	w	Zn	Al
2024	0.5	4.5	0.6	1.5	0.10	0.25	REM

and the mechanical properties are given in the following table:

Alloy	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Shearing strength (MPa)
2024-T3* Alclad	450	310	18	275

T3: Means alloy is heat treated and then cold worked

Sheets of thickness equal to 2.0 mm were cut to pieces of dimensions 120×22 mm, then shaped to the final configuration as in Figure (1) by using a milling machine.

The specimens were heated to 495±5°C, and were maintained at this temperature to 10 min., quenched in water at 10 to 30°C. Ageing was carried out at ambient temperature of 20°C for four days to allow for structural hardening.

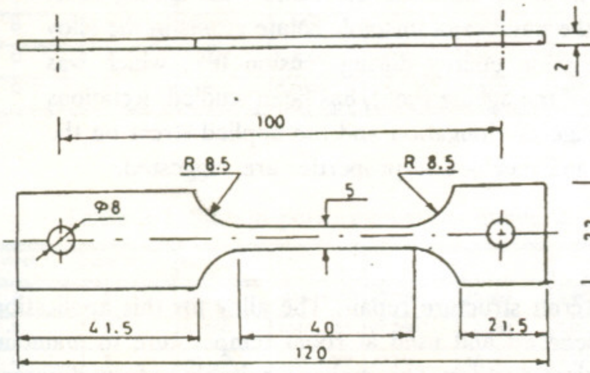


Figure 1. Specimen dimensions.

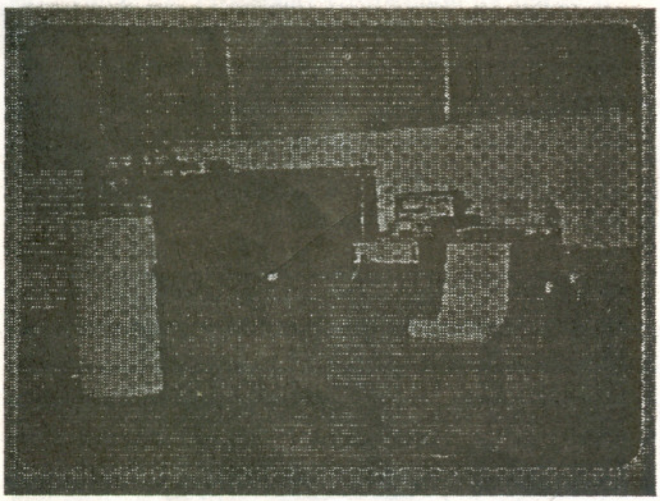
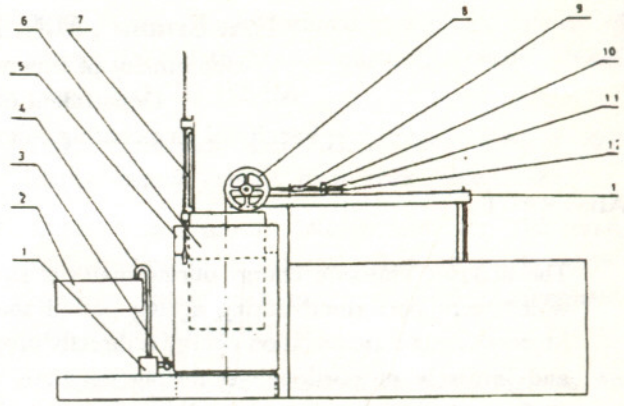


Figure 2. General view of the testing machine.

2- *Testing Machine and Measuring Instruments*

A photograph of the experimental set up is shown in Figure (2). Figure (3) presents a schematic diagram of the tensile testing machine.

Full description of the machine and the measuring instruments is detailed elsewhere [8]



1 Water Pump
2 Water sink
3 Valve
4 Flexible Hose
5 Outer Tank
6 Inner Tank
7 Resistance Wire
8 Two Pulleys with shaft
9 Free Clamp
10 Holder of Displacement Transducer
11 Fixed Clamp
12 Displacement Transducer
13 Chassis

Figure 3. Schematic diagram of the tensile testing machine.

Tensile tests were carried out on specimens after different ageing times, each time the force, elongation, and the root mean square (rms) voltage of the AE were recorded on by a chart recorder to a time base.

RESULTS

Figure (4) shows the result of the first tensile test carried out after half an hour of ageing. Figure (5) represents the result of the third test (ageing time is 1½ hour), while the result of test number 7, carried out at the end of the ageing time is given in Figure (6). The results of the tests in addition to the energy of acoustic emission calculated from the equation:

$$E_a = \sum V^2.dt \quad \overline{mV^2}.S$$

where V is the rms volt, are summarized in Table (1).

From these figures and the table it is clear that there are two maxima in the AE record, the first one is at the yield point, and the second maximum occurs at about 6.5% elongation. Both maxima decrease by increasing the ageing time, the first almost disappears, while the second one takes its steady value at the end of ageing.

Table 1.

Test No.	Ageing time after which the specimen is tension tested [hours]	yield strength σy [MPa]	Ultimate strength σu [MPa]	maximum percentage of elongation [%]	Total detected A.E energy $\times10^{-8}$ [mv^2.S]	First Peak A.E. [mV] $\times10^{-3}$	First Peak [%]	Second Peak A.E. [mV] $\times10^{-3}$	Second Peak [%]
1	0.5	120	313	22.0	18390	4.5	0.98	not well defined	not well defined
2	1.0	125	325	21.9	13700	3.3	1.0		
3	1.5	130	334	18.9	10836	1.4	1.0		
4	3.0	180	365	18.6	4920	0.8	1.1	0.65	6.3
5	5.0	190	394	18.4	2830	0.5	1.76	0.6	6.7
6	44.0	228	410	18.2	2120	0.3	1.72	0.6	6.4
7	100.0	230	440	18.0	1318	0.05	1.8	0.5	6.6

Also from figures we notice that the AE in the first part is of the continuous type, while in the second part it is a combination of continuous and burst type. At the last two tests the AE is all of the continuous type. Slips are noticed in the elongation curve which also disappear at the end of ageing, these slips correspond to the bursts in the root mean square voltage of AE.

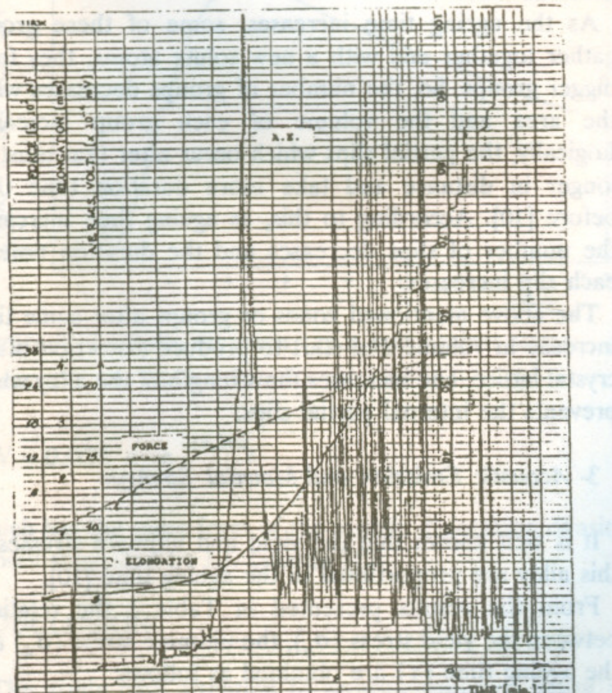


Figure 4. Force, elongation and acoustic emission root mean square volt against time for test No. 1.

DISCUSSION

1- *Acoustic Emission and Ageing Time*

Heating the specimen to 495° C for the prescribed time dissolves the chemical compounds, and the other phases into the matrix forming α-solid solution. Quenching in water attains α-solid solution at room temperature which is unstable because solute atoms have excess energy. These atoms form chemical compounds, and others congregate in definite planes of the crystal lattices forming zones, rich in solute atoms. These zones with increased concentration of solute atoms have the form of extremely thin discs [9]. These changes take place during ageing time.

When the specimen is loaded under tension, the crystals are subjected to elastic and then plastic deformation.

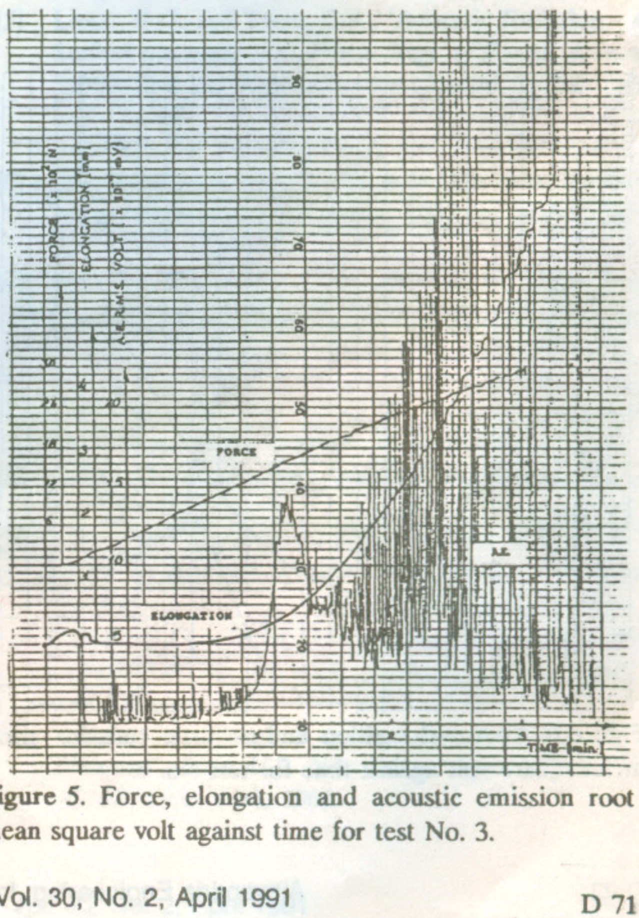


Figure 5. Force, elongation and acoustic emission root mean square volt against time for test No. 3.

These deformations help solute atoms to move to more stable positions. S.T. Konobeyevsky and D.A. Petrov [9] proved that the number of unstable solute atoms is inversely proportional to the ageing time. The main mechanism acting during ageing time is the motion of unstable solute atoms. At the end of ageing (96 hours) these atoms are gathered in stable zones. The unstable solute atoms having high energy need small energy to move, they start moving about the end of the elastic region. The number of these atoms reaches its maximum value at the yield point causing the first peak in the AE-time record. Since the number of unstable solute atoms is decreased with the ageing time, this peak will decrease as one can predict for tests conducted after long ageing times. Due to the motion of atoms and the intersection of dislocation lines, the number of solute atoms moving will decrease until the energy given to the specimen (elastic and plastic) enables them to move once more (besides the dislocation motion). Hence a second peak is achieved (at about 6.5% strain), this AE decreases until fracture. At the end of the ageing time only the acoustic emission caused by the dislocation motion is obtained, so the first peak almost vanishes and the second peak takes its steady value.

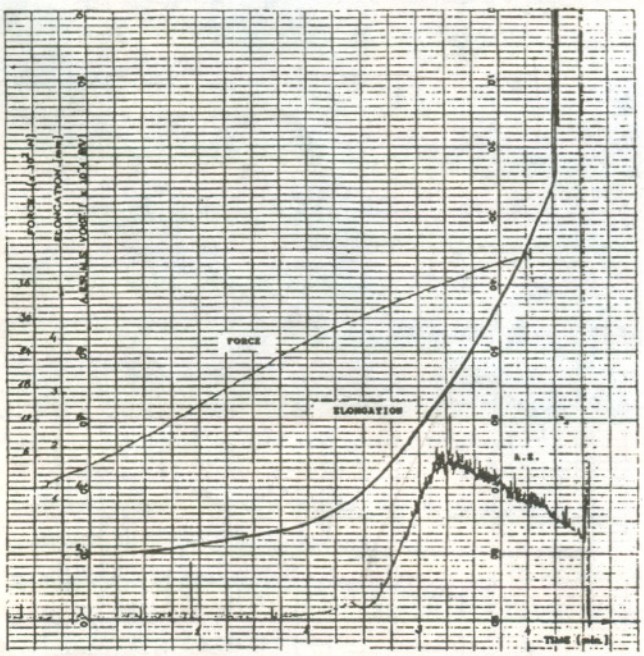


Figure 6. Force, elongation and acoustic emission root mean square volt against time for test No. 7.

2- Acoustic Emission and Internal Partial Slips

An interesting phenomenon which is clear in acoustic emission results is the internal partial slips. It occurs inside the specimen and appears as burst signals on acoustic emission curve. This phenomenon occurs in the first period of ageing time and decreases with ageing time. It disappears after 20 hours. This phenomenon may be due to the discs formed from solute atoms.

Specimen number 1, which is tested at the first period of ageing time, has high number of unstable solute atoms. The time elapsed for these atoms to move is short, so the number of atoms which may be gathered to form group is small, consequently the number of groups or zones of these atoms is high, but each group has small number of atoms. If the specimen is subjected to external stress, the above mentioned groups (discs) work as small rollers causing internal partial slips. Although the number of slips is high, the duration time of each slip is small. The corresponding pulses in acoustic emission curve have short duration time.

As the ageing time increases, some of these groups gather together and with a new solute atoms, they form bigger groups. So, the number of groups decreases while the area and the volume of each group increases. Logically, the partial slips which occur after that must be longer in distance and take more duration time than before [10]. According to this, as ageing time increases, the number of slips decreases and the duration time of each slip increases.

The above mentioned zones or groups after some time increase in volume and start to produce distortion of the crystal lattice, and increases the strength of the alloy which prevents the internal partial slips.

3- Acoustic Emission and Material Strength

It is well known that the yield and ultimate stresses of this alloy are proportional to the ageing time [10].

From the results presented in Table 1 the relations between the yield stress (σ_y), the ultimate stress (σ_u) and the ageing time (τ) are obtained as follows:

$$\sigma_y = 136.2 + 23 \ln\tau, \quad \sigma_u = 332.5 + 23 \ln\tau$$

where σ_y and σ_u are in MPa and τ in hours.

The relation between the AE energy and the ultimate stress of the alloy during the ageing time takes the form

$$E_a = \left(\frac{982}{\sigma_u - 270} - 4.6\right) \times 10^{-5} \ \overline{mv^2}.S$$

The term (-4.6) in this equation might be due to the attenuation in the specimen and the small part of the AE masked by the background noise. This relation shows inverse proportionality between the AE and the material strength.

4- *Acoustic Emission and the Material Strain after Ageing*

Figure (7) shows the relation between the rms volt of the AE and the strain at the end of ageing, test no.7. Very weak AE is obtained before the yield point which was not recorded by using the ring down counting technique [11] since the amplitude of AE signal is lower than the trigger level. The rms volt starts to increase at the yield point arriving its maximum value at about 6.5% strain then decreases until fracture.

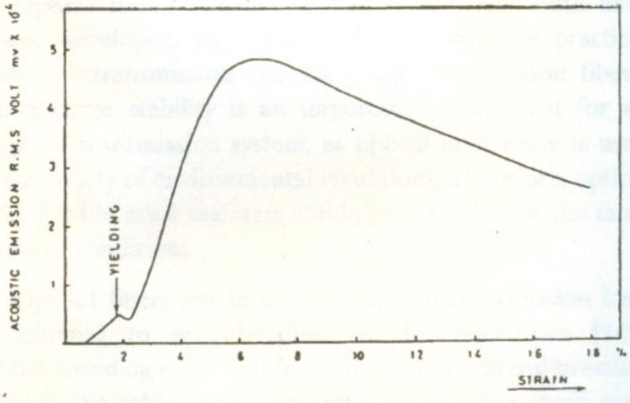


Figure 7. Acoustic emission r.m.s. volt against strain.

The curve can be fitted to the relation:

$$V = 0.025\ e_p\ e^{-18.24\, e_p}$$

which has the same form of the mobile dislocation density model suggested by J.J. Gliman [12].

CONCLUSION

This study pays attention to acoustic emission which is released from 2024-T3 Alclad aluminium alloy during tension loading at the steady state condition of the alloy and during ageing period.

It is found that the acoustic emission energy is inversely proportional to ageing time. It is suggested that the unstable solute atoms are the main source of the higher acoustic emission energy which is detected during ageing time. So, one can say that acoustic emission energy depends on percentage of transformation.

Since the mechanical properties of the aluminium alloys have a direct proportionality with ageing time, accordingly, the recorded acoustic emission energy shows an inverse relationship with the alloy strength.

When the alloy attains its steady state conditions, results of test number 7 performed at the end of the ageing period show that the alloy produces acoustic emission before and in the plastic region. Also, we find that the acoustic emission energy has a direct proportionality with material strain.

REFERENCES:

[1] Dunegan H.L., Harris D.O., and Tatro C.A., "Fracture Analysis by use of Acoustic Emission", *Eng. Fract. Mech.*, Vol. 1, No. 1, (1968) pp 105-122.

[2] Fisher, R.M. and Lally, J.S., "Microplasticity detected by acoustic technique", *Can. J. Phys.*, Vol. 45, No. 3, part 3, (1967) pp 1147-1159.

[3] Evans, A.G. and linzer, M., "Acoustic Emission in Brittle Materials", *Ann. Rev. Mater. Sci.*, (1977), pp 179-208.

[4] Schofield, B.M., "Acoustic Emission under Applied stress", Report-Aeronautical Research laboratory, Wright-patterson Air Force Base, Ohio, 1964.

[5] Liptai, R.G. and Tatro, C.A., "Acoustic Emission - A Surface phenomenon", *Proceedings of Fourth Annual Symposium on Nondestructive Testing of Aircraft and Missile Components*, Southwest Research Institute, San Antonio, Texas (1963) pp 287-341.

[6] Dai, Z.Z. and Harris, B., "Acoustic Emission study of Impact-Damaged GRP pipes", *NDT int.*, vol. 21, No. 4, (1988) pp 259-265.

[7] Mcnally, "Inspection of composite rocket motor case using acoustic emission", *Mater Evel.*, 43 (1985) pp 728-732.

[8] Esmail, E., Abouelwafa, M.N. and Shokry, A., "A New Testing Machine For Acoustic Emission Detection During Tension", to be published.

[9] Lahtin, Y., *Engineering physical Metallurgy*, (1971) pp 404-410.

[10] Albert G. Guy, *Physical Metallurgy for Engineering*, (1962), Addison-Wesley Publishing Company, London.

[11] Liptai, R.G, Harris, D.O. and Tatro, C.A., "An Introduction to Acoustic Emission", 1972 *ASTM, STP*, 505, pp 3-10.

[12] Gilman, J.J., "Progress in Microdynamical Theory of Plasticity", *Proc. U.S. Nat. Congr. Appl. Mech.*, 5th ASME, New York, 1966.