ACOUSTIC EMISSION FROM FLAWED SPECIMENS

E. Esmail
Department of Math., and Eng., Physics Faculty of Engineering,
Alexandria University, Alexandria, Egypt

ABSTRACT

The acoustic emission during tensile testing of pre-cracked aluminum alloys was studied. During the advance of plastic zone at the crack tip no acoustic emission was detected. When the stress intensity factor reached its critical value the crack advanced with a very high speed accompanied by very high rate acoustic emission. The number of ringdown counts is found to be linearly related to the crack length while the energy of the emitted signals is proved to be proportional to the elastic energy released during crack advance.

INTRODUCTION

Crack surfaces are stress-free boundaries adjacent to the crack tip and therefore dominate the distribution of stress in that area. Remote boundaries and loading forces affect only the intensity of the stress field at the crack tip.

The elastic stress components near the tip of a crack in the opening mode can be obtained according to Irwin [1] by the equations:

$$\left.\begin{aligned}\sigma_x &= \frac{K}{(2\pi r)^{1/2}}\cos\frac{\theta}{2}\left[1-\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right]\\[2ex] \sigma_y &= \frac{K}{(2\pi r)^{1/2}}\cos\frac{\theta}{2}\left[1+\sin\frac{\theta}{2}\sin\frac{3\theta}{2}\right]\end{aligned}\right\}(1)$$

where r is the distance from the crack tip
and θ is the angle made to the x direction.
while K is the stress intensity factor given by:

$$K_I = Y\sigma\,(\pi a)^{1/2} \qquad (2)$$

where a is the half length of a central crack or the full length of an edge crack,
σ is the nominal stres
and Y is a geometry factor.

For a single edge crack in a plate of finite width the geometry factor is given by:

$$Y = 1.12 - 0.23\left(\frac{a}{W}\right) + 10.6\left(\frac{a}{W}\right)^2 - 21.7\left(\frac{a}{W}\right)^3 + 30.4\left(\frac{a}{W}\right)^4 \qquad (3)$$

in which W is the width of the specimen.

At the crack tip r=0, σ_y will have infinite value if equation 1 is rigorously obayed which is physically unrealistic since the yield stress will normally be exceeded locally prior to fracture. Thus a plastically deformed zone will be formed at the crack tip. For two dimensional case it was suggested [2] that the plastic zone may be represented by a circular boundary of radius r_p as shown in Figure (1). Thus, where r = r_p, = 0 and $\sigma_y = \sigma_p$ (yield stress) equation (1) gives:

$$r_p = \frac{1}{2\pi}\left[\frac{k}{\sigma_p}\right]^2 \qquad (4)$$

Outside the plastic zone, where r > 2 r_p the stress distribution is approximately the same as the elastic distribution given by equation (1).

Acoustic emission (AE) has proved especially useful for detecting cracks and other flaws. Flaws act as stress concentrators to cause localized plastic deformations at normal stress levels well below general yielding. AE associates plastic deformation, it can be used to detect flaws and provide information on the integrity of engineering structures [3].

In present work AE is studied during the tensile tests of pre-cracked aluminum alloys in order to characterize the crack propagation and to study the correlation between AE and the crack length.

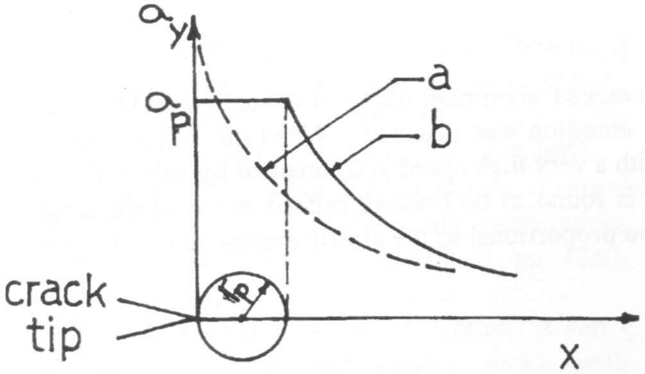

Figure 1. The stress distribution due to crack
a- elastic solution.
b- elastic solution transposed to effect of crack.

EXPERIMENTAL PROCEDURE

The specimens used are made of 2024 T3 Al alloy. They were cut from plate 2.1 mm thickness to rectangular pieces 2.8 x 12 cm with two holes and pre-cracked as shown in Figure (2). Mechanical properties and chemical composition of this alloy is described elsewhere [4].

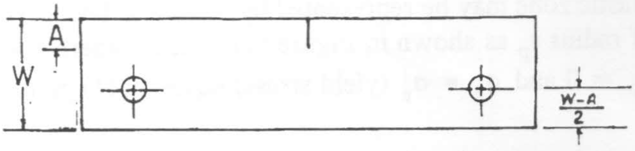

Figure 2. Specimen configuration.

Tensile tests were made on five specimens with different initial crack lengths, using the tensile testing machine described in [5]. During the load increase: the load and AE; root mean square (rms) voltage and the ring-down counting number, were measured and recorded to a time base using a TYY recorder at 1000 times amplification (60 dB voltage gain). Details about the measuring system can be found in [4] and [5].

RESULTS AND DISCUSSION

Figure (3) is the record of the ring-down counting number (N), root mean square value (V) and the force (F) versus time for specimen of initial crack length 1.5 cm. During the force increase no AE was recorded since the failure of the specimen. At this moment very rapid crack advance occurs accompanied by very high rate AE as seen from the ring-down counting and the rms voltage record.

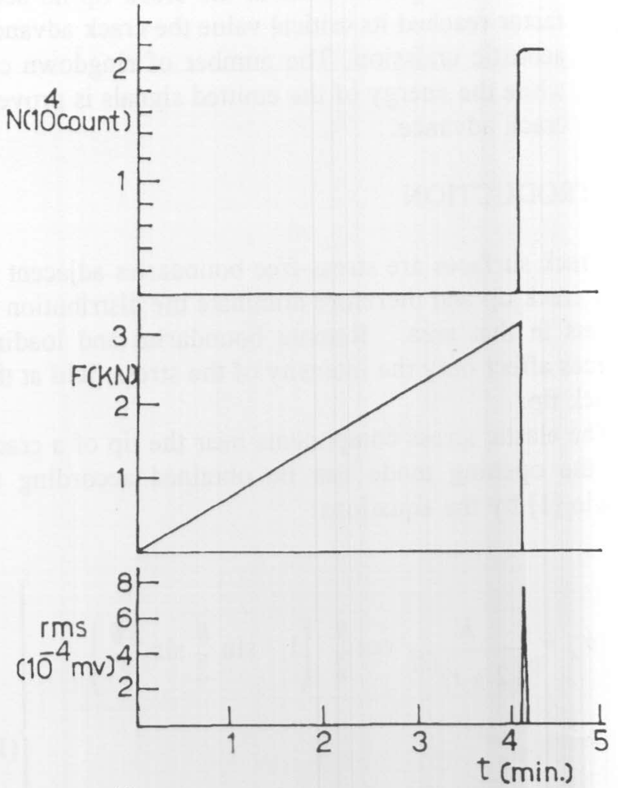

Figure 3. Ring-down counting number, rms volt and force versus time for initial crack length 1.5 cm.

The above behaviour is different from the case of AE during tensile testing on unflawed specimens in which AE starts near the yield point increasing to a maximum value then decreases untill faulure. For the sake of comparison between the two cases Figure (4) is presented (adopted from [4]).

According to J.J. Gilman [6] AE is due to dislocations motion caused by plastic deformation. The ring-down counting number is given by the equation:

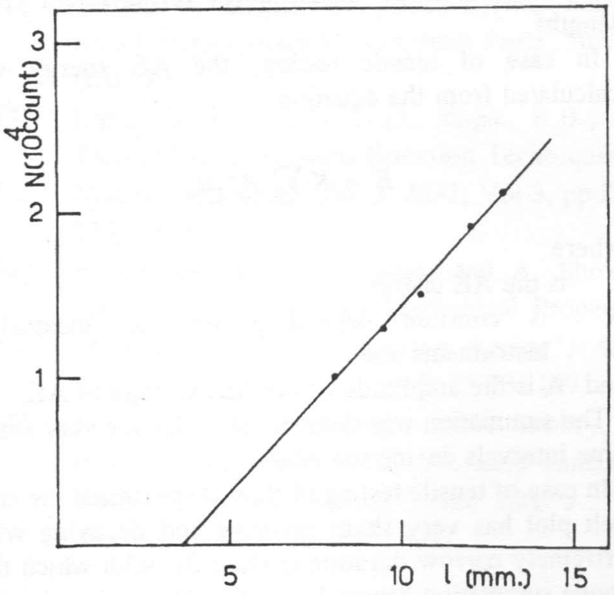

Figure 4. Plot of the ring-down counting number against the crack propagation length.

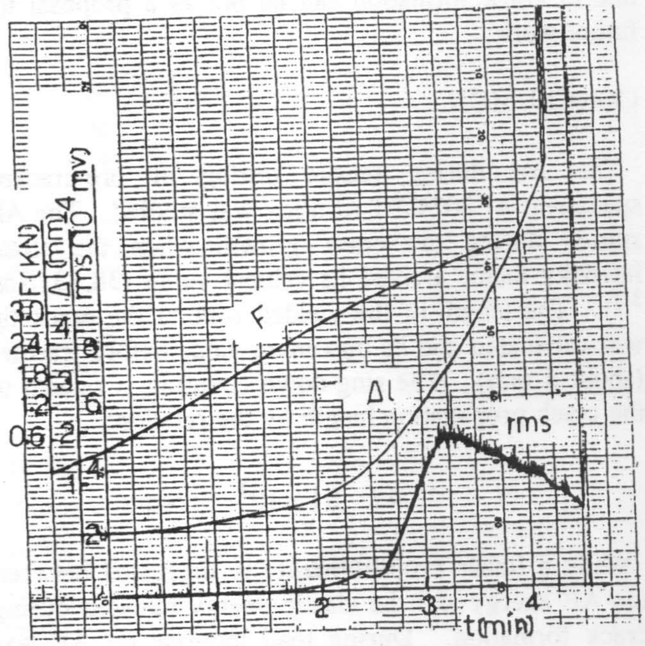

Figure 5. Acoustic emission rms during tensile testing of unflawed specimen (adopted from [4]).

$$N(\epsilon_p) = M\epsilon_p e^{-\phi/\epsilon_p} \qquad (5)$$

where ϵ_p is the plastic strain $= (\epsilon - \epsilon_{yield})$, M and ϕ are material constants. $N(\epsilon_p)$ is the number of ring-down counts per unit volume.

The above equation shows that the ring-down counting number is proportional to the strained volume of the unflawed specimens. This shows that each AE burst is due to co-operative motion of big number of dislocations.

In flawed specimens, plastic deformation occurs at the high stress region at the crack tip in the circle of radius r_p. As seen in Figure (1) the maximum stress is limited by the yield stress consequently ϵ_p in equation (5) is zero. This explains why no AE is obtained during the advance of the plastic zone preceeding the crack tip.

During load increasing the stress intensity factor increases until a critical value (K_{IC}) at which a very rapid crack advance occurs till the rupture.

The crack advance causes high plastic strain and gives rise to the high AE as seen in Figure (3).

The initial crack length, the maximum load, the crack advance, and the ring-down counting number untill failure of the five specimens are given in Table 1.

Table 1.

Initial crack length: A (cm)	2.0	1.85	1.75	1.60	1.50
Maximum load Pm (N)	1425	1800	2250	2700	3300
Critical stress intensity factor: K_{IC} ($Nm^{3/2}$)	38.50	37.66	39.79	37.31	38.88
Crack advance: 1 (cm)	0.8	0.95	1.05	1.20	1.30
Ring-down counting number N (1000 count)	10	13	15	19	21

From the table it is seen that the critical stress intensity factor is approximately the same. Its average value is $K_{IC} = 38.43\ Nm^{-3/2}$ which is the same value obtained by Baram [7]. Substituting this value in equation (4) and the value of σ_y by 310 MPa the maximum value for r_p is 2.45 mm. This means that the length of the yielded zone in front of the crack tip is 4.9 mm just before fracture occurance.

The ring-down counting number N is plotted as a function of the crack advance l(= W-A). The plot is a straight line represented by the equation

$$N = (22.4\, l - 8) \times 10^3 \quad count \qquad (6)$$

where l is in cms.

The relation shows that the AE during crack advance does not depend on the initial crack length and that for small crack advance (0.36 cm) no AE is detected. As explained before, each AE burst is due to commulative motion of big number of dislocations which is smaller for shorter crack. The amplitude of AE burst is then either equal to or lower than the background noise level and they are not detected, since the discriminator level is adjusted a little bit higher than the noise level.

The relation between the ring-down counting from a single AE burst is given by the relation :

$$N = \frac{f}{\mu} \ln \frac{A}{A_{th}} \qquad (7)$$

where f is the resonant frequency of the transducer
μ is the attenuation coefficient
A is the amplitude of of the AE burst.
and A_{th} is the discriminator threshold level.

Since f, μ, A_{th} are constants it is seen that the ring-down counting is proportional to the signal amplitude. Since the energy of the AE burst is proportional to the square of its amplitude and hence to the square of the ring-down counting number it is concluded that the AE energy is proportional to the square of the crack advance.

Parker [8] proved that the elastic energy released by the formation of a crack is given by:

$$U_e = \frac{\pi \sigma^2 a^2}{8E} (1 + \nu)(K + 1) \qquad (8)$$

where
a is the crack length.
E is the mdulus of elasticity.
ν is the Poisson's ratio and
$K = (3 - 4\nu)$.

The above relation shows that the elastic energy released during a crack formation is proportional to the square of the crack length which is the same relation between the AE energy and the crack length. This shows that the AE energy is proportional to the elastic energy released due to the crack advance.

It would be of great importance to measure the AE energy and correlate it to the elastic energy which can be calculated from Equation (8) for different crack lengths.

In case of tensile testing, the AE energy was calculated from the equation :

$$E = K \sum A^2 \, dt \qquad (9)$$

where
E is the AE energy
K is constant depending on the measuring instruments and
and A is the amplitude of the rms voltage of AE.

The summation was done numerically for very small time intervals during the whole test.

In case of tensile testing of flawed specimens the rms volt plot has very sharp growing and decaying with extremely narrow duration (Figure 3), with which the above summation cannot be made. Measuring the AE energy in such case needs more sophisticated instruments [9]. For this reason finding the correlation between the AE energy and the elastic energy released due to crack formation can be put as a proposal for future work.

CONCLUSION

The AE during tensile testing of pre-cracked specimens of 2024-T3 Al alloy was studied. The AE started during the crack growth when the stress intensity factor arrived its critical value (38.43 $\mathrm{Nm}^{-3/2}$). The length of the yielded zone at the crack tip was calculated and its maximum value before fracture (about 4 mm). The ring-down counting is related to the crack propagation length by the relation:

$$N = (22.4\,l - 8) \times 10^3 \quad \text{count}$$

while a linear proportionality is suggested between the AE energy and the elastic energy released during crack formation. During load increase no AE was detected before fracture which make it necessary to use proof testing technique [10] to study the integrity of structures instead of direct tensile testing.

REFERENCES

[1] Irwin, G.R., *Fracture Machines*, J. Appl. Phys., 24, 361, 1957.

[2] Terance V. Duggan and James Byrne, "Fatigue As a Design Criterion", *Gresham Press*, Surrey, G.B, 1977.

[3] Liptai, R.G., Harris, D.O., Engle, R.B., and Tatro, C.A., "Acoustic Emission Techniques in Material Research", *Int. J. NDT*, Vol 3, pp 215-275, 1971.

[4] E. Esmail, M. Abouelwafa, and A. Shokry, "Acoustic Emission and Mechanical Properties of Aluminium Alloys During Ageing", *Alex. Eng. J.*, Vol 30, No. 2, pp D 69-73, 1991.

[5] E. Esmail, M. Abouelwafa, and A. Shokry, "A new Testing Machine For Acoustic Emission Detection During Tension", *Alex. Eng. J.*, Vol 30, No. 2, pp A 137-141, 1991.

[6] Gilman, J.J., "Progress in Microdynamical Theory of Plasticity", Proc. *U.S. Nat. Cong. Appl. Mech. 5th ASME*, New York, pp 385-403, 1966.

[7] Baram, J., "prediction of Low-Cycle Fatigue-Life by Acoustic Emission-1:2024 T3 Aluminum Alloy", *Eng. Fract. Mech.*, V15, No. 3-4, pp 477-386, 1981.

[8] Parker, A.P., *The Mechanics of Fracture and Fatigue*, E.F. Spon, London, 1981.

[9] Beattie, A.G., and Jaramillo, R.A., "The Measurement of Energy in Acoustic Emission", *Rev. Sci. Instrum.*, V45, No.3, pp 352-357, 1974.

[10] McNally, D.J., "Inspection of Composite Rocket Motor Cases Using Acoustic Emission", *Mater Eval.*, 43, pp728-732, 1985.