BIDIMENSIONAL STABLE CRACK GROWTH IN THIN PLATES OF 7020 T 6 ALUMINIUM ALLOY

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Crack front evolution for part through cracks is determined by colour ink tinting for twelve different flaw configurations.

The crack growth parameters da (increment of crack depth) and ds (increment of crack area) are correlated with the crack opening or the crack opening work in order to generate a resistance curve.

A compliance calibration combined with partial unloadings for part-through cracks is proposed to generate resistance curves with a single specimen technique.

INTRODUCTION

The behaviour of part through cracks is of considerable importance in pressure vessels technology and has been studied by many workers.

Only a few papers, principally [1] and [2] experimentally studied the stable crack growth of semi-elliptical cracks with the two following principal conditions :

- Only the through thickness propagation is considered
- The plate thickness tested is high (> 50 mm)

The objective of this work is to characterize the evolution of surface cracks from crack initiation to break through for plates of small thickness and for large crack depth to thickness ratios (a/t).

EXPERIMENTAL PROCEDURE

3 mm thick welded plates, 200 mm wide, 600 mm long (figure 1) were tested at room temperature in monotonic loading (imposed cross head displacement). Semi circular notches (table 1) were electro-eroded in the middle of the weld and several parameters were measured (figure 2) :

- crack mouth opening
- back face remaining ligament deformation
- load line displacement
- crack front growth by colour tinting.

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RUPTURE MECHANISM

The fracture surface is composed of two different zones (figures 3 and 4) the rupture starts, as explained in [3], by a flat fracture mode under plane strain conditions. The crack grows bidimensionally and the crack front geometry moves from a semi-circular configuration to a more complex geometry (side horns) which can be approximated by a truncated ellipse (figure 4).

Considering the deepest point, the crack grows until the slip mechanism takes over from the tearing mechanism. Shear rupture prevails when the remaining ligament depth at the deepest point falls below a critical value which can be correlated theoretically [4] and experimentally to the crack opening.

Some theoretical approaches [5] assumed that the ligament is subjected only to tension during crack growth. Figure 5 shows the rate of bending present for our geometry during crack growth, where δ_1 is the mouth and $\delta 2$ the ligament deformation. The bending can be deduced from the difference with the Y = x line.

There is a balance between the elastic bending and the plasticity in the remaining ligament. The bending decreases when the plastic zone spans the ligament but must be in any cases taken into account following [6] or [7] in order to predict precise mouth opening values.

RESISTANCE CURVES

As shown in [8], if the mouth opening is plotted against the increment of crack growth in the through direction at the deepest point a linear behaviour is observed and the experimental derivation obtained with the ink marking technique is shown in figure 6.

For different flaw geometries, we obtain families of lines dependant on initial crack geometry. The global mouth opening is not suited as a parameter to characterize the through thickness crack propagation at the deepest point. A CTOD approach is more rigourous and can be deduced from bending measurements.

A value of COD close to the real CTOD can be calculated from the difference $\delta_1 - \delta_2$

$$COD = \delta_2 + (\delta_1 - \delta_2)(1 - a/t)$$

The experimentally determined COD versus da curves are shown in figure 7-a and curves obtained using plates of larger dimensions (width 300 mm, length 900 mm, tested in Aerospatiale Laboratories) as shown in figure 7-b. The COD at initiation was found to be in between 0,1 mm and 0,12 mm.

As the crack tip opening varies along the crack front, the mouth opening gives general information on the bidimensional crack growth behaviour.

The plasticity is located in the weld and the rest of the structure remains elastic. The plastic work can therefore be measured from a local approach.

If the opening work is taken to be the area under the load versus opening curve and assuming a rigid plastic behaviour of the weld the local energy release rate for an extension of the cracked area dS can be expressed as :

$$\Delta_n = \frac{Un}{Wt - Sn}$$

Un : area under the load versus opening curve (daN. mm)
W : specimen width
t : specimen thickness
dSn = Sn - So

The relation Δ- dS is shown in figure 8 and was found to be unique for the twelve initial crack geometries tested over a very wide range of crack propagation Δ at initiation was found to be about 0,025 MPa. m and the value Δ/σ_y is very close to the estimated value of CTOD (σy = Yield strength of the weld : 240 MPa).

COMPLIANCE CALIBRATION

With the ink marking technique only three or four crack traces can be obtained. So a precise resistance curve must be built with much more than one specimen.

A compliance calibration is proposed in order to determine the resistance curve using only one specimen. From a load versus opening record with partial unloadings of less than 10% of the current load (figure 9), the compliance was taken to be the inverse value of the unloading slope. If compliance and the corresponding opening are plotted on a semi logarithmic scale a family of parallel lines is obtained as shown in figure 10. So in the exponential relation between compliance and opening one constant is dependent on crack geometry and the second is not for our material and the thickness tested.

The experimentally determined relation is :

$$C = Co \exp(1.93\,\delta)$$

$$Co = (9.3\ 10^{-8}\ So + \frac{e}{EtW})$$

e : weld length
E : Young's Modulus

The compliance can also be related to the real cracked area obtained by ink tinting as shown in figure 11.

SINGLE SPECIMEN TECHNIQUE FOR RESISTANCE CURVE DETERMINATION

The partial unloading technique gives the evolution of the compliance with the opening. As the compliance is related to the cracked area the total resistance curve can be obtained.

Following the same idea, the resistance curve can be deduced from a single load versus opening record as shown in figure 12. For a value of opening δn corresponding to the current load Pn the area under the curve can be calculated. Through the exponential relation between opening and compliance the corresponding value of compliance can be deduced and also the area of the crack using the compliance calibration. This area is used to calculate S_n and by subtracting the initial cracked area, dS is obtained. The total resistance curve is deduced.

CONCLUSION

The stable growth behaviour of a part through crack is bidimensional, and so a bidimensional tool has to be used. Materials, heat treatments, welding procedures can be compared for bidimensional propagation, using a simple specimen technique to determine the resistance curve.

CKNOWLEDGEMENTS

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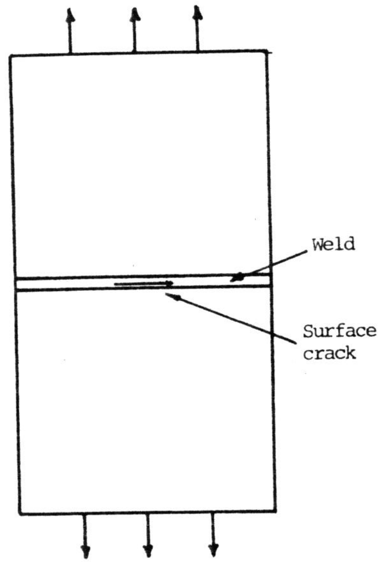


FIGURE 1

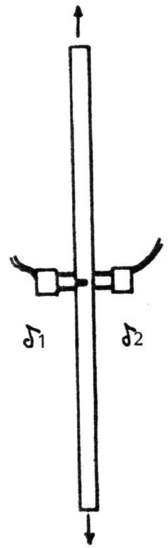
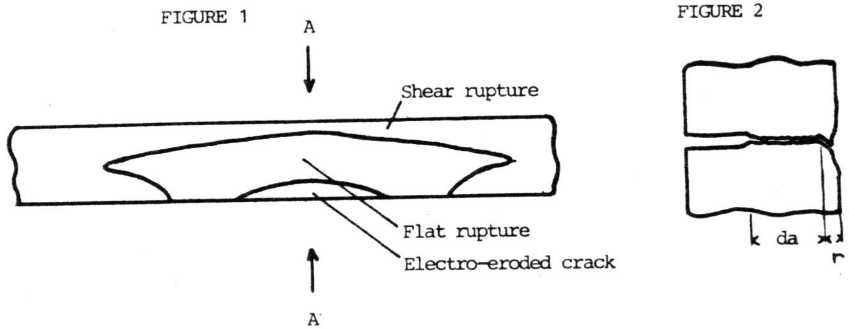


FIGURE 2



a) b)

FIGURE 3

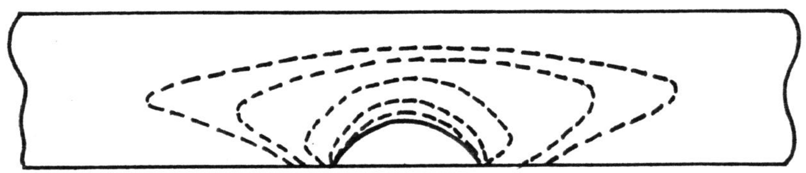


FIGURE 4

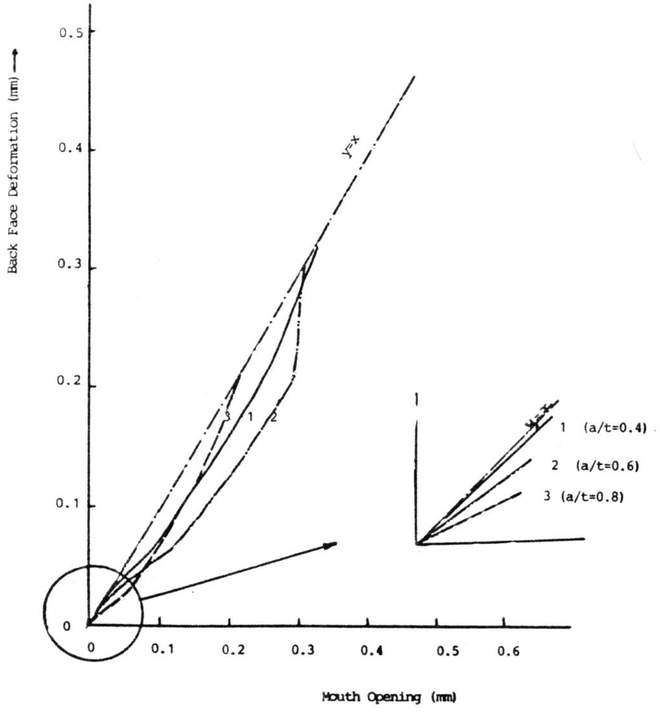


Figure 5

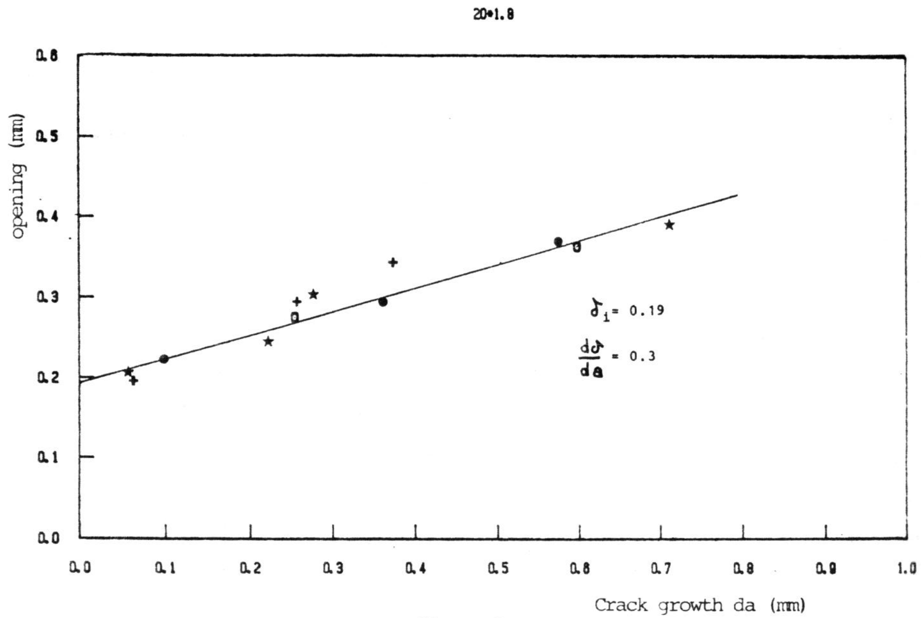


figure 6

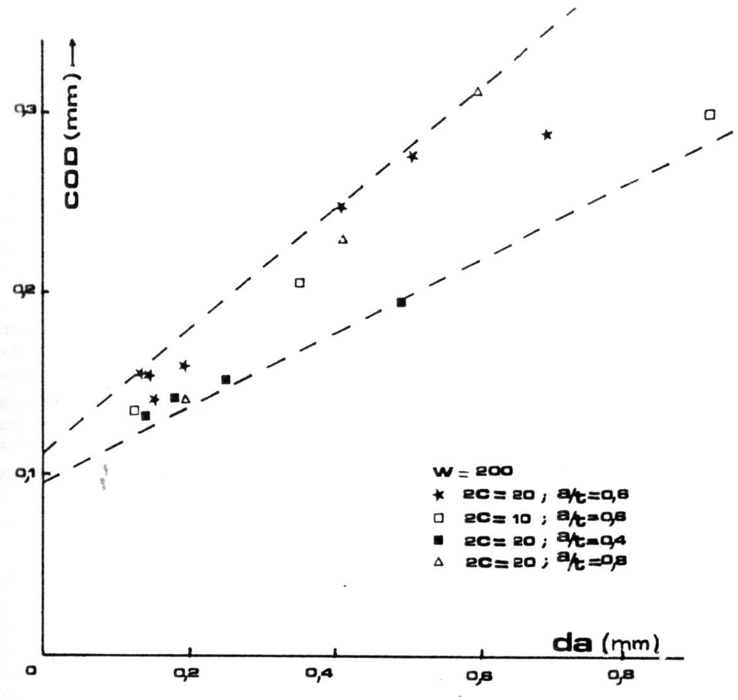


Figure 7-a

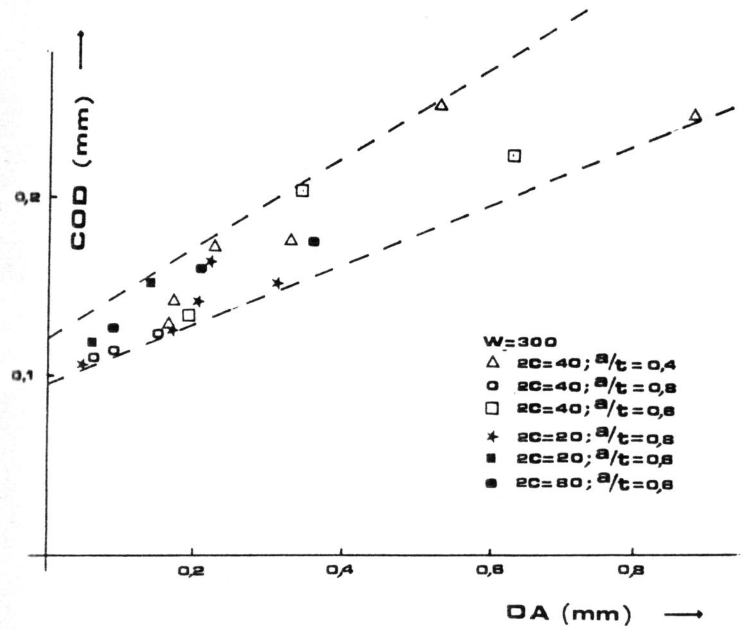


Figure 7-b

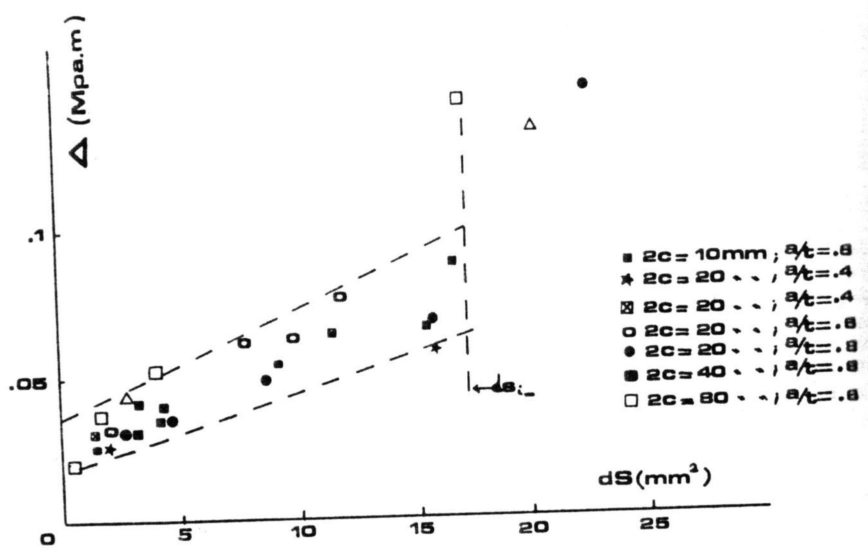


Figure 8

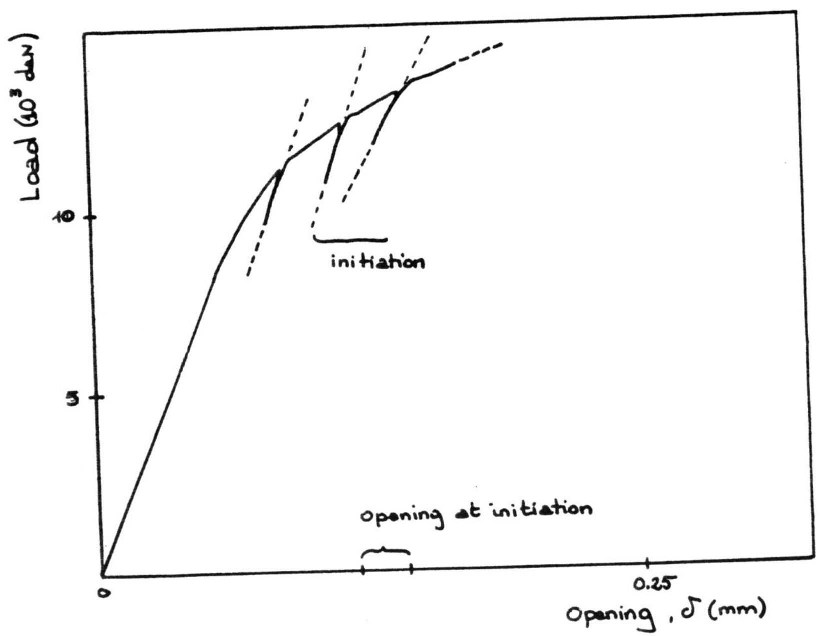


Figure 9

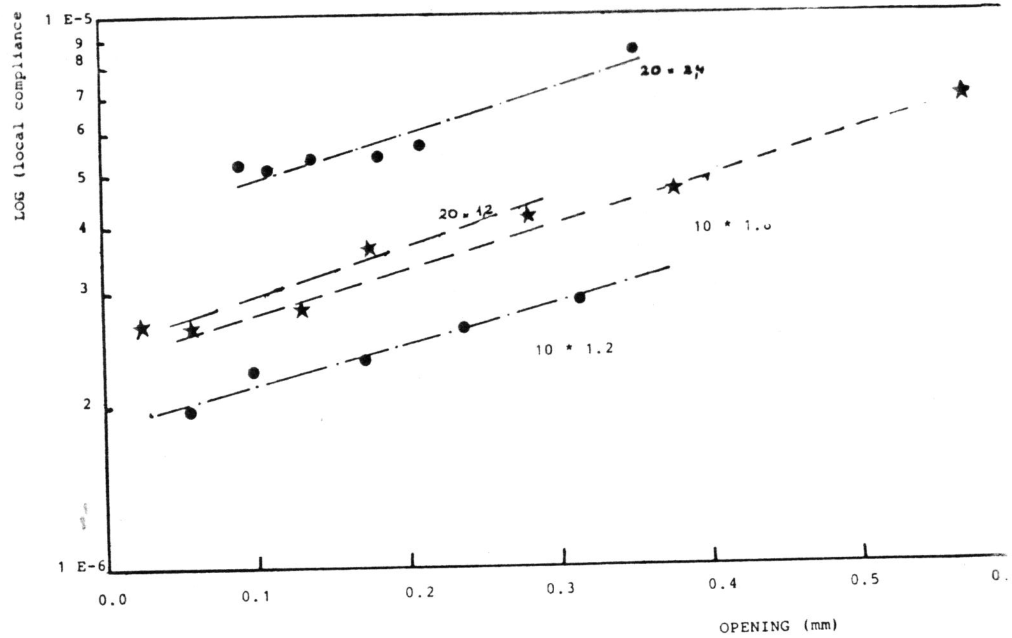


Figure 10

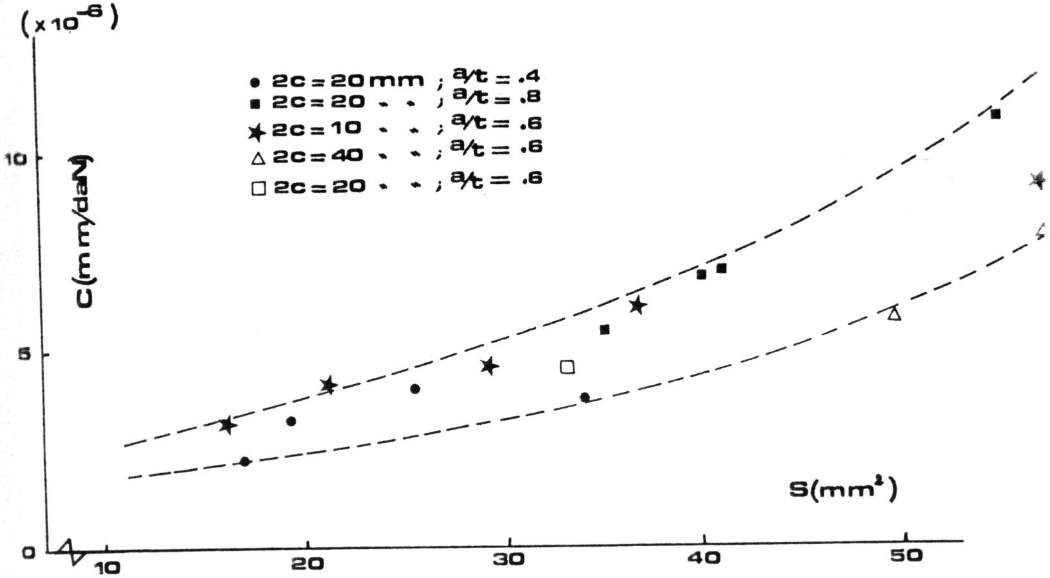


Figure 11

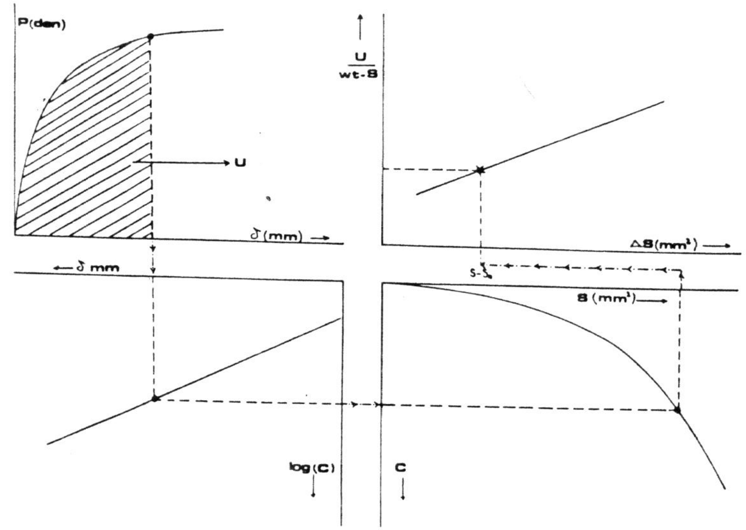


figure 12

2*C (mm)	a/t= 0.4	a/t= 0.6	a/t=0.8
10	2	2	2
20	4	4	4
40	2	2	2
80	2	2 *	2

* two specimens tested

Table 1