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CRANFIELD

PREDICTION OF UNSTABLE CRACK LENGTH IN ALUMINIUM ALLOYS

by

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Prediction of Unstable Crack Length in Aluminium Alloys

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SUMMARY

A method was set down for predicting the unstable length of a crack in a flat sheet of aluminium alloy subjected to a steady tensile stress.

The basis of the method was to take the work done to failure in the 'neck' region of a tensile test specimen and apply it, with a suitable constraint factor, to the flat sheet to give the work rate required to propagate the crack.

Experimental evidence is produced in support of the method.

CONTENTS

1. Procedure

Tensile tests were first carried out, load and deflection being recorded right to failure. This produced a stress-strain curve of the form of Fig. 1. The usual type of specimen is given in Fig. 2.

The total work done in the region of the neck was composed of two parts, viz. that prior to commencement of necking, V_p, and that after necking, V_n.

In Fig. 1.,

OACDF represents the basic stress-strain curve of the material at thickness t_o

XBCDF represents the stress-strain curve of the material (based on t_o) after some pre-straining.

A pre-strain parameter H is defined as $\frac{\text{Area XBCDF}}{\text{Area OACDF}}$.

V_p may be calculated from, (Ref. 1),

$$V_p = t_o\, C \times (\text{Area XBF}), \qquad \text{where } C = \frac{n_f - L_g \cdot e_n}{(1 + e_p)}$$

where
t_o = initial thickness of specimen
e_n = OF (or XF for a prestrained material)(Fig. 1)
n_f = final length of neck
e_p = OE (or XE for a prestrained material)(Fig. 1)

V_n may be calculated as follows :-

$$V_n = \left[L_1\, t_o \times (\text{Area ECG}) \right] + \left[4\, L_2\, t_o \frac{w_1}{(w_1 + w_3)} \times (\text{Area JCG}) \right] + \left[2L_3\, t_o \frac{w_1}{w_3} \times (\text{Area JCG}) \right] + L_g \cdot t_o \times (\text{Area GCDF}).$$

where L_1, L_2, L_3, L_g, w_1, w_3 are defined in Fig. 2.

The areas refer to Fig. 1.
The terms in square brackets come from the elastic energy released to the neck by the bulk of the specimen, the remaining term being the work done by the loading machine after necking commenced. It was assumed that after point C no further work is done on the specimen other than in the neck.

The work rate required to propagate the crack in the sheet is given by,

$$\frac{dW}{dl} = V_p + k\, V_n \,.$$

where l = crack length
and k is a factor necessary to allow for the constraint of the surrounding elastic material on the neck region at the end of the crack.

The energy release rate from the sheet is assumed to be given by,

$$\frac{dV}{dl} = \sigma_\infty^2 \; y\,\beta\, \frac{\pi\, wt}{E} \qquad \text{(Reference 1)}$$

where σ_∞ = nominal stress in sheet well away from crack
$y = {}^{l}/_{w}$

w = specimen width

$$\beta = \frac{(2 + y^4)}{(2 - y^2 - y^4)} \qquad \text{(Reference 2)}$$

t = sheet thickness
E = Young's Modulus

The condition for instability is :-

$$\frac{dV}{dl} \geq \frac{dW}{dl} \qquad \text{(Reference 3)}$$

Therefore we have

$$\sigma_\infty^2 \; y\beta = {}^{E}/_{\pi wt} \;\; (V_p + k\, V_n)$$

or

$$\underline{\sigma_\infty^2 \; y\beta\, wt = {}^{E}/_{\pi} \;\; (V_p + k\, V_n)}$$

2. Experimental Work

Tests have been carried out on specimens approximately 21" long by 7" wide in unclad materials generally conforming to specifications L. 70, L. 71 and DTD. 687. Each specimen was subjected to a measured degree of plastic strain before the initial (artificial) crack was introduced in the centre of the sheet.

The application of this formula to the experimental results is given in Figs. 3, 4 and 5, where both sides of the last equation are plotted against the pre-strain parameter, H.

Values of k were chosen to give lines passing through the experimental points. The results showed good agreement for the slope of the lines indicating that the effect of V_p had been correctly estimated.

The values of k found should be related to the amount of strain achieved during necking. This was not true for these tests, indicating probable errors in measurement of the final portion of the stress-strain curve.

Further experimental work is required to investigate this latter point.

3. References

1.	Ryder, R. H.	The effect of work hardening on the static crack propagation properties of some aluminium alloys. College of Aeronautics Thesis. June 1960.
2.	Greenspan, M.	Axial rigidity of perforated structural members. National Bureau of Standards, Vol. 31, 1943.
3.	Griffith, A. A.	Phil. Trans. Royal Soc., A. Vol. 221, 1921, pp 180.

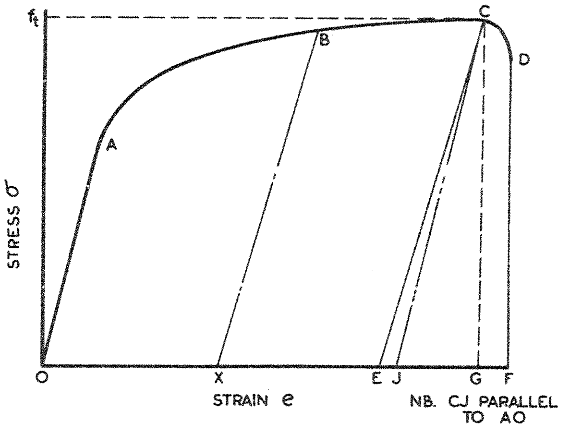

FIG. 1. TYPICAL STRESS-STRAIN CURVE FOR ALUMINIUM ALLOY

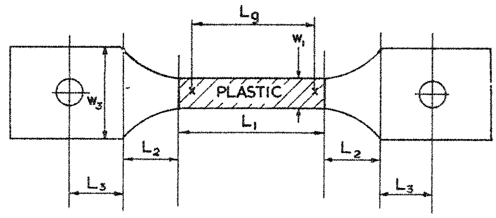

FIG. 2. TENSILE SPECIMEN REGIONS ($L_g = 2''$)

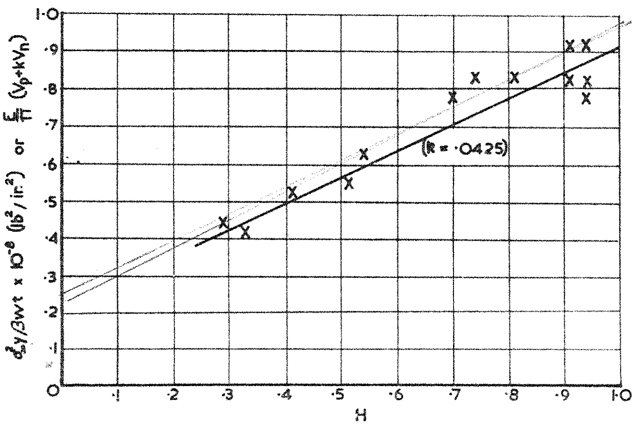

FIG. 3. EXPERIMENTAL RESULTS. MATERIAL – L70

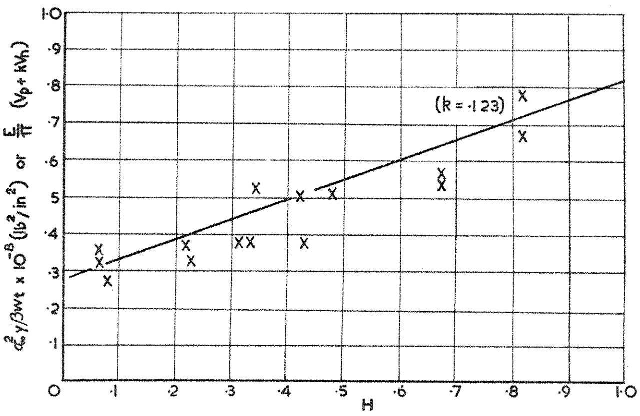

FIG. 4. EXPERIMENTAL RESULTS. MATERIAL – L71

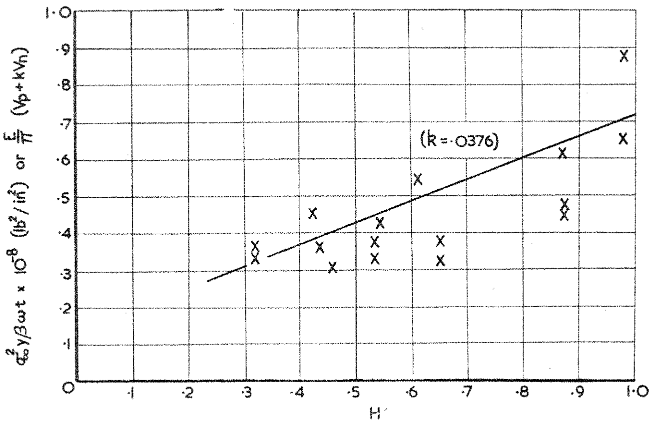

FIG. 5. EXPERIMENTAL RESULTS – MATERIAL DTD 687