A THREE DIMENSIONAL WAX ANALOGUE FOR THE CALIBRATION OF THE ELECTRICAL POTENTIAL TECHNIQUE OF CRACK GROWTH MONITORING

R. A. Smith* and A. D. Cameron**

**Cambridge University Engineering Department, Trumpington Street, Cambridge, England*
***Lloyds Register of Shipping, London, England*

ABSTRACT

Three dimensional wax models have been used to obtain calibrations for the DC potential drop measurement method. By taking potential readings at both sides of the specimen, quarter thumbnail cracks can be identified.

KEYWORDS

Crack growth measurement, DC technique, thumbnail cracks, three dimensional geometry.

INTRODUCTION

In recent years much research has been performed on crack growth monitoring techniques. Of the methods available the electrical potential method has the advantages of being relatively cheap, easily automated and giving a continuous record.

To date the direct current potential drop (dcpd) (Beevers, 1980) has proved very successful for monitoring long through cracks since these are essentially two dimensional problems. In these situations various theoretical, experimental and analogue techniques have proved useful to provide calibration curves of voltage versus crack length. However, for the more realistic situation of short thumbnail crack growth only experimental techniques have been extensively employed. The development of a 3-D analogue technique would be of great assistance for these more practical problems. Some 3-D finite element solutions have been presented for a few particular geometries (Beevers 1982). Their (presumed) better accuracy is of course balanced against vastly increased development time and computing costs.

EXPERIMENTAL

The requirements of a 3-D technique are similar to those of an analogue paper method which is used for 2-D situations (Smith, 1974). Typically, geometrical

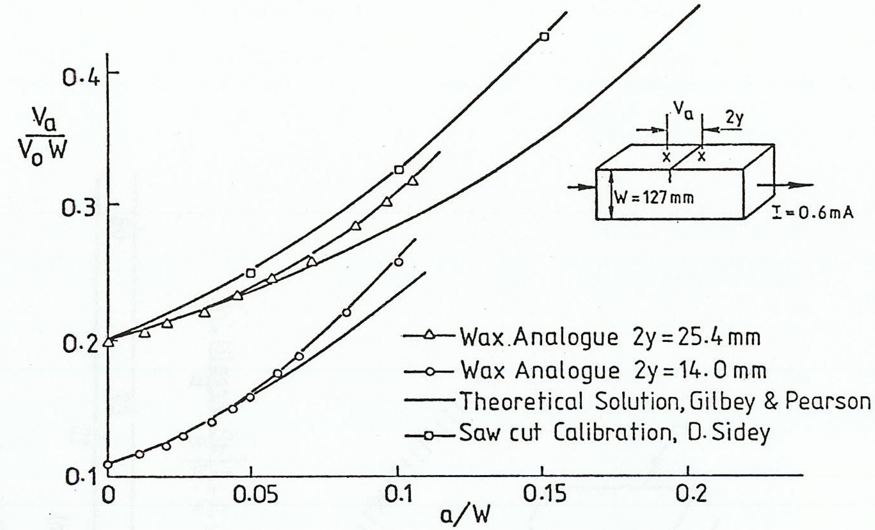

Fig. 1: Calibration for a through crack in a rectangular specimen

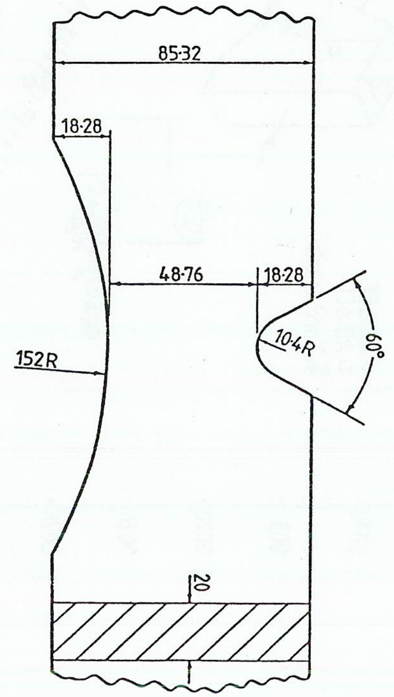

Fig. 2: Scale model of notched fatigue specimen (all dimensions in mm)

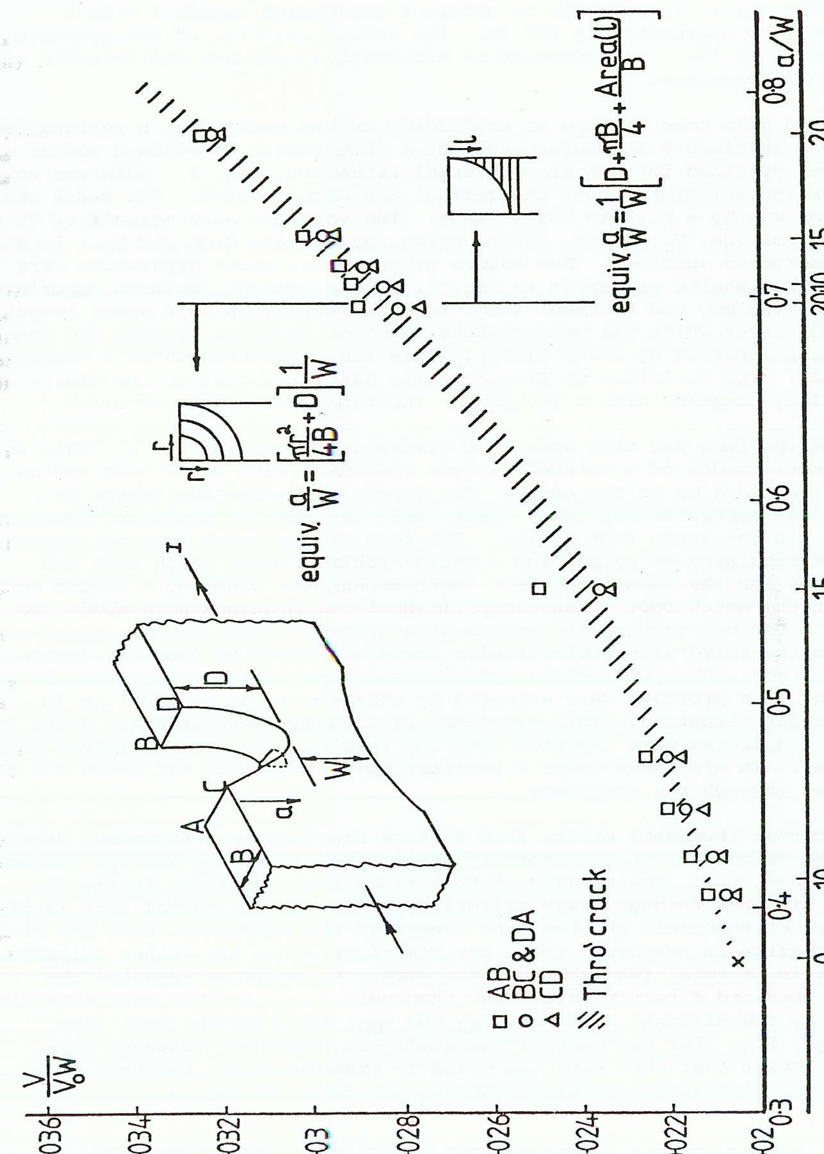

Fig. 3: Calibration for a single quarter crack

similarity must be maintained between the specimen and the model whilst a relatively high resistivity in the model is useful to ensure that the changes in voltages are measureable when using a small current. By mixing graphite powder with wax it is possible to obtain a conducting material with a resistivity of approximately 100 Ωm. The volume fraction of the graphite is in the order of 14%. The compound is machinable, castable and reusable after melting and recasting.

In order to give some measure of confidence in the technique, a rectangular, un-notched specimen was manufactured and a calibration of voltage versus crack length was obtained for the through crack situation, Fig. 1. This was compared with existing solutions, both theoretical and experimental. The crack was cut in the wax by a 0.13 mm thick blade. The voltages were normalised by a reference voltage, V_o (Smith, 1974), being the voltage drop per unit length in the uncracked specimen. Two values of potential probe separation were used and the results are shown in Fig. 1. The agreement between experiment and theory (Gilbey and Pearson, 1966) is satisfactory up to a crack length of a/w = 0.05 after which the wax/graphite solution diverges towards the saw-cut calibration obtained by Sidey (1973). This was considered to be a satisfactory comparison. The deviation in Sidey's tests was attributed to the finite width of the slot, compared with a (supposed) infinitely thin fatigue crack.

A notched specimen was then made with dimensions shown in Fig. 2. This is a 4 times scale model of a notched fatigue specimen, with notch root radius 2.6 mm, i.e. 10.4 mm in the model. The stress concentration factor is estimated as approximately 3.6. Great care was taken to maintain dimensional accuracy in the notch root region. The form of the notch root was attained by direct machining or by placing a solid machined metal shape into the casting box for the larger notches. Both techniques produced a smooth surface finish at the notch root. Three experimental calibrations were made, the first with through cracks, the second with quarter cracks at one corner of the notch and the third with semi-circular cracks originating from the centre of the notch root. When the cracks were large enough to cover the whole of the notch root, the profiles were extended by straight steps in order to join the through crack situation. This procedure is clearly shown on Figs. 3 and 4. The profiled cracks were inserted into the specimens by cutters shaped from shim steel. In all these cases a constant uniform current (of about 0.6 mA) was passed through the specimens.

For the corner thumbnail crack, four voltage readings were recorded; directly across the thumbnail, V_{AB}, diagonally across the crack, V_{AD} and V_{BC} and across the back face, V_{CD}. The results of this experiment are shown in Fig. 3, together with the through crack calibration. On the horizontal axis is plotted the radius of thumbnail and then the length of the extension until the through crack situation is reached. These are scaled with the a/w values calculated on the basis of equal fractured surface area. As would be expected the readings obtained directly across the thumbnail, V_{AB}, are the most sensitive followed by the diagonal readings, V_{AD} and V_{BC}, and then the back face recordings, V_{CD}. For the central thumbnail the same four voltages were recorded except that this time V_{AB} would be expected to be the same as V_{CD}. The results, plotted in a similar manner, are shown on Fig. 4.

DISCUSSION AND CONCLUSIONS

In Figs. 3 and 4 the shaded region shows the average scatter of four experiments for straight through cracks. This represents the reproducibility of the wax analogue model technique - for a particular voltage reading an error

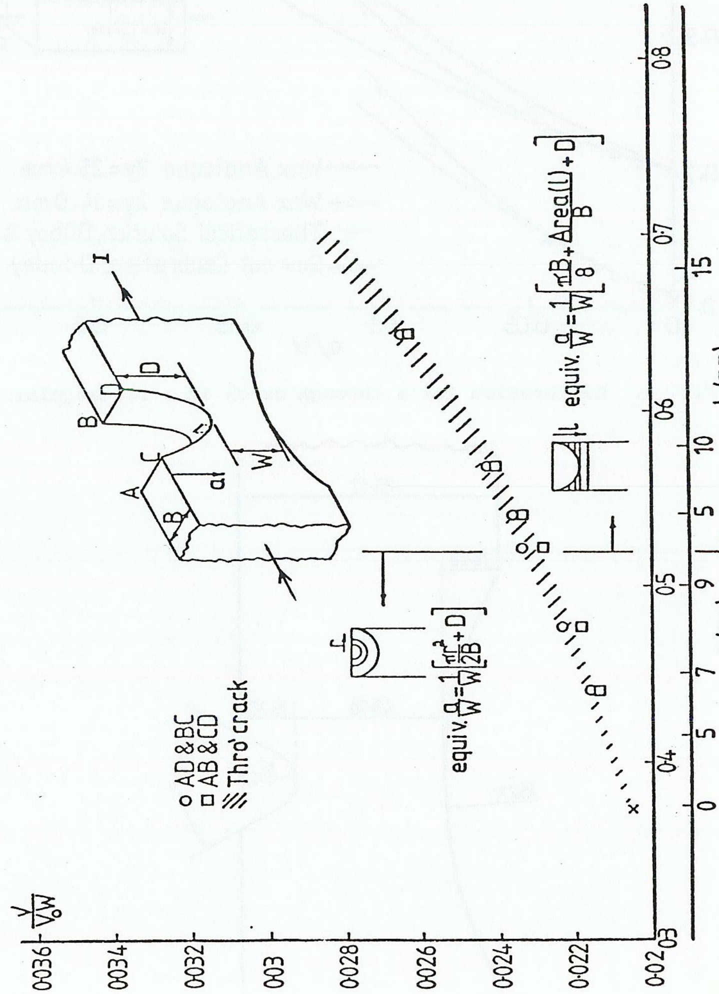

Fig. 4: Calibration for a central semi-circular crack

of about 0.015 a/w can result. This is equivalent to about 0.2 mm of crack length in the real size specimen. For the quarter crack calibration, Fig. 3, the voltage readings directly across the site of the crack (referred to as "same") clearly exceed the equivalent area through crack readings, whilst the converse is true of the voltage measured on the side "opposite" the crack. The "cross" voltage readings fall in the middle of the through crack scatter band. For this geometry therefore, the size of quarter cracks on one side of the specimen could be measured by this technique. The larger of the "same" and "opposite" voltage readings would identify the site of the crack, whilst the average of the "cross", "same" and "opposite" readings would give an equivalent through crack size.

The situation is different for the results from the centre semi-circular crack in Fig. 4. In this case, of course, the "same" and "opposite" readings are consistently but only slightly higher, still falling within the through crack scatter band. Clearly in this case experimental results would be too similar for position differentiation to be possible.

For both specimens, greater sensitivity would be achieved by placing the potential probes at the bottom of the notch root, but this would lead to problems of reproducibility of placement. The current input would probably have to remain at the ends of the specimen because of stress concentration problems arising through screwed, etc., inputs placed elsewhere.

Thus, in conclusion, the wax analogue technique has provided a sufficiently accurate calibration to suggest that quarter cracks can be identified in this geometry specimen. Central thumbnails will not be possible to distinguish clearly, whilst improvements could be made to the sensitivities of both calibrations by moving the potential probes. The role of the wax analogue has been well illustrated by this exercise - as a preliminary design tool which can point out which major parameter needs to be studied using more accurate, but expensive and time consuming methods.

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