CRACK-GROWTH MONITORING: OPTIMISATION OF THE ELECTRICAL POTENTIAL TECHNIQUE USING AN ANALOGUE METHOD

R. O. Ritchie, G. G. Garrett, and J. F. Knott
Department of Metallurgy and Materials Science
University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, England
tel: 0223 65151

It is generally recognised that the failure by fast fracture of an engineering component is often preceded by slow crack growth. Consequently, much effort has been devoted in recent years to studies of the initiation and propagation of such slowly growing cracks. One of the most popular techniques, used both to determine the onset of cracking and to measure crack growth rates, has been the electrical potential method, with D. C. current.

Briefly, this entails passing a constant current through a cracked testpiece under load, and measuring the potential difference across the crack. As the crack extends, the uncracked cross-sectional area of the testpiece decreases, its electrical resistance increases, and the potential difference between two points on either side of the crack rises. By monitoring this potential increase (V_a) and comparing it with a reference potential (V_o) measured elsewhere on the testpiece, preferably in a region which is not affected by crack growth, the crack length to testpiece-width ratio (a/W) may be determined. The technique has been used with success for the detection of pop-in in fracture toughness tests [1-3], of crack initiation in tension [4] and fatigue [5], of crack extension in COD tests [6], and for the measurement of crack growth rates in fatigue, creep [7], and hydrogen embrittlement tests [8,9].

If accurate measurements of crack length are to be made, the testpiece must first be calibrated to a high degree of precision. Several theoretical calibrations have been published [10-12]; a typical method used being that of Gilbey and Pearson who derived analytical solutions for Laplace's equation for the potential distribution in a homogeneous strip of metal containing a transverse crack. However, for complicated specimen geometries, direct experimental calibrations often need to be determined [13]. These may be obtained by measuring the potential distributions in standard testpieces, containing narrow slots or cracks of accurately known lengths.

In order to determine the optimum positions for the input of current and for the potential measuring probes, the use of graphitized electrical analogue paper to determine potential field distributions has proved to be invaluable. The analogue technique is able to indicate the positions of the lines of equi-potential inside the fracture specimen when a constant current is flowing through it. Two such patterns are shown in Fig. 1 for a single edge-notched (SEN) bend or tension specimen in the uniform current configuration (where current is introduced through the ends of the specimen). It can be seen that the presence of a crack causes a large disturbance in the potential field near the crack tip.

Fig. 2 shows the potential field distributions for three different current input positions on SEN specimens, (a) uniform current configuration; (b) point application of current at positions close to the notch; (c) point application further away from the notch. The optimum configuration can be derived by examining the three cases in detail.

Case (b), (application of current at a point close to the notch) gives the greatest *sensitivity* because the potential gradients are extremely steep in the vicinity of the crack. Sensitivity is lost as the current positions are moved further from the notch, e.g., case (c) and case (a). However, for case (b), slight variations in the positioning of the current leads from testpiece to testpiece give large variations in the distribution of equipotential lines and hence in the potential measurement for a given crack length. In case (a), since uniform current is obtained within a distance of 2W from the input point, precise positioning and mode of attachment of the current leads at the ends of the specimen is virtually of no consequence, and far greater *reproducibility* can be achieved. We have been able to obtain satisfactory results (unambiguous detection of less than 0.05 mm of fatigue crack growth) using uniform current (30A for a thickness of 15 mm in mild steel testpieces of length ℓ = 5W = 100 mm, as shown in Fig. 1). This obviously involved careful consideration of thermal emf (necessitating iron probe wires with a temperature-stabilized Fe-Cu junction); of efficient electrical and magnetic screening of all cables; and of the provision of a good earth.

The optimum positioning of the potential measurement probes for the determination of V_a will now be considered. These are usually fine wires (typically 0.2 mm diameter) spot welded to the specimen. Very accurate positioning is therefore not easily achieved practically. Two locations are commonly employed namely, close to the notch on the top surface of the specimen (position A-A) or at the crack tip (position B-B), as shown in Fig. 3. These probes may be offset diagonally across the notch "to average out the effect of non-uniform crack fronts" [7]. From the equi-potential patterns it can be seen that B-B is likely to give more sensitive but less reproducible results, because the potential gradients at the crack tip are very steep and positional variations of the probes here will cause much larger errors for a given crack length. It has also been pointed out that probes in position B-B are relatively more sensitive to crack tip plasticity, which can be confused with increase in crack length [14].

Similar equi-potential patterns have been obtained for compact tension (CTS) specimens (Fig. 4) with the current introduced by area contact on a) the top face and b) the side flanks; no uniform current configuration being possible. Here, with the potential probes in the optimum A-A position, case a) (Fig. 4) gives more sensitive results than for case b), where the potential gradients in the vicinity of the probes are so shallow that only a slight increase in potential is obtained for small crack extensions.

Difficulties in using electrical potential techniques may be encountered for some materials when the current is introduced by an area contact along the top face, as in case a) Fig. 4, or cases b) and c), Fig. 2. In practice, there appear to be few problems in situations where copper terminals can be affixed by brazing or soldering, but, in aluminium alloys for example, the alternative joining methods which must be employed can lead to variable results. Any flat plate terminals attached by bolts or conducting glues cannot be guaranteed to give reproducible results, because the proportion of area contact is likely to vary from testpiece to testpiece. Consequently, the most suitable method for introducing the current in testpieces made of aluminium or its alloys seems to be point contact through single screws attached at positions on either side of the notch on the top surface of the testpiece.

Conclusions

1) Electrical potential field distributions have been obtained for SEN and CTS fracture testpieces and used to derive the optimum conditions for current input and probe positions.

2) The most suitable position for the potential measurement probes is on the top face of the specimen as close to the open end of the notch as possible, since attachment near the crack tip leads to much larger errors from any slight variations in positioning the probes.

3) For SEN specimens, the greatest sensitivity is obtained by introducing the current at points close to the notch. However, the uniform current configuration (input of current at specimen ends) is preferred since it is not liable to errors from slight variations in current input position.

4) Introduction of the current by area contact on the top surface in CTS specimens is preferred because very low sensitivity is achieved for the initial stages of crack growth when the current is applied from the side flanks.

5) The mode of current lead attachment on CTS testpieces is dependent on the testpiece material. In steels, reproducible area contact may be achieved by the use of brazed or soldered copper terminals. However, in aluminium and its alloys, the same degree of reproducibility cannot be achieved for any practical application by area contact. Point application of current through a single screw is therefore advocated.

ACKNOWLEDGEMENTS: The authors would like to thank Sensitized Coatings Ltd, Croydon, for the loan of the potential field plotter from which the equi-potential patterns were obtained.

REFERENCES

1. J. E. Srawley and W. F. Brown, *ASTM S.T.P. 381* (1965) 175.

2. J. E. Srawley and W. F. Brown, *ASTM S.T.P. 410* (1966) 36.

3. P. N. T. Unwin and G. C. Smith, *J. Inst. Metals* 97 (1969) 299.

4. E. A. Steigerwald and G. L. Hanna, *Proc. ASTM* 62 (1962) 885.

5. A. R. Jack and A. T. Price, *Int. J. Fracture Mech.* 6 (1970) 401.

6. J. Davies, D. F. Cannon, and R. J. Allen, *Nature* 225 (1970) 1240.

7. A. R. Jack and A. R. Yeldham, C.E.G.B. Technical Report SSD/MID/R/215/70 (1970).

8. H. H. Johnson and A. M. Willner, *Appl. Mats. Research* 4 (1965) 34.

9. W. J. Barnett and A. R. Troiano, *J. of Metals* 9 (1957) 486.

10. D. M. Gilbey and S. Pearson, R.A.E. Technical Report 66402 (1966).

11. H. H. Johnson, *Mats. Research and Standards* 5 (1965) 442.

12. Che-Yu Li and R. P. Wei, *Mats. Research and Standards* 6 (1966) 392.

13. A. A. Anctil, E. B. Kula, and E. Dicesare, *Proc. ASTM* 63 (1963) 799.

14. G. D. Fearnehough. Private Communication.

13 August 1971

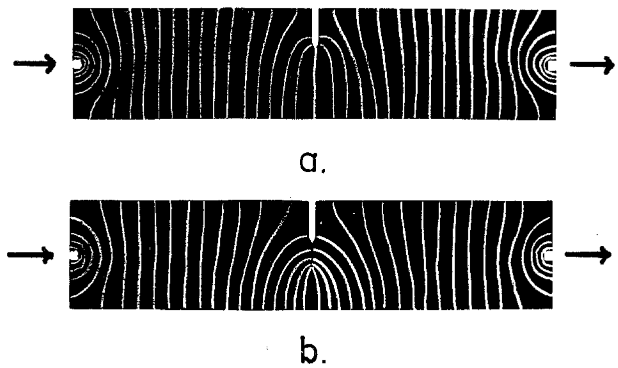

Fig. 1. Equi-potential distributions for SEN specimen in the "uniform current" configuration: a) uncracked, b) cracked (arrows indicate positions of current input and output).

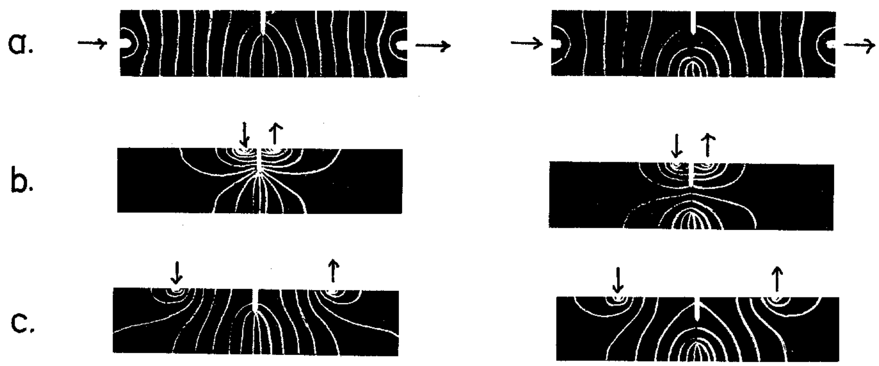

Fig. 2. Equi-potential distributions for SEN specimens (uncracked and cracked) with different current input positions

a) "uniform-current" configuration
b) "point-application" on top surface close to notch
c) "point-application" on top surface further away from notch.

Int. Journ. of Fracture Mech., 7 (1971) 462-467

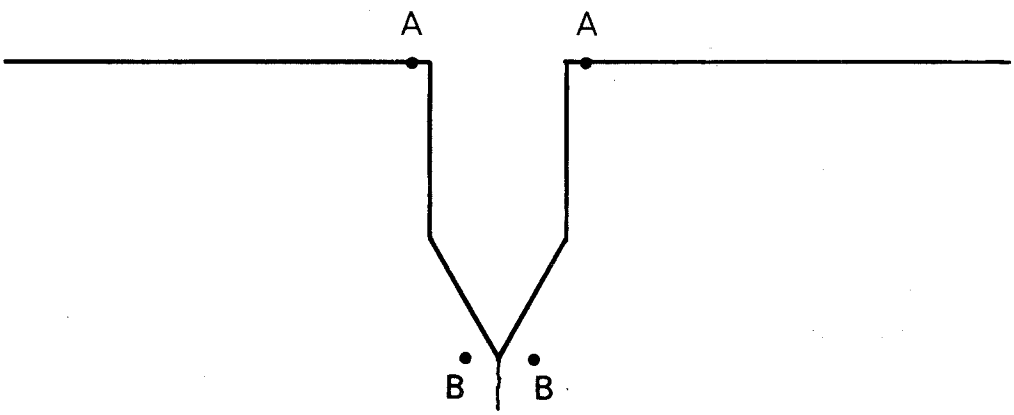

Fig. 3. Potential measurement probe positions.

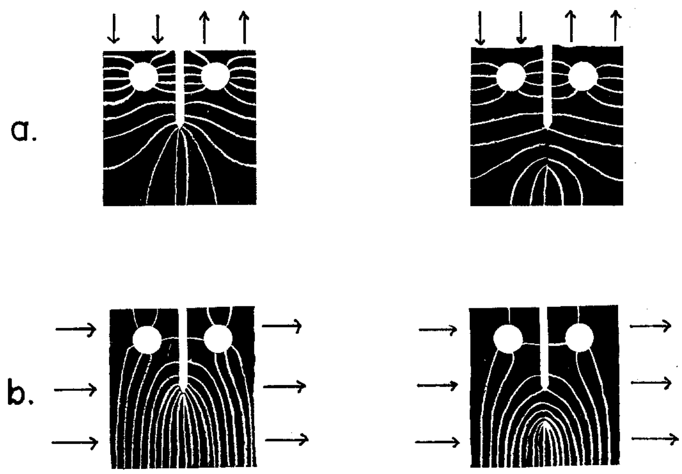

Fig. 4. Equi-potential distribution for CTS specimens (uncracked and cracked) with different current input positions

a) "area-contact" along top face.
b) "area-contact" along side flanks.