THEORETICAL, NUMERICAL AND EXPERIMENTAL ANALYSIS OF CRACKED WELDED TENSILE PANEL

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Theoretical, finite element and experimental analysis of the welded tensile panel with surface crack was performed, including problem of path independency of J integral for the multi-phase body. It has been shown that the direct measurement of Rice's J integral along an outer contour of the panel introduces certain error in the crack driving force evaluation. Therefore, the generalization of Rice's J integral is introduced in a form which includes additional line integrals along the phase boundaries. By applying the finite element method it is shown that such an integral expression recovers path independency and can be used as a crack driving force.

INTRODUCTION

Direct measurement of J integral, introduced by Read [1], has been recently applied for a number of problems, including welded tensile panels with surface crack, Božić, Sedmak, Petrovski and Sedmak [2]. As it has turned out, there are several problems regarding path independency of J integral, like heterogeneity of welded joint, three-dimensional nature of surface cracks and residual stress effects. We shall focus our attention on the first one, with an aim to perform theoretical and numerical analysis, in addition to the experimental one. Toward this end the welded tensile panel with surface crack is treated as a multi-phase body, consisting of three regions (phases) of material with different properties regarding plastic deformation: base metal (BM), weld metal (WM) and heat-affected-zone (HAZ). Such an approach involves calculation of Rice's J integral and several additional integrals, along the phase lines, in the form which is actually a generalization of the J integral for bi-material body, introduced by Gurtin [3] and applied by Sedmak, Sedmak and Ogarević [4] for the similar problem.

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J INTEGRAL FOR MULTI-PHASE BODY

J integral for multi-phase body will be introduced using welded tensile panels with surface crack, Fig. 2, which have been already experimentally analyzed, [2]. The cross-section of welded tensile panel, shown in Fig. 1, is characterized by three different phases, BM, WM and HAZ, not to mention heterogeneity of HAZ itself. In this paper HAZ is treated as homogeneous hard layer with the higher yield strength and hardening ratio than both BM and WM, as follows: R_e = 600 MPa and n = 0.05 for WM, R_e = 800 MPa and n = 0.02 for BM and R_e = 1000 MPa and n = 0.10 for HAZ. It should be noticed that the further complication in this analysis is the position of the crack tip, which is placed in HAZ, producing the asymmetrical problem.

Starting point in the theoretical analysis is Rice's J integral, with the contours along outer surfaces of tensile panel, chosen as suitable for direct measurement technique. Anyhow, because of the heterogeneity of welded joint, it is obvious that such an application of Rice's J integral involves path dependency problem, which can be overcome (theoretically and numerically, at least) if the conservation law of J integral type is applied on the contours Γ_1 - Γ_5, defined in Fig. 1:

$$J = \int_{\Gamma_1}\left(Wn_1 - \sigma^{ij}n_j\frac{\partial u^i}{\partial x^1}\right)ds \qquad (1)$$

$$0 = \int_{\Gamma_a}\left(Wn_1 - \sigma^{ij}n_j\frac{\partial u^i}{\partial x^1}\right)ds, \qquad \Gamma_a = \Gamma_2, \Gamma_3, \Gamma_4, \Gamma_5 \qquad (2)$$

since only Γ_1 encompasses the crack tip. Notation used in (1-2) is as usual (see e.g. [4]). There is no obstacle to combine these five equations into the following integral expression

$$J = \int_{\Gamma}\left(Wn_1 - \sigma^{ij}n_j\frac{\partial u^i}{\partial x^1}\right)ds - \sum_{1}^{4}\int_{l_a}\left([W]n_1 - \left[\sigma^{ij}n_j\frac{\partial u^i}{\partial x^1}\right]\right)ds \qquad (3)$$

where Γ denotes the outer contour, which is used for the direct measurement and l_a, a=1,2,3,4; are the contours along phase lines (see Fig. 1).

We shall not take into account the problem of symmetry because the experimental analysis has proved that the crack growth was along X_1 axes, regardless on the crack tip position. Therefore, the expression (3) will be treated as the crack driving force, i.e. as the energy release rate due to unit self-similar crack growth.

FINITE ELEMENT METHOD APPLICATION AND RESULTS

Calculation of integral expression (3) has been performed using specially written post-processor, based on displacement and stress fields, previously obtained by finite element method. Methodology was completely analogous to the one described by Owen and Fawkes in [5] and is in fact extended in order to incorporate the line integral terms along the phase boundaries. The elastic-plastic problem was solved using von Mises criterion of plastic flow.

The differences in material properties become evident only when plastic deformations are reached. Therefore, as far as the elastic analysis is performed, Rice's J integral is path independent, as it is shown in Fig. 3, where the results for both elastic and elastic-plastic analysis are presented. The results are shown for the complete integral expression 3 (denoted by o) and for the first term only (denoted by □). As it can be seen, the difference becomes evident as soon as plastic deformations occur or integration path crosses the phase boundary, confirming the path independency of integral expression 3.

DISCUSSION AND CONCLUSIONS

Direct J integral measurement has been proved to be one of the most suitable experimental technique for an evaluation of crack behaviour in complex structures which include welded joints. Nevertheless, as it has been shown, J integral is path dependent, unless additional line integrals (along phase boundaries) are taken into account. Having in mind that direct measurement technique can not be extended for an integral path which is along depth of tensile panel, it is essential to combine theoretical and numerical analysis with the appropriate experiment procedure.

REFERENCES

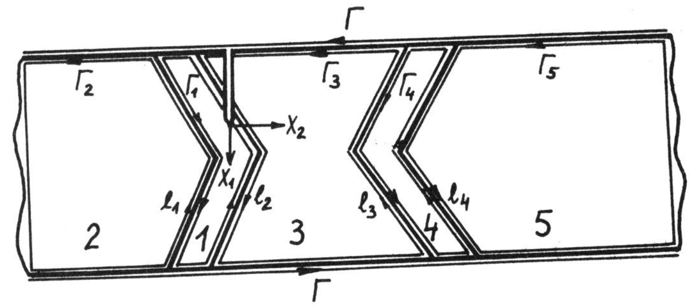
(1) Read, D.T. "Experimental method for direct evaluation of J contour integral", STP 791, ASTM, Philadelphia, USA, 1983, pp. II-199-208

(2) Božić, B, Sedmak, S., Petrovski, B., Sedmak, A. "Crack growth resistance of weldment constituents in a real structure", Bulletin of Serbian Academy of Science, No 25, 1989.

(3) Gurtin, M.E., J. Elasticity, Vol. 9, 1979, pp. 186-195.

(4) Sedmak, A., Jarić, J. and Berković, M., Proceedings of the ECF7 on the "Failure Analysis - Theory and Practice", Edited by E. Czoboly, EMAS, 1988.

(5) Owen, D.J.R. and Fawkes, C., Engineering Fracture Mechanics, Pinerigde Press, Swansea, 1984.



1, 4 - HAZ
3 - WM
2, 5 - BM

Fig. 1 Integration paths for the three-phase body

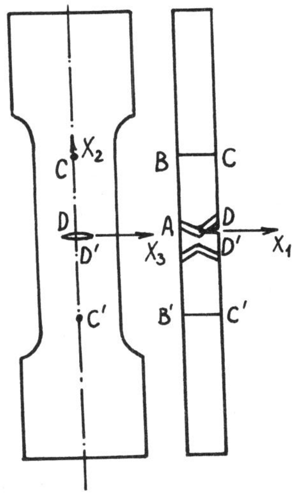


Fig. 2 Welded tensile panel

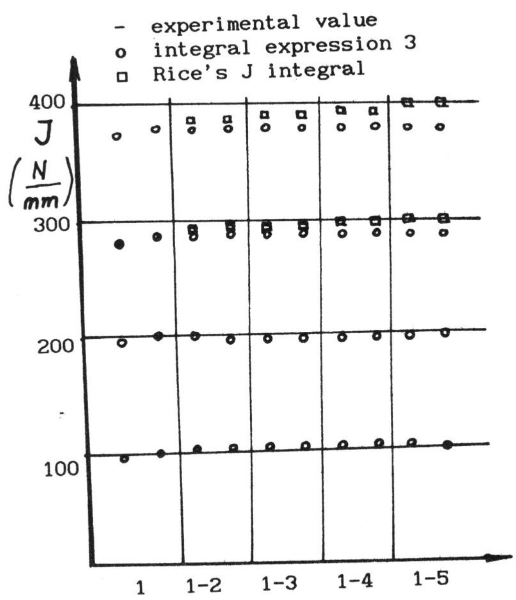


Fig. 3 J vs path distance