Effect of 3D Stress States at Crack Front on Deformation, Fracture and Fatigue Phenomena

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By

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Abstract

Theoretical, numerical and experimental studies involving elastic plate components, weakened by through-the-thickness cracks and subjected to loading parallel to the plane of the plate, are often based on plane stress or plane strain simplifications. These simplifications essentially reduce the dimensionality of the physical three-dimensional problem and enable the achievement of effective analytical and numerical solutions for many important practical problems. The influence of various three-dimensional effects, such as the variation of stresses across the plate thickness, effects of the three-dimensional corner (vertex) singularities and coupling of fracture modes II and III, on the deformation and stresses near the crack front are at present largely ignored or viewed as negligible for all practical purposes. As a result of this view, the outcomes of experimental studies and fracture tests are also commonly analysed within the framework of the plane theories of elasticity. Nevertheless, a number of theoretical and experimental studies over the past two decades have demonstrated that the predictions made within these theories can be unsatisfactory and the effect of three-dimensional stress states at the crack front on deformation, fatigue and fracture of plate components can be significant.

This thesis aims to elucidate the role of three-dimensional stress states in the deformation, fracture and fatigue phenomena further. The main outcomes of this thesis are: (1) the development and validation of a simplified method for the evaluation of the fatigue crack front shapes and their effect on the steady-state fatigue crack growth rates in plate components; (2) investigation of the effect of three-dimensional corner (vertex) singularities on the stress intensities and displacement field near the crack front; and (3) development and validation of a new experimental approach for the evaluation of mode I and mode II stress intensity factors from the measurement of the out-of-plane displacements in the near crack tip region, which are affected by three-dimensional effects, and, in particular, by the 3D corner (vertex) singularity.

This new research is important in many engineering contexts. For example, the new theoretical model, which takes into account the actual shape of the crack front, can be utilised in advanced fatigue life calculations, as well as in failure investigations. The latter is possible as the shape of the fatigue crack front can now be related to the parameters of fatigue loading. The new experimental approach developed in this thesis can be useful in fracture characterisation of thick plate components with through-cracks. This approach specifically addresses the situation when the K-dominance zone, or William's solution convergence domain, are relatively small. In this case, the data extraction region can be affected by the three-dimensional stress states leading to significant errors in the evaluation of the stress intensity factors when using traditional approaches.

This thesis is presented in the form of a compendium of published papers that are the summation of the research undertaken by the author. The five articles which form the main body of the thesis are united by a common theme, which is the investigation of three-dimensional effects near the crack front on stresses and displacements, fracture and fatigue phenomena. Two appendices are also included; they represent a compilation of the candidate's publications related to the main topic of the thesis.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and, where applicable, any partner institution responsible for the joint-award of this degree.

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Zhuang He Date

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List of Publications

Journal publications

1. **He, Z,** Kotousov, A & Branco, R 2014, 'A simplified method for the evaluation of fatigue crack front shapes under mode I loading', *International Journal of Fracture*, vol. 188, no. 2, pp. 203-211.

2. **He, Z,** Kotousov, A & Berto, F 2015, 'Effect of vertex singularities on stress intensities near plate free surfaces', *Fatigue and Fracture of Engineering Materials and Structures*, vol. 38, no. 7, pp. 860-869.

3. **He, Z,** Kotousov, A, Fanciulli, A, Berto, F & Nguyen, G 2015, 'On the evaluation of stress intensity factor from displacement field affected by 3D corner singularity', *International Journal of Solids and Structures*, vol. 78-79, pp. 131-137.

4. **He, Z,** Kotousov, A, Fanciulli, A & Berto, F 2015, 'An experimental method for evaluating mode II stress intensity factor from near crack tip field', *International Journal of Fracture*, published online.

5. **He, Z** & Kotousov, A 2015, 'On evaluation of stress intensity factor from far and near vertex fields', *Experimental Mechanics*, under review.

6. **He, Z,** Kotousov, A, Berto, F & Branco, R 2015, 'A brief review of recent three-dimensional studies of brittle fracture', *Physical Mesomechanics*, accepted: 18 December 2015.

7. Gardeazabal, D, **He, Z** & Kotousov, A 2014, 'On influence of non-singular stress states on brittle fracture', *International Journal of Fracture*, vol. 185, no. 1, pp. 201-208.

8. Kotousov, A, **He, Z** & Fanciulli, A 2015, 'Application of digital image correlation technique for investigation of the displacement and strain fields within a sharp notch', *Theoretical and Applied Fracture Mechanics*, vol. 79, pp. 51-57.

Conference publications

1. Kotousov, A, **He, Z** & Gardeazabal, D 2013, 'On scaling of brittle fracture', in CH Wang (ed), *Proceedings of the 8th International Conference on Structural Integrity and Fracture*, CD-ROM, Melbourne, Australia, pp. 93-96.

2. **He, Z,** Kotousov, A & Rose, LRF 2014, 'Effect of vertex singularities on the displacement and strain fields near a crack front', in L Ye (ed), *Recent advances in structural integrity analysis, Proceedings of the International Congress (APCF/SIF-2014)*, Sydney, Australia, pp. 12-16.

3. **He, Z** & Kotousov, A 2015, 'Estimation of stress intensity factors from near crack tip field', *International Scholarly and Scientific Research and Innovation*, *Proceedings of the 17th International Conference on Applied Mechanics and Mechanical Engineering*, Stockholm, Sweden, pp. 526-530.

4. **He, Z,** Kotousov, A & Branco, R 2015, 'Evaluation of fatigue crack front shape for a specimen with finite thickness', *Proceedings of the 4th International Conference on Advances in Mechanics Engineering*, Madrid, Spain.

Table of Contents