NUMERICAL STUDY ON INTERACTION EFFECT IN MULTIPLE CRACK PROBLEMS AND SOME PRACTICAL APPLICATIONS

アバス, アディンカ

https://hdl.handle.net/2324/7157348

出版情報：Kyushu University, 2023, 博士（工学）, 課程博士
バージョン：

（様式２）

氏　　名　：　アバス　アデインカ（Abass Adeyinka）

論 文 名　：　NUMERICAL STUDY ON INTERACTION EFFECT IN MULTIPLE CRACK PROBLEMS AND SOME PRACTICAL APPLICATIONS
（多重き裂の干渉効果に関する数値解析的研究とその応用）

区　　分　：　甲

論　文　内　容　の　要　旨

Prior to the emergence of a dominant major crack, many engineering fracture processes such as those observed in corrosion fatigue, fracture of weldments, fracture of casted component, stress corrosion cracking, thermal fatigue and fracture of additive-manufactured components can be modelled as a multiple crack problem. The computation of the stress intensity factors (SIFs) of the distributed cracks is an essential step in the application of fracture mechanics (FM) to such practical engineering problems. The determination of SIFs of a 3-D crack is a challenging endeavor since it is generally much more intricate, both analytically and numerically, than that of a 2-D crack. The presence of a free surface, such as in a semi-infinite body, results in greater difficulty. High computational cost becomes an additional bottleneck when multiple cracks are involved in the analysis. Since the early 1970s, several FM models have been proposed for assessment of fracture process dominated by initiation, interaction, and coalescence of distributed cracks. These models can be divided into two categories, i.e., Size Dominant Model (SDM) and Interaction Dominant Model (IDM). In SDM, the crack with the largest size is assumed to be the primary actor in the fracture process, hence the existence of other cracks is irrelevant. Therefore, according to SDM, the task is simply to determine the dimensions of the largest crack, followed by estimation of relevant SIFs and comparing the results with threshold values. Majority of existing models are of SDM type.

In IDM, it is assumed that cracks in close proximity interact with each other. Therefore, it is necessary to include the interaction effect in the estimation of their SIFs and threshold conditions. However, development of IDMs has been stagnating instead of its engineering importance. This is perhaps due to the additional complexity involved in IDM, i.e., interaction effects among cracks. The interaction effect manifests itself in two forms i.e., interaction effect on threshold conditions (material resistance) and interaction effect on SIFs (load actions). Recently, papers on interaction effect on threshold conditions started to appear in literature. It seems that research on crack interaction is experiencing a renaissance.

This study aims to address some of the challenges faced by FM based models targeted to engineering problems whose fracture processes are dominated by multiple interacting cracks. The main focus is the development of an efficient tool for numerical analysis of SIFs for multiple, 3-D, distributed, semi-elliptical cracks on the surface of a semi-infinite elastic body under arbitrary loading condition. A complementary objective is to develop a tool that can quantitatively characterise the spatial distribution of features, such as inclusions, pits, and cracks, on a given surface. The aspiration of this thesis is that such tools (numerical analysis of SIFs for multiple 3-D cracks and characterisation of spatial distribution of surface defects) will facilitate further research in this field, serves as valuable aid to advance our understanding of

crack interaction phenomenon, and improve the performance of existing FM models targeted to multiple crack problems. This dissertation consists of 6 Chapters which can be summarized as follows.

Chapter 1 described the central theme of this study, i.e., interaction effect in fracture processes that are dominated by initiation, propagation, and coalescence of multiple, distributed surface cracks. It introduced existing models for assessment of engineering problems whose fracture processes are dominated by multiple interacting cracks. Existing solutions and research gap in the SIFs analysis of interacting 3-D surface cracks were briefly reviewed. Then, the objectives and outline of this study were introduced.

Chapter 2 provided the basic formulation, numerical procedure, and MATLAB codes for the numerical analysis of SIFs for multiple non-planar, semi-elliptical cracks that were distributed on the surface of a semi-infinite elastic body under arbitrary loading conditions. The eigenstrain method adopted for the study is based on the technique of distributing infinitesimal dislocation loops (IDLs) on the crack surfaces in order to satisfy their respective boundary conditions. This formulation led to a set of 2-D, hyper-singular integral equations. The integral equations had a singularity of order three and were interpreted in the Hadamard finite-part sense. In the numerical calculation, the crack regions were discretised into triangular sections. The discretisation transformed the integral equations into a system of algebraic equations. Corresponding MATLAB code for each stage of the numerical procedure is provided.

Chapter 3 applied the procedure of Chapter 2 to some problems of practical importance. Firstly, the accuracy of the analysis result was confirmed with a simple example, i.e., a single semi-elliptical surface crack under tension, by comparison with result from earlier work and known extreme cases. Then, more complex cases such as two parallel non-aligned cracks and random array of semi-elliptical surface cracks under tension were analysed.

Chapter 4 proposes two Nearest Neighbour Analysis (NNA)-based procedures as suitable statistical tools to quantitatively characterise the spatial distribution of cracks, defects, or inclusions (henceforth collectively refer to as “defects”). By using these procedures, the spatial distribution of defects can be categorised as ordered, random, clustered, or random with superimposed clusters. The validity of this approach was confirmed by the experimental results for a medium-carbon steel, previously exposed to a mist of 3.5% NaCl solution for a duration of 0.5h to 6.0h. Finally, a new cleanliness rating method for materials exposed to corrosive environment was proposed.

Chapter 5 focused on different practical application area of the techniques developed in this study. The novel multiple 3-D crack analysis procedure was combined with Monte-Carlo simulation approach to propose a new method for material quality assessment, in consideration of the interaction effect of distributed material defects and loading. Pioneering study on when multiple cracks problem can be classified as crack size dominance or crack interaction dominance was reported. Finally, application to corrosion-fatigue prediction model was suggested.

Chapter 6 provided a summary of major findings from this study and suggestion for future research in this area.