THE UNIVERSITY OF ADELAIDE
Department of Mechanical Engineering

Advanced Modelling of the Fatigue of Butt-Welded Structures

A Thesis

by

Ninh T. Nguyen

B.E.(Hons.)(Slovakia), M.E. (AIT, Bangkok)

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ABSTRACT

The effects of various influential weld geometry parameters, residual stresses and the combined axial and bending loadings on the fatigue behaviour of butt-welded steel joints are studied by developing a mathematical model to predict the fatigue S-N curves and fatigue notch factor. This model is broadly based on the principles of Dimensional Analysis, Linear Elastic Fracture Mechanics (LEFM) and Finite Element Analysis (FEA) approaches, Weight Function Technique and Superposition Principles. A dimensional analysis for the prediction of fatigue behaviour of butt joints is carried out by considering the effects of all the important parameters including: weld geometry, welding process, residual stresses and cyclic loading condition. In the present model, only the most influential parameters of weld geometry (tip radius at the undercut, weld toe radius, flank angle and plate thickness), residual stresses at the weld toe and the combined loading ratio (the ratio between the bending and axial loads) are considered.

The fatigue strength and the fatigue life of butt welded joints are found to be strongly influenced by the weld geometry parameters i.e the tip radius at the undercut, weld toe radius, flank angle, plate thickness as well as the misalignments but less strongly influenced by the edge preparation angle. The effect of the flank angle and the weld toe radius is more pronounced than that of the plate thickness. Furthermore, the fatigue test data of welded specimens of different thicknesses are influenced by the combined effect of all the weld geometry parameters, not solely by the effect of the

plate thickness as suggested by the data available in the literature. It has also been found that the fatigue strength of butt welded joints can be improved by reducing the flank angle, increasing the weld toe radius, eliminating the effect of undercut at the weld toe by post-weld grinding or using specific welding techniques which improve weld geometry profile. The flank angle needs to be reduced to less than 20° for a noticeable improvement.

The effect of the induced surface compressive residual stresses on the welded joints for the improvement of the fatigue life is successfully simulated. The study suggests that these processes are effective only in the early stage of crack propagation and up to a crack length corresponding to the depth of the compressive residual stress field. Once the crack has propagated beyond that length, the induced compressive residual stresses have an insignificant effect on the fatigue life. Furthermore, using a relatively low levels of the induced compressive residual stresses would result in an improvement of the same order as those obtained by thermal stress-relieving treatments (e.g. annealing).

Good agreements are found among the predicted fatigue S-N curves, predicted fatigue notch factors, the author's fatigue test results and the experimental data from the literature. Furthermore, the present study provides the basic understanding of the combined effect of weld geometry, residual stresses and the combined loadings on the fatigue behaviour of butt-joints. It also explains the phenomenon of large scatter band associated with fatigue test results and suggests a new procedure for performing and evaluating the fatigue tests which can ensure a reduced scatter band.