Low Cycle Fatigue Estimation of Welded Butt Joints and Weld Treatments Subjected to Cyclic Bending

by

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources a literature used are indicated in the thesis.

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ABSTRACT

In this report a procedure to estimate fatigue life for welded joints under bending load has been presented. The methodology of fatigue life prediction used in this investigation is based on strain-life method. The research carried out within the project develops a method for determination of plastic stress and strain distribution in welded parts by using three-dimensional solid cubic finite elements.

The first part of the research deals with fatigue analysis of a welded butt joint in a cantilever type flat plate under periodic bending load. Elasto-plastic finite element analysis has been carried out for this joint using software ANSYS. The local plastic stress and strain obtained from ANSYS were used in Morrow's modified Manson-Coffin equation and Smith-Watson-Topper damage equation to estimate the number of cycles the weld can tolerate.

One of the most important and influential phenomena in fatigue life prediction is residual stress. The presence of residual stresses in welded parts can noticeably affect fatigue behaviour. Tensile Residual stress generated during the welding process is inevitable. Therefore, applying residual stress as an initial condition in finite element analysis is an important part of the modelling. The stress and strain distributions at critical regions caused by combination of residual stress and loading were obtained for chosen specimens and subsequently used to determine the fatigue life. The effect of residual stress on fatigue life and positive improvement of weld durability against cyclic loads by eliminating of residual stress or converting tensile stress to compressive stress in high cycle fatigue cases are well known and clear but these effects in low cycle cases are less clear and known. The finite element modellings undertaken in this study show that although the presence of tensile residual stress has a significant effect on fatigue life in high cycle cases, in low cycle fatigue situations, it is almost unimportant and negligible. This finding reveals that any effort and cost to eliminate the residual stress or improve it, when the low cycle fatigue is the main problem, would be unnecessary and uneconomical.

The stress concentration is another phenomenon that effects on fatigue life. Any irregularity, discontinuity or abrupt changes in cross section such as holes, notches or angels could change stress distribution so that the common stress equations no longer work to describe the stress field at these locations. Real stress due to stress concentration is higher than nominal stress calculated by regular methods. Stress concentration factor is directly related to the geometry. The materials protruded outside the base plate at the weld zone produce sharp angles between weld material and base plate material which is the main reason of the stress concentration. By removing the material protruding outside the base plate to eliminate the discontinuity angels, it could be assumed that the stress concentration factor has been eliminated and the stress has been reduced, subsequently, the fatigue life has been improved. Grinding is a very common weld finishing and treating method that removes the stress concentration sources.

Comparison between regular weld and grinding finite element models reveals that the stress concentration factor has important effects on both high-cycle and low-cycle fatigue situations so that improving the stress concentration condition by using a grinding process can significantly increase the fatigue life.

In order to compare and validate the predicted fatigue lives by numerical modellings with the experimental data, a series of laboratory tests were performed. Therefore, a fatigue testing set-up was prepared. This set-up consists of a cantilever type flat plate set on a frame and the whole assembly is then installed on a shake table. A loading arm installed to a fixed frame next to the shake table, generated constant amplitudes of bending deflection on the specimens. The experimental testing included two parts. Firstly, fatigue tests were performed for five different loading situations applied on the regular weld specimens. Secondly, the same loading situations were used for welded specimens ground by hand disk grinder. To achieve an acceptable statistical accuracy three samples for each loading were tested. The experimental tests show a good agreement with computational models for regular weld specimens but contrarily, in ground specimen cases the opposite results were observed which would be discussed in the body of the thesis.

PUBLICATION BASED ON THIS RESEARCH PROGRAM

- **“Investigation of Residual Stress Effect on Fatigue Life of Butt Weld Joints Subjected to Cyclic Bending”,** A. Gharizadeh, B. Samali, A. Saleh, 5th Asia Pacific Congress on Computational Mechanics (APCOM2013) 11th-14th Dec. 2013, Singapore. (accepted and presented)

- **“Effect of weld treatments to improve residual stress and stress concentration on fatigue strength”,** A. Gharizadeh, B. Samali, International Journal of Fatigue. (under review)

- **“Experimental and Numerical Study of low cycle Fatigue Life for Welded Butt Joints and Weld Treatments Subjected to Cyclic Bending” ”,** A. Gharizadeh, B. Samali, International Journal of Fatigue. (under review)

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NOTATION

The symbols used in this report, including their definitions, are listed below.

ε_e	Amplitude of the elastic component
ε_p	Amplitude of the plastic component
σ'_f	Fatigue strength coefficient
ε'_f	Fatigue ductility coefficient
E	Modulus of elasticity
N	Number of cycles to failure
b	Fatigue strength exponent
c	Fatigue ductility exponent
$\Delta\varepsilon$	Total strain range
$\Delta\sigma$	Total stress range
σ_m	Mean stress
S or σ_n	Nominal stress
σ_{max} or σ_{peak}	Maximum stress
σ_{min}	Minimum stress
σ_r	Residual stress
ε_r	Residual strain
e	Nominal strain
K_I	*S*tress intensity factor
ΔK_I	Stress intensity range per cycle
β	Stress intensity modification factor
a	Crack length
C	Strain-strengthening coefficient (empirical material constants)

m	Strain-strengthening exponent (empirical material constants)
a_i	Initial crack size
a_c	Final (critical) crack size
K_t	Theoretical stress concentration factor
K_σ	Local stress concentration factor
K_ε	Local strain concentration factor
K_w	Notch stress concentration factor
$K_{t,hs}$	Hot spot stress concentration factor
σ_{hs}	Hot spot stress
σ_{hs}^{m}	Pure axial hot spot stress
σ_{hs}^{b}	Pure bending is hot spot stress
$K_{t,hs}^{m}$	Axial stress concentration factor
$K_{t,hs}^{b}$	Bending stress concentration factor
K_w	Notch SCF due to the weld profile
θ	Local weld angle
ρ	Weld toe radius
t	Plate thickness
BM	Bending moment per unit width
F	Bending load
l	Length
w	Width