Development of Procedure for Improved Fatigue Life Assessment by Prediction of Fatigue Crack Growth in a Residual Stress Field

PUBLISHABLE SUMMARY

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Background

In current fatigue design methods, the residual stress, usually caused by welding, is accounted for by using different sets of parameters (variation of S-N curves with R ratio or Paris' law parameters in BS 7910) to determine the fatigue damage from the loading range. Little quantitative guidance is given on methods for changing the values of the parameters during the assessment in order to account for the variation of residual stresses by proof loading, high fatigue load, or by the change of geometry due to crack growth. This relaxation of residual stresses can reduce the damage caused by subsequent stress cycles. There is a need to quantify this relaxation, which will depend on loading and material behaviour, and to use the updated residual stress value in fatigue assessment.

The aim of this project was to develop a procedure by which the effect of applied loading on residual stress fields could be quantified and thus be used with confidence in fatigue assessments. The findings of this project would save cost and have a positive environmental impact through life extension of existing components, increased safety, and optimisation of designs allowing for savings of material and energy.

TWI Ltd, Granta Park, Great Abington, Cambridge CB21 6AL, UK. Tel: +44 (0)1223 899000

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Objectives

- Obtain fatigue crack growth data for 304L parent metal and 308 weld metal from laboratory test specimens.
- Measure the residual stress after welding in two structural specimen geometries, and obtain fatigue data from these specimens.
- Identify the parameters of an elastic-plastic constitutive law at various temperatures for prediction of residual stresses after welding 304L stainless steel components.
- Determine fatigue damage accumulation relationships in terms of material properties and history of residual stress through an effective stress range.
- Develop an advanced procedure for finite element prediction of residual stress, including stress relief under applied loads, crack growth, and assessment of the associated fatigue life of structures.
- Validate the procedure by comparing predictions with experimental data obtained from structural components of geometry different to that used in the procedure development.

Benefits

- Fatigue assessment with lower conservatism will allow an increase in the tolerable flaw size, or justify increasing the service load.
- Improved accuracy in life prediction will reduce the over-design of engineering structures, whose fabrication will require less material for a lower environmental impact.
- Life extension of installations, whose prediction is based on a known or assumed crack, will be less conservatively estimated, reducing the cost and environmental impact of replacement.

This work will produce evidence to be used for presentation of the assessment method to regulatory bodies and standards organisations

Participants

The Sponsor Group comprised:

- AREVA NP SAS
- Sellafield Ltd
- Rolls-Royce Marine Power Engineering

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Scope of Work

The work combined experimental measurements and numerical analyses. Experiments were carried out on SENB test specimens, butt-welded tubular specimens, and specimens representing a nozzle through a plate joined by two fillet welds. These specimens were fatigue tested under three-point or four-point bending. The materials investigated were 304L stainless steel as parent metal, and 308 as weld metal. Numerical analyses were performed in order to predict the residual stress caused by welding and to calculate the stress intensity factors at crack tips when analytical solutions were not available.

The results obtained from the SENB tests were used for characterising the materials (parent and weld) in terms of crack growth rate. The fatigue test results obtained with both structural specimens were used to produce S-N data, and crack growth rate data. These fatigue tests were conducted with various R ratios, and some involved variable amplitude loading.

Low cycle fatigue tests were carried out in order to determine the behaviour of the parent and the weld, at temperatures varying from 21ºC to 1000ºC. This data was used in finite element models for the prediction of the residual stress fields after welding in the tubular butt weld, and in the nozzle-in-plate specimens. The predictions were validated by measurement of the residual stress near the surface by centre hole drilling.

The crack growth rate data obtained from small scale tests on SENB specimens were used with the calculated residual stress field to determine the effective stress intensity factor that needed to be applied in order to obtain the crack growth rate measured from the structural specimens.

Deliverables

- Literature review on the effect of residual stress on fatigue crack growth, and on the effect of variable amplitude loading.
- Fatigue life and crack growth rate data for the parent and weld materials.
- Data for modelling of the plastic behaviour of the parent (304L) and the weld (308) materials for FE computation of residual stress after welding.
- Guidance on the use of FE analyses for the prediction of fatigue crack growth in a residual stress field.
- Guidance based on the material properties and loading history will also be issued for analytical calculations using either stress intensity factor solutions or nominal stress data and stress concentration factors.

Project Budget

The project had a duration of 3 years and a budget of £200,000. It was funded by 3 Sponsors each making a contribution of £50,000. TWI made an additional contribution of £50,000 from its own funds. The fee for additional companies buying-back into the project results is £50,000.

Further Information

For further information on how a Joint Industry Project (JIP) runs please visit:

http://www.twi-global.com/services/research-and-consultancy/joint-industry-projects/

JIP Co-ordinator: Tracey Stocks

Ref: 19848/12-1/14

Email: jip@twi.co.uk

Project Leader: Philippe Bastid

Email: Philippe.bastid@twi.co.uk