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**Notes:** Paper #47 contained in Parent sysnum #511874
Fatigue Crack Initiation and Growth in A517 SAW Weldments Under Variable Amplitude Loading

by Christopher Bayley¹ and John Porter²

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ABSTRACT

A comparison between experimental and analytical predicted fatigue lives is made for a A517 SAW Weldment subjected to variable amplitude loading. Three, 10 inch wide butt-welded specimens were tested under a variable amplitude load spectrum consisting of 3 yearly storms. The magnitude of the loads in the storm increased and then decreased in a linear manner with the winter storm representing the most severe loading condition. Fatigue crack monitoring was achieved through the use of 20 localized potential drop probes affixed along the length of the weld. Multiple and independent fatigue crack initiation sites were found along the length of the weld. These eventually coalesced and formed a dominant fatigue crack, which led to the eventual failure of the specimens.

Fatigue life estimates using local notch strain and fracture mechanics approaches were obtained. Fatigue crack initiation life estimates using the strain life approach were found to be un-conservative while the estimates of the fatigue crack propagation life were conservative. Accurate knowledge of the structural and weld geometries was found to be critical in the estimation of the fatigue lives.
Fatigue Crack Initiation and Growth in A517 SAW Weldments

By: Christopher Bayley FTL
    John Porter DREA
    May 13 1999

Objectives

- Effects of Variable Amplitude Load Spectrum on Fatigue Crack Initiation, Propagation and Coalescence
- Generate Experimental data on Fatigue Initiation and Propagation
- Compare Experimental and Numerical Fatigue Crack Predictions
Experimental Work

- Material Properties
  - Cyclic Stress/Strain Curves
  - Fatigue Crack Initiation
  - Fatigue Crack Growth

- Weld Residual Stresses

- Variable Amplitude Tests on 10” Wide Specimens

Material

- 10 mm A517 SAW Material Received from Dockyard Labs

- Representative of the Deck Material used in the Halifax Class Patrol Frigates

- Samples
  - 6 Round Specimens
  - 3 Center Crack Panels
  - 3 10” Wide Specimens for VA Tests
Material Properties

Cyclic Stress Strain Curve

\[ \Delta \varepsilon = \frac{\Delta \sigma}{2E} + \left( \frac{\Delta \sigma}{2K} \right)^n \]

- Data Points
- A517/SAW
- A517 Base
- A517/SMAW

Material Properties

Fatigue Crack Initiation

\[ \Delta \varepsilon_{\text{init}} = \frac{\sigma_f N^b}{E} + \varepsilon_f N^c \]

- Data Points
- A517/SAW
- A517 Base
- A517/SMAW

Number of Cycles to Failure
Material Properties
Fatigue Crack Growth

Sample 1 R=0.5
Sample 2 R=0.5
Sample 3 R=0.0

Variable Amplitude Tests
Fatigue Specimens
Specimen Characterization
Specimen Preparation

DREA Provided Material

Extender Plates

SAW Weld

Specimen Characterization
Hot Spot Stress

Normalized Stress ($\sigma_{ac}/\sigma_{nom}$)

Distance From Weld Toe (mm)

- Plate 1
- Plate 2
- Plate 3
Variable Amplitude Tests
Stress Sequences

Specimen Characterization
Residual Stress Profiles
Variable Amplitude Tests
Crack Shape Development

![Graph showing aspect ratio (a/c) vs. (a/t)]

Analytical Approach

- Fatigue Crack Initiation and Propagation Software
  - FALIN and FALPR
- Work Completed by: Dr Gregory Glinka University of Waterloo, Waterloo Ontario
- Stress Life (SN) Approach
- Strain Life (εN) Approach
- Fatigue Crack Growth (da/dN)
Analytical Approach

Stress Life

- BS-5400 ‘D’ Detail Weld Transverse to Principle Stress dir.
- Miner’s Summation used to sum damage from individual cycles
- Significant Damage Caused by Small Stress Ranges

Analytical Approach

Strain Life

- Local Strain Approach accounts for:
  - Geometry of the notch
  - Angular Distortion and Straightening of Plates
  - Membrane and Bending Components
  - Residual Stress State
  - Hot Spot Stress
Analytical Approach
Fatigue Crack Growth

- Fatigue Crack Growth based on SIF and cycle by cycle integration
- Local Geometry affects included in SIF
- Model includes Variation in Membrane and Bending Stress
- FCR of a Single Semi-Elliptical Flaw

Results
Experimental & Numerical

![Graph showing Storms to Initiation versus Hot Spot Stress]

- Plate 1
- Plate 2
- Plate 3

\( e - N R = 0.5 \text{ mm} \)
\( e - N R = 0.4 \text{ mm} \)

S-N
Results
Experimental & Numerical

<table>
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<tr>
<th>Storms to Failure</th>
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<tr>
<td>100</td>
</tr>
<tr>
<td>75</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>25</td>
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- Plate 1
- Plate 2
- Plate 3
- a/c=1.0
- a/c=0.1

Hot Spot Stress

Conclusions
Numerical

- S-N VERY Conservative
- ε-N Over-Predicts Fatigue Initiation
  - Requires detailed information specific to each geometry
- Fatigue Crack Growth
  - Conservative if omit Retardation effects
Conclusions
Experimental

- Fatigue Crack Initiation accounts for 70% of Total Fatigue Life

- Variable Amplitude Loading affects the Number of Initiation Sites

- Fatigue Life Affected by:
  - Hot Spot Stress Concentration
  - Notch Geometry
  - Angular Distortion of Specimens
  - Load Spectrum

Recommendations
Future Research

- Determine the influence of weld shape and residential strains on the fatigue performance of butt welded joints

- Variable and Constant Amplitude Tests

- Weld Toe Improvements and Fatigue Life

- Examine Agreement between Numerical Predictions and Experimental tests