Fatigue life prediction of welded joints at sub-zero temperatures using modified Paris-Erdogan parameters

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Abstract

The fatigue life of welded steel components is usually determined by the weldment; in these cases, fracture mechanical approaches are widely used for their prediction. Ferritic steels are known to have a fatigue strength that is dependent on temperature. Therefore, this study evaluates fatigue tests of cruciform joints and transverse stiffeners at different sub-zero temperature levels, with regard to fatigue life. Simultaneously, the stress intensity factors over the crack length are calculated for the individual experiments using analytical solutions. Then, using the Paris-Erdogan relation with temperature and material adjusted C and m parameters as well as tabular values, the fatigue lives are calculated with analytical solutions and compared with the experimental results. It is shown that, the prediction accuracy is significantly increased for the sub-zero temperature range by using temperature-adjusted Paris-Erdogan parameters, as long as the temperature are above the fatigue transition temperature.

1. Introduction

For the installation of offshore wind turbines off the coasts of the Nordic countries; the harsh climatic conditions must be taken into account in the design and dimensioning of the structures. It is known that the material properties, including fatigue behaviour, of ferritic steels and their weldments at sub-zero temperatures differ from those at room temperature (RT). The main concern of design guidelines for structures made of ferritic steels at sub-zero temperatures is the safety against brittle fracture. But in procedures, there are no comprehensive recommendations regarding the changes in fatigue behaviour at sub-zero temperatures. E.g., the Lloyd's Register FDA ICE Fatigue Induced by Ice Loading procedure, states that fatigue strength of welded joints is not lower than at RT and the same design curves can be used. However, there is an increasing number of publications which show that the fatigue crack growth rate of ferritic steels decreases with temperature until a so-called fatigue transition temperature (FTT) is reached. Accordingly, using the same design curves as RT for sub-zero temperatures levels ignores the beneficial effects on fatigue life above the FTT and results in the over-dimensioning of the structures. The aim of this study is to examine whether the prediction accuracy can be improved in the sub-zero temperature range by using temperature-adjusted Paris-Erdogan parameters.

2. Results

The procedure used in the study is described below:

a. Determination of the weld geometry of transverse stiffener and cruciform joint specimens using laser triangulation.
b. Experimental determination of fatigue lives under CA loads at $R = 0$ at a temperature level of RT, -20°C or -50°C.
c. The stress intensity factor (SIF) ranges have been determined for each sample using analytical standard solutions and the local geometries.
d. Prediction of fatigue lives using SIF ranges and Paris-Erdogan parameters, both from standards and from temperature- and material-specific parameters
e. Comparison of predicted and experimentally determined fatigue lives. To compare the prediction accuracy of the test series, first-order best-fit lines are generated using the least-squares method, see Fig.1.
f. To assess whether the prediction accuracy of the adapted parameters has changed compared to the not-adapted Paris-Erdogan parameters, the standard deviations (SD) have been evaluated, see Tab. 1.

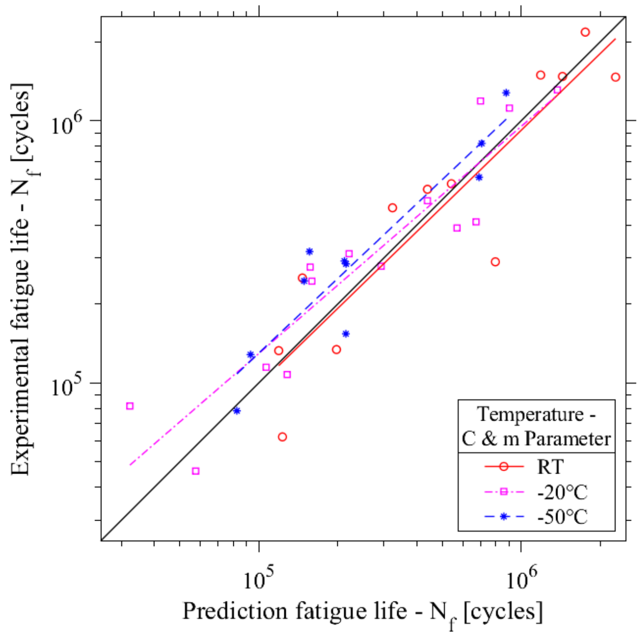

Fig.1 – : Comparison with the experimental fatigue lives conducted at three temperature levels using one Paris-Erdogan parameter set obtained from room temperature tests for S500 steel specimens

Tab.1 – : Standard deviation with adapted and non-adapted Paris-Erdogan parameters from the best fit line for RT

Weldment type	Material zone	Exp. Temp.	SD_{na}	SD_a	SD_{na}/SD_a
Cruciform joint	Weld material	-20°C	0.1711	0.1795	0.95
		-50°C	0.1843	0.1575	1.17
Transverse Stiffener	Base material	-20°C	0.0819	0.0791	1.04
		-50°C	0.1666	0.1416	1.18

3. Conclusions

For the specimens of S500, the fatigue lives have increased with decreasing temperature. By using the Paris-Erdogan parameters for RT, the predicted fatigue lives have become more conservative, i.e., the prediction accuracy has decreased. At -20°C, the temperature related effects were not measurable for the S500 material, therefore no improvement of the prediction accuracy was achieved with the adapted parameters. For the temperature level of -50°C, however, a significant improvement of the prediction accuracy was shown for both the cruciform joints and the transverse stiffeners, see Tab.1.