PROBABILISTIC STRUCTURAL INTEGRITY ASSESSMENT OF WELDED JOINTS

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Abstract

The fatigue assessment of welded joints requires several input data, which can be subdivided into three categories: geometry, material and loading. The number of input data depends essentially on the complexity of the models employed and on the level of accuracy of the analysis. It is common practice to use safety factors in design to account for the scatter of the input parameters. Nevertheless, overly-conservative factors lead often to unrealistic estimations of fatigue life. This work presents a fracture mechanics-based model for the structural integrity assessment of welded joints under constant amplitude fatigue loading, in which the local geometry at the weld toe and the fatigue crack growth properties are considered statistically distributed. The approach is validated against a large number of experimental data.

1. Introduction

The application of fracture mechanics to the fatigue assessment of welded joints was first proposed by John Maddox from TWI in the seventies [1]. Since then, countless studies have been published on this topic and fracture mechanics-based procedures have been included in recommendations and guidelines for the fatigue design of welded joints [2]. Nevertheless, these approaches suffer from several modelling simplifications that limit their application. In particular, three aspects are considered to be critical: i) linear fracture mechanics is employed in the calculation of the crack driving force, even for small cracks, for which the plasticity-induced effects must be taken into account; ii) the phenomenon of the multiple crack initiation and interaction is ignored; iii) the scatter associated to the local geometry at the weld toe and the crack growth properties is not considered.

The *post-mortem* analysis of the fracture surfaces carried out in a recent work [3] revealed that multiple cracks initiate at micro-notches along the weld toe and that a large portion of the fatigue life of the joints is spent in the short crack propagation regime (see Fig. 1).

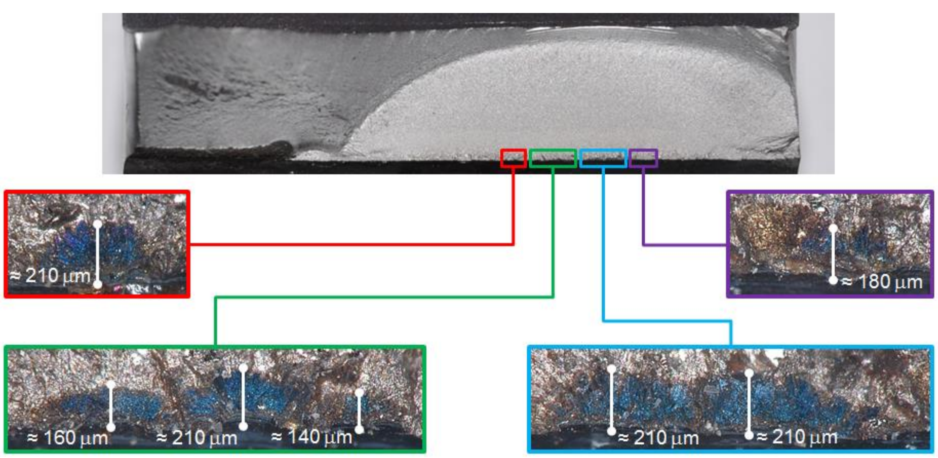

Fig.1 – Small surface fatigue cracks at the weld toe of a cruciform welded joint made of medium strength steel (S355NL) under constant amplitude pulsating loading [3]. The cracks have been marked by means of heat-tinting at about 40% of the total life of the joint.

Based on the experimental observations, a fracture mechanics-based procedure for the fatigue life assessment of welded joints was developed accounting for the following aspects: i) adequate description of the crack driving force in the mechanically short crack regime, where the linear elastic ΔK was replaced by an elastic-plastic crack tip parameter such as the cyclic J-integral (ΔJ); ii) the gradual build-up of the crack closure effect in the mechanically short crack regime was experimentally determined and modelled; iii) statistical distributions of the local geometry at the weld toe and the crack propagation data were determined.

2. Results

The distributions of the fatigue lives and fatigue limits for different joints were obtained by Monte Carlo simulations. Due to the geometrical irregularity of the weld toe, it was decided to partition the weld toe into a finite number of equidistant independent stripes, each one containing a single crack. To reproduce the variability of the local geometrical parameters, the weld toe radius ρ, the flank angle α and the depth of the secondary notch k were determined by random sampling from their statistical distributions per stripe. A new geometry was generated, as well as new crack growth parameters were randomly extracted per each simulation. Partitions were merged when two or more cracks grew to form a new larger crack.

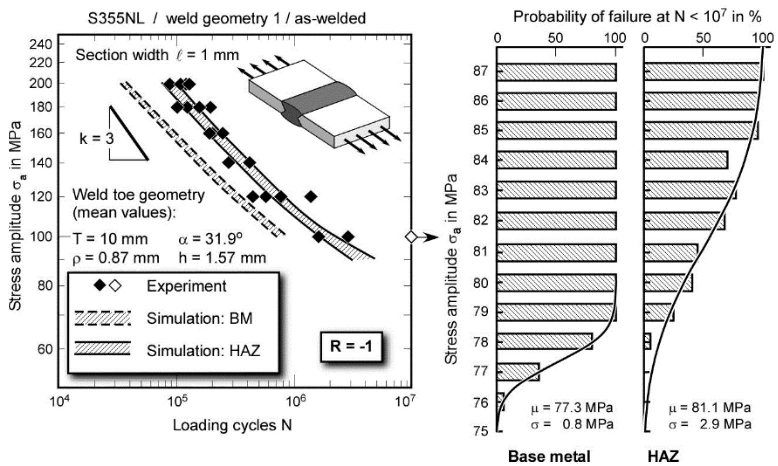

Fig.2 – Fatigue strength predictions in case of a butt-weld made of S355NL in as-welded condition at R = -1. Simulations performed with using base material (BM) and heat affected zone (HAZ) properties.

The model was able to provide good predictions both in the finite life and endurance limit regime for most of the simulated joints and materials. An example is provided in Fig. 2 for a butt-weld made of S355NL

3. Conclusions

Fracture mechanics proved to be a powerful fatigue assessment method for welded structures when short-crack propagation, multiple crack growth and coalescence, and local geometrical features are considered. The statistical description of the input variables enabled the prediction of the experimental distribution of fatigue lives,

References

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