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Numerical simulation of a cylindrical fatigue specimen loaded under mixed-mode conditions

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Although a significant number of service failures occur due to the fatigue crack propagation under mixed-mode loading conditions, this area is still relatively unexplored [3]. That is why study of mixed mode fatigue crack propagation has become much more relevant recently. The mixed mode crack behaviour is also the subject of this paper. It is focused mainly on numerical modelling of cylindrical fatigue specimen containing small cracks, loaded under mixed mode conditions. The simulation results are needed to successfully evaluate experimental measurements of crack propagation in the cylindrical fatigue specimens made of the austenitic stainless steel 316L. Some of the experimental data are also presented in this paper. Comparison of mixed mode results and pure mode I data is also carried out.

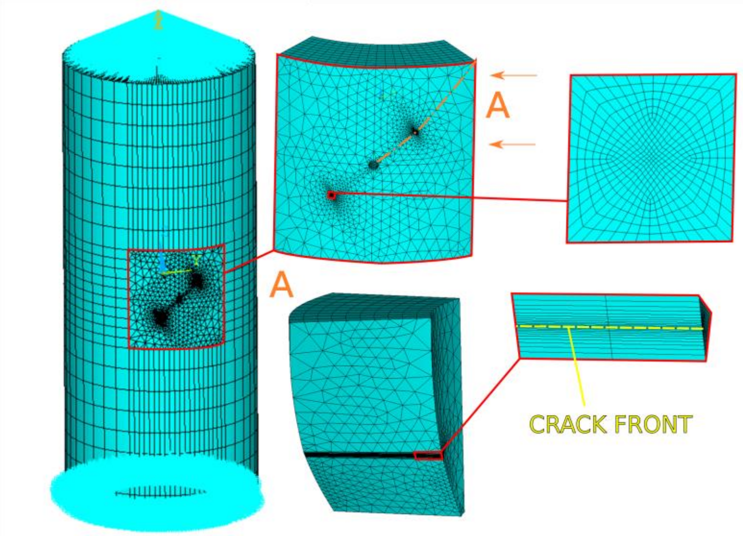

Fig. 1. Meshed model with boundary conditions and details of mesh

It is important to note that cracks that are dealt with in this paper belong to short cracks area of fracture mechanics [4]. In case of short cracks, large scale yielding conditions at the crack tip are typical. Therefore, linear elastic fracture mechanics cannot be applied [2] and non-linear fracture mechanics approach has to be used. Therefore, in our case, the parameter describing the fatigue crack growth rate is the plastic part of the J-integral, see [1].

A numerical model of the cylindrical fatigue specimen with cracks was set up to calculate J-integrals of cracks at several crack lengths. An important aspect of numerical model concerning fracture mechanics was the quality of the mesh. Very fine mesh had to be created in the close vicinity of the crack tip. Meshed specimen with boundary conditions, zoomed details and cross sections can be seen in Fig. 1. The boundary conditions of the model were set up to simulate torsional loading. Upper surface was loaded by structural displacement – rotation around Z axis (see Fig. 1). Bottom surface was fixed.

The numerical model was solved twice for every crack length – at first using a simple linear elastic material model and then again with an elastic-plastic multilinear model based on cyclic stress-strain curve of the 316L steel. After solving the numerical models, J-integral could be calculated along the crack front. The plastic part of J-integral was evaluated as the difference between J-total (elastic-plastic problem) and elastic part of J-integral (linear elastic problem). Finally, the results of the simulation were used to calculate plastic part of J-integral of crack lengths measured in the experiments on real specimens. Plastic part of J-integral was then used for description of crack growth rate and compared with pure mode I data, see Fig. 2.

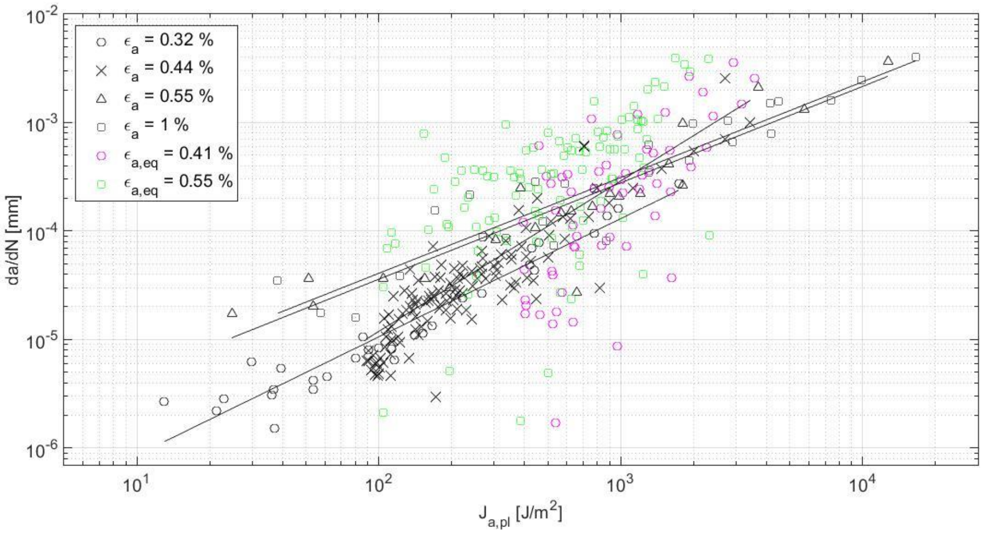

Fig. 2. Comparison of crack growth rates for mixed mode (purple, green) and pure mode I (black)

Conclusion: Numerical model was created in order to calculate the J-integral, which was afterwards used for description of the crack growth rate under mixed mode loading. Results were compared with pure mode I data [1]. Two sets of data with equivalent strain 0,41% and 0,55% was calculated. Obtained data indicate a significant amount of similarity compared to the pure mode I results.

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