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BIAXIAL LOADING IMPACT ON FATIGUE CRACK PROPAGATION IN METALLIC MATERIALS

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Abstract
Multiaxial fatigue testing generates curved cracks that are extremely difficult to characterize using standard compliance based and potential drop-based methods. Therefore, an automated online system was developed to monitor the crack tips positions in plate cruciform specimens. The system periodically evaluates the deformation fields at small areas around the crack tips by performing digital image correlation (DIC) on images obtained by a moving camera triggered at desired phases of the loading cycle. The displacement field obtained by DIC is fitted by a simple model that specifies the crack propagation direction and enables it to iteratively find new crack tip positions. Moreover, the model is capable of computing the crack opening displacements near the crack tip and thus characterizes the local loading. This approach enables fully automated multiaxial testing with controlled crack length and crack tip loading. The method was successfully tested on an AA5754 aluminium alloy sheet..

1. Introduction

The biaxial fatigue is recognized as an important loading mode of engineering structures, despite the difficulties the contemporary fracture mechanics has with its description. From the time fatigue of materials was discovered by Wöhler and other pioneers, many attempts to measure and describe fatigue crack growth under multiaxial loads were performed. It appears, that the crack driving force is characterised by a simple time course of crack plane normal stress σ_N and its tangential shear stress τ_N seen at the crack tip. In terms of harmonic loading, these quantities may have different amplitudes, mean values and phase shifts and all these quantities depend on the crack orientation and loading protocol. This complexity of the phenomena in many cases does not enable to give direct answers to the two basic questions: What is the suitable driving force to characterize the loading ? What shape will the crack path have for a given multiaxial loading type ?

2. Results

The stress intensity factors KI and KII for both cracks wre calculated using the fracture analysis module of Ansys WorkBench 2021R1 (Ansys Inc, Canonsburg, PA, USA) using the appropriate crack tip elements. A table of design points was created to define a matrix of left and right crack lengths. For each couple (a_l;a_r), the geometry and the mesh were automatically updated and the corresponding values of stress intensity factors were
calculated.

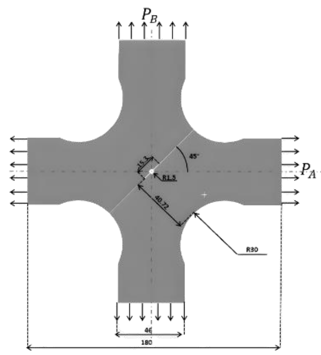

Fig.1 – Specimen drawing.

The specimen is submitted to a biaxial tension: P_A and P_B denote the applied force in the A and B cylinder pairs. The material properties typical to of Al alloys, i.e. $E = 70GPa$ and $\nu = 0.33$ were used.
The resulting shape functions for straight cracks are plotted in Fig. 2. The difference of crack length $\Delta a = a_s - a_p$ of $-1mm$ and $1mm$ are shown. Clearly, the effect of the secondary crack is highest at low crack length, then it virtually disappears at $a/h \approx 0.6$ and it again appears at high crack lengths.
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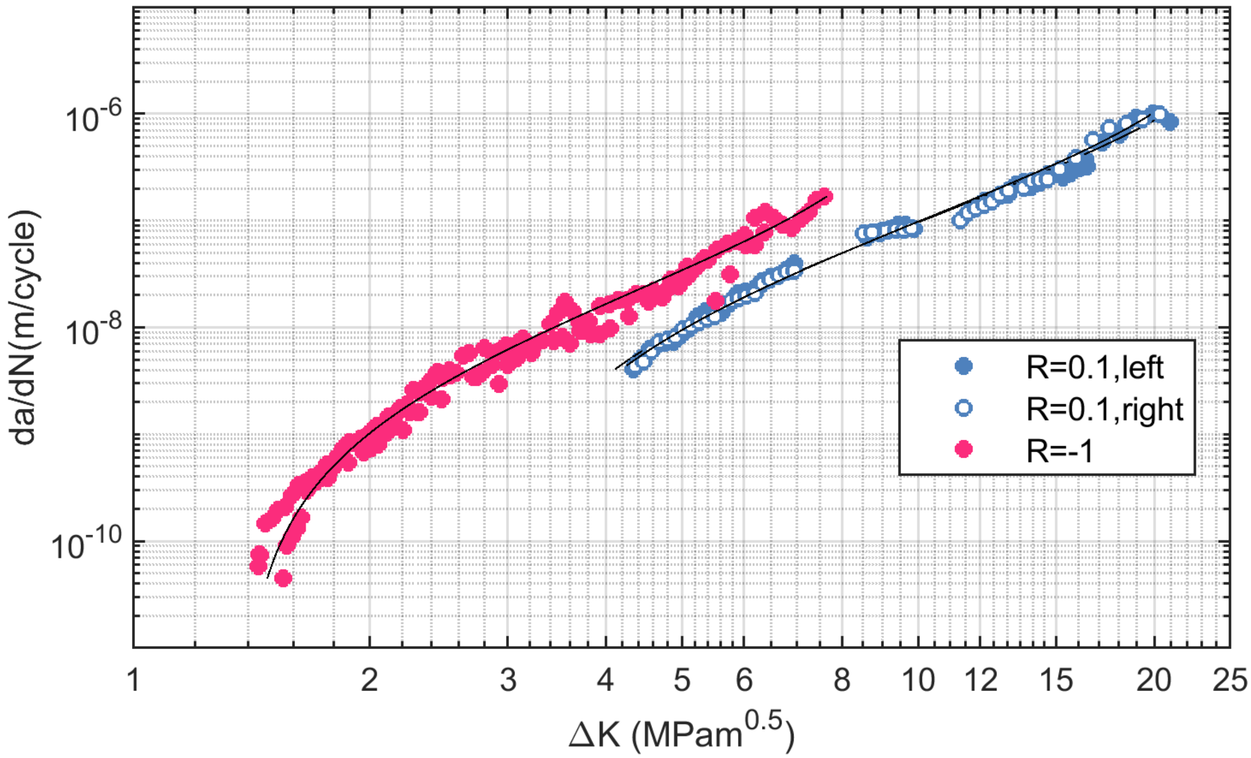

Fig.2 – Fatigue crack growth rate of left and right crack in the 5754 aluminium sheet loaded in biaxial proportional loading at R = 0.1. The same material, tested in bending at R = −1 is included for reference.

3. Conclusions

The DIC based crack automated crack tracking system was developed and used by obtaining fatigue crack growth rate curves of 5754 aluminium alloy under proportional biaxial loading. The system provides on-line data on crack tip position during the fatigue test and such data can be used to control the experiment by adjusting loading in order to obtain desired crack driving force gradient or to reach predefined crack path. Reaching predefined crack path will enable the pre-computation of the crack driving force before the test and may significantly increase the possibilities of biaxial testing of cruciform specimens.

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