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Procedia Engineering 2 (2010) 2021–2026

Procedia Engineering

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Fatigue 2010

Fatigue crack growth and closure behaviour under multiaxial loading

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2 March 2010; revised 10 March 2010; accepted 15 March 2010

Abstract

The three dimensional finite- element analysis of fatigue crack growth and closure was used to investigate crack- opening and closure stresses of elastic-perfectly plastic Aluminium 2024 alloy under constant amplitude crack extensions.. The 3D analysis was applied to the middle-crack specimen with a specified thickness value under multiaxial and uniaxial loadings. Then, crack-opening and closure stresses and the v-displacements of nodes on the crack surface plane for both multiaxial and uniaxial cases were investigated.
The finite element analysis was developed using isoparametric eight nodded hexahedron elements.
The plasticity part of the program uses initial stress approach. In the analysis, the crack was advanced one element size as the applied load reached the maximum Value of each load cycle.

Keywords: finite-element, elastic-plastic, cracks, opening stress crack closure, multiaxial loading.

1. Introduction

Cracks grow in a three dimensional manner in engineering materials. This growth behaviour is affected by the closure of crack-surface plane which depends on the state of stress. The closure behaviour is associated with the plastic deformation left at the vicinity of the cracked body.

Microscopically, the plastic deformation is furnished by means of dislocation movement in the highly stressed region of the material. Since the discovery of closure by W. Elber [1], many researchers and experimentalists, have devoted so much effort to investigate the closure behaviour of metallic materials for a number of decades.

The works of many researchers have shown that closure under plane stress is much larger than that under plane strain conditions. The closure behaviour for a three –dimensional cracked geometry varies along the crack front and depends on the crack geometry, crack size, stress level and imposed boundary conditions. The three- dimensional closure behaviour of finite thickness plates for different cracked geometries are investigated under both constant and variable amplitude loading [2-16].

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doi:10.1016/j.proeng.2010.03.217

Multiaxial fatigue theorem, models, tests and applications are fully described in a practical useful book by D.F. Socie and G.B. Marquis [18].

As mentioned above, numerical works mostly emphasizes on the uniaxial type of loading. The aim of this study was to investigate the growth behaviour of engineering components under multiaxial loading because of importance of this phenomenon in the industry.

2. Specimen Condition and Loading

The three-dimensional middle- crack specimen Fig. 1 was used under constant amplitude crack extensions with R-ratio (0.1) and stress level of 105MPa. The dimensions of the specimen was b=38.1mm, h=76.2mm. The crack was extended one element size (0.02 mm) at the maximum applied stress of each load cycle. The initial crack length was 18.57 mm. The modules of elasticity E was 70000 MPa, Poisson ratio was 0.3 and the effective yield stress was 345 MPa (Aluminium 2024 Alloy).

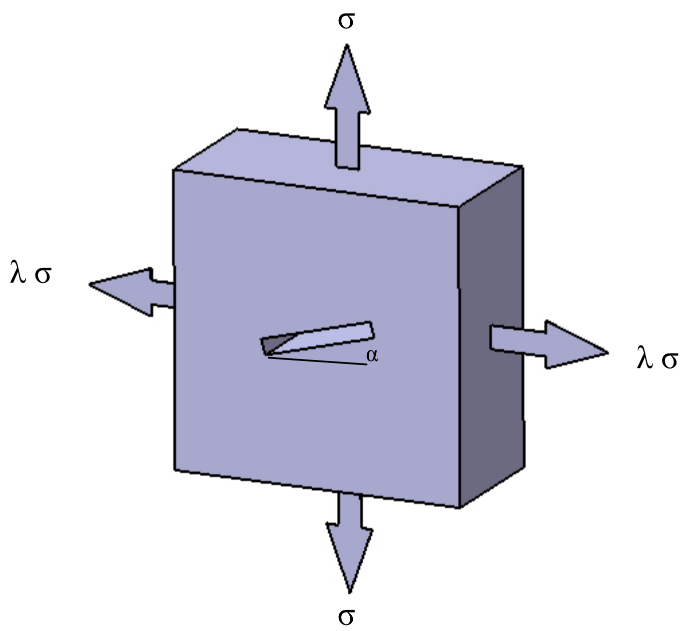

Fig. 1. Multiaxial geometry and loading

The finite element idealization of specimen is shown in Fig. 2. The finite-element mesh in the z=0 plane, is shown in Fig. 3.

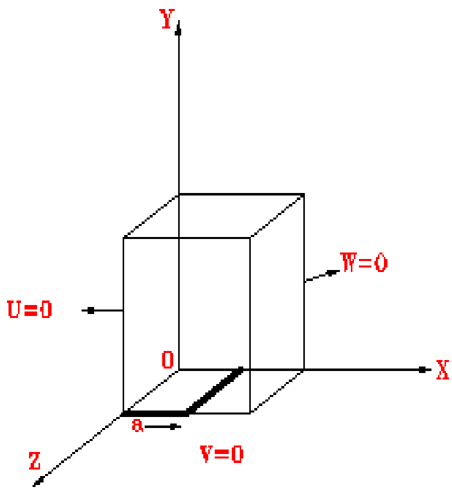

Fig. 2. 1/8 of the middle-crack tension specimen analysis.

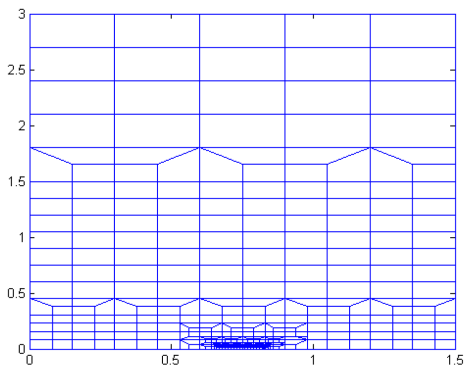

Fig. 3. Specimen idealizations in x-y plane.

3. Results

The three-dimensional finite element model was subjected to the middle crack specimen under both multiaxial and uniaxial conditions ($\lambda = 1$, $\lambda = 0$).

The initial crack length for both multiaxial and uniaxial loadings was 18.57mm.

The model was fatigued for forty cyclic loads. The load at initial yield.

For the case of multiaxial loading was 11.7 MPa. The model was further loaded until the maximum applied stress was reached (105 MPa).At this stress level, the nodes on the crack front were released incrementally and crack was advanced one element size.

Upon unloading, the exterior node on the crack surface plane was closed at stress level of 60.50 MPa. Upon further loadings, the nodes towards the interior were closed and opened during reloading portions of cyclic loads. This procedure was repeated for almost forty cyclic loads.

Crack opening and closure stresses of nodes on the crack surface plane for reloading portion of cycle thirty was investigated as shown in right side of Fig. 4.

Crack opening displacements of the first nodes on the crack surface plane for both multiaxial and uniaxial cases are shown on the left and right sides of Fig. 5, respectively.

The model was subjected under uniaxial case at which alpha=0 (σ_x=0).For this case, the load at initial yield was 11.60 MPa.

The model was further loaded until the maximum applied stress was reached(105 MPa).At this stress level, the nodes on the crack front were released incrementally and crack was advanced one element size.

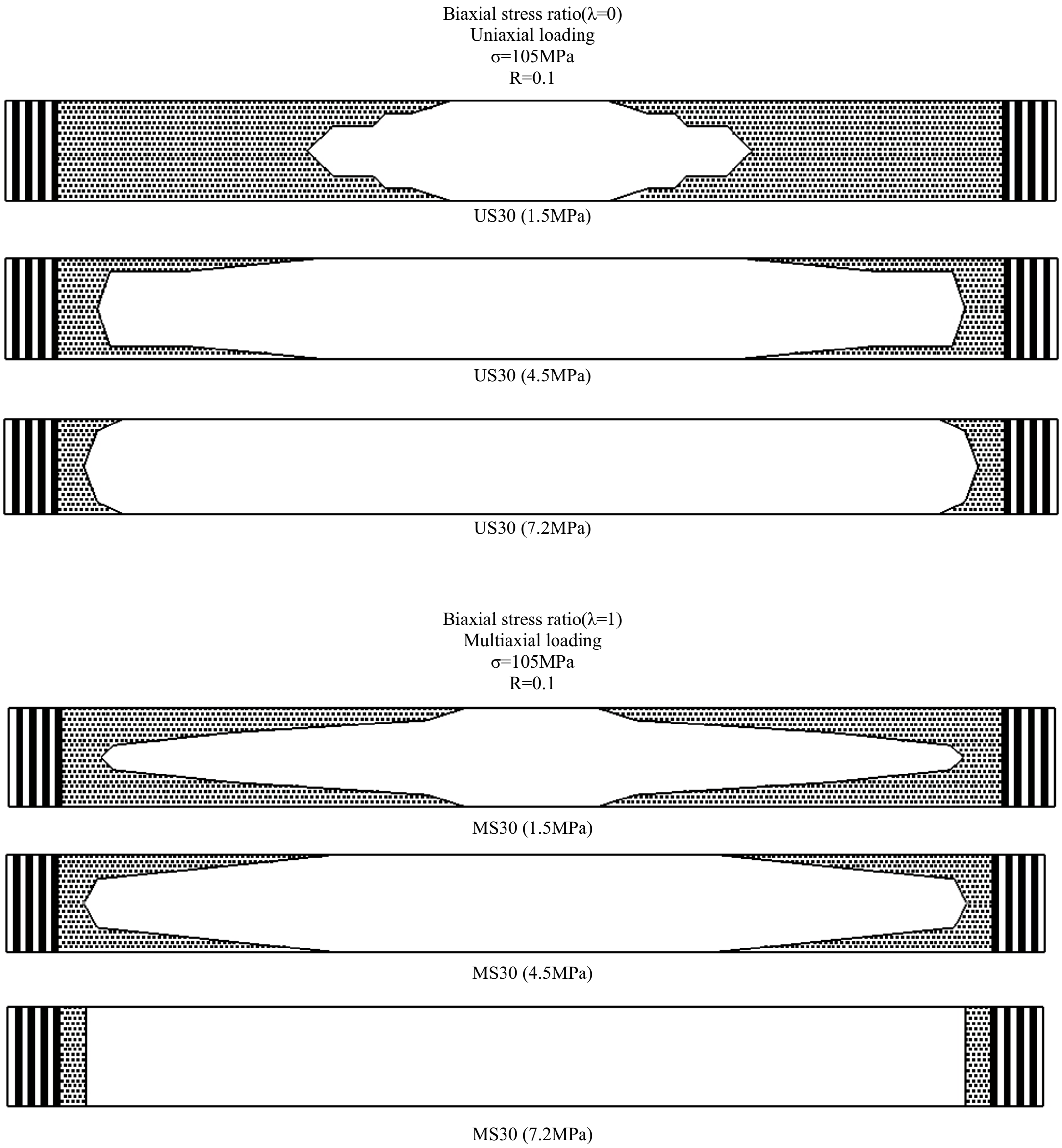

Fig. 4. Variation of crack opening and closure stresses of nodes on the crack surface plane for reloading portion of load cycles after thirty cyclic crack extensions.

Under model crack extensions, the plastic zone size of multiaxial loading will decrease with increasing λ(18). The work is under way for the different cases of alpha orientations and biaxial stress ratios (λ).

Then, the model was unloaded. During unloading, the node on the exterior region closed at stress level of 58.30 MPa. The multiaxial procedure was repeated for uniaxial case for almost forty cyclic loads. The crack opening and closure stresses of nodes on the crack surface plane for reloading portion of cycle thirty is investigated as shown in the right side of Fig. 4.

Multiaxial loading uniaxial loading

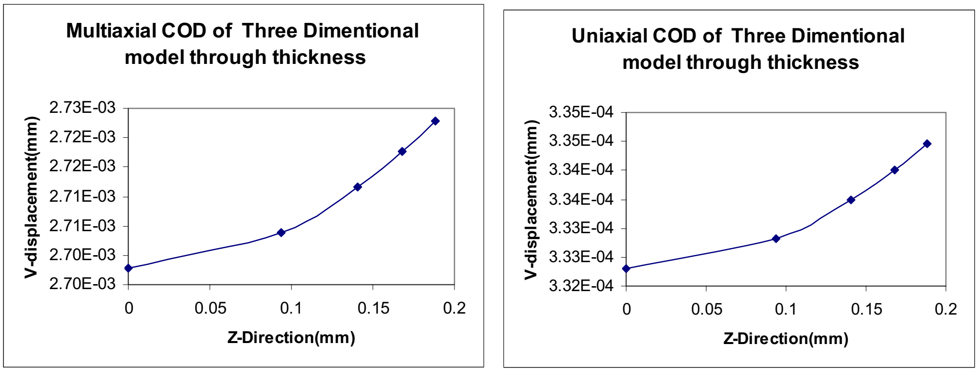

Fig. 5. Crack opening displacements for multiaxial and uniaxial loadings.

4. Conclusions

The finite element model was subjected to both multiaxial and uniaxial crack extensions under constant amplitude crack extensions for stress level of 105MPa under R-ratio of 0.1.Based on the above analyses, the following conclusions can be made.

The crack closure stresses of multiaxial case are lower than that of uniaxial case due to the effect of biaxial stress ratio(λ).Therefore, the crack growth rate is faster in the multiaxial components of engineering materials.

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