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Research article

Crack behavior investigation and crack opening stresses for plane stress, plane strain and 3D cases

Rahmat Ghadimi Chermahini[1,*], Majid Jabbari[2]

[1]*Mobarakeh Steel Research Center, the core of fatigue and fracture in solids*
[2]*Department of Mechanical Engineering, Khomeinishahr Branch, Islamic Azad University, Isfahan, 84175-119, Iran*

[*]Rgcher31@gmail.com

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Abstract

Two and three dimensional finite element programs of fatigue crack growth and closure were applied to multi axial elastic perfectly plastic aluminum 2024 alloy under constant amplitude crack extensions. Crack opening and closing stresses of nodes on the crack surface plane were investigated for different stress ratios and thicknesses for the desired unloading and reloading portions of load histories. The finite element programs incorporate linear strain isoperimetric rectangular and cubic elements. The plasticity part of the analysis uses initial stress approach under small strain assumptions. The crack was extended one element size as the applied load reached the maximum stress of each load cycle. The variation of local stresses at the crack tip plus the behavior of v-displacements of nodes on the crack surface plane are also investigated. The results show that the closure behavior of multiaxial loading is lower than that of uniaxial case. The magnitude of maximum shear stress at the crack tip of multiaxial case which is lower than that of uniaxial loading. The crack growth in the axial mode will be slower than in the multiaxial mode.

Keywords: Finite elements, Crack growth, Crack closure, Plasticity, Opening stresses.

1- Introduction

Fatigue cracks are always a major problem in engineering components. The growth behaviors of such cracks are affected by the closure of crack-surface plane which depends on the state of stress, loading, and imposed boundary conditions.

The ground vehicle components are mostly subjected to multiaxial loading. The survey shows almost 80 percent of fatigue life of these components is due to multiaxial loading. Because of importance of this phenomenon in industry, so much work both theoretically and experimentally are devoted to this subject. The closure behavior of some three-dimensional cracked bodies are investigated under both constant and variable uniaxial loading [1-10].The multiaxial three- dimensional loading is investigated for R-ratio of 0.1 Under stress level of 105 MPa [11]. Vikram and Kumar[12] showed that fatigue life has been considered to be composed of three phases crack initiation, crack propagation and final failure. Sedmak [13] presented that XFEM is discussed in respect to its accuracy and efficiency. It was concluded that XFEM is a versatile tool for simulation of FCG, providing an excellent option for precise and reliable fatigue life of a cracked component.Wu et al.[14] showed that the newly-developed iLAPS model can simulate the entire crack growth region as like modified NASGRO does. Bergara et al. [15] presented that the capabilities of the XFEM-based LEFM approach to simulate fatigue crack growth in complex crack fronts are validated. Alshoaibi et al. [16] discusses the latest developments in FEM, including the Extended Finite Element Method, Cohesive Zone Modeling, Virtual Crack Closure Technique, Adaptive Mesh Refinement, Dual Boundary Element Method, Phase Field Modeling, Multi-Scale Modeling, Probabilistic Approaches, and Moving Mesh Techniques. Neto et al[17] showed that the crack propagation in the compressive residual stress field produced a decrease in the FCG rate. On the other hand, without the contact of crack flanks, the TRS showed no effect on FCG. Therefore, the TRSs only affect FCG by changing the crack closure level.

The purpose of this study is to use two and three dimensional finite element analysis to investigate the closure behavior of nodes on the crack surface plane under constant amplitude crack extensions for different R-ratios. The aim is to construct the stabilized crack opening stresses as a function of specimen thickness under plane stress,plane strain and 3D analysis. The variation of local normal stresses and the V-displacements of nodes on the crack-surface plane after thirty cyclic crack extension are investigated.

2- Specimen Configuration and Loading

The three-dimensional middle-crack specimen Fig. 1 was used under constant amplitude crack extensions with different R-ratios (0. .. 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 (0.02mm) at the maximum applied stress of each load cycle. The initial crack length was 18.57mm. The modules of elasticity E was 70000 Mpa, Poisson ratio was 0.3 and the effective yield stress was 345Mpa (Aluminum 2024 Alloy). The finite element idealization of specimen is shown in Fig. 2. The element size at the crack position is 0.02 mm.

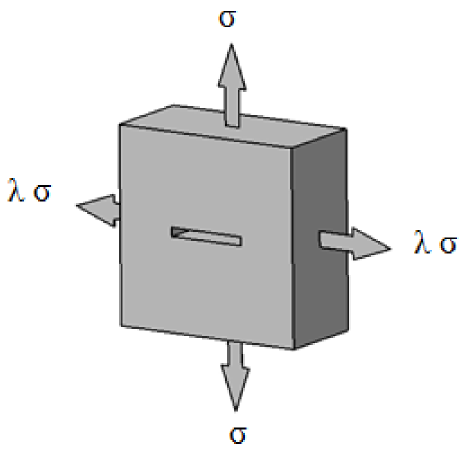

Fig. 1 Three-dimensional finite element model subjected to multiaxial loading

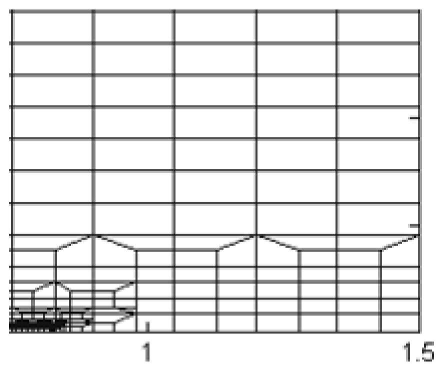

Fig. 2 Specimen idealizations in x-y plane (symmetry model)

3- Results and discussion

The two and three –dimensional finite element meshes were used under forty cyclic crack extensions under uniaxial and multiaxial cases with initial crack length of 18.57mm for plane stress, plane strain and three–dimensional analysis as follows. The analysis was performed using Fortran programming language. The boundary conditions were created as symmetry conditions. The mesh size was selected based on creating the best element shape and the final convergence result is presented.

-PLANE STRESS ANALYSIS

The two dimensional mesh was subjected to forty cyclic crack extensions with initial crack length of 18.57mm for stress level of105MPa under R-ratio of 0.1.

The loads at initial yield for uniaxial and multiaxial analysis were 9.324MPa and 9.338MPa, respectively.

The two dimensional mesh was again subjected to forty cyclic crack extensions with initial crack length of 18.57mm under stress level of 105MPa under R-ratio of 0. The loads at initial yield for uniaxial and multiaxial analysis were 9.324MPa and 9.338MPa, respectively.

-PLANE STRAIN ANALYSIS

The two dimensional mesh was subjected to forty cyclic crack extensions with initial crack length of 18.57mm for stress level of 105MPa under R-ratio of 0.1. The load at initial yield for uniaxial and multiaxial analysis were 11.746MPa and 11.9MPa, respectively.

The two dimensional mesh was again subjected to forty cyclic crack extensions with initial crack length of 18.57mm under stress level of 105MPa under R-ratio of 0. The loads at initial yield for uniaxial and multiaxial analysis were 11.746MPa and 11.9 MPa, respectively. Crack-opening stresses of the above cases as a function of cycle are shown in Fig. 3.

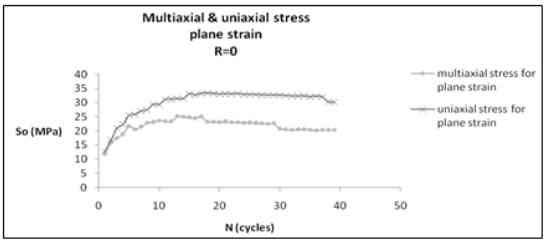

Fig. 3 crack opening stresses as a function of cycles

-THREE_DIMENSIONAL ANALYSIS

The three dimensional analysis was composed of four layers having different thicknesses to take into account the states of plane stress and plane strain conditions for the exterior and interior regions of the model. The model was subjected to stress level of 105MPa under R-ratio of 0.1.The load at initial yield was 11.70MPa for the element situated on the exterior region. The model was fatigued under forty cyclic crack extensions. The unloading and reloading portions of cycle thirty was investigated to show crack closure and opening stresses of nodes on the crack surface plane. The variation of crack closure and opening of nodes on the crack surface plane for multiaxial case is shown in Fig. 4. The model again was subjected to stress level of 105MPa under R-ratio of 0. The load at initial yield was 11.7MPa for the element situated on the exterior region. The model was fatigued under forty cyclic crack extensions. The unloading and reloading portions of cycle thirty were investigated to show crack closure and opening stresses of nodes on the crack surface plane. The variation of crack closure and opening of nodes on the crack surface plane for multiaxial case is shown in Fig. 5. The variation of stabilized crack opening stresses as a function of thickness for uniaxial and multiaxial under stress ratio of 0.1 is shown on Fig. 6. With referring to the above curves, the level of closure stresses of multiaxial loading is lower than the uniaxial one due to the presence of landa coefficient which consequently results in a lower shear stress at the crack tip.

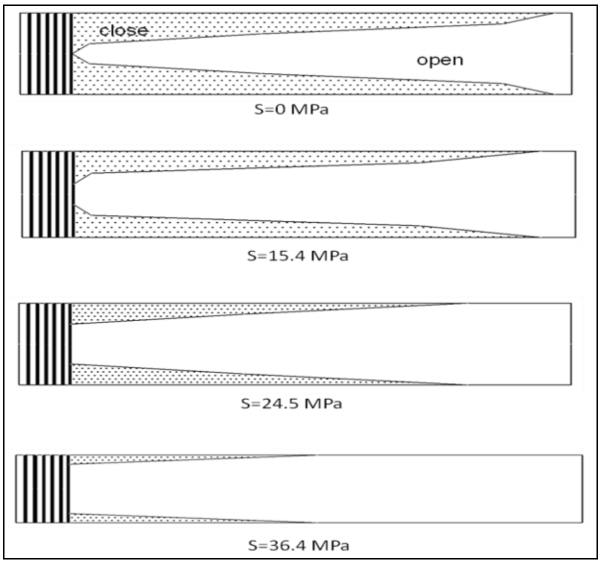

Fig. 4 Variation of crack-opening and closure stresses of nodes on the crack-surface plane for reloading portion of load cycles after thirty cyclic crack extensions.(Multiaxial loading(λ=1), 3D analysis, Smax=105MPa, R=0.1)

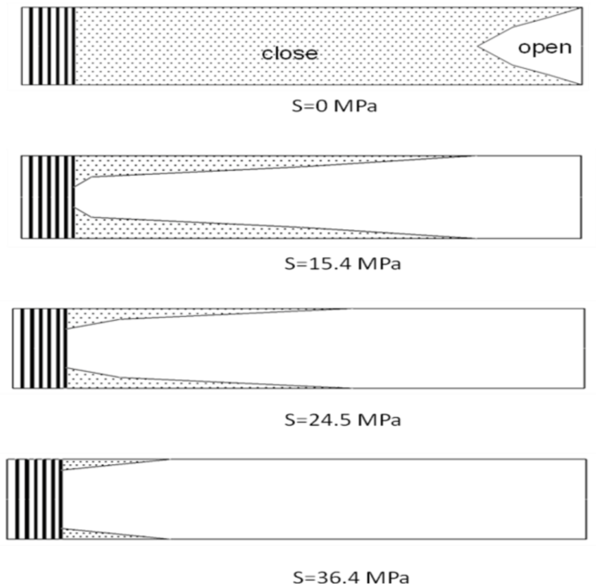

Fig. 5 Variation of crack-opening and closure stresses of nodes on the crack-surface plane for reloading portion of load cycles after thirty cyclic crack extensions.(Multiaxial loading(λ=1), 3D analysis, Smax=105MPa,R=0.)

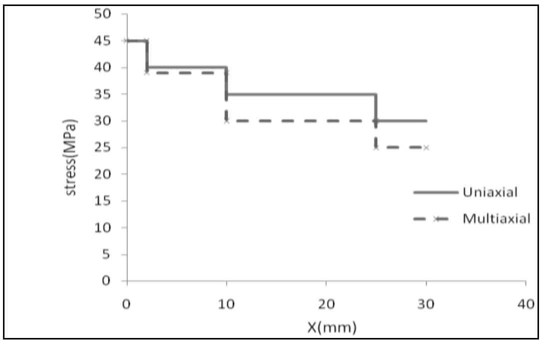

Fig. 6 stabilized crack opening stress as a function of thickness(R=0.1)

4- Conclusion

Analysis of fatigue crack growth and closure were applied to the multiaxial specimens using constant amplitude crack extensions. According to the results obtained, the closure behavior of all the above cases for multiaxial loading is lower than that of uniaxial case which is due to the magnitude of maximum shear stress at the crack tip of multiaxial case which is lower than that of uniaxial loading. The crack growth in the axial mode will be slower than in the multiaxial mode.

In the research conducted, the most important innovation was to investigate the effect of loading on how cracks grow, which can be used to create a basis for how to increase the life of components.

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