Journal of Applied and Computational Sciences in Mechanics, Vol. 27, No. 2, 2016.

The Effect of Fatigue Crack Growth on Mechanical Residual Stress Redistribution

M. Noghabi[1], I. Sattarifar[2] , H. HosseiniTodeshki[3]

1- Introduction

Fatigue life is an important dynamic property and it is affected by the residual stress field near the crack tip. Residual stresses can be produced during many manufacturing processes such as forming, welding and machining. Residual stresses have a significant influence on the fatigue life of structures. It is well-known that tensile residual stresses will reduce the fatigue life of the structure by increasing the fatigue crack growth rate, while compressive residual stresses will decrease the growth of the fatigue crack. In the last decades, several efforts have been devoted to the investigation of residual stress effects on fatigue crack growth rates. Farrahi et al. have presented crack propagation tests using compact tension specimens to investigate the effects of the residual stress field resulting from shot peening and the indentation technique on crack growth behavior. They concluded that residual stress affected the fatigue crack growth behavior by delaying crack propagation. The effect of the residual stress obtained by cold expansion process on the crack growth in aluminum alloy was studied by Semari et al. They found that compressive residual stresses near crack tip reduce the effect of the applied stress field and have a tendency to decrease the crack growth rate.

There are two common methods to calculate FCG rates in residual stress fields. One employs the superposition rule to determine the effective stress ratio to account for the residuals stress effect. The other is based on the crack closure concept originally proposed by Elber by calculating the crack opening stress intensity factor and then the effective stress intensity factor range in a combined stress field of the applied force and residual strain. The validity of both methods has been generally accepted.

The initial induced residual stresses relax during component's operating life and it is important to consider the relaxation phenomenon in the design of the component. A relatively small number of investigators have considered the redistribution of initial residual stress during fatigue crack growth. In this work, fatigue crack growth in CT specimens is considered under the influence of mechanical residual stress. The fatigue crack growth is simulated with the commercial finite element software ABAQUS. The results were compared with experimental data.

2- Material and Test Procedure

The tested CT specimens are prepared by the wire-cut process with the dimensions as shown in Fig. 1 from 8.4 mm thickness of 5000 series of the Al Alloy plate with mechanical properties according to Table 1.

Table 1. Mechanical properties of Al Alloy

Young's Modulus E (GPa)	Poisson's Ratio ν	Yield Stress S_y (MPa)	Ultimate Strength S_{ut} (MPa)
70	0.3	200	350

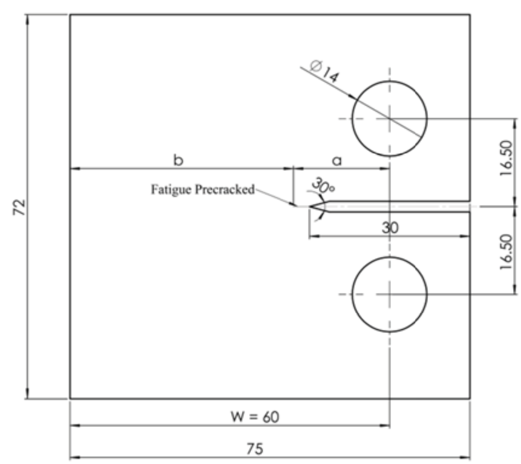

Fig. 1. Geometry of CT specimen.

3- Experimental Study

Fatigue Crack Growth Tests

All fatigue tests were conducted at a frequency of 10 Hz, stress ratio of 0.1 with different load ranges of ΔP=3.6 kN and ΔP=5.4 kN. The visual observation method was used for the calculation of crack length during the fatigue tests.

Fatigue crack growth behavior is illustrated in Fig. 2 for both specimens with and without the mechanical residual stress.

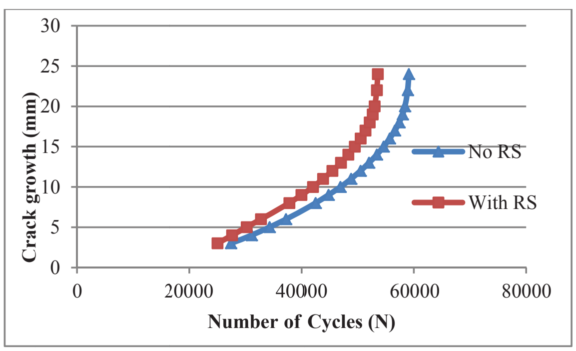

Fig. 2.Crack growth versus the number of cycles.

1- Ph.D. Student, Amirkabir University of Technology, Department of Mechanical Engineering
2- Corresponding Author, Assistant professor, Amirkabir University of Technology, Department of Mechanical Engineering, sattari@aut.ac.ir
3- Professor, Amirkabir University of Technology, Department of Aerospace Engineering

4-Finite Element Analysis

Mesh and Boundary Conditions

The mesh sensitivity analysis is carried out in order to obtain the appropriate mesh size. The mesh was created with an increasing level of refinement towards the crack tip region as shown in Fig. 3.

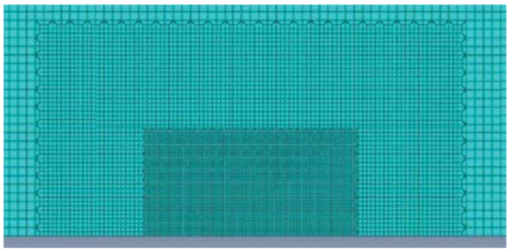

Fig. 3. Mesh detail close to crack tip.

5- Results

Fig. 4 and Fig. 5 present the change of J integral with an increase in the number of cycles during fatigue loading for different amplitudes of fatigue loading. The J integral of specimen with residual stress continues to decrease with the increase of cycles. After a few cycles, the J integral reaches a stable value. Its stable value is greater than the specimen with no residual stress.

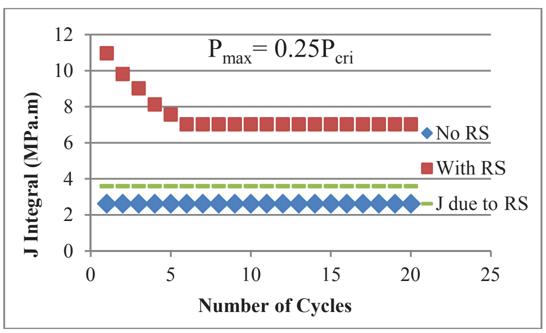

Fig. 4. The J integral during fatigue in ΔP = 3.6 kN.

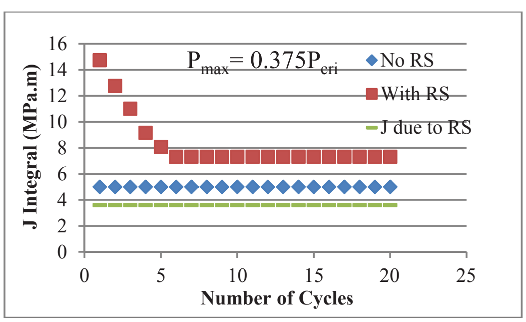

Fig. 5. The J integral during fatigue in ΔP = 5.4 kN.

Fig. 6 and Fig. 7 present the change of the plastic zone area with the increase in the number of cycles during fatigue loading for two different loading conditions. The plastic zone area continues to decrease with the increase in cycles. After a few cycles, the plastic zone area reaches a stable value.

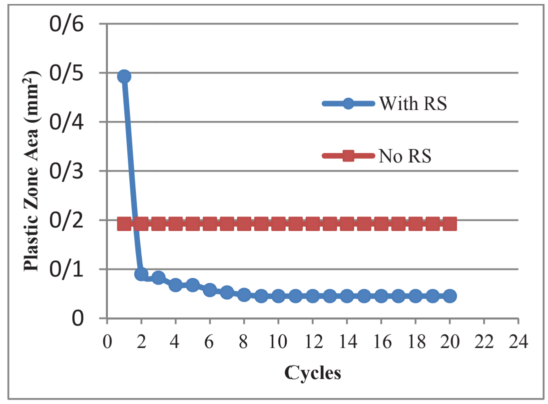

Fig. 6. The crack tip plastic zone size during fatigue in ΔP = 3.6 kN.

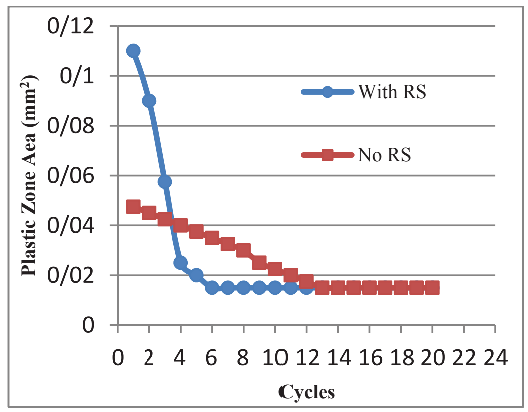

Fig. 7. The crack tip plastic zone size during fatigue in ΔP = 5.4 kN.

6- Conclusion

Fatigue crack growth from a fatigue pre-cracked under the influence of mechanical residual stress field was investigated using FEM. The FEM results were compared with the experimental data. It is concluded from this study that the tensile mechanical residual stress increases the fatigue crack growth rate. From the numerical results, we can deduce the following conclusions:

- The initial mechanical residual stresses decrease rapidly after a few number of cycles. In a higher amplitude loading, redistribution of the initial residual stress is done faster.
- The J integral of specimen with residual stresses decreases after fatigue loading. The rate of decrease depends on the loading amplitude.