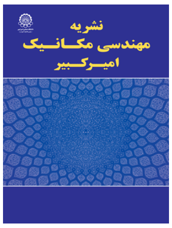

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A Numerical and Experimental Study on Fatigue Crack Growth of Ti-6Al-4V Specimens in Presence of Tensile Residual Stresses

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ABSTRACT: Fatigue crack growth is one of the failure mechanisms in engineering structures, which is intensified by the presence of tensile residual stress. In this research, the effect of tensile residual stress in front of the crack front on fatigue crack growth has been investigated. The mechanical residual stress has been applied to the samples using the four-point bending method, and the residual stress has also been measured using the hole drilling method. Fatigue crack growth tests were performed on single edge notch bend samples with residual stress and without residual stress and the repeatability of the test was checked. To investigate the plastic area ahead of the crack tip, the applied residual stress, and obtain the fracture mechanics parameters, Abaqus commercial software has been used. The results of this study show the increase in the rate of fatigue crack growth in the presence of tensile residual stress. This increase in fatigue crack growth rate can reduce fatigue life up to 50%.

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1- Introduction

Titanium alloys have high tensile strength and toughness and good corrosion and creep resistance. The above characteristics have led to the use of this alloy in the aerospace industry, chemical industry, medical equipment, and making electronic equipment [1].

Estimating the fatigue life of the structure in the presence of residual stresses is still a challenge for design engineers. Many researchers have investigated the effects of residual stresses on fatigue life. “McClung” and colleagues [2] reviewed the works done in the field of the effects of residual stress and its stability during fatigue crack growth. Vaidai et al. [3] investigated crack growth in the welding residual stress field along the weld line and perpendicular to the weld line. Tensile residual stress reduces the fatigue life, and compressive residual stress leads to a decrease in the fatigue crack growth rate [4].

With the increasing use of titanium alloys in various industries such as aerospace, where the parts are subjected to repeated loading, a lot of research has been done on the fatigue life of parts made of titanium alloys. Neto et al. [5] investigated fatigue crack growth in Ti-6Al-4V samples under “overload” loading. The results of their research showed that the “crack closure” mechanism caused by overload has a significant effect on fatigue crack growth. “Lou” et al. [6] experimentally investigated the effect of “shot peening” and “laser punching” on the microstructure and fatigue properties of Ti-6Al-4V alloy. Their results showed that the residual stress caused by the shot peening process improves the fatigue life. “Zhang” et al. [7] investigated the growth of fatigue cracks in titanium alloys in the presence of residual stresses caused by the “laser peening” process. The results of their research showed that compressive residual stresses greatly improve fatigue life.

Although there has been a lot of research on fatigue crack growth in titanium alloys in the last decade, the effects of mechanical residual stresses on the fatigue life of these alloys need more research. The purpose of this research is to investigate the behavior of fatigue crack growth in the presence of mechanical residual stresses. The residual stress was created in the samples using the four-point bending method. The samples were subjected to fatigue loading and fatigue crack growth in samples with residual stress were compared with samples without residual stress.

2- Methodology

A 4-point bending method was utilized to induce tensile residual stresses in front of the crack tip. Measurement of residual stresses was carried out by the incremental hole-drilling approach.

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Table 1. Mechanical properties of grade 5 titanium alloy

Young's modulus	Yield Stress	Ultimate Stress
113.8 GPa	950 MPa	1010 MPa

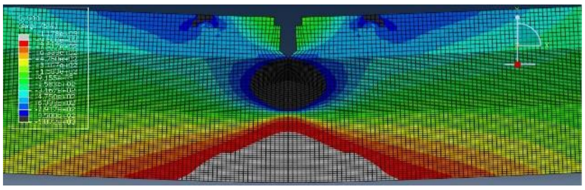

Fig. 1. Stress distribution after loading

In the finite element analysis, the Bauschinger effect is ignored. The behavior of the material in the plastic region of the stress-strain diagram is considered as isotropic hardening. Material properties were defined as elastic-plastic isotropic hardening behavior based on Ti-6Al-4V mechanical properties, which were measured by tensile strength test (Table 1). Figure (1) shows the stress distribution along the length of the sample after loading.

The simulation of fatigue crack growth for three-point bending loading is performed by Abaqus in two samples, one with mechanical residual stress created by four-point bending and the other without the presence of residual stress.

In the present study, the Paris equation is used to express the crack propagation law based on the stress intensity factor as follows:

$$\frac{da}{dN} = C(\Delta K)^m \quad (1)$$

3- Results and Discussion

The experimental diagram of crack length growth in terms of the number of fatigue loading cycles for samples with mechanical residual stress and without residual stress is given in Figure (2). The measurement of crack growth was done by visual method.

In Figure (3), the experimental diagram of the fatigue crack growth rate in terms of the range of the stress intensity factor is shown. Using the curve-fitting on the data of the diagram in Figure (3), the coefficients related to the material in Paris law are obtained.

The parameters of Paris Law given in Table (2) are of great importance. With the help of these parameters, fatigue life can be estimated in different loadings and geometries.

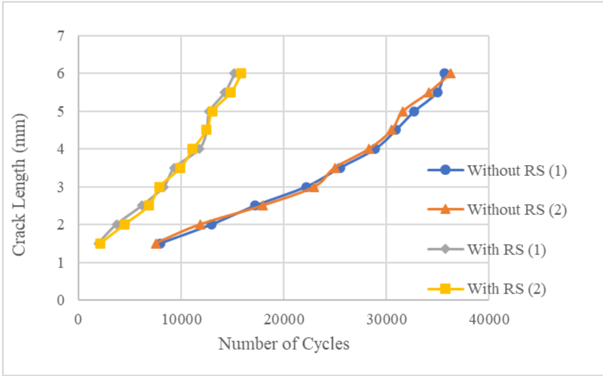

Fig. 2. Experimental diagram of crack growth according to the number of cycles for 2 samples with residual stress and 2 samples without residual stress

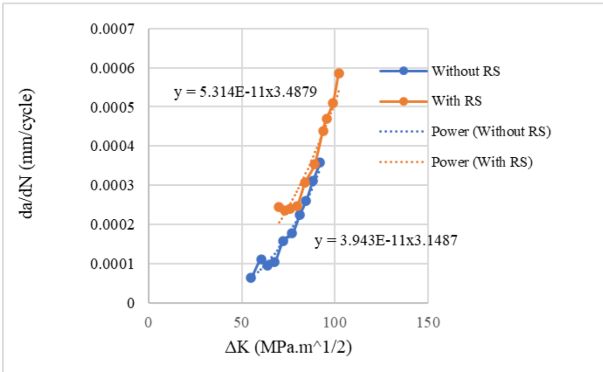

Fig. 3. Experimental graph of crack growth rate for samples with residual stress and without residual stress

Table 2. Calculated values of C and m parameters

Parameter	With RS	Without RS
C	$5.31*10^{-11}$	$3.94*10^{-11}$
m	3.49	3.15

4- Conclusions

In this research, the effect of residual stress on fatigue crack growth of grade 5 titanium alloy was studied. The mechanical residual stress was created by the four-point bending method. The distribution of this residual stress was validated using the hole strain method. Simulation of residual stress and fatigue crack growth was done by Abaqus finite element software. The results of this research are as follows:

1- Residual stresses have a significant effect on fatigue life and failure characteristics of samples.

2- Tensile residual stress causes an increase in fatigue crack growth rate, which leads to a reduction in fatigue life. Tensile residual stresses reduce fatigue life by about 50%.

3- The J-Integral is a suitable parameter to investigate fatigue crack growth in the presence of residual stresses.

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