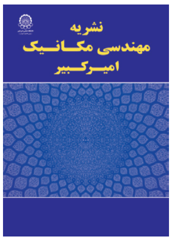

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Investigation of Thermal Cycle Effect Prior to Cyclic Loading on Fatigue Life of Interference Fitted Specimens and Fatigue Life Prediction

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ABSTRACT: Interference fit process, as a popular method, is used in aerospace and automotive industries to improve fatigue life of the joints. Investigating studies on interference fit process demonstrates that the effect of temperature variations has not been studied as an effective factor on fatigue life. In the present study, the effect of short time exposure to thermal cycle before cyclic loading on fatigue life of interference fitted fastener holes has been evaluated by experimental and numerical methods. So, to investigate the effect of temperature variations two different temperatures (i.e. 60 °C and 120 °C), aside from room temperature, were selected to accomplish this study. Fatigue tests were carried out on the specimens of Al-alloy 7075-T6 to obtain S-N curves. In relation to fatigue tests, three-. dimensional finite element analyses were used to explain the experimental results. The interference fit process, and subsequent thermal cycles and remote cyclic loading were simulated using Ansys package. The results obtained from the finite element analyses of the interference fit were employed to predict the fatigue life.

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1- Introduction

Interference fit process refers to a fastener which has a large diameter than the hole. Interference Fit (IF) process produces beneficial pre-stress around the hole that substantially lowers the magnitude of the amplitude stress and increases the mean stress. The stress amplitude decreasing is suitable for postponing of the fatigue crack initiation and propagation [1]. When the structural component is under an external cyclic load, the pre-stress distributions from interference fitted hole were altered. This phenomenon is known as the pre-stress redistribution. When the external load is so large that causes plastic region around the hole, the positive effect of the consciously introduced pre-stresses is removed. Additionally when thermal loading is applied to the structural stress relaxation can occur. Thermal relaxation is the probable mechanisms for the loss or redistribution of residual stresses and pre-stresses after creep and impact damage [2].

The structures of an aircraft at normal working conditions are under a severe temperature variation [3]. For instance, during supersonic flight the speed of concorde can reach 2.05 Mach and temperatures can be raised in the range 100–130°C [4]. In addition, at near engine components, high temperatures can be generated in the structure of aircraft sitting idle on blacktop runways in the sun. The fatigue life enhancement of the interference fitted holes is associated with the presence of the pre-stresses induced by an interference fit. Exposure to high temperature can affect the fatigue life of interference fitted specimens. However, to the best of our knowledge, there is no report about temperature effect on fatigue life of components with interference fitted holes.

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2- Methodology

Fatigue test specimens were cut from an Al-alloy 7075-T6 plate with dimensions of 1.25m×1.25m×6.35mm. To conduct interference fit process, a bolt with a bigger diameter than that of the hole was inserted into the fatigue specimen. The most important parameter in the interference fit process is the interference fit size that can be defined as follow:

$$I\% = \frac{D - d}{d} \times 100 \tag{1}$$

To implement the interference fit, the force fitting of the bolt into the specimens' hole was carried out with a hydraulic test machine. After the interference fitting, thermal cycles were applied to the specimens. Two different temperatures were selected. The maximum values of the cycles are 60 °C and 120 °C. The temperature was increased from 25 °C (i.e. room temperature) to the desired temperature (60 °C or 120 °C) and then cooled to the ambient temperature. For the reason that the temperature increase rate was small enough, the process can be considered a quasi-static thermo-mechanical loading. As a result of low heating and cooling rate, the thermal shock can be ignored during the thermal cycle application. So in order to achieve this aim, the thermal cycles were performed slowly. An electro-hydraulic fatigue testing machine with a maximum load capacity of 500 kN have been used for fatigue tests. The stress ratio and frequency in fatigue test were R = 0.1 and 4 Hz respectively in all tests.

In relation to fatigue tests, three-dimensional finite element analyses were used to explain the experimental results. The interference fit process, and subsequent thermal cyclic and remote cyclic loading were simulated. The pre-stress distribution due to interference fitted hole and its redistribution after thermal cycle and its interaction with remote loading were estimated.

The fatigue life of the interference fitted specimens that subjected to thermal cycles was predicted. Total fatigue life was predicted with a method that combines initiation and propagation lives. The number of cycles to crack initiation *(Ni)* calculated using FS criterion [5] and the number of cycles to crack growth until the final fracture *(Np)* evaluated using walker equation. The total fatigue life *(Nt=Ni + Np)* is obtained by adding the initiation life and the propagation life of a crack from the initiation length to the final fracture.

3- Discussion and Results

The number of load cycles until specimen failure, at the applied cyclic load ranges, have been recorded and displayed in the S-N diagram (Fig. 1). The results also indicate that the treated interference fitted samples with thermal cycles (60 °C and 120 °C) endure longer fatigue life compared to ‘‘interference fitted” specimens.

The finite element simulation shows that the interference fit tangential pre-stress distribution is not uniform through the thickness around the hole as the stress states are different through the plate thickness and pin insertion is a directional loading. There is a plane stress state at the entrance and exit planes and near plane strain state at the mid-plane. The pre-stress around the entrance and exit planes is tensile but around the mid-plane is compressive. When the thermal cycle was applied the pre-stress distribution curve is shifted down at the hole edge in the entrance and exit planes and shifted up in the mid-plane. This shift is bigger for the temperature cycle of 120 °C in comparison with the temperature cycle of 60 °C. The applied thermal cycle on the interference fitted specimens reduces the mean stress especially on the entrance and exit planes while no notable difference between the amplitude stress of interference fitted specimens and the specimens subjected to the thermal cycle is observed

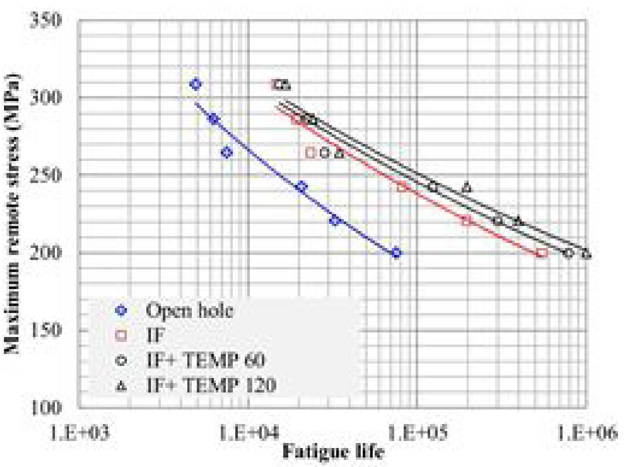

Figure 1. Fatigue test results.

Total fatigue life was predicted with a method that combines initiation and propagation lives. The number of cycles to crack initiation is calculated using FS criterion and the number of cycles to crack growth until the final fracture is evaluated using the NASGRO equation. The total fatigue life is obtained by adding the initiation life and the propagation life of a crack from the initiation length to the final fracture. Total fatigue lives from the addition of crack initiation and the crack propagation lives are portrayed in a graph in Fig. 2.

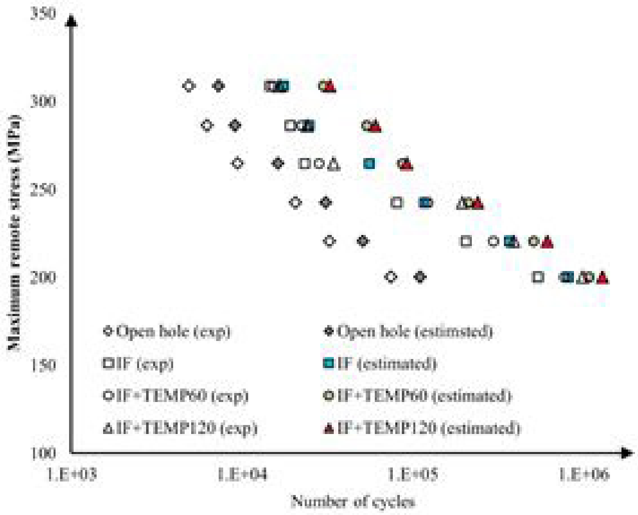

Figure 2. Comparison between the estimated and experimental total fatigue lives.

4- Conclusion

- Fatigue tests results illustrated that interference fitted specimens with and without thermal cycles endure longer fatigue life compared to non- interference fitted specimens (open hole specimens).
- Experimental results show that thermal treated interference fitted specimens have a longer fatigue life compared to ”only interference fitted” specimens and fatigue life improvement for specimens subjected to 120 °C temperature is more than the specimens subjected to 60 °C temperature.
- 3-D finite element simulations provide the explanation for fatigue performance. The finite element results show that the applied thermal cycles on the interference fitted specimens have redistributed the pre-stresses. When the thermal cycles are applied to the interference fitted specimens the magnitude of the pre-stress decreases, especially on the entrance plane, and the reduction is higher for the specimen treated with 120 °C compared to 60 °C.
- Temperature increasing and decreasing during thermal cycles redistributes the pre-stresses near the hole. The pre-stress redistribution can occur because of the material softening in elevated temperature. The relaxation of the pre-stresses happened around the mid-plane where the pre-stressed was higher than the yield strength of the tested sample.
- The fracture sections of the interference fitted and thermal treated interference fitted specimens show fatigue crack initiates at entrance plane. At low level load the crack nucleates far away from the hole edge

while at high level load the crack nucleates from the hole edge. Fatigue crack initiates from the mid-plane at the 'open hole'.

- The estimated results show that there is a good agreement between the numerically predicted total fatigue life of specimens and experimental fatigue test results.

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