Residual stress relaxation in Inconel718 cold expanded hole under loading at elevated temperature

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Abstract

The cold expansion process is widely used in industry in order to introduce compressive residual stresses around fastener holes, up to 2 mm beneath the surface. These compressive residual stresses are beneficial since they will prevent crack initiation from the surface and decrease subsequent crack growth rates. However, residual stress relaxation may occur due to the thermomechanical loading of the area. This study aims to investigate residual stress relaxation under thermo-mecanical cyclic loads.

1. Introduction

Turbine disks are critical componants of aeroengines. The failure of such compenant is strictly forbiden for safety reasons. This components must meet the certification requirements in terms of fatigue life to initiation as well as crack growth life via damage tolerance approach. Fastener holes are highly stressed areas. The cold expansion process is used in aeronautical industry on fastener holes in order to introduce compressive residual stress around the hole up to 4 mm beneath the surface of the hole. These residual stress will prevent early initiation and reduce the crack growth rates. However, residual stress relaxation may occur due to the thermomechanical loading of the area. This residual stress relaxation must be characterized and modeled in order to take into account te beneficial effect of cold expansion on the crack growth rates during the lifing procedure. This study aims at characterizing the initial residual stress state on cold expanded specimens and its thermomechanical relaxation for serveral loading cases. FE simulations are also performed in order performed and correlated to experimental data.

2. Results

During allocated beamtime on ENGIN-X (RB1710155), experimental measurements of the residual strain field were performed on samples made of *Inconel718* with different residual stress states. Three samples have been prepared prior to the experiment with the following conditions:

a. - reference sample “B”, subject to cold expansion treatement .
b. - two samples “C” and “D”, subjects to cold expansion treatement followed by thermo-mechanical loads:
    - 200 fatigue cycles at 450°C and -80kN applied compressive loading (“C”)
    - 40h of creep testing at 650°C and 80kN applied load (“D”)

The neutron diffraction measurements on samples “B”, “C” and “D” were made along a line at the centre of the samples from the hole edge towards the free side of the sample. Six points, shown fn figure 1, were measured on each sample at a distance of 0.9mm, 1.6mm, 2.3mm, 3.7mm, 5mm and 9mm.

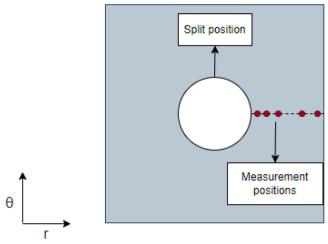

Fig.1 – Measurment positions.

The measurements were performed with a gage volume of 1x1x1mm^3 gage volume and a counting time of 2h in order to obtain sufficient statistics to analyse the diffraction patterns from each detector. The procedure described above for strain measurements along axial and radial directions was repeated with the samples rotated by 90° in order to measure strains along the tangential direction. Thus, residual macroscopic stresses can be computed based on the three strain components measured.

A three dimensional finite element model of the split-sleeve cold expansion has been created to study the distribution of the residual strain field around an *Inconel718* cold expanded hole. ABAQUS was used to carry out the numerical simulation of the split-sleeve cold expansion process. An elasto-viscoplastic model , Chaboche-type, was used in this study. The simulation contains three steps. The first step was dedicated to simulate the cold expansion of the hole. In the second step, the hole was reamed and beveled to the required size. Meanwhile, the sample was subject to thermo-mechincal load during the final step. The experimental elastic strains for the three samples were compared with elastic strains estimated by 3D finite element model.

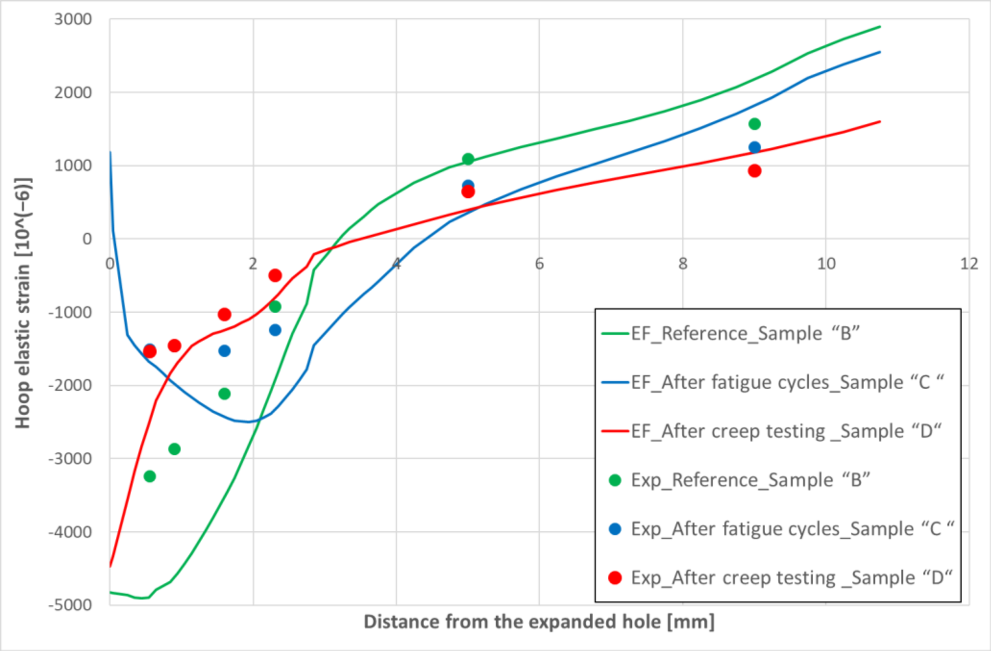

Fig.2 – Correlation between experimental (solid dots) and numerical results (solid lines) of the hoop elastic strain only for the three samples measured during the beam time.

Figure 2 shows a comparison between experimental and numerical results of hoop elastic strains for the three samples measured during the beam time. The analyses, illustrated in figure 2, show a good correlation between elastic strains estimated by the numerical simulation (solid lines) and the neutron diffraction measurements (solid symbolsdots). Although the correlation of absolute values of experimental and numerical strains can be discussed, one can see that the trends are correctly predicted by the finite element model for the different samples. In addition, one can see that the relative position arrangement of the strain gradients predicted by the model for the different samples is also recovered from neutron diffraction data.

3. Conclusions

Although the model proposed here is able to predict the trends of neutron diffraction measurements an experimental study on residual stress relaxation is required to benchmark the numerical model.