ISOTROPIC AND KINEMATIC HARDENING FOR COLD EXPANDED AL7050 AND MILD STEEL BY FINITE ELEMENT ANALYSIS

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Introduction

A fastener hole is considered as a potential crack initiation (premature failure) site for structures that undergo cyclic fatigue loading because of the stress and strain concentrations [1]. To improve the life of the fastener the cold hole expansion (CHE) process has been widely used in aircraft structures [2-4], wherein an oversized tapered mandrel passes through the hole developing compressive residual stress as the material is plastically deformed around the hole edge. These compressive residual stress remain tangential to the hole edges, delaying the initiation and growth of under fatigue cycling. This induced compressive residual stresses around fastener holes enhance the fatigue life of service components in aircraft structures.

By using finite element methods, residual stresses can be calculated more efficiently and effectively as it can cover material, geometrical and boundary non-linearities and so is not restricted like in mathematical models. Maximov et.al [5] performed a two dimensional thermo-mechanical finite element analysis for simulation of the spherical mandrelling process of holes with cracks. A tensile stress is then applied to the cold-expanded pre-cracked hole to assess the benefit of the spherical mandrelling process. The variation of residual stresses at various sections along the thickness as it happens in the actual split sleeve cold expansion process can be captured using Babu et al., approach [6]. Lacarac et al. [7] have also reported that compressive residual stresses are introduced in fastener holes in order to reduce the fatigue crack growth rate from the edge of the hole resulting in increased fatigue life. Lacarac et al. have shown that, in general, cracks initiate at different locations on the hole edge. However, cracks initiating at the corner of the hole and entrance face grow faster and become dominant. This is because this is the location of the least compressive residual stress. However, the actual cold hole expansion process as an axisymetric problem utilizing a finite element code, by simulating the mandrel motion and the frictional effect at the contact surfaces has not been undertaken hitherto.

Thus the objective of the paper is to predict the effect of cold working on drilled holes by finite element approach (FEA). This will then be subjected to a load created by the interference between hole and mandrel. This paper also deals with determining the stresses for both isotropic hardening and kinematic hardening for Al 7050 and Mild Steel.

Analysis

The specification for the cold-hole expansion process has three steps that are useful to the residual stress model development:

1. Hole expansion by the ball mandrel expansion
2. Recovery of expanded hole on removal of the load
3. Removal of thin layer of material around the hole

The FEA is carried out for different degree of expansion, for a given plate thickness-to-hole radius ratio using ANSYS. The removal of the mandrel and the corresponding unloading process is simulated by the removal of the boundary condition at the hole-edge. The material removal is done using element removal function.

Meshing

For cold hole expansion process of hole without cracks, because of the symmetry, one half of the hole is representative of the entire hole. The size of the specimen analyzed is 25.4 x 25.4 x 6.35mm (L x W x T). The hole diameters is 3.075 mm and pin radius depending on the percentage of expansion. These values follow the experimental specifications. SOLID 185 has been chosen to model the plate. Two surface-surface contact pairs were generated (one between the mandrel and the sleeve, the second between the sleeve and the plate) using TARGET 170 and CONTACT 174 elements respectively. The mesh used is as shown in Fig.1.

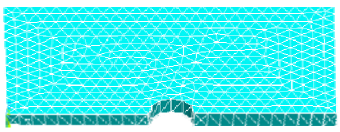

Fig. 1: Meshed models of base plate with hole

Results and Discussion

The FE simulation for both aluminium and mild steel was carried out using isotropic and kinematic hardening models as shown in the Fig. 2. The residual stresses are high at the entry and exit faces, the variation of co-efficient of friction from 0.1 to 0.4 yielded a change of only 4% of the residual stress. The zone of compressive stresses was larger at the entrance and exit faces than in the mid-thickness. It is also observed that the stress on the exit side is more compare to that of entry side.

It is noted that during cold expansion larger plastic zones would be expected at the surface as a result of plane stress conditions. It might therefore be expected that near surface and average through thickness residual stresses would differ as observed by Lacarac et.al [7]. Also, with increase in strain hardening, the pressure required is higher and the corresponding displacement at the edge of the hole is smaller in magnitude.

Figure 3(a) and 3(b) shows variation of residual stresses with coefficient of friction (COF) for isotropic and kinematic hardening for aluminium and mild steel. The residual stresses were calculated with isotropic and kinematic hardening by simulating the conditions in ANSYS and the results are plotted.

From Fig 3 (a, b), the isotropic residual stresses of both aluminium and mild steel are higher than the respective yield stresses. Hence, it is not advisable to go with isotrpically hardened material for aerospace applications. For COF 0.1-0.4, the residual stress for kinematically hardened mild steel is more than the yield stress (400MPa) and for kinematically hardened aluminium, its less than the yield strength (425MPa) and hence it is best suited for aerospace applications.

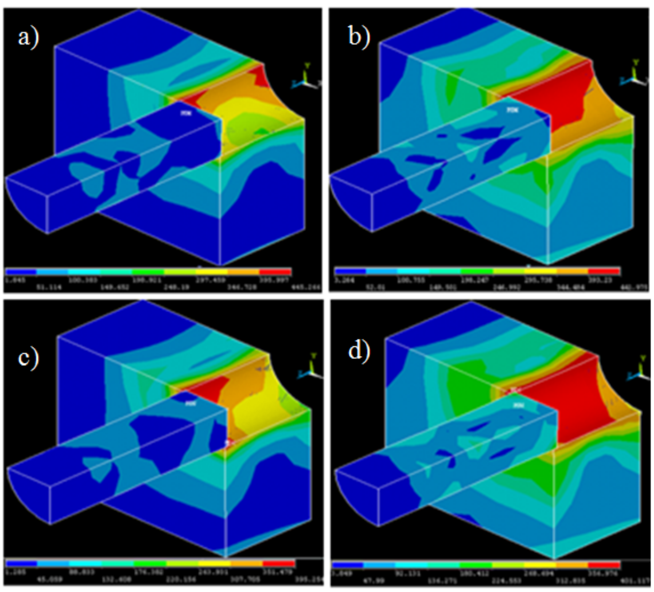

Figure 2: Residual stresses for isotropic (2(a), 2(b)); and kinematic hardening (2(c), 2(d)) for aluminium and mild steel

Conclusion

The cold expansion method can be successfully employed as a retrofit technique as it can restore the original fatigue life or extend the fatigue life beyond the

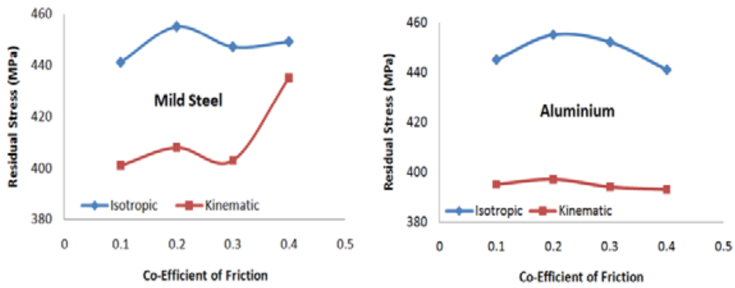

Figure 3(a), (b): variation of residual stresses with COF for isotropic and kinematic hardening for aluminium and mild steel

original life. The materials analyzed revealed the maximum stress values and distribution of the residual stresses at the surface and the mid-section. The kinematically hardened component aluminium with coefficient of friction between 0.1-0.4 are suitable for aerospace applications. Maximum stresses are concentrated at the edge of the hole. Residual stress distribution in different sections surrounding the expanded hole can be visualized in the model easily.

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