Verifying the Effect of Element Birth and Death Technique on Stress Distribution in Cracked Areas

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\textbf{ABSTRACT}

In this paper a numerical method is assessed for simulation of the crack in a mechanical joint. ANSYS finite element package is employed to assess the method based on “Element Birth and Death” technique. An aluminum alloy T3-2024 holed plate is selected as a case study to implement cold expansion process and create residual stress distribution around the hole. Once cold expansion process is performed and the residual stress is created. Compressive residual stress is obtained near the hole edge which is not uniform across the thickness of specimen. The minimum magnitude of compressive stress is occurred in entrance plane of pin therefore crack initiation as started from hole edge of entrance plane. Then element Birth and Death technique is used to kill some elements of smallest section of the joint. The results revealed the significance of Element Death in residual stress distribution. In other word, killed elements can act as crack and have pronounced effects on residual stress distribution.

\textbf{KEYWORD}

Finite Element, Residual Stress, Element Birth and Death, Crack.

\textbf{INTRODUCTION}

Most of the mechanical joints degrade as a result of fatigue loading. Fatigue process starts by crack initiation, continues by crack propagation and finally fracture. Most of the primary aircraft structural components connect to each other by clamped or riveted joints, therefore damaged joints are exchanged easily. These kinds of joints include holes and geometrical discontinuities that cause local stress concentration. As a result, the probability of initiation and propagation of crack is increasing and it is important to reduce the effect of stress concentration to prolong the fatigue life of holed joints. Cold expansion is a technology that is widely used for the improvement of fatigue life of holed joints \cite{1}. Cold expansion is a mechanical method for creating compressed residual stress field which reduces the effect of stress concentration. Based on expansion tools several techniques are used to perform cold expansion process. Four main techniques are practically used for hole cold expansion: hole edge expansion, direct mandrel expansion (without sleeve), ball expansion, and split sleeve expansion \cite{1}.

Analytical solutions and experimental investigations are employed to obtain stress distribution caused by cold expansion process. By using these methods stresses on surfaces can be obtained whereas it cannot be measured on depth of the specimen. Recently numerical solutions are used for studying cold expansion technique. With the development of computers, finite element simulation can be widely applied to study the residual stress generated by the cold expansion process and accurate result can be obtained \cite{1}. In recent years, 3D finite element models are simulated to investigate cold expansion. Chakherlou and Vogwell \cite{2} studied the effect of direct cold expansion on fatigue life of joints. The results showed that crack growth on cold expanded specimen starts from hole edge of entrance surface.

During the fatigue process, residual stress distribution can be affected by crack propagation. In order to study the effect of crack growth on residual stress distribution, it is necessary to implement a method for simulating crack growth after cold expansion process. The element birth and death feature is useful for analyzing many applications in which one can easily identify activated or deactivated elements by their known locations. The birth and death is a built-in feature of the ANSYS Multiphysics, ANSYS Mechanical, and ANSYS Structural products \cite{3}. In this paper using birth and death feature is assessed for simulating crack after cold expansion process.

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A mechanical joint of aluminum alloy T3-2024 was selected to assess element birth and death method. The joint was cold expanded and residual stress distribution around the hole was created. Geometrical feature of joint is shown in Fig.1. Chemical composition and mechanical properties of aluminum alloy T3-2024 are shown in table1 and table2 respectively. As shown in Fig.2, a tapered pin with the Young’s modulus of 210 GPa and Poisson’s ratio of 0.3 was used to cold expand the hole [4].

![Fig. 1. Dimensions of modeled specimen](image1.png)

![Fig. 2. Dimensions of tapered pin used for cold expansion](image2.png)

| Tab. 1 Chemical composition of Al 2024-T3 |
|-----------------|---------|-------|-------|-------|-------|-------|-------|-------|
| Alloy (wt. %)   | Si      | Fe    | Cu    | Mn    | Mg    | Cr    | Zn    | Ti    | Al    |
| 2024-T3         | 0.50    | 0.50  | 3.8   | 0.30-0.9 | 1.2-1.8 | 0.10  | 0.25  | 0.15  | Balance |

| Tab. 2 Mechanical properties of Al 2024-T3 |
|-----------------|---------|-------|-------|
| Alloy           | 0.2 % proof stress (Mpa) | Tensile strength (Mpa) | Modulus of elasticity (Gpa) | Poisson’s ratio |
| 2024-T3         | 375     | 535   | 71.5 | 0.33 |

The ANSYS finite element package was employed to simulate the cold expansion process. Owing to the geometric and loading symmetry with respect to X–Y plane only half of the actual model is used. All the parts are meshed with eight-node hexahedral structural solid elements Solid185. Linear elements are preferred in this analysis to the higher-order elements on the account that the higher-order elements in ANSYS use only the corner integration points for the elastic–plastic analysis. Contact 174 and target 170 elements were used at the interfaces between the hole and the mandrel (tapered pin), between the lower surface of the specimen and the cylindrical support, and also between the fastener pin and the holes of the plates. These contact elements allow pressure to be transferred between the pin and the plates at the hole surfaces. The generated finite element mesh is shown in Fig.3 and is used for all steps of the simulation.

As shown in Fig.4, fracture occurs on smallest cross section of mechanical joints (θ=90º) therefore the investigation emphasizes on studying the residual stress distribution on entrance, mid and exit plane (Z= 0 & 1.6 & 3.2 mm) of tapered pin [4]. By using contact technology
cold expansion process is simulated (Fig.5). Residual stress contour caused by cold expansion is shown in Fig.6 where it shows that stress distribution around the hole is almost uniform.

Among the three principal residual stresses, i.e. hoop, transverse and radial, created around the hole edge by cold expansion, the hoop (tangential) stress has considerable effects on improving the fatigue life by a factor of two to ten, either by delaying crack initiation or more often by reducing crack growth rate [5,6].

Fig. 3. Finite element model of the specimen

Fig. 4. Nomination of different planes of specimen

Fig. 5. FE model after cold expansion

Fig. 6. Tangential residual stress (MPa) contour caused by cold expansion

Fig. 7. Tangential residual stresses at the smallest cross sectional area

Tangential residual stress distributions on entrance, mid and exit plane are shown in Fig.7. It is inferred that stress distribution through the plate thickness around the hole is not uniform. There is an acceptable agreement between the stress field caused by cold expansion process and the result obtained by Chakherlou and Vogwell [2].

**ELEMENT BIRTH AND DEATH**

If material is added to or removed from a system, certain elements in the model may become come into existence or cease to exist. In such cases, one can use element birth and death options to activate or deactivate selected elements, respectively. To achieve the “element death” effect, the program does not actually remove “killed” elements. Instead, it deactivates them by multiplying their stiffness (or conductivity, or other analogous quantity) by a severe reduction factor. This factor is set to 1.0E-6 by default, but other values are also possible [3].

**ELEMENT BIRTH AND DEATH**

Element birth and death feature is used to simulate crack on the hole edge. As illustrated in Fig.7, the smallest compressive tangential residual stress occurs at the hole edge of entrance plane therefore crack initiation starts at this point [2,7]. For this reason mesh killing method was used to kill the nearest element to the hole edge of entrance plane. As shown in Fig.8, 6*6 element array is selected to be killed.

Fig. 8. (6*6) array of killed elements

The results of mesh killing showed that residual stress distribution is totally different in comparison to the case without mesh killing. Residual stress contour after mesh killing is depicted in Fig.9.
Fig. 9. Tangential residual stress (MPa) contour after mesh killing

The variation of tangential residual stress due to crack growth at the three plane of the hole edge is demonstrated in Fig. 10, 11 and 12. Based on the obtained results, the effect of crack on residual stress distribution is shown on and around crack tip.

Fig. 10. Variation of tangential residual stresses at entrance plane after crack growth

Fig. 11. Variation of tangential residual stresses at mid plane after crack growth

Fig. 12. Variation of tangential residual stresses at exit plane after crack growth

CONCLUSION

Tangential residual stress caused by cold expansion is not uniform across the thickness of the hole edge. The maximum compressive tangential residual stress occurs at the hole edge near the mid-plane, whereas the smallest compressive residual stress occurs at the entrance face. Crack growth reduces magnitude of compressive residual stress on crack tip, whereas the magnitude of compressive residual stress around the crack tip is increased. By using the element birth and death feature, simulating crack after cold expansion process is feasible and acceptable results can be obtained.

REFERENCES


