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OPTIMUM FATIGUE PERFORMANCE IN AL7050 ALUMINIUM ALLOY OF PRE STRESSED FASTENER HOLE BY FE ANALYSIS

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Abstract: **Plastic deformation of material around a hole, radially is achieved by in introducing residual compressive stress, the process is known as pre-stressing. Adverse effect of cyclic stresses and retardation of growth of fatigue crack due to material flow can be minimized by pre-stressed zones. The expansion of hole is achieved by the use of split-sleeve process, by putting tapered mandrel prefitted with a lubricated split sleeve through the hole. The objective is to highlight the effect of pre stressing on the fatigue life of 7050 Aluminum test specimen. FE simulation was used to get the result for tangential & radial stresses through the thickness of plate as a function of radial position. Analysis shows remarkable improvement in fatigue life & specimen sustaining good stress cycles. By optimum expansion of hole, the maximum fatigue life & the stresses associated with that were also determined.**

Keywords: **Residual stresses, split sleeve, Fatigue life, pre stressing.**

1. INTRODUCTION:

There is greater demand for higher strength to weight ration of engineering components, and for this fatigue has become a very important phenomenon especially in automobiles and aircrafts which are subject to repeated loading and vibration. Considerable interest in the influence of residual stresses on fatigue behavior of components exists in the aircraft industry [1]. These compressive residual stresses are highly effective in preventing premature fatigue failure under conditions of cyclic loading [2, 5,]. An ideal solution would be to build in order to fatigue resistance into the critical assemblies themselves provide increased safety and fatigue life. One such solution, attempted here, is to form a controlled compressive residual stress field around the fastener hole [6]. The technology of cold hole expansion is used to impart a favorable residual compressible stress on surfaces subjected to highly alternating stress and thus increases fatigue life [7]. The change of cold expansion residual stresses due to static compressive loading was studied by Stefanescu et al [10] using an experimental approach. Manufacturing and other defects are very common at holes. The highest incidence of aircraft structural fatigue has been associated with holes in fastener joints and other in the structure. The majority of civil aircraft components are designed using the damage-tolerant approach. In this approach, the emphasis is on the control of crack growth rate and effective periodic inspection, with the requirement that crack detection techniques should be able to identify flaws of a certain size [8]. During aircraft operation, the adverse effects of these flaws or defects are magnified by the high stress concentration factors associated with holes, which lead to fatigue cracks. Modern manufacturing technologies and improved detailed design and analysis of fatigue sensitive joints have substantially reduced the occurrences of severe structural fatigue damage at holes. Nevertheless, the challenges of the aerospace industry continue to be the production of larger, more efficient, less costly and considerably more durable and damage tolerant airframes. These goals, coupled with the growing need to extend the operational lives of exiting aircraft will require the use of all tools available to maximize the fatigue lives of holes and other stress concentrations. Fatigue crack growth may be significantly delayed or even arrested by the compressive cold expansion residual stresses [7, 9]. Generation of permanent compressive stresses near holes has long been recognized as a means to extend fatigue life by retarding crack initiation and growth. Methods commonly used to induce compressive stress around holes include shot penning, roller burnishing, mandrelizing & coining. However, these techniques produce only relatively shallow residual compression zones, which are sensitive to manufacturing variables and operator proficiency. Consequently, these hole treatments have only a limited ability to effectively prolong fatigue life. Split sleeve cold expansion system is a cost effective solution to problems associated with fatigue cracks and holes in metal structures. Split sleeve cold expansion is accomplished by pulling a tapered mandrel, pre-fitted with a lubricated split sleeve through a hole in aluminum, steel or titanium. The function of the disposable split sleeve is to reduce mandrel pull force, ensure correct radial expansion of the hole, preclude damage to the hole and allow one-sided processing. The process works by imparting beneficial compressive residual stress around the hole.

2. SPLIT SLEEVE PROCESS:

One sided processing is done by sleeve which shields the hole from frictional forces generated by the high stresses created by cold expansion significantly increase fatigue life by reducing the stress intensity factor and crack growth by reducing the

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applied stress ration at the hole. The magnitude of the peak residual compressive circumferential stress is about equal to the compressive yield stress for the material. The compressive stress zone spans one for diameters up to 12.5mm for most materials.

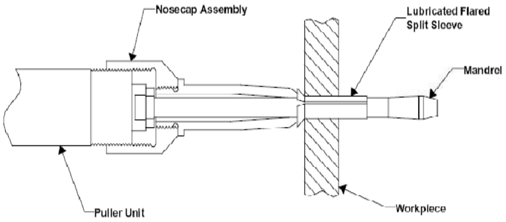

Figure 1: Split Sleeve Process

The fatigue life benefit associated with the cold expansion process has been validated on numerous occasions by both experimental testing and in-services. The challenge is to predict the fatigue life benefit without extensive testing. The most common method used today is a two-dimensional (2-D) stress intensity factor (K) solution using liner superposition associated with cold expansion (Cx). This method can be summarized in Equation. 1.

$K_{\text{noncold expanded}} + K_{\text{residual stress}} = K_{\text{effective}}$ (1)

Past studies by various authors have shown varying levels of success in predicting the overall fatigue life [12]. Many researchers have focused attention on ftest programs with the purpose of individuating the effects of various significant parameters (viz material, stress level, expansion level)

3. EXPERIMENTAL PROCEDURE:

The present work attempts to find the tensile strength characteristics of cold worked specimen. The first step includes the cold hole expansion of aluminum specimen (with centrally drilled hole) under constant pressure condition and varying mandrel velocity. The second deals with the tension tests performed on a universal testing machine for evaluation of tensile properties. Fig 2 shows the geometry of the test specimen & Table 1 shows the properties of Al 7050 alloy.

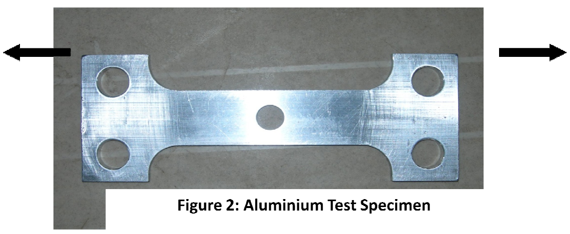

Figure 2: Aluminium Test Specimen

Table 1: Aluminium Test Specimen

Alloy	E (GPa)	Y	ρ (gm/cc)
Al 7050	72	0.3	2.7
Thickness	4mm and 6mm plates		

1. Circular Holes of diameter 13.5mm are drilled in aluminum plates of 6mm thickness at a cutting speed of 350 rpm.
2. The holes are reamed to an exact diameter of 14mm using a straight reamer at a speed of 120 rpm. The test specimens are pre-stressed for 2%, 4% & 6% expansion.

4. METHODOLOGY OF FE ANALYSIS:

1. Uniform displacements are added to the nodes at the hole edge simulate 2-6% cold expansion
2. The removal of the mandrel and the corresponding unloading process is simulated by the removal of the boundary condition at the hole-edge.
3. Removal of the material surrounding the hole to bring the hole to the final size is simulated by the powerful function of element removal in ANSYS.

Meshing:

In cold hole expansion process of hole without cracks, because of the symmetry, one half of the hole is representative of the entire hole because of symmetry. The size of the specimen analyzed is 100 mm × 100 mm × 4 mm in length, width and thickness, respectively. The initial and final hole diameter are 14 mm and 14.84 mm respectively. These values follow the experimental specification. The 20-node 3-D solid element has been adopted for the analysis. The analysis model contains 8020 elements and 9324 nodes. The mesh used in Figs 3 (a) & 3 (b) show cold expansion of the hole without & with crack.

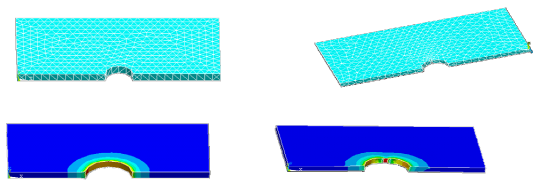

Fig. 4(a) Cold hole expansion of hole without a crack

Fig. 4 (b) Cold expansion of hole with a corner crack A/C =1, C/T = 0.6

A typical development of plastic deformation in terms of VonMises stresses in Al 7050 is shown in Fig 4. The materials analyzed revealed maximum stress values distribution of the residual stresses at the surface and the mid-section. For comparison purposes, the ratio of residual stress to yielding stress of the materials is introduced. 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. Results were obtained from the FE simulation for radial and tangential residual stress through the thickness of the plate as a function of the radial position. The radial position is also at the hole edge. The obvious feature of the radial residual stress is the high tensile stress at the entrance face close to the hole edge. The tensile stress however, occurs only in a thin layer about 50-100 µm thick. The residual radial stress is compressive throughout the plate expect at the exit face near the hole edge where normalized stresses up to 0.2 may be observed. Tensile

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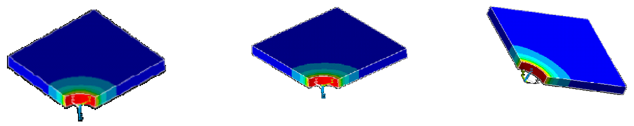
tangential residual stresses are also found, particularly, at the entrance face slightly away from the hole edge. The stress regions exist only in thin layers. The stresses differ in the vicinity of the hole where reverse plasticity occurs but are similar throughout the rest of the plate.



(a) Expanded hole (b) Released hole (c) Reamed hole

Fig. 4 FEM analysis of cold hole expansion in AI 7075

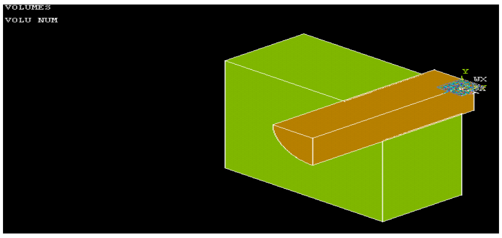


Figure 5: Quarter Symmetry Model

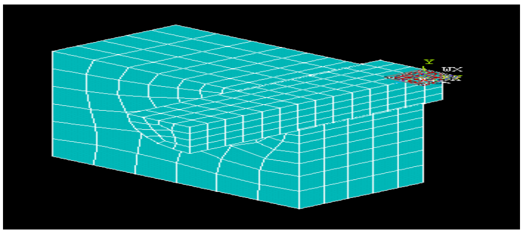


Figure 6: Meshed Quarter Symmetry Model

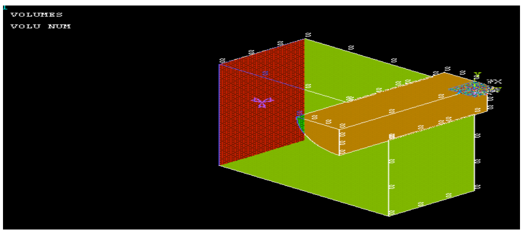


Figure 7: Constraints Applied for Load Step 1

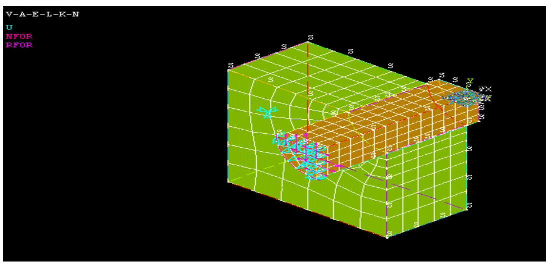


Figure 8: Constraints Applied for Load Step 2

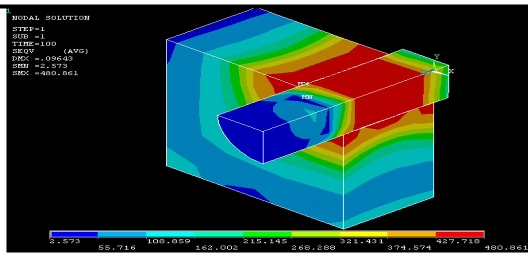


Figure 9: Aluminum - Load Step 1 (□□̃ı

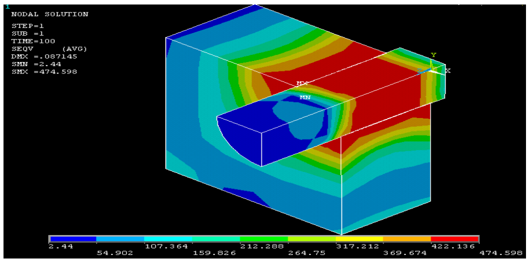


Figure 10: Aluminum - Load Step 2 (□□̃ı

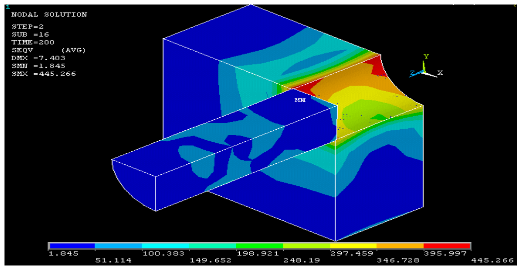


Figure 11: Aluminum - Load Step 1 (□□̃□

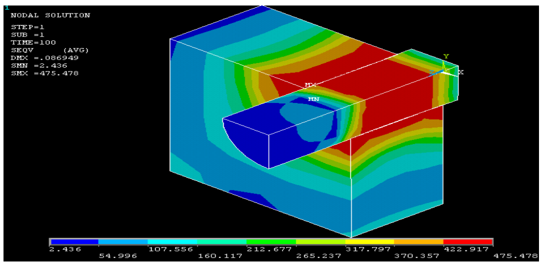


Figure 12: Aluminum - Load Step 2 (□□̃□

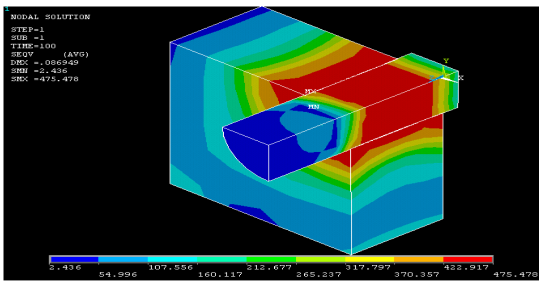


Figure 13: Aluminum - Load Step 1

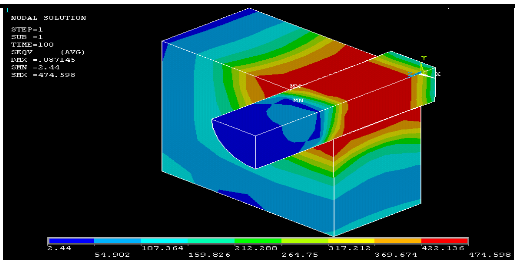


Figure 14: Aluminum - Load Step 1

5. FATIGUE RESULTS:

In all the stresses tested, the log average total fatigue lives and fatigue lives after rework was considerably longer than the log average baseline Cx fatigue lives. At the low maximum stress levels, rework cold expansion prevented failures at the holes. At these stresses, despite the presence of fatigue cracks at many holes, the cracks did not result in filure.

The minimum fatigue lives after rework of specimens (initially cold expanded) were comparable to or greater than the corresponding Cx baseline lives. The improvement in fatigue life afforded by Cx rework can be explained primarily by the removal of most of the initial fatigue damage during reaming and the high compressive residual stress created by cold expansion. In general, plastic deformation produces atomic level dislocations. In a strain hardening material, further plastic deformation is made difficult by increase in the effective yield stress of the material as plastic deformation increases. With strain hardening cold expansion rework of previously cold expanded or otherwise overstrained hole can produce higher residual stress than cold expansion of untreated hole.

6. CONCLUSIONS:

Failure by fatigue is reduced at the holes improving the resistance by using cold expansion. It is achieved effectively when the hole surface is expanded locally beyond the material's yield point. The contraction of the material means there are negative residual stresses remaining at the hole edge as depicted in the FEA. The percentage of expansion increases, the fatigue strength increases & optimum expansion is found to be 4%. Thus the method of cold hole expansion slows down the rate of crack initiation and propagation or will arrest the growth of small cracks under normal operating load condition. It is concluded that an axisymmetric finite element model, accounting for the mandrel motion, the frictional effect at contact surfaces, and the actual supporting arrangement, results in the best correlation with experimental results.

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