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On the Fretting Fatigue Behavior of the Cold Expanded Aluminum Alloy 2024-T3 Plates

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ABSTRACT: Cold expanded holed plates are widely used in bolted joints which are subjected to clamping force. Previous studies on the effect of clamping force together with cold expansion on the fatigue behavior of the bolted joints revealed that the size of cold expansion has a great influence on the fatigue durability of these joints due to the increase of the possibility of fretting fatigue occurrence. For better understanding this phenomenon, it is necessary to have detailed information about the effect of cold expansion on frictional force evolution during fatigue loading and the resulting stress field around the stress concentration zone. Therefore, in this paper, the fretting fatigue testing apparatus was designed and fabricated for conducting fretting fatigue tests on the cold expanded specimens. Moreover, finite element simulation was used for evaluation of the residual stress distribution due to cold expansion and its effect on the fretting fatigue behavior of the joint. Smith-Watson-Topper multiaxial fatigue parameter was engaged for comparing the fatigue durability of the test specimens. The obtained results indicated that the cold expansion process reduces the stress concentration effect near the hole edge while it increases the possibility of fretting fatigue occurrence by generating tensile residual stress at areas away from the hole edge.

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1. INTRODUCTION

Bolted joints are vulnerable to fatigue failure because of stress concentration around the unavoidable hole. Therefore, several practical methods such as cold expansion [1] and bolt clamping [2] have been developed for attenuating the effect of stress concentration and improving the fatigue durability of the bolted joints. Most of the studies on the effect of cold expansion and bolt clamping demonstrated that both of these methods are effective in enhancing the fatigue strength of bolted joints. However, a recent study by Chakherlou et al, [3] revealed that the combination of a higher level of cold expansion and clamping force decreases the fatigue life of the double shear lap joints considerably due to the dominance of fretting fatigue. The unexpected results of this study revealed the necessity of further investigations on this subject. Hence, in this study, a fretting fatigue test configuration has been designed and fabricated for understanding the effect of cold expansion on the fatigue behavior of the holed plates. Using this kind of test configuration makes the recording of the frictional force possible. Moreover, finite element simulations are performed for evaluating the distribution of residual stress around the hole and its effect on the stress distribution under fretting fatigue tests. The fatigue crack initiation locations are predicted based on the resultant stress field around the hole edge.

2. METHODOLOGY

Fretting fatigue test specimens and pads are made of aerospace Al-alloy 2024-T3. The dog-bone type specimens are cut from a 3.2 mm thick plate parallel to the rolling direction of the plate. Two holes of 5.9 mm diameter are drilled and reamed on the specimens at the distance of 40 mm (between the centers of the holes). Some of these specimens are cold expanded using oversized pins with diameters of 5.988 and 6.177 to create cold expansion degrees of 1.5% and 4.7%, respectively. The specimens are polished to minimize any possible surface scratches.

Fretting fatigue test configuration consists of a proving ring, bridge type fretting pads, loading pads and load adjusting bolt. Strain gauges are bonded to the sides of the proving ring to measure the magnitude of the applied normal load. The fretting fatigue pads are cut from AL-alloy 2024-T3 plate parallel to the rolling direction of the plate. The friction force due to sliding between the specimen and pads is measured by strain gauges bonded to the underside of the fretting pads.

Experimental tests are performed on a Dartec Servo-hydraulic testing machine with a loading capacity of 50 kN. Sinusoidal cyclic loads with a maximum load of 6 and 10 kN and load ratio of 0.1 are applied on the specimens at the frequency of 12 Hz. Normal loads of 200 N and 400 N on each fretting pad feet are applied on the load pads through the load adjusting bolt, resulting in nominal contact pressure of 8.33 and 16.66 MPa, respectively. Therefore, 4 series of tests regarding longitudinal fatigue load and normal contact load are conducted on three batches of “as drilled” (0% cold expanded), “1.5% cold expanded” and “4.7% cold expanded” specimens.

In order to better understand the cold expansion process

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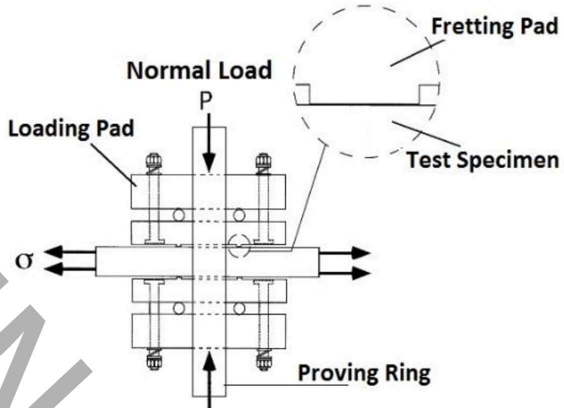


Fig. 1. Schematic of the fretting fatigue test fixture

and its effect on material deformation and residual stress distribution around the hole edge, finite element analyses are carried out. Three-dimensional (3-D) finite element models are generated by employing the ANSYS finite element package.

3. RESULTS AND DISCUSSION

All the test conditions and results on three batches of the specimens are summarized in Table 1. According to this table, Cold Expansion (CE) size is an important factor in the fretting fatigue life of the specimens. The maximum fatigue life has been achieved by applying 1.5% Cold expansion.

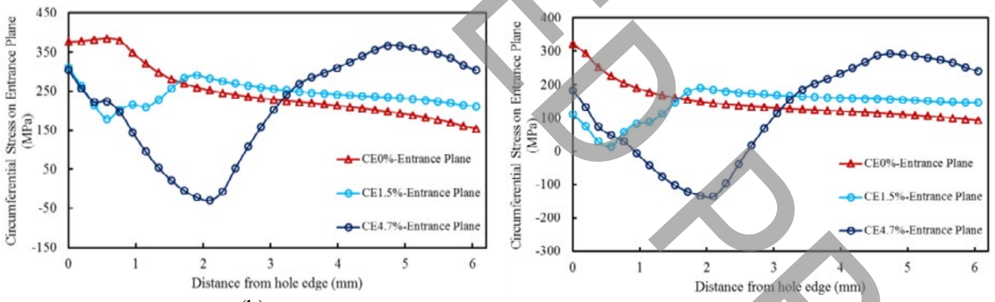
The distribution of circumferential stress on the specimens (Fig. 3) indicates that by applying the cold expansion the circumferential stress decreases around the hole edge. The level of reduction is higher for 4.7% cold expansion. Hence, a higher level of cold expansion reduces the possibility of crack initiation on areas near the hole edge. On the other hand, on areas far from the hole edge, increasing the level of cold expansion intensifies the circumferential stress. Since fretting fatigue specimens are subjected to multi-axial loads, Smith-Watson-Topper (*SWT*) parameter is employed [4] for comparing the fretting fatigue strength of the specimens. This parameter can be derived through Eq. (1).

$$SWT = \frac{\sigma_{n\max}\,\Delta\varepsilon_{n\max}}{2} \qquad (1)$$

Distribution of the *SWT* parameter on the entrance plane of the specimens subjected to 10 kN longitudinal load (Fig. 3 b) reveals that the possibility of fatigue crack initiation in

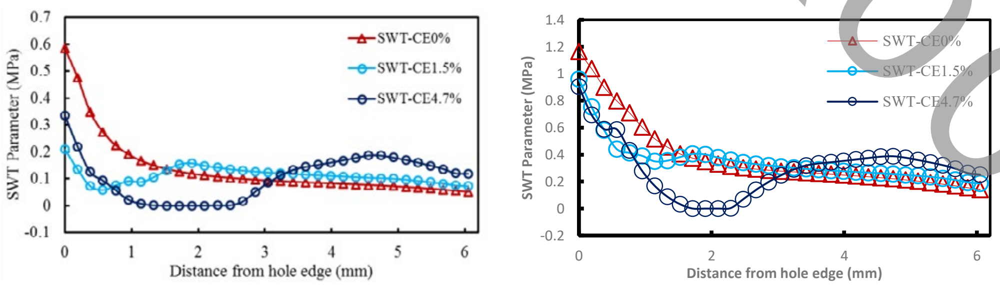
Table 1. Summary of the test results

CE size (%)	Stress (MPa)	Normal load (N)	Life (Cycles)	*Qmax/P* Entrance plane	*Qmax/P* Exit plane
0	104	400	240000	0.184	0.181
0	104	400	263600	0.180	0.182
1.5	104	400	415000	0.177	0.175
4.7	104	400	239300	0.190	0.151
0	170	400	41200	0.291	0.291
1.5	170	400	49900	0.282	0.287
4.7	170	400	39500	0.298	0.246



(b) (a)

Fig. 2. Circumferential stress distribution on the entrance plane of specimens at a) 6 kN & b) 10 kN axial load



(a) (b)

Fig. 3. *SWT* Parameter distribution on the entrance plane of specimens at a) 6 kN & b) 10 kN axial load

this case is higher on the edge of the hole for all specimens. On the other hand, when the longitudinal load is equal to 6 kN, the value of *SWT* parameter near the hole edge on 0% CE specimen is much higher than its value on the cold expanded specimens, hence the fatigue crack is intended to initiate on the hole edge on this specimen. On areas away from the hole edge, the value of *SWT* parameter on 4.7% CE specimen is higher than the 1.5% CE specimen, which increases the possibility of fretting fatigue crack initiation on this specimen. This is in accordance with the obtained results from the experiments (Table 1).

4. CONCLUSIONS

The obtained results show that the high degree of cold expansion does not increase fretting fatigue life, while it increases plain fatigue life by retarding crack propagation. Moreover, the mode of fatigue failure depends on the level of longitudinal loading. Plain fatigue failure is dominant on specimens subjected to high fatigue loads, while fretting fatigue failure is observed on specimens exposed to lower cyclic loads. The numerically obtained results revealed that on an area far from the hole edge, where the fretting fatigue cracks are initiated, the tensile residual stress is superimposed to the tensile fatigue load and makes the plate to be prone to fretting fatigue.

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