Effect of double cold expansion on the fatigue life of rivet hole

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Abstract— The use of riveting as assembly technique, especially in the aeronautical construction, requires the implementation of several holes in aluminium alloy sheets, which leads to a stress localization in the drilled zones and affect the fatigue life. The cold expansion technic is largely employed to obtain improvement in fatigue life of rivet holes. This paper presents the results of an experimental work whose main objective was to evaluate the new enhancement of fatigue life by double cold expansion process of rivet holes.

Keywords— Crack propagation, double cold expansion, fatigue life, rivet hole.

I. Introduction

THE aeronautical structures components are generally assemblies by rivet which lead to geometrical discontinuities and to a stress concentration zones, the risks of initiation and propagation of the fatigue cracks are located close to these zones. The cold expansion of rivet hole is a mechanical technique, an oversized ball or tapered pin can be forced through the hole locally yielding the material to create a plastic region. The resulting compressive residual stresses around a hole edges is very beneficial at resisting fatigue, it can delay cracks initiation and slow their propagation. Several authors [1]-[4] have shown the beneficial effect of the cold expansion technique used to enhancing the fatigue life of rivet holes but few studies have examined the effect of double cold expansion on cracks propagation and fatigue life. The main objective of this work is to evaluate the new enhancement of fatigue life by double cold expansion.

II. Experimental Condition

A. Material properties

The material used in this study is an aluminum alloy AERO TL 2024-T3. The mechanical properties of this alloy are given in table 1.

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TABLE I
MECHANICAL PROPERTIES OF ALUMINUM ALLOY 2024-T3

Ultimate strength	476 MPa
Yield strength	378 MPa
Displacement	18.1 %
Elastic Modulus	72.22 GPa
Poisson's ratio	0.33

B. Specimens geometry

The specimen geometry and dimension are shown in Fig. 1

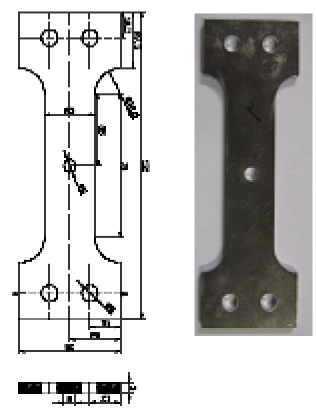

Fig. 1 Specimens geometry and dimension (mm)

C. Double could expansion process

To achieve the double cold expansion two tapered pin were forced through the hole in opposite direction (Fig. 2). The degree of cold expansion (DCE) for the two pass is 4.5%. It is defined by the following equation[5].

$$DCE\% = \frac{(D-d)}{d} \times 100 \qquad (1)$$

Where, d and D represent the diameter of the drilled hole and the cylindrical part of the pin. The final diameter of the obtained hole is 6 mm. Yielding the material by this process create a plastic region, when the surrounding material which is elastically deformed, springs back from the expanded state the yielded material contracts resulting in compressive tangential residual stress around hole. This residual stress will be measured using X-ray diffraction. The pin was pushed through the hole using a 10 KN Instron fatigue machine.

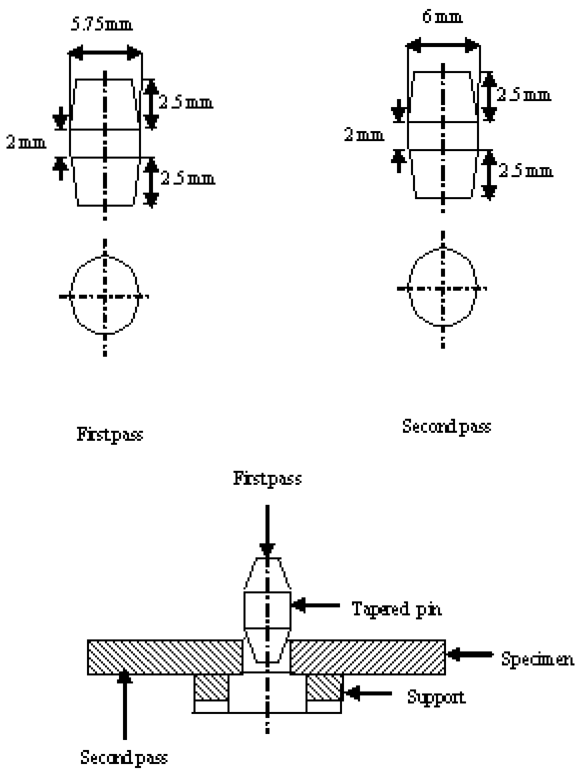

Fig. 2 Double cold expansion process using tapered pins

III. Experimental Results

A. Measurement of residual stresses caused by tapered pins using X-ray diffraction

The X-ray diffraction measurements were performed on a 4-circle goniometer, on both faces of the specimen, entrance and exit faces for each pass. Each measured point corresponds to the centre of one irradiated rectangle area of 2 X 1 mm ^{2} (1mm in the radial direction). The aluminium (422) reflection was used at a diffraction angle of $2\theta = 137.44°$. This means a mean depth penetration of 30 μm for the X-ray radiation. The residual stress results are presented in Fig. 3

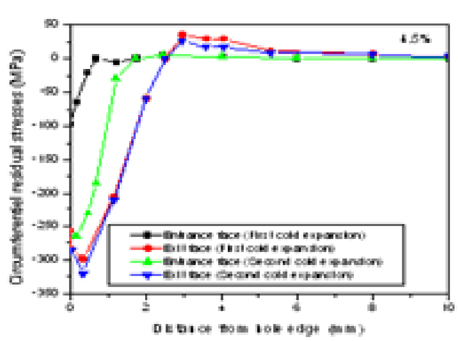

Fig. 3 Residual stresses distribution for the first and the second pass of cold expansion process

We can see clearly the benefic effect of a second cold expansion to enhancing the compressive residual stresses level on entrance face used for the first cold expansion.

B. Fatigue test

Fatigue tests were carried out using constant amplitude, sinusoidal cycling loads with a load ratio R of 0.1. The fatigue tests were run at a frequency of 20 Hz in a servo hydraulic Instron machine. The fatigue tests parameters must be selected in such way that the maximum stress level for all tests was 96 MPa (29.26 % of the yield stress) which corresponds to a load of 12 KN. Eight fatigue tests will be made for each specimen batch (without cold expansion, with cold expansion one pass, with cold expansion double pass). All fatigue lives reported on figure 4 correspond to specimen failure. For specimen with first pass only, the cracks which preceded the failure were firstly initiated on the entrance faces where the values of the residual stresses are weaker compared to the exit faces.

C. Fatigue life comparison

Fig.e 4 present the Wöhler curves of three specimen's batches (Without cold expansion, with one pass of cold expansion and with double pass in opposite direction). As the fatigue results show the cold expanded specimens (one pass) generally achieved a fatigue life improvement of almost 7 times compared to specimens with no expanded holes. The increase in fatigue life at low alternating stresses is greater than at high alternating stresses. With the double cold expansion in opposite direction, fatigue life enhancement can reach 11 times (4times again compared to one pass). These results showed the beneficial effect of the double cold expansion for a new improving of fatigue life.

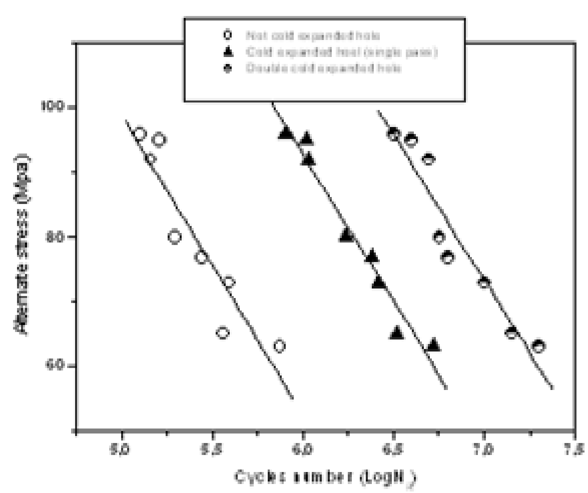

Fig. 4 Wöhler curves for the three batches of specimens

D. Cracks growth comparison

During the fatigue tests many images were acquired in order to locate the crack initiation and propagation. A camera with 4x zoom and a resolution of 4 million of pixels, interfaced with a computer, was used. The curves of Fig. 5 and 6 show that crack initiation in the cold expanded specimens (one pass) make a delay of 6 to 7 times compared to specimens with not expanded hole.

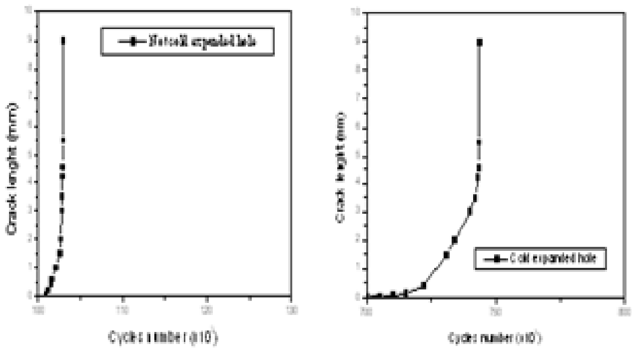

Fig. 5 Comparison of cracks growth (Not expanded hole and cold expanded hole – Single pass)

A new delay of crack initiation of 10 times (Fig. 6) was found with the use of double cold expansion process. In addition the crack growth is very slow for the double cold expanded specimens. The recorded delay in the crack birth and growth show the beneficial effect of the double cold expansion on enhancing fatigue life.

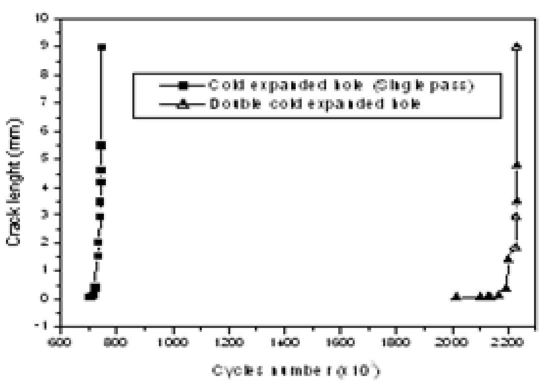

Fig. 6 Comparison of cracks growth (Single pass and double pass)

IV. Conclusion

Experimentally, by the X-ray diffraction measurements, it has been found that for single pass of the tapered pin, residual stresses are low at the entrance face of the pin and maximum at the exit face. Fatigue tests have showed also the beneficial effects of compressive residual stresses and that firstly cracks are initiated on the entrance face where the residual stresses are low compared to those at the exit face. For these raisons, the purpose of this work was to study the effect of the double cold expansion of rivet hole on fatigue life of rivet hole of an aluminum alloy 2024-T3. The obtained results have shown that we can enhancing the level of residual stresses at the entrance face by double cold expansion process in opposite direction which can delay the cracks initiation and propagation at this face.

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