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Numerical study of double cold expansion of the hole at crack tip and the influence on the residual stresses field

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Abstract

Hole cold expansion (HCE) is an effective method to prolong the fatigue life of mechanical structures because it introduces residual compressive tangential stresses around the expanded hole. In the present work, experimental and numerical studies have been carried out in order to analyse the effect of the application of both single and double HCE procedures, on the subsequent fatigue life of 6082-T6 aluminium alloy. In the double HCE experiments, the second expansion was conducted both in the same direction (SESD) and in the opposite direction (SEOD) of the first expansion, employing a rigid ball of a diameter slightly larger than that used in the first expansion. The distribution of the residual tangential stresses resulting from the double expansion procedure is compared with that obtained after the application of a single expansion. The results obtained indicate that the SEOD method can give rise to an improvement in the fatigue life of the material.

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Keywords: Hole cold expansion; Residual stresses; Fatigue life; Aluminium alloys; Fastener hole

1. Introduction

The hole cold expansion method (HCE) has been the most commonly used technique, employed in the past few years, to improve the fatigue life of fastener holes. Numerous investigations have explored the effectiveness of the process of inhibiting the initiation and growth of fatigue cracks [1–5]. The HCE method leads to a prolongation of fatigue life since the hole, drilled at the crack tip, decreases the notch sharpness, whereas its subsequent cold expansion induces a residual compressive stress field around its vicinity. In this study, the HCE is carried out by inserting an oversized rigid steel ball from one side (entry face) of the holed plate, followed by the removal of the ball from the other side (exit face). The degree of cold expansion is thus defined by the following relation:

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

where d and D represent the diameter of the drilled hole and rigid ball, respectively.

Bernard et al. [6] have conducted an investigation on the expansion of fastener holes in samples of a 7475-T7351 aluminium alloy, using two successive expansion (DCE = 5.58% and 4.8%). The procedure that was used to improve the fatigue resistance of the mechanic structures after the application of the first expansion was the re-expansion of the hole, by passing a mandrel through it, both in the same and in the opposite direction to the first expansion. A single expansion with a DCE = 5.58% gave rise to a prolongation of the fatigue life of 2.4 times greater than that achieved

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Nomenclature

HCE	hole cold expansion	d	drilled hole diameter
SESD	second expansion applied in the same direction as the first one	ρ	hole radius
SEOD	second expansion in the opposite direction to the first one	σ_θ	residual tangential stress
DCE	degree of cold expansion	$\sigma_{\theta\,\max}$	maximal compressive residual tangential stress
ZCRS	size of the compressive residual stress zone	$\sigma_{\theta\,\mathrm{edge}}$	compressive residual tangential stress at the hole edge
ZPD	size of the plastic deformation zone	σ_y	yield stress of the material
D	final diameter = 6 mm (or rigid ball diameter in experimental tests)		

by only drilling a hole. Also, it was observed that the re-expansion of the hole produced an additional improvement in fatigue life, in comparison with the initial expansion and that the delay in crack propagation was not affected by the direction of second expansion.

In the experimental studies of Ghfiri [7], fatigue cracks were observed to appear first at the entry side of steel ball passage. This result was accounted for by the non-uniformity in the tangential residual stress distribution through the specimen thickness [3,5]. Özdemir and Hermann [8] have also carried out fatigue tests on specimens after HCE, in which the residual stresses were determined by Sachs' boring. It was observed that the residual compressive stresses close to the hole did not rise after applying an initial expansion with a high DCE. This result led to the comparison of the residual tangential stress distribution after the application of both double and single HCE, as well as the analysis of the effect of the application of a second expansion in the opposite direction (SEOD), to overcome the problem of the non-uniformity in the residual tangential stresses distribution through the specimen thickness. The experimental model of Ghfiri [7] has been chosen to simulate the results obtained in the present work.

2. Numerical simulation

2.1. Material used

The mechanical properties of the aluminium alloy (6082-T6) used in the numerical simulation are identified with the Ramberg–Osgood law and are given in Table 1, whereas Fig. 1 illustrates a typical strain–stress curve.

Table 1
Mechanical properties of aluminium alloy 6082-T6

Material	Yield strength σ_y (MPa)	Young's modulus E (GPa)	Poisson's coefficient ν	K (MPa)	Hardening coefficient n
Al 6082A-T6 alloy	250	68	0.3	652	0.85

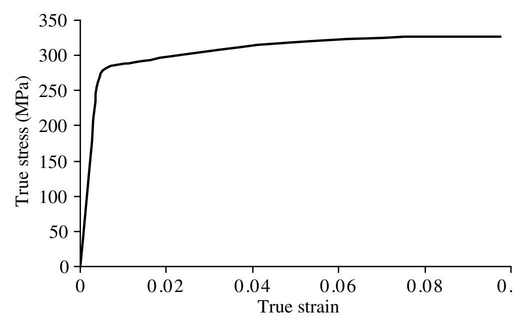

Fig. 1. True stress vs. true strain of the aluminium alloy 6082.

2.2. Experimental HCE process employed

The specimens were cut from plates of 8 mm thick, with the axis parallel to the plate rolling direction. A slit of 1 mm width and 15 mm length was machined from one edge of the specimen. A pre-crack from the slit tip was introduced by cyclic loading and subsequently a hole was drilled at the crack tip. The total length of the slit, plus the pre-crack and hole ($a_0 + \rho$), was of ~27.5 mm, where a_0 represents the crack length and ρ the hole radius. The HCE process was then carried out by forcing a hard steel ball of 6 mm through the hole, as depicted in Fig. 2.

2.3. Experimental process simulation

For numerical modelling purposes, a crack of length a_0 and a hole with radius ρ located at its tip are assumed to be

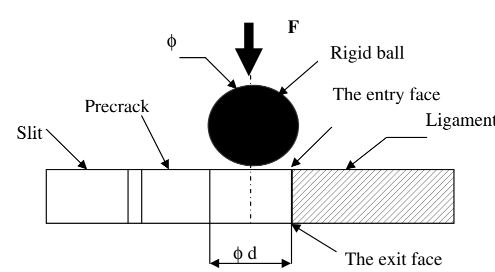

Fig. 2. Cold expansion processes.