The effects of surface corrosion on the fatigue behaviour of aluminium alloy specimens containing cold expanded holes

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ABSTRACT

The purpose of this work was to determine the influence of prior surface corrosion on the fatigue life improvement produced by cold expansion of fastener holes in an aluminium alloy. Results for corroded and uncorroded material are presented and the effects of cold expansion on fatigue endurance and crack propagation rates are evaluated.

INTRODUCTION

Fatigue damage is one of the most important problems in aircraft structures particularly in structural joints, where cracks frequently initiate at fastener holes. Significant improvements in the fatigue life of joints can be achieved by hole cold expansion which introduces residual compressive hoop stresses around the circumference of the hole (see figure 1 ref. 1) which tend to reduce the growth rates of cracks which subsequently form. The cold expansion technique used in this programme was the split sleeve method marketed by Fatigue Technology Incorporated of Seattle,Washington (ref. 2).

In the UK cold expansion is more commonly used as a repair process than as a manufacturing process. Fastener holes are "cleaned out" and reamed oversize if necessary, prior to cold expansion. There is a possibility, that surface corrosion exists on free or mating surfaces due to service exposure, which is not removed during the rework programme. The plastic deformation which occurs during cold expansion could initiate cracks from corrosion pits in the vicinity of the hole and hence reduce its fatigue life enhancing quality. The balancing tensile residual hoop stress field around the compressive region could also cause acceleration of any cracks so formed and hence reduce the effectiveness of the cold expansion process.

This research programme was proposed in order to investigate the influence of cold expansion on corrosion pits in the vicinity of the open holes and quantify any detrimental effect on fatigue endurance caused by corrosion.

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TEST PROGRAMME

Material Specification and Specimen Configuration

The material chosen for this study was the high strength aluminium alloy 7050-T76, used extensively in aircraft structures, the composition and mechanical properties of which are given in Table 1 and 2 respectively (ref 2). A number of sheets of the alloy were protected (uncorroded) whilst others were subjected to normal atmospheric corrosion for a period of approximately two years (corroded) which caused pitting corrosion at the surface of the material. Microscopic investigation revealed corrosion pits varying in size between about 20 μm and 50 μm.

Rectangular specimens, 300 mm x 40 mm, were manufactured from the two material types and each contained a centrally drilled hole. Specimens denoted Plain were drilled and reamed and specimens denoted CX were subjected to about 4% cold expansion prior to the final reaming operation. 4% expansion results in optimum fatigue endurance (ref.4).

The "inlet" and "outlet" sides of the specimen refer to the positions where the mandrel enters and exits the specimen during expansion. For both "inlet" and "outlet" side , a left and a right side have been defined from the hole centre.

	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Zr
Min	90.4	-	1.9	-	1.9	-	-	-	5.7	0.08
Max	87.4	0.04	2.6	0.15	2.6	0.1	0.12	0.06	6.7	0.15

Table 1. Chemical Composition of the 7050-T76

0.2% yield stress	UTS	Elongation	Modulus of Elasticity
555 MPa	582 MPa	11%	69.5 GPa

Table 2. Mechanical Properties of the 7050-T76

Fatigue Testing Programme

Sinusoidal loading at a frequency of 10 Hz was applied to all specimens with a maximum gross stress of 174 MPa at a stress ratio of R = 0.1.

A surface replication technique using cellulose acetate sheet softened with acetone was used to monitor crack initiation and growth both in the bore of the hole and on the specimen surfaces. Crack lengths were measured using a

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shadow graph projector . Crack growth rates were calculated from these measurements using the ASTM seven point polynomial methods (ref.5).

RESULTS

The distribution of fatigue cracks in corroded cold expanded specimens was quite different to that observed in all of the other test types. Maps of crack distributions for a corroded cold expanded specimen are shown in figures 2a (inlet side) and 2b (outlet side) 50 cycles before final failure. It can be seen that cracks not only initiated at the edge of the hole but also in regions remote from the hole. The largest crack was on the right outlet side (figure 2b) which propagated through the plate causing the large breakthrough crack (shown in fig. 2a) to be initiated at a corrosion pit on the left inlet side. Figures 2c (front surface) and 2d (rear surface) are for a corroded plain specimen and show that cracks initiated only from the edge of the hole. Similar distributions to those shown in figs 2c and 2d were observed in uncorroded plain and cold expanded specimens.

The log mean endurance (cycles) for both plain and cold expanded specimens in the corroded and uncorroded conditions are presented in Table 3. It can be seen that the presence of corrosion pits reduced the fatigue life endurance of cold expanded specimens to about one quarter of that for uncorroded specimens, but had little affect on the fatigue life of plain specimens.

The cold expansion does however have a beneficial effect on the specimens tested. The life improvement ratio (log mean endurance of cold expanded specimens/log mean endurance of plain specimens) shows a net increase for both the uncorroded and the corroded specimens, the ratios being 21.65 and 3.20 respectively.

Hole and surface condition	Log mean endurance (cycles)
Cold expanded corroded	119874
Cold expanded uncorroded	507818
Plain corroded	28418
Plain uncorroded	22420

Table 3. Fatigue endurances in 7050-T76

The growth rates of cracks emanating from the central hole are presented in figure 3 for the plain specimens and figure 4 for the cold expanded specimens. The growth rate of cracks emanating from corrosion pits in cold expanded specimens are presented in figure 5. The solid curve shown in this figure represents long crack data for alloy 7050-T76 at an R ratio of 0.1. Figure 6 shows the location of crack origins which caused failure in the corroded cold expanded specimens and also shows the residual hoop stress distributions on the mandrel inlet and outlet faces.

DISCUSSION

It can be seen from Table that the fatigue endurance of plain hole specimens was little affected by the presence of corrosion pits. This is supported by an examination of Figure 3 which shows that the fatigue crack growth rates in plain specimens were similar for both corroded and uncorroded material. This is to be expected as cracks initiated at the edge of the central hole and grew to failure before any significant cracks were observed from pits in the corroded material.

In contrast to this behaviour, significant reductions in the endurance of cold expanded specimens occurred due to the presence of corrosion (see Table 1). As observed earlier, this was due to the growth of cracks from corrosion pits which caused premature fatigue failures from locations remote from the central hole. For cold expanded corroded material, numerous cracks were observed, about 17% of which initiated at the edge of the hole, less than 2% in the compressive residual stress region and about 81% in the tensile residual stress region. About 90% of the cracks which caused failure initiated from corrosion pits in the tensile residual stress region, the majority of which (about 84%) initiated on the mandrel outlet face. This is to be expected as the tensile residual hoop stresses are greater on the mandrel outlet face than on the mandrel inlet face.

The growth rates of cracks from cold expanded holes are presented in figure 4. For the uncorroded material, fatigue cracks on both inlet and outlet faces rapidly decreased in growth rate as the crack length increased. On the inlet face, cracks reached a minimum in growth rate at a length of about 0.75mm and on the outlet face a minimum was reached at a length of about 0.25mm at which point the cracks on the outlet face arrested. The reduction in growth rate at short crack lengths is because the cracks are growing (initially) into a progressively more compressive residual stress field. The different crack growth behaviour between the inlet and outlet faces is due to the different residual stress distributions on the two faces (see figure 1). For the corroded material, the observed crack growth rates initially were similar to those of the uncorroded material (see figure 4) with cracks on the inlet face reaching a minimum in growth rate at about the same crack length. On the mandrel outlet face, however, cracks in the corroded material did not arrest after reaching a minimum in growth rate, but increased rapidly in growth rate as they interacted with long cracks growing from pits.

The growth rates of cracks initiating from corrosion pits, which caused specimen failure, are presented in figure 5. The growth rates are remarkably consistent despite the different locations of crack origin (see figure 6) and hence different residual and applied stress distributions. The stress intensity factor solution for pit crack growth was for cracks growing from semicircular defects in a uniform stress field and hence did not correct for the different stresses present. The solid curve in figure 5 represents the mean of measured long crack data on this material at a stress ratio of R=0.1. The much faster crack growth rates observed in the corroded cold expanded specimens results partly from the increased applied stress due to the proximity of the hole and partly from the tensile residual stresses in the vicinity of the pit. Further work will be undertaken to model the crack growth from pits in residual stress fields which will aim to predict the observed crack growth.

CONCLUSIONS

Corrosion had no significant effect on the fatigue life of open hole specimens containing plain holes.
Cold expansion increased the fatigue life of 7050-T76 specimens containing open holes however the presence of surface corrosion significantly reduced its beneficial effect.
Cracks which caused failure in uncorroded cold expanded specimens started from the edge of the hole on the mandrel inlet side, whilst in the corroded condition cracks which caused failure initiated remote from the hole and on the mandrel outlet face.
This is a significant consideration for the inspection of aircraft structures where such cracks could be overlooked by conventional inspection programmes.

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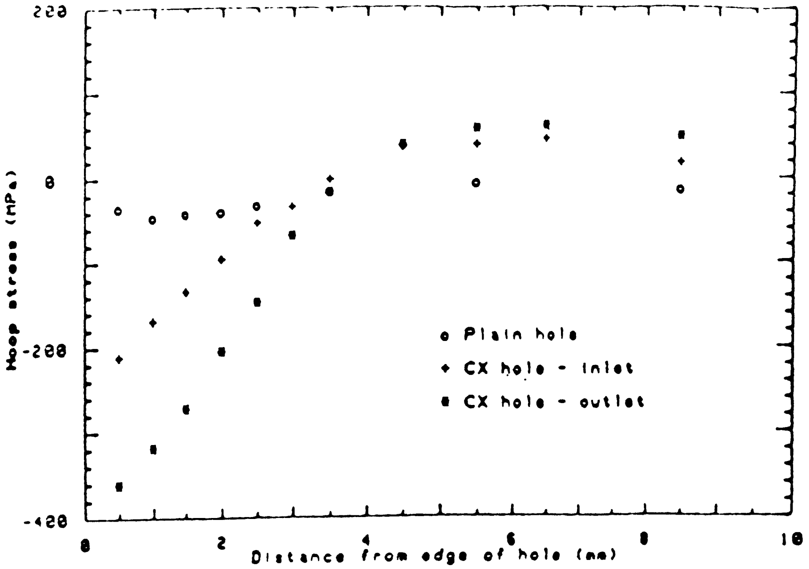
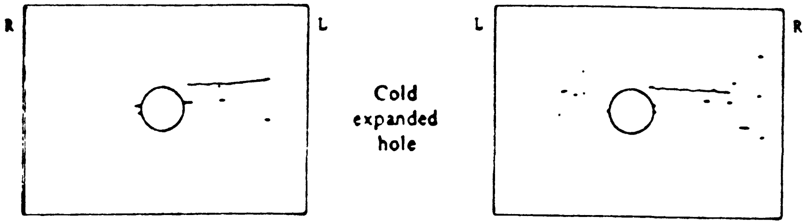
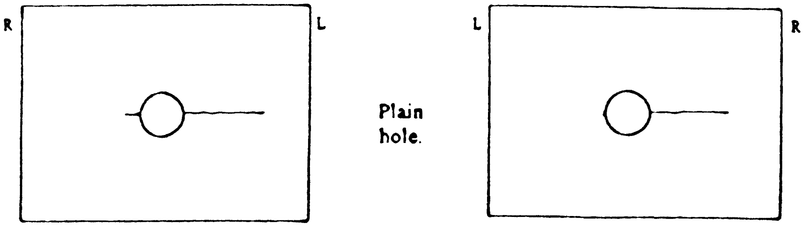


Fig.1 Residual stresses at plain and cold expanded (CX) holes



A Inlet side

B Outlet side



C. Front surface.

D. Rear surface.

Fig.2 Cracks distribution

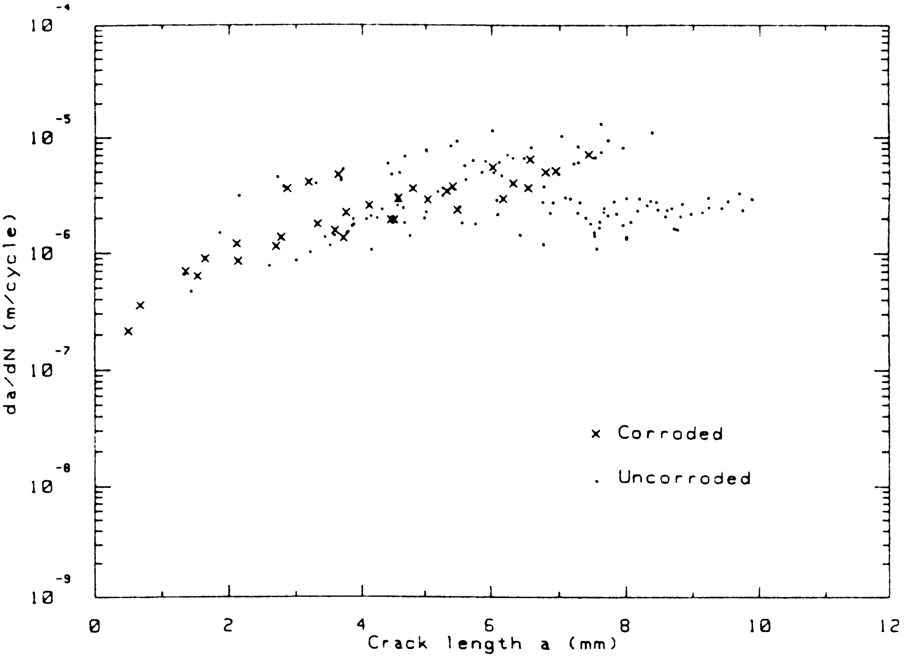


Fig.3 Crack growth rates in plain specimens of corroded and uncorroded material

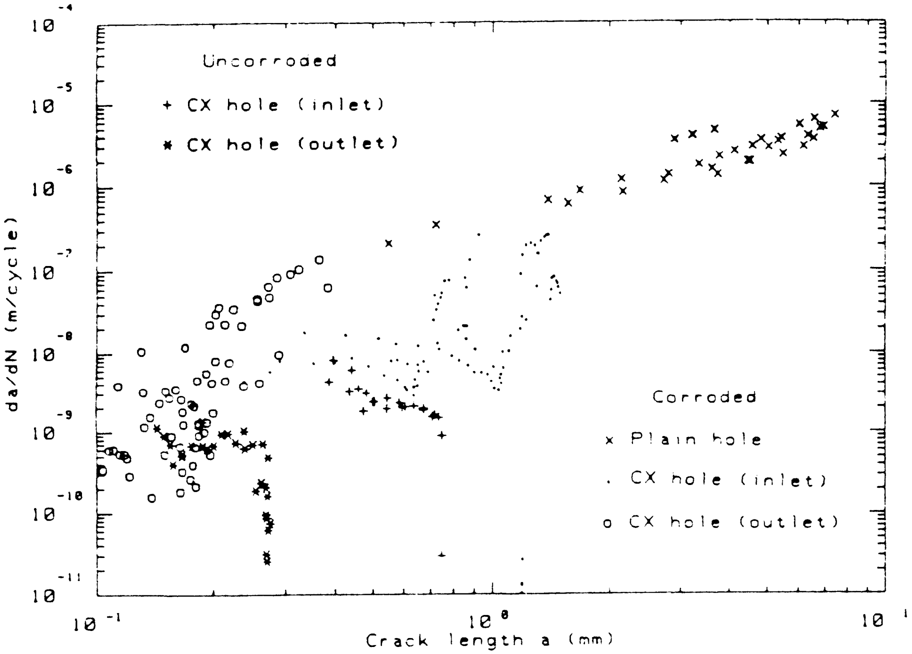


Fig.4 Crack growth rates from plain and cold expanded holes

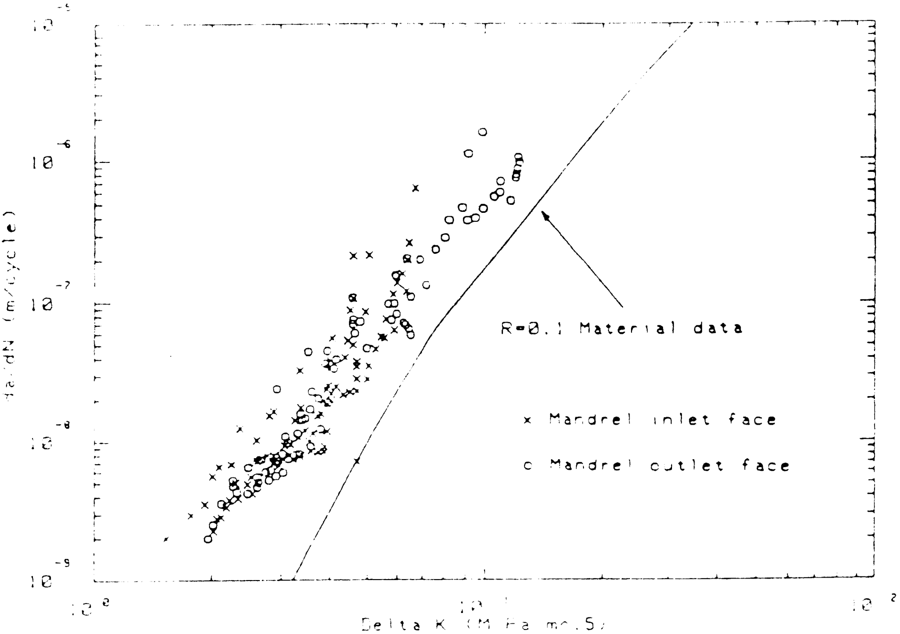


Fig.5 Crack growth rates from pits in cold expanded corroded specimens

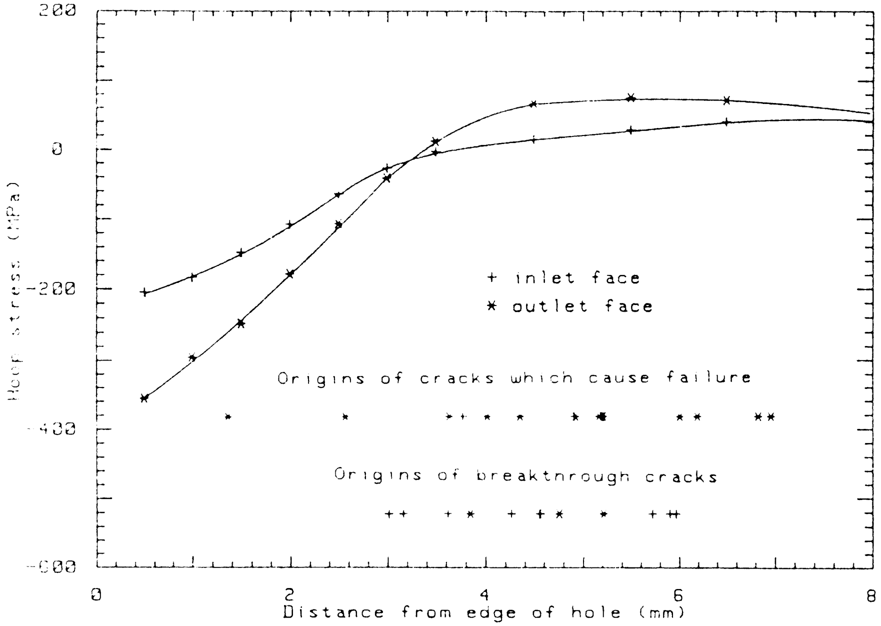


Fig.6 Residual distributions and failing crack origins