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A Short Study of the Effect of a Penetrant Oil on the Fatigue Life of a Riveted Joint

by

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A SHORT STUDY OF THE EFFECT OF A PENETRANT OIL ON THE FATIGUE LIFE OF A RIVETED JOINT

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R. J. Smith

SUMMARY

This Report describes the results of laboratory fatigue tests on riveted joints, half of which had been impregnated with a water-displacing, oil-based penetrant which is commonly being used in airline service to combat corrosion. The results showed that the lives of the treated specimens were significantly shorter than those of the untreated specimens. Further work, however, would be necessary to determine the effect of the penetrant under more realistic conditions over a longer time.

* Replaces RAE Technical Report 73174 - ARC 35284

CONTENTS

1 INTRODUCTION

Corrosion sometimes occurs inside riveted lap joints in the fuselages of civil aircraft. One remedy is to impregnate the joints with an oil-based penetrant which resists the entry of water and displaces water already present. Tests were carried out to establish whether the addition of the penetrant had any effect on the fatigue life of the joint. To limit the testing time, specimens were tested at a high rate of loading as is usual in the laboratory and no attempt was made to represent long term environmental effects.

It was found that the lives of the treated specimens were significantly shorter than those of the untreated specimens. Further work, however, would be necessary to determine the effect of the penetrant under more realistic conditions over a longer time.

2 SPECIMEN

The specimen shown in Fig.1 comprised a lap joint connecting two flat sheets, 0.063 in (1.60 mm) thick, of clad aluminium alloy to specification 2024-T3; the connection was by three rows of $\frac{3}{16}$ in (4.8 mm) diameter countersunk rivets to specification 2014-T4. Before assembly one surface of each sheet was coated with a chemically resistant epoxy primer, BOAC designation PD101.5 and allowed to dry; the other surface was left untouched. The sheets were assembled to represent a typical aircraft lap joint, that is, the primed surface of one sheet faced the unprimed surface of the other. In the case of the treated specimens the mating surfaces of the sheets were sprayed before assembly with a water-displacing, oil-based penetrant to specification PX-24, Defence Standard 68-10/ Issue 1, Ministry of Defence; the untreated specimens were assembled dry. The specimens were manufactured by BOAC in their workshops at Heathrow.

3 TESTS

The specimens were tested in a Schenck resonant fatigue machine, PB10/60. To fit a specimen in the machine, two steel plates with copper shims were clamped to each end of the specimen by eight $\frac{3}{8}$ in (9.5 mm) diameter bolts. The steel plates were connected to the fatigue machine by forked lugs and pins. A photograph of the specimen in the machine is shown in Fig.2. Constant amplitude loading was applied at about 29 Hz such that the specimen was always in tension, and the minimum load was kept above zero by a small amount to avoid loading instability. The investigation covered two loading cases giving peak stresses of 12940 lb/in^2 (89.2 MN/m^2) and 22350 lb/in^2 (154.1 MN/m^2) calculated on the gross cross-sectional area of the sheet; the ratio of the minimum stress to the maximum stress in a cycle, commonly referred to as R, being in each case 0.15.

The results of the tests are shown in Table 1 and an S-N diagram is plotted in Fig.3. All the joints failed by cracking in one of the sheets through an end row of rivet holes as illustrated in Fig.4. Five of the six specimens tested at the higher stress level failed in the sheet with countersunk holes; by contrast, in the tests at the lower stress level only one of six specimens failed in the countersunk sheet. In the case of specimens containing penetrant, it was noticed that on the internal surface of the sheet surrounding each rivet hole, a circular 'pool' of black liquid had accumulated as seen in Fig.4. This presumably was composed of penetrant with fretting debris held in suspension. The dry specimens showed only small traces of black discolouration over a much smaller annular area than for the wet specimens.

4 DISCUSSION

Before discussing the results, it is worthwhile speculating on some possible effects of the penetrant which could influence the fatigue behaviour. These would include the following:-

(1) A reduction in the fraction of the load transmitted by friction between the two sheets and concomitantly an increase in the load transmitted by shear in the rivets.

(2) A change in fretting action due to lubrication of the surfaces and transportation of debris by flotation in the penetrant.

(3) Diffusion of the penetrant into the fatigue cracks, particularly when the fluid has fretting debris in suspension; this might cause mechanical action by providing fulcrum points for leverage near the tip of the crack. Chemical action might occur as well, but would be small in the tests described herein owing to their short duration.

Considering the effects in turn, the effect of increasing the proportion of load taken by the rivets would be to encourage failure through a line of rivet holes. In fact all failures were of this type and it is seen in Fig.3 that the effect of penetrant was to reduce mean endurance at both stress levels tested, which is consistent with the rivets transmitting a greater share of the load. With regard to the alleviation of fretting in the rivet holes, the effect of this would be expected to increase the life of the joint, but the test results indicate that this effect was, if anything, much smaller than the effect of the loss of friction. It is not possible to comment on the effect of penetrant seeping into the crack.

The overall effect of the penetrant was to reduce the mean endurance to 33% at the high stress level and to 50% at the low stress level. However, the purpose of the penetrant, as already mentioned, is to combat corrosion in aircraft in service and in such a situation it might well result in an overall improvement in life.

5 CONCLUSION

The conclusion to be drawn from this investigation is that in the conditions stated, the use of an oil-based penetrant reduced the fatigue endurance of riveted joints to 33% at high stress and to 50% at low stress when they were tested at a high loading frequency in the sheltered conditions of a laboratory. A different environment and a time of operation extending over years instead of hours, might produce a different result. Likewise, any other change in the conditions, such as the use of a different type of penetrant, might alter the result. Nevertheless, sufficient change of performance has been demonstrated to warrant careful examination of the use of oil-based penetrants in any particular case.

Table 1

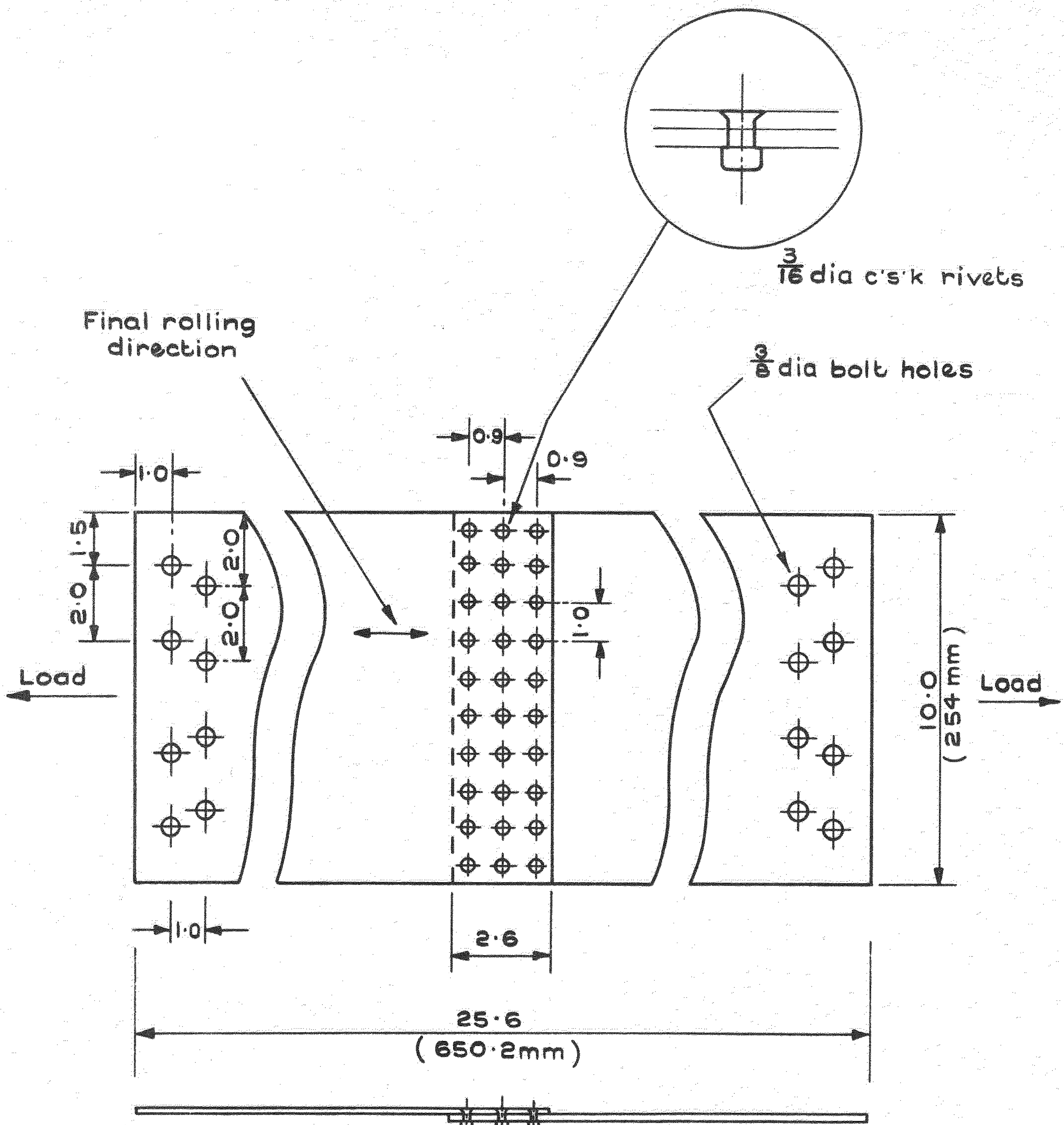
TEST DETAILS

Test No.	BOAC's specimen No.	Condition	Gross peak stress lb/in^2 (MN/m^2)	Cycles to failure	Type of failure*
1	1	Dry	12940 (89.2)	1 122 500	1
2	2	Dry	12940 (89.2)	670 200	1
3	3	Dry	12940 (89.2)	358 400	1
4	10	with penetrant	12940 (89.2)	487 400	1
5	11	with penetrant	12940 (89.2)	336 100	1
6	12	with penetrant	22350 (154.1)	25 200	2
7	4	Dry	22350 (154.1)	69 800	2
8	5	Dry	22350 (154.1)	Fatigue machine developed a fault - Test discounted	
9	6	Dry	22350 (154.1	86 200	1
10	13	with penetrant	22350 (154.1)	25 200	2
11	7	Dry	22350 (154.1)	75 600	2
12	14	with penetrant	22350 (154.1)	26 500	2
13	15	with penetrant	12940 (89.2)	246 500	2

Note: The value of R, i.e. the ratio of the minimum stress to the maximum stress in each cycle, was 0.15 for all the tests.

* Type 1 - Fracture along line of rivet holes in sheet containing tails of rivets.

* Type 2 - Fracture along line of rivet holes in sheet containing countersunk heads of rivets.



Material :– 2024–T3 Alclad
Thickness :– 0·063in (1·6mm)

Dimensions :– inches (unless otherwise stated)

Fig.1 Test specimen

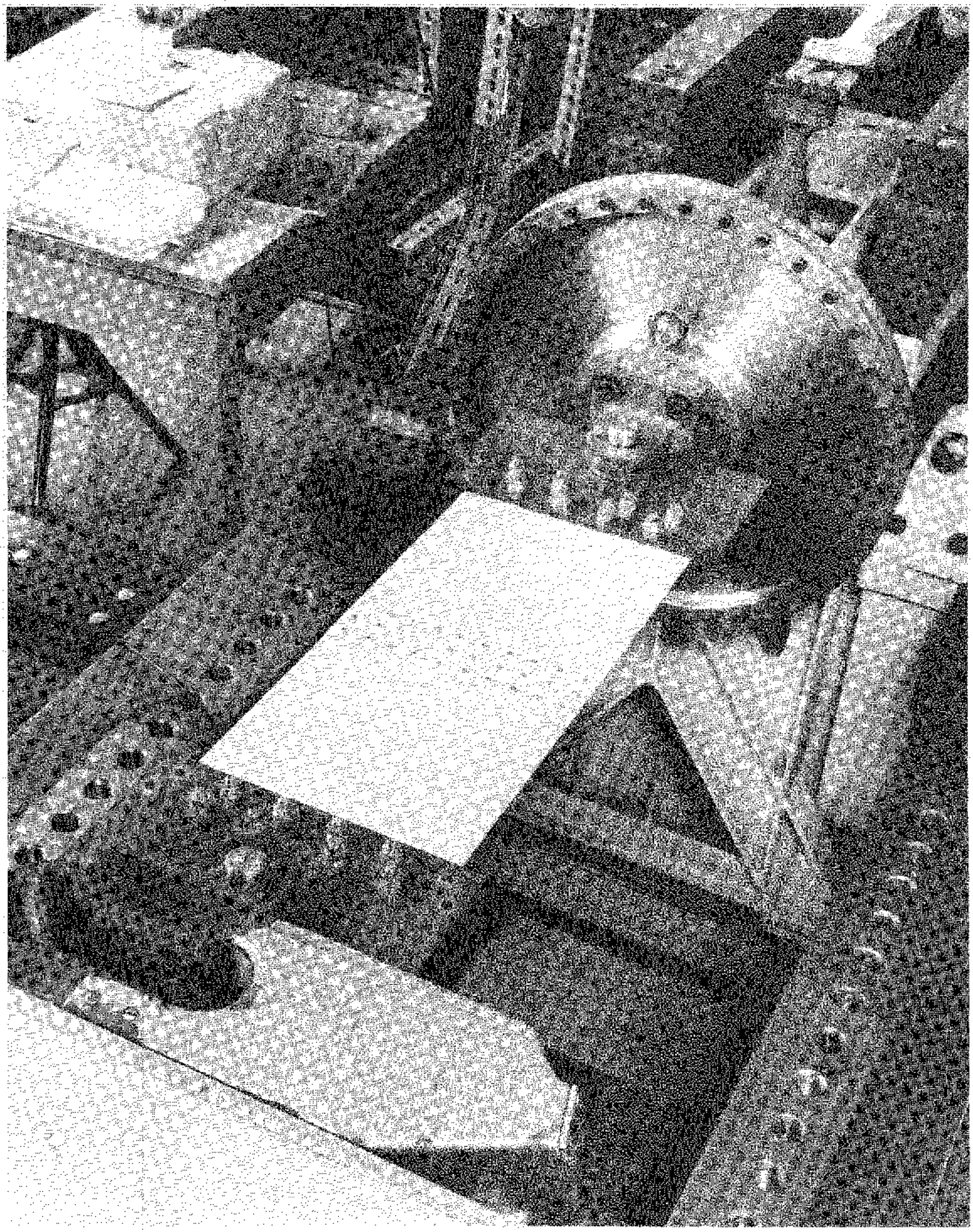


Fig.2 Specimen in fatigue machine ready for testing

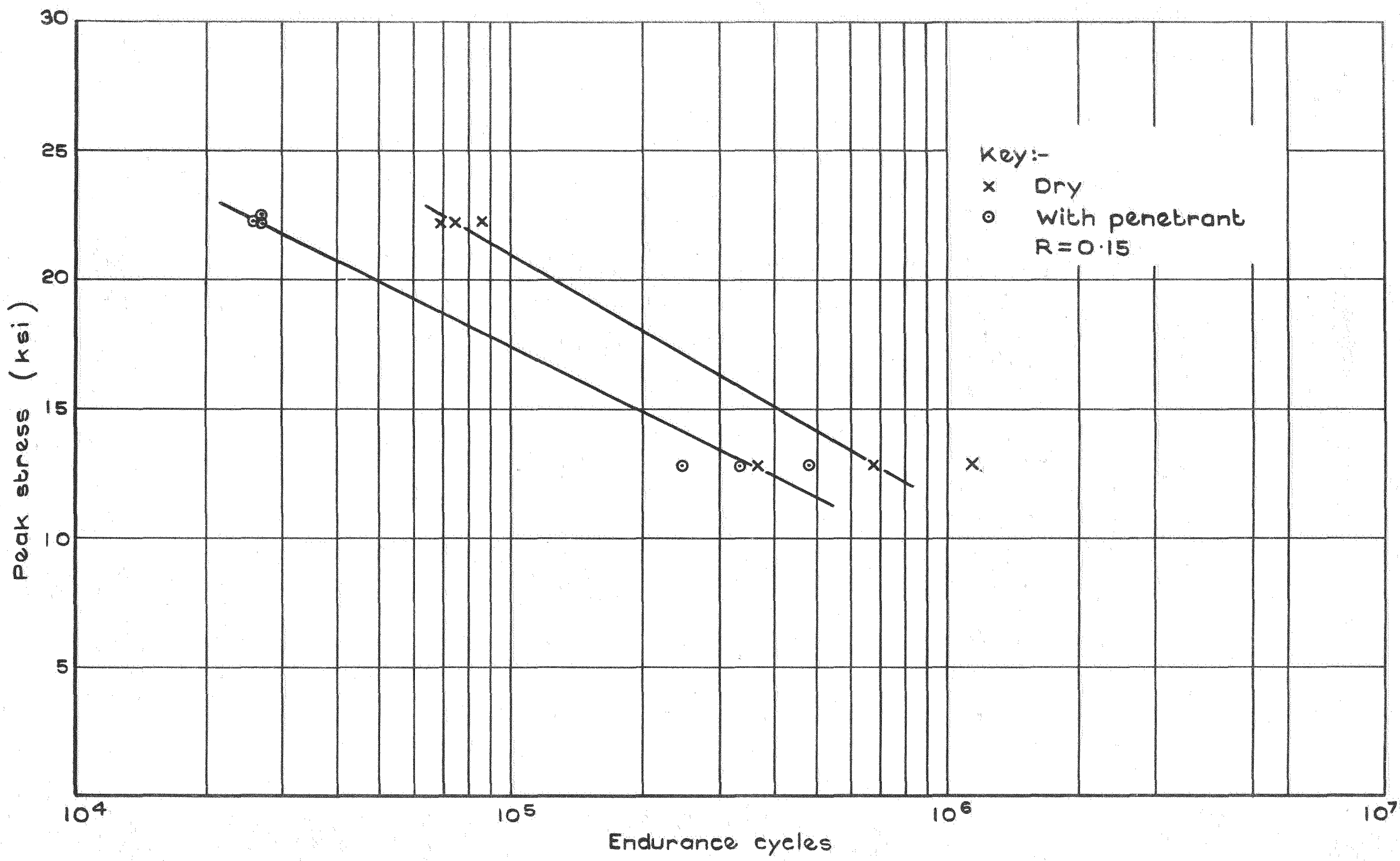


Fig.3 Plot of endurance versus stress for riveted joint specimens

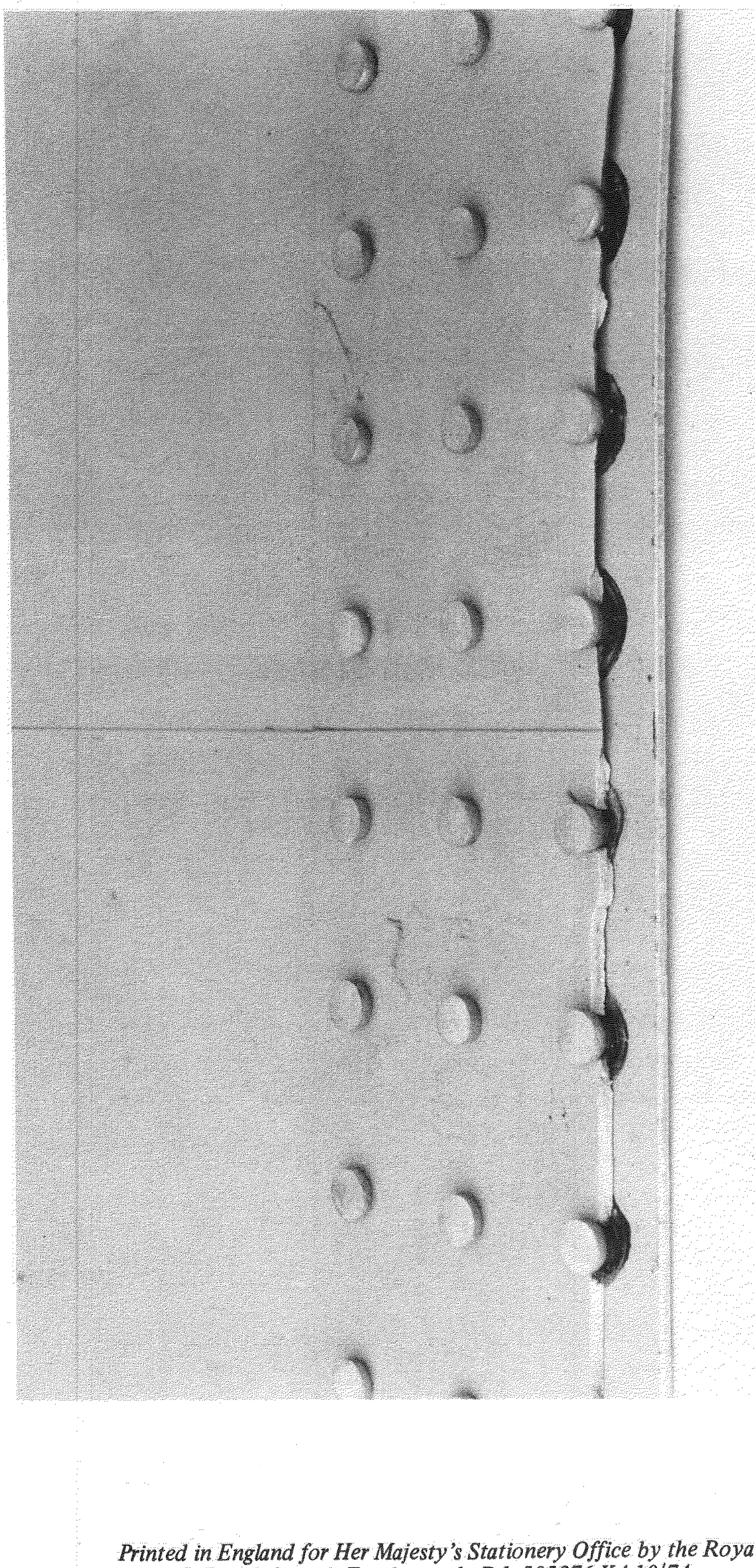


Fig.4 Fracture line showing pools of dark liquid surrounding rivets

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