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Fatigue Behavior of Bolted Joints in RR58 Aluminium Alloy with and without Interfay Sealant

by

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FATIGUE BEHAVIOUR OF BOLTED JOINTS IN RR58 ALUMINIUM ALLOY WITH AND WITHOUT INTERFAY SEALANT

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SUMMARY

Simple bolted joint specimens in DTD 5014 (RR58) aluminium alloy were tested in fluctuating tension of constant amplitude. The effect of introducing a flexible sealant between the faces of the joint was significant: at high alternating stress levels life was decreased, while at low alternating stress levels life was increased.

* Replaces RAE Technical Report 76006 - ARC 36726.

CONTENTS

Conversions: $1000 lb(f)/in^2 = 6.894 MN\,m^{-2} = 0.689 Hb$

1 INTRODUCTION

Lap joints both with and without an interfay sealing compound are commonly used in aircraft structure. Whilst sealant is beneficial in suppressing fretting between the faying surfaces and in excluding corrosive environment from the joint, it is nevertheless a possible disadvantage that the flexibility of the sealant will result in less load being transmitted by clamping friction between the faying surfaces and more load being taken by the fasteners in shear. Under fatigue loading a greater degree of load transfer at the fasteners means increased load at points of high stress concentration which is likely to be deleterious to fatigue performance.

It is obviously important therefore to assess the relative fatigue performance of dry and sealed joints but no evidence is known of any systematic comparison having been made. However the opportunity has arisen to compare the performance of two similar joints of simple design, one with sealant and one without, using data extracted from two different test programmes. These programmes were primarily aimed at providing information for Concorde; one was carried out by Hawker Siddeley Aviation Ltd. under Mintech Contract and the other by Structures Department RAE. The results of the latter programme have been published previously[1].

The data are restricted to RR58 aluminium alloy tested under constant amplitude loading but the comparison is valuable in demonstrating that the interfay sealant significantly affects the mode of fatigue failure and the endurance such that the relative performance of the joints is dependent on the level of the applied loading.

2 MATERIALS AND SPECIMENS

The material used for all specimens was a fully heat treated Al 2% Cu alloy to specification DTD 5014 (RR58) in the form of rectangular extruded bar. One melt of the material was used for the specimens tested at HSA Ltd. and another melt for those tested at RAE; for brevity these specimens will be referred to as HSA joints and RAE joints. The chemical cpmposition and tensile properties of the material given in the British Standard Specification are reproduced in Table 1. All specimens were extracted in the longitudinal direction from the bar materials and the bars were selected so that the relatively coarse grain at the surface of the bars was shallow enough to ensure its elimination during machining of specimens.

The HSA and RAE joint specimens (see Figs.1 and 2) both utilised double-ended lug specimens as centreplates to which steel sideplates were clamped by bolts tightened on assembly to provide a clamping load consistent to within ±5%. The outer ends of the sideplates were clamped to the end fittings of the fatigue machines.

For the HSA joint illustrated in Fig.1, the centreplates were anodised to BAC MP 2028 [2] and painted with one coat of barium chromate primer (ICI F580/2022) to BAC MP 1261 [3]. The steel sideplates were also painted with the primer. On assembly a fluorocarbon polymer interfay sealant, in the form of Viton Non-reactivating tape of type PR 1720X/35S, was placed between the sideplates and centreplate according to BAC MP 219 [4] so that there was good adherence between them. Upon applying sealant the specimen was jointed and the bolts were wet-assembled to BAC MP 245 [5]. By the use of Proof Load Indicating (PLI) washers the bolts were tightened to produce an average core stress in the bolt of 81000 lb/in^2, equivalent to a clamping load of 7500 lb. After assembly the specimens were stored at room temperature for at least two weeks before commencing tests to ensure a degree of curing of the sealant.

The RAE joint, shown in Fig.2, was somewhat larger than the HSA joint but of similar construction. It was assembled from bare metal components, thoroughly degreased with an organic solvent, and no interfay sealant was used. In this case accurate bolt tension was achieved by measuring bolt extension via small steel balls set in the end faces of the bolt. A standard extension of 0.0020in was estimated to correspond with a core stress of 83000 lb/in^2, equivalent to a clamping load of 18500 lb.

3 FATIGUE TESTS

All fatigue testing was at ambient temperature in fluctuating tension ($0 < R < 1$) of constant amplitude. RAE joints were tested in a Schenck PP6D resonant fatigue machine and HSA joints in a Losenhausen multipoint hydraulic fatigue rig (see Fig.3). A range of stress levels was chosen to give endurances in the range 10^4 to 10^7 cycles and for each S-N curve the mean stress was kept constant. All stresses quoted are based on the net cross-sectional area.

Specimens were tested until failure or to 10^7 cycles. Whereas all HSA joints failed through the net cross section, cracks being primarily initiated by fretting between bolt and lug hole, RAE joints failed through the gross section by cracks initiated at many points over a circular arc of fretting damage at the boundary of the clamping area (see examples of centreplate failures illustrated in Fig.4).

Tables 2 and 3 give details of fatigue stress and number of cycles to failure for the HSA and RAE joints respectively. Fig.5 compares the corresponding S-N diagrams in which, for the sake of clarity, the endurances of individual RAE joint tests are not plotted - the S-N curve is based on a faired line through the log mean endurance at each stress level and the overall scatter in results is indicated.

4 EFFECT OF INTERFAY SEALANT ON ENDURANCE

A measure of the effect of interfay sealant on endurance can be obtained by comparing the fatigue performance of the RAE joint which contained no interfay and the HSA joint which did. As the two joints are of somewhat different size and design, such a comparison is only meaningful if other differences between the joints are not significant to the fatigue performance. Differences between the two joints in geometry, size, clamping load and surface finish are shown in the following table:

Parameters	RAE joint	HSA joint
Geometry: d/D ratio	0.39	0.39
a/D ratio	0.63	0.49
t/D ratio	0.19	0.18
Size: Bolt diameter inch	0.625	0.375
Gross section in^2	0.480	0.163
Core stress in bolt lb/in^2	83000	81000
Clamping load lb	18500	7500
Surface condition	Bare metal	Anodised and painted

With regard to geometry, lug fatigue strength is primarily dependent on the ratio of the diameter of pin to specimen width (d/D)[6,7]. The ratios of bearing area to width (a/D) and thickness to width (t/D) are of secondary importance. It is seen in the table that only the a/D ratios are significantly different but it is known from previous work by the author investigating lug geometry effects[7], that this magnitude of difference is unlikely to be significant. The applied clamping load for the RAE joint is approximately two and a half times that for the HSA joint and is approximately in correct proportion to its greater dimensions. Turning to differences in surface condition, although these are of importance to load transfer, they are considered to have no effect on fatigue sensitivity as, in both types of joint, crack initiation was from positions of metallic contact and was influenced by fretting.

Fig.5 presents mean S-N curves for the two joints. In the case of the HSA joint individual test results have been plotted whereas for the RAE joint, because of the large number of tests, scatter bands are indicated which include all results at each stress level. It is seen from Fig.5 that the effect of including interfay in a joint is to reduce fatigue endurance by a factor of about 10 at the highest stress level studied but tends to improve endurance at low alternating stress levels.

The modes of failure in the two types of joints were described in section 3; all RAE joints failed through the gross section (see Fig.4), and all HSA joints through the net cross section. In the RAE joint, fatigue cracks nucleated in the centreplate at many points over a circular arc of fretting damage corresponding to the boundary of the clamping area. When the RAE joints were dismantled after failure, the bore of the lug showed no signs of bearing or fretting and it is deduced that virtually the whole of the applied load was transmitted by friction between the sideplates and centreplate. By contrast failure of the HSA joint through the hole indicates that a proportion of the applied load was transmitted via the bolt in the lug hole. Presumably at the high load amplitudes the flexibility of the interfay allowed significant bearing of the bolt in the hole and at the low load amplitudes although the proportion of load transmitted in this way was much smaller, failure at the gross section was effectively prevented by the action of the interfay compound in suppressing fretting between the faces of the joint.

From the above discussion it is concluded that the effect on endurance of introducing a flexible sealant between the faces of a bolted joint is to decrease life significantly at high stress levels by encouraging the transfer of load via the bolt in the hole where stress concentration is high, but to increase life at low stress levels and raise the fatigue limit by suppressing fretting between the faces of the joint.

5 CONCLUSIONS

Simple bolted joint specimens in DTD 5014 (RR58) aluminium alloy were tested in fluctuating tension of constant amplitude. The effect of introducing a fluorocarbon polymer interfay sealant in the joint was significant: at high alternating stress levels life was decreased while at low alternating stress levels life was increased.

Table 1

CHEMICAL COMPOSITION AND TENSILE PROPERTIES OF DTD 5014

Chemical composition

Element	% by weight	
	Minimum	Maximum
Cu	1.8	2.7
Mg	1.2	1.8
Si	-	0.25
Fe	0.9	1.4
Mn	-	0.2
Ni	0.8	1.4
Zn	-	0.1
Pb	-	0.05
Sn	-	0.05
Ti + Zr	-	0.2
Aluminium	-	Remainder

Heat treatment

(1) Solution treat at 530°C for 4 to 24 hours, quench in water.

(2) Precipitation treat at 200°C for 16 to 24 hours, cooling in air.

Minimum tensile properties

0.2% proof stress = 50000lb/in^2

UTS = 61000lb/in^2

Elongation = 7%

(on 2in gauge length).

Table 2

FATIGUE TEST RESULTS - HSA JOINT SPECIMEN

Clamping stress 81000 lb/in^2, full Viton interfay treatment

S-N curve Reference Number	Average stress on net section lb/in^2	Specimen Number	Endurance (N) 10^5 cycles	Log. mean endurance 10^5 cycles
9A/L/6	25000 ± 20000	4AL4	0.093	0.147
	"	4AL3	0.323	
	"	4AL2	0.105	
	25000 ± 15000	4AL5	0.167	0.801
	"	4AL6	1.79	
	"	4AL7	1.72	
	25000 ± 10000	4AL8	37.0	7.20
	"	5AL1	1.10	
	"	5AL2	9.18	
	25000 ± 7000	5AL3	100^{UB}	100+
	"	5AL4	100^{UB}	
	"	5AL5	100^{UB}	

UB = Unbroken

Table 3

FATIGUE TEST RESULTS - RAE JOINT SPECIMEN

Clamping stress 83000 lb/in^2, joints assembled dry and degreased

Average stress on net section lb/in^2	Specimen Number	Endurance (N) 10^5 cycles	Log. mean endurance 10^5 cycles
24600 ± 19800	51101	1.63	1.84
"	51105	1.22	
"	51110	0.899	
"	51115	1.56	
"	53401	1.78	
"	53405	6.01	
"	53410	6.36	
"	53415	2.94	
"	53418	1.10	
"	53507	1.11	
"	53512	1.45	
"	53513	1.50	
24600 ± 16400	53502	3.13	3.13
24600 ± 14700	51102	2.86	3.04
"	51113	2.86	
"	52509	2.92	
"	54002	3.04	
"	54006	2.66	
"	54010	2.95	
"	54015	1.92	
"	54019	3.00	
"	54501	2.97	
"	54505	2.82	
"	54510	3.76	
"	54515	4.64	
"	54519	3.45	
"	54902	4.11	
"	54905	3.55	
"	54910	3.61	
"	54915	4.41	
"	54919	3.07	
"	59301	3.24	
"	59307	2.47	
"	59310	2.48	
"	59315	3.24	
"	59319	1.74	
24600 ± 13000	53503	4.59	4.59
24600 ± 11500	50907	5.24	4.92
"	53417	4.30	
"	54407	5.29	

Table 3 (concluded)

Average stress on net section lb/in^2	Specimen Number	Endurance (N) 10^5 cycles	Log. mean endurance 10^5 cycles
24600 ± 9900	53504	9.01	9.01
24600 ± 9850	54016	6.06	6.06
24600 ± 8200	53509	13.6	10.9
"	54513	8.77	
24600 ± 7500	53514	13.6	13.6
"	53515	13.6	
24600 ± 6900	50902	20.0	15.1
"	50905	11.4	
"	50910	16.7	
"	50915	14.4	
"	50919	17.7	
"	51401	9.62	
"	51405	21.6	
"	51410	17.0	
"	51415	22.3	
"	51419	13.3	
"	52501	10.1	
"	52505	8.87	
"	52510	10.2	
"	52515	11.9	
"	52519	8.00	
"	53518	23.0	
"	53519	21.2	
"	54401	32.1	
"	54405	9.60	
"	54410	16.0	
"	54415	20.7	
"	54419	19.6	
24600 ± 6500	53506	37.0	37.0
24600 ± 4900	51407	42.8	58.0
"	54013	78.5	
24600 ± 4800	53510	120	120

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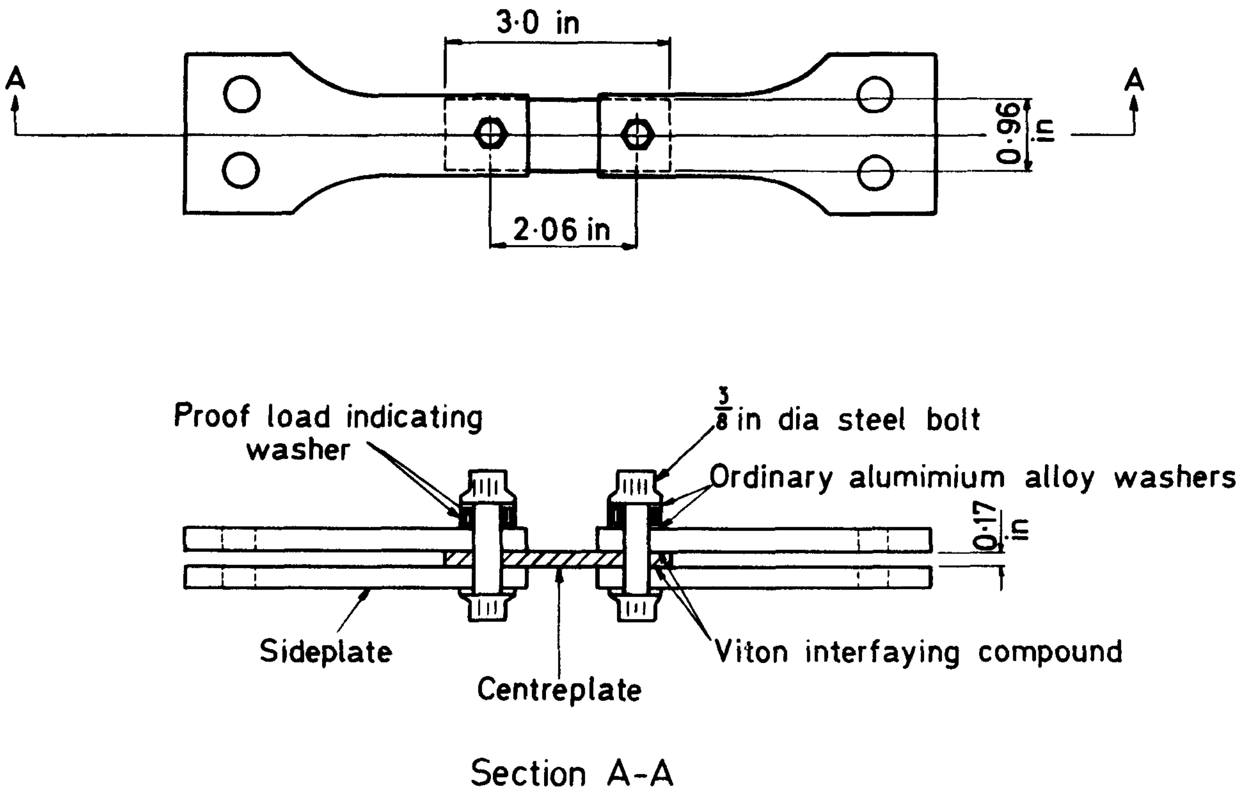


Surface finish 15 micro-inches (centreline average)

After manufacture centreplates are anodised and painted with a barium chromate primer

Fig.1 'HSA' joint specimen

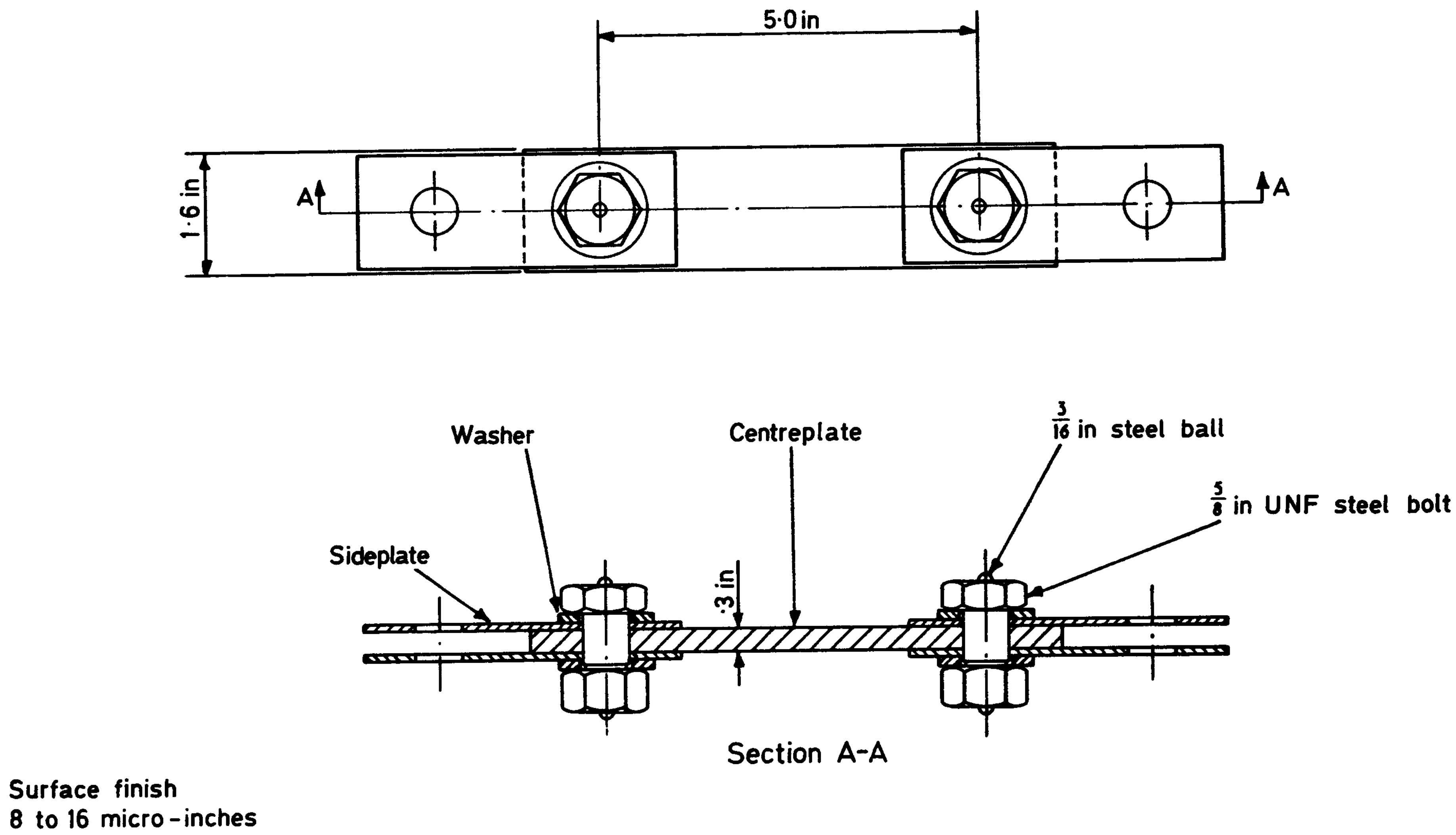


Fig.2 RAE joint specimen

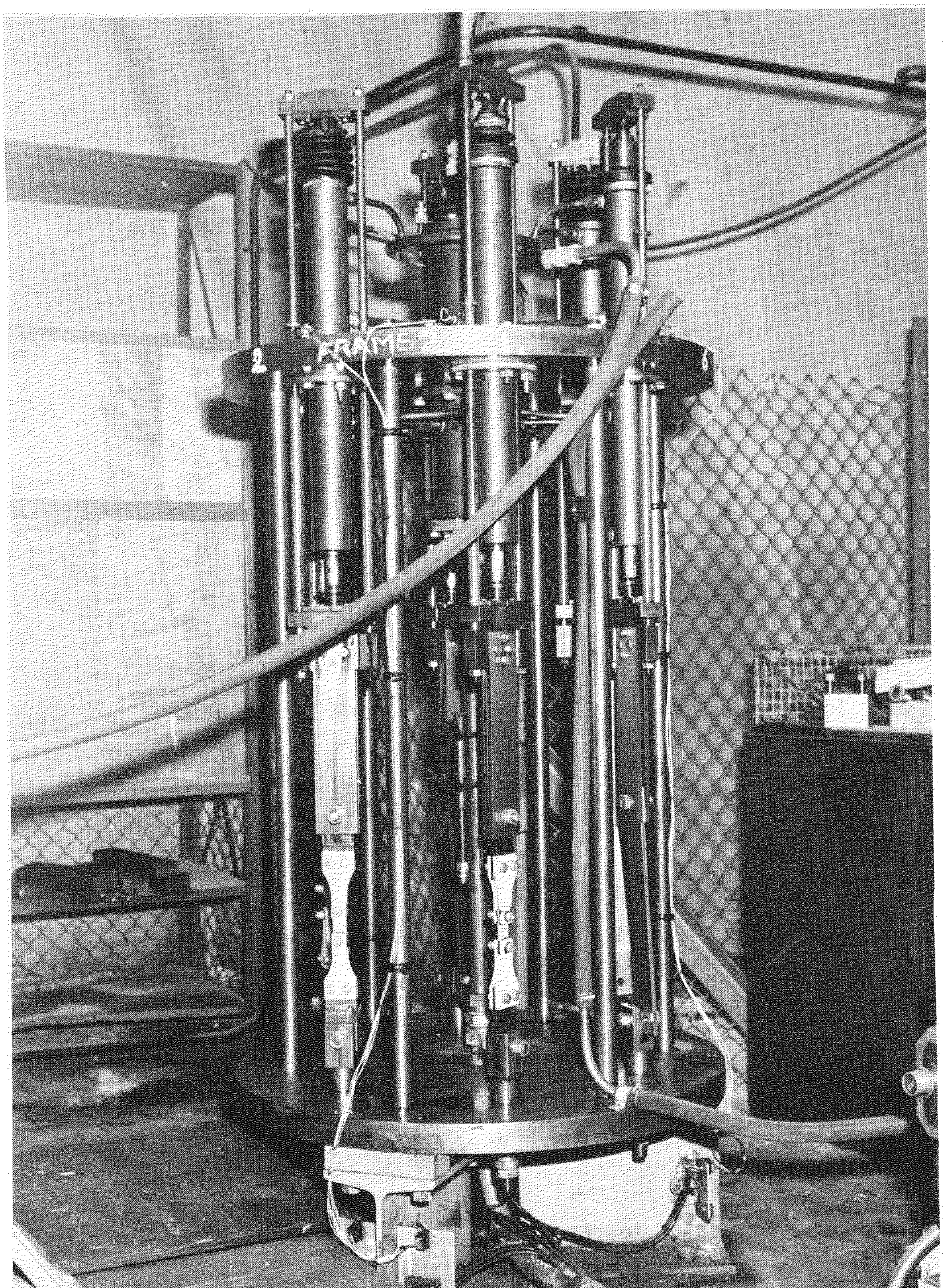
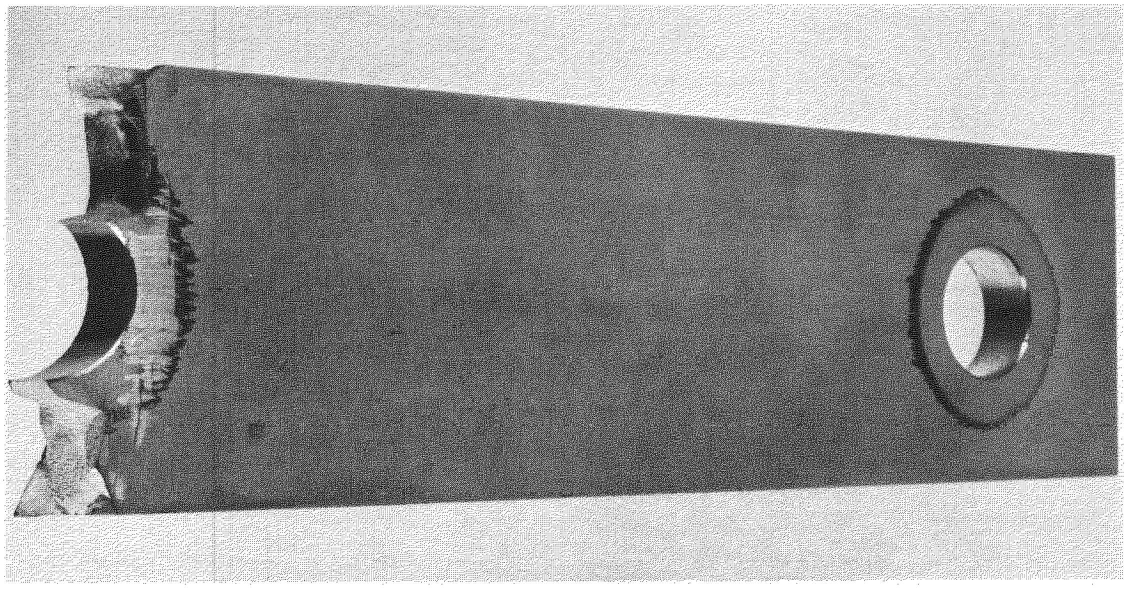
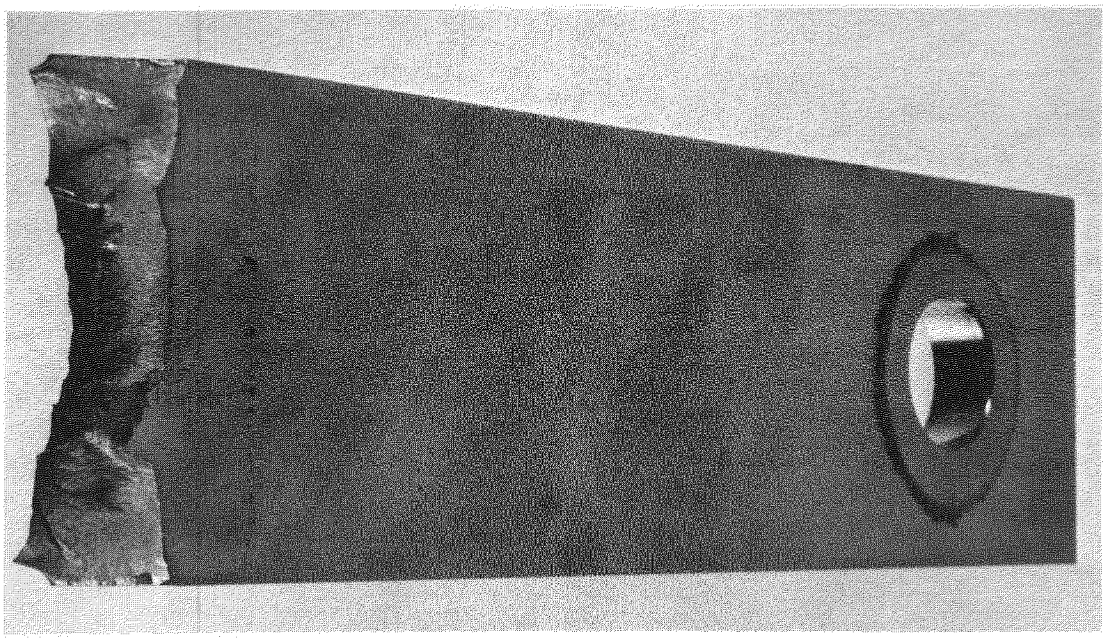


Fig.3 Losenhausen multipoint hydraulic fatigue rig



a. Joint (failure through hole)



b. Joint (failure away from hole)

Fig.4 Typical fractures on RAE joint specimens

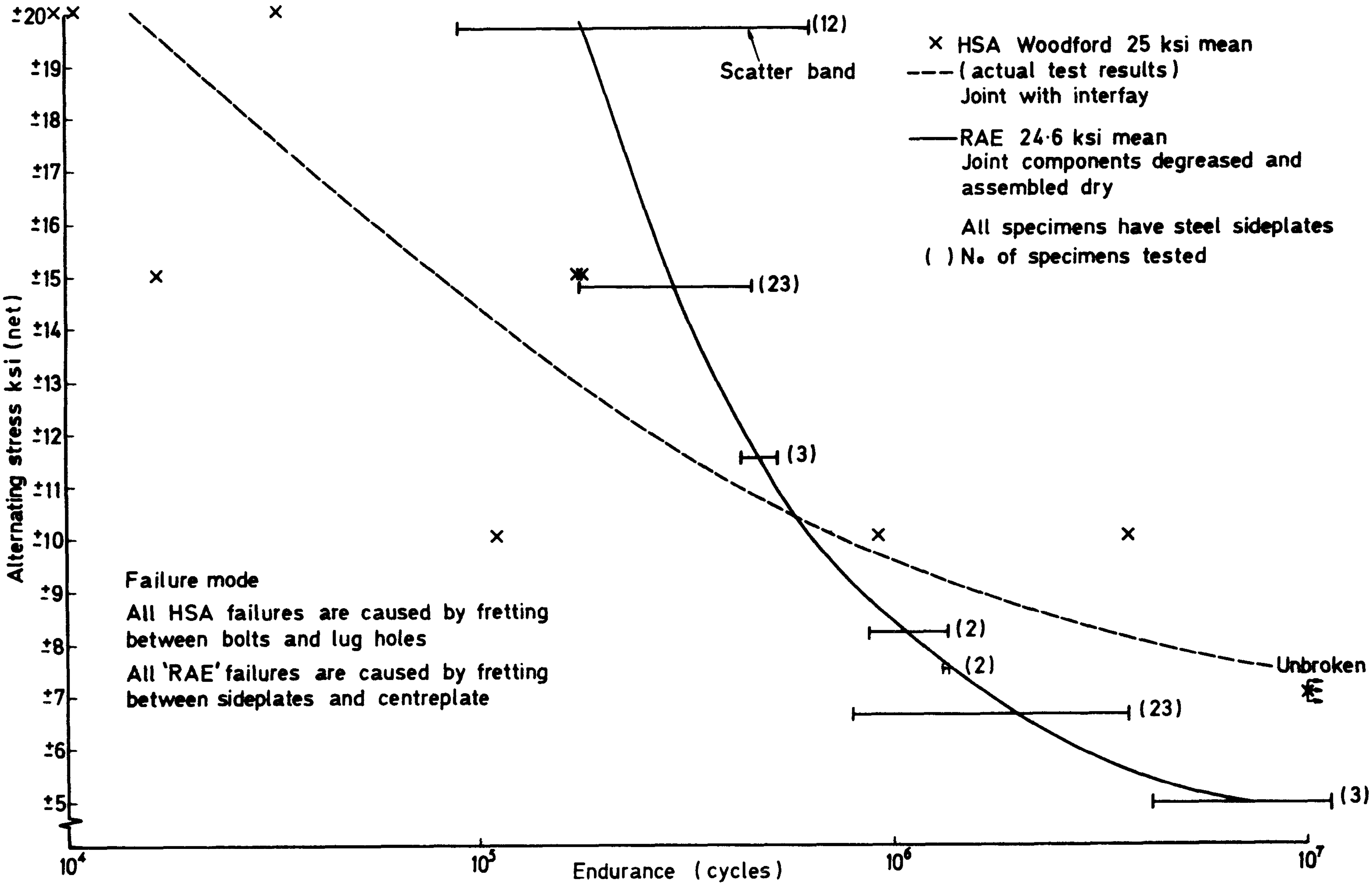


Fig. 5 Comparison of joints with and without interfay

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