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**EVALUATION OF 7010 ALUMINIUM ALLOY
PART 1: MATERIAL TO
DTD 5120 AND DTD 5130 SPECIFICATIONS**

by

V. C. R. McLoughlin

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V.C.R. McLoughlin

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Aluminium alloy to the DTD 5120 (7010-T7551) and DTD 5130 (7010-T73651) specifications was supplied by Alcan (UK) Ltd to DFLVR, NLR, ONERA and RAE for evaluation of the alloys' stress corrosion resistance and other properties. The four laboratories used their preferred test methods and made comparisons with other stress corrosion resistant alloys (7050-T73651 and 7075-T7351). The alloys' tensile properties, fracture toughness, fatigue crack propagation rates and repassivation kinetics were assessed. The effects of special heat treatments on the mechanical and stress corrosion properties of 7010 alloy were also investigated.

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PART I. MATERIAL TO DTD 5120 AND DTD 5130 SPECIFICATIONS

by

V. C. R. McLoughlin

SUMMARY

Aluminium alloy to the DTD 5120 (7010-T7651) and DTD 5130 (7010-T73651) specifications was supplied by Alcan (UK) Ltd to DFLVR, NLR, ONERA and RAE for evaluation of the alloys' stress corrosion resistance and other properties. The four laboratories used their preferred test methods and made comparisons with other stress corrosion resistant alloys (7050-T73651 and 7075-T7351). The alloys' tensile properties, fracture toughness, fatigue crack propagation rates and repassivation kinetics were assessed. The effects of special heat treatments on the mechanical and stress corrosion properties of 7010 alloy were also investigated.

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1 INTRODUCTION

Aluminium alloy 7010 has been developed in the UK to meet the requirement for a high strength alloy with good stress corrosion resistance and fracture toughness, and with less quench-rate sensitivity than 7075-type alloys. The alloy, manufactured to UK Ministry of Defence Specifications DTD 5120 and DTD 5130, has been supplied by Alcan to DFVLR, NLR, ONERA and RAE for evaluation.

In earlier collaborative programmes in GARTEur 3, DFVLR, ONERA and RAE used common batches of various aluminium alloys to compare their different laboratory stress corrosion test methods. These methods were the constant strain rate test which DFVLR had used quite extensively, the constant load test which ONERA had used for several years, and the constant tensile strain test which RAE favoured. A logical extension of these investigations was the evaluation of the stress corrosion resistance of 7010 alloy using these same procedures. NLR also agreed to collaborate and to introduce their own test procedures, the constant strain, tuning-fork stress corrosion test and double cantilever beam (DCB) stress corrosion crack growth test method.

Additional investigations were included to widen the scope of the evaluation of 7010 alloy, again by making use of the particular expertise and equipment of the participating laboratories. DFVLR agreed to use their new constant load equipment to study stress corrosion resistance, and their established electrochemical technique to investigate repassivation kinetics of 7010. NLR included fracture toughness and fatigue crack propagation measurements, and comparative stress corrosion testing of 7050 and 7075 alloys. ONERA also included fracture toughness tests, investigation of the effects of quench rate and ageing conditions on the properties of 7010 and comparative work with 7050 alloy. RAE included comparative stress corrosion testing of 7075 alloy and natural environment testing.

This Report contains the results obtained by the four participants since the Action Group on The Evaluation of Aluminium Alloy 7010 was formed towards the end of 1979, but reference is made to earlier results (obtained under the auspices of GARTEur 3) when necessary, for example in making comparisons with the properties of other samples of 7010 alloy and other aluminium alloys.

The following have been involved in the collaborative programme:

from DFVLR, H. Buhl, G. Mierke, D. Brunner, P. Kuhn and W. Schönau

from NLR, W.G.J.'t Hart and L. Schra

from ONERA, Mme C. Renon and G. Lapasset

from RAE, Miss J.A. Gray.

2 EXPERIMENTAL

2.1 Materials

All aluminium alloys were in plate form and to aerospace standards. 7010 was supplied to the DTD 5120 and DTD 5130 specifications, referred to in this Report as

7010-T7651 and 7010-T73651, respectively, so that comparisons can be more readily made with 7050-T73651 and 7075-T7351 alloys used. Table 1 identifies the alloys used by the four participants in terms of batch numbers, plate thickness and chemical compositions. It is noteworthy that the Fe and Si contents of the two 7075-T7351 plates are very low and the overall compositions approximate to the requirements for a 7475 material.

The tensile properties of the alloys appear in Table 2. The alloys can be ranked in the order 7010-T7651 > 7050-T73651 > 7010-T73651 > 7075-T7351; the 7050 tested was about 5% stronger than the two batches of 7010 in the T73651 temper, which in turn had a similar advantage over the two batches of 7075-T7351.

2.2 Stress corrosion tests

2.2.1 Constant load tests

(a) At DFVLR 3.57mm diameter tensile bar test pieces (see Fig 1) were machined so that the load was applied in the short transverse direction. Tests were done in 3.5% NaCl contained in glass cells equipped with means to aerate the solution, and to control and measure the test piece potential. Tests were done under freely corroding conditions for approximately 1000 h, or until failure occurred.

The results are shown graphically in Figs 2 and 3 as applied stress against the logarithm of time-to-failure. The results indicate that stress corrosion failures occur at the very high stresses used (up to 93% of the 0.2% proof stress for 7010-T73651 and up to 88% of the 0.2% proof stress for 7010-T7651), but the rapid increase in time-to-failure as the stress level is reduced suggests that both alloys are very resistant to stress corrosion cracking under the test conditions used. The alloy appears to be more resistant in the T73651 temper, as would be expected. Further details are given in Ref 1.

(b) At ONERA 4.0mm diameter short transverse tensile bar test pieces were exposed to alternate immersion in either 3% NaCl or 3% NaCl + 0.2% $K_2Cr_2O_7$ solutions at room temperature. The equipment² employs a closed cell surrounding the test piece, the cell being filled for 10 min in each hour. Tests continued for 2000 h or until failure occurred.

No failures occurred in the chromate-containing solution at stresses of 400 MPa or 350 MPa; in previous work³ on other batches of 7010 failures occurred at 400 MPa. The results of tests in 3% NaCl are shown as graphs of stress against the logarithm of time-to-failure in Fig 4. Comparison of these results with those obtained with 7050-T73651 alloy plate is made in Fig 5 and it is apparent that the two alloy systems react to the test method in a very similar manner.

Earlier work³ on 7010 gave similar results, and demonstrated that the corrosive attack by alternate immersion can reduce the strength of 7010 very markedly, so that the failures after long periods of alternate immersion were not due to stress corrosion. These results are shown in Fig 6. The extent of corrosion attack caused by alternate immersion in 3% NaCl is illustrated in Fig 7 which shows sections of 7010 test pieces after 1870 h exposure. In general, it appears that in the T73651 temper the alloy was slightly more susceptible to pitting attack.

The results of both the DFVLR and ONERA constant load tests in NaCl are combined in Figs 8 and 9 as graphs of stress against time-to-failure.

2.2.2 Constant strain tests

(a) At NLR constant strain, tuning-fork test pieces (see Fig 10) were loaded at a constant strain of 0.6% applied in the short transverse direction. The test pieces were clamped to a Ferris wheel which rotated so that each test piece was immersed in a test solution for 10 min, and then allowed to dry for 50 min in each hour in air at 20°C and 38-45% RH. Tests were continued for 1457 h (ca 60 days). The conditions approximate to the ASTM requirements⁴, although the time of exposure is much longer than the 20 days recommended⁵ for 7000 series alloys. 7010 and 7050 alloy plates were examined, sampling the alloys at five different locations through the plate (see Fig 10), with quadruplication of each test. Two test solutions were used: 3.5% neutral NaCl and 2% NaCl + 0.5% Na₂Cr₂O₇ at pH 3 which is the test solution described⁶ in LN 65666. Natural environment tests are also being conducted.

No stress corrosion cracks have been detected under any of the test conditions, using low powered (×10) magnification. A number of test pieces exposed to 3.5% NaCl were chemically cleaned of corrosion product to allow closer examination of the quite severe pitting attack which occurred. It appeared that there was no difference in the degree of attack in test pieces taken from different locations in the plates, but that 7050 was attacked slightly more than 7010, which in turn was attacked more than 7075. Natural environment tests had been underway for 2 years and 8 months. For further details see Refs 7 and 8.

(b) At RAE constant tensile strain (Alcoa-type) tests were applied to 3.175mm diameter short transverse tensile bar test pieces using RAE straining frames (see Fig 11). The test frame assemblies were immersed for 10 min in each hour in 3.5% neutral NaCl at 30° ± 1°C, the test conditions conforming in other respects to ASTM requirements⁴. Most tests continued for 30 days, but some were limited to 20 days as recommended⁵ by ASTM. In earlier work⁹ the same constant tensile strain test frames were used for 2 year natural environment tests and 30 day total immersion (to LN 65666) tests⁶ of 7010 alloy.

The results of the alternate immersion tests of 7010 in T7651 and T73651 tempers are given in Table 3, together with previous results⁹ obtained for 7075-T7351. Two criteria for stress corrosion cracking were applied. The first, and the one most generally used, is the detection of surface-breaking cracks at low magnification (typically ×10). The second is the detection of intergranular fissures on examination of ST/L polished sections at high magnification (typically ×500). No surface-breaking cracks were detected on the 7010 test pieces, the maximum stress applied being 300 MPa. Microfissures were detected down to much lower stress levels: 75 MPa for the 7010 test pieces and 175 MPa in 7075-T7351. In earlier work⁹ microfissures were detected at 175 MPa and above in 7010-T7651 and at 225 MPa and above in 7010-T73651, while macroscopic stress corrosion cracks were observed in 7010-T7651 at 300 MPa, in 7075-T7351 at 325 MPa, but not in 7010-T73651 even at 350 MPa.

2.2.3 Constant strain rate tests

At DFVLR constant strain rate machines were employed, equipped with synchronous motors and gearboxes to give cross-head speeds of 10^{-2} to 2 mm/h, corresponding to strain rates of between 10^{-7} and 10^{-5} s⁻¹. Tests were performed on short transverse tensile bar test pieces (see Fig 1) at $21^{\circ} \pm 1^{\circ}\text{C}$ in vacuum, in 3.5% neutral NaCl and in the LN 65666 test solution⁶. The stress-strain curves were recorded using a data logger and evaluated by a computer so that the fracture energy for each test piece was obtained, together with the ultimate and 0.2% proof stress and fracture elongation. Reduction in area was measured separately.

The results expressed in terms of the fracture energy of test pieces in the three environments and at the various strain rates employed are shown graphically in Figs 12 to 17. The scatter obtained was markedly worse than with other alloys investigated by DFVLR, and of the 48 tests done in vacuum the elongation values for five test pieces were less than 2%, the minimum value allowed in the DTD 5120 and 5130 specifications. These low values are surprising in view of the acceptable values obtained by Alcan, ONERA and RAE (see Table 2) from the same batch of alloy. A brief investigation by Alcan of material supplied to DFVLR yielded elongation values of about 5% at a strain rate of 2×10^{-6} s⁻¹ in dry air¹⁰.

Because of the large amount of scatter it is not clear how strain rate and environment affects fracture energy. However, by applying the scatter bands which enclose the results obtained in vacuum (Figs 12 and 15) to the results obtained in the two aqueous environments it appears that in LN 65666 solution there is some reduction in fracture energy of 7010-T7651 (but not at the lower strain rates) and very little effect on 7010-T73651 (see Figs 13 and 16), while there is a noticeable reduction in fracture energy in 3.5% NaCl (Figs 14 and 17) at the lower strain rates, indicating some stress corrosion. For detailed results see Ref 1.

2.2.4 Stress corrosion crack growth measurements

At NLR DCB test pieces (see Fig 18) were used to measure stress corrosion crack growth in 3.5% NaCl. Two conditions of test were used: application of a few drops of salt solution to the test piece notch twice each working day, and immersion of the test piece in salt solution for 1 h in every 12 h. Earlier work at NLR⁷ involved test pieces of 7010 being totally immersed in the LN 65666 solution⁶.

The DCBs were pre-cracked by fatigue loading and loaded to give stress intensities of about $22 \text{ MPa}\sqrt{\text{m}}$ for 7010 and 7050 in the T73651 temper, and $18 \text{ MPa}\sqrt{\text{m}}$ for 7010-T7651 test pieces. Crack growth was monitored weekly until, after about 3 months, general corrosion prevented meaningful measurements. After 202 days' exposure the straining bolts were released to measure the final displacement of the beams before the DCBs were broken open. The total stress corrosion crack growth was determined from the fracture surfaces and the mean rates of stress corrosion crack growth obtained (see Table 4). In previous work⁷ crack growth in LN 65666 solution was less than 1 mm for 7010 alloy in both tempers over a period of 198 days. For further details see Refs 7 and 8.

Comparing the results in neutral 3.5% salt solution it appears that alternate immersion is a somewhat more aggressive technique than moistening the notch of the DCB twice daily. The crack growth measurements indicate the 7010 and 7050 are very similar in resistance to stress corrosion crack growth in the T73651 temper and, as would be expected, 7010-T7651 is less resistant than the alloy in the T73651 temper.

2.3 Other corrosion studies

2.3.1 Repassivation kinetics

At DFVLR the repassivation kinetics of 7010 alloy were examined in three solutions: 3.5% NaCl, the LN 65666 solution⁶, and 2% NaCl at pH 3. Samples of alloy were held at various potentials and the decay of the repassivation currents was monitored. From these measurements of current decay with time it was possible to establish the potentials above which freshly exposed alloy surfaces would not repassivate in the two uninhibited NaCl solutions (see Table 5). The non-passivation potentials obtained correspond to the critical potentials for pitting, or the protection potentials, for the alloys. The results suggest that 7010 will be slightly more susceptible to pitting attack in the T73651 temper. Measurements in the LN 65666 solution demonstrated the efficiency of chromates as inhibitors of the corrosion of aluminium alloys: non-repassivation potentials could not be established and repassivation occurred at potentials 600 mV more noble than those at which pitting occurred in the non-chromate solutions. Further details appear in Ref 11.

2.3.2 Effects of heat treatments

At ONERA the effects of various heat treatments on mechanical properties, corrosion resistance and stress corrosion resistance were studied. 7010 alloy was re-solution treated at 475°C for 24 h in the form of 4mm diameter short transverse tensile bar test pieces, 11mm diameter cylindrical blanks for these test pieces, blocks 14 × 60 × 200 mm, and compact tension test pieces. On quenching into cold water or oil different quench rates were experienced by the three different forms. The alloy was then given various duplex heat treatments to achieve T7X tempers. The mechanical properties obtained, summarised in Tables 6 to 8, show the improvements that can be achieved by rapid quenching of small section pieces of alloy. The stress corrosion properties of these experimental heat treatments were evaluated using the constant load tests described in section 2.2.1(b) and the results (Figs 19 to 21) indicated that major improvement in times-to-failure can be achieved. These improvements are probably obtained by the greater resistance of the rapidly quenched samples to corrosion, and this effect is illustrated in photomicrograph cross-sections of test pieces (see Fig 22). However, the results also show that small changes in the secondary ageing times and temperatures have dramatic effects.

2.4 Fracture toughness measurements

Compact tension test pieces (see Fig 23) were used at NLR and ONERA to measure fracture toughness of the 7010 alloy in both tempers. NLR results (see Table 9) using LT, TL, ST and SL test piece orientations gave values well in excess of the minimum requirements for the DTD 5120 and 5130 specifications. Comparisons were made with 7050-T73651

which suggested that 7010 was slightly superior, but the differences could fall within the variation from batch to batch of the alloys. The ONERA results on a different batch of 7010 alloy to that used by NLR gave markedly lower values (see Table 7), but values which are well above the minimum acceptable for the alloy.

2.5 Fatigue crack propagation measurements

At NLR centre notched test pieces (110 × 235 mm) of various thicknesses from 2-15 mm were cut from 7010-T73651, 7010-T7651 and 7050-T73651 (see Fig 24). Test pieces were also made from laminates consisting of five bonded sheets of 2 mm thick 7010-T73651 (machined from 150mm plate). Tests were performed under flight simulation loading using a gust spectrum and, for the laminated test pieces, under constant amplitude loading.

The results of tests on solid test pieces are summarised in Table 10, in which the number of simulated flights to produce crack growth from 8-30 mm are given, and the mean values are used in the graphical presentation in Fig 25. There appears to be little difference in the fatigue crack growth resistance of 7010 and 7050 in the T73651 temper, while 7010-T7651 is less resistant than the more over-aged material. The results from the laminated test pieces were disappointingly poor in comparison to those for the solid test pieces. However, the laminated test pieces were not completely flat and this would have introduced bending loads during the fatigue cycles, and might well have resulted in unrealistically high crack growth rates. For more detailed results see Refs 7, 8 and 12.

3 DISCUSSION

In the evaluation of stress corrosion resistance of 7010 alloy several test methods have been applied and comparisons made with other stress corrosion resistant 7000 series aluminium alloys. Observations made during these tests suggest that 7010 alloy is intermediate between 7075 and 7050 alloys in resistance to general pitting corrosion, in agreement with the accepted effect of copper content on the corrosion resistance of 7000 series alloys: as copper content increases (from 7075 to 7010 to 7050) an increase in susceptibility to pitting corrosion would be expected. 7010-T7651 was found to be more resistant to pitting attack than 7010-T73651, which again would be expected. Increasing copper content of 7000 series alloys is generally accepted to have a beneficial effect on stress corrosion cracking characteristics. No clear evidence of this effect was observed, and 7010 and 7050 appeared to be equivalent in their stress corrosion resistance. Of far greater significance was heat treatment, and while 7010-T73651 was clearly more resistant than 7010-T7651, the alloy could be classified as resistant to stress corrosion cracking in both tempers.

Two aspects of the stress corrosion evaluation were inconclusive. The first aspect, which will be further examined at RAE, is that dealing with intergranular fissures (or stress corrosion cracks) detected metallographically. It appears that over-aged (T7) alloys in the 7000 series exhibit the phenomena of microscopic intergranular fissures when tested at stresses well below the accepted threshold stress values for stress corrosion cracking. There is also a degree of variability in the results obtained, in contrast to the very reproducible results obtained with aluminium alloys which are

susceptible to stress corrosion cracking. Further work is necessary to establish the significance of these microfissures; for example will they propagate over a long time scale to cause stress corrosion failures, and can they initiate early fatigue cracking. The indications from NLR and other work using DCB test pieces is that 7010 has very good resistance to stress corrosion crack growth, even at quite high stress intensity factors.

The second aspect that warrants further investigation is the very large scatter in the DFVLR constant strain rate results, and the low elongation values obtained with some of the tests in vacuum. No satisfactory explanation can be offered for these observations, which have not been made with other aluminium alloys. The results are forming the basis of discussions between DFVLR and Alcan (UK) Ltd.

The low elongation values obtained by the slow strain rate test in vacuum contrast with the more normal values obtained by the other laboratories in standard mechanical tests. However, there were differences of up to 10% in the (ST) tensile strength measured by the different laboratories on the same batch of alloy. Allowing for differences between laboratories it appeared that 7050 used for comparative tests was about 5% stronger than the two batches of 7010 in the T73651 temper, which in turn were stronger by a similar amount than the two batches of 7075-T7351 used (which approximated to 7475-T7351 in composition).

The fracture toughness and fatigue crack propagation results obtained for 7010 and 7050 in the T73651 temper are very similar. In both properties 7010-T7651 appears to be inferior to 7010-T73651; this is as would be expected in fracture toughness, but not necessarily in fatigue crack growth resistance. It is possible that the superior toughness of the T73651 material dominates the fatigue crack growth rate in the particular programme loading used, *ie* for a transport aircraft. Under constant amplitude loading one would not expect to see a great difference in crack propagation rates.

The ONERA experiments on the effects of quench rates and duplex heat treatments on the properties of 7010 alloy have shown that mechanical properties, corrosion resistance and stress corrosion resistance can all be markedly improved by using specific secondary ageing conditions and very rapid quench rates. It would only be possible to apply these improvements to products of relatively low mass and with maximum section about 15 mm, but this may well be possible with thin plate and certain forgings.

4 CONCLUSIONS

- (1) The agreed collaborative evaluation programme on 7010 aluminium alloy in plate form in the T7651 and T73651 tempers has been completed.
- (2) The results from various test methods indicate that 7010 alloy in both T7651 and T73651 tempers is very resistant to stress corrosion, 7010-T73651 being the more resistant.
- (3) From the results of a limited number of comparative tests 7010-T73651 appears to be as resistant to stress corrosion cracking as 7050-T73651, and does not appear to be any less resistant than 7075-T7351.

- (4) Observations made in the various corrosion studies suggest that the resistance to pitting corrosion of the three alloys studied is in the order 7075 > 7010 > 7050, and that 7010 is more resistant to pitting corrosion in the T7651 temper than in the T73651 temper.
- (5) The tensile properties in the T7351 temper of 7010 alloys used were slightly lower (by about 5%) than those of the 7050 alloy used, and slightly higher (by a similar amount) than those of the 7075-T7351 alloys used.
- (6) The chemical compositions of the two 7075 alloys used approximate to the requirements for 7475.
- (7) Fracture toughness measurements indicate that the 7010 and 7050 alloys used have equivalent properties in the T7351 temper.
- (8) The fatigue crack growth rates of 7010-T73651 and 7050-T73651 were virtually the same under flight simulation loading for a transport aircraft wing structure, and 7010-T7651 showed a higher crack growth rate.
- (9) The mechanical, corrosion and stress corrosion properties of 7010 can be enhanced by very rapid quenching from solution treatment temperatures and a duplex heat treatment of 16 h at 115°C followed by 8 h at 175°C.

5 RECOMMENDATION

Collaboration between GARTEUR countries should be continued so that the properties of 7010 alloy can be evaluated further. This collaboration should be concentrated on 7010 plate alloy in a T651 temper but should also include aspects related to other tempers of the alloy in plate, extrusion and forged structures.

Table 1

COMPOSITION OF ALUMINIUM ALLOYS USED

Alloy	Section	Batch number	User	Composition, weight %							Analysis
				Zn	Mg	Cu	Zr	Cr	Fe	Si	
7010-T7651	80 mm	70JH1	NLR	6.13	2.31	1.72	0.12	-	0.08	0.06	Alcan
				6.45	2.36	1.72	0.12	-	0.18	0.08	NLR
		823 X A2	DFVLR ONERA RAE	6.30	2.38	1.92	0.12	-	0.08	0.09	Alcan
7010-T73651	80 mm	129 KH1	NLR	As for 70JH1 - by Alcan							
		865 X A1	DFVLR ONERA RAE	As for 823 x A2 - by Alcan							
7050-T73651	85 mm	-	NLR	6.4	2.32	2.35	0.05	-	0.10	0.12	NLR
7075-T7351	60 mm	-	NLR	6.24	2.46	1.66	-	0.20	0.12	0.08	NLR
7075-T7351	76 mm	-	RAE	5.68	2.55	1.95	-	0.17	0.11	0.11	RAE

Table 2

TENSILE PROPERTIES OF ALUMINIUM ALLOYS USED

Alloy	User	0.2% Proof stress (MPa)			Tensile strength (MPa)			Elongation (%)			Determined by
		L	LT	ST	L	LT	ST	L	LT	ST	
7010-T7651	NLR	474	469		521	527		11.3	10.3		NLR [†]
		480	473	414	527	533	502	12.4	10.7	5.7	Alcan*
	DFVLR			444			477			2.76	DFVLR**
	ONERA			410			470			3.1	ONERA
	RAE			441			498			5.0	RAE
		459	452	401	518	517	467	10.8	9.6	3.8	Alcan*
7010-T73651	NLR	436	432		498	502		12.5	10.7		NLR [†]
		440	436	384	501	510	481	13.8	11.7	6.9	Alcan*
	DFVLR			408			447			3.30	DFVLR**
	ONERA			384			453			4.1	ONERA
	RAE		441	425		511	488			6.0	RAE
		435	435	397	500	511	454	9.0	10.0	4.2	Alcan*
7050-T73651	NLR	462	456		520	521		10.5	9.4		NLR [†]
7075-T7351	NLR	429	427		501	504		12.5	12.0		NLR [†]
	RAE			366			447			5.0	RAE

* L and LT properties measured at the t/4 plane

** Mean values from slow strain rate ($<10^{-5} \text{ s}^{-1}$) tests in vacuum

† Mean values from tests at surface, core and t/4 planes

Table 3

RESULTS OF CONSTANT TENSILE STRAIN 30 DAY ALTERNATE IMMERSION STRESS CORROSION TESTS

Approx stress (MPa)	7010-T7651			7010-T73651			7075-T7351		
	% of 0.2% Proof stress	F/N		% of 0.2% Proof stress	F/N		% of 0.2% Proof stress	F/N	
		Macro	Macro + Micro		Macro	Macro + Micro		Macro	Macro + Micro
350	-	-	-	83	0/2	2/2	96	0/3	3/3
325	-	-	-	-	-	-	89	1/2	2/2
300	68	0/2	1/2	71	0/2	2/2	82	0/3	2/3
275	-	-	-	-	-	-	75	0/2	2/2
250	57	0/2	2/2	58	0/3	3/3	69	0/3	2/3
225	-	-	-	-	-	-	62	0/2	2/2
200	46	0/2	2/2	48	0/3	3/3	55	0/3	2/3
175	40	0/2	2/2	41	0/4	3/4	48	0/3	1/3
175*	-	-	-	41	0/3	2/3	-	-	-
150	34	0/2	2/2	35	0/3	2/3	41	0/3	0/3
150*	-	-	-	35	0/2	0/2	-	-	-
125	28	0/5	4/5	29	0/4	0/4	33	0/3	0/3
125*	28	0/3	2/3	-	-	-	-	-	-
100	23	0/5	4/5	24	0/4	1/4	-	-	-
100*	23	0/3	1/3	-	-	-	-	-	-
75	17	0/2	1/2	18	0/4	2/4	-	-	-

F/N - Number failed/number tested

Macro - Stress corrosion failure based on the detection of surface cracks (at $\times 10$ magnification)Micro - Stress corrosion failure based on the detection of intergranular fissures (at $\times 500$ magnification)

* - 20 day alternate immersion tests

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Table 4

SURVEY OF STRESS CORROSION CRACK GROWTH AFTER 202 DAYS EXPOSURE

Test method	Material	Specimen number	Initial* crack length (mm)	Actual initial stress intensity factor, K_i (MPa \sqrt{m})	SCC* growth (mm)	Remaining** displacement (%)	Mean crack growth rate (m/s 10^{-10})
Alternate immersion in 3.5% NaCl	7050-T73651	G 1.5	37.5	22.0	1.7	24	0.97
		G 2.5	37.8	21.8	1.4	24	0.80
		G 3.5	37.6	22.2	2.8	27	1.60
	7010-T7651	A 1.12	38.7	18.0	5.2	37	2.98
		A 3.12	38.4	17.8	5.0	40	2.86
	7010-T73651	B 1.11	37.2	22.2	2.8	26	1.60
B 3.11		37.5	22.0	2.3	27	1.32	
Periodically moistening with 3.5% NaCl	7050-T73651	G 1.4	37.9	22.1	1.3	25	0.74
		G 2.4	37.7	22.4	1.3	23	0.74
		G 3.4	37.8	21.7	2.4	27	1.38
	7010-T7651	A 1.11	37.5	17.9	4.4	35	2.52
		A 3.11	37.4	18.0	3.6	31	2.06
	7010-T73651	B 1.12	38.0	22.2	1.9	28	1.09
		B 2.12	37.4	22.1	0.8	22	0.46
		B 3.12	37.8	21.8	1.7	27	0.97

* Mean value of the crack lengths at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the specimen thickness

** Percentage of initial prescribed displacement which is left after unloading the specimen

Table 5

REPASSIVATION/NON-REPASSIVATION POTENTIALS OF ALUMINIUM ALLOY 7010
IN DIFFERENT SOLUTIONS AT ROOM TEMPERATURE

Electrolyte	3.5% NaCl (pH = 5.5)		2% NaCl adjusted to pH 3 by addition of HCl	
	T7651	T73651	T7651	T73651
Heat treatment				
Repassivation potential in mV _{NHE} (correlates to critical potential of pitting)	-570	-570	-540	-550
Non-repassivation potential in mV _{NHE}	-560	-560	-535	-540

Table 6

SHORT TRANSVERSE TENSILE PROPERTIES OF 7010 ALLOY AFTER VARIOUS HEAT TREATMENTS

Ageing conditions after solution treatment at 475°C for 24 h and cold water quenching	As received alloy			Individual test pieces (4 mm diameter) heat treated			Test piece blanks (11 mm diameter) heat treated			Alloy blocks (200 × 60 × 14 mm) heat treated		
	0.2% Proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	0.2% Proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	0.2% Proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	0.2% Proof stress (MPa)	Tensile strength (MPa)	Elongation (%)
16 h 115°C + 8 h 160°C				511	543	3						
" + 24 h 160°C				484	518	3.4						
" + 8 h 168°C				501	534	2.6						
" + 16 h 168°C				467	507	4.8	466	506	4.5	463	507	4.5
" + 8 h 175°C				458	496	3.9	473	508	3.6	463	504	4.3
" + 16 h 175°C				417	466	4.9						
T7651	410	470	3.1									
T73651	384	453	4.1									

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Table 7

EFFECT OF AGEING CONDITIONS ON THE FRACTURE TOUGHNESS OF 7010 COMPACT TENSION TEST PIECES

	Ageing conditions	K_{Ic} (MPa \sqrt{m}) SL orientation	K_{Ic} (MPa \sqrt{m}) ST orientation
As received alloy	T 7651	24/23.2	22.7/22.7
	T 73651	25.1/23.2	23.5/23.8
Cold water quenched after 24 h at 475°C	24 h 135°C	29.5*/28.2*	32.2/30.7
	16 h 115°C + 8 h 160°C	26.7*	
	16 h 115°C + 8 h 168°C	26.1*/30.2*	
	16 h 115°C + 8 h 175°C	30.8*/34.3*/33.6*	30.6/31.9

* K_Q value.

Table 8

EFFECT OF QUENCH RATE ON THE MECHANICAL PROPERTIES OF 7010 AGED TO A T73 TEMPER
(24 h 475°C + 16 h 115°C + 8 h 175°C)

	0.2% Proof stress (MPa)	Tensile strength (MPa)	Elongation (%)	K_{Ic} (MPa \sqrt{m})	
				SL orientation	ST orientation
Quenched in water	453	496	3.7	30.8*/34.3*/ 33.6*	30.6/31.9
	463	502	3.6		
	459	498	3.7		
Quenched in oil	468	502	3	23.9/23.9	24.6/25.4
	460	495	1.4		
	466	502	2.7		

* K_Q value.

(Short transverse tensile properties obtained from compact tension test pieces)

Table 9

SURVEY OF FRACTURE TOUGHNESS DATA

Material producer	Orientation	Speciman No.	K_{Ic} , $MPa\sqrt{m}$ Individual result	Mean
7050- T73651 Alcoa	LT	GLT 1	34.4	35.4
		GLT 2	36.5	
	TL	GTL 1	33.2	32.0
		GTL 2	30.8	
	ST	GST 1	27.0	28.1
		GST 2	29.1	
SL	GSL 1	27.5	27.8	
	GSL 2	28.0		

7010- T7651 Alcan	LT	ALT 1	33.2	33.6
		ALT 2	33.9	
	TL	ATL 1	31.4	30.4
		ATL 2	29.4	
	ST	AST 1	27.1	27.1
		AST 2	27.1	
SL	ASL 1	27.6	27.3	
	ASL 2	27.0		
7010- T73651 Alcan	LT	BLT 1	36.8	36.5
		BLT 2	36.1	
	TL	BTL 1	32.1	32.6
		BTL 2	33.0	
	ST	BST 1	29.3	29.0
		BST 2	28.7	
SL	BSL 1	29.0	29.8	
	BSL 2	30.6		

All specimens met ASTM requirements and gave valid K_{Ic} values except for specification BLT 2: $a/w = 0.44$.

Table 10

NUMBER OF FLIGHTS FOR CRACK GROWTH FROM 8-30 mm

Alloy	Thickness (mm)	$N_{30} - N_8$			
		Surface	Centre	Surface	Mean
7050 T73651	2	5272	5405	4890	5189
	4	4358	3691	4341	4130
	9	3530	3712	3515	3585
	14	3275	3143	3385	3267
7010 T73651	2	5335	5548	4995	5292
	5	4123	4201	4010	4111
	10	3695	3115	3643	3484
	15	3094	3189	3174	3152
7010 T7651	2	3909*	4781	4979	4880
	5	3439	3619	3565	3541
	10	3386	2900	3255	3180
	15	2842	2820	2970	2877

* Not used for calculation of the mean (unreliable result)

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<u>No.</u>	<u>Author</u>	<u>Title, etc</u>
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2	H. Martinod F. Gourcuff C. Renon	Influence des conditions de revenu sur la résistance a la corrosion sous tension de l'alliage d'aluminium A-U4SG. La Recherche Aérospatiale No.1971-4, pp219-225 (1971)
3	C. Renon	Etude de la résistance a la corrosion sous tension de l'alliage 7010. ONERA Rapport Technique No.12/5069M (1978)
4	ASTM	Alternate immersion stress corrosion testing in 3.5% sodium chloride solution. ASTM Standard G44-75, Philadelphia (1975)
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6	German Federal Republic	Spannungsrisskorrosions - Prüfung von Aluminium - Knetlegierungen für Luftfahrtgerät. Deutsche Luftfahrtnorm LN 65666
7	W.G.J. 'tHart L. Schra	Engineering properties of the recently developed aluminium alloy designation 7010. NLR TR 79017 (1979)
8	W.G.J. 'tHart L. Schra	Engineering property comparisons of the aluminium plate alloys 7050-T73651, 7010-T73651 and 7010-T7651. NLR TR 80108 (1980)
9	Josephine A. Gray	The stress corrosion cracking resistance of 7010 aluminium alloy plates. RAE Technical Memorandum Mat 342 (1980)
10	G. Scamens	Private communication, Alcan (UK) Research Laboratories.
11	H-J. Rätzer-Scheibe U. Fuchs	Repassivation behaviour of the aluminium alloy 7010. DFVLR IB-354-80/6
12	W. van der Hoeven L. Schra	The effect of sheet thickness and laminating on the fatigue resistance of the aluminium alloy Al 7010-T73651. NLR TR 81056 (1981)

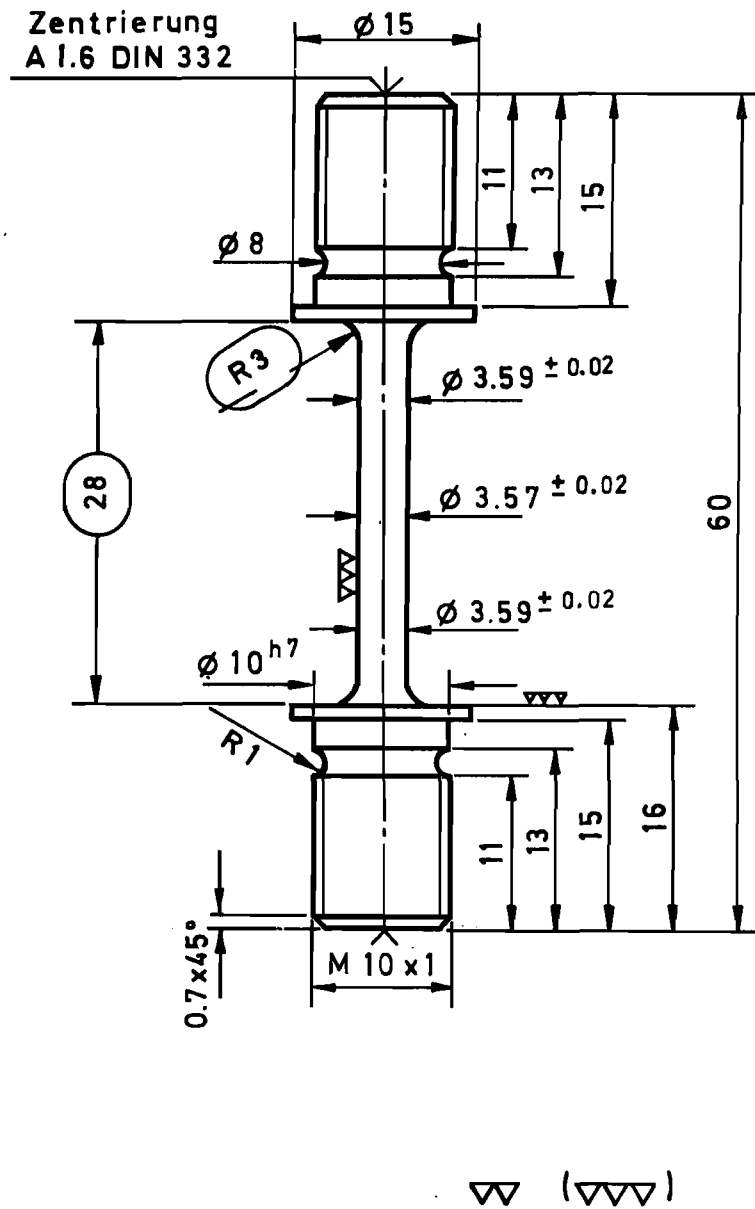


Fig 1 Test piece for DFVLR constant load and constant strain rate stress corrosion tests

Fig 2

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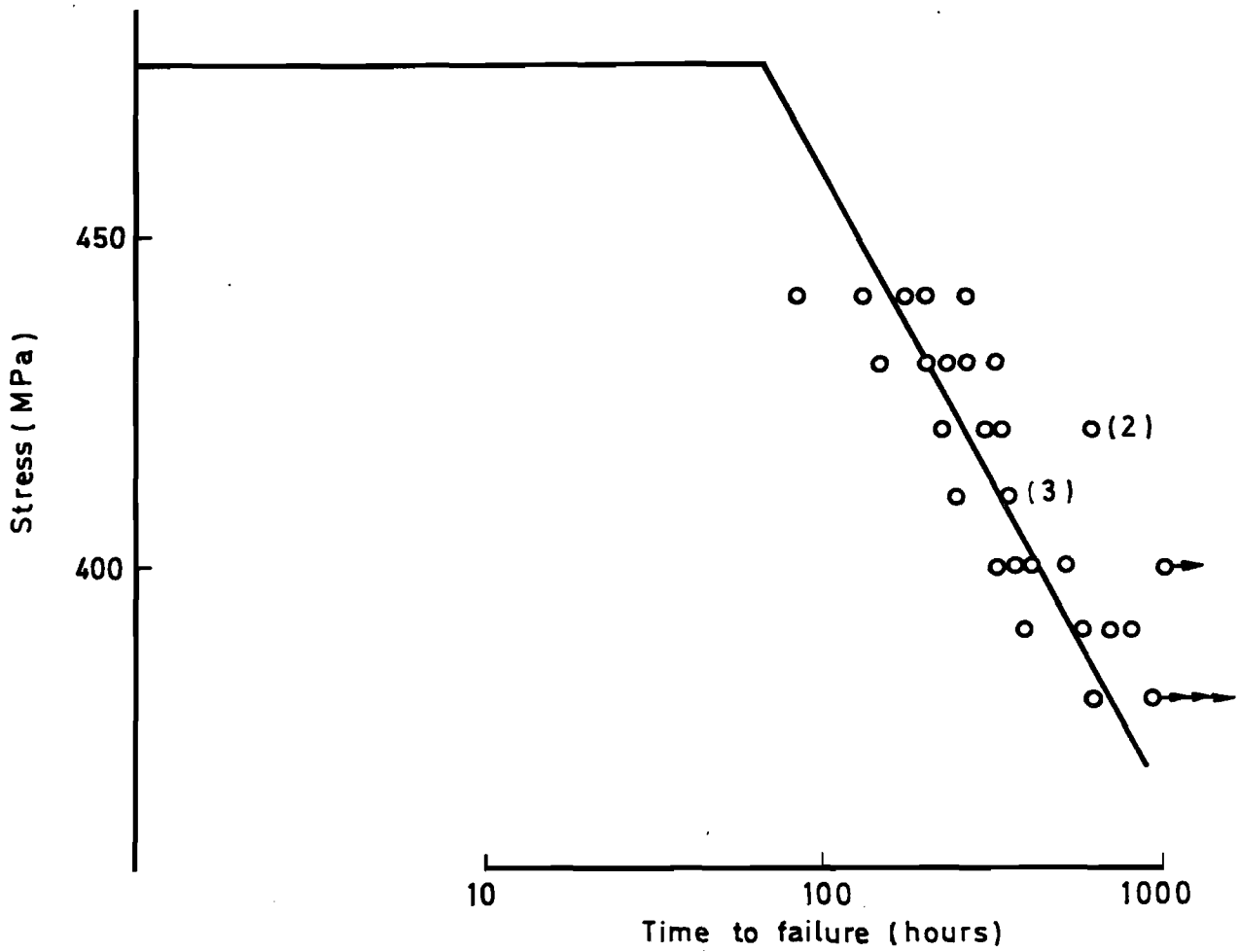


Fig 2 Relationship between time to failure and stress of 7010-T7651 alloy measured in 3.5% NaCl

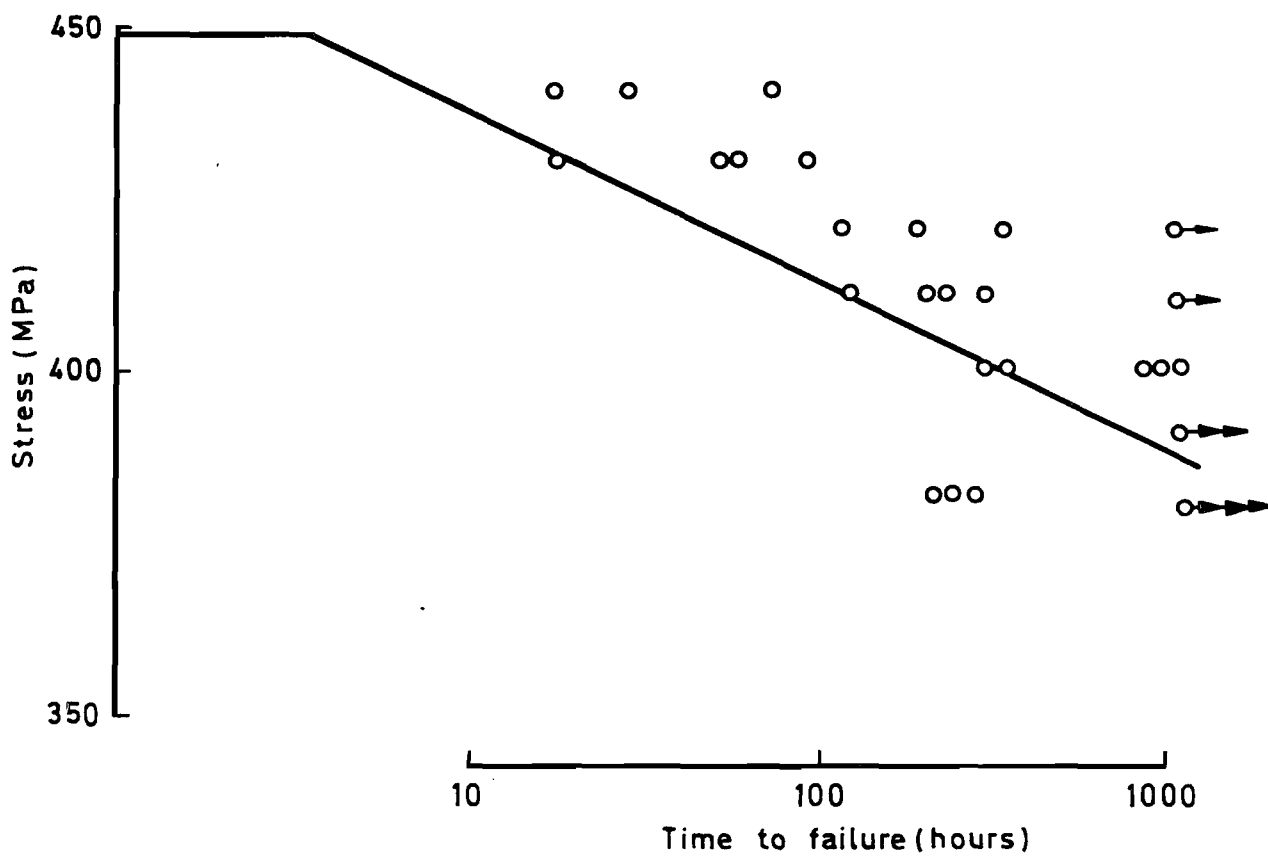


Fig 3 Relationship between time to failure and stress of 7010-T73651 alloy immersed in 3.5% NaCl

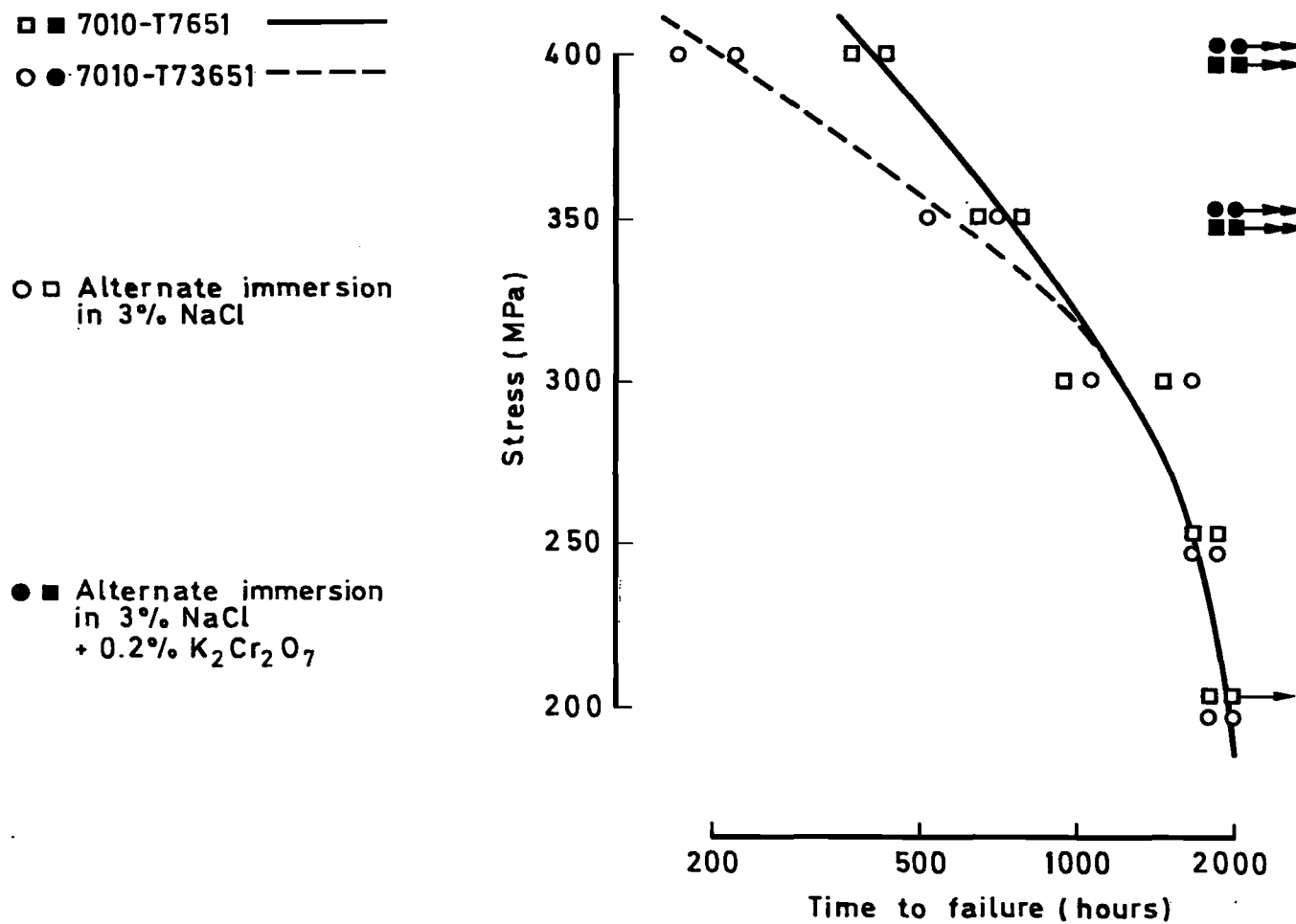


Fig 4 Results of sustained load alternate immersion stress corrosion tests on 7010 alloy

7010-T7651 □
7010-T73651 ○
7050-T73651 △

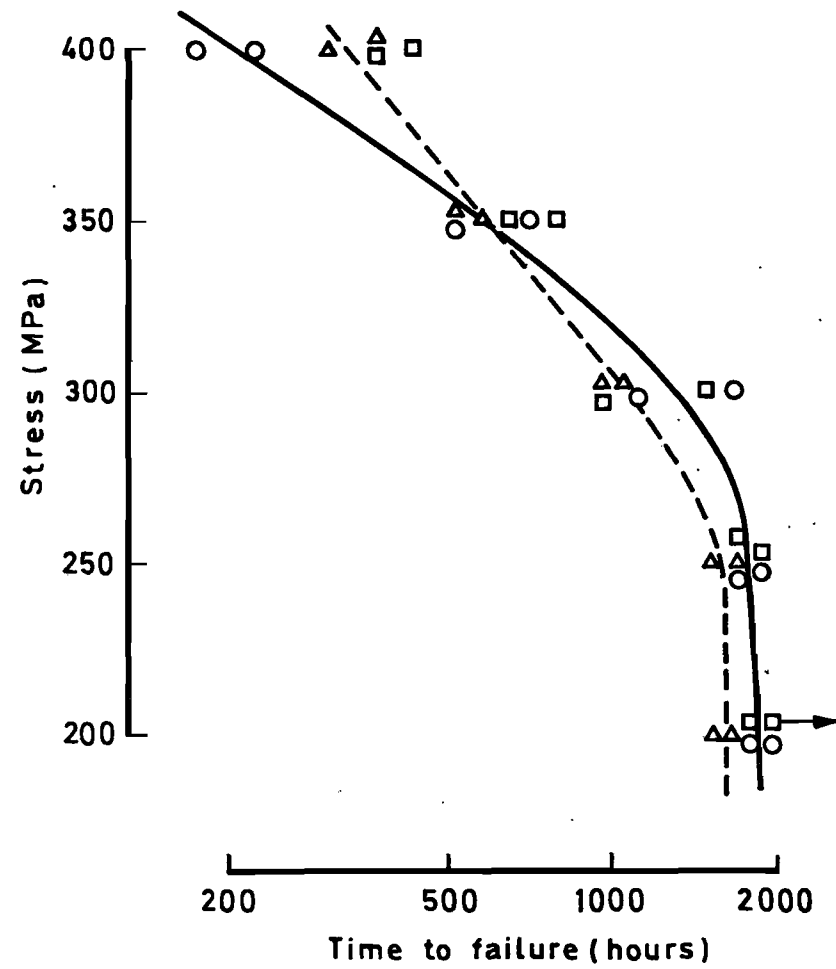


Fig 5 Results of sustained load alternate immersion stress corrosion tests in 3% NaCl on 7010 and 7050 alloys

Fig 6

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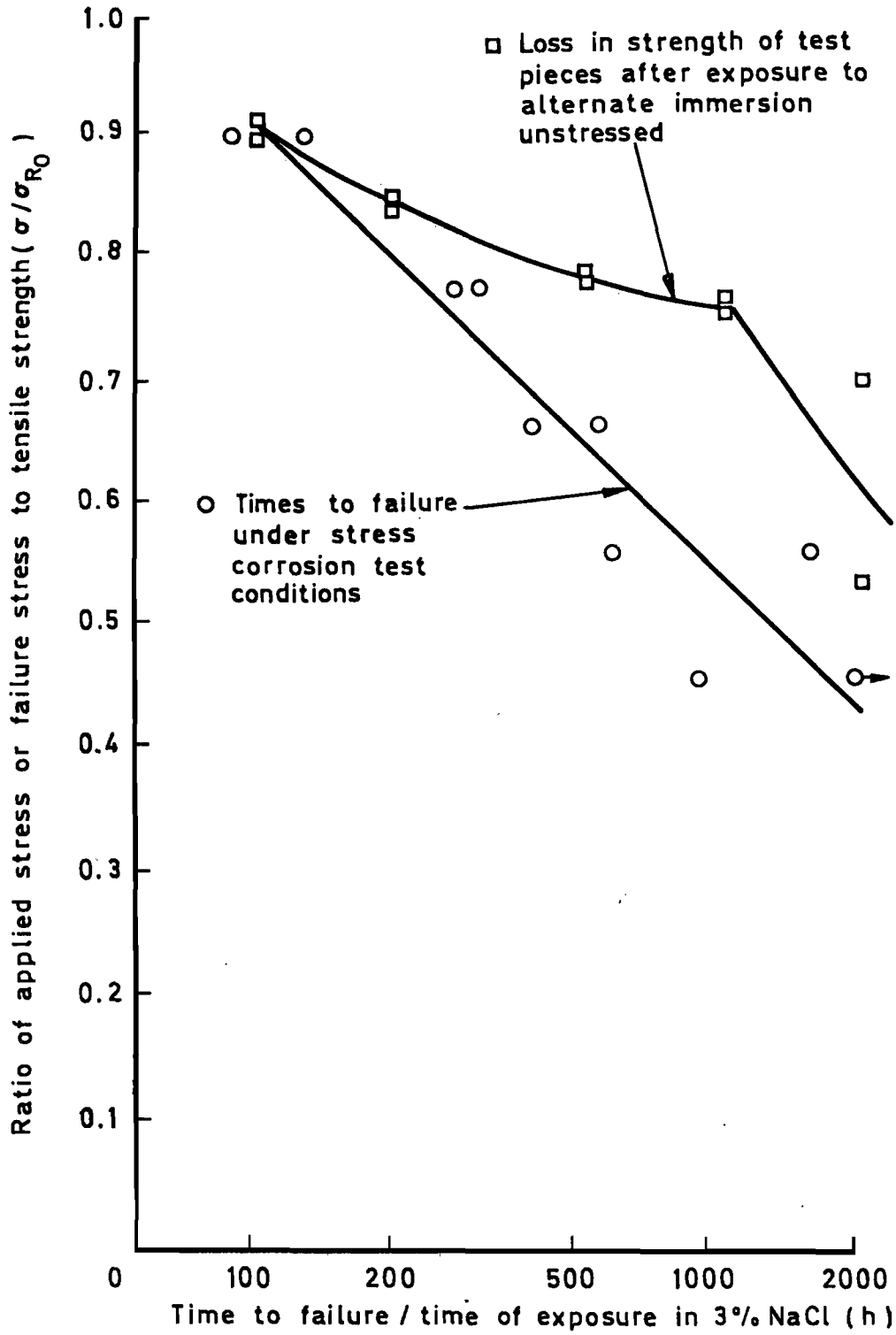
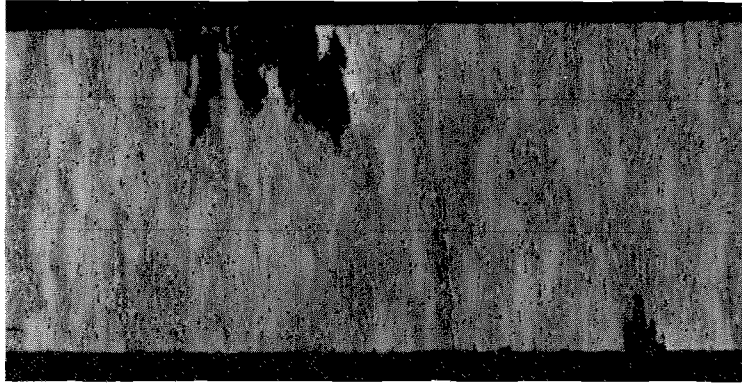
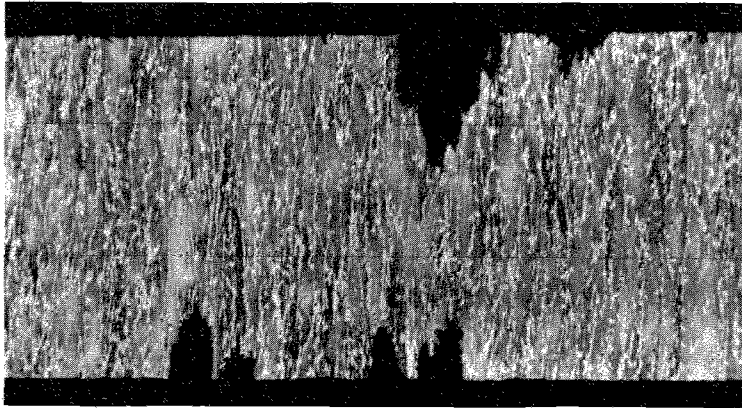


Fig 6 Comparison of stress corrosion time to failure and effect of alternate immersion on failure strength of 7010-T73651



T7651
Failed after 1870 hours at 200 MPa

x15



T73651
Failed after 1870 hours at 200 MPa

x15

Fig 7 Sections of 7010 alloy test pieces exposed to 3% NaCl by alternate immersion

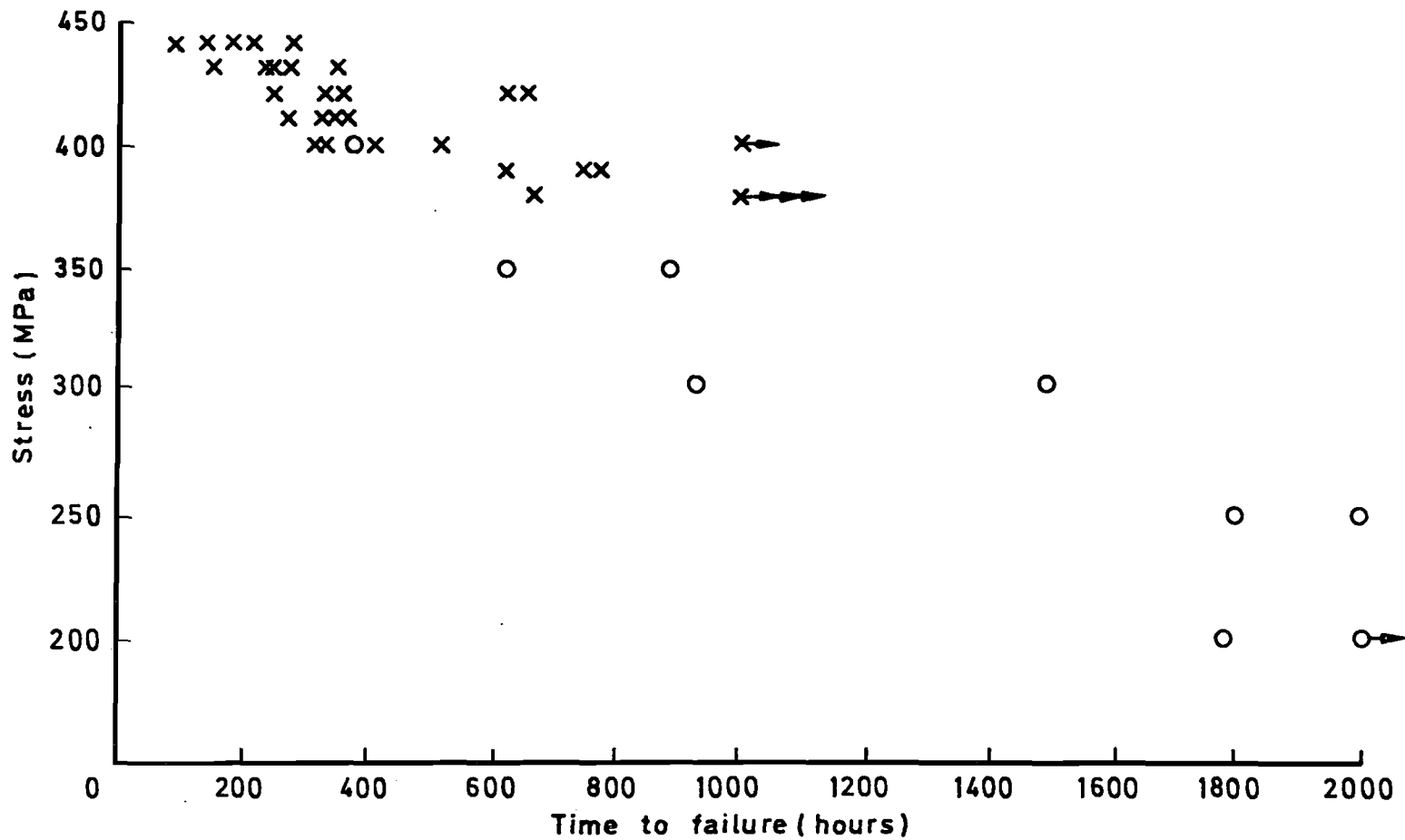


Fig 8 Sustained load stress corrosion tests on 7010-T7651 in neutral NaCl
X-DFVLR results, O-ONERA results

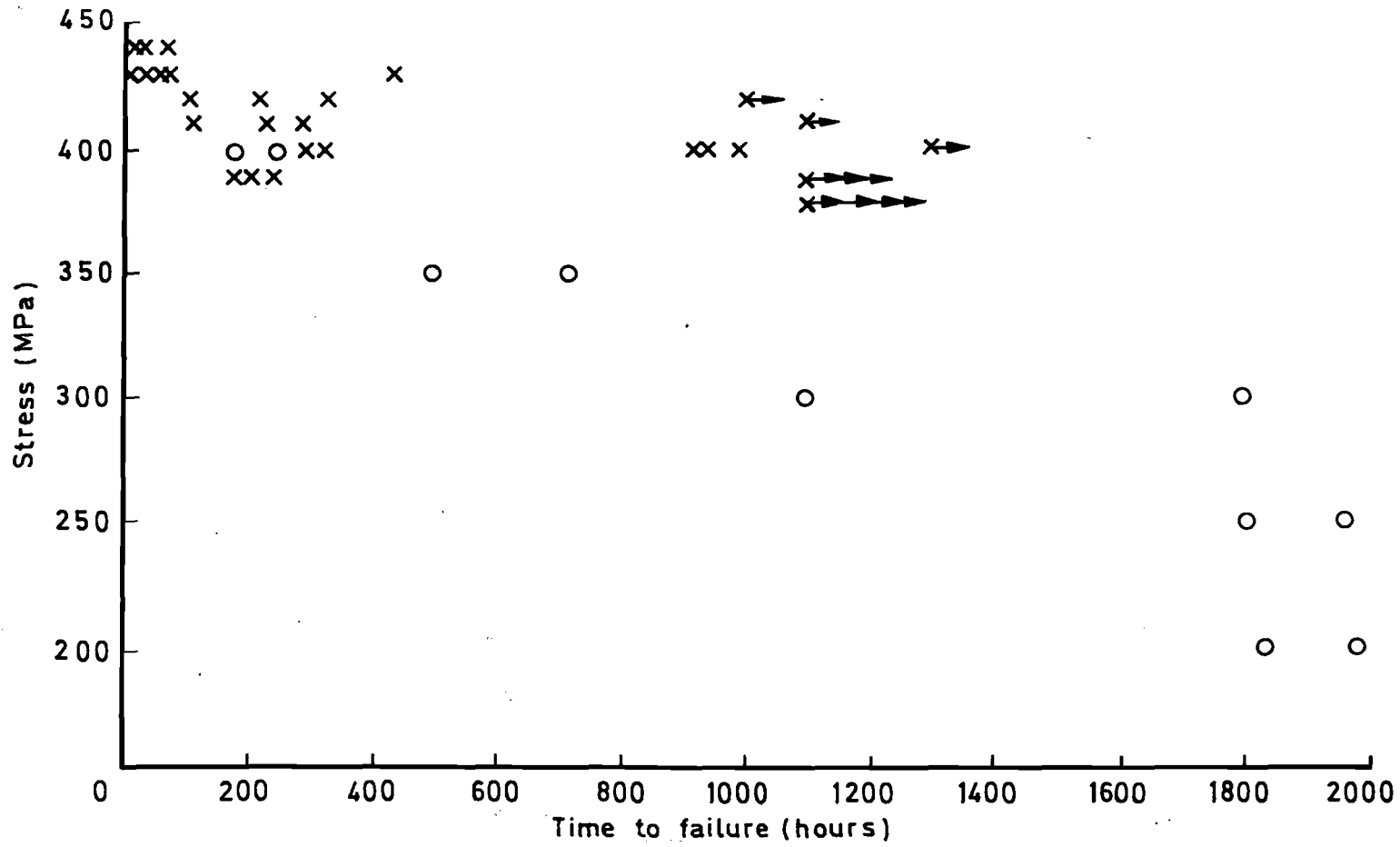


Fig 9 Sustained load stress corrosion tests on 7010-T73651 in neutral NaCl
 X-DFVLR results, O-ONERA results

Fig 10

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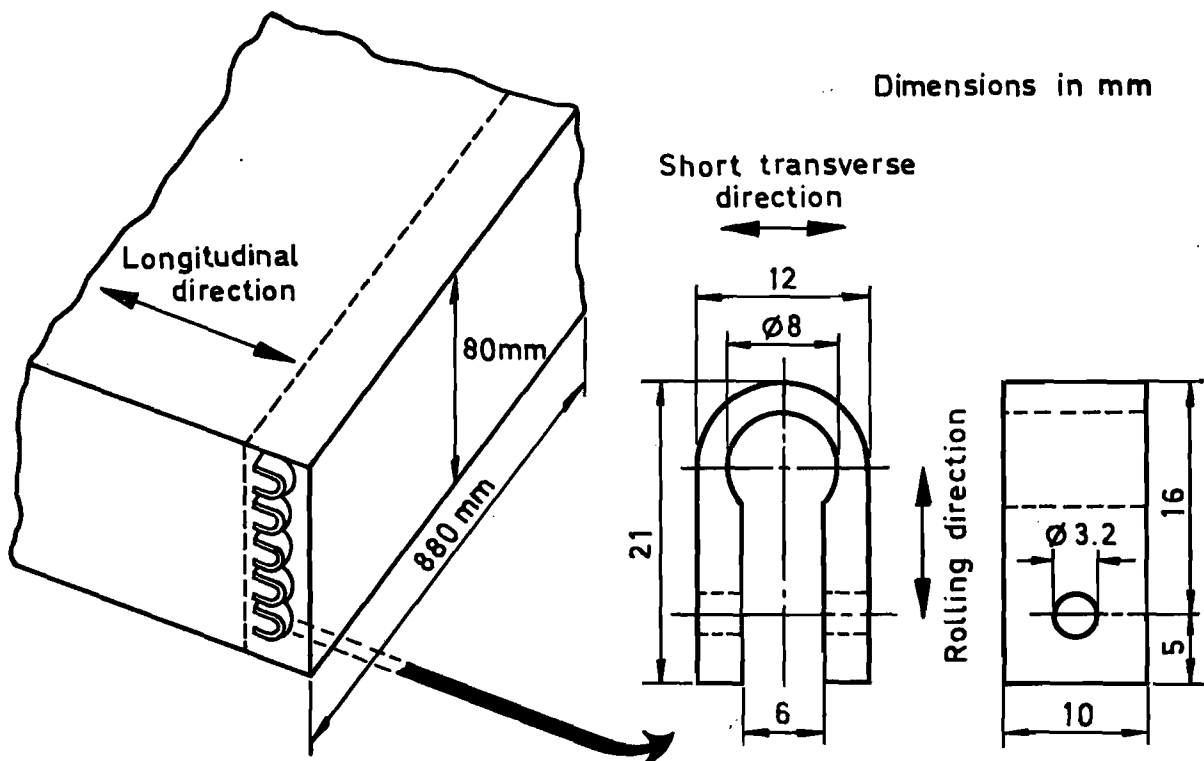


Fig 10 Location and dimensions of NLR stress corrosion crack initiation test piece

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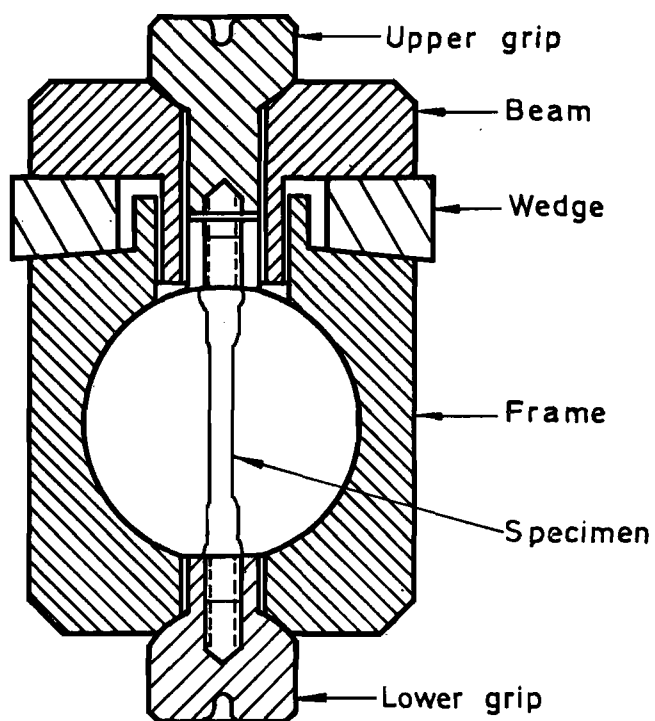
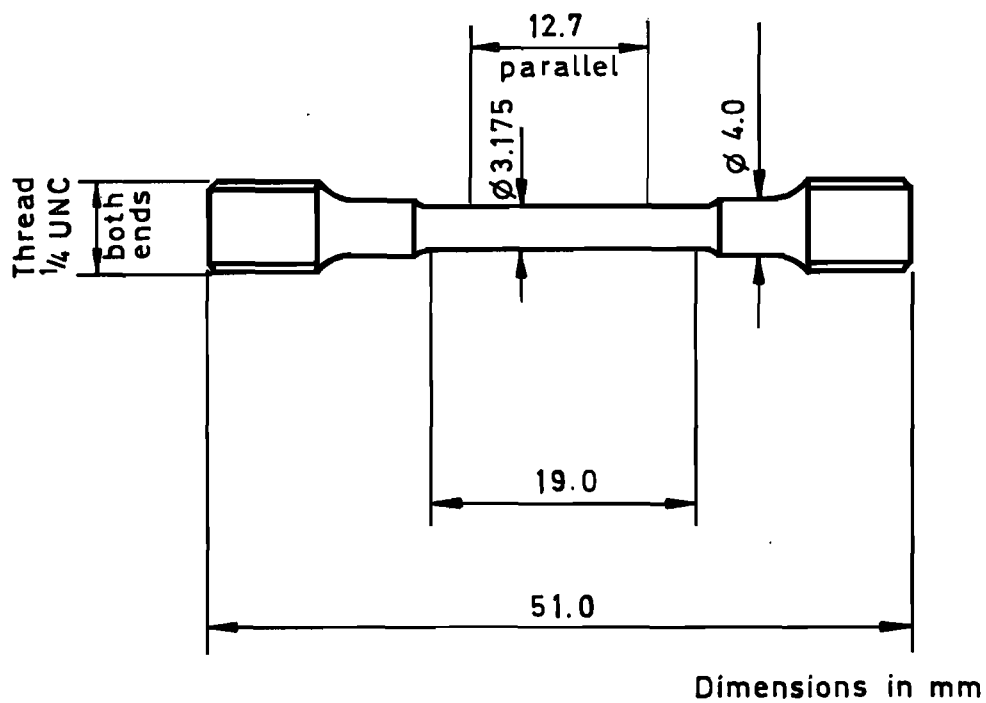


Fig 11 Test piece and straining frame for RAE constant tensile strain test

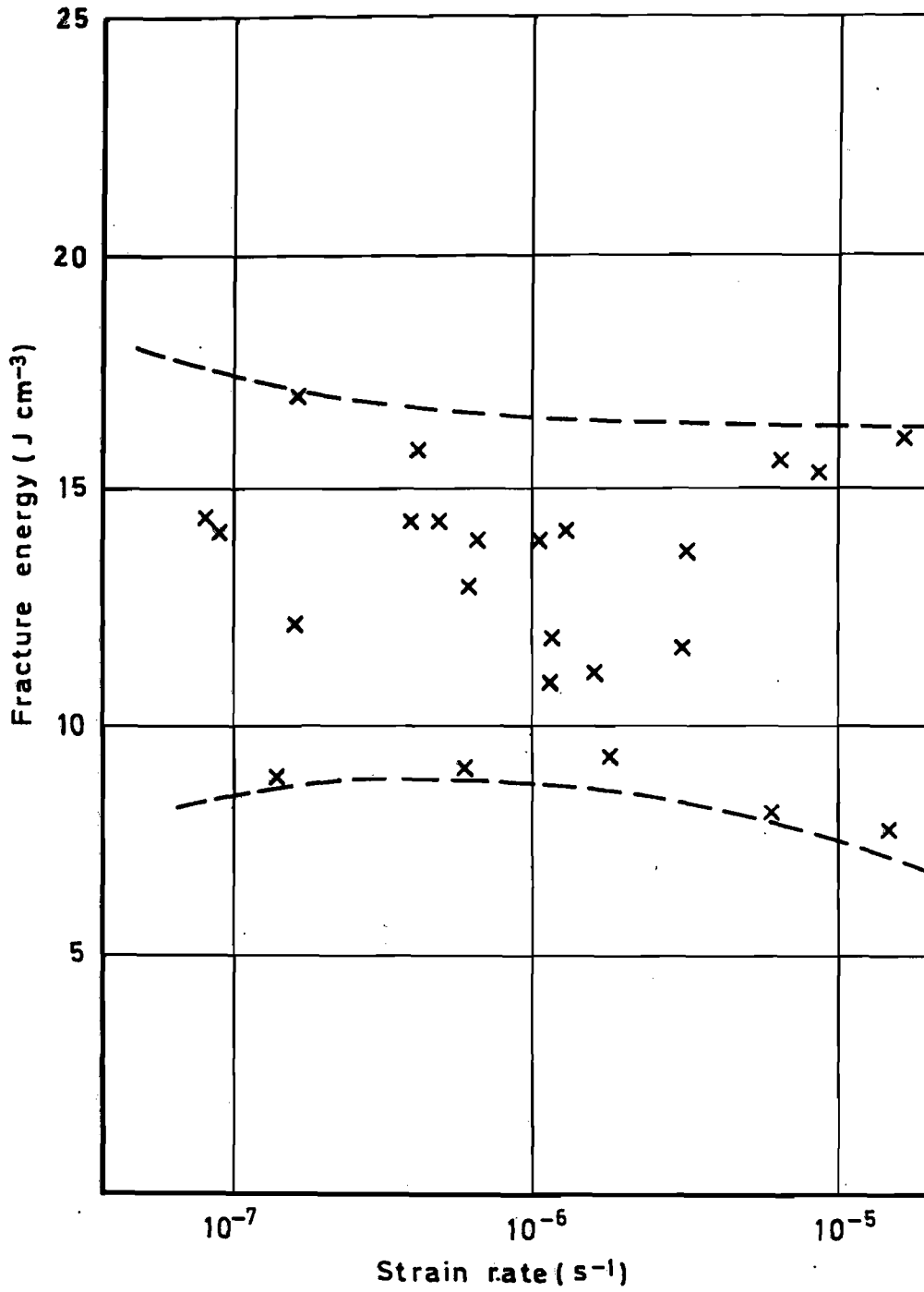


Fig 12 Relationship between strain rate and fracture energy of 7010-T7651 measured in vacuum

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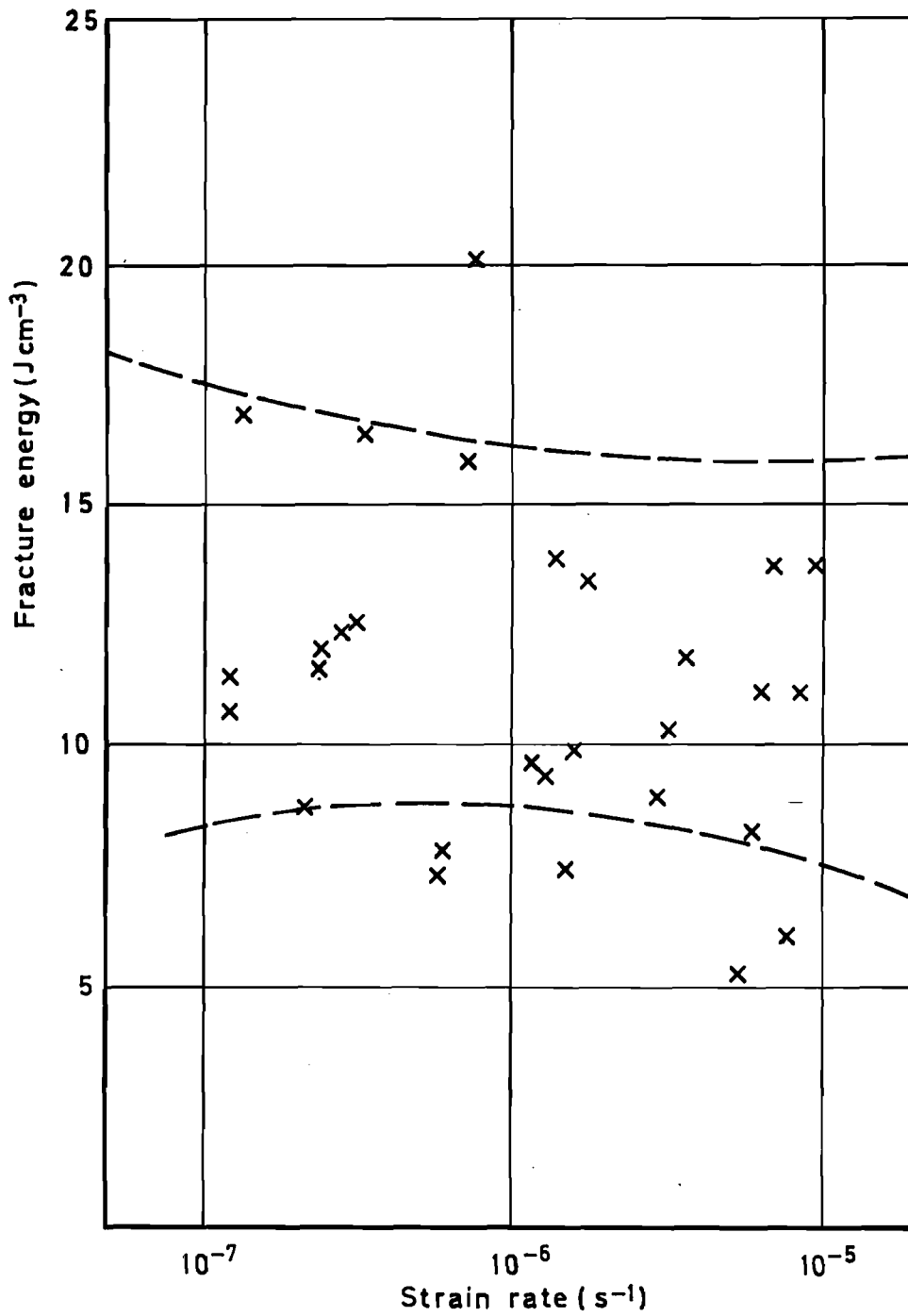


Fig 13 Relationship between strain rate and fracture energy of 7010-T7651 measured in the LN 65 666 solution

Fig 14

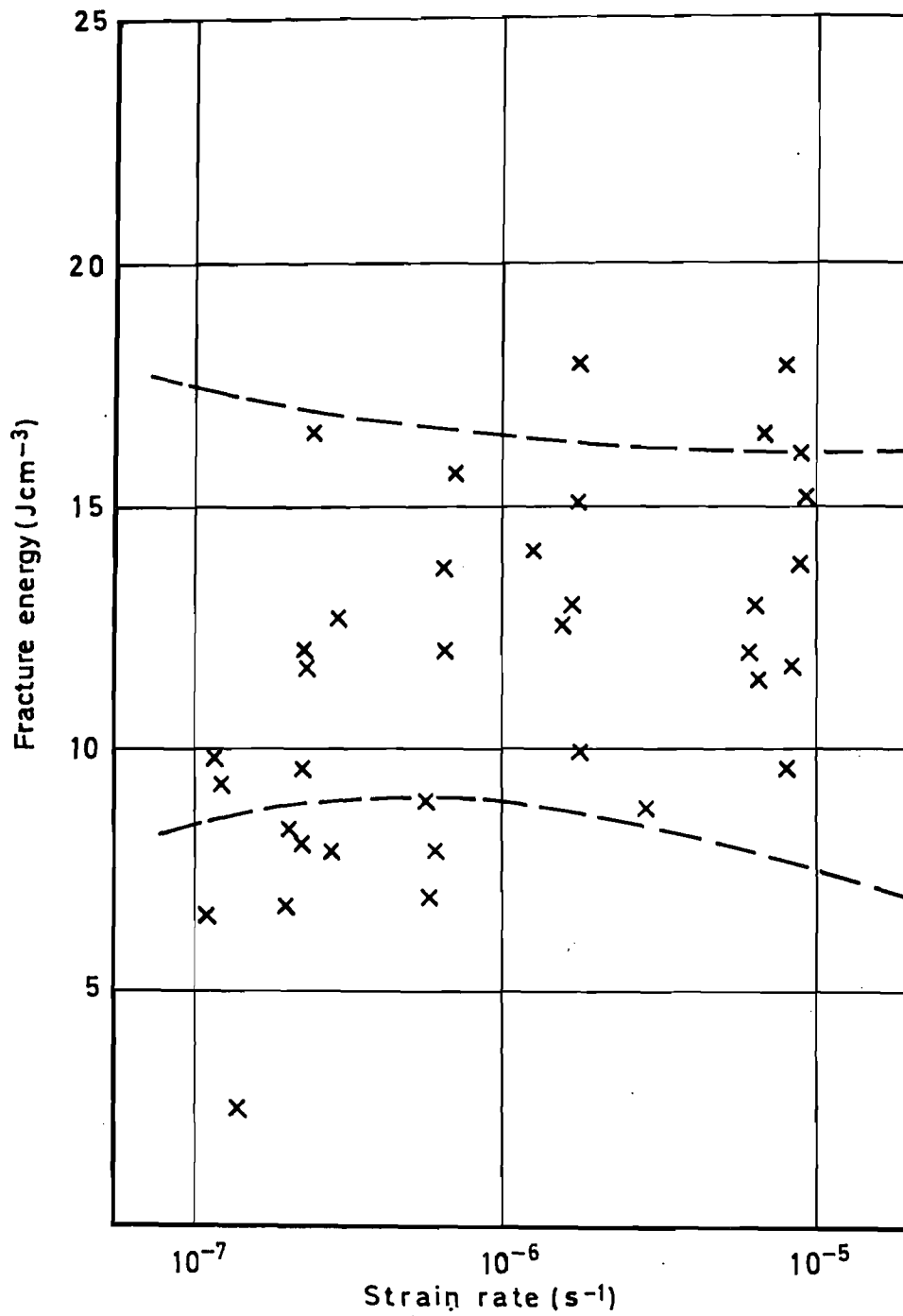


Fig 14 Relationship between strain rate and fracture energy of 7010-T7651 measured in 3.5% NaCl

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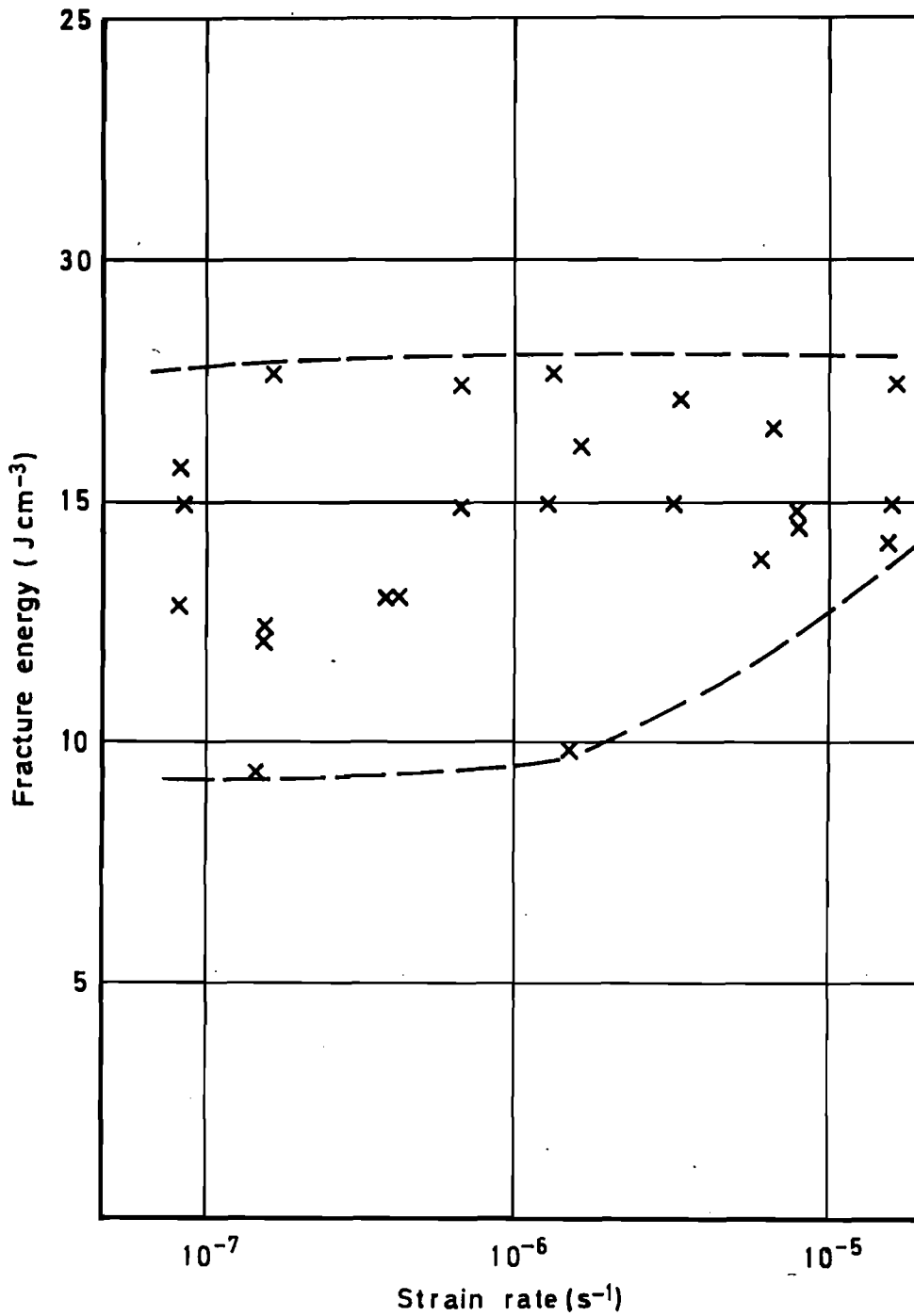


Fig 15 Relationship between strain rate and fracture energy of 7010-T73651 measured in vacuum

Fig 16

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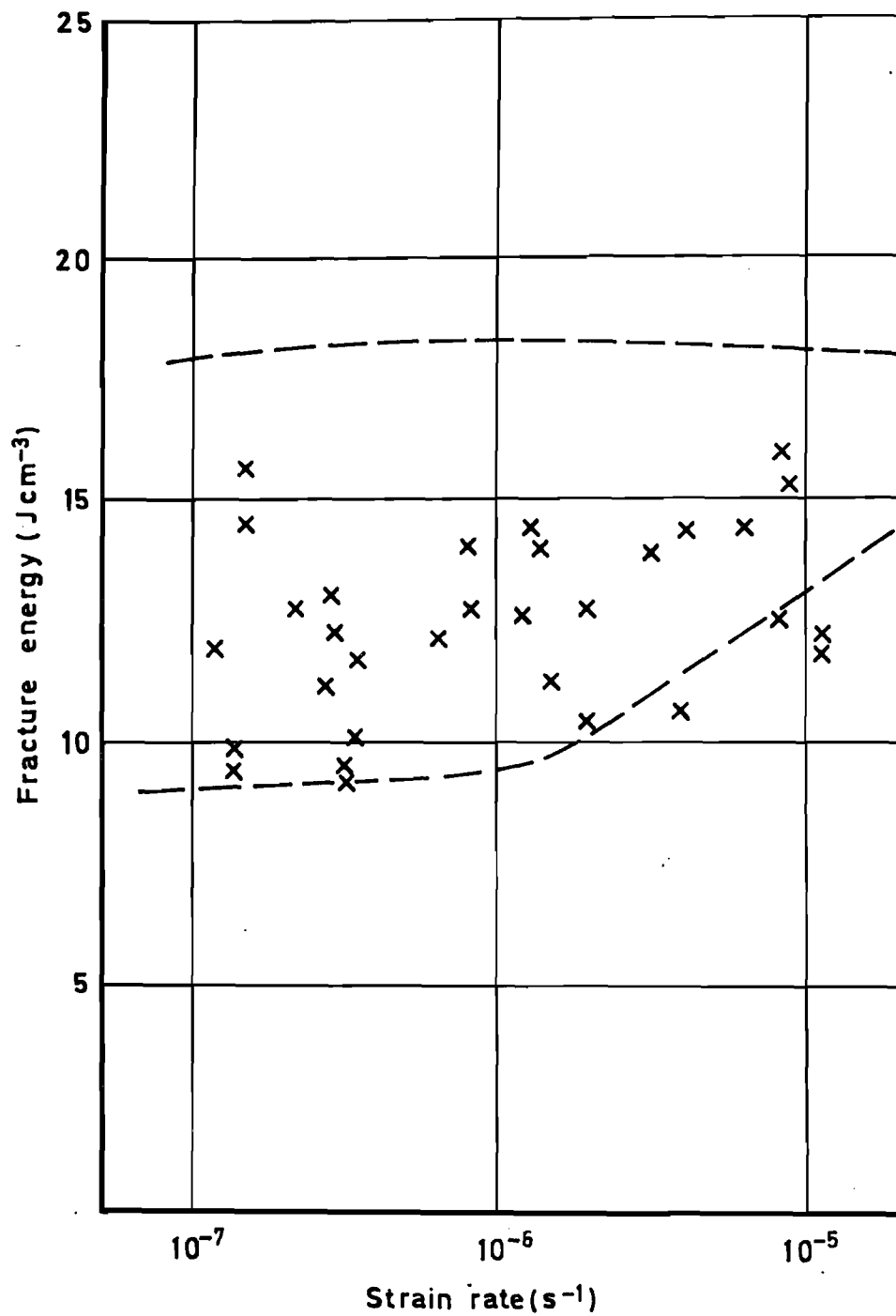


Fig 16 Relationship between strain rate and fracture energy of 7010-T73651 measured in the LN 65 666 solution

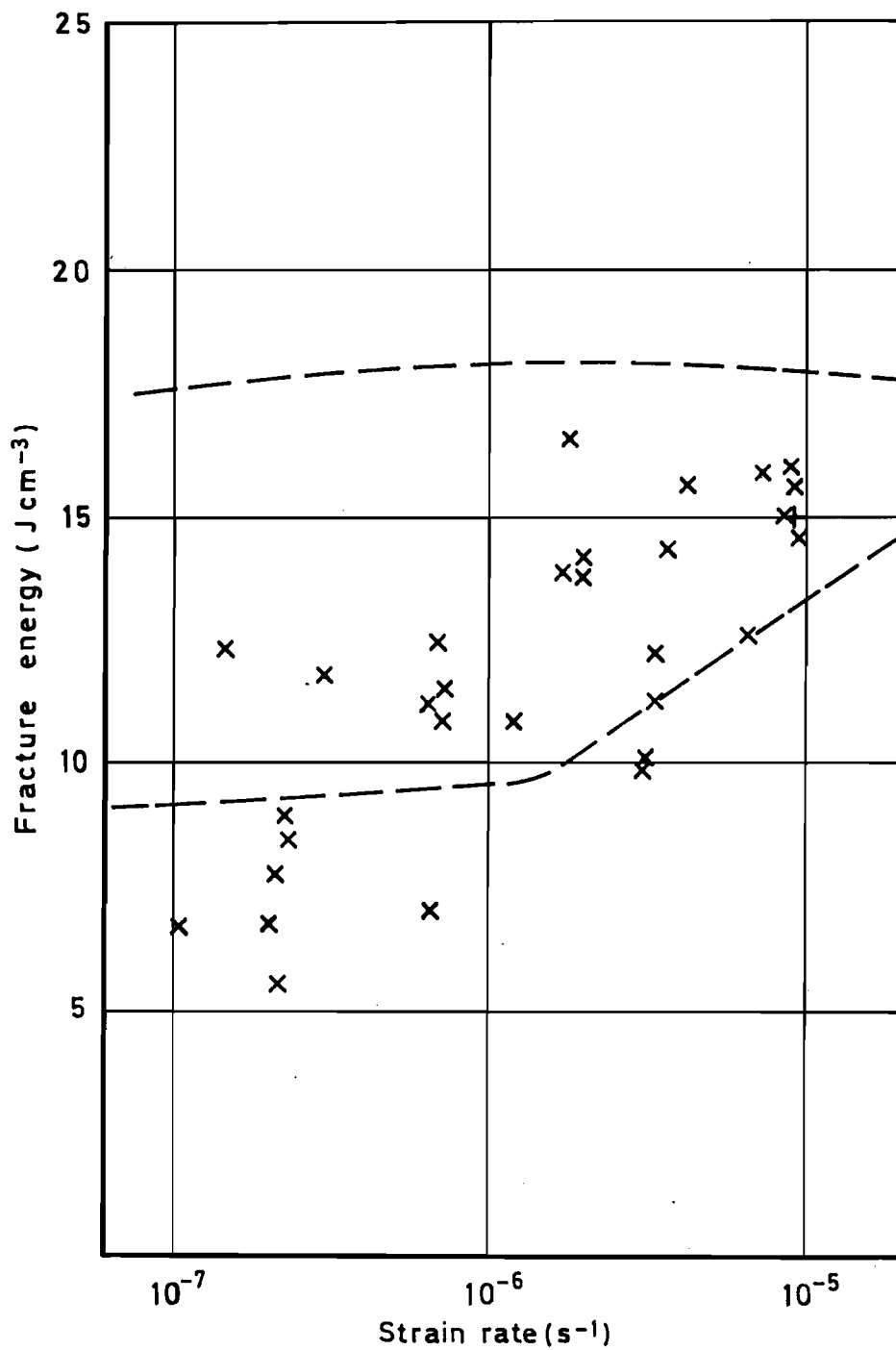


Fig 17 Relationship between strain rate and fracture energy of 7010-T73651 measured in 3.5% NaCl

Fig 18

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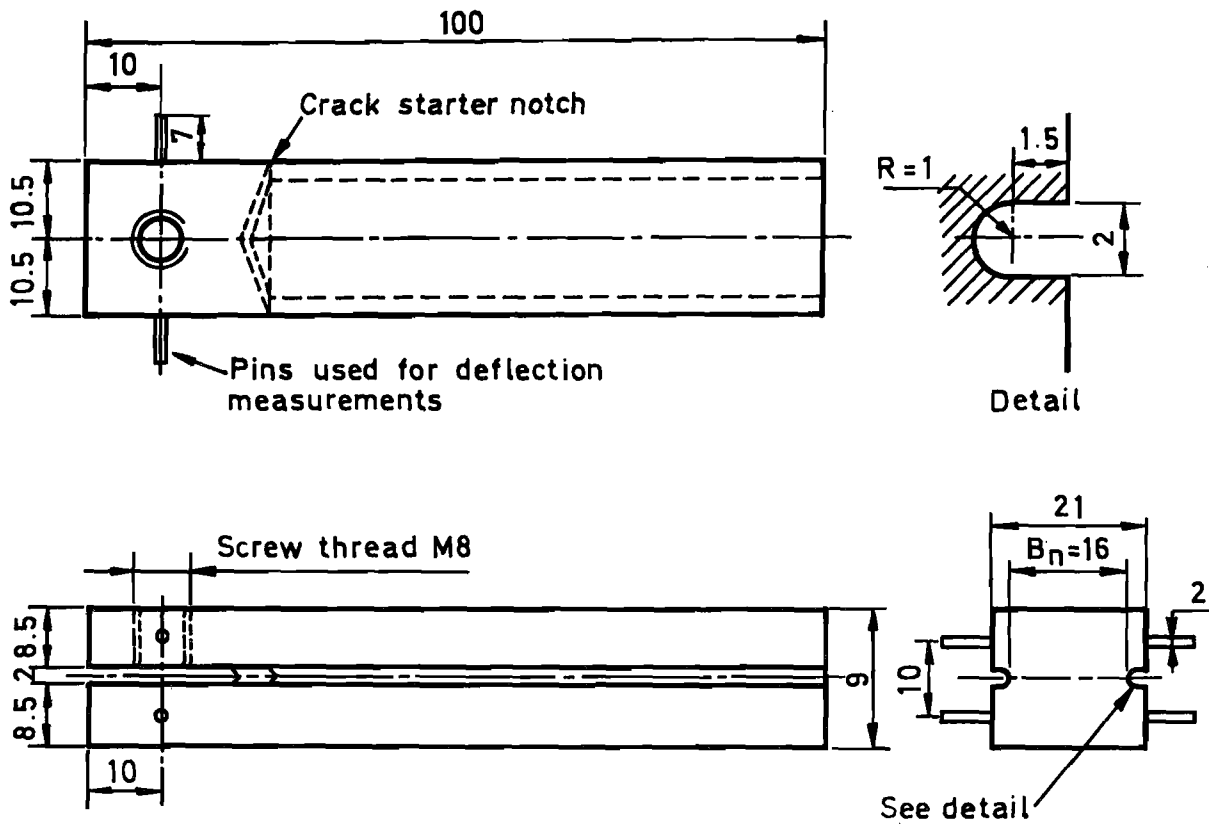


Fig 18 NLR double cantilever beam (DCB) test piece

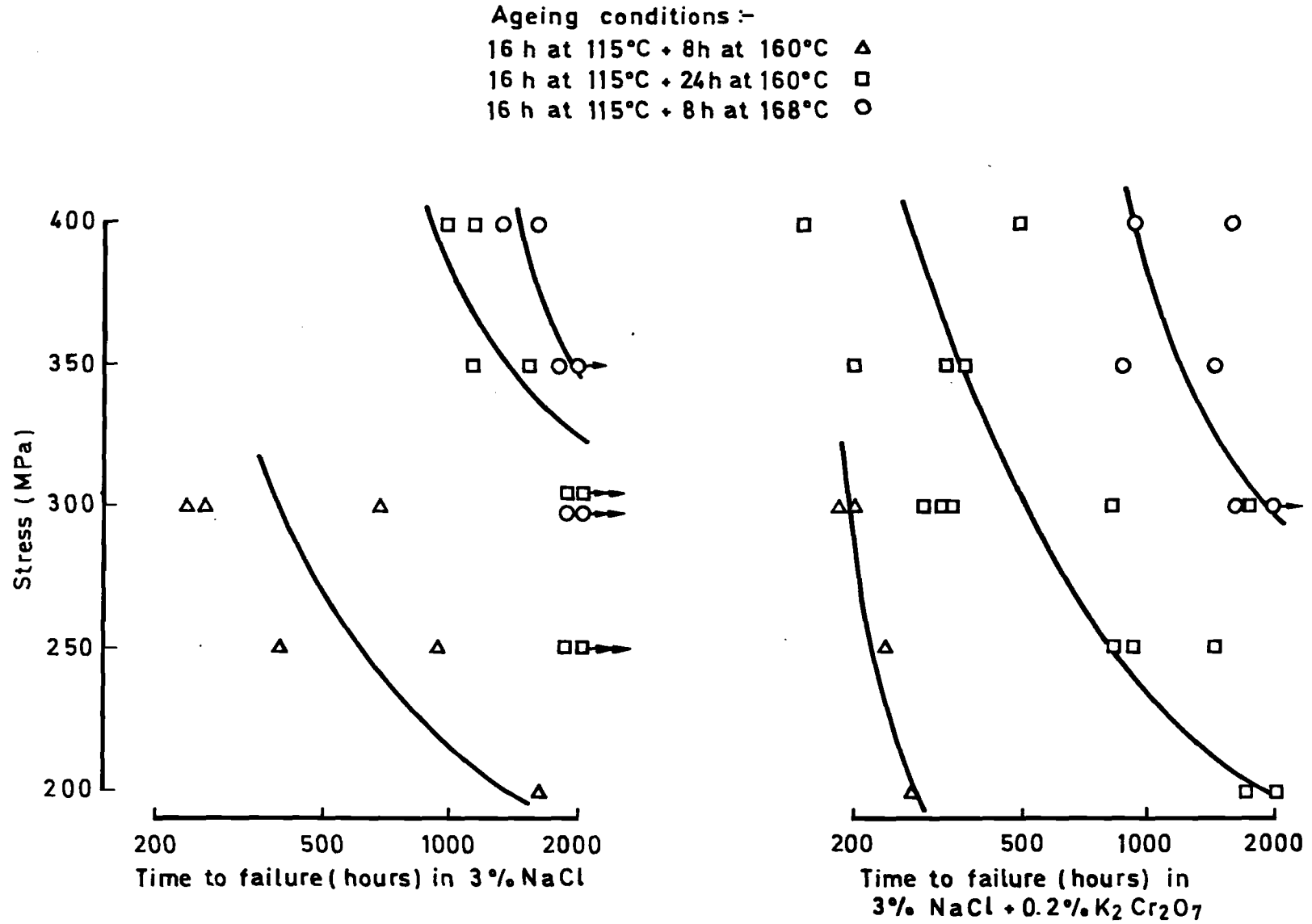


Fig 19 The effect of ageing conditions on the stress corrosion properties of 7010 alloy test pieces re-solution treated and cold water quenched

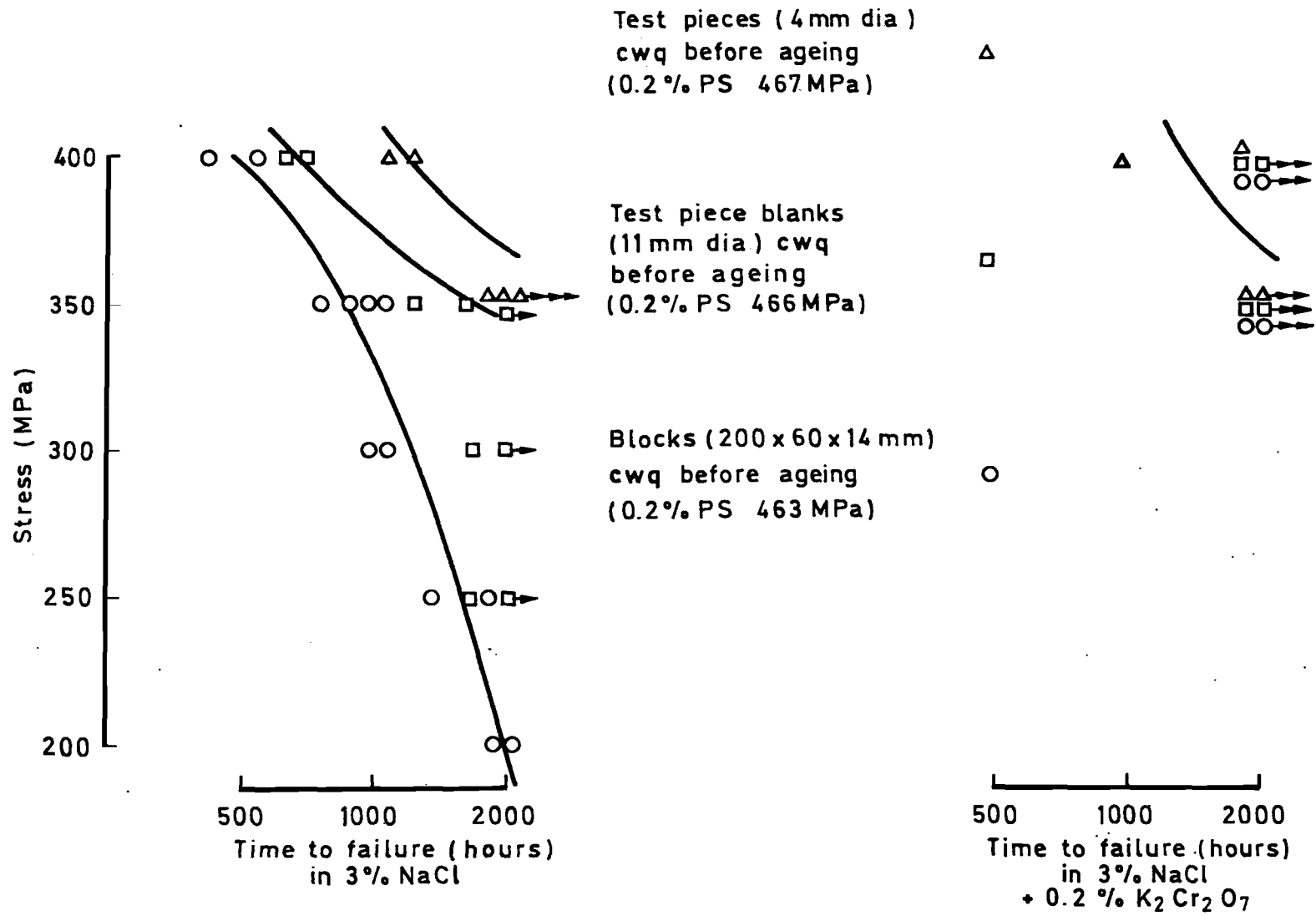


Fig 20 The effect of section size (quench rate) on stress corrosion properties of 7010 alloy (cold water quenched after solution treatment) aged 16 h at 115°C plus 16 h at 168°C

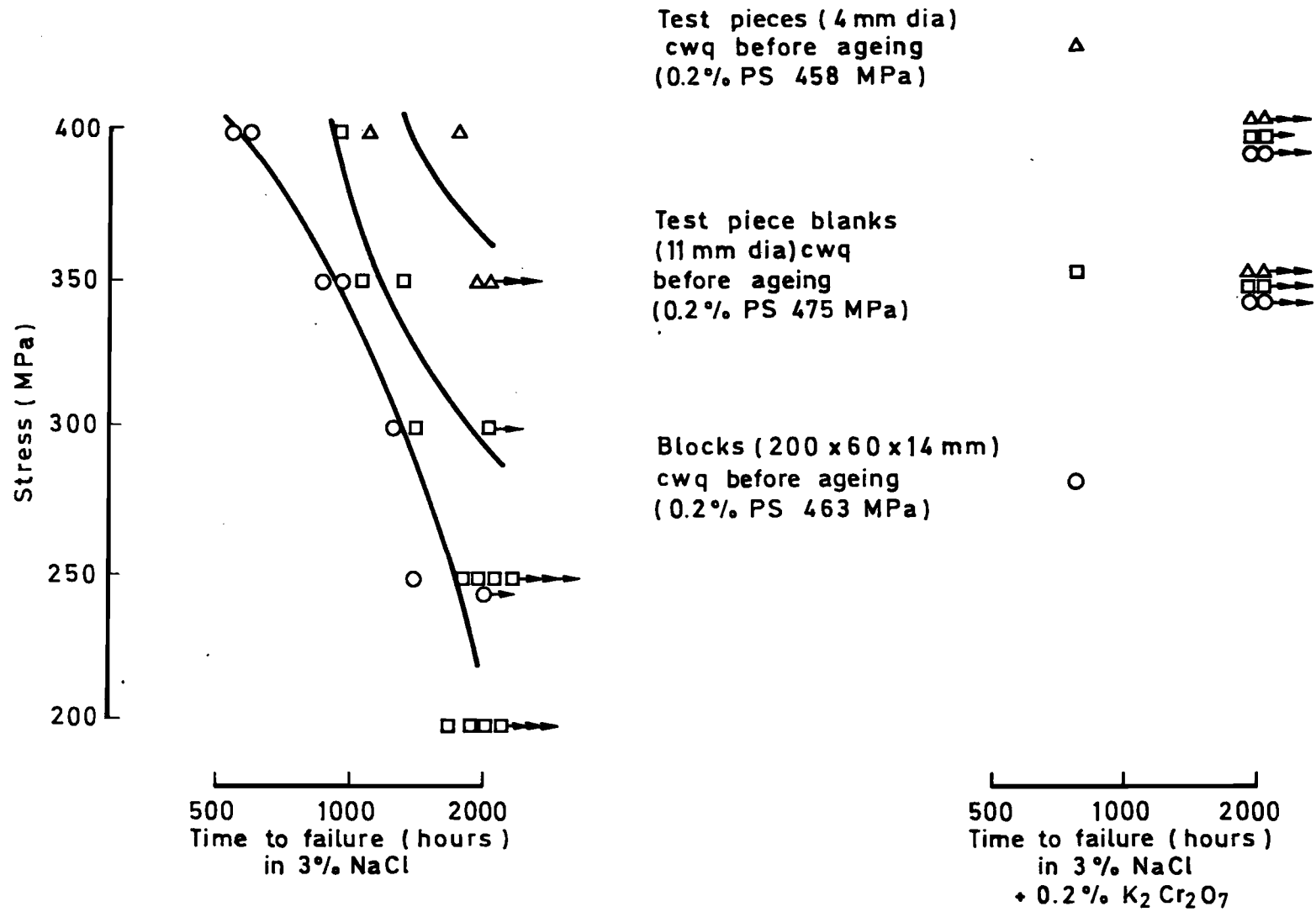
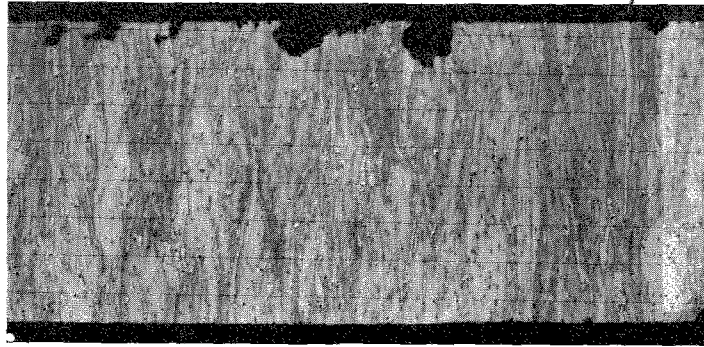
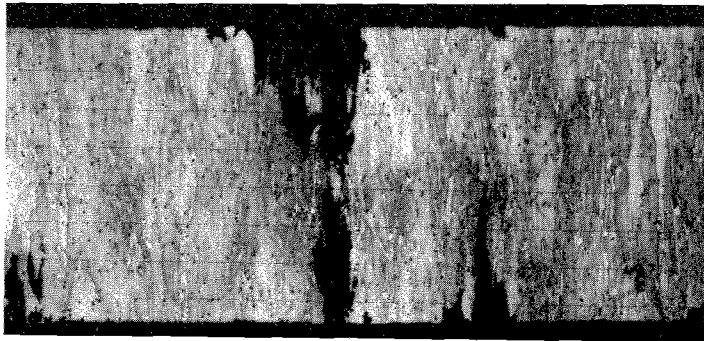


Fig 21 The effect of section size (quench rate) on stress corrosion properties of 7010 alloy (cold water quenched after solution treatment) aged 16 h at 115°C plus 8 h at 175°C



Rapid quenching (individual test piece quenched).
Unbroken after 2000 hours at 250 MPa

x15



Slow quenching (200 x 60 x 14 mm blocks quenched).
Failed after 1300 hours at 200 MPa

x15



As received (T73651).
Failed after 1600 hours at 250 MPa

x15

Fig 22 Sections of 7010 alloy test pieces given different quenching treatments, aged to a T73 condition and exposed to 3% NaCl by alternate immersion

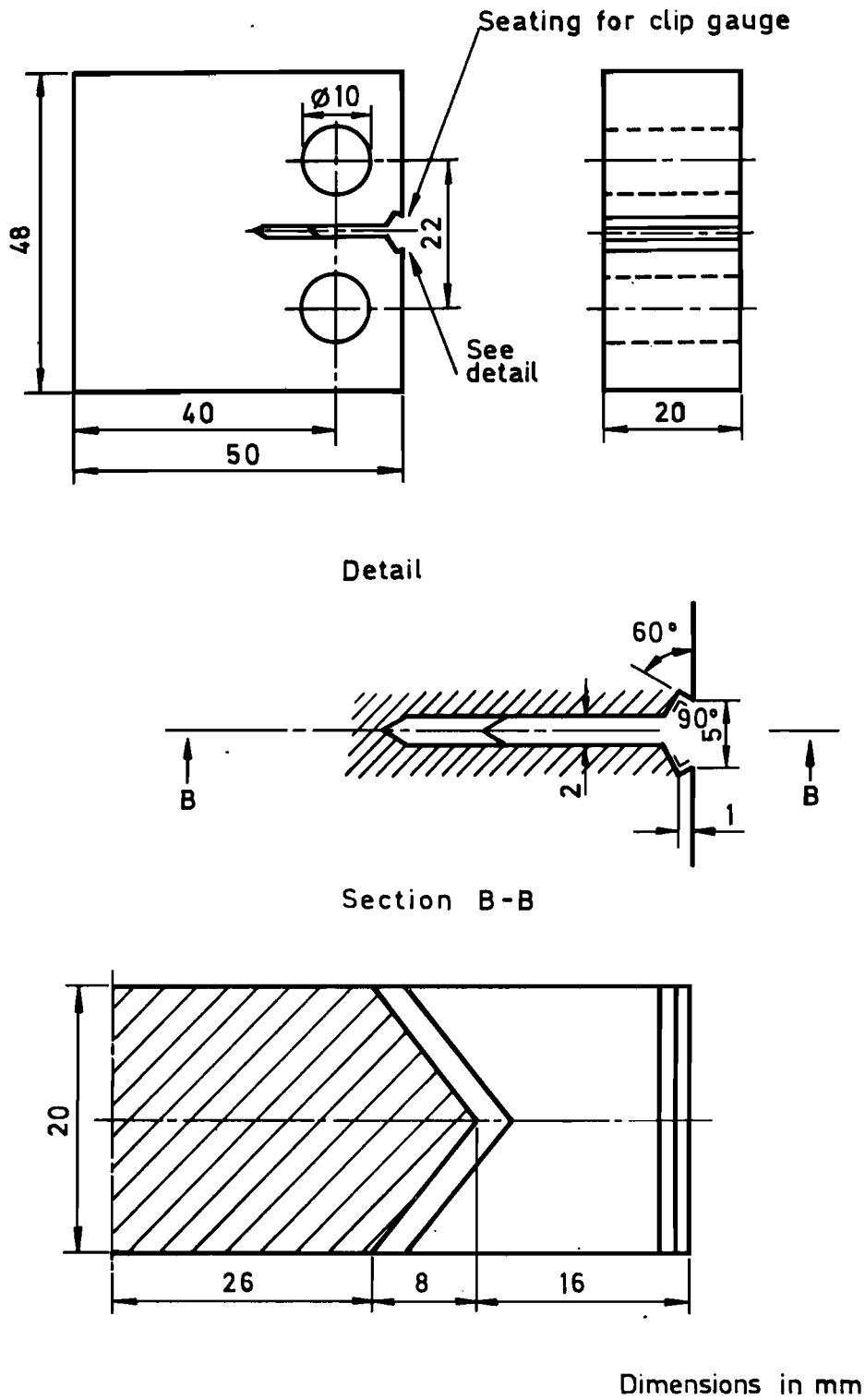


Fig 23 NLR fracture toughness test piece of the type: compact tension (CT)

Fig 24

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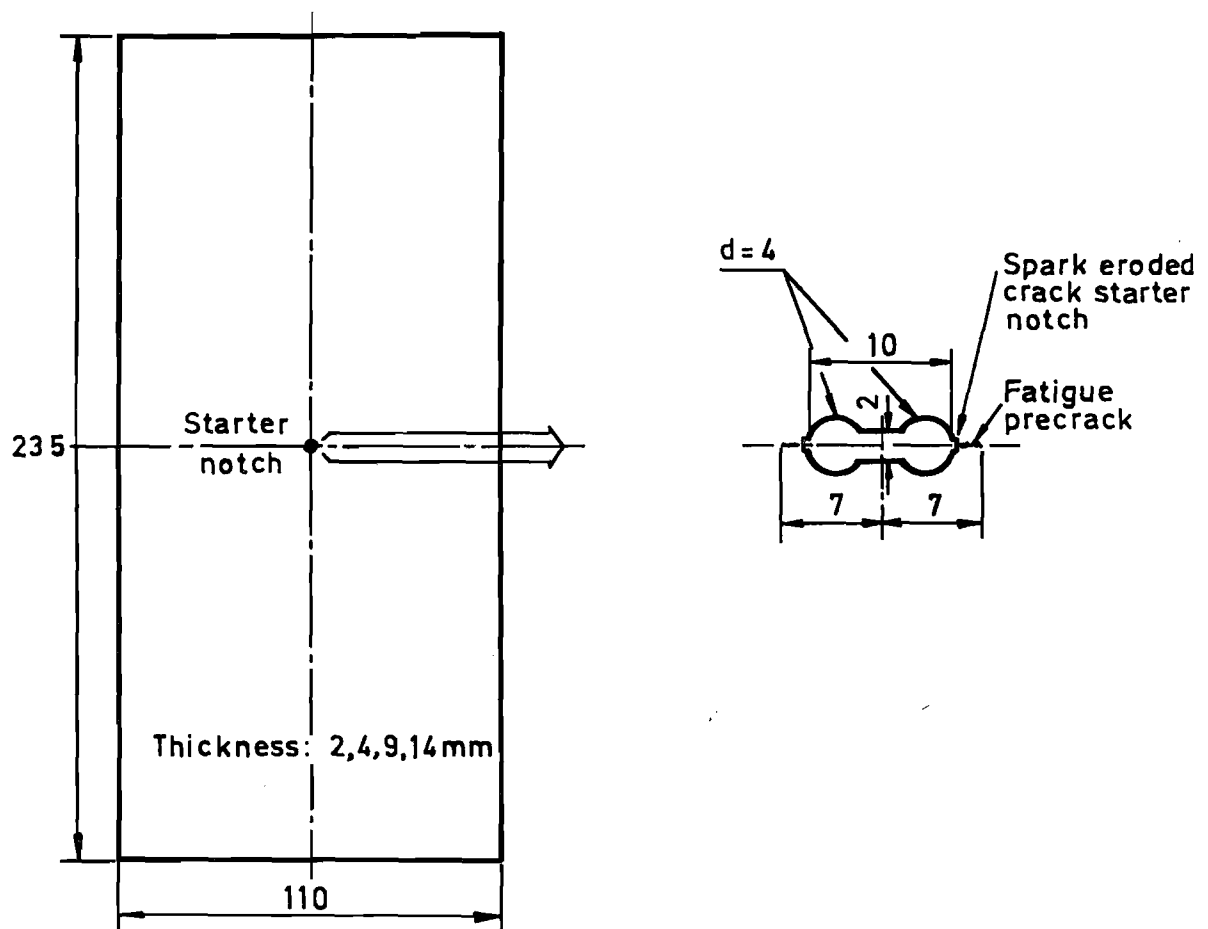


Fig 24 Dimensions of NLR fatigue test piece

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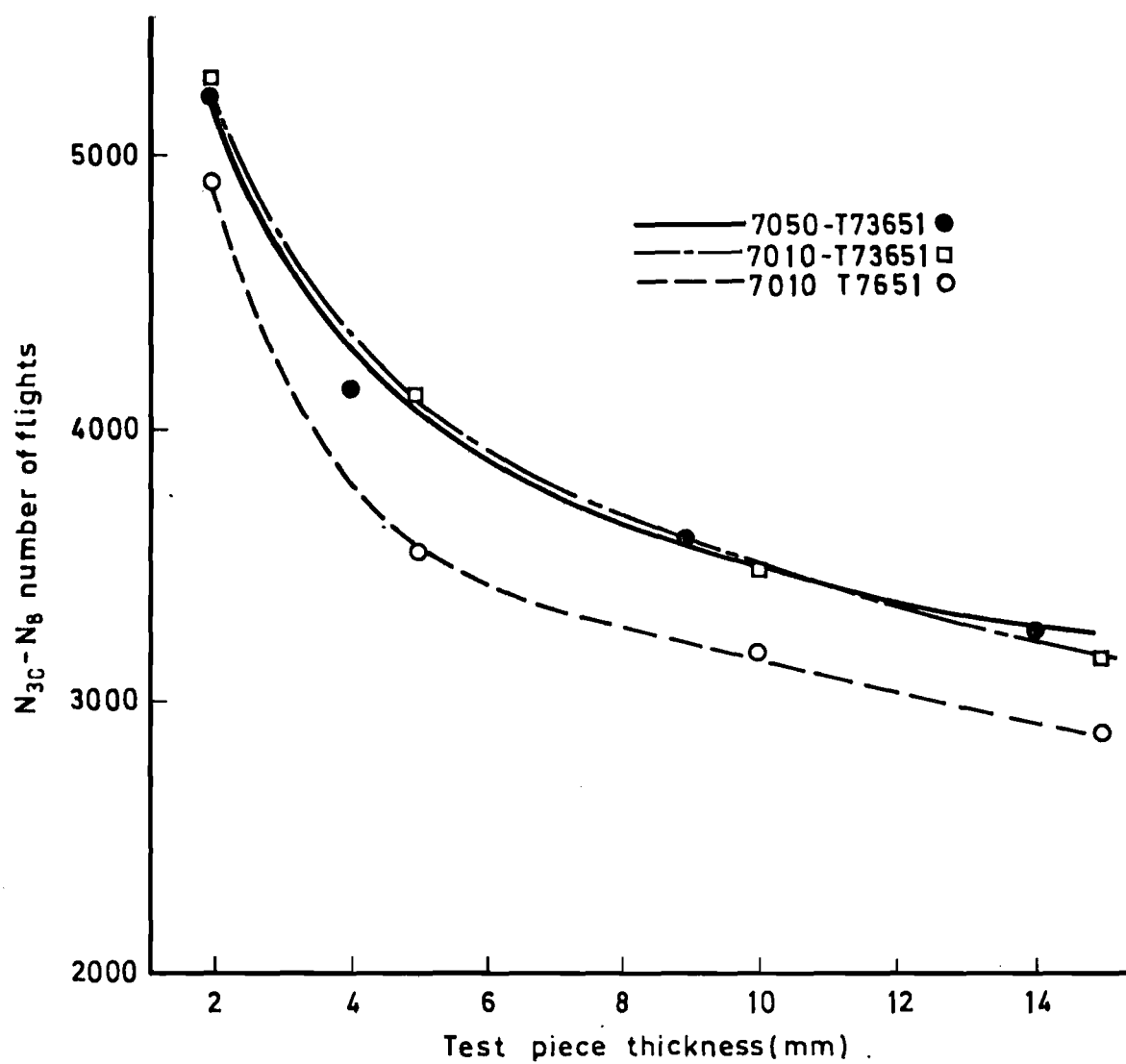


Fig 25 Influence of sheet thickness on fatigue crack growth

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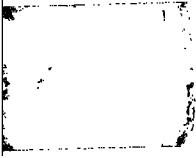
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8. Author 1. Surname, Initials McLoughlin, V.C.R.	9a. Author 2	9b. Authors 3, 4	10. Date November 1981
			Pages 46
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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST) Aluminium alloys*. Corrosion resistance*. Evaluation*. Fatigue tests*. Stress corrosion tests*. Tensile properties*. Toughness*.			
17. Abstract Aluminium alloy to the DTD 5120 (7010-T7651 and DTD 5130 (7010-T73651) specifications was supplied by Alcan (UK) Ltd to DFLVR, NLR, ONERA and RAE for evaluation of the alloys' stress corrosion resistance and other properties. The four laboratories used their preferred test methods and made comparisons with other stress corrosion resistant alloys (7050-T73651 and 7075-T7351). The alloys' tensile properties, fracture toughness, fatigue crack propagation rates and repassivation kinetics were assessed. The effects of special heat treatments on the mechanical and stress corrosion properties of 7010 alloy were also investigated.			

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