THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE CORROSION FATIGUE BEHAVIOUR OF STAINLESS SPRINGS

by

A.R. Hood, B.Sc., M. Met.

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SUMMARY

The in-air and corrosion fatigue properties of springs coiled from three different stainless steel wires have been investigated.

Results showed that, for springs surviving 10^7 cycles, the fatigue strength of 17/7 PH was much greater than that of En 58J which was in turn greater than that of En 58A for both in-air and corrosion fatigue conditions.

For higher applied stresses the En 58A and En 58J springs displayed similar in-air fatigue properties, both being inferior to the 17/7 PH springs.

Preliminary work on the effect of low temperature heat treatment (LTHT) of the En 58J wire indicated an optimum LTHT of ½ hour at 450°C for this material.

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1. INTRODUCTION

A considerable amount of work has been undertaken at SRAMA into the fatigue properties of a variety of spring materials. All these tests, however, have been carried out in a normal air environment.

In the present work an attempt has been made to assess the effect of a corrosive environment on the fatigue properties of three common stainless steel spring materials.

17/7 PH is a precipitation hardening 17% chromium/7% nickel material which can be aged to give higher tensile strengths than are usual with stainless wires.

En 58A is a straight 18/8 type austenitic stainless steel, but on hard drawing sufficient martensite is formed to give a slight increase in tensile strength compared to a fully austenitic wire

En 58J is a molybdenum bearing 18/8 material which is almost fully austenitic even after hard drawing, and has, therefore, the lowest tensile strength of the three materials. As no previous work on this material had been carried out at SRAMA, a preliminary investigation was undertaken into the effect of low temperature heat treatment on the tensile and fatigue properties of wire and springs.

In-air S/N curves were produced for springs coiled from the three materials. From these curves, fatigue strengths for survival beyond 10^7 cycles were obtained. Corrosion fatigue tests were then undertaken, in a salt-laden atmosphere, to detect and evaluate any changes in the 10^7 cycles fatigue strengths.

2. SPRING DESIGNS AND MATERIALS

Springs were coiled from En 58A (302S25), En 58J (316S16) and 17/7 PH, the wire diameters being 2.64 mm, 2.5 mm and 2.65 mm respectively. The chemical analyses of the three materials are given in Table I, while the standard specifications are shown in Table II. Table III contains the design data for the three sets of springs.

After coiling, the En 58A and En 58J springs were given a stress-relieving low temperature heat treatment (LTHT) for ½ hour at 400°C(4) and 450°C respectively. The 17/7 PH precipitation hardening alloy was aged for one hour at 480°C (± 5°C) after coiling, in accordance with DTD 5086(1). All springs were end-ground after LTHT. A vertical Amsler multi-range tensile testing machine was used to determine the tensile properties of the materials in both the as-received and LTHT'd conditions. The results are recorded in Table IV. The torsional data given in Table V was obtained either using a horizontal multi-range Tinius-Olsen torsion testing machine or using an Amsler torsion testing machine type 0.5 TA89.

3. EFFECT OF LTHT ON THE PROPERTIES OF EN 58J WIRE

3.1 Fatigue Properties

Sets of springs coiled from the En 58J wire were given LTHTs of ½ hour at temperatures of 350, 400, 450, 500, 550 and 600°C. Springs from each LTHT set were tested on a horizontal forced motion fatigue testing machine at an initial stress of 100 N/mm^2.

Ten springs from each LTHT set, plus ten springs in the as-coiled condition, were fatigue tested at a maximum applied stress level of 600 N/mm^2. The results of these tests are expressed in Fig. 1. Statistical 't' tests showed there to be no significant difference (at the 95% level of confidence) between the fatigue properties of adjacent sets of springs until a LTHT temperature of 550°C was reached.

The 550°C and 600°C results show an improvement which is apparently anomalous, as the tensile strength of the material has been shown (3.2) to decrease sharply after LTHT above 500°C. However, previous work(4) on the LTHT of En 58A wire showed that for high LTHT temperatures (i.e. > 500°C) the stress-relaxation properties of the material deteriorated as the LTHT temperature increased. In view of the similarity of the other properties of En 58A and En 58J one would expect this trend to be repeated in the En 58J material. Hence, the 550°C LTHT springs would be likely to relax and set down during fatigue testing so that the experimentally applied stresses would be lowered. (The fatigue testing machine used has a fixed stroke, so that when a spring sets down during testing the applied loads decrease).

Although the results for the remaining sets of springs show no statistically significant variation, the springs given a 450°C LTHT tend to have a longer fatigue life than the other sets. For each of the 400, 500 and 600°C sets of springs, ten springs were also fatigue tested at a maximum applied stress of 800 N/mm^2. The results of these tests are expressed in Fig. 2. Statistical 't' tests on this data showed no significant difference between either the 400°C and 500°C or the 500°C and 600°C results. For the springs tested at 800 N/mm^2 maximum applied stress, breakage occurred at a much lower number of cycles so that there was insufficient time for excessive relaxation to occur.

3.2 Tensile Properties

Samples of En 58J wire were tensile tested after LTHT for ½ hour at temperatures of 150, 250, 350, 400, 450, 500, 550 and 600°C. The results of these tests are recorded in Table VI and expressed graphically in Fig. 3, from which it can clearly be seen that a decline in tensile properties occurs when the LTHT temperature is increased above 450-500°C.

3.3 Choice of LTHT

The fatigue results are complicated by the possibility of relaxation so that no definite trend can be detected. However, the best fatigue resistance seems to coincide with the greatest tensile strength at 450°C. Therefore, a temperature of 450°C for ½ hour was chosen for the stress relief of the En 58J springs after coiling.

4. CORROSION FATIGUE MACHINE

One of the Association's forced motion multiple station fatigue machines was adapted for use in the corrosion fatigue tests.

The carbon steel parts which could not be isolated from the corrosive environment were either chromium plated on top of copper and nickel flash coatings, or replaced with Monel metal. The area immediately surrounding the springs was then totally enclosed in perspex (Fig. 4). The driving rods on either side of each spring passed through close fitting 'Nylatron' seals in the perspex casing.

The corrosion medium (salt solution) was contained in two small reservoirs above each set of stations (four on each side). An asbestos wick above each station allowed the solution to drip down onto the springs below at a reasonably constant rate, the solution then being recirculated, via a much larger reservoir, by means of a small kidney pump.

5. FATIGUE TESTS

5.1 In-air Tests

Testing was carried out on a forced motion multiple station fatigue machine, using a minimum applied stress of 100 N/mm^2.

Springs which had not broken by 10^7 cycles were removed from the machine and checked for dynamic relaxation. In all cases this relaxation was negligible i.e. very much less than 1%.

From the results, S/N curves were constructed (Fig. 5). The sloping portions of the curves were obtained by linear regression analysis of the broken spring data and are 50% confidence lines. All correlation coefficients were of > 99.9% significance. Non-ferritic stainless materials do not show a fatigue limit - the horizontal parts of the curves represent the estimated fatigue strength at 10^7 cycles i.e. all springs tested at stresses below these levels survived beyond 10^7 cycles.

5.2 Corrosion Tests

Testing was carried out on the modified machine described in section 4. The corrosion medium consisted of an artificial sea water, the composition of which complied with BS 3900: Part F4: 1968(5) (Table VII).

A minimum of eight springs from each material were tested at each maximum stress level, using a minimum applied stress of 100 N/mm^2. The maximum applied stresses were initially chosen from the in-air test results, the first sets of springs being tested at a maximum stress 50 N/mm^2 below the horizontal portions of the S/N curves. For 17/7 PH this first stress level was 550 N/mm^2, for En 58J 425 N/mm^2 and for En 58A 350 N/mm^2.

Further sets of springs were then tested at stresses decreasing in 50 N/mm^2 intervals until the majority of the springs once more survived beyond 10^7 cycles.

The results of these tests are shown in Figs 6, 7 and 8, together with the corresponding in-air S/N curves for comparison. It was found that, for all three materials, the fatigue strength at 10^7 cycles in the corrosion conditions was 150 N/mm^2 below the in-air value.

6. DISCUSSION

6.1 Materials

The chemical analyses of the En 58A and En 58J materials conform not only to BS 2056(2) but also satisfy the more recent 302S25 and 316S16 specifications of BS 970:Part 4:1970(3)

For the 17/7 PH wire the aluminium content of 0.070 wt.% is 0.05% below the specified value(1). However, in more recent specifications for stainless materials e.g. BS 1449: part 2: 1975(6), a variation of 0.05% from specification is acceptable for this level of aluminium content. Also, the tensile strength of the material showed the expected large rise after ageing and is well within specification. It was, therefore, decided that the material was suitable for the work to be undertaken.

The tensile properties of the other two materials conformed with the relevant specifications, all the mechanical properties of the two 18/8 steels being very similar. The higher tensile strength of the 2.64 mm diameter En 58A wire compared to the 2.5 mm diameter En 58J was probably due to its partially martensitic micro-structure(7).

6.2 Fatigue Results

The higher tensile strength of the aged 17/7 PH wire would be expected to give the springs coiled from this material a greater fatigue life. This theory is born out by the results obtained from the in-air tests (Fig. 5).

For the other two materials, the similarity in the mechanical properties of the wire is, to a large extent, repeated in the S/N curves. No significance should be attached to the 'cross-over' between the two curves at 680 N/mm^2 applied stress (Fig. 5). In fact, the 50% confidence line for the En 58A springs as shown on Fig. 5 lies within the 95% confidence band of the En 58J springs (Fig. 7) down to an applied stress of 500 N/mm^2. Below this stress level the divergence of results became more pronounced and in both in-air and corrosion tests the En 58J springs had superior low stress fatigue properties to the En 58A springs.

The measured drop in 10^7 cycle fatigue strength of 150 N/mm^2 for all three materials represents a decrease of 25% for 17/7 PH 31.6% for En 58J and 37.5% for En 58A.

Hence, the relative order of 10^7 cycle fatigue strengths determined by the in-air tests was maintained during the corrosion tests i.e. 17/7 PH >> En 58J > En 58A. Thus, it would appear likely that, for stainless materials, comparison of in-air fatigue test results can be used to predict the relative low stress corrosion fatigue strengths of comparable materials.

7. CONCLUSIONS

1. The in-air fatigue properties of 17/7 PH are superior to those of En 58J and En 58A.

2. The low stress in-air fatigue properties of En 58J are superior to those of En 58A.

3. The high stress in-air fatigue properties of En 58A and En 58J are very similar.

4. The corrosion fatigue strength at 10^7 cycles for 17/7 PH is much greater than that of En 58J, which is itself superior to that of En 58A.

8. SUGGESTIONS FOR FURTHER WORK

1. The programme of work undertaken here could be extended in several directions e.g. use of different types of corrosive media, other spring materials, high stress corrosion fatigue tests etc.

2. Different combinations of corrosion and fatigue could be investigated e.g. corrosion followed by fatigue, fatigue

followed by corrosion, intermittent fatigue in corrosive media etc.

3. Comparison of effects of corrosion on various spring materials in static uses.

9. REFERENCES

1. Ministry of Technology Aerospace Material Specification DTD. 5086, October 1969.

2. British Standard 2056: 1953. "Rust, Acid and Heat Resisting Steel Wire for Springs".

3. BS 970: Part 4: 1970. "Specification for Wrought Steels (blooms, billets, bars and forgings), Part 4. Stainless, heat resisting and valve steels.

4. Hale, G.E. "The effect of low temperature heat treatment on compression springs manufactured from En 58A hard drawn stainless steel wire". SRAMA Report No. 303.

5. British Standards Institute. BS 3900: 1968. "Methods of test for paints. Part F4. Resistance to continuous salt spray".

6. BS 1449: Part 2: 1975. "Specification for steel plate, sheet and strip. Part 2. Stainless and heat resisting steel plate, sheet and strip".

7. Hale, G.E. and Hood,-A.R. The fatigue and relaxation behaviour of helical compression springs coiled from type 301 hard drawn stainless steel wire". SRAMA Report No. 315

TABLE I CHEMICAL ANALYSES

Material	Elements (wt. %)										
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Nb	Ti
17/7 PH	.05	.38	.63	.020	.016	17.9	—	7.5	.70	—	—
En 58A (302S25)	.05	.55	1.6	.022	.023	18.3	—	9.05	—	—	—
En 58J (316S16)	.08	.72	1.28	.022	.010	17.9	2.59	10.4	—	.02	.03

TABLE II CHEMICAL SPECIFICATIONS

Material	Elements (wt. %)										
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Nb	Ti
17/7 PH(1)	0.09 max	1.0 max	1.0 max	.035 max	.025 max	16.0-18.0	—	6.50-7.75	0.75-1.50	—	—
En 58A(2)	0.16 max	0.20 min	2.00 max	.045 max	.045 max	17.0-20.0*	—	7.0-10.0*	—	—	—
302S25(3)	0.12 max	0.20-1.00	0.50-2.00	.045 max	.030 max	17.0-19.0	—	8.0-11.0	—	—	—
En 58J(2)	0.12 max	0.20 min	2.00 max	.045 max	.045 max	17.0-20.0	2.50-3.50	8.0-12.0	—	optional	optional
316S16(3)	0.07 max	0.20-1.00	0.50-2.00	.045 max	.030 max	16.5-18.5	2.25-3.00	10.0-13.0	—	—	—

* Σcr + Ni ≥ 25 wt. %.

TABLE III SPRING DESIGNS

Spring Parameter	Magnitude		
	En 58A	En 58J	17/7 PH
Wire diameter (mm)	2.64	2.5	2.65
Mean coil diameter (mm)	22.9	22.0	22.9
Total coils	5.5	5.5	5.5
Active coils	3.5	3.5	3.5
Free length after LTHT and prestressing (mm)	44.1	41.3	46.6
Solid stress (N/mm^2)	1100	1050	1365
R_m (as-received).(N/mm^2)	1690	1640	—
R_m after heat treatment(N/mm^2)	—	—	2100

TABLE IV TENSILE PROPERTIES

Material	Condition	R_m (N/mm^2)	Proof Stresses (N/mm^2)			Limit of Proportionality (N/mm^2)	Elongation (%)	Reduction in area (%)
			R_p 0.2	R_p 0.1	R_p 0.05			
17/7 PH	As received	1690 1690	1610 1620	1490 1490	1350 1330	670 760	3 3	48 48
17/7 PH	1 hour at 480°C	2100 2100	-	-	-	930	3	18
En 58A	As received	1690 1690	1530 1530	1340 1390	1120 1210	710 720	3 3	43 43
En 58A	½ hour at 400°C	1850 1860	1750 1680	1500 1470	1270 1250	850 780	3 3	36 36
En 58J	As received	1640 1640	1370 1380	1180 1190	950 960	410 440	-	-
		1800 1790	1640 1650	1500 1520	1370 1390	960 1000	-	-

TABLE V TORSIONAL PROPERTIES

Material and Condition	G $(N/mm^2 \times 10^4)$	Torsional Proof Stresses (N/mm^2)		Limit of Proportionality (N/mm^2)
		0.2%	0.1%	
17/7 PH as received	7.6 7.8	980 990	870 880	510 480
17/7 PH LTHT 480°C 1 hour	7.9 8.0	1360 1400	1280 1280	910 900
En 58A as received	6.6 6.6	790 780	670 670	460 450
En 58A LTHT 400°C ½ hour	7.2 7.0	920 920	820 800	470 460
En 58J as received	6.7 6.6	780 710	660 580	360 280
En 58J LTHT 450°C ½ hour	6.9 6.9	880 950	740 850	410 510

TABLE VI EFFECT OF LTHT ON THE TENSILE PROPERTIES OF EN 58J WIRE

LTHT	R_m (N/mm^2)	Proof Stresses (N/mm^2)			Limit of Proportionality (N/mm^2)
		R_p 0.2	R_p 0.1	R_p 0.05	
As-received (20°C)	1640 1640	1370 1380	1180 1190	950 960	410 440
150°C, ½ hour	1660 1670	1450 1450	1280 1290	1090 1160	600 700
250°C, ½ hour	1720 1720	1570 1560	1440 1410	1310 1260	970 930
350°C ½ hour	1780 1740	1600 1600	1460 1460	1330 1330	970 1000
400°C, ½ hour	1770 1780	1610 1610	1470 1460	1340 1330	960 960
450°C, ½ hour	1800 1790	1640 1650	1500 1520	1370 1390	960 1000
500°C, ½ hour	1800 1800	1670 1630	1540 1480	1410 1350	1060 1000
550°C, ½ hour	1760 1780	1620 1620	1510 1490	1390 1370	1060 1040
600°C, ½ hour	1690 1680	1530 1520	1420 1410	1300 1300	1030 1000

TABLE VII COMPOSITION OF SALT SOLUTION

Salt	Weight (g)
Sodium chloride as NaCl	26.5
Magnesium chloride as $MgCl_2$	2.4
Magnesium sulphate as $MgSO_4$	3.3
Potassium chloride as KCl	0.73
Sodium hydrogen carbonate as $NaHCO_3$	0.20
Sodium bromide as NaBr	0.28
Calcium chloride as $CaCl_2$ (to be added last)	1.1
De-ionised water	to 1,000 ml

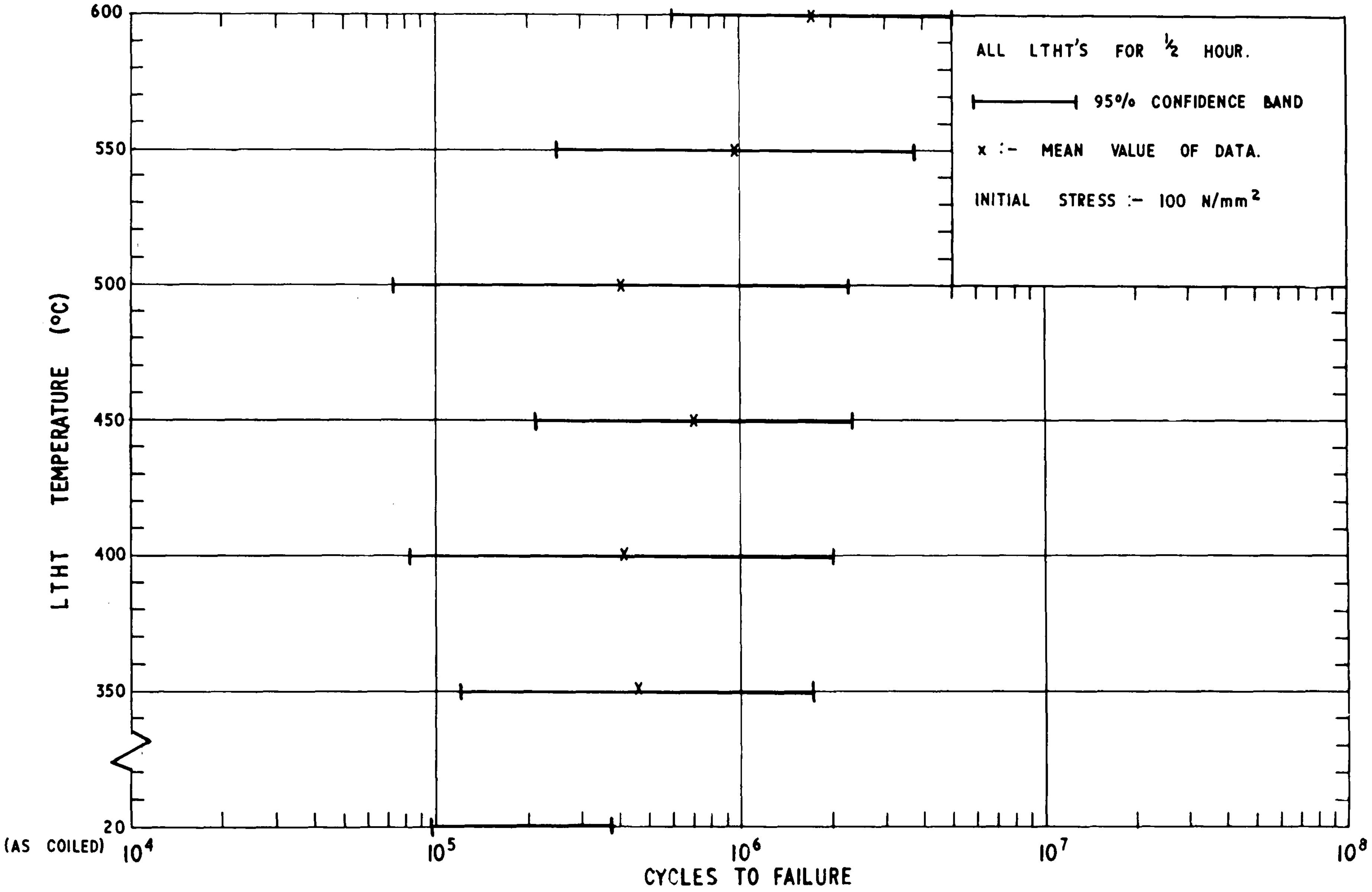

FIG. 1. EFFECT OF LTHT TEMPERATURE ON FATIGUE OF EN58 J SPRINGS AT A MAXIMUM STRESS OF 600 N/mm²

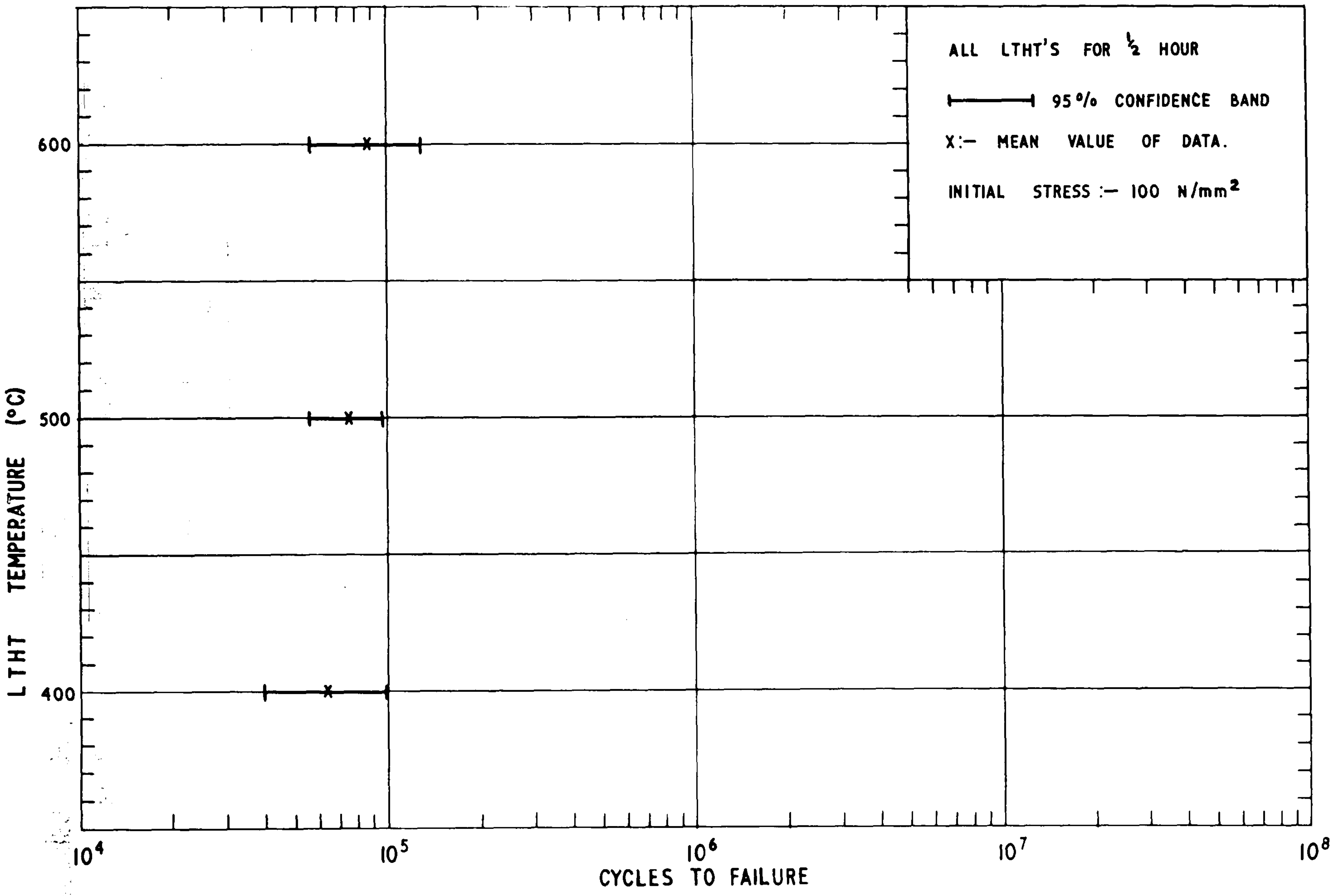

FIG. 2. EFFECT OF LTHT TEMPERATURE ON FATIGUE OF EN58 J SPRINGS AT A MAXIMUM STRESS OF 800 N/mm²

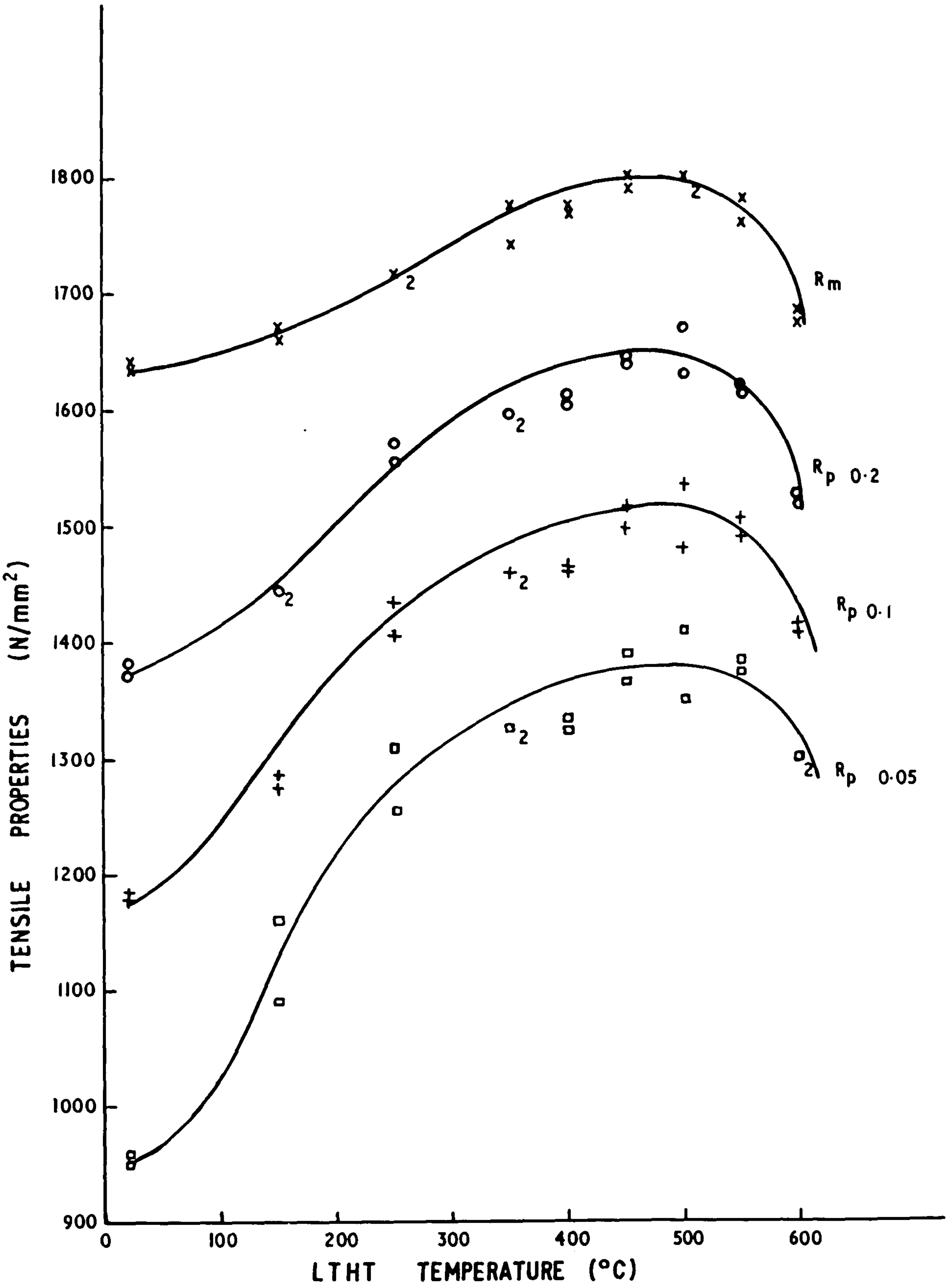

FIG. 3. EFFECT OF LTHT TEMPERATURE ON THE TENSILE PROPERTIES OF EN 58 J WIRE.

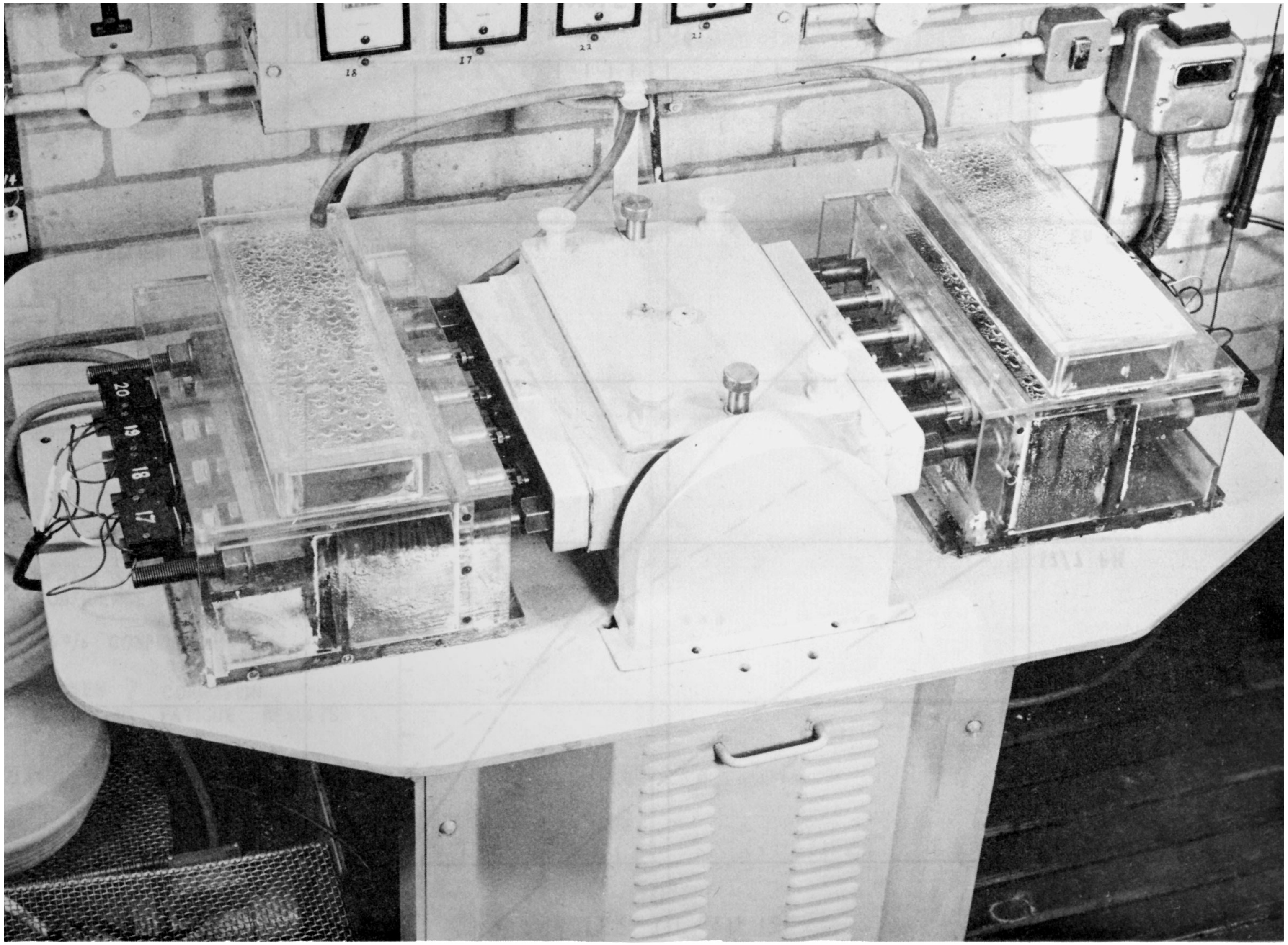

FIG. 4 CORROSION FATIGUE MACHINE

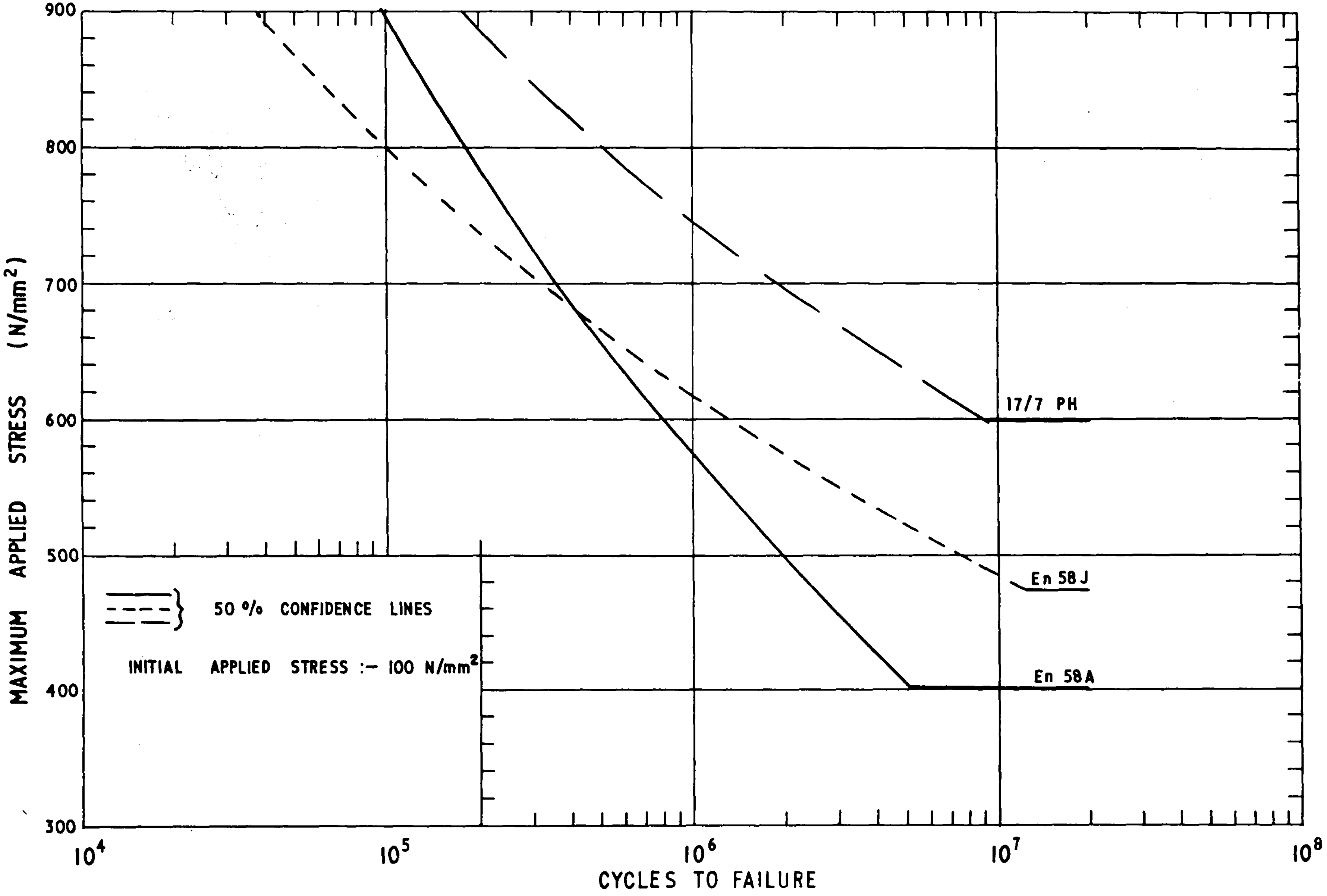

FIG. 5 IN-AIR FATIGUE CURVES FOR 17/7 PH, EN 58A AND EN 58 J SPRINGS.

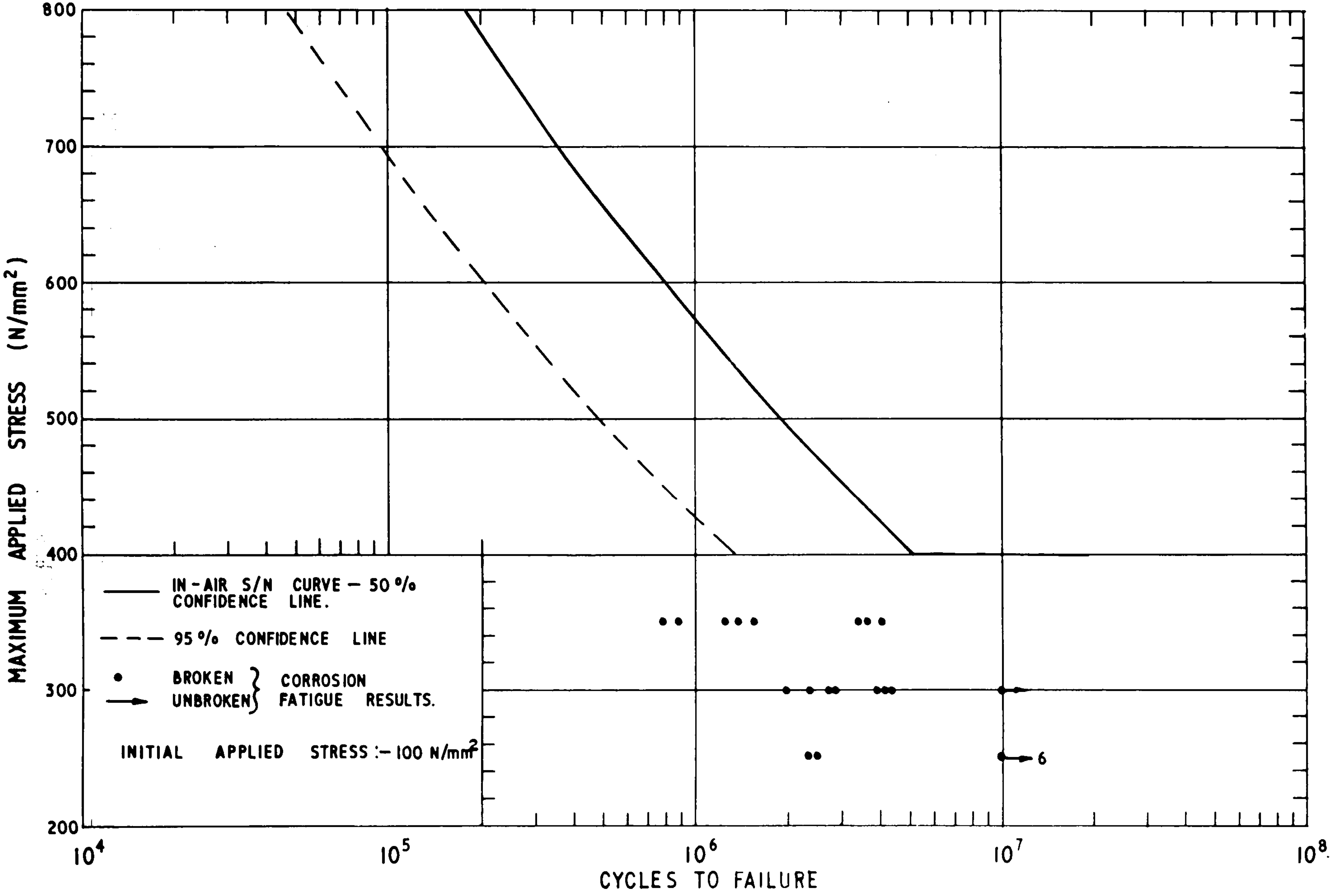

FIG. 6. COMPARISON OF IN-AIR AND CORROSION FATIGUE DATA. — EN 58 A.

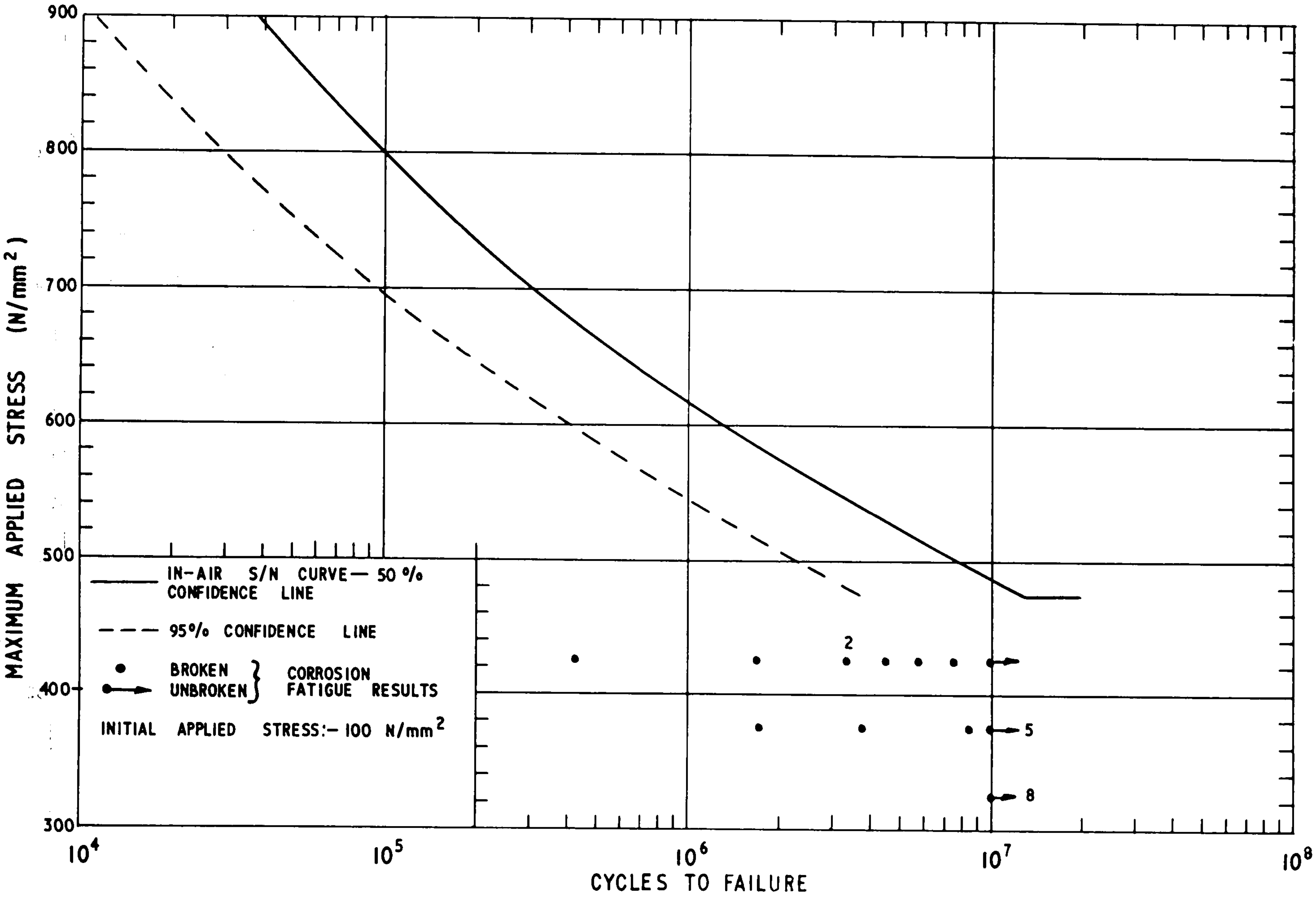

FIG. 7. COMPARISON OF IN-AIR AND CORROSION FATIGUE DATA — En 58 J.

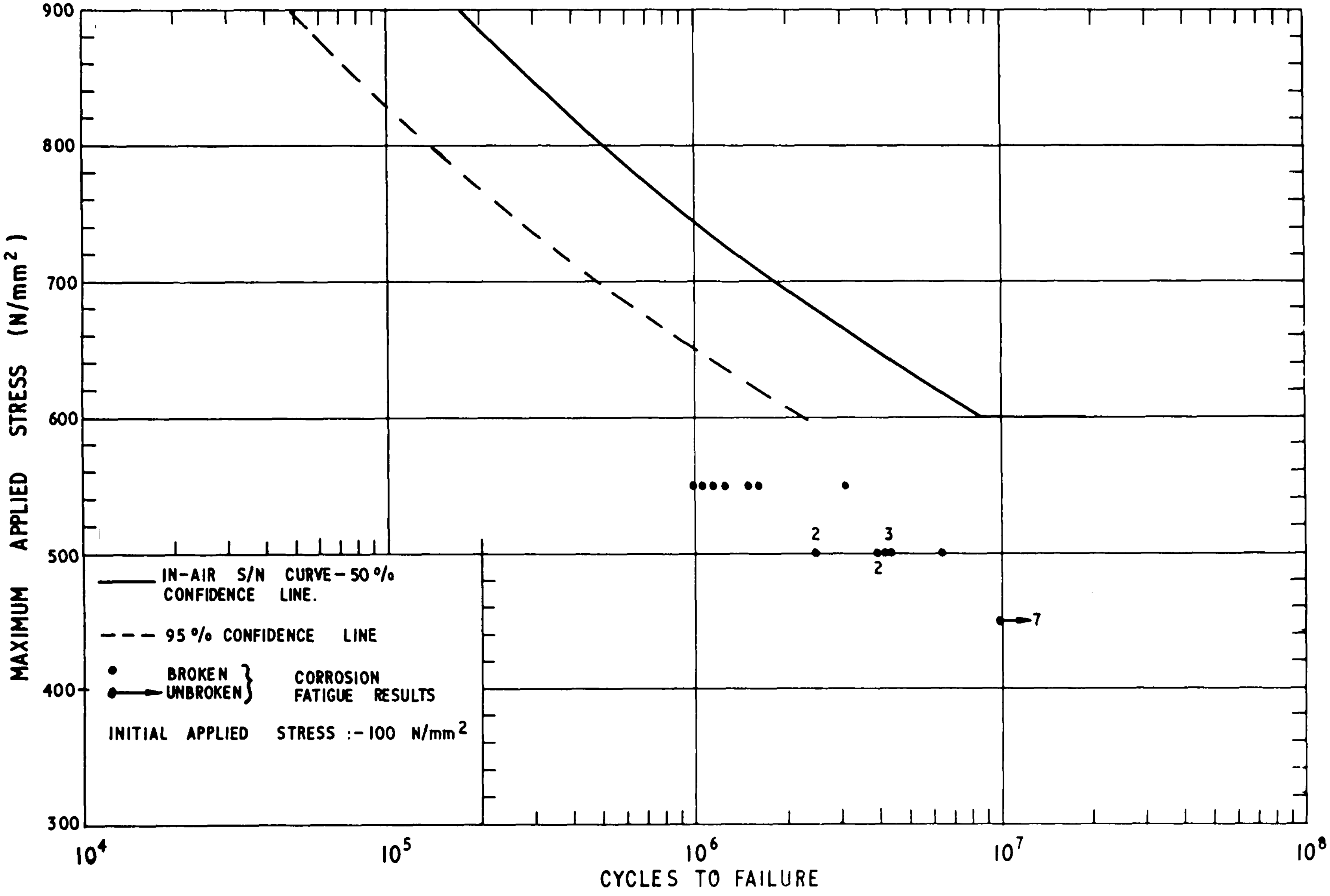

FIG. 8. COMPARISON OF IN-AIR AND CORROSION FATIGUE DATA – 17/7 PH.