THE SPRING RESEARCH ASSOCIATION

THE ELEVATED TEMPERATURE FATIGUE PROPERTIES OF SPRINGS MANUFACTURED FROM THREE TYPES OF STAINLESS STEEL WIRE

(Contract No. K43A/65/CB43A2)

Progress Report No. 6

by

S. D. Gray, A.P. (Sheff.), A.I.M.

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SUMMARY

Elevated temperature fatigue tests have been carried out on low temperature heat treated unpeened springs manufactured from three 4.0 mm (0.160 in) diameter stainless steel spring wires, to the following specifications:-

1. 17% chromium - 7% nickel, semi-austenitic, precipitation hardening stainless steel.
2. S205 18% chromium - 8% nickel, austenitic stainless steel.
3. F. V. 520(S), semi-austenitic, precipitation hardening stainless steel.

S/N curves had been produced for 100 N/mm^2 initial stress at temperatures of 150 and 250°C

Springs manufactured from 17-7 PH wire revealed the best elevated temperature fatigue properties at all endurance levels, and the fatigue limit for all materials was found to rise with increases in temperature.

Results from this investigation indicated that room temperature spring design data were safe to use for temperatures up to 250°C in particular for infinite life applications.

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1. INTRODUCTION

A programme of work has been carried out by the SRA, on behalf of the Procurement Executive, Ministry of Defence, to investigate the effect of temperatures up to 250°C, on the fatigue performance of unpeened helical compression springs manufactured from 4.0 mm (0.160 in) S205 austenitic stainless steel, 17-7 PH and F.V. 520(S) semi-austenitic stainless steel wires.

2. MATERIAL

2.1 Wire

Three qualities of stainless steel wire were selected for this investigation, as follows:-

(a) 17-7 PH wire, from a British source, cold drawn from rod to 4.0 mm (0.160 in) diameter.

(b) Austenitic stainless steel wire to specification S205, 4.0 mm (0.160 in) diameter.

(c) Precipitation hardening, semi-austenitic F.V. 520(S) quality steel wire, 4.0 mm (0.160 in) diameter.

All wire was supplied in the 'as-drawn' condition, and the actual compositions are shown in Table I.

2.2 Springs

Springs were coiled from the above 4.0 mm diameter wires to the design details given in Table II. Coiling was carried out in the 'as-drawn' condition, followed by batch low temperature heat treatments as indicated below.

MATERIAL	HEAT TREATMENT
17-7 PH	480°C - 1 hr. (AGEING)
S205	450°C - 2 hrs. (L.T.H.T.)
F.V. 520(S)	450°C - 2 hrs. (AGEING)

The springs were finally end-ground and cold prestressed to solid.

3. EXPERIMENTAL PROCEDURE

3.1 Fatigue Testing

Load tests were carried out on individual springs to establish the necessary fatigue machine strokes to give the required stress ranges. Springs from each quality were fatigue tested at an initial stress of 100 N/mm^2 (6.5 $tonf/in^2$) and at a speed of 1500 cycles per minute, at temperatures of 150 and 250°C.

The stresses indicated on the elevated temperature fatigue diagrams refer therefore to the room temperature stress and not the stress at the testing temperature. Data were presented in this form since the room temperature stress can be calculated with less uncertainty.

To facilitate elevated temperature fatigue testing, the existing standard forced motion multiple valve spring testing machines were modified to incorporate rectangular box-type furnaces which were constructed around the test springs, thereby enclosing four springs per furnace (Fig. 1). The furnace temperatures were controlled to $\pm 5^{\circ}$C by indicator controllers connected to base metal thermocouples.

3.2 Relaxation Measurements

The load and corresponding length required to produce the desired maximum torsional stress within each spring was noted prior to testing. Springs which had been fatigue tested and survived 10^7 cycles were again load tested at the original maximum compressed height, and hence from the data obtained the dynamic relaxation or recovery calculated (Table VI).

3.3 Mechanical Testing

Ambient temperature tensile and torsional properties are shown in Tables III and IV; these results have been extracted from previous SRA reports, as indicated in the actual tables. The data are for wire which had received the recommended low temperature heat treatment and in the case of S205 material, quality C has been selected (see Report 206) which had marginally the best fatigue properties.

4. DISCUSSION

4.1 Fatigue Properties

The effect of temperature on the fatigue properties of the three materials under investigation can be seen in Figs. 2 to 7 inclusive, and for comparison purposes the fatigue strengths for various endurance limits are shown in Fig. 8 and Table V, together with additional data previously obtained at ambient temperatures.

4.1.1 17-7 PH Springs

The effect of temperature on the fatigue limit of unpeened springs manufactured from 17-7 PH wire was very significant, producing approximately a 30% increase in strength from ambient to 150°C, and approximately 40% from ambient temperature to 250°C.

In comparison to the relatively high increases at the fatigue limit the limited life data at 10^5 cycles revealed a small decrease in fatigue strength for the above temperature increase.

Table VI shows the results of dynamic relaxation tests on the three materials under investigation, and it can be seen that the unbroken 17-7 PH springs had a recovery in load of approximately 1%.

Examination of the limited life data in Figs. 2 and 3 indicated that springs surviving greater endurances than 10^6 cycles did not break before the tests were terminated at 10^7 cycles.

4.1.2 S205 Springs

The effect of temperature on the fatigue limit of springs manufactured from S205 wire was of the same order as that observed for 17-7 PH springs.

Endurances of 10^5 cycles showed negligible change in fatigue strength with temperature, as was similarly observed for 17-7 PH wire.

An average dynamic recovery in load of approximately 3% was observed. As observed in 4.1.1, springs sustaining endurances of approximately 10^6 cycles did not fail even after 10^7 cycles.

4.1.3 F.V. 520(S) Springs

The increase in fatigue strength with temperature for an endurance of 10^7 cycles was not as large as for 17-7 PH. The effect of temperature on limited life data was not consistant, producing a maximum elevation in fatigue strength at 150°C. However, from close examination of the S/N curves, Figs. 2 to 7 inclusive, it will be seen that in order to obtain limited life data for 10^5 cycles on springs made from F.V. 520(S) wire, tested at 150°C (Fig. 6) it was necessary to extrapolate the existing 50% confidence line. Although the two lines show the best fit for two confidence levels, the slope was strongly influenced by a few springs which unexpectedly ran-on, and therefore the actual value required at 10^5 cycles would probably have been less than the recorded value of 970 N/mm^2.

In summarising therefore, Fig. 8 shows directly the effect of temperature on the fatigue strength of springs manufactured from the three materials, and it can be seen that unpeened springs made from 17-7 PH wire possessed the most superior elevated temperature fatigue properties. It is evident from this investigation that the fatigue limit for all materials was found to rise for increases in temperature, and therefore room temperature spring design data were safe to use for temperatures up to 250°C.

Virtually no relaxation occurred on springs tested around the fatigue limit. However, a small variation in recovery was observed and this is attributed in part to the fact that this was calculated over a range of stress levels, i.e. S205 springs revealed the greatest recovery, but showed the lowest fatigue limit.

5. CONCLUSIONS

1. Springs made from 17-7 PH wire possessed the best elevated temperature fatigue properties of all endurance levels, when compared with S205 and F.V. 520(S) springs.

2. The fatigue limit for all materials increased with rises in temperature between 25 and 250°C.

REFERENCE

1. H. J. Graver. "Fatigue of Metals at High Temperatures." Metal Fatigue, pp. 232. McGraw-Hill.

TABLE I

CHEMICAL ANALYSIS

MATERIAL	COMPOSITION %										
	C	Si	Mn	S	P	Ni	Cr	Al	Mo	Cu	Ti
17-7 PH	0.08	0.48	0.89	0.007	0.018	6.90	17.60	1.02	-	-	-
S205	0.07	0.47	0.69	0.008	0.009	8.30	17.70	-	-	-	-
F.V. 520(S)	0.048	0.37	1.05	0.014	0.020	5.47	16.18	-	1.72	2.08	0.10

TABLE II SPRING DESIGN DATA

	4.0 mm (0.160 in) Diameter Wire	
	METRIC	IMPERIAL
Spring Mean Diameter	26.9 mm	1.05 in
No. of Active Coils	3.5	3.5
Total No. of Coils	5.5	5.5
Spring Index	6.5	6.5
Free Length after End Grinding and Prestressing	50 mm	2.0 in
Solid Stress after End Grinding and Prestressing	1282 N/mm^2	83.0 tonf/in^2

TABLE III

TENSILE PROPERTIES OF 4.0 mm DIAMETER WIRE

MATERIAL	SRA REPORT NO.	U.T.S.		PROOF STRESS %						Reduction in Area %	Elongation % (2 in gauge length)
				0.1		0.2		0.5			
		N/mm^2	tonf/in^2	N/mm^2	tonf/in^2	N/mm^2	tonf/in^2	N/mm^2	tonf/in^2		
17-7 PH (480°C-1hr)	198	1543	100.0	1146	74.2	1302	84.3	1512	98.0	48.0	2.8
S205 (450°C-2hr)	206	1521	98.5	1101	72.9	1311	84.9	1480	95.8	31.0	2.0
F.V. 520(S) (450°C-2hr)	211	1846	119.5	1744	112.9	1805	116.9	-	-	46.0	2.0

TABLE IV TORSIONAL PROPERTIES OF 4.0 mm DIAMETER WIRE

MATERIAL	MAXIMUM SHEAR STRENGTH		PROOF STRESS %						TWISTS TO FAILURE
			0.1		0.2		0.5		
	N/mm^2	$tonf/in^2$	N/mm^2	$tonf/in^2$	N/mm^2	$tonf/in^2$	N/mm^2	$tonf/in^2$	
17-7 PH (480°C-1hr)	1371	88.8	849	55.0	954	61.8	-	-	17
S205 (450°C-2hr)	1275	82.6	717	46.4	816	52.9	-	-	-
F.V. 520(S) (450°C-2hr)	1369	88.7	1142	74.0	-	-	-	-	-

TABLE V

FATIGUE DATA

MATERIAL	REPORT NO.	TEMPERATURE °C	Fatigue Strength at 100 N/mm^2 I.S. 10^5 N/mm^2	10^5 $tonf/in^2$	10^6 N/mm^2	10^6 $tonf/in^2$	10^7 N/mm^2	10^7 $tonf/in^2$
17-7 PH	198	Ambient	1000	64.7	680	44.0	500	32.3
		150	970	62.8	650	42.1	650	42.1
		250	960	62.2	710	68.0	710	68.0
S205	206	Ambient	870	56.3	535	34.7	450	29.1
		150	870	56.3	580	37.6	580	37.6
		250	890	57.6	610	39.6	600	38.8
F.V. 520(S)	211	Ambient	890	57.6	640	41.4	500	32.3
		150	970	62.8	580	37.6	580	37.6
		250	870	56.3	620	40.1	620	40.1

TABLE VI

SPRING STABILITY

MATERIAL	Dynamic % Relaxation (-) and % Recovery (+) at Temperature	
	150°C	250°C
17-7 PH	+ 1.0	+ 1.0
S205	+ 3.0	+ 3.0
F. V. 520(S)	+ 0.5	- 0.5

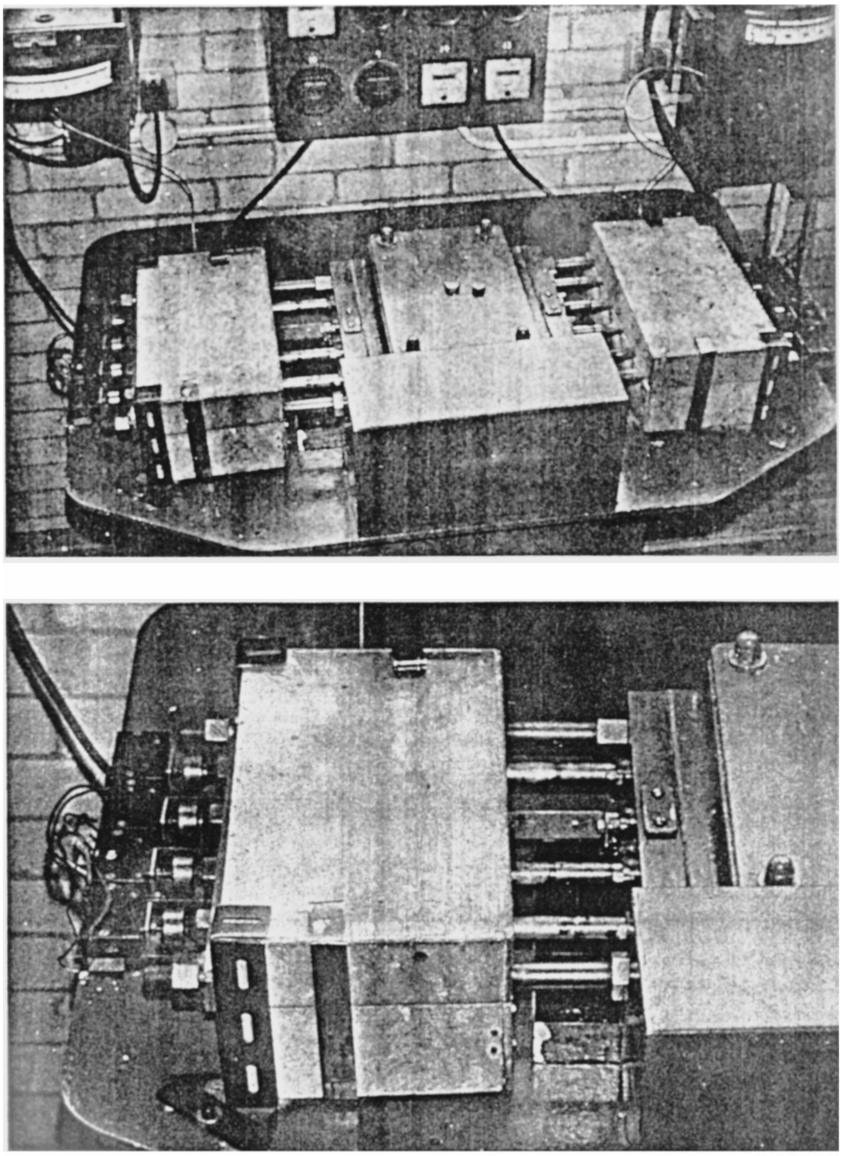

FIG. 1. FORCED MOTION MULTIPLE SPRING FATIGUE TESTING MACHINE INCORPORATING HOT BOXES

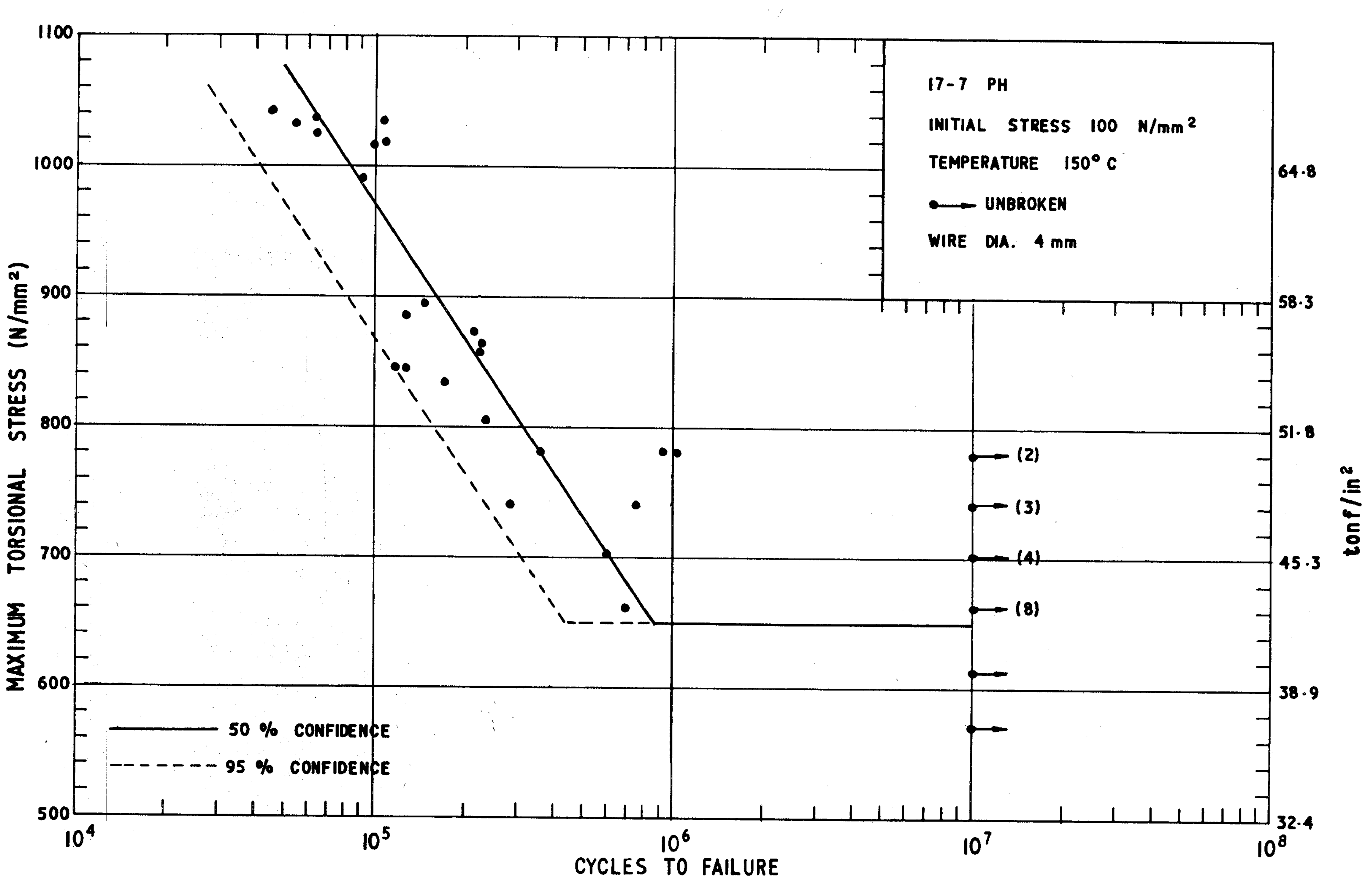

FIG. 2 S/N CURVE FOR 17-7 PH UNPEENED SPRINGS.

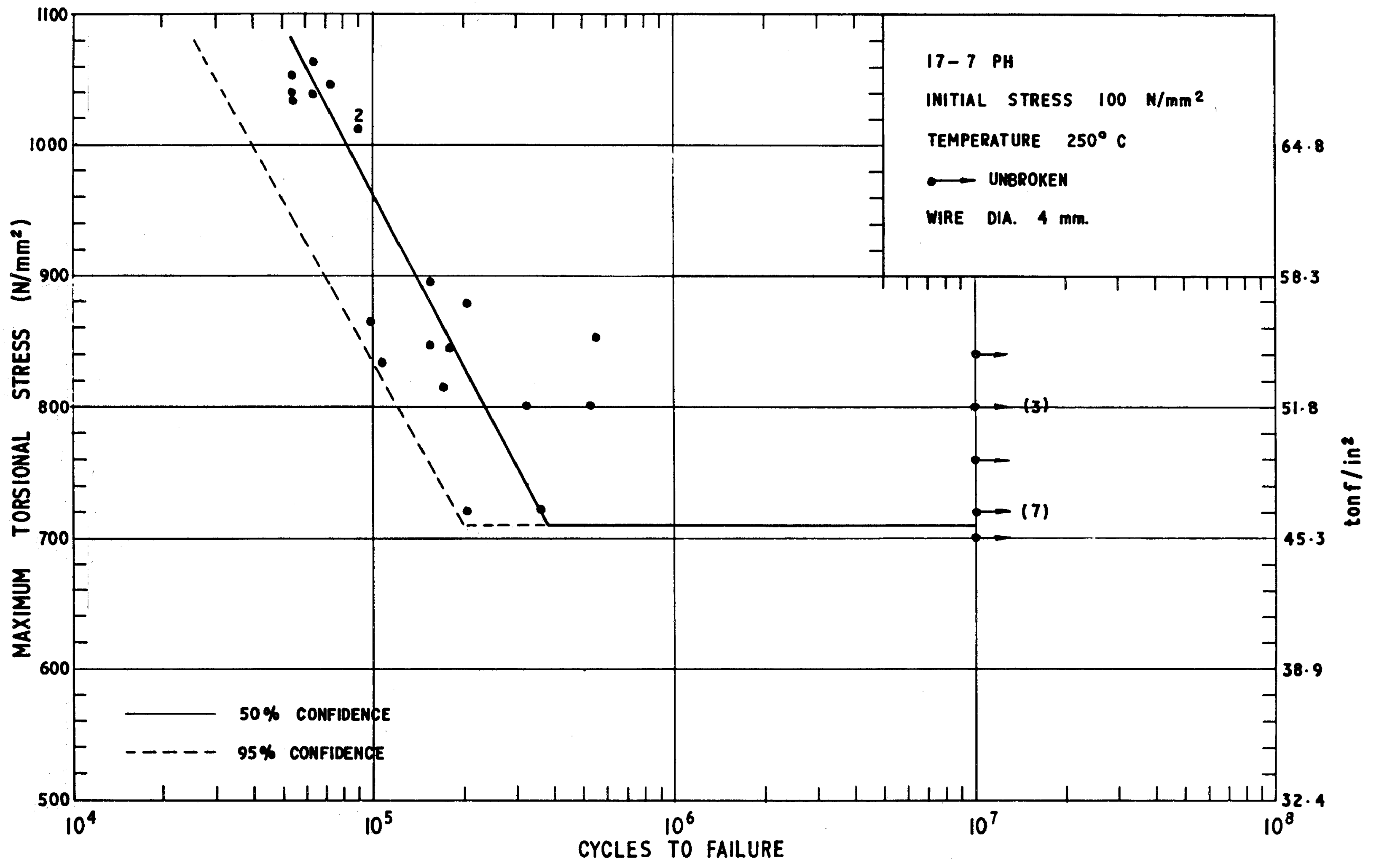

FIG. 3. S/N CURVE FOR 17-7 PH UNPEENED SPRINGS.

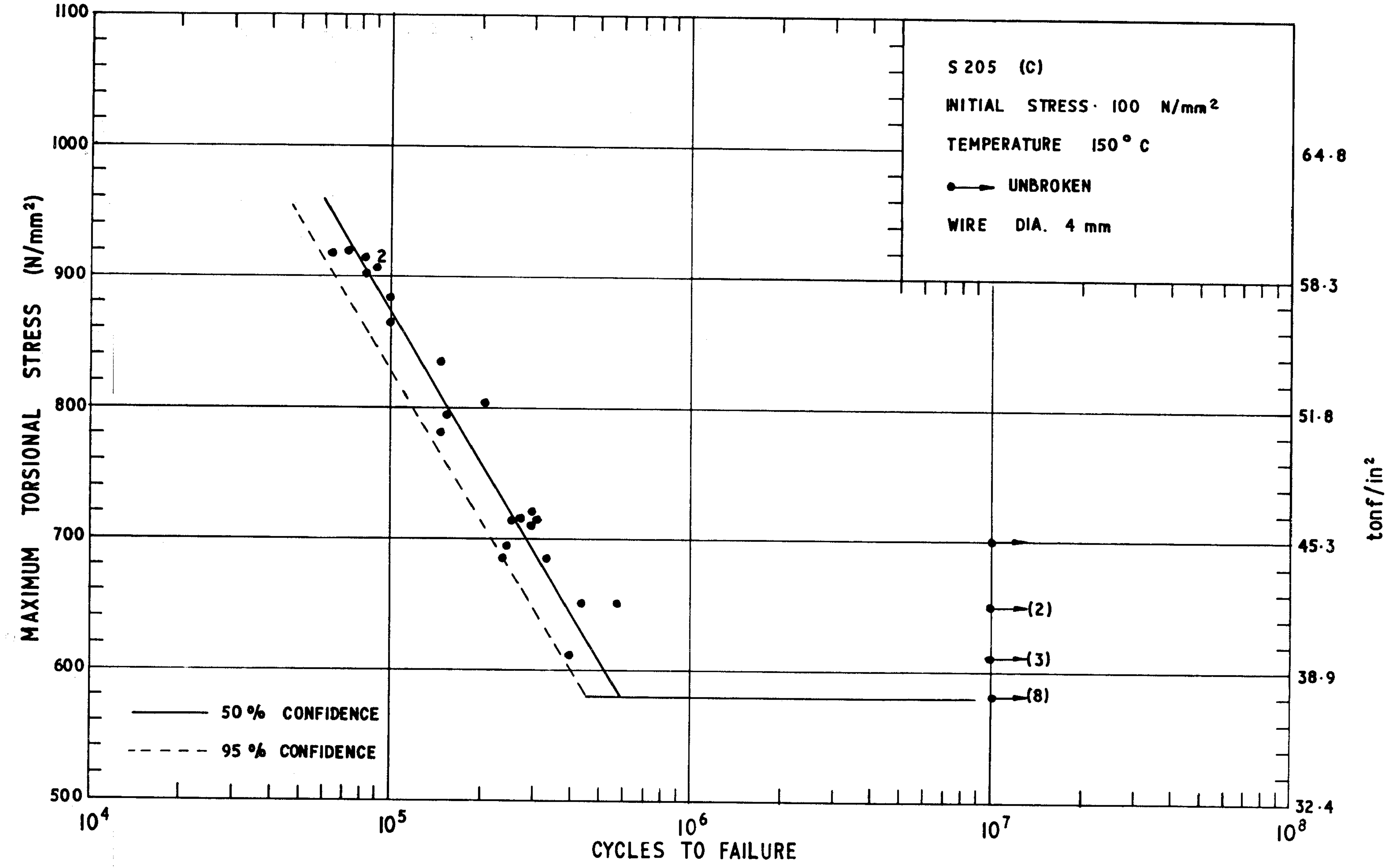

FIG. 4. S/N CURVE FOR S205 UNPEENED SPRINGS.

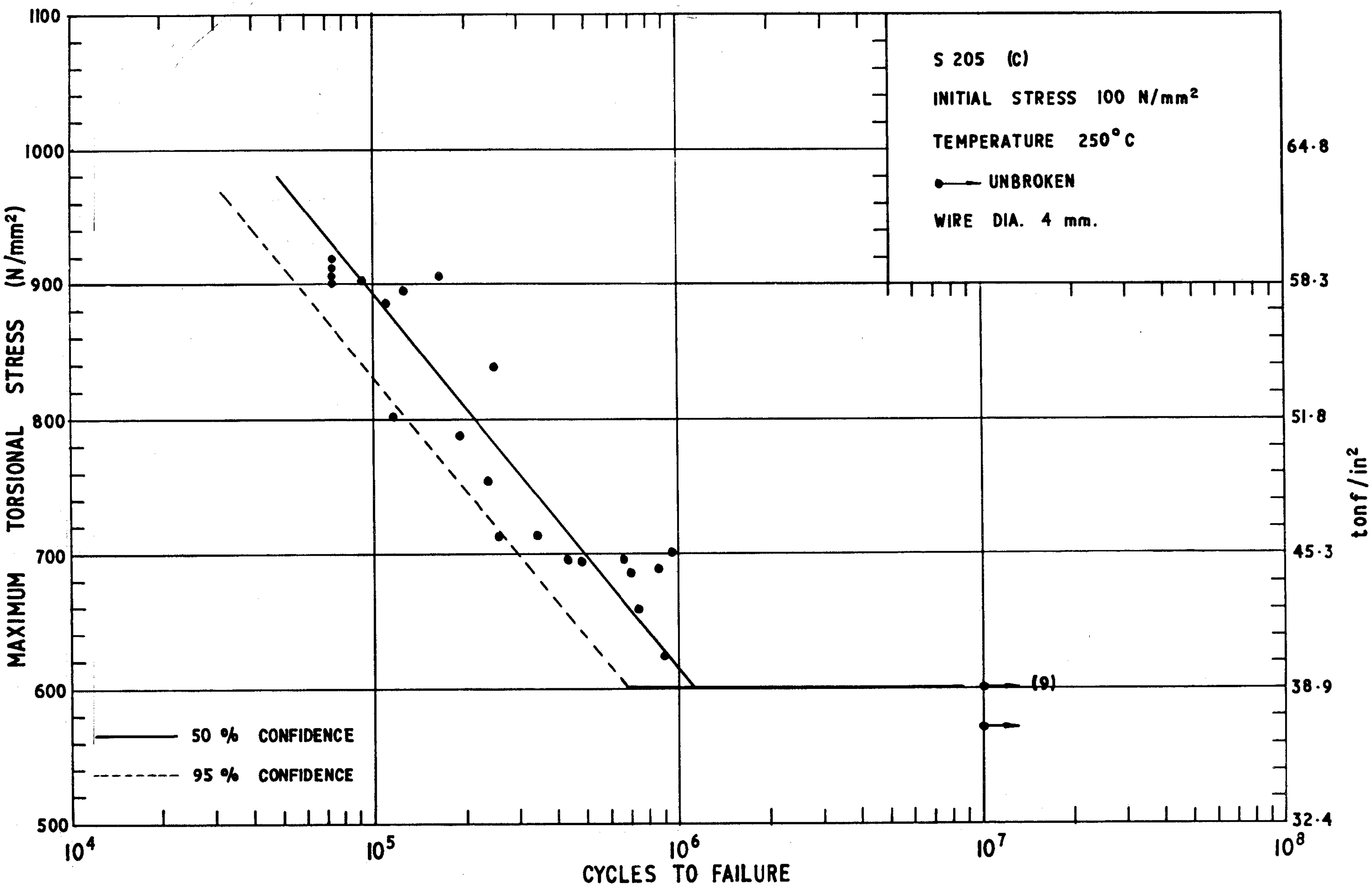

FIG. 5. S/N CURVE FOR S 205 UNPEENED SPRINGS.

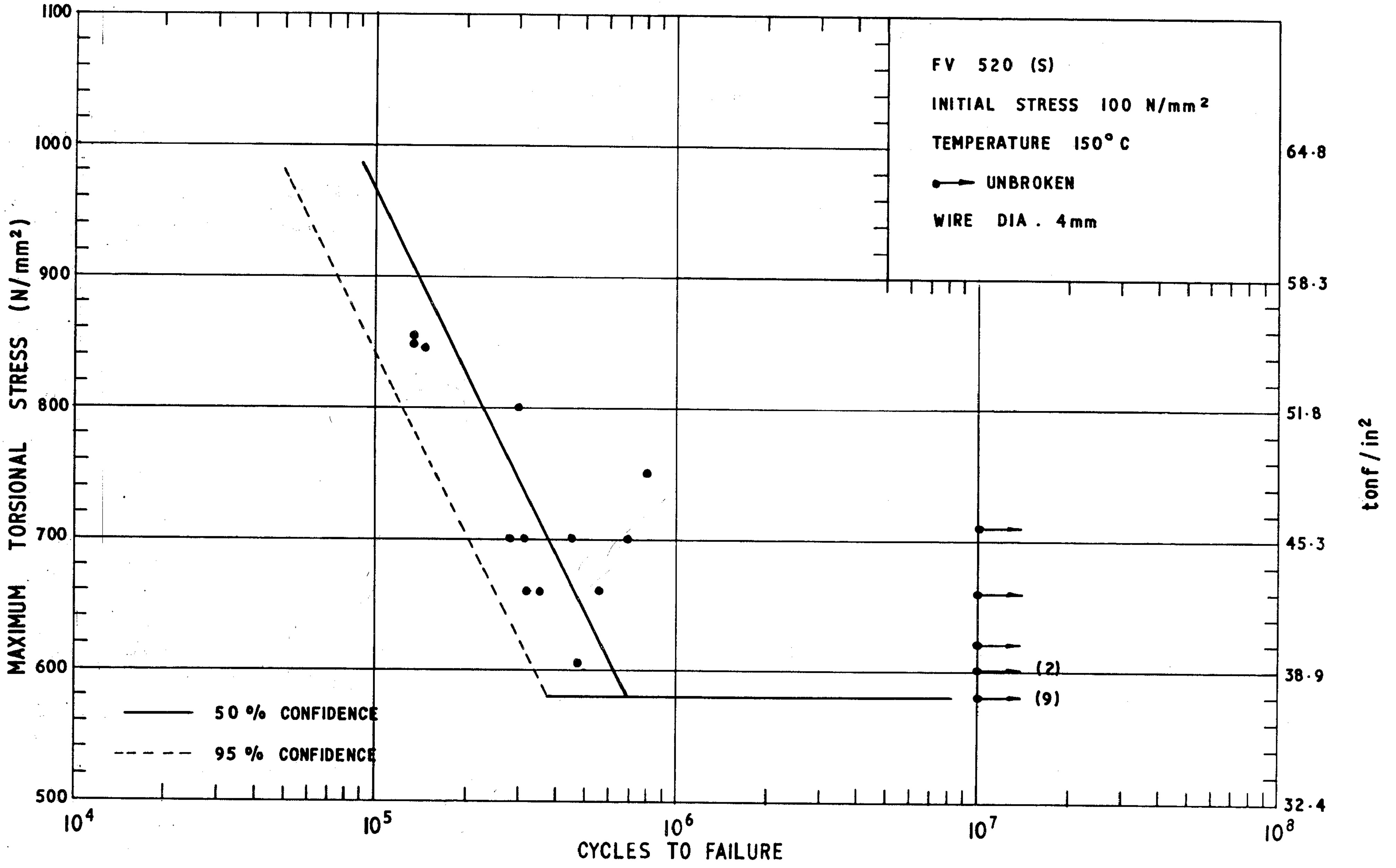

FIG. 6. S/N CURVE FOR FV 520 (S) UNPEENED SPRINGS

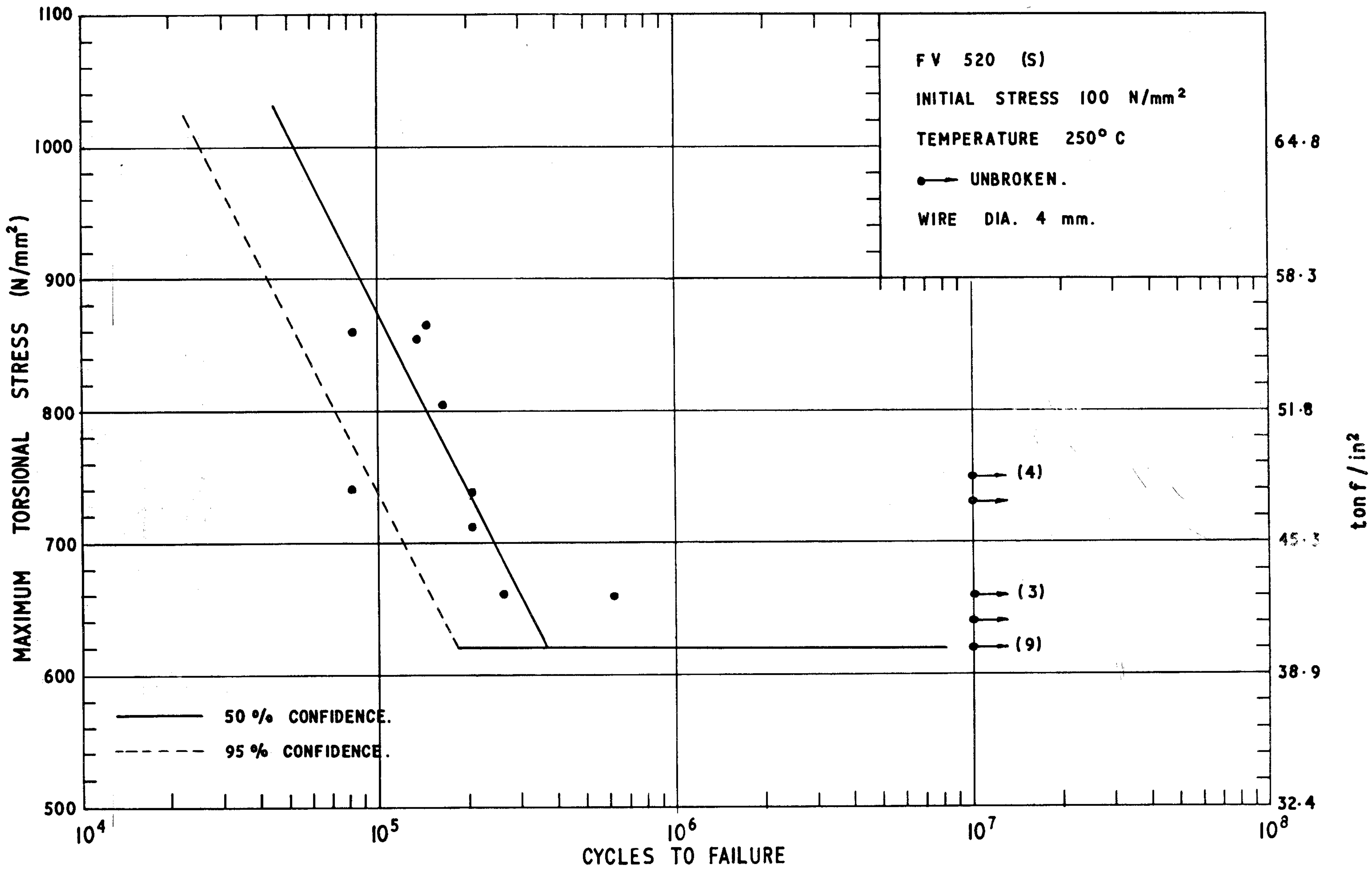

FIG. 7. S/N CURVE FOR F V 520 (S) UNPEENED SPRINGS

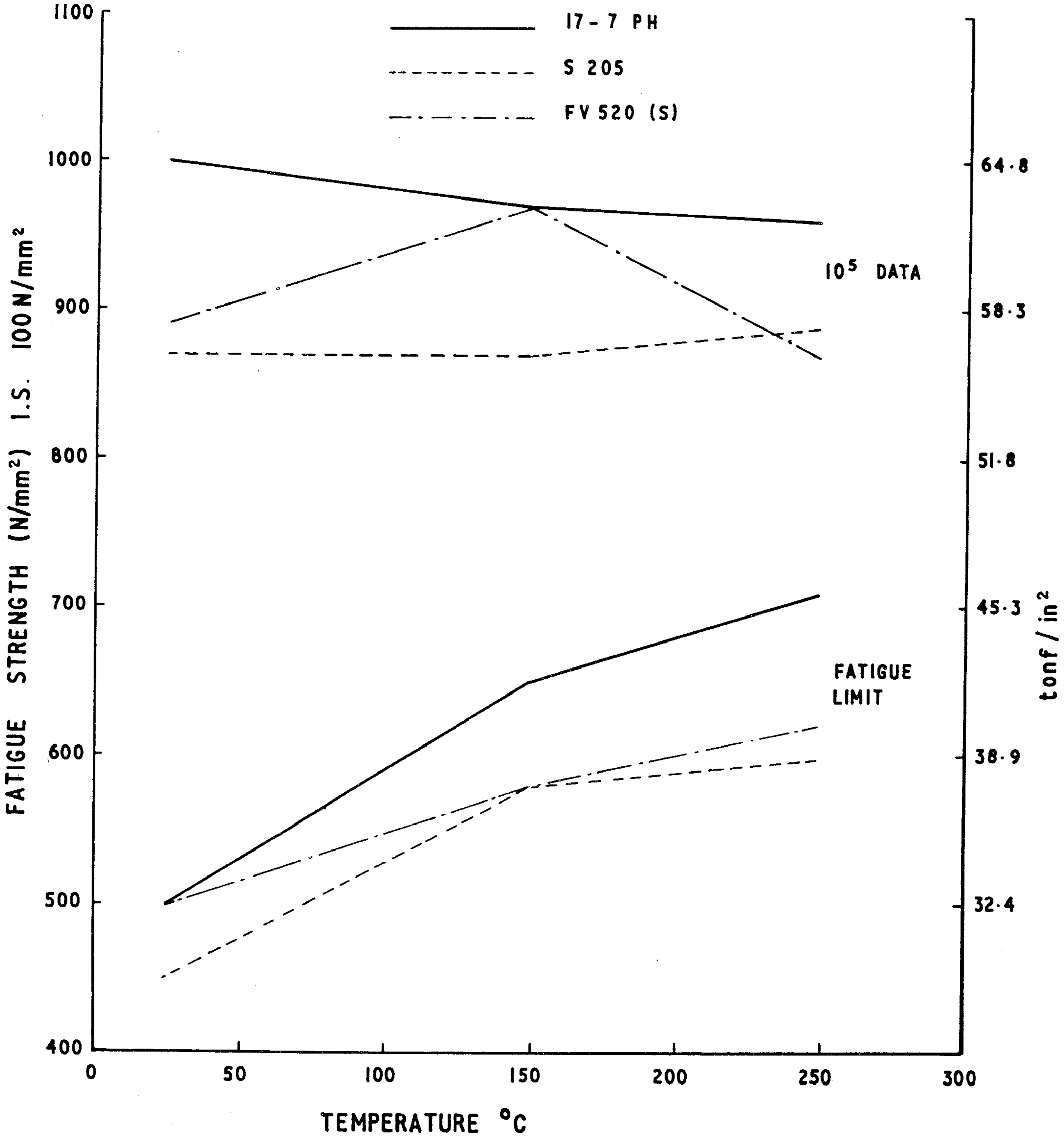

FIG. 8 THE ELEVATED TEMPERATURE FATIGUE PROPERTIES OF THREE STAINLESS STEELS.