THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

FATIGUE FAILURES OF LIGHT SPRINGS

First Progress Report

PRELIMINARY EXAMINATION OF BS 5216 ND 3 WIRES AND THE FATIGUE CHARACTERISTICS OF ASSOCIATED COMPRESSION SPRINGS

Report No. 351

by

L. F. Reynolds, M.Sc.Tech., C.Eng., M.I.M.

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SUMMARY

Patented, hard drawn carbon steel wire was obtained to BS 5216 ND3 from four sources, and the metallurgical characteristics were determined.

Compression springs of one design were coiled on the same coiling machine, and exploratory fatigue tests were carried out at one level of initial stress, so as to establish the S/N curves and the associated scatter of fatigue data.

This preliminary work has shown that all the wires conformed to the tensile and surface quality requirements stipulated in BS 5216.1975. Permissible levels of partial decarburization in one of the wires were found to be associated with increased scatter of fatigue data and a small but statistically significant reduction in the fatigue properties of the springs made from this wire.

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1. INTRODUCTION

Previous work at SRAMA has shown that the scatter of limited life fatigue data for carbon and low alloy springs can be significantly influenced by both the wire source and the spring manufacturer[1,2]. The present work was intended to throw further light upon the effects of wire source upon the scatter of fatigue data. Wires were obtained from several manufacturers to one wire specification and these were coiled to one nominal spring design by one spring manufacturer. The springs thus produced were fatigue tested at equivalent stresses to produce S/N curves from which the intrinsic scatter of fatigue data could be determined.

Full tensile and torsional properties of the wires were determined, particular attention being directed towards the variation in properties about the mean values of the appropriate measurements. Further samples of the wire were removed and stored with silica gel in sealed containers for future examination of the wire surfaces on the Scanning Electron Microscope.

This report is essentially concerned with the characterisation of the wires, together with the results of preliminary fatigue work which was necessary to establish the scatter of fatigue data derived for springs made from wires obtained from four sources of supply.

Future reports will involve detailed examination of the wire and spring properties together with the results of examination of appropriate spring fatigue fractures on the Scanning Electron Microscope, and correlation of these results with the scatter of fatigue data, where possible.

2. EXPERIMENTAL TECHNIQUES AND RESULTS

2.1 Materials and Wire Properties

Wire of 2.65 mm diameter was obtained to BS 5216 ND3 from four wire manufacturers, identified as wire sources A, B, C, and D. Full tensile and torsional properties were determined for all the wires, both in the "as received" condition and after low temperature heat treatment at 250°C/½ hour.

Tensile tests were carried out using a vertical Amsler multi-range machine which had been substantially modified for direct load/ extension readout and which was equipped with an automatic X/Y plotter. The latter was used with an extensometer having a gauge length of 50 mm.

Torsion testing was carried out using a Tinius-Olsen machine which had a continuously variable angular velocity of 0 - 180°/min. Details of the test technique have been given in an earlier report[2].

The results of the mechanical tests on the four wire batches are shown in Tables I - IV, and it can be seen that the "as drawn" tensile strength of all four wires fell within the range 1690-1890 N/mm^2 which is stipulated for BS 5216 ND3 at 2.65 mm diameter.

Transverse microsections were taken through each of the wires to assess the general surface quality of the material.

Examination on the optical microscope showed that all the wires exhibited surfaces with small defects, which were occasionally oxidised, to depths between 12 μm and 25 μm.

Wires A, B and D were completely free of decarburization.

Wire C exhibited partial decarburization to a depth of 12 μm, with occasional areas to a depth of 25 μm.

All the wires thus complied with the surface quality requirements stipulated in BS 5216 for normal duty dynamic wire, which would permit surface defects and partial decarburization to radial depths equal to 1.5% of the nominal diameter of the wire i.e. 39.75 μm depth for 2.65 mm diameter wire.

2.2 Spring Design and Manufacture

Springs were coiled at SRAMA, on an automatic coiling machine to the nominal design shown in Table V.

After coiling, the springs were stress relieved at 250°C./½ hour. and pre-stressed (6 scrags) after which the ends were ground at SRAMA on a machine adapted for wet grinding.

2.3 Fatigue Testing

The fatigue tests were carried out at 48 Hz using single station fatigue machines. The machines each had a maximum stroke and load of 30 mm and 1000 N. respectively.

The appropriate springs were individually load tested and preliminary S/N curves were derived for the four batches of springs using an initial stress of 100 N/mm^2.

Testing was carried out up to 10^7 cycles at maximum stresses of 700 - 1050 N/mm^2 in 50 N/mm^2 intervals, using 4 springs at each value of maximum stress.

The S/N results for the springs from each wire batch were analysed statistically using reciprocal/reciprocal Log relationships to give regression curves with regression coefficients which were each significant at the 99.9% level of confidence of the 't' distribution.

The standard errors for each of the relationships were derived from the residuals obtained via the regression relationships and the appropriate raw S/N data.

The standard errors of estimate thus obtained and shown in Table VI, were used as a measure of the overall scatter of results exhibited by the spring batches. The mean regression lines are shown in Figs. 1 - 4 together with the appropriate life for 95% confidence.

Statistical comparisons of the four fatigue curves showed that there was no significant difference between the mean S/N data derived for springs made from wires A, B and D. The mean data obtained for springs made from Wire C may have been significantly lower than that obtained for springs made from Wire A, however, the difference in the mean curves being significant at the 95% level of confidence.

Springs made from Wire C therefore tended to give fatigue lives which were generally lower than those obtained for springs made from Wires A, B and D, whilst simultaneously displaying a tendency to increased scatter, as can be seen from a comparison of the standard errors of estimate shown in Table VI.

These findings are interesting in that, of the four wires used for this work, Wire C was the only material exhibiting any evidence at all of partial decarburization, to a maximum of 0.9% of the wire diameter.

3. CONCLUSIONS

It is clear from the results of the wire examination that all four materials conformed to the requirements stipulated in BS 5216. 1975 for normal duty dynamic wire, in respect of tensile strength and surface quality.

Future work will report the results of more detailed examination of the wire surfaces and fatigue characteristics of springs made from wires A and C. These wires represent the extremes of fatigue scatter and surface quality, in respect partial decarburization, found in the present work.

4. REFERENCES

1. Bird, G.C., "The production of spring fatigue data with statistical levels of confidence. Part 1: Introduction and Methods of Testing". SRAMA Report No. 223, Feb. 1974.
2. Reynolds, L.F., "The influence of surface roughness of as drawn wire upon the fatigue performance of helical compression springs". SRAMA Report No. 298, Oct. 1978.

TABLE I MECHANICAL PROPERTIES OF 2.65 MM BS 5216 ND3 WIRE: SAMPLE A.

Condition	Statistical Function	Tensile Properties, N/mm^2				Torsional Properties, N/mm^2			
		Rm	L of P	$Rp_{0.05}$	$Rp_{0.1}$	L of P	0.1% Proof Stress	0.2% Proof Stress	G
As Drawn	Mean	1890	487	1049	1308	272	660	780	7.67×10^4
	Standard Deviation	10	192	105	92	35	26	23	1.55×10^3
	No. of Tests	5	5	5	5	5	5	5	5
L.T.H.T. 250°C ½ hour.	Mean	1961	1267	1684	1792	852	1058	1116	7.78×10^4
	Standard Deviation	4	140	26	14	24	17	15	2.8×10^2
	No. of Tests	4	4	4	4	5	5	5	5

TABLE II MECHANICAL PROPERTIES OF 2.65 MM BS 5216 ND3 WIRE: SAMPLE B

Condition	Statistical Function	Tensile Properties, N/mm^2				Torsional Properties, N/mm^2			
		Rm	L of P	$Rp_{0.05}$	$Rp_{0.1}$	L of P	0.1% Proof Stress	0.2% Proof Stress	G
As Drawn	Mean	1722	472	938	1117	332	669	765	7.73×10^4
	Standard Deviation	3	82	48	50	9	24	17	1.87×10^3
	No. of Tests	6	6	6	6	5	5	5	5
L.T.H.T. 250°C ½ hour.	Mean	1827	1201	1640	1711	823	1013	1071	7.88×10^4
	Standard Deviation	4	126	29	21	27	29	22	5.9×10^2
	No. of Tests	5	5	5	5	5	5	5	5

TABLE III MECHANICAL PROPERTIES OF 2.65 MM BS 5216 ND3 WIRE: SAMPLE C

Condition	Statistical Function	Tensile Properties, N/mm^2				Torsional Properties, N/mm^2			
		Rm	L of P	$Rp_{0.05}$	$Rp_{0.1}$	L of P	0.1% Proof Stress	0.2% Proof Stress	G
As Drawn	Mean	1751	658	1016	1184	306	673	782	7.78×10^4
	Standard Deviation	10	267	202	131	62	23	9	5.3×10^2
	No. of Tests	5	5	5	5	5	5	5	5
L.T.H.T. 250°C ½ hour.	Mean	1827	1332	1658	1730	736	1007	1068	7.96×10^4
	Standard Deviation	5	98	19	12	74	32	24	5.1×10^2
	No. of Tests	5	5	5	5	5	5	5	5

TABLE IV MECHANICAL PROPERTIES OF 2.65 MM BS 5216 ND3 WIRE: SAMPLE D

Condition	Statistical Function	Tensile Properties, N/mm^2				Torsional Properties, N/mm^2			
		Rm	L of P	$Rp_{0.05}$	$Rp_{0.1}$	L of P	0.1% Proof Stress	0.2% Proof Stress	G
As Drawn	Mean	1789	532	1047	1235	313	608	719	7.62×10^4
	Standard Deviation	24	181	121	93	33	31	43	6.5×10^2
	No. of Tests	6	6	6	6	5	5	5	5
L.T.H.T. 250°C ½ hour.	Mean	1896	1450	1709	1778	805	1012	1072	7.74×10^4
	Standard Deviation	1	61	20	15	27	6	5	3.2×10^2
	No. of Tests	4	4	4	4	5	5	5	5

TABLE V SPRING DESIGN

Wire Diameter	2.65 mm
Mean Coil Diameter	21.7 mm
Total Coils	5.5
Active Coils	3.5
Free Length*	43 mm

* After L.T.H.T. 250°C/½ hour, pre-stressing and end grinding.

TABLE VI STANDARD ERROR OF ESTIMATE FOR RESIDUALS (LOG N) DERIVED FROM "BEST FIT" S/N CURVES

Parameter	Wire identification			
	A	B	C	D
Standard error of Estimate (Log N)	0.213	0.254	0.285	0.296
Number of S/N data points	28	29	28	28

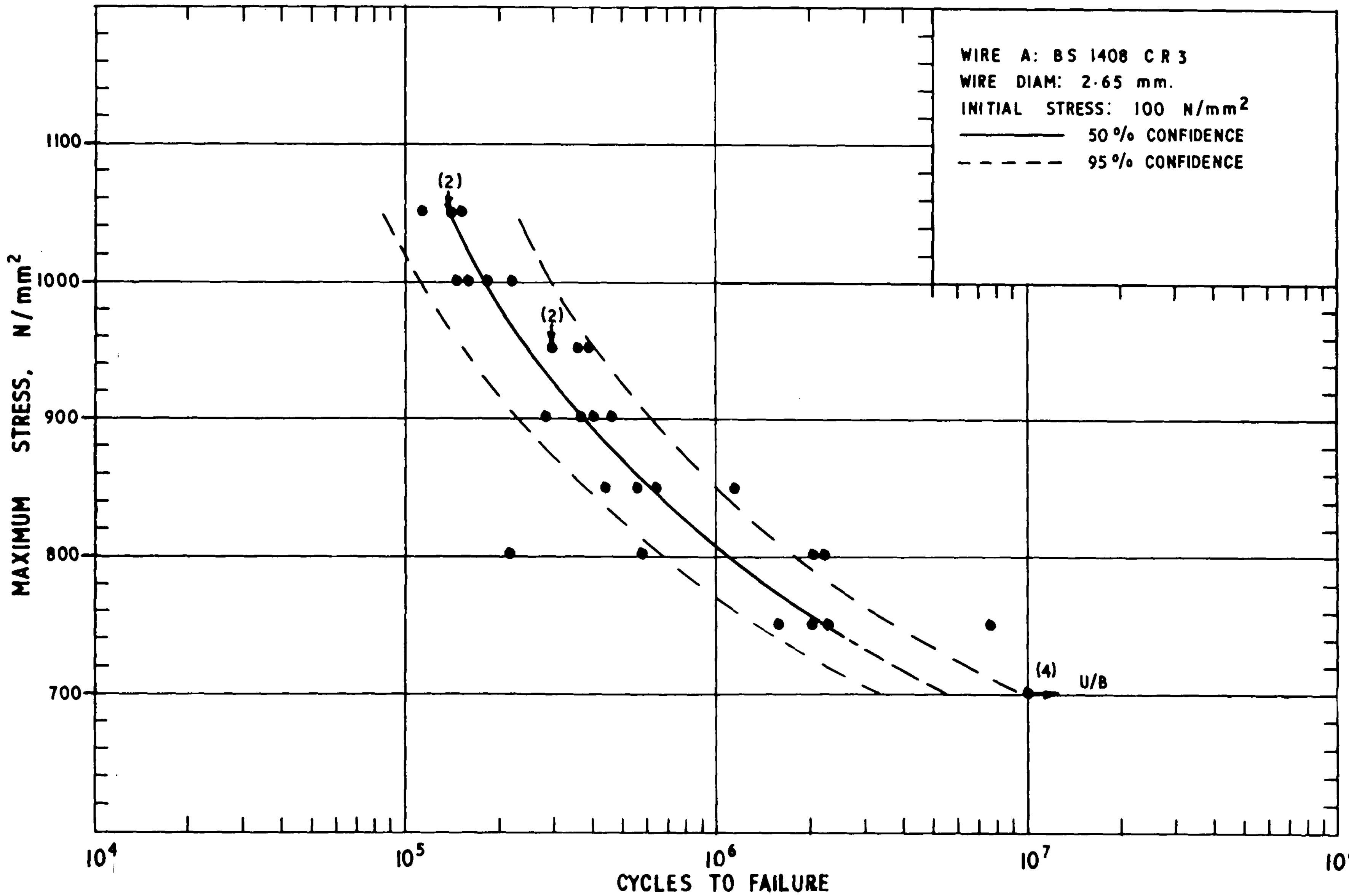

FIG. I. PRELIMINARY S/N DATA FOR HELICAL COMPRESSION SPRINGS MADE FROM WIRE A.

SRAMA

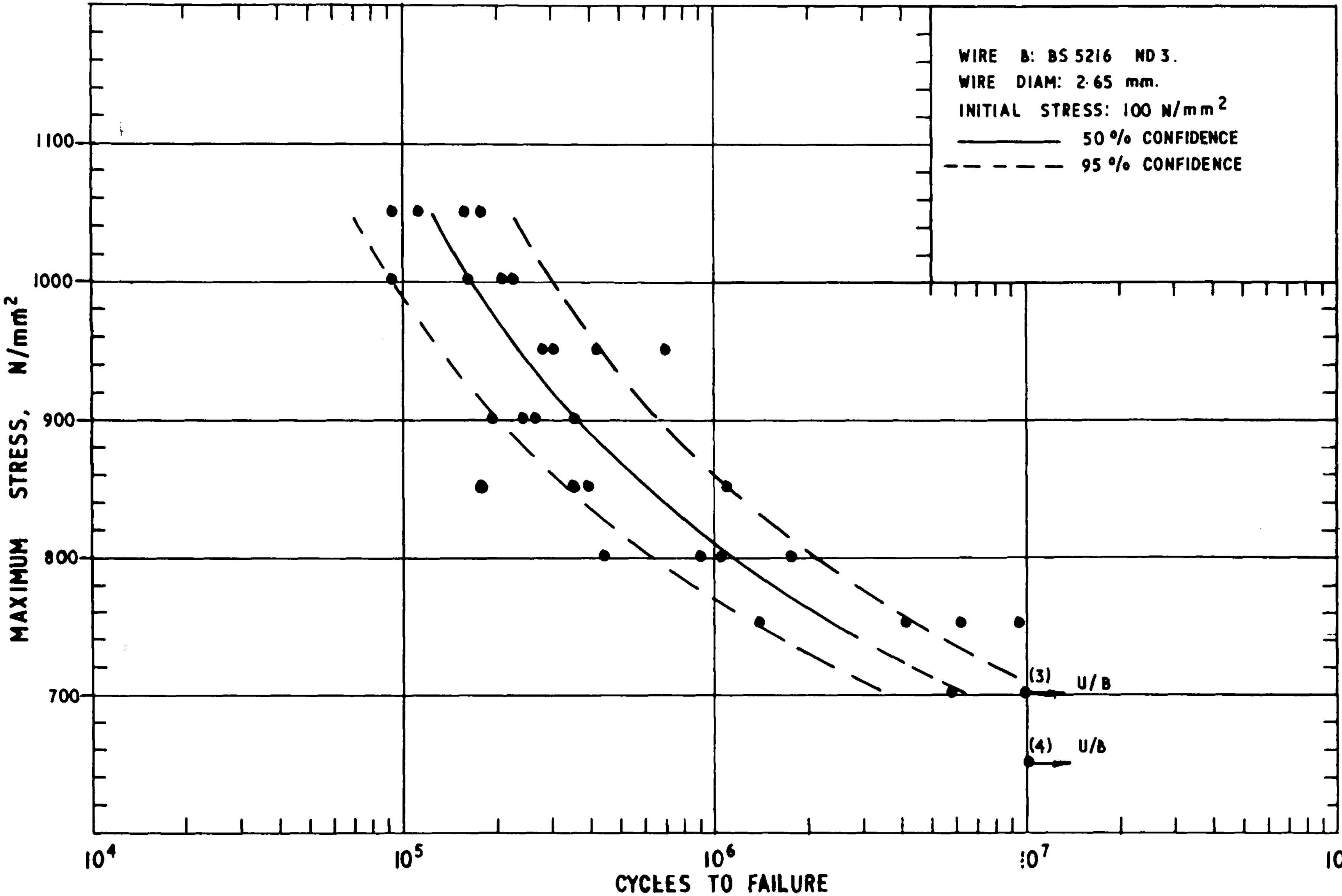

FIG. 2. PRELIMINARY S/N DATA FOR HELICAL COMPRESSION SPRINGS MADE FROM WIRE B.

SRAMA

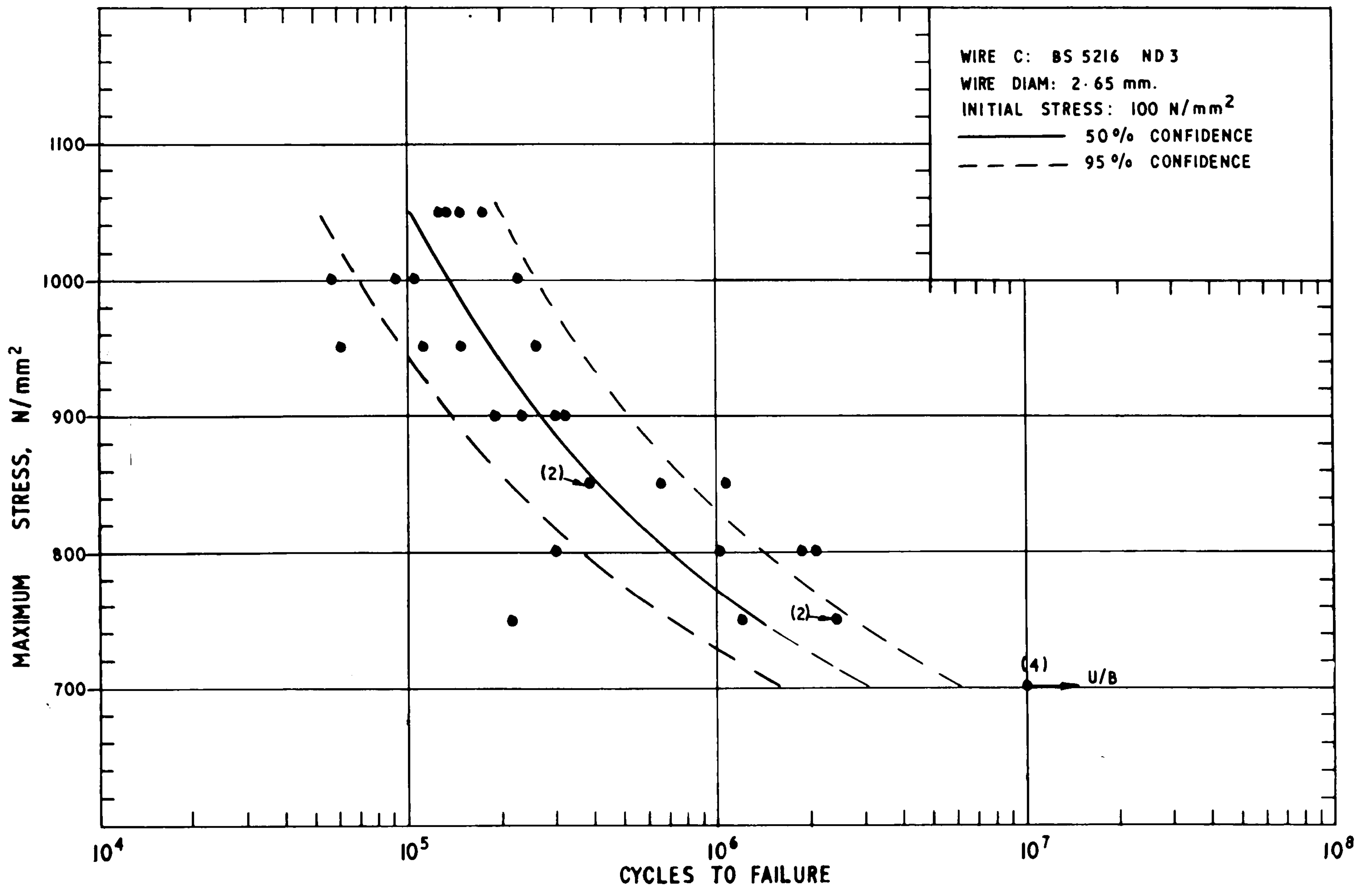

FIG. 3. PRELIMINARY S/N DATA FOR HELICAL COMPRESSION SPRINGS MADE FROM WIRE C.

SRAMA

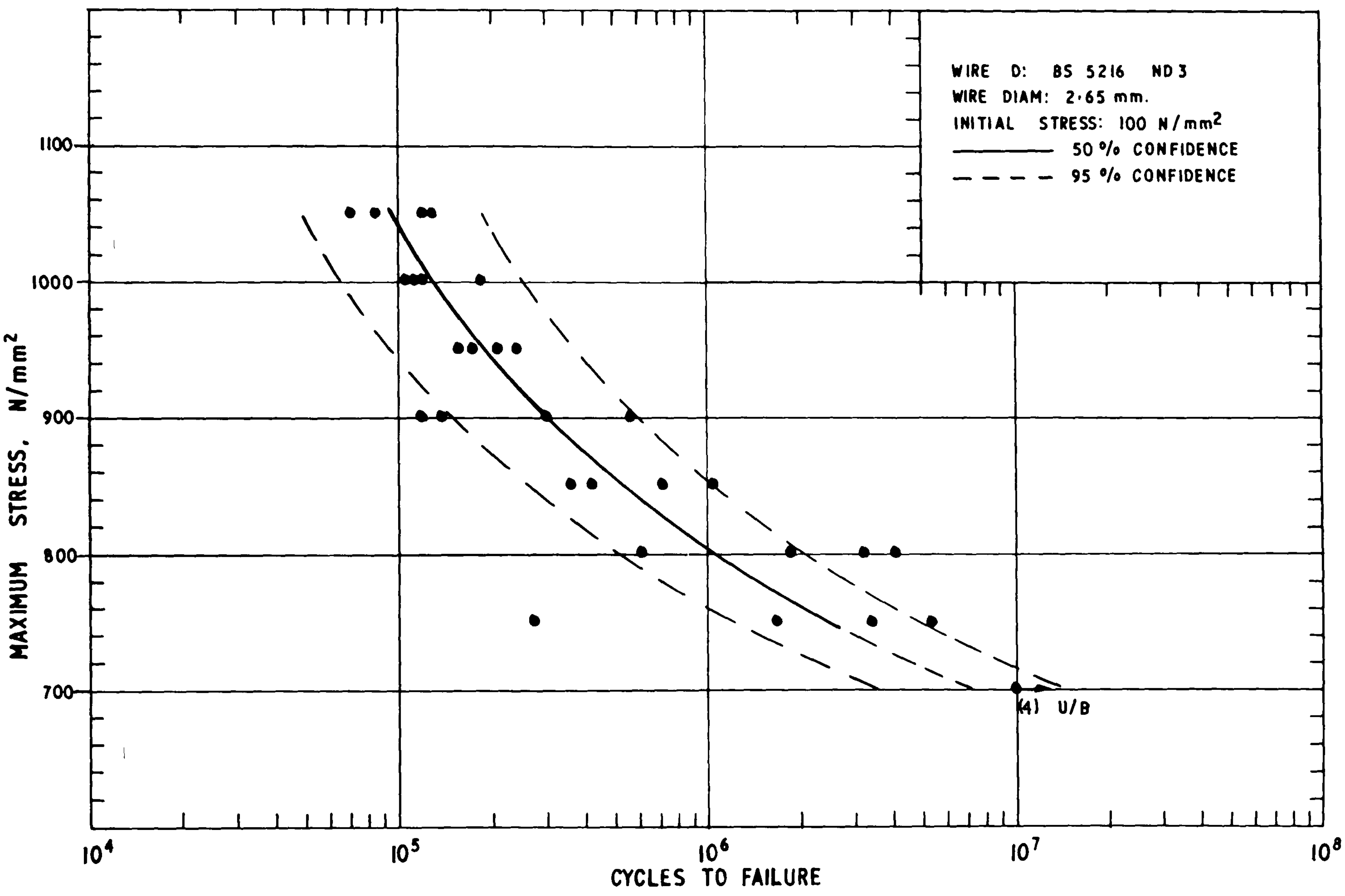

FIG. 4. PRELIMINARY S/N DATA FOR HELICAL COMPRESSION SPRINGS MADE FROM WIRE D.