THE SPRING RESEARCH ASSOCIATION

The Fatigue Properties of Springs made from Patented Cold Drawn Wire to B.S.1408C and B.S.1408D in 3 Ranges of Tensile Strength

Report No. 164

by

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LSG/P.35

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Summary

Fatigue tests have been carried out on helical compression springs made from 0.104 in diameter patented cold drawn wire to B.S.1408 C and B.S.1408 D in each of the 3 tensile ranges 90/100, 100/110 and 110/120 tonf/in^2. The fatigue strength at 10^7 cycles increased with increasing tensile strength for both wires and was 3 tonf/in^2 higher for ground wire than for unground wire of the same tensile strength. Limited-life data indicated that an increase in the tensile strength of the wire resulted in a considerable increase in the life to failure of springs tested at stresses just above the fatigue limit but that there was no appreciable increase in life to failure if the stress applied was very high.

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(June 1967)

PRODUCTION BRIEF

The Effects of Tensile Strength on Fatigue Strength of B.S.1408 Springs

Fatigue tests undertaken by the Association on helical compression springs made from 0.104 in diameter patented cold drawn wire to B.S.1408 C and D specifications have shown the influence the tensile strength of the wire is having on the fatigue properties of the springs.

Increasing the tensile strength of B.S.1408 C wire within the limits laid down in the B.S. specification, from 99 tonf/in^2 to 120 tonf/in^2, improves the fatigue strength of springs intended for unlimited life by as much as 12%, i.e. 42.5 tonf/in^2 to 47.5 tonf/in^2 with 5 tonf/in^2 initial stress. It will also increase the life of springs designed for limited life applications. For instance, the number of cycles a B.S.1408 C spring, stressed to 50 tonf/in^2, (initial stress of 5 tonf/in^2) can withstand without failure can be increased over ten fold by the use of a Range 3 (120 tonf/in^2) wire as opposed to a Range 1 wire (99 tonf/in^2).

At high maximum stress levels of 57 to 60 tonf/in^2 however, from the point of view of fatigue resistance, there would appear to be no advantage in using the higher strength wires.

The B.S.1408 D quality wire follows the same trend as the B.S.1408 C but with a fatigue strength at 10^7 cycles of about 3 tonf/in^2 higher.

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1. INTRODUCTION

A programme of research has been initiated to investigate the fatigue properties of springs made from wire to B.S.1408 C and D in 3 tensile ranges and subsequently low temperature heat treated.

2. MATERIALS

2.1 Wire

Wire of 0.104 in diameter was obtained to specifications B.S.1408 C and B.S.1408 D. Both grades were drawn from the same cast of steel with analysis as follows:

0.69% C   0.22% Si   0.55% Mn   0.012% S   0.024% P

The analysis was within the range of chemical composition given in B.S.1408. Each grade was supplied at 3 different levels of tensile strength, one in each of the ranges specified in B.S.1408; the tensile values are tabulated below:

Range No	Specified Tensile Strength tonf/in^2	Actual Tensile Strength	
		B.S.1408C tonf/in^2	B.S.1408D tonf/in^2
1	90 to 100	99	95
2	100 to 110	102	100
3	110 to 120	120	116

2.2 Springs

Springs were manufactured from each of the six batches of wire to the following design:

Wire Diameter	0.104 in
Spring Mean Diameter	0.945 in
Free Length	1.65 in
No. of active coils	3.5
Total no. of coils	5.5
Spring Rate	56 lb/in

All the springs after coiling were given a low temperature heat treatment at 350°C for 30 minutes followed by rough end grinding, prestressing and final end grinding.

3. EXPERIMENTAL PROCEDURE

3.1 Fatigue Tests

Springs from each batch were fatigue tested on multiple spring testing machines (1) at initial stress levels of 5, 10 and 20 tonf/in^2. At the 5 tonf/in^2 initial stress level the maximum stresses were selected to obtain full S/N curves but at the 10 and 20 tonf/in^2 initial stress levels springs were only tested at sufficient levels of maximum stress to produce a fatigue limit with at least two springs remaining unbroken to 10^7 cycles at or just below the fatigue limit.

3.2 Metallurgical Examination

Transverse sections were cut from each batch of wire, mounted, polished, etched and examined microscopically.

4. RESULTS.

The results of the fatigue tests for springs made from B.S.1408 C, Ranges 1 to 3, and B.S.1408 D, Ranges 1 to 3, are presented as S/N curves in Figs. 1 to 6 respectively. The results for the broken springs in each batch were analysed statistically to determine the position of the curve and to ensure that its correlation was at least 95% significant.

The fatigue stresses for survival to 10^7 cycles at initial stress levels of 5, 10 and 20 tonf/in^2 are plotted as modified Goodman diagrams in Fig. 7 in which the maximum stress curves for each batch of wire are extrapolated to zero initial stress.

The fatigue stresses for 10^7 cycles are tabulated in table 1 together with the tensile strength values. The relationship between these two parameters is illustrated in Fig. 8.

The metallurgical examination of transverse sections (Figs. 9 to 14) taken from each wire batch showed that the wire to ranges 1 and 2 of B.S.1408 C was partially decarburised to a depth between 0.001 and 0.0015 in. There was no total decarburisation.

The wire to range 3 of B.S.1408 C showed no obvious signs of decarburisation until a very careful examination of the surface had been carried out. One isolated area of partial decarburisation was noticed approximately 0.001 in in depth. Further preparation of the sample to allow a photograph to be taken removed this region indicating the very small zone and patchy nature of the defect. In an endeavour to find any further zones of decarburisation, a further six transverse samples were taken from the batch of wire and examined metallographically. No decarburised areas were identified but it was noticed that the surface roughness of this quality was extremely variable, ranging from a smooth surface, more akin to a B.S.1408 D wire, to that illustrated in Fig. 11. To determine whether a carbon gradient existed, surface and core hardness measurements were carried out on both the B.S.1408 C R3 wire and also, for comparison purposes, on the B.S.1408 D quality range 3 wire. No hardness gradient was found, thus indicating no carbon gradient either.

All the wires to B.S.1408 D were free from decarburisation.

5. DISCUSSION OF RESULTS

The tensile strength of the wires conformed to the ranges specified in B.S.1408 although some were at the limit of the range. The ground wire was free from decarburisation; the unground wires exhibited decarburisation within the permitted limit of the specification and in one case it was very slight.

The results of the fatigue tests showed that for both grades of wire the fatigue strength for 10^7 cycles increased with an increase in the tensile strength of the wire (Fig. 8).

It is clear that the B.S.1408 D wires, which had a smoother surface and were free from decarburisation possessed greater resistance to fatigue than the B.S.1408 C wires. However, this difference in fatigue strength was not great, being approximately only 3 tonf/in^2 for any given tensile strength. Even though the B.S.1408 C range 3 wire was virtually free from decarburisation its fatigue properties do not match those for B.S.1408D range 3. This was considered to be due to the much rougher surface found in places on the B.S.1408 C wire.

An important feature of the S/N curves shown in Figs. 1 to 6 is that for both grades of wire an increase in the tensile strength improved the life to failure at stresses above the fatigue limit but the improvement gradually decreased to a negligible amount as the level of fatigue stress was increased to 60 tonf/in^2. In the curves for range 3 (Figs. 3 and 6) the knee has not been reached after 10 x 10^6 cycles and would require tests to be run to at least 30 x 10^6 cycles to establish definitely a fatigue limit. This information indicates that for limited life springs there would be an advantage in using a wire with higher tensile strength for a maximum stress level of the order of 50 tonf/in^2 (with 5 tonf/in^2 initial stress) but that at a maximum stress approaching 60 tonf/in^2 there would be little improvement in fatigue life with an increase in tensile strength.

Examination of Fig. 7 shows the fatigue strength of B.S.1408 D springs to increase with increase in U.T.S. when tested at an initial stress of 5 tonf/in^2. At the highest initial stress level (20 tonf/in^2) however, there is an apparent crossover for springs manufactured from range 2 and 3 wires. Under these particular test conditions the test springs at maximum stress were close to solid, in some cases only 8% residual stress range remaining. It could well be that due to this the true stress on the spring differed from the calculated stress. It is suggested, therefore, that as an adjunct to this work further springs be designed having a higher solid stress to enable more reliable data to be produced at the 20 tonf/in^2 initial stress level.

A comparison can be made between the fatigue properties of B.S.1408 D springs resulting from this investigation and those obtained from earlier researches [1, 2].

The fatigue strength of springs made from the current B.S.1408 D R2 wire is 44 tonf/in^2 (zero initial stress) and is very similar to that given in Report No. 144 for En 49D R2 0.104 in dia. wire springs at 46 tonf/in^2 (zero initial stress). However, both these results are higher than that obtained for En 49D R2 0.128 in dia wire springs at 39 tonf/in^2 (zero initial stress) published in Report No. 148.

6. CONCLUSIONS

Fatigue tests carried out on springs made from patented hard drawn ground wire, showed that increasing the tensile strength of the wire within the limits of B.S.1408, increased the fatigue strength for 10^7 cycles. The fatigue strength for 10^7 cycles of springs made from ground wire was higher than that of springs made from unground wire (B.S.1408 C) at the same level of tensile strength.

The fatigue life of medium stressed limited life springs made from B.S.1408 D can be increased by increasing the tensile strength within the limits of the specification. The fatigue life of highly stressed limited life springs made from ground wire is not improved appreciably by a change in tensile strength within the limits of the specification.

The results obtained on the B.S.1408 C quality wire followed a similar trend as that for the ground material except that the tensile strength/fatigue strength curve was lower. It was noted that there were differing degrees of decarburisation on the 'C' qualities (although within specification) and different surface conditions and these may also have had an influence.

7. REFERENCES

1 J.W. Mee
The Mechanical and Fatigue Properties of Helical Compression Springs made from Patented Hard Drawn and Oil Tempered Wires.
C.S.F.R.O. Report No. 114, January 1960.

2 J.W. Mee and G.B. Graves.
A Comparison of the Static Mechanical and Fatigue Properties of Three Spring Steel Wires.
S.M.R.A. Report No. 148, May 1964.

TABLE I THE FATIGUE PROPERTIES OF SPRINGS MADE FROM B.S.1408C AND B.S.1408D WIRES

Wire Specification	Range	Tensile Strength $tonf/in^2$	Fatigue Strength for 10^7 cycles ($tonf/in^2$)			
			No Initial Stress	5 $tonf/in^2$ Initial Stress	10 $tonf/in^2$ Initial Stress	20 $tonf/in^2$ Initial Stress
BS 1408C	1	99	40.5	42.5	46	50
	2	102	41	45	48	56
	3	120	43.5	47.5	50	57
BS 1408D	1	95	43	47.5	50	58
	2	100	44	48	53	61
	3	116	46	48.7	53	59

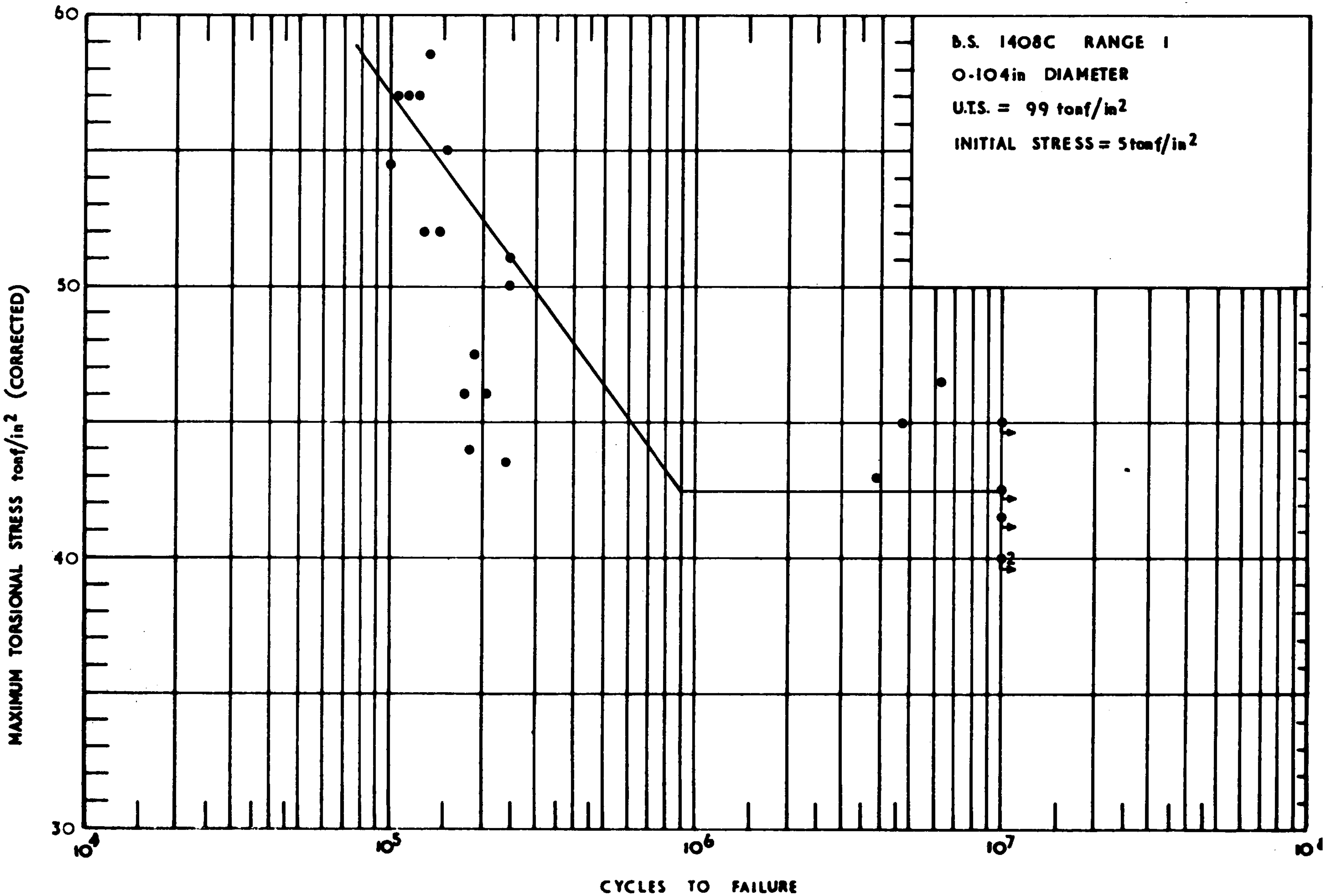

FIG. I. S/N CURVE FOR SPRINGS MADE FROM B.S. 1408C WIRE RANGE I.

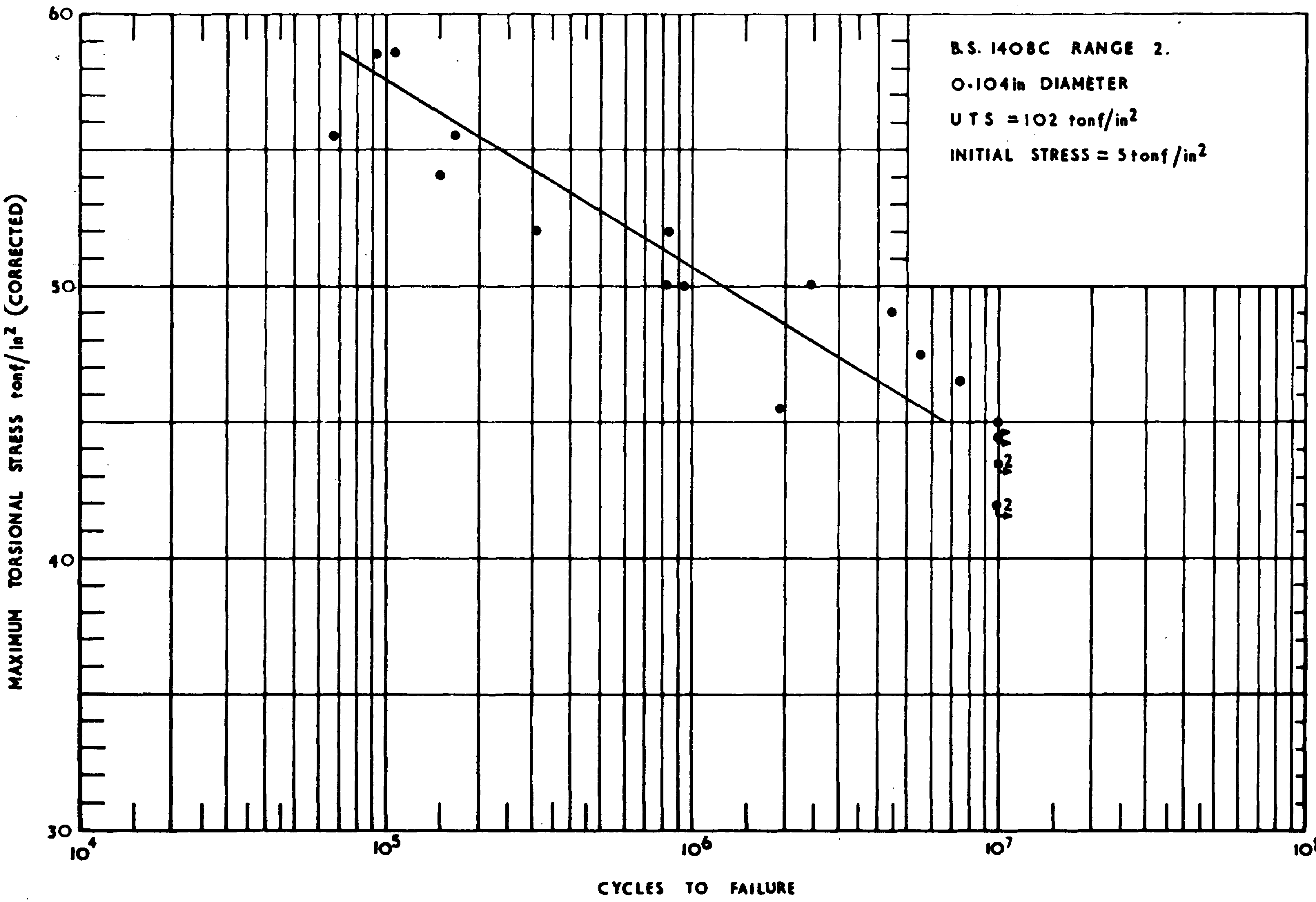

FIG. 2. S/N CURVE FOR SPRINGS MADE FROM B.S. 1408C WIRE RANGE 2.

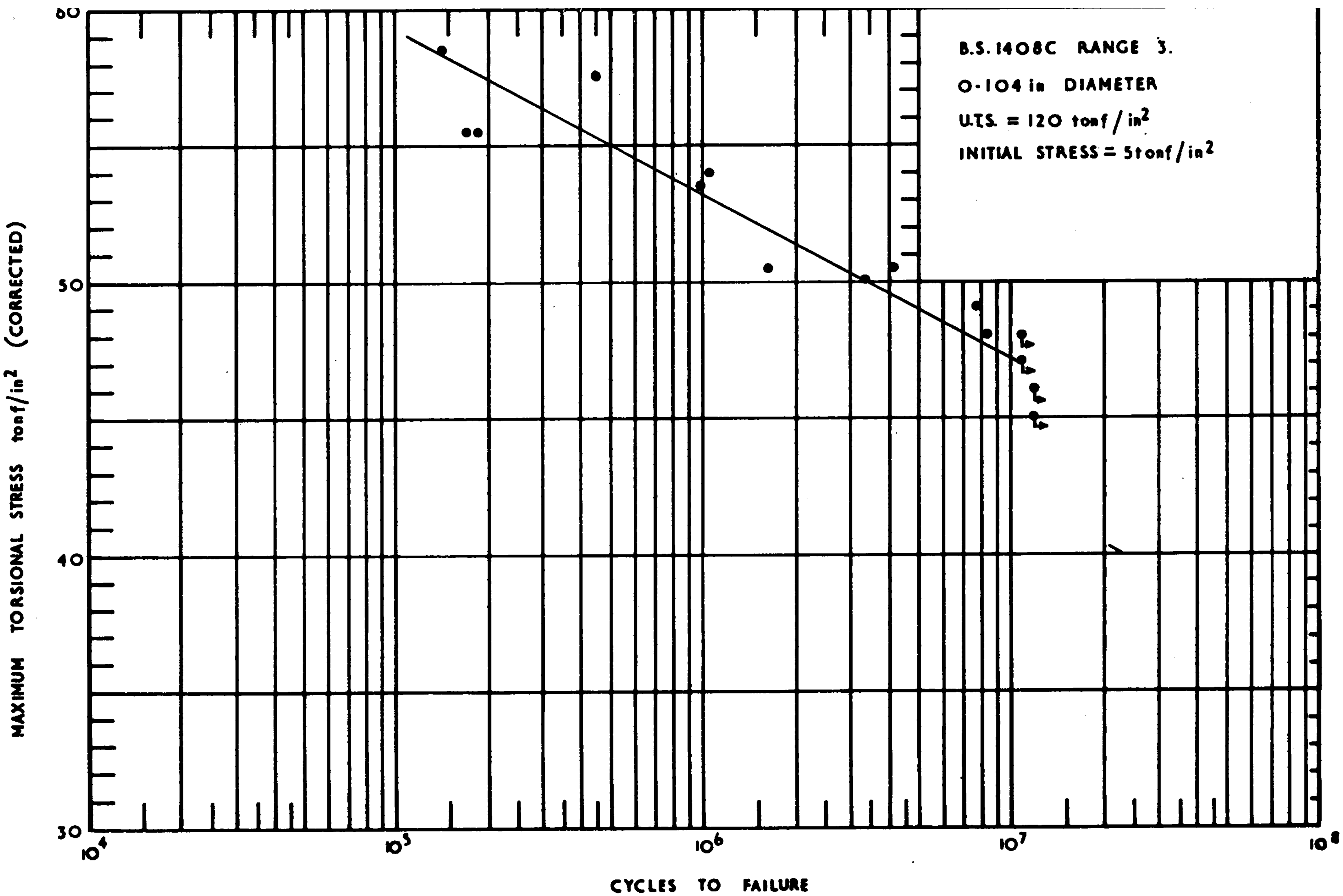

FIG. 3. S/N CURVE FOR SPRINGS MADE FROM B.S. 1408C WIRE RANGE 3.

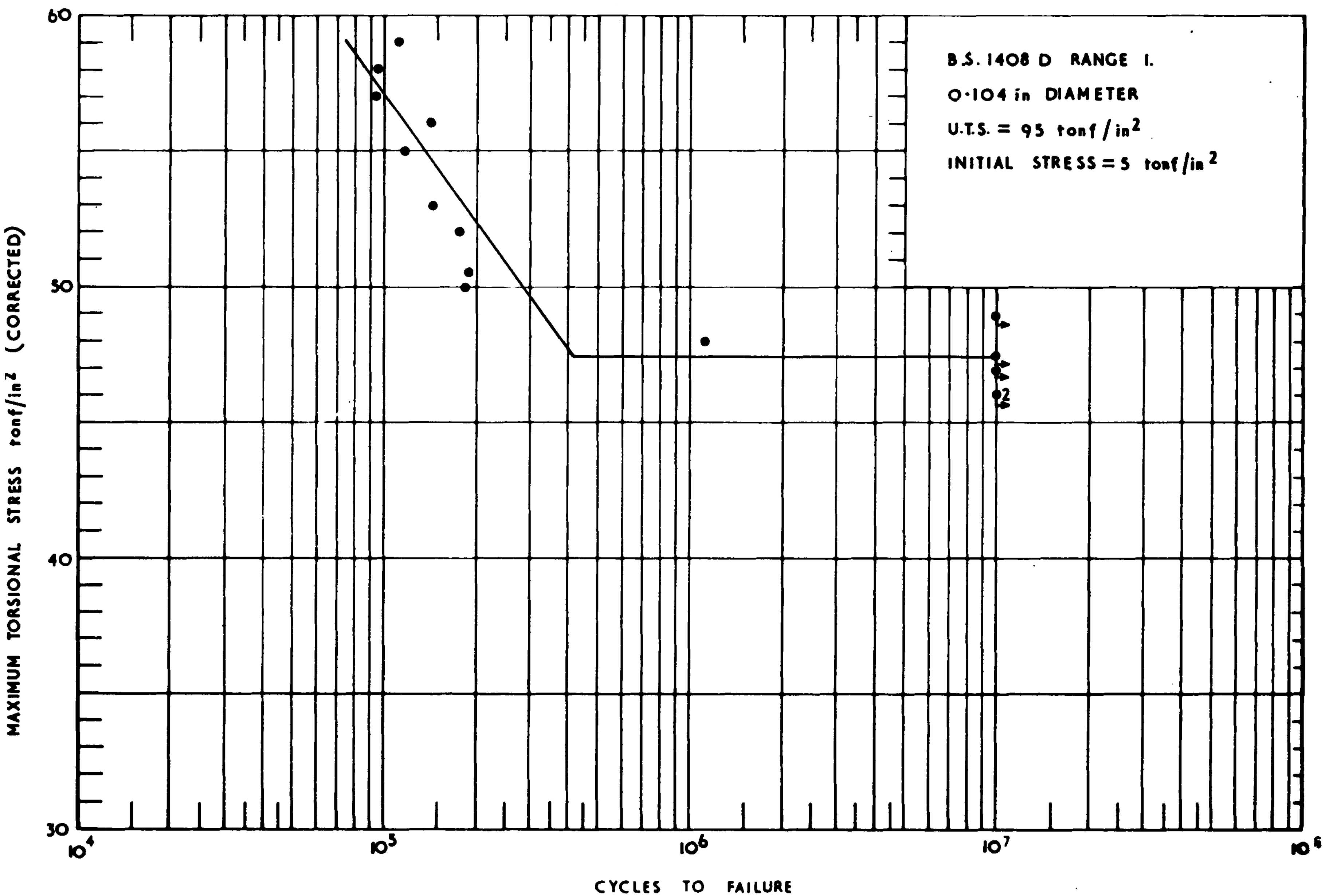

FIG. 4. S/N CURVE FOR SPRINGS MADE FROM B.S. 1408D WIRE RANGE I.

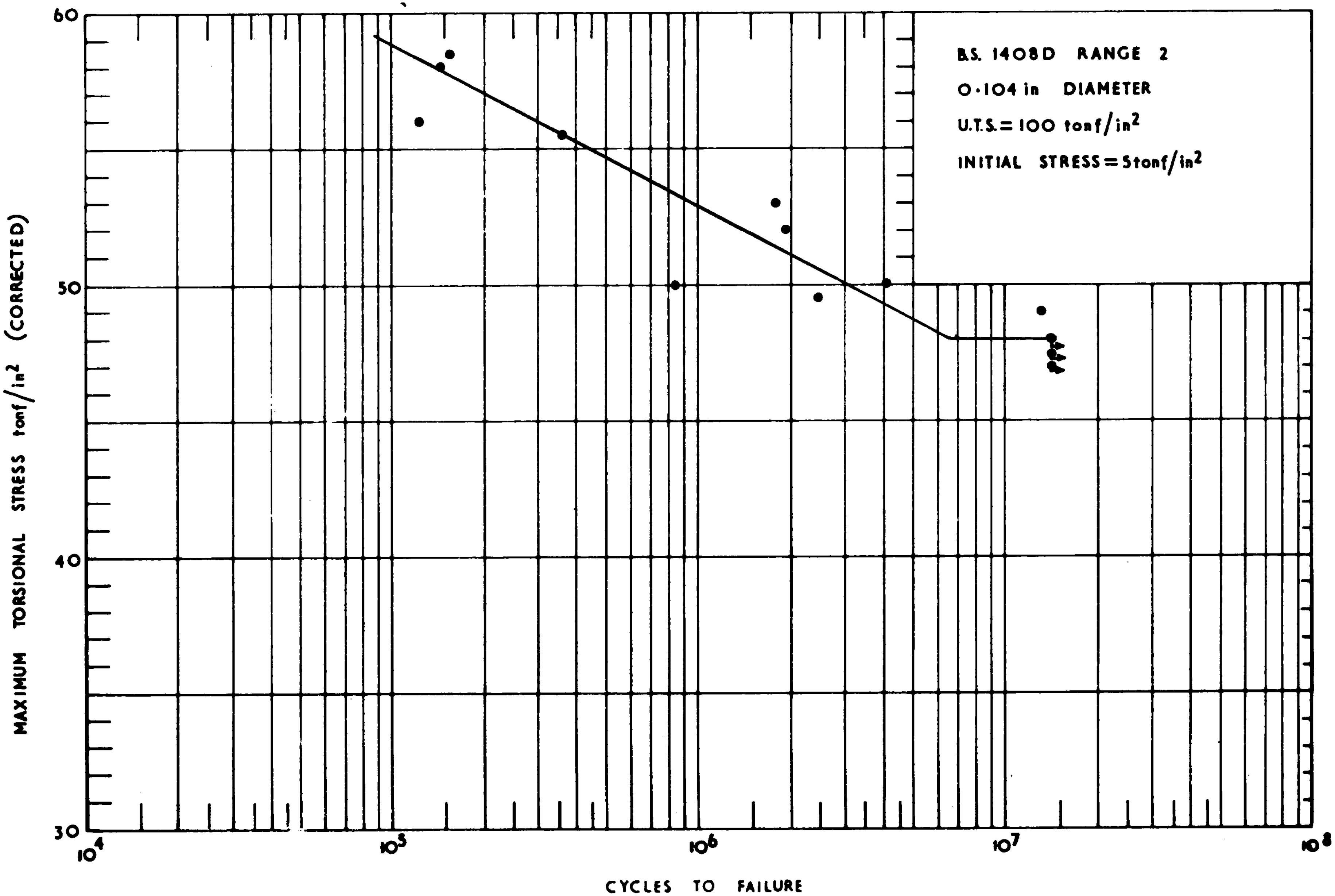

FIG. 5. S/N CURVE FOR SPRINGS MADE FROM B. S. 1408D WIRE RANGE 2.

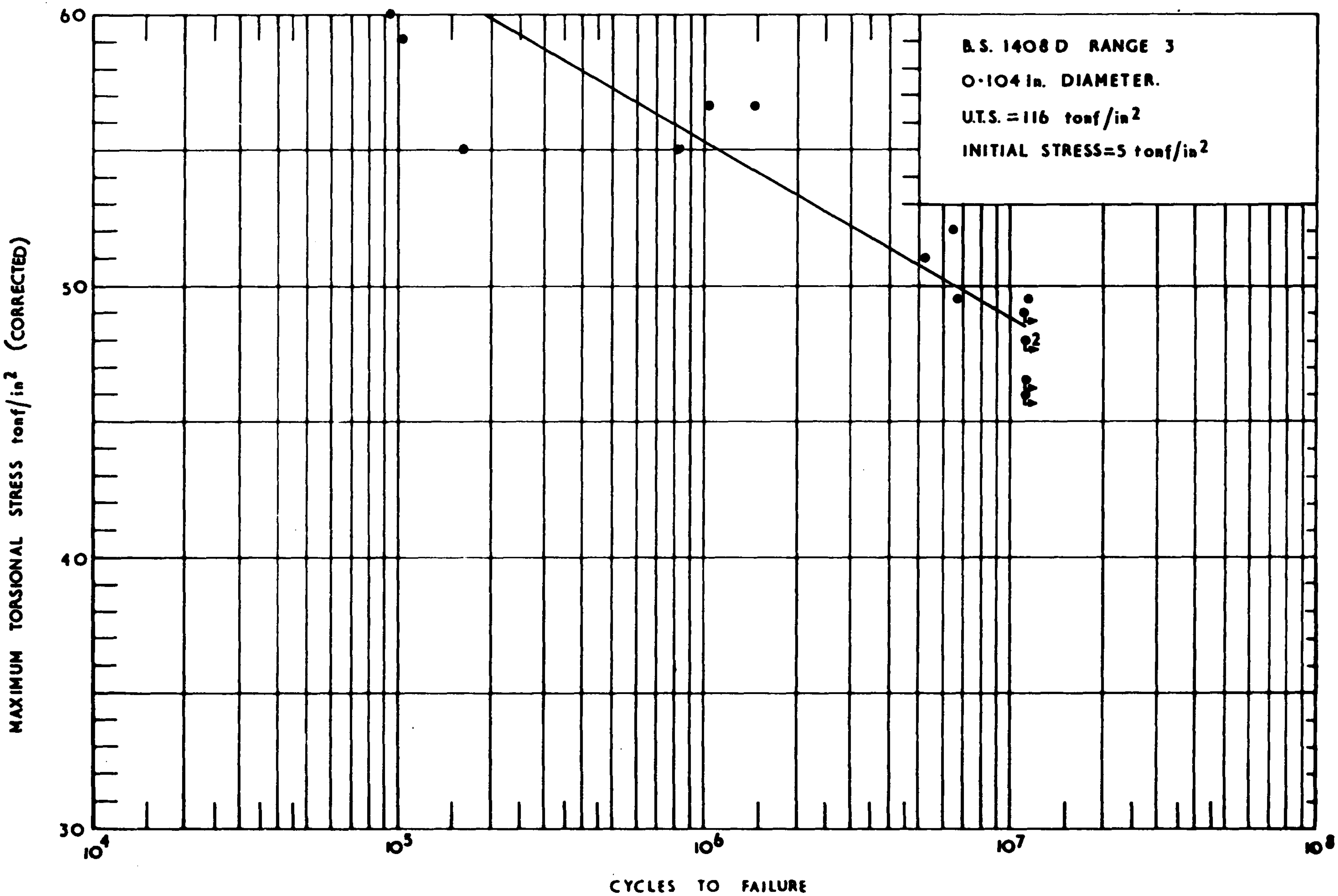

FIG. 6. S/N CURVE FOR SPRINGS MADE FROM B.S. 1408D WIRE RANGE. 3.

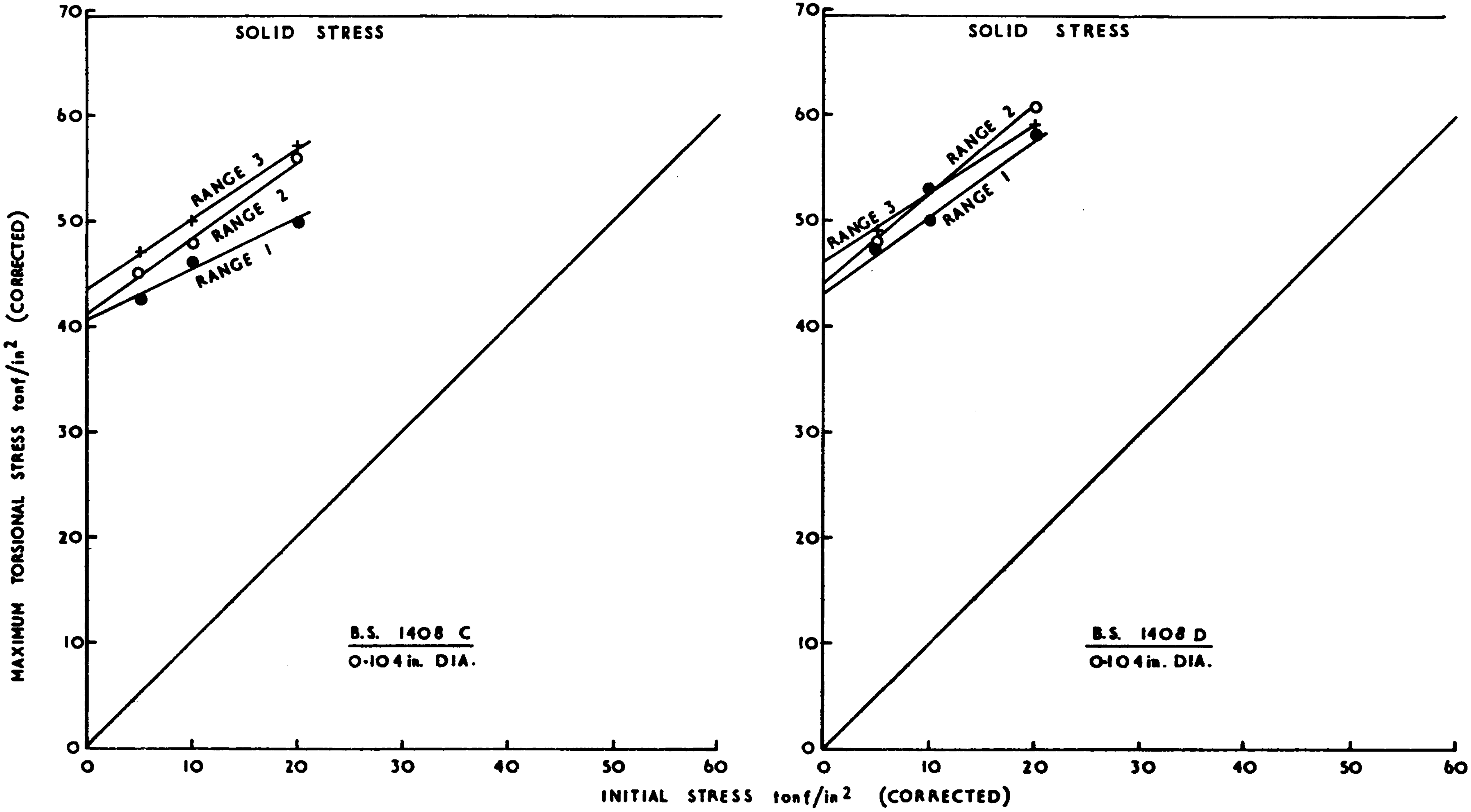

FIG. 7. MODIFIED GOODMAN DIAGRAMS FOR 10^7 CYCLES FOR SPRINGS MADE FROM B. S. 1408 C AND D WIRE.

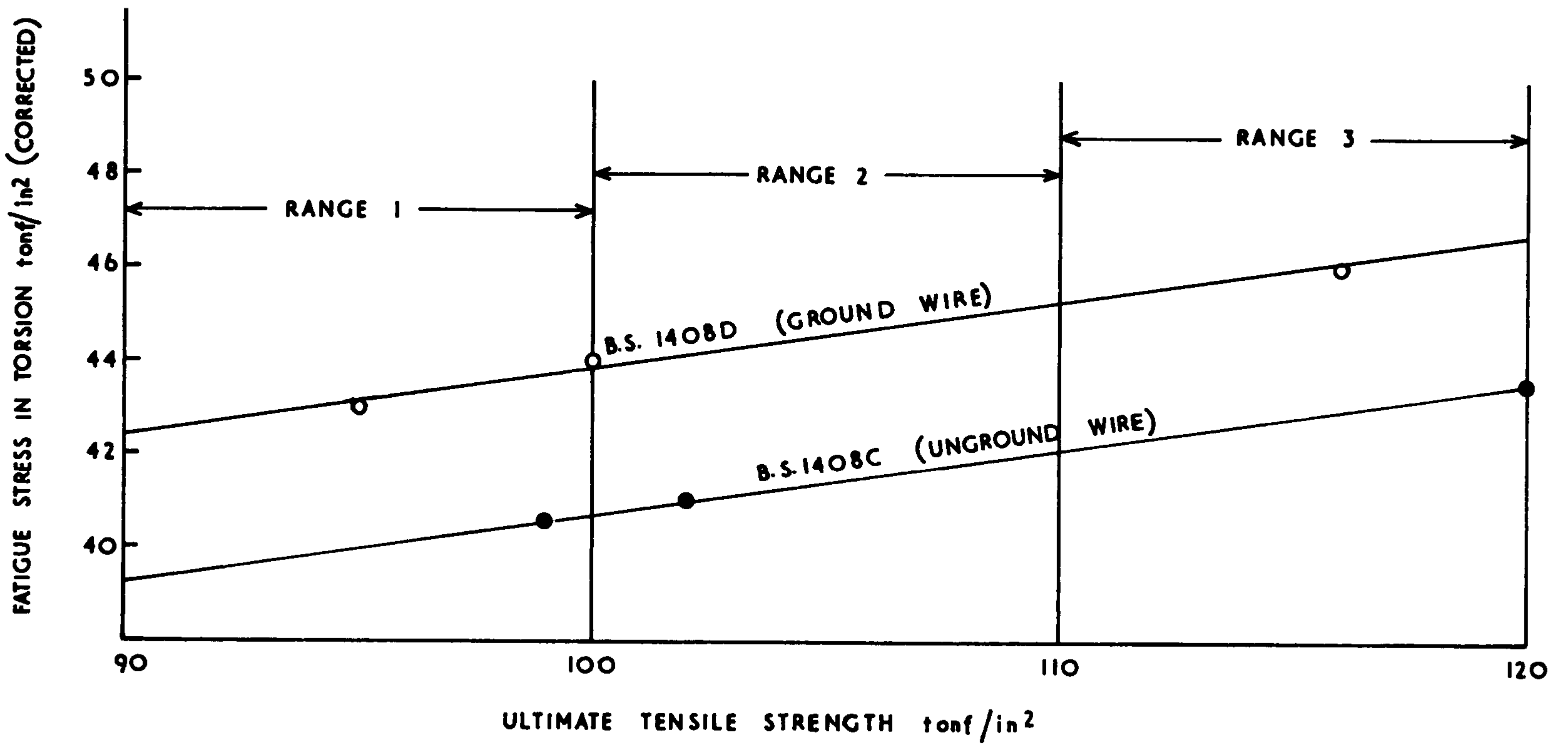

FIG 8 THE TORSIONAL FATIGUE STRENGTH (FOR 10^7 CYCLES) OF SPRINGS MADE FROM B.S.1408C AND D WIRE WITH NO INITIAL STRESS.

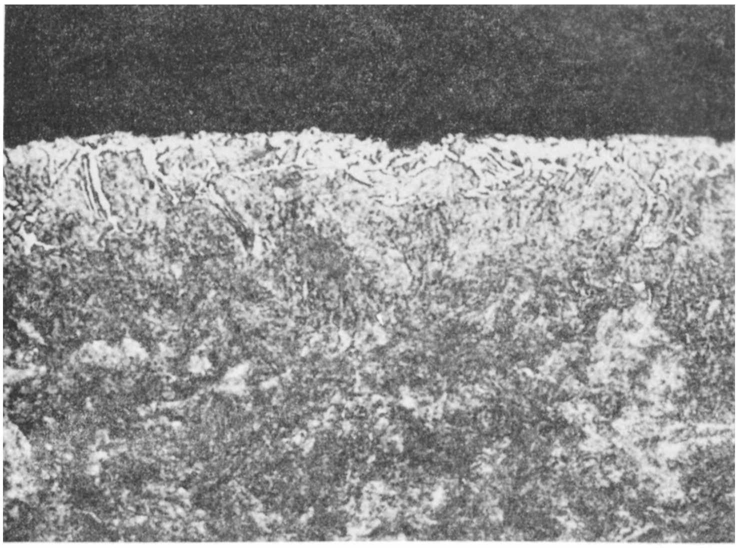

FIG.9 X500

TRANSVERSE SECTION OF BS1408C R.1 WIRE

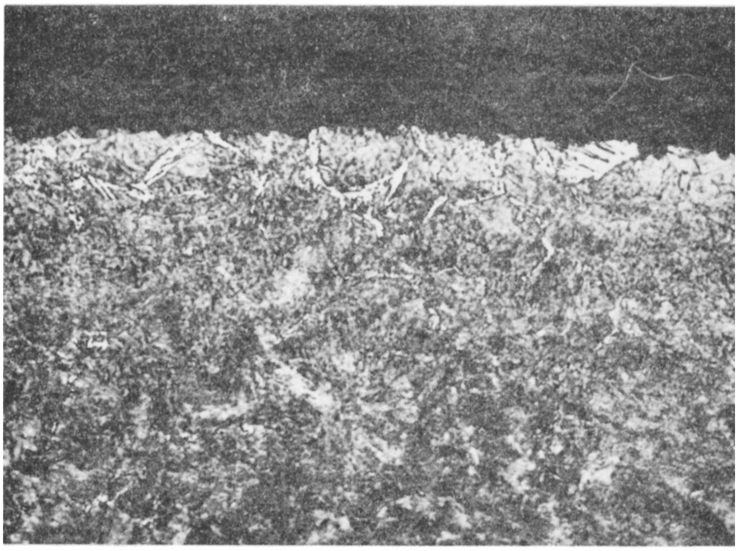

FIG.10 X500

TRANSVERSE SECTION OF BS1408C R.2 WIRE

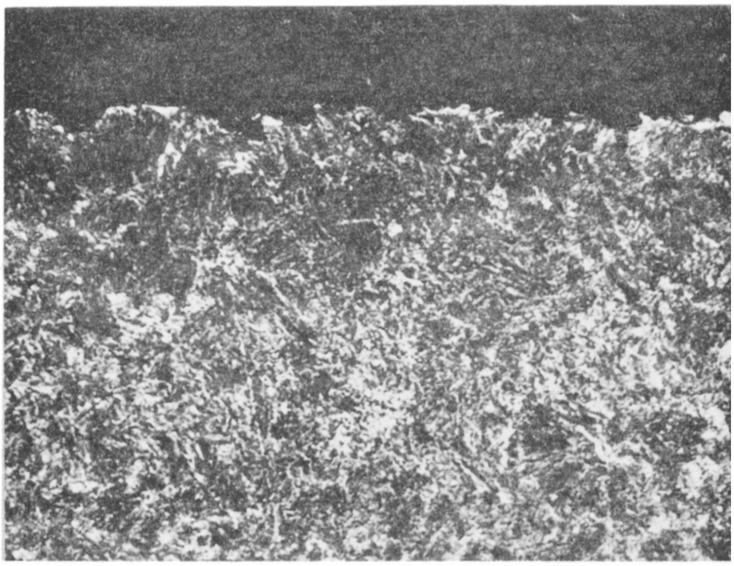

FIG.11 X500

TRANSVERSE SECTION OF BS1408C R.3 WIRE

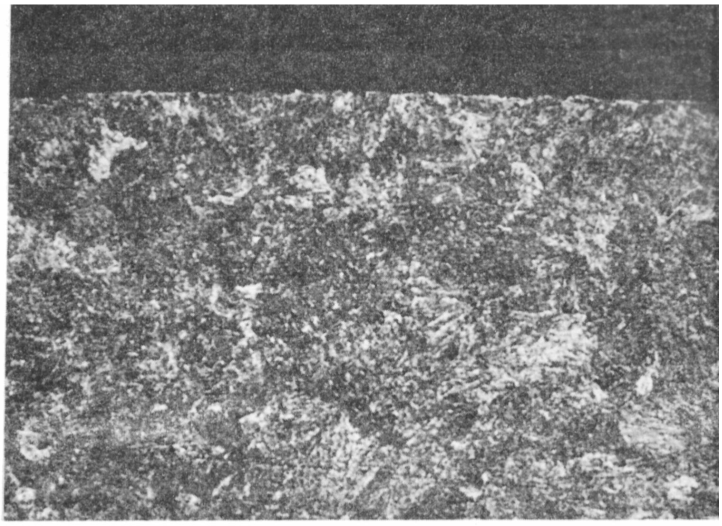

FIG. 12 X500

TRANSVERSE SECTION OF BS1408D R.1 WIRE

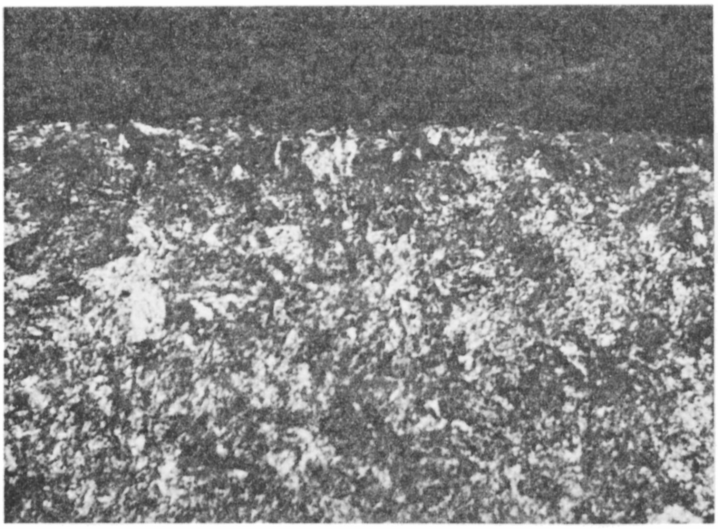

FIG.13 X500

TRANSVERSE SECTION OF BS1408D R.2 WIRE

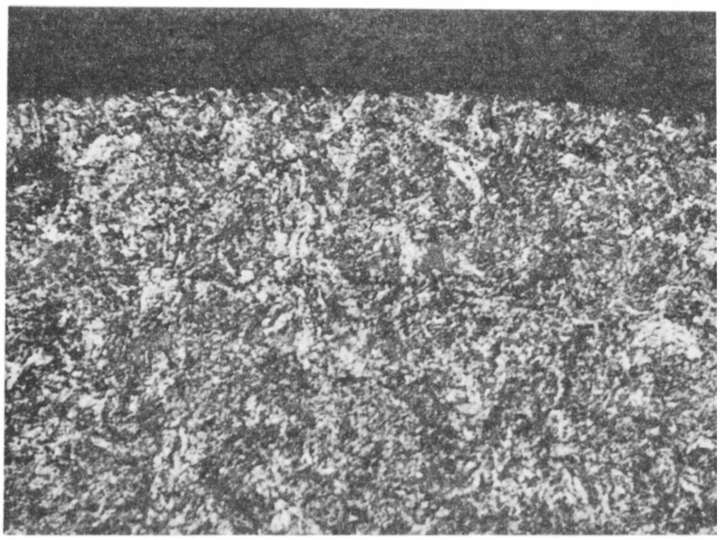

FIG. 14 X500

TRANSVERSE SECTION OF BS1408D R.3 WIRE