THE SPRING RESEARCH ASSOCIATION

THE FATIGUE PROPERTIES OF HELICAL COMPRESSION SPRINGS MANUFACTURED FROM S202 SPRING MATERIAL

(Contract No. K43A/65/CB43A2)

Progress Report No. 1

by

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

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SUMMARY

Fatigue tests have been carried out on shot peened helical compression springs manufactured from 4 mm (0.160 in) diameter S202 quality spring wire. S/N curves have been produced for different initial stress levels which have enabled a modified Goodman diagram to be constructed.

Springs manufactured from the above quality in the shot peened condition had a lower fatigue strength than shot peened springs manufactured from En 49D and unpeened springs made from 1408D, quality spring wires.

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1. INTRODUCTION

Fatigue data for D.T.D. spring materials have already been obtained by the SRA (1) under Contract No. KS/1/0333 and discussed by Panel D (Spring Materials) of the J.A.C. Metallic materials Sub-Committee. As a follow up to this earlier work a new research contract was instituted by the Ministry of Aviation Supply (formerly known as the Ministry of Technology (Aviation)) under No. K 43A/65/CB43A2. The object of the current work is to provide additional fatigue data on aircraft material qualities already investigated, particularly with regard to the effects of shot peening, and to study the fatigue behaviour of austenitic and precipitation hardening stainless steels which are, or may be, used as spring materials.

This present report deals with the fatigue properties of shot peened springs manufactured from 4 mm diameter patented cold drawn wire to S202 quality (superseding D.T.D. 5B).

2. MATERIAL

2.1 Wire

Wire of 4 mm diameter was obtained in the patented and hard drawn condition to specification S202. The analysis of the wire is given in Table I.

2.2 Springs

The design details of the springs are given in Table II.

After coiling the springs were given a low temperature heat treatment of 200°C for ½ hr, as suggested in earlier SRA work, to give optimum static properties (2).

Following end grinding and prestressing to solid the springs were shot peened to an Alman Arc rise of 0.018/0.022 A2 followed by a second low temperature heat treatment of 220°C for ½ hr.

3. EXPERIMENTAL PROCEDURE

3.1 Fatigue Testing

Load tests carried out on the springs established the necessary fatigue machine strokes to give the required stress ranges. Springs were fatigue tested at two initial stress levels of 100 and 500 N/mm^2 (6.5 and 32.4 tonf/in^2) on forced-motion multiple spring testing machines.

By varying the stress range applied to the springs the endurance of the springs could be measured and used to construct S/N curves.

Subsequently, by transposing relevant data from the S/N curves, a modified Goodman type fatigue diagram was obtained.

4. RESULTS

Table I gives the chemical composition of the wire and its nominal diameter.

The design data of the test springs are recorded in Table II.

Table III gives the fatigue data, for springs made from S202 quality wire.

The results of the fatigue tests are presented as S/N curves in Figs. 1 and 2.

The results from the broken springs were analysed statistically to provide the appropriate regression line and to determine whether the correlation coefficient provided a significance of at least 95%. In the case of the data for 100 N/mm^2 initial stress correlation was significant at 99.9% and for 500 N/mm^2 initial stress the data were significant at the 99% level.

The fatigue strengths at 10^7 cycles for the two initial stress levels employed are plotted as a modified Goodman diagram in Fig. 3.

Table IV, V, and VI show fatigue data previously obtained for springs made from D.T.D. 5B (now S202), B.S. 1408D, and En 49D quality materials. These data have also been included in Fig. 3 for ease of comparison. Unfortunately, it is not possible to effect an exact comparison of the data since the springs had somewhat different physical characteristics; Table VII sets out these differences.

5. DISCUSSION

It can be seen from Fig. 3 that the springs made from En 49D Range II spring wire, in the shot peened condition, exhibited the best fatigue resistance.

Springs made from material to B.S. 1408D, in the unpeened condition showed a lower fatigue strength than peened En 49D springs, at maximum torsional stress levels below 1010 N/mm^2. However, above this stress level a reversal of the fatigue strengths occurred, the B.S. 1408D unpeened springs revealing slightly better properties.

Cadmium plated D.T.D. 5B and unpeened En 49D springs possessed the poorest fatigue properties whilst the peened springs to S202 quality, the main subject of this investigation, displayed an intermediate performance between the B.S. 1408D and D.T.D. 5B springs. The differences in physical characteristics, process treatments and material structure as listed in Table VII will be examined in detail in an attempt to explain the observed fatigue properties, and at the same time to indicate where more experimental work could be undertaken so that a better understanding of the factors which determine the fatigue life of springs can be obtained.

a) Comparison of wire specifications. In essence the material specifications, S202, B.S. 1408D, D.T.D. 5B, and En 49D are the same; a careful examination of these has not revealed any feature in the various specifications which would account for the differences in the fatigue strengths recorded. Each steel can be melted by open hearth or electric process and in the two more recent specifications, S202 and B.S. 1408D, also by an oxygen process. In every case surface preparation of the billet, rod and wire is called for and deep etch tests are mandatory to ensure freedom from harmful defects. Similar compositions are specified, although in the specifications S202, B.S. 1408D, and En 49D a wider carbon range of 0.55-0.85%C is quoted compared to 0.70-0.85%C for the earlier D.T.D. 5B specification. However, as will be seen from Table VIII, the carbon contents of the four materials, as well as the percentage of the other elements present, are similar and would not be expected noticeably to affect fatigue resistance.

b) Effect of wire diameter. A difference in wire diameter existed particularly between the B.S. 1408D wire and the S202 and D.T.D. 5B qualities. It is known that in the majority of cases specimen size affects the fatigue resistance of materials, in that increasing the specimen diameter decreases the fatigue limit. However, these observations have been made where gross changes in specimen diameter have occurred e.g. 7.6 mm to 150 mm (5) and 6.3 mm to 50 mm (6). It seems unlikely, however, that small changes such as 2.6 mm to 4 mm would account for the wide variation in the fatigue strengths of the various materials.

c) Effect of solid stress. The amount of beneficial residual stress which can be induced in a spring is a function of both the solid stress to which the material is subjected, and also the form of the torsional stress-strain relationship. In materials with identical stress-strain characteristics the higher the prestressing stress, the greater the amount of beneficial residual stress and the better the expected fatigue life.

In the case of the four materials under discussion the torsional stress-strain characteristics are not known and hence the amount of beneficial stress cannot be calculated.

The fact that the fatigue lives of these four materials do not reflect the degree of pre-strain which the materials have received can be explained either by the different behaviour of the materials in torsion (7), or by the fact that the effect of prestrain is masked by some other manufacturing or material factor.

d) Effect of surface condition. Shot peening is perhaps the most widely used and effective method of improving the fatigue resistance of springs and therefore one would have expected the fatigue properties of the shot peened S202 springs to have equalled those obtained from shot peened En 49D springs. The shot peening of the S202 springs was carried out under very closely controlled conditions to a high intensity of 018/022 A2, but even so the springs made from En 49D wire, shot peened to an intensity of 015 A2 had superior properties. It can also be seen that unpeened B.S. 1408D quality springs, revealed a better fatigue resistance than peened S202 springs. This would suggest that some other feature of the material or spring was having an overriding influence on the fatigue properties. Exactly what feature is not known, but an examination of Table VI would suggest perhaps heat treatment after coiling and differences in the patented cold drawn structure.

e) Effect of heat treatment after coiling. Little data are available concerning the effects of low temperature heat treatment on fatigue strength. Opinions vary as to the most suitable treatment temperature necessary to obtain maximum elevation in fatigue resistance but customary practice within the spring industry is to use temperatures in excess of those employed to confer maximum elevation in elastic properties. The work undertaken on S202 material was a follow up to the earlier work on DTD 5B material and was designed to show the effects of peening the aircraft quality wire. Since the original work employed a L.T.H.T. of 200°C (the temperature which conferred maximum elevation in elastic properties) the present investigation on S202 employed a similar treatment temperature. On the other hand springs manufactured from En 49D and B.S. 1408D received a L.T.H.T. of 350°C for $\frac{1}{2}$ h, a temperature known to stabilise the stress temperature relaxation properties of springs, but it is not known, with any certainty, whether such a temperature would improve the fatigue resistance of patented cold drawn carbon steel wires.

To clarify this point it is suggested that an experiment be designed to measure the influence of L.T.H.T. on the resultant fatigue properties of cold drawn wire helical compression springs as well as on straight wires.

f) Effect of tensile strength. Variation in tensile strength is known to affect the fatigue resistance of springs made from patented drawn wire (4); an increase in tensile strength of 309 N/mm^2 (20 tonf/in^2) causing an increase of about 46 N/mm^2 (3 tonf/in^2) in fatigue strength. In the case of the three materials under consideration there is little difference in tensile strength between the qualities therefore this can be ruled out as a possible explanation.

g) Effect of decarburisation. Since all the qualities were completely free from decarburisation this can be dismissed as a possible cause for the differences in fatigue properties.

h) Effect of cleanliness. Metallographic examination of the S202, B.S. 1408D and En 49D materials indicated that they were clean and of similar inclusion content.

i) Effect of structure. S202, B.S. 1408D and En 49D were examined and comparisons made. It is suggested that perhaps differences in the inter-lamellar spacing of the cementite (Fe_3C) plates of the patented structures of the two qualities might be a possible explanation. Examination of the respective metallographic structures would tend to suggest this, but for a reliable confirmation of this observation a study in depth of the two structures would be needed. Such an investigation falls outside the terms of reference of the present contract but nevertheless could form the basis for future work which might help in a more complete understanding of the influence of patented structures on fatigue strength.

6. CONCLUSIONS

1. Springs manufactured from S202 quality wire and shot peened had a lower fatigue strength than springs manufactured from En 49D quality wire also in the shot peened condition.

2. Springs manufactured from S202 quality wire and shot peened had a lower fatigue strength than unpeened springs made from conventional B.S. 1408D range 2 wire quality of similar tensile strength.

3. Springs manufactured from S202 quality wire and shot peened had a greater fatigue strength than cadmium plated springs manufactured from DTD 5B quality wire.

7. RECOMMENDATIONS FOR FUTURE WORK

The unexpected difference in fatigue resistance between peened S202 springs and the remaining qualities has been considered at length in the discussion of this paper. From this it is clear that a number of parameters may affect the fatigue resistance of springs and could well offer a possible explanation why, in this instance, peened springs exhibited a somewhat lower fatigue strength than unpeened springs manufactured from technically similar materials. These various features include:-

1. Prestressing
2. Low temperature heat treatment
3. Patented structure

In view of the findings of this research it is suggested that the above topics could usefully be investigated in an attempt to understand more fully the effects of these manufacturing variables on the fatigue strength of compression springs.

8. REFERENCES

(1) Graves, G. B. and Sanderson, G. K. "The fatigue properties of helical compression springs manufactured from three DTD spring materials". SRA Report No. R50/5-4.

(2) Graves, G. B. "Evaluation of DTD spring materials". SRA Report No. R50/5-2

(3) Graves, G. B. and Horan, M. "The effect of prestressing on the properties of helical compression springs manufactured from three DTD spring steel wires". SRA Report No. R50/5-5

(4) Mee, J. W. "The fatigue properties of springs made from patented cold drawn wire to B.S. 1408C and 1408D in three ranges of tensile strength. SRA Report No. 164

(5) Horger, O. J. "Fatigue" A.S.M. 1953.

(6) Morkoim, D. and Moore, H. F. Proc. A.S.T.M., Vol. 44 p. 137.

(7) Graves, G. B. and Heap, J. M. A. "An evaluation of the relationships between the mechanical tests conducted on spring steel wires manufactured to B.S. specifications. SRA Report No. 172

(8) Mee, J. W. and Graves, G. B. "A comparison of the static mechanical and fatigue properties of three spring steel wire". SRA Report No. 148

TABLE I CHEMICAL COMPOSITION OF S202 QUALITY WIRE

Nominal Wire Dia	%C	%Si	%Mn	%S	%P	%Cr	%Ni
4 mm (0.160 in)	0.74	0.15	0.49	0.011	0.016	0.03	0.01

TABLE II SPRING DESIGN DATA

	METRIC	IMPERIAL
Wire Diameter	4.0 mm	0.16 in
Spring Mean Diameter	28.98 mm	1.141 in
No. of Active Coils	3.5	3.5
Total No. of Coils	5.5	5.5
Spring Index	7	7
Free Length After Grinding and Prestressing	50 mm	1.97 in
Solid Stress After Grinding and Prestressing	1260 N/mm^2	81.6 $tonf/in^2$

TABLE III FATIGUE DATA FOR SHOT PEENED SPRINGS MADE FROM S202 4 mm (0.160 in) DIAMETER WIRE

TENSILE STRENGTH AFTER L.T.H.T. 200°C-½h	FATIGUE STRENGTH N/mm² (tonf/in²) AT AN INITIAL STRESS OF:-		
N/mm² (tonf/in²)	CYCLES	100 N/mm² (6.47 tonf/in²)	500 N/mm² (32.4 tonf/in²)
1544 (100.0) to 1637 (106.0)	10^5	980 (63.5)	
	10^6	840 (54.4)	1000 (64.8)
	10^7	690 (44.7)	1000 (64.8)

TABLE IV FATIGUE DATA FOR CADMIUM PLATED SPRINGS MADE FROM DTD 5B 4mm (0.160 in) DIAMETER WIRE

TENSILE STRENGTH	FATIGUE STRENGTH at 10^7 CYCLES N/mm² (tonf/in²) AT AN INITIAL STRESS OF:-		
N/mm² (tonf/in²)	77 N/mm² (5 tonf/in²)	154 N/mm² (10 tonf/in²)	309 N/mm² (20 tonf/in²)
1652 (107.0)	618 (40.0)	627 (40.6)	757 (49.0)

TABLE V FATIGUE DATA FOR UNPEENED SPRINGS MADE FROM B.S. 1408D 2.64 mm (0.104 in) DIAMETER WIRE

RANGE	TENSILE STRENGTH N/mm^2 (tonf/in^2)	FATIGUE STRENGTH IN N/mm^2 (tonf/in^2) AT 10^7 CYCLES AT AN INTIAL STRESS OF:-		
		77 N/mm^2 (5 tonf/in^2)	154 N/mm^2 (10 tonf/in^2)	309 N/mm^2 (20 tonf/in^2)
1	1467 (95.0)	733 (47.5)	772 (50.0)	896 (58.0)
2	1544 (100.0)	741 (48.0)	818 (53.0)	942 (61.0)
3	1791 (116.0)	752 (48.7)	818 (53.0)	911 (59.0)

TABLE VI FATIGUE DATA FOR SPRINGS MADE FROM EN 49D 3.25 mm (0.128 in) DIAMETER WIRE(8)

TENSILE STRENGTH N/mm^2 (tonf/in^2)	SURFACE CONDITION	FATIGUE STRENGTH IN N/mm^2 (tonf/in^2) AT 10^7 CYCLES AT AN INITIAL STRESS OF:-		
		77 N/mm^2 (5 tonf/in^2)	154 N/mm^2 (10 tonf/in^2)	309 N/mm^2 (20 tonf/in^2)
1558 (100.9)	Shot Peened	896 (58.0)	926 (60.0)	973 (63.0)
1578 (102.2)	Unpeened	664 (43.0)	695 (45.0)	803 (52.0)

TABLE VII

COMPARISON OF SPRINGS

	QUALITY			
	S202	En 49D RII	BS 1408 RII	DTD 5B
WIRE DIAMETER	4 mm	3.25 mm	2.64 mm	4 mm
SOLID STRESS	1270 N/mm^2	1081 N/mm^2	1080 N/mm^2	1450 N/mm^2
SURFACE CONDITION	Shot Peened	Shot Peened	Unpeened	Cd. Plated
L.T.H.1.	200°C - ½h then 220°C - ½h	350°C - ½h then 220°C - ½h	350°C - ½h	200°C - ½h then 200°C -18h
SUPPLIER	Bruntons Ltd.	Bruntons Ltd.	Bruntons Ltd.	Bruntons Ltd.
TENSILE STRENGTH	1544-1637 N/mm^2	-	1540 N/mm^2	1652 N/mm^2
DECARBURISATION	Nil	Nil	Nil	Nil
CLEANLINESS	Similar	Similar	Similar	-
STRUCTURE	Pearlite coarser than 1408D	Similar to 1408D	Fine Pearlite	-

TABLE VIII COMPARISON OF ANALYSES

Quality	Composition %:-				
	C	Si	Mn	S	P
S202	0.74	0.15	0.49	0.011	0.016
B.S. 1408D	0.69	0.22	0.55	0.012	0.024
D.T.D. 5B	0.73	0.19	0.57	0.012	0.018
En 49D	0.74	0.20	0.57	0.020	0.030

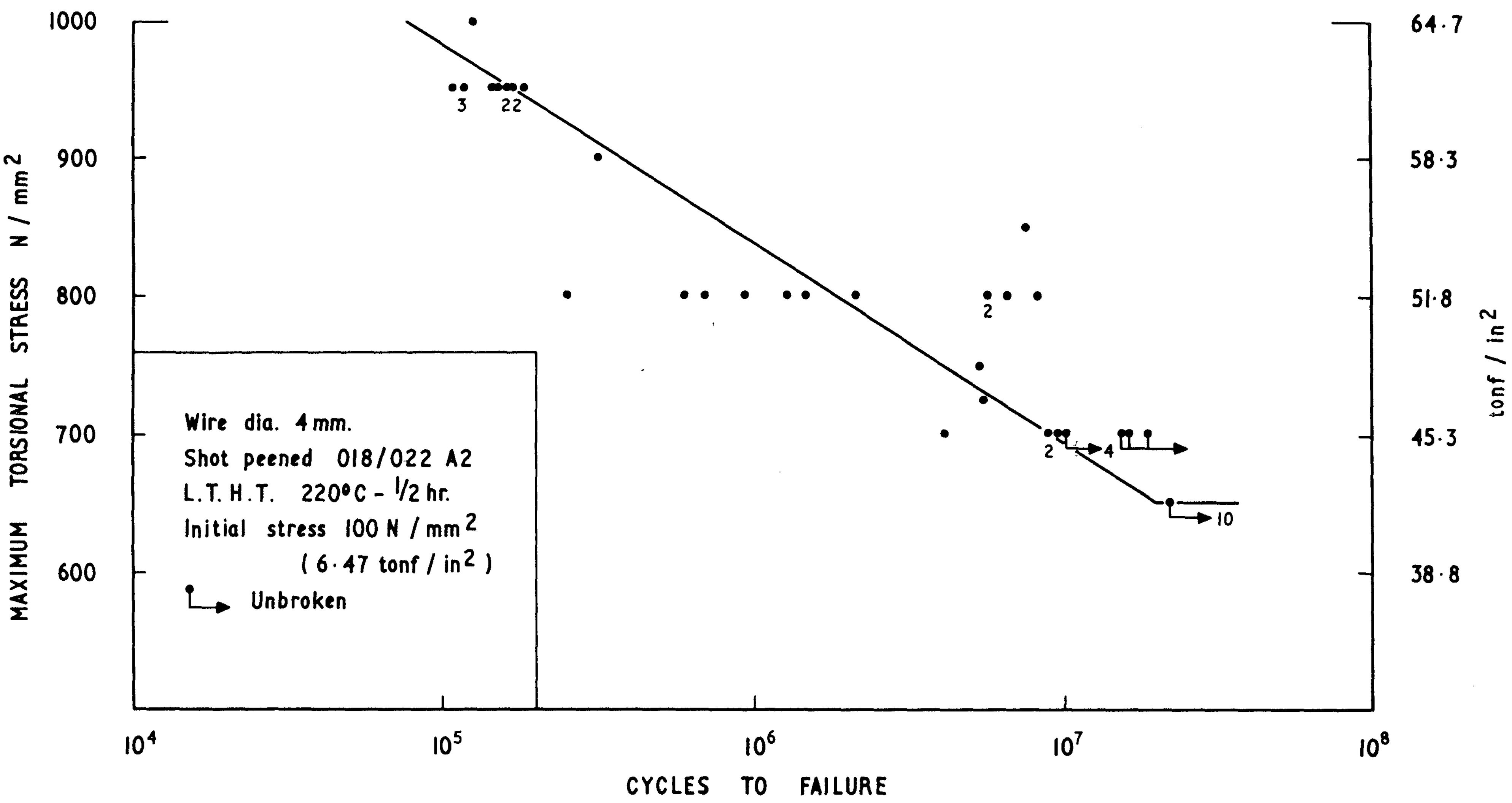

FIG. I. S/N CURVE FOR S 202 SHOT PEENED SPRINGS

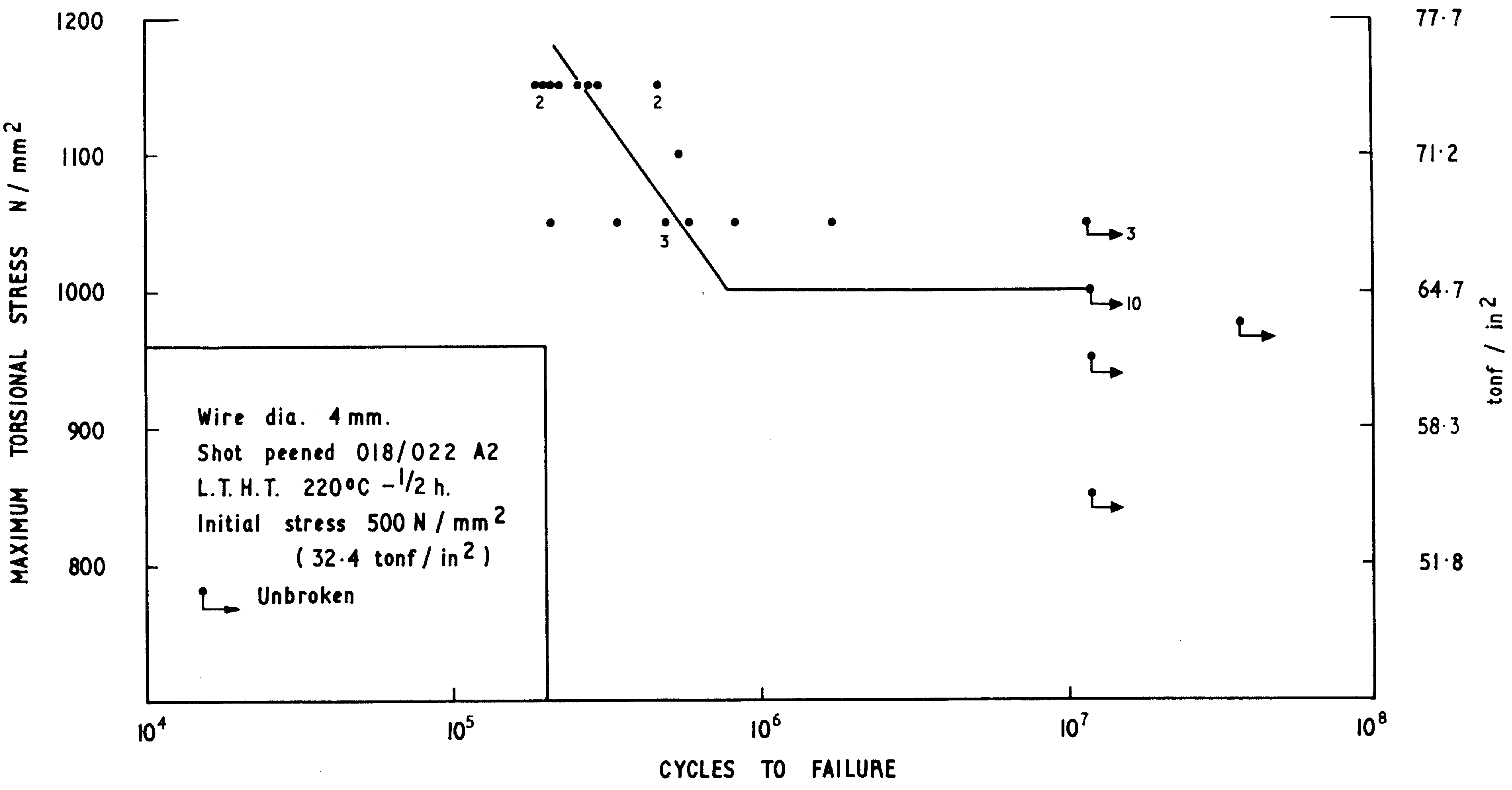

FIG. 2. S/N CURVE FOR S 202 SHOT PEENED SPRINGS

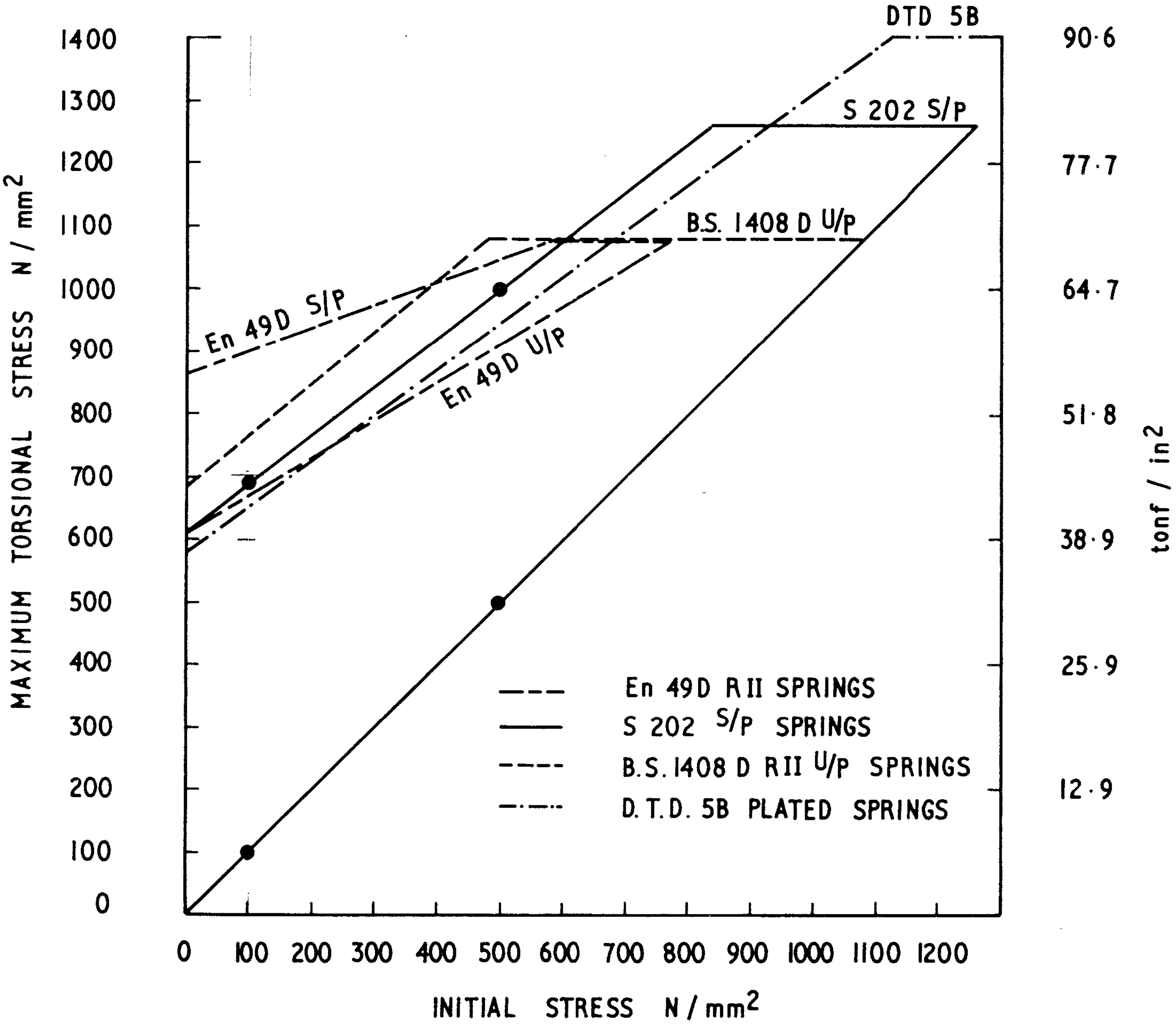

FIG. 3. MODIFIED GOODMAN DIAGRAMS FOR 10^7 CYCLES