THE SPRING RESEARCH AND MANUFACTURERS ASSOCIATION

FATIGUE DATA FOR TORSION SPRINGS

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SUMMARY

This report gives, for the first time, reliable and clearly defined fatigue test data for torsion springs. Goodman diagrams for torsion springs that operate without any interaction with a mandrel have been drawn up and the effects of mandrel/spring interactions on the reduction of spring fatigue life have been quantified. The data is applicable to hard drawn carbon steel wire springs.

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FATIGUE DATA FOR TORSION SPRINGS

1. INTRODUCTION

Reliable and clearly defined fatigue data for torsion springs are not available. A recent SRAMA report indicated that such data could be obtained using two methods, which together would generate complementary data (1).

The first method involved the testing of double torsion springs on SRAMA's 8 station machine in order that no spring/mandrel interaction were affecting the fatigue results. However, the previously identified test method needed to be modified to avoid problems of friction between the test machine and the central leg portion of the double torsion spring. Details of this modification are included in this report.

The second method involved the testing of single torsion springs on SRAMA's clock spring machine. The purpose of this testing was to quantify the effects of various mandrel materials on the fatigue life of a batch of single torsion springs.

2. MATERIALS AND SPRING DESIGNS

The spring designs have been fully described in a previous SRAMA report (1). Single torsion springs were made from 1.42 mm diameter pre-galvanized BS 1408 CR3 wire, whilst the double torsion springs were coiled from 2 mm diameter BS 5216 ND3 material.

Tensile tests on the wire gave the following results:

Material	Condition	Tensile Strength N/mm^2	Specified TS N/mm^2
1.42 mm BS 1408 CR3	As drawn	1970	1860-2020
2 mm BS 5216 ND3	As drawn	2020	1770-1970
2 mm BS 5216 ND3	Stress relieved 250°C	1990	1770-1970

The materials were therefore of equivalent tensile strength . However, the tensile strength of the ND3 wire was slightly higher than that permitted in the specification.

3. FATIGUE TESTING

All springs were fatigue tested in the "wind up" direction, to take advantage of any beneficial residual stresses arising from the coiling operation.

3.1 Double Torsion Springs

3.1.1 Method

The springs were fatigue tested both in the "as coiled" condition and after stress relieving at 250°C for 30 minutes, since torsion springs are generally stress relieved to stabilise their relative leg positions. An eight station valve spring machine was used for the fatigue tests, estimates of the precision suggesting that the individual stations could be set to a stress value ± 20 N/mm^2.

During the previous exploratory work, loads were applied to the central legs of the springs via hardened steel plattens which were polished and grease lubricated.

However, detailed load tests showed that friction between the spring and the platten gave stress variations of ± 65 N/mm² for the "as coiled" springs and ± 40 N/mm² for the stress relieved springs. The loading jigs were therefore modified and individually identified to load the central legs via a roller bearing system. This reduced the stress variations to ± 40 N/mm² for the as coiled springs and ± 20 N/mm² for the stress relieved springs, which were considered acceptable for the present work.

The load corresponding to a particular stress level was calculated from the relationship:

$$P = \text{Stress}\,\frac{\pi d^3}{32L} \times 2 = \frac{\text{Stress}}{22.43}$$

where P = Load, N, applied to 2 handed torsion spring

Stress = Bending stress, N/mm²

L = Effective length of central leg (35.5 mm)

d = Wire diameter (2.005 mm)

All springs were individually load tested on complete jigs prior to fatigue testing at 17 Hz from initial stresses of 150 N/mm² and 450 N/mm². Springs could not be tested faster than 17 Hz because the roller bearing system would not tolerate a higher speed. Testing was discontinued for springs unbroken at 2×10^6 cycles.

3.1.2 Results

Fatigue data thus obtained for the as coiled springs are presented in Figures 1 and 2, whilst Figures 3 and 4 give the fatigue results for springs stress relieved at 250°C. It is clear that a significant number of springs remained unbroken at 10^6 cycles. The Goodman diagram derived from the fatigue data is shown as Figure 5.

The broken springs failed at the region of maximum bending moment on the first active coil associated with a moving leg. The lognormal data for the springs which broke before 2×10^5 cycles were analysed using linear regression techniques to give a conservative estimate of the fatigue performance.

All the data were also examined by Weibull analysis using a computer program developed to simplify the calculations.

Weibull analysis of the data gave results which were very similar to the lognormal analysis. However, the Weibull results were generally 25000 cycles higher than the lognormal data at a maximum stress of 1600 N/mm^2.

For the present work, therefore, the lognormal results were adopted as being more likely to give conservative designs for torsion springs with expected lives of less than 10^5 cycles.

The endurance limit at 10^6 cycles was estimated as the stress at which no spring failures were recorded after operation at 10^6 cycles.

3.1.3 Conclusions

1. S/N curves and Goodman diagrams have been generated for torsion springs operating without a mandrel.

2. The work confirmed that stress relieving reduces the fatigue performance of torsion springs.

3.2 Single Torsion Springs

3.2.1 Method

The previous work established that single torsion springs could be successfully fatigue tested at 0.3 Hz on the SRAMA clock spring tester using a carbon steel mandrel hardened to 600 Hv. However, consistent results were obtained only when lubrication was used to reduce friction between the springs and the mandrel.

Although continuous oil-drip lubrication was used to circumvent these problems in the previous work, such a technique would not be practical for most service conditions.

The work on single torsion springs was therefore extended to identify practical combinations of mandrel material and lubrication which might be usefully employed in torsion spring assemblies.

After discussion with spring engineers, the following combinations of mandrel and lubricant were selected for examination:

1. Unlubricated mild steel
2. Mild steel sleeved with 1 mm thick PTFE
3. Mild steel and grease
4. Hardened steel and grease
5. Hardened steel and oil drip

Based on the results of previous work, fatigue tests were carried out from an initial stress of 200 N/mm^2 to a maximum stress of 1600 N/mm^2, a total of

12 springs being tested for each mandrel/lubricant combination.

3.2.2 Results

The full results are presented in Table I and are illustrated graphically in Figure 6.

3.2.3 Conclusion

Operation over a stress range of 1400 N/mm² (70% Rm) on a mandrel reduced the fatigue life of as coiled torsion springs to give the following values:

Mandrel

Unlubricated steel:	13% of "no mandrel" life
PTFE/lubricated steel:	20-40% of "no mandrel" life

4. DISCUSSION

4.1 Double Torsion Springs

The data presented in Figures 1 - 5 for double torsion springs without a mandrel effectively provide a measure of fatigue performance in bending for the spring material. Using the Goodman diagram shown as Figure 5, the fatigue strength at zero initial stress, expressed as % of tensile strength (Rm), was estimated as follows:

	Estimated Fatigue Strength at Zero Initial Stress, % Rm			
	SRAMA data			
Cycles to Failure	Present work without mandrel data obtained from double torsion springs	With mandrel & oil lubrication 50% Mean data (Ref 1)	Published data (Ref 2)	Published data (Ref 3)
5 x 104	74*+		-	44
105	72* 68+	65* 61+	53	40
106	72* 68+		50	35

* As coiled springs

\+ Stress relieved 250°C

The SRAMA data are essentially conservative estimates of fatigue life, since a significant number of springs survived unbroken at 10^6 cycles. Probit analysis will be required to establish the fatigue performance at 10^5 and 10^6 cycles with known levels of confidence.

For the double torsion springs, stress relieving at 250°C appeared to have little effect upon the limited life performance at 5×10^4 cycles, but tended to reduce the maximum stress for 10^5 and 10^6 cycles from 72% Rm "as coiled" to 68% Rm.

4.2 Single Torsion Springs

Similarly, for single torsion springs operating on a lubricated steel mandrel, stress relieving reduced the fatigue strength at zero initial stress from 65% Rm "as coiled" to 62% Rm.

More detailed examination suggested the following results for single torsion springs operating on mandrels at short lives and high stresses.

Mandrel configuration	Estimated mean fatigue life for stress range of 1400 N/mm^2	
	Cycles failure	% of "no mandrel"
No mandrel (double torsion spring data)	80000	100
Mild steel mandrel	10000	13
PTFE	18000	23
Mild steel and grease	33000	41
Hardened steel and grease	31000	39
Hardened steel and oil	27000	34

These data confirm that operation on a mandrel significantly reduced the fatigue performance of highly stressed torsion springs. Examination of the springs during testing indicated that rotation of the spring coils was restrained by the unlubricated mild steel mandrel, suggesting that hysteresis of the spring/mandrel combination may repay investigation in the future.

The work suggests that highly stressed torsion springs operating on a mild steel mandrel without lubrication will be likely to give approximately 13% of the limited life estimated for springs operating without a mandrel.

The fatigue performance on a mandrel was consistently improved by using appropriate lubricants such as grease and oil or by using a PTFE sleeved mandrel. However, the PTFE showed signs of severe wear after 10^4 cycles of operation.

When considered in their entirety, the SRAMA work suggests that the published design data for torsion springs is essentially satisfactory for springs operating up to 10^5 cycles either without a mandrel or with an adequately lubricated mandrel. However, from the results of the present work, the published data are optimistic for torsion springs operating on unlubricated mandrels.

Stress relieving consistently reduced the maximum stress for fatigue performance of torsion springs at $10^5/10^6$ cycles by approximately 5% due to the reduction in residual compressive stress caused by low temperature heat treatment. The work confirmed that stress relieving stabilized the torsion springs, reducing the variability in measured loads to approximately 50% of that for the "as coiled" springs (5). Stress relieving should therefore be specified to obtain consistent load/deflection characteristics for torsion springs, but the maximum design stress for stress relieved springs should be reduced by 100 N/mm² to allow for a slight reduction in fatigue performance at lives over 10^5 cycles.

4.3 Note On Applying Torsion Spring Data To Extension Spring

It has been suggested that extension spring end hooks, which operate in bending, can be designed using fatigue data generated for torsion springs (3). However, torsion springs should always operate in the "wind up" direction to take advantage of any "as coiled" residual compressive stresses. By contrast, end hooks are stressed in the "wind down" direction and the residual tensile stresses due to forming act to reduce the fatigue life (4).

Therefore, fatigue data for torsion springs should not be used to design end hooks for extension springs.

5. RECOMMENDATIONS

1. The data provided here will enable spring designers to estimate torsion spring fatigue life, but any new design will be sensitive to the particular service conditions of that application, and so confirmatory fatigue tests should be carried out to ensure that the estimate was satisfactory. The confirmatory fatigue test should be run under identical conditions with respect to spring/mandrel interaction and spring loading that will be seen in service.

2. Stress relieving reduces the maximum stress for fatigue at $10^5/10^6$ cycles. Probit analysis will be required to establish more precisely the effect of stress relieving treatment upon fatigue performance of torsion springs at the fatigue limit.

3. The influence of shot peening or the fatigue life of torsion springs should be investigated. Shot peening may be particularly relevant for highly stressed torsion springs with open coils operating on a mandrel.

4. Investigation may be required to establish the effects of hysteresis upon fatigue performance of single torsion springs operating on mandrels.

6. REFERENCES

1. Reynolds, L F, "Fatigue Testing of Torsion Springs", SRAMA Report 408, August 1987.
2. Design Handbook, Barnes Group Inc (Associated Spring), 1970 and 1987.
3. Carlson, H, "Spring Designer's Handbook", Pub Marcel Dekker, 1978. Sole UK Agents: SRAMA.
4. M O'Malley, M, "Fatigue of Extension Springs". SRAMA Report No 423, May 1988
5. O'Malley, M, "The Effect of Low Temperature Heat Treatment on the Wind up/down and Elastic Limit of Torsion and Extension Springs". SRAMA Report 396, April 1986.

TABLE I RESULTS OF FATIGUE TESTS FOR SINGLE TORSION SPRINGS TESTED ON MANDRELS.

Life at 200 - 1600 N/mm^2 on mandrels shown				
Mild Steel Without Lubrication	PTFE	Mild Steel And Grease	Hardened Steel And Grease	Hardened Steel And Oil
7423	10839	21092	9974	16780
8710	14040	22370	17310	18341
8710	14586	22709	19869	19876
9322	14591	22917	25211	22378
9816	15990	24501	27525	23744
10454	18448	25750	32161	29010
10750	20296	26174	36238	29473
12127	20328	26363	40505	31929
12127	23864	39804	42842	34759
12789	24108	41416	71379	38468
13181	24427	82013	83115	49548
	28880	126989	132573 U/B	

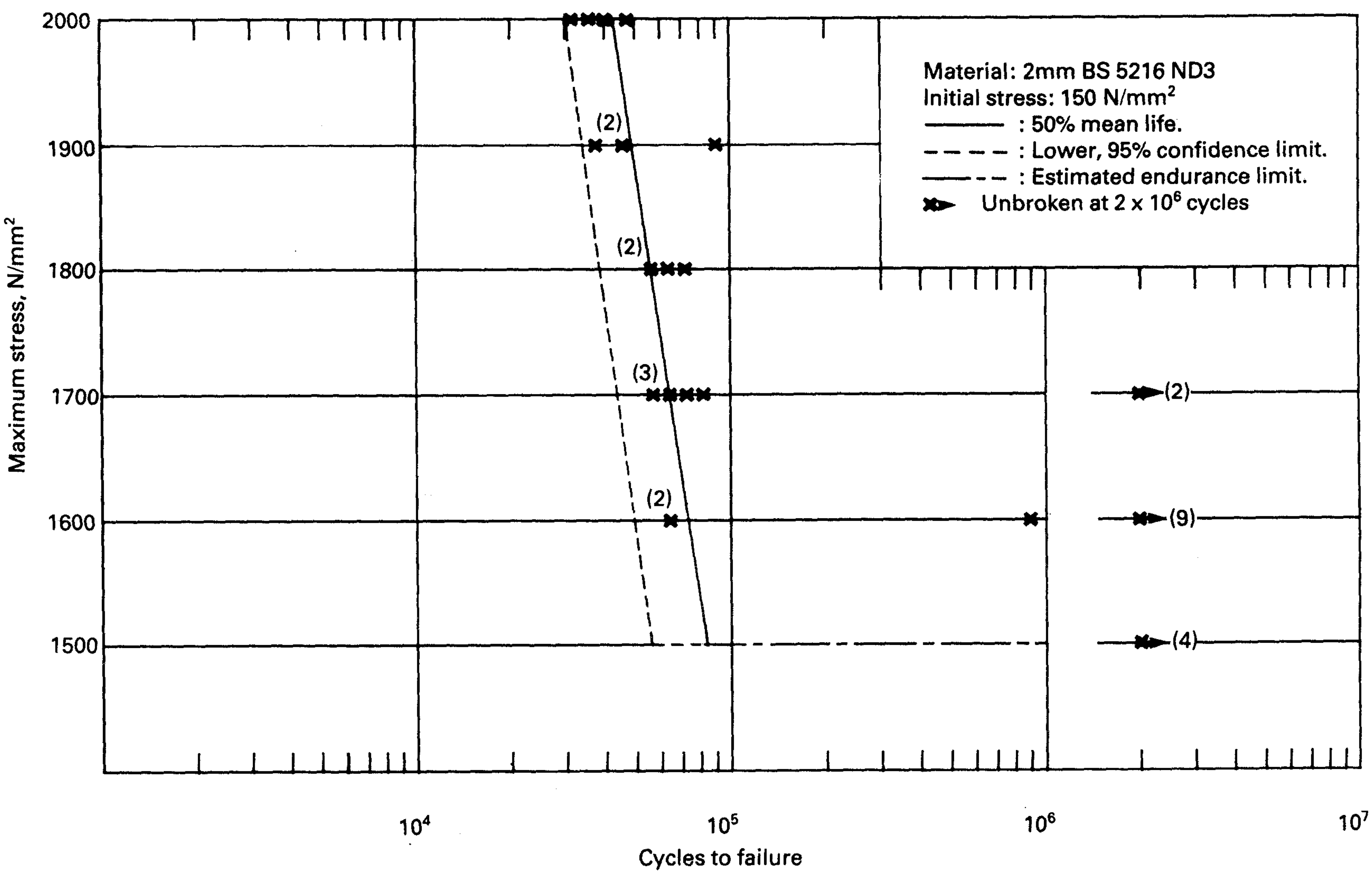

Fig 1 FATIGUE CURVE FOR 'AS COILED' DOUBLE TORSION SPRINGS

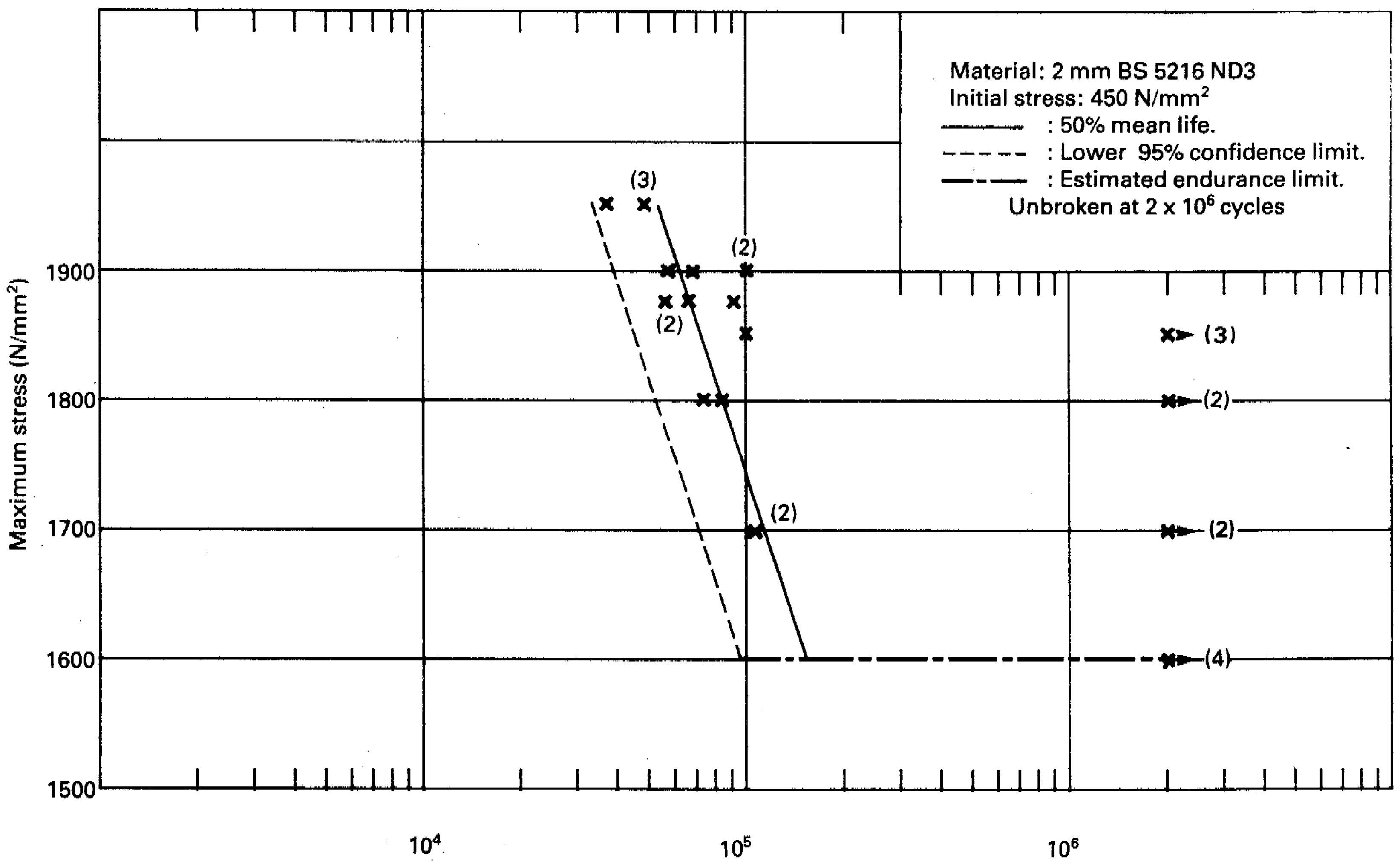

Fig 2: FATIGUE CURVE FOR 'AS COILED' DOUBLE TORSION SPRINGS

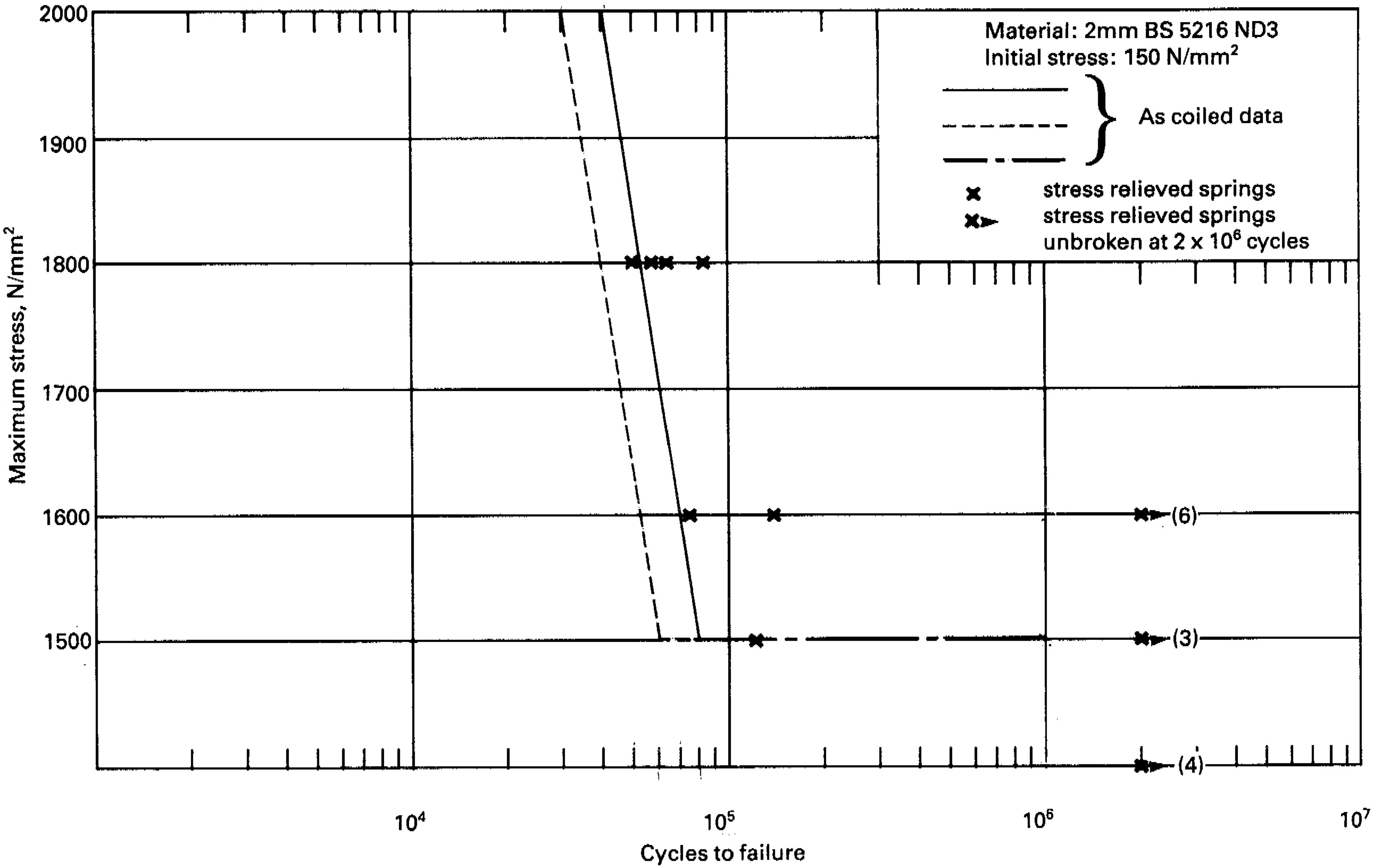

Fig 3: FATIGUE DATA FOR DOUBLE TORSION SPRINGS STRESS RELIEVED AT 250°C FOR 30 MINUTES

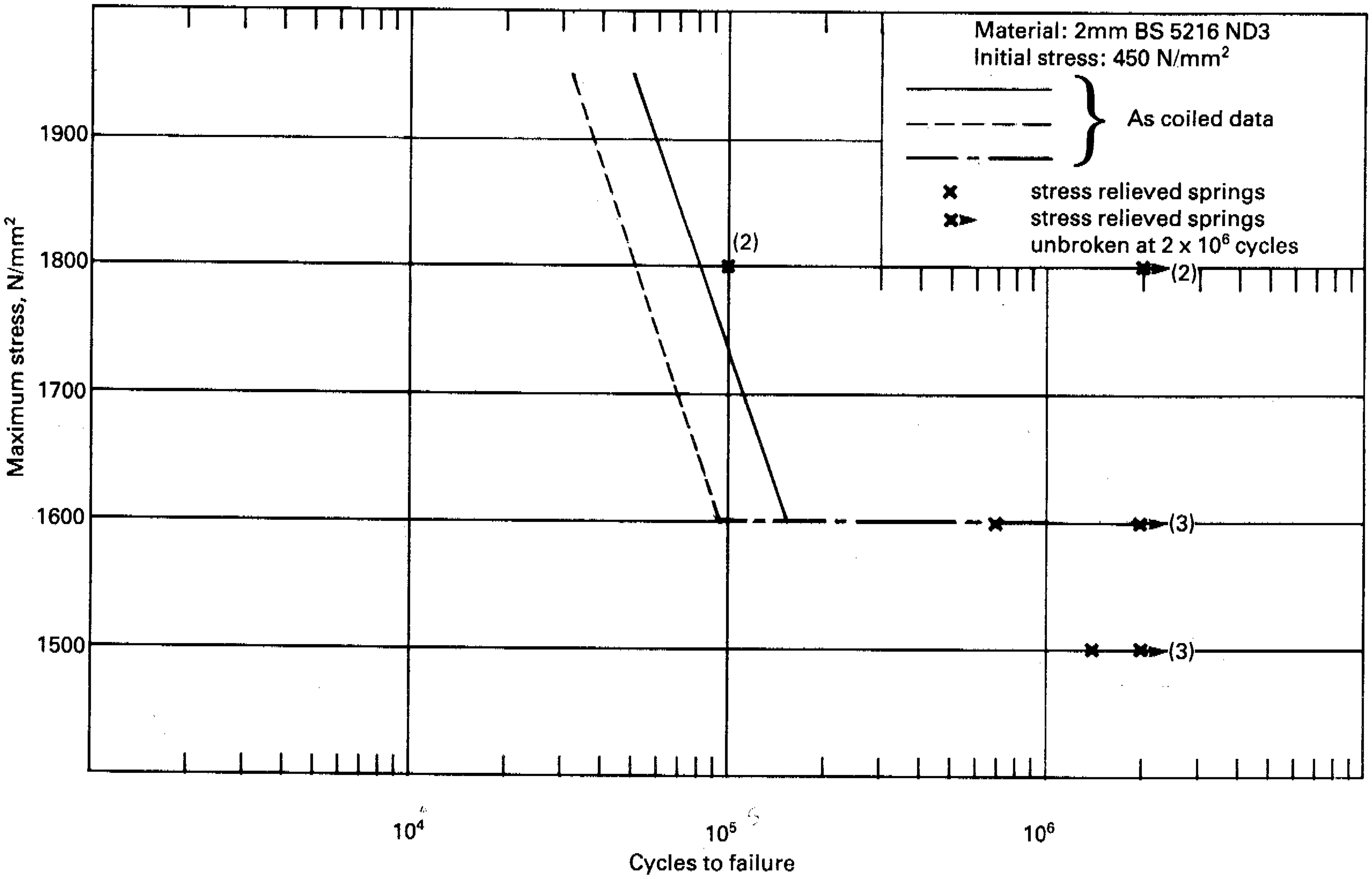

Fig 4: FATIGUE DATA FOR DOUBLE TORSION SPRINGS STRESS RELIEVED AT 250°C FOR 30 MINUTES

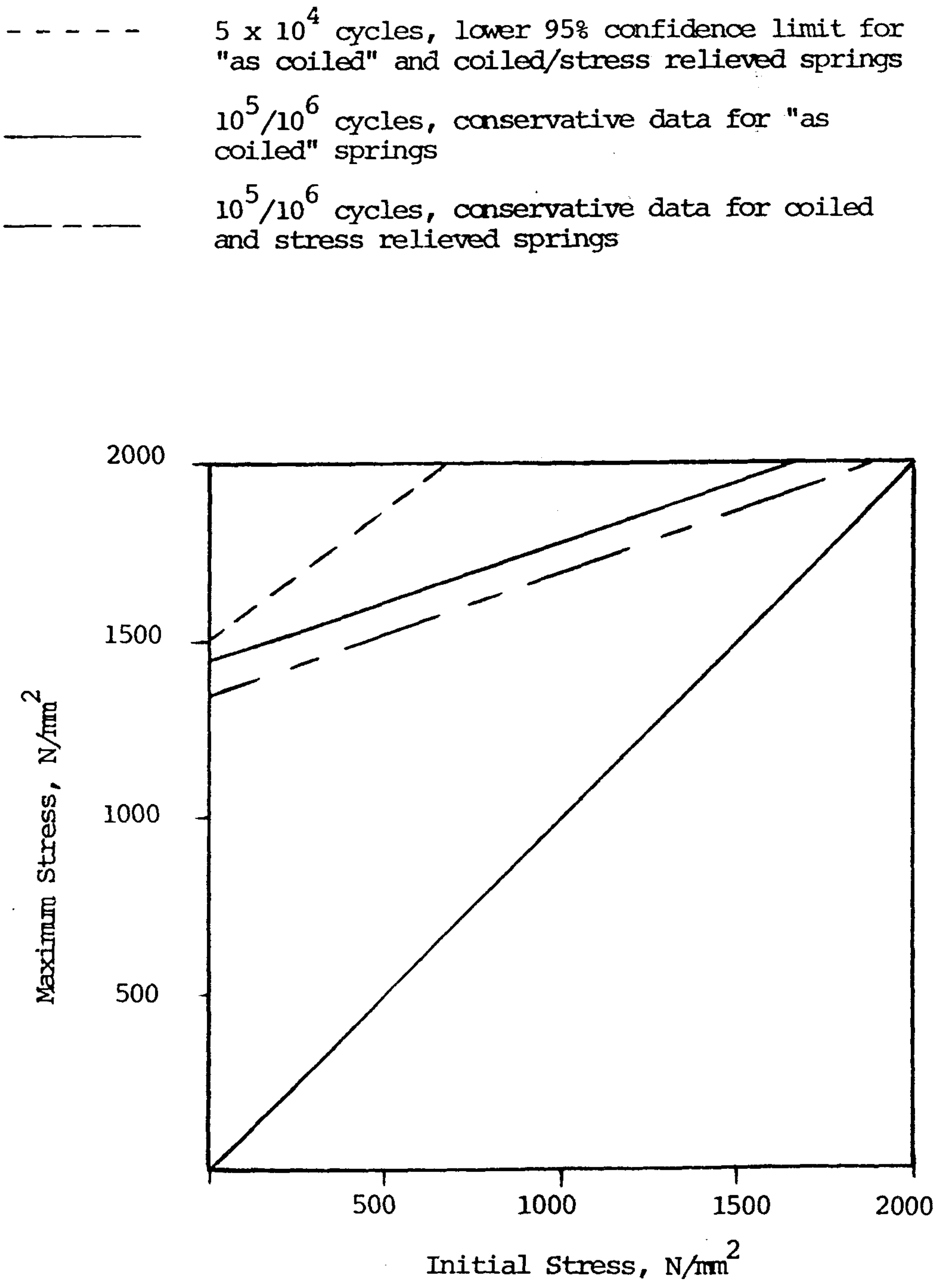

Fig 5 GOODMAN DIAGRAM FOR DOUBLE TORSION SPRINGS MADE FROM 2 MM BS 5216 ND3 WIRE

(Tensile strength: 2000 N/mm^2)

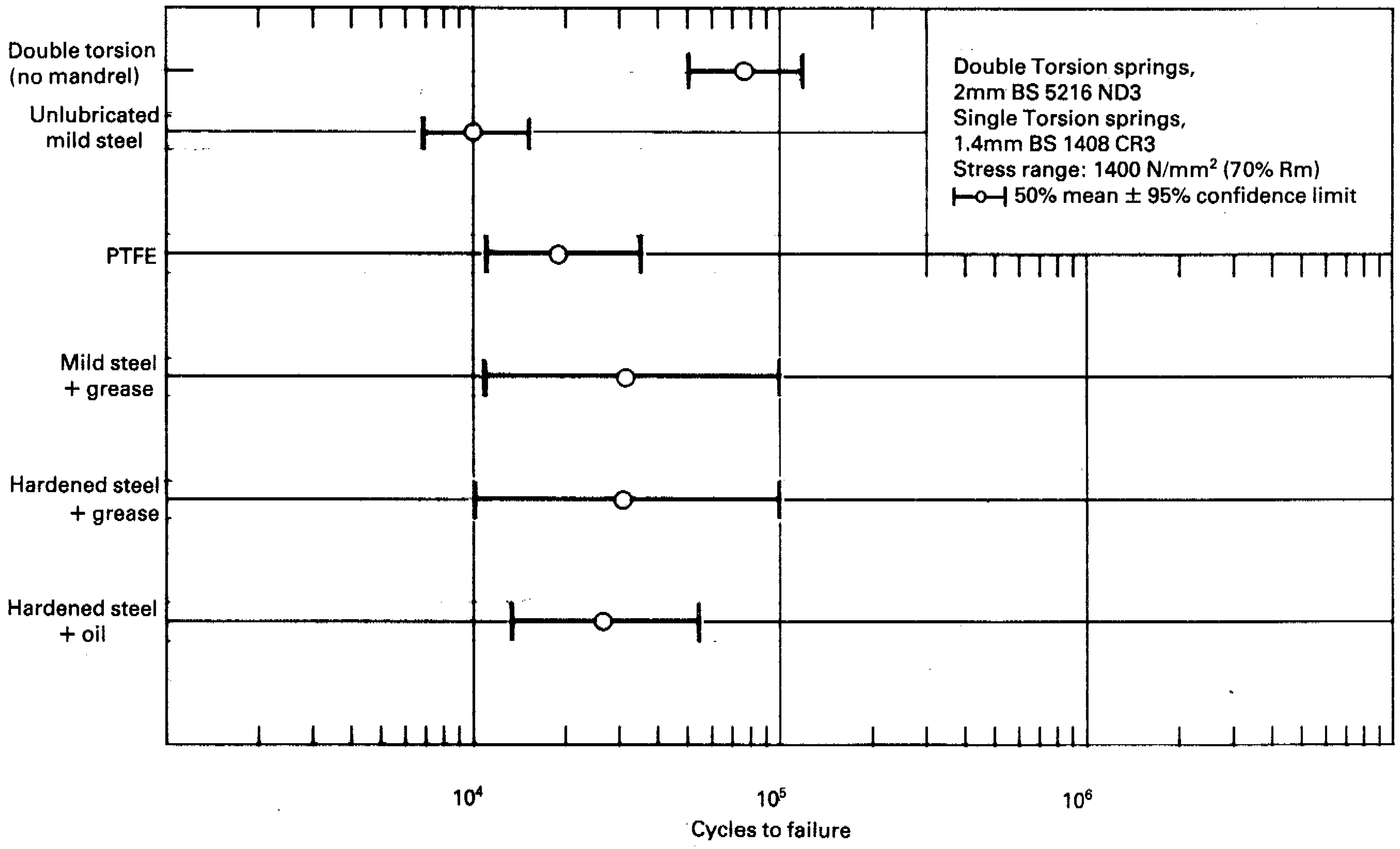

Fig 6: EFFECT OF MANDREL ON FATIGUE PERFORMANCE OF SINGLE TORSION SPRINGS MADE FROM HARD DRAWN CARBON STEEL WIRE