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FATIGUE TESTING OF TORSION SPRINGS

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by

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Research Summary

This report gives details of preliminary research test techniques which might be used to generate consistent and meaningful design data for carbon steel torsion springs working in dynamic applications.

Single torsion springs gave consistent fatigue results when tested on a hardened steel mandrel with continuous oil dip lubrication. By contrast, fatigue testing without lubrication on a soft steel mandrel gave inconsistent data with early spring failures. Fatigue tests on double torsion springs, without a mandrel, gave results consistent with those obtained for single torsion springs tested with lubrication on a hardened steel mandrel.

These preliminary findings suggest that the mandrel material and lubrication play an important part in fatigue of single torsion springs. However, design data can be produced after this effect has been surmounted.

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4. Fatigue results for "as-coiled" torsion springs. Initial stress: 200 N/mm^2

5. Fatigue results for torsion springs stress relieved at 250^{o}C for 30 minutes. Initial stress: 200 N/mm^2

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7. Goodman diagram for stress relieved torsion springs

FATIGUE TESTING OF TORSION SPRINGS

1. INTRODUCTION

Several sources of information are available for the design of torsion springs, but specific fatigue information is very limited, being restricted essentially to one Goodman diagram in DIN 2088 and a limited amount of general data published by Carlson.[1,2] The lack of fatigue data can leave spring designers in some difficulty when torsion springs must be designed for fatigue applications.

A high proportion of torsion springs operate on a mandrel during service, often with minimal or non-existent lubrication which will lead to wear and friction. Faced with this situation, designers may be forced to treat each spring/mandrel combination individually, with little guidance from the available fatigue data regarding the likely effects of mandrel material, hardness, and lubrication conditions.

To some extent, these complex operating conditions have discouraged attempts to generate meaningful design data for fatigue of torsion springs.

However, "nothing ventured, nothing gained" and, in an attempt to rectify this situation, a programme of exploratory work was undertaken at SRAMA to assess the feasibility of producing reliable fatigue data for torsion springs. The need for such data has been demonstrated by frequent requests from SRAMA's members.

2. MATERIALS AND SPRING DESIGN

Single torsion springs were manufactured from 1.42 mm diameter pre-galvanised BS 1408 CR3 wire to the following spring design:

Wire Diameter	= 1.42 mm
Outside Coil Diameter	= 16.3 mm
Leg Length	= 25 mm
Total Coils	= 15.2

Double torsion springs were made from 2 mm diameter BS 5216 ND2 wire to the design shown as Fig 1.

All the springs were made commercially by SRAMA member firms.

3. FATIGUE TESTING TECHNIQUES

For this exploratory investigation, most of the fatigue tests were carried out using unpeened single torsion springs working on a carbon steel mandrel of 11.1 mm diameter.

Fatigue testing of unpeened double torsion springs was confined to examining the proprietry of the technique by general comparison of the results at one stress level with those produced for single torsion springs.

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

3.1 Single Torsion Springs

Nominal stresses were calculated using the SRAMA CAD program for torsion springs.

Springs were fatigue tested at 0.3 Hz using the SRAMA clock spring tester, which incorporates an automatic cut-out to detect individual spring failures.

Initial trials quickly revealed that springs tested without lubrication on a soft steel mandrel showed excessive wear of both the springs and the mandrel. The data thus produced showed no consistency and exhibited unacceptably high scatter.

Wear between springs and mandrel was reduced by using a carbon tool steel mandrel, without lubrication, hardened to 600 Hv.

However, there was little improvement in the scatter of fatigue data, springs operating over a stress range of 1060 N/mm^2 typically showing some failures at 13000 cycles with unbroken run-outs at 160,000 cycles.

Detailed examination of the springs during fatigue testing indicated that the scatter in results was probably associated with friction between springs and mandrel. This friction effectively caused the number of active coils to vary from spring to spring, resulting in a wide variation of the real stresses in the spring during operation.

Further work showed that the generation of reliable (ie reproducible) data required the springs to be tested on a hardened steel mandrel with oil drip lubrication, as shown in Fig 2.

Fatigue tests were thus carried out on springs in the "as coiled" condition and after stress relieving at 250°C for 30 minutes, this temperature being representative of that often used for stress relieved torsion springs.[3] The "as coiled" springs were tested at an initial stress of 200 N/mm^2, whilst the stress relieved springs were tested at initial stresses of 50 N/mm^2 and 200 N/mm^2.

3.2 Double Torsion Springs

Suitable jigs were designed and built to allow fatigue testing of springs on an eight station valve spring machine operating at 25 Hz, as shown in Fig 3. The central legs of the springs were loaded via hardened steel flat platens which were polished to a 6 micron diamond finish, and were grease lubricated to reduce wear of the spring material as the central legs moved across the platens. The tests were carried out predominantly on "as coiled" springs, although a small number of springs were tested after stress relieving at 250° for thirty minutes.

The relationship between linear deflection and stress for the springs was determined via load/deflection tests on the 2 KN SRAMA load tester.

The loaded deflection, in mm, was related to stress by the expression:-

$$\text{Loaded Deflection (mm)} = 0.1479 + (9.7878 + 10^{-3} \times \text{stress}) + (5.607 \times 10^{-6} \times \text{stress}^2) - (1.877 \times 10^{-9} \times \text{stress}^3)$$

The double torsion springs could thus be readily set up for fatigue testing by appropriate adjustment of both the initial deflection and the stroke. These exploratory fatigue tests were carried out at an initial stress of 200 N/mm^2 with a maximum stress of 1700 N/mm^2.

4. RESULTS

The results of the tests are presented in Tables I-IV.

All the broken springs failed at the region of maximum bending moment on the first active coil associated with the moving leg.

The fatigue results for "as coiled" torsion springs are shown plotted in Fig 4.

The summarized results for the stress relieved springs are shown in Figs 5 and 6.

A Goodman diagram for 10^5 cycles was produced for the stress relieved single torsion springs, and this is shown as Fig 7.

5. DISCUSSION

The results plotted shown in Figs 4-6 indicate that consistent fatigue data can be generated for both single and double torsion springs, once the effects of spring/mandrel friction have been reduced or eliminated. In effect, the basic fatigue properties of torsion springs can be successfully characterized for spring materials.

However, an important finding of the work was that, for single torsion springs, meaningful fatigue data could only be generated consistently when the springs were tested with oil lubrication on a hardened steel mandrel. The influence of lubrication and the mandrel material/hardness thus requires more detailed investigation. As can be seen from Figs 4 and 5, a further interesting finding of the work was that, for both single and double torsion springs, stress relieving at 250°C apparently reduced the fatigue life slightly when compared with that observed for "as coiled" springs. This finding merits further investigation, since stress relieving may be desirable to stabilize the leg positions during storage and to give a more consistent torque during deflection.[3]

Finally, the Goodman Diagram shown as Fig 7 for BS 1408 CR3 springs suggests a 50% mean fatigue strength at 10^5 cycles of 1200 N/mm^2 for zero initial stress, which represents approximately 65% of the tensile strength. These data compare favourably with a stress range of 1100 N/mm^2 suggested by Carlson for the equivalent ASTM A227 MB torsion springs.[2]

6. <u>CONCLUSIONS</u>

1. It is possible to generate design data for torsion springs made from carbon steel in the absence of significant friction/wear between spring and mandrel.

2. Fatigue data and confidence limits can be generated for carbon steel using single torsion springs which operate with lubrication on a hardened steel mandrel. Alternatively, double torsion springs can be employed without a mandrel, thus eliminating spring/mandrel effects.

3. The mandrel material, hardness and lubrication condition are critical factors affecting the fatigue performance of single torsion springs made from carbon steel.

4. This exploratory investigation suggests that stress relieving at 250°C may reduce the fatigue life of torsion springs made from carbon steel wire.

5. The data generated from this work are in good agreement with the available published data for limited life operation of torsion springs made from a similar grade and size of hard drawn steel wire.

7. RECOMMENDATIONS

Basic design data for fatigue of torsion springs made from appropriate materials can now be generated using the techniques established by this preliminary work.

The influence of spring design, mandrel/material hardness and lubrication conditions on fatigue of single torsion springs warrants further examination. Initially, a factorial design approach may be appropriate to identify the range of effects associated with mandrel conditions.

The effects of stress relieving require further investigation, since optimum treatments may exist for the required fatigue/relaxation characteristics of the springs.

The effects of shot peening should be investigated, since this process is known to improve the fatigue performance of components.

8. REFERENCES

1. DIN 2088: 1969, "Helical Springs made from Round Wire and Rod. Calculation and design of torsion springs." Fig 7.

2. Carlson, H., "Spring Designer's Handbook". Pub Marcel Dekker, 1978. Sole UK Agents: SRAMA.

3. 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 AS COILED SINGLE TORSION SPRINGS MADE FROM BS 1408 CR3 WIRE

Spring Condition: As coiled

Mandrel: Hardened steel with oil lubrication

Initial stress: 200 N/mm^2

Maximum Stress N/mm^2	Cycles to Failure*
2500	4733
"	3171
"	2968
"	4748
2000	11021
"	9428
"	7723
"	10428
1600	42406
"	45298
"	178378
"	29140
1450	43605
"	41340
"	300000 U/B
"	300000 U/B
1350	100052
"	309446 U/B
"	309446 U/B
"	309446 U/B

U/B = Springs unbroken when test terminated

TABLE II RESULTS OF FATIGUE TESTS FOR STRESS RELIEVED SINGLE TORSION SPRINGS MADE FROM BS 1408 CR3 WIRE

Spring Condition: Stress relieved 250°C/½ hour

Mandrel: Hardened steel with oil lubrication

Initial Stress: 200 N/mm^2

Maximum Stress N/mm^2	Cycles to Failure*
1700	16089
"	8614
"	8370
"	12084
1600	42398
"	38550
"	15757
"	21139
1500	17269
"	17379
"	22306
"	20016
1450	25509
"	450000 U/B
"	450000 U/B
"	450000 U/B
1400	27727
"	30571
"	209771 U/B
"	209771 U/B

* U/B = Springs unbroken when test terminated

TABLE III RESULTS OF FATIGUE TESTS FOR STRESS RELIEVED SINGLE TORSION SPRINGS MADE FROM BS 1408 CR3 WIRE

Spring Condition: Stress relieved 250°C/½ hour

Mandrel: Hardened steel with oil lubrication

Initial Stress: 50 N/mm^2

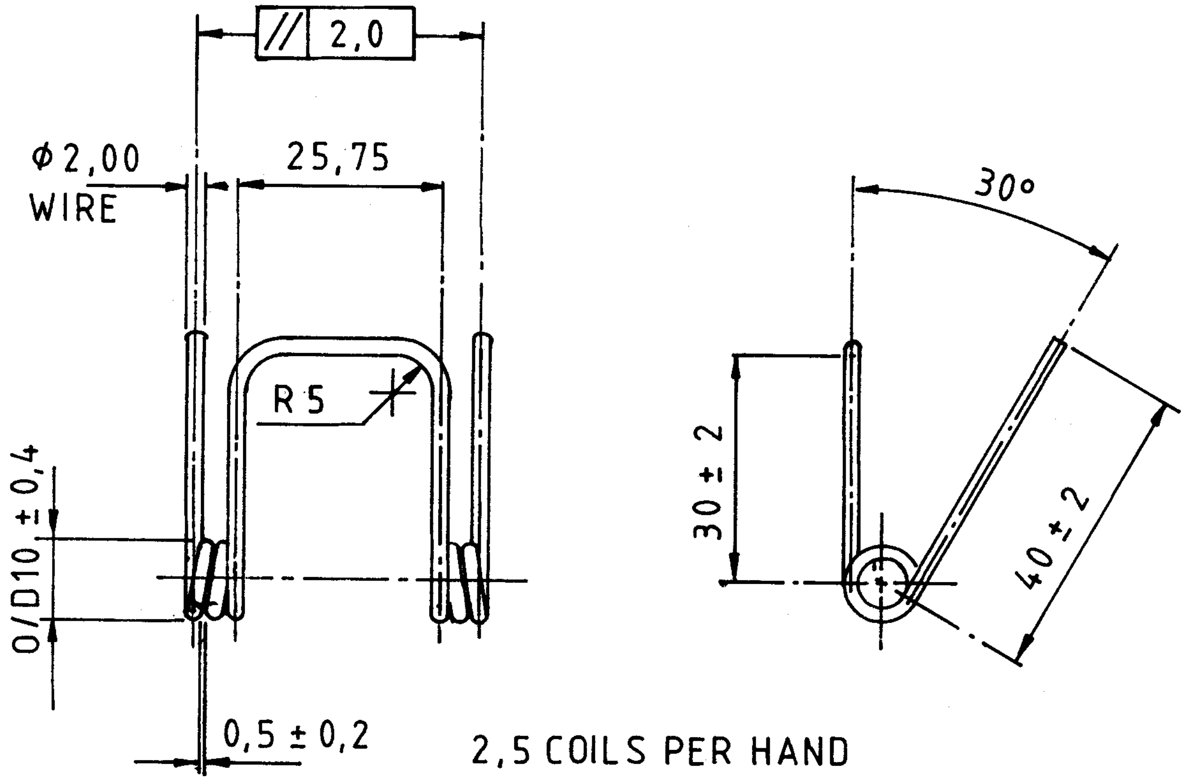
Maximum Stress N/mm^2	Cycles to Failure*
1450	30303
"	28736
"	26228
"	19604
1350	42592
"	45312
"	25003
"	34757
1250	23494
"	58900
"	336299 U/B
"	336299 U/B
1150	59656
"	80522
"	336299 U/B
"	336299 U/B

* U/B = Springs unbroken when test terminated

TABLE IV RESULTS OF FATIGUE TESTS FOR DOUBLE TORSION SPRINGS MADE FROM BS 5216 ND2 WIRE

Stress Range: 200-1700 N/mm^2

Cycles to Failure	
As Coiled	Stress Relieved 250^oC/½ hour
34690	34820
59950	18190
41700	47240
41000	
28790	
40240	
52110	
29180	
45310	
48730	
63810	
63630	
54910	
41961	
49680	
80910	



MATERIAL: BS5216:1975:ND2. 2.00mm

FIG 1 : DOUBLE TORSION SPRING FOR FATIGUE TESTING

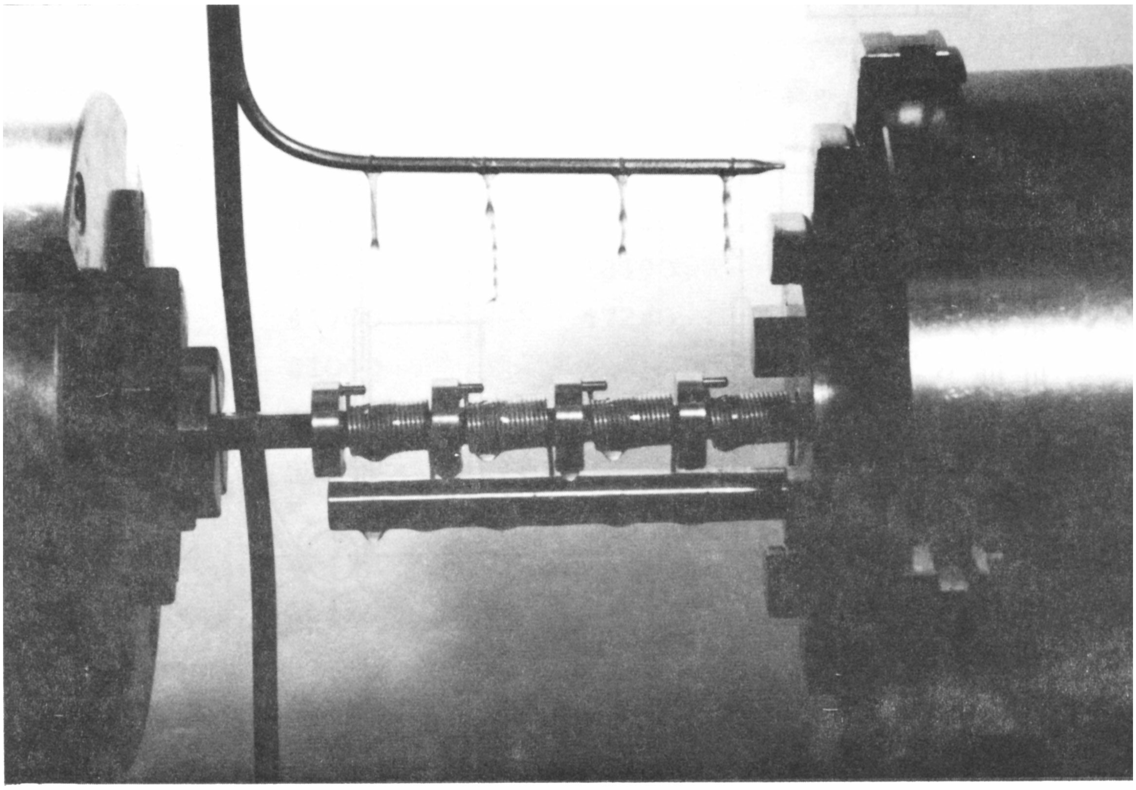


Fig 2

Experimental jig for fatigue testing of single torsion springs.

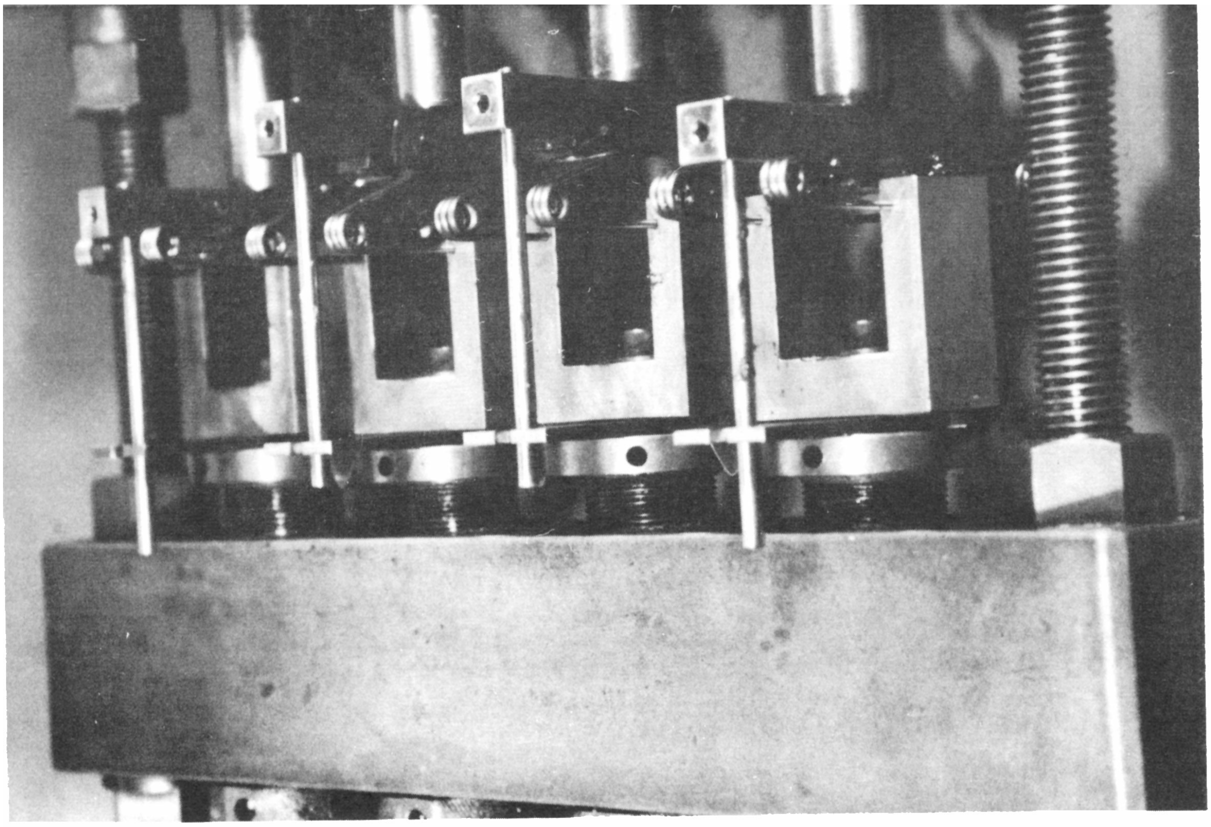


Fig 3
Experimental jigs for fatigue testing of double torsion springs.

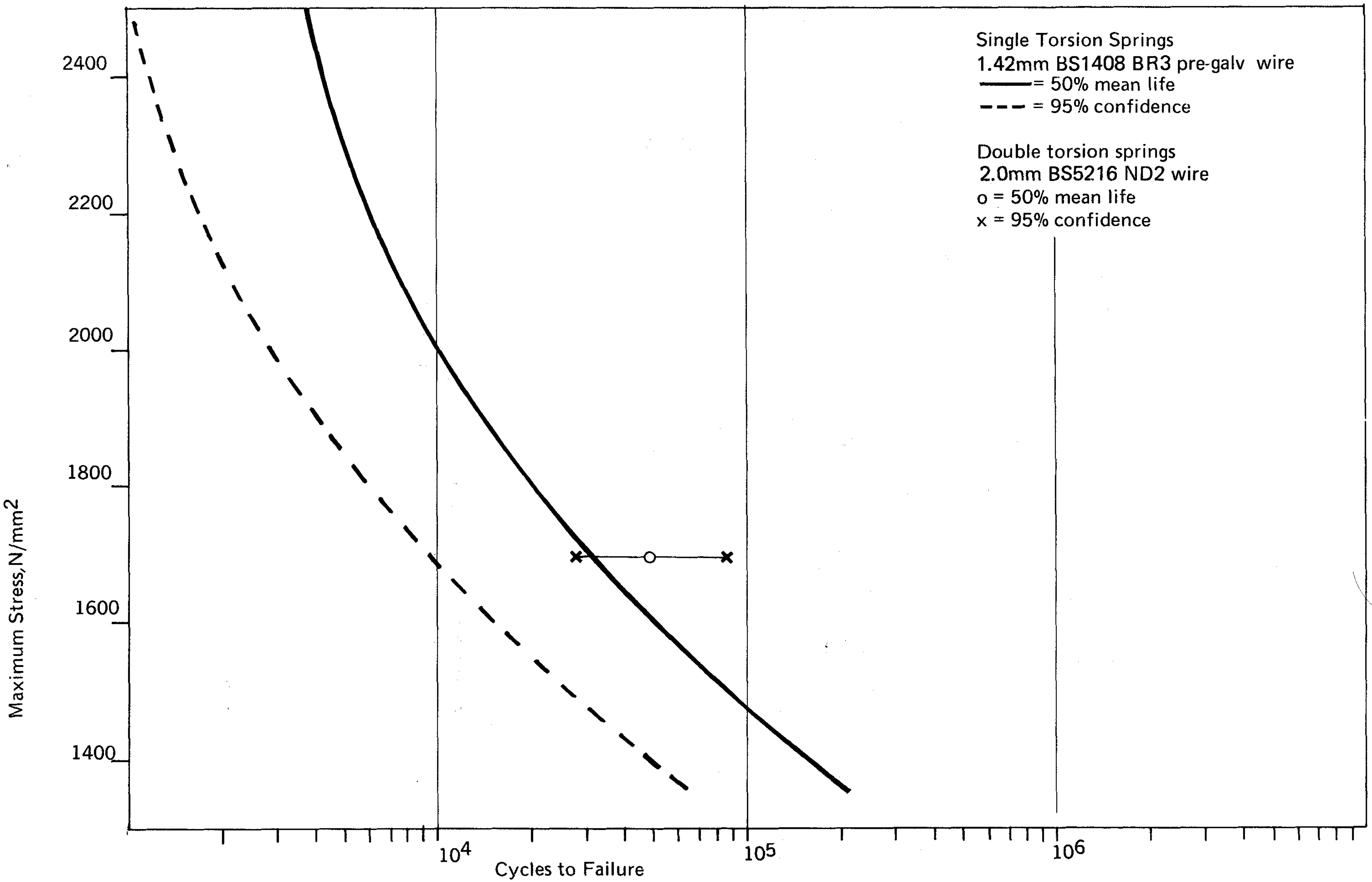


FIG 4 Fatigue results for "as-coiled" torsion springs. Initial Stress: 200N/mm^2

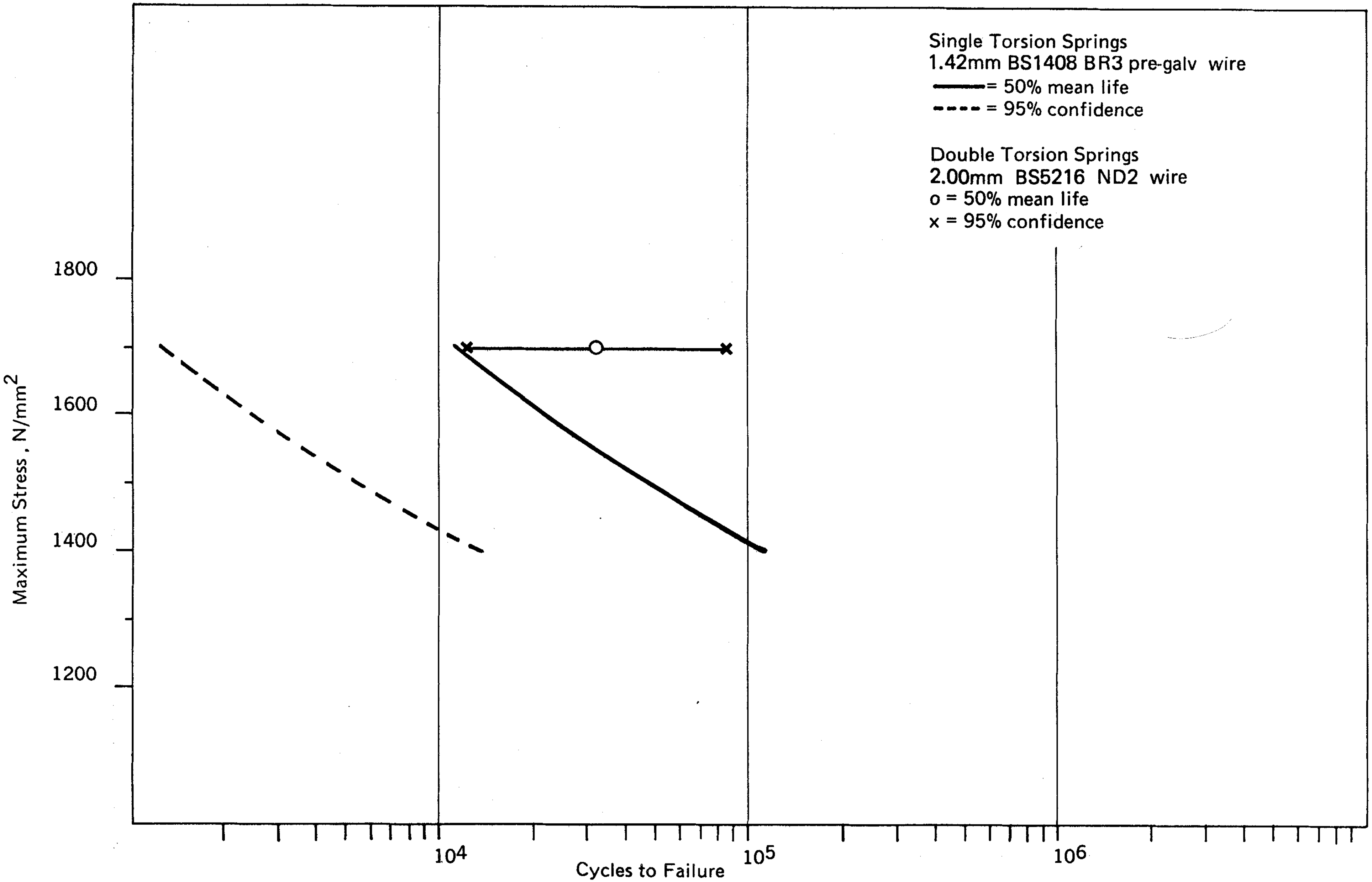


FIG 5 Fatigue results for Torsion Springs stress relieved at 250°C for 30 minutes, Initial Stress : 200N/mm^2

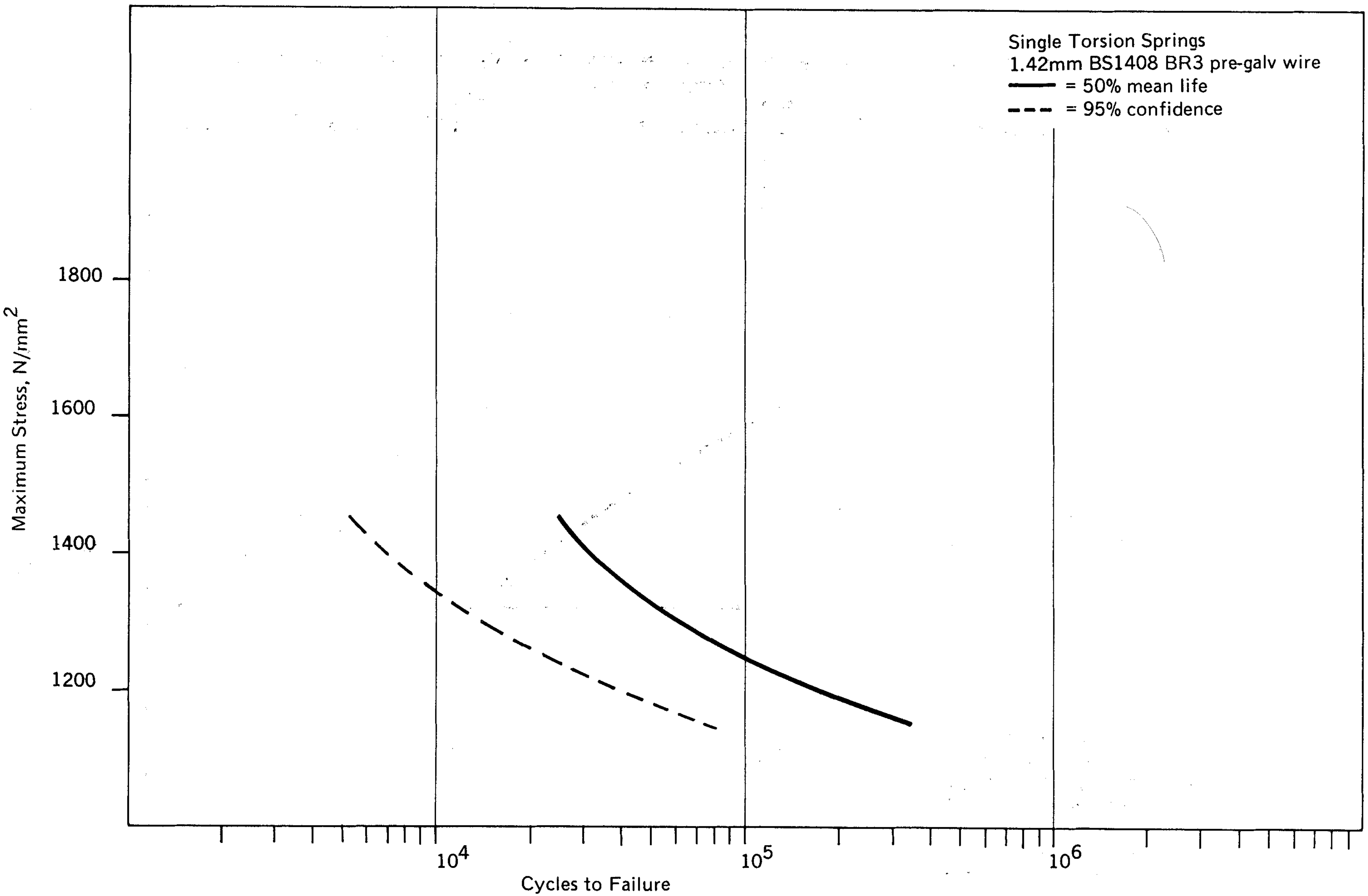


FIG 6 Fatigue results for single torsion springs, stress relieved at 250°C for 30 minutes: Initial Stress : 50 N/mm^2

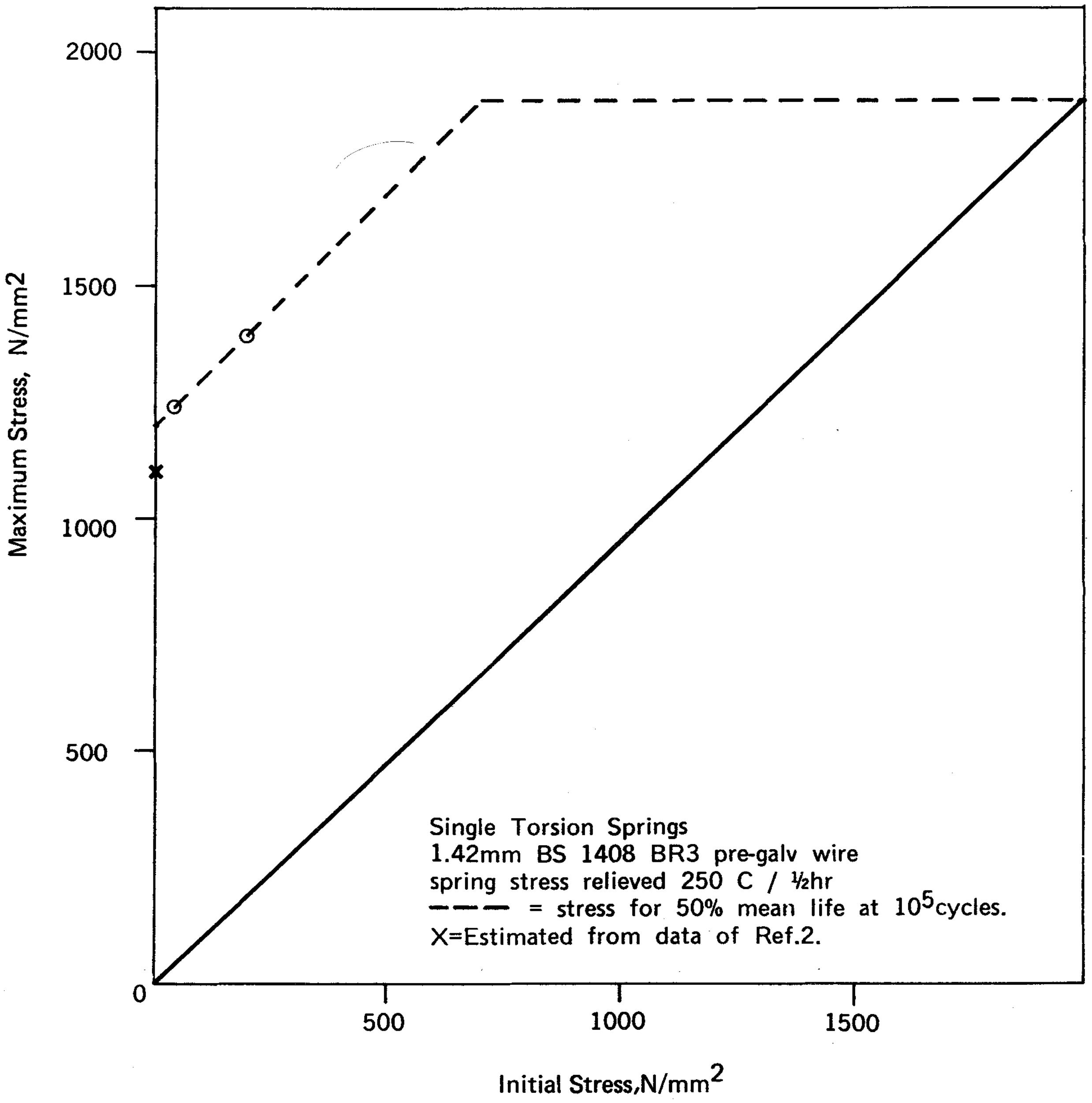


FIG 7 Goodman diagram for stress relieved torsion springs.