THE SPRING RESEARCH AND MANUFACTURERS´ ASSOCIATION

THE DYNAMIC RELAXATION BEHAVIOUR OF SHOT PEENED AND HOT PRESTRESSED HELICAL COMPRESSION SPRINGS AT ELEVATED TEMPERATURE

Report No 412

by

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SUMMARY

As a continuation of a previous investigation which examined the dynamic relaxation behaviour of shot peened compression springs, further testing has been conducted on shot peened and hot prestressed springs made from BS5216 HD2, BS2803 carbon, chrome vanadium and chrome silicon quality wires at a temperature of 120 C.

All four grades of material generally exhibited either very low levels of relaxation or slight recovery under dynamic test conditions, with the dynamic relaxation performance being considerably superior to the static performance. The chrome vanadium material exhibited slightly higher levels of recovery than the other three grades which could be problematic in practice due to spring "growth". From a practical view point, the chrome silicon material had the most desirable behaviour experiencing negligible recovery or relaxation at all test stress levels, and exhibiting a mean level of approximately 0%.

Alternating dynamic and static testing to simulate spring usage in internal conbustion engines revealed that the slight relaxation experienced during the static period is negated by the recovery experienced during the dynamic operation and the overall performance of the springs is not affected.

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1. INTRODUCTION

This report is a continuation of a previous investigation [1] which examined the dynamic relaxation behaviour of shot peened springs made from two grades of carbon steel wire (BS 5216 HD2 and BS 2803 094A65) and from two grades of low alloy steel wire (BS 2803 735A50 and 685A55).

Very little data are available for the springmaker on dynamic relaxation, so this investigation has been undertaken to generate this much needed data. Shot peened and hot prestressed springs combine good fatigue and relaxation properties, as shot peening enhances fatigue performance while hot prestressing counters the deleterious effects of the peening process on the relaxation performance [2].

2. MATERIALS AND SPRING DESIGNS

The work was carried out on springs made from 4 grades of spring wire; patented cold drawn carbon steel to BS 5216 HD2 and three prehardened and tempered grades to BS 2803 ie a carbon steel 094A65, a chrome vanadium steel 735A50 and a chrome silicon steel 685A55. Details of the spring designs are given in Table I.

The springs were coiled on an automatic spring coiling machine, given a low temperature heat treatment of 375°C for 30 minutes for the carbon steel grades and 400°C for 30 minutes for the alloy steel grades. They were then end ground and shot peened using S330 steel shot to an arc rise on Grade A Almen strips of 0.4 mm minimum followed by stress relieving at 220°C for 30 minutes.

The springs were then hot prestressed using the Association's pneumatic hot prestressing rig, a full description of which is given in a previous SRAMA report . The hot prestressing temperatures used were based on previous results from static testing and were 300 C for the BS 5216 HD2 grade and 350 C for the 3 prehardened and tempered grades.

As the hot prestressing temperatures used in industry vary from company to company, a limited number of springs of hard drawn carbon steel and chrome-vanadium grades were hot prestressed using a temperature of 275 C for comparison purposes.

The hot prestressing process involved heating the springs to the appropriate temperature in an air circulating oven, transferring them individually to the hot prestressing rig, compressing while still hot to approximately 95% of their compressed length, holding at this length for 3 seconds and then quenching into water. When cold, the springs were released from the rig. The reason for hot prestressing to only 95% of the compressed length is that this allows for spring to spring variations so that no springs are over compressed as could happen when compressing to solid, and the possible distortion of the springs is avoided.

For comparison purposes, a set of commercially shot peened and hot prestressed chrome-vanadium springs were also obtained for testing, the spring design being shown in Table I.

3. TESTING PROCEDURE

3.1 Dynamic Relaxation Tests

Tests were conducted at 3 maximum stress levels for each set of springs to a life of 10^7 cycles using the Association's 8 station forced motion fatigue testing machine fitted with thermostatically controlled hot boxes operating at 120°C. The test speed was kept constant at 1500 rpm throughout the course of testing.

After hot prestressing, the highest stress level that could be obtained for all four sets of springs was 800 N/mm^2, and so testing was conducted at maximum stress levels of 800, 700 and 600 N/mm^2. The minimum stress level used throughout the course of testing was 100 N/mm^2. The loads necessary to produce the required stress levels in the springs were calculated from the standard design formulae, and the springs were load tested both prior to and after testing using the Association's electronic 2000 N spring load tester. From the data obtained, the dynamic relaxation was calculated.

3.2 Static Relaxation Tests

Static relaxation tests were conducted on each of the 4 materials at the same maximum stress levels as used for the dynamic testing, using standard nut and bolt techniques. The springs were load tested, bolted up and subjected to a temperature of 120 C in air circulating ovens for a period of 111 hours, ie equivalent to a test to 10 cycles during dynamic testing.

3.3 Cumulative Testing

In a real life situation, engine valve springs operate dynamically whilst the engine is running, then spend a period of time statically compressed with the engine gradually cooling down after it has stopped running. This sequence is repeated everytime the engine is used. In order to assess the effect of this repeated dynamic and static usage on the spring performance, a series of tests were conducted alternating dynamic and static stressing conditions.

A set of eight springs of the prehardened and tempered carbon steel grade were dynamically tested at 120 C at a maximum stress of 600 N/mm for 4 hours which was equivalent to approximately half a million cycles, and after testing the dynamic relaxation was noted. The springs were then statically tested at the same temperature and stress level for 4 hours and the resultant relaxation noted. This sequence was repeated once more and then finally the springs were dynamically tested.

4. DISCUSSION OF RESULTS

The data obtained were statistically analysed using standard linear regression techniques, and the resultant curves, together with the data range, for the dynamically and statically tested springs are presented in Figures 1 to 4 for the BS 5216 HD2, BS 2803 094A65, BS 2803 735A50 and BS 2803 685A55 materials respectively. In addition, the individual tests for the BS 5216 HD2 and BS 2803 735A50 springs hot prestressed at 275°C are presented on Figures 1 and 3 respectively; the results for the commercially hot prestressed BS 2803 735A50 springs are also presented on Figure 3.

As can be seen from Figures 1 to 4, all four grades of material generally experienced either very low levels of relaxation or recovery under dynamic stressing conditions, and the dynamic relaxation performance was considerably superior to the static relaxation performance, with the exception of the BS 2803 094A65 tested at 800 N/mm^2 (see Figure 2). It can be assumed, therefore, that relaxation should not be a problem for hot prestressed engine valve springs.

From examination of the results for the 4 test materials, it can be seen that the dynamic relaxation performance of the BS 2803 735A50 material could be construed to be better than the other 3 test materials in that, at all 3 test stress levels, the springs experienced recovery (between 0 and 3% depending on the stress level). However, in some instances this behaviour may be problematic to the spring user as, in experiencing recovery, the springs "grow" and can support a higher load at a set length; this, in turn, may alter the running conditions of the machinery in which the springs are operating. In this particular case, the dynamic performance of the BS 2803 685A55 material may be more desirable as only negligible recovery or relaxation was experienced at all stress levels (0.3% recovery to 0.7% relaxation) with a mean level of 0.1% relaxation.

For the BS 2803 685A55 material, the relaxation/recovery behaviour under dynamic stressing conditions appeared to be independent of applied stress as similar levels of relaxation/recovery were experienced at all 3 test stress levels (see Figure 4).

The dynamic relaxation behaviour of the BS 5216 HD2 material (see Figure 1) was similar to that experienced by the BS 2803 735A50, except that the carbon steel grade experienced lower levels of recovery and higher levels of relaxation (2% recovery to 1.5% relaxation).

The dynamic performance of the BS 2803 094A65 material was very different to the other 3 spring materials tested in that at the 2 lower stress levels the springs experienced recovery (between 0.5 and 2%), but at the highest test stress level the springs experienced a similar level of relaxation to that obtained under static test conditions, ie between 3 and 4.5%.

For this material there appears at be a cut off stress level after which the dynamic relaxation performance deteriorates rapidly, and this stress level is between 700 and 800 N/mm^2.

Comparing the results in Figures 1 and 3, it can be seen that the lower hot prestressing temperature had very little effect on the level of dynamic relaxation, and that the commercially procured springs give similar results to the SRAMA hot prestressed springs.

The results of the alternating dynamic and static testing are presented in Table II and indicate that although the springs may suffer some relaxation during the static period, the recovery experienced during the dynamic period does not appear to be lessened by this. Thus for engine valve springs, any relaxation experienced while the engine is not running should not affect the performance of the springs as it will be negated by the recovery experienced during the dynamic operation of the springs.

5. CONCLUSIONS

1. Hot prestressed springs experience only very low levels of relaxation or recovery during dynamic operation, these levels being as follows:-

Material	Dynamic Relaxation Level (%)
BS 5216 HD2	-2 to 1.5
BS 2803 094A65	-2 to 4.5
BS 2803 735A50	-3 to 0
BS 2803 685A55	-0.3 to 0.7

2. Under alternating dynamic and static conditions, relaxation is not cumulative as the relaxation experienced under static conditions is nullified by the recovery experienced under dynamic conditions.

6. REFERENCES

1. O'Malley, M, "The Dynamic Relaxation Behaviour of Helical Compression Springs". SRAMA Report No 394, Oct 1986.

2. Heyes, P F, "The Effects of Hot and Cold Prestressing on the Fatigue and Relaxation Properties of Compression Springs made from Cr-V Steel Wire". SRAMA Report No 248, June 1975.

3. Hale, G E, "The Effect of Hot Prestressing on the Relaxation Behaviour of Compression Springs Coiled from En 58AHard Drawn Stainless Steel Wire." SRAMA Report No 306, May 1979.

4. O'Malley, M, "The Effect of Hot Prestressing on the Long Term Relaxation Behaviour of Springs at Elevated Temperatures". SRAMA Report No 350, May 1982.

TABLE I - SPRING DESIGNS

	BS 5216 HD2	BS 2803 094A65	BS 2803 735A50	BS 2803 685A55	Commercially Procured BS 2803 735A50
Wire Diameter (mm)	4.07	4.98	4.06	4.21	4.73
Mean Coil Diameter (mm)	28.35	36.78	28.23	32.15	28.83
Spring Index	6.97	7.39	6.95	7.64	6.10
Total Coils	5.5	5.5	5.88	5.5	7.0
Free Length After End Grinding and Hot Pre-stressing (mm)	41.57	55.18	48.74	47.23	55.00
Solid Stress After End Grinding and Hot Pre-stressing (N/mm^2)	840	875	890	835	775

TABLE II - RESULTS OF ALTERNATE DYNAMIC AND STATIC RELAXATION TESTS ON BS 2803 094A65 SPRINGS

Cumulative Relaxation at 120°C (%)				
Dynamic 4 Hrs	Static 8 Hrs	Dynamic 12 Hrs	Static 16 Hrs	Dynamic 20 Hrs
-1.8	-0.3	-2.2	0.3	-2.6
-1.4	0.3	-1.6	0.5	-1.2
-2.1	-0.5	-2.1	-0.2	-2.3
-1.5	0.2	-1.3	0.3	-1.2
-1.8	0.3	-1.8	0.5	-1.8
-0.6	0.5	-1.0	0.3	-1.1
-2.0	-0.5	-1.8	0.2	-2.8
-0.8	0.5	-1.0	-0.2	-2.1
x-1.5	x0.1	x-1.6	x0.2	x-1.9

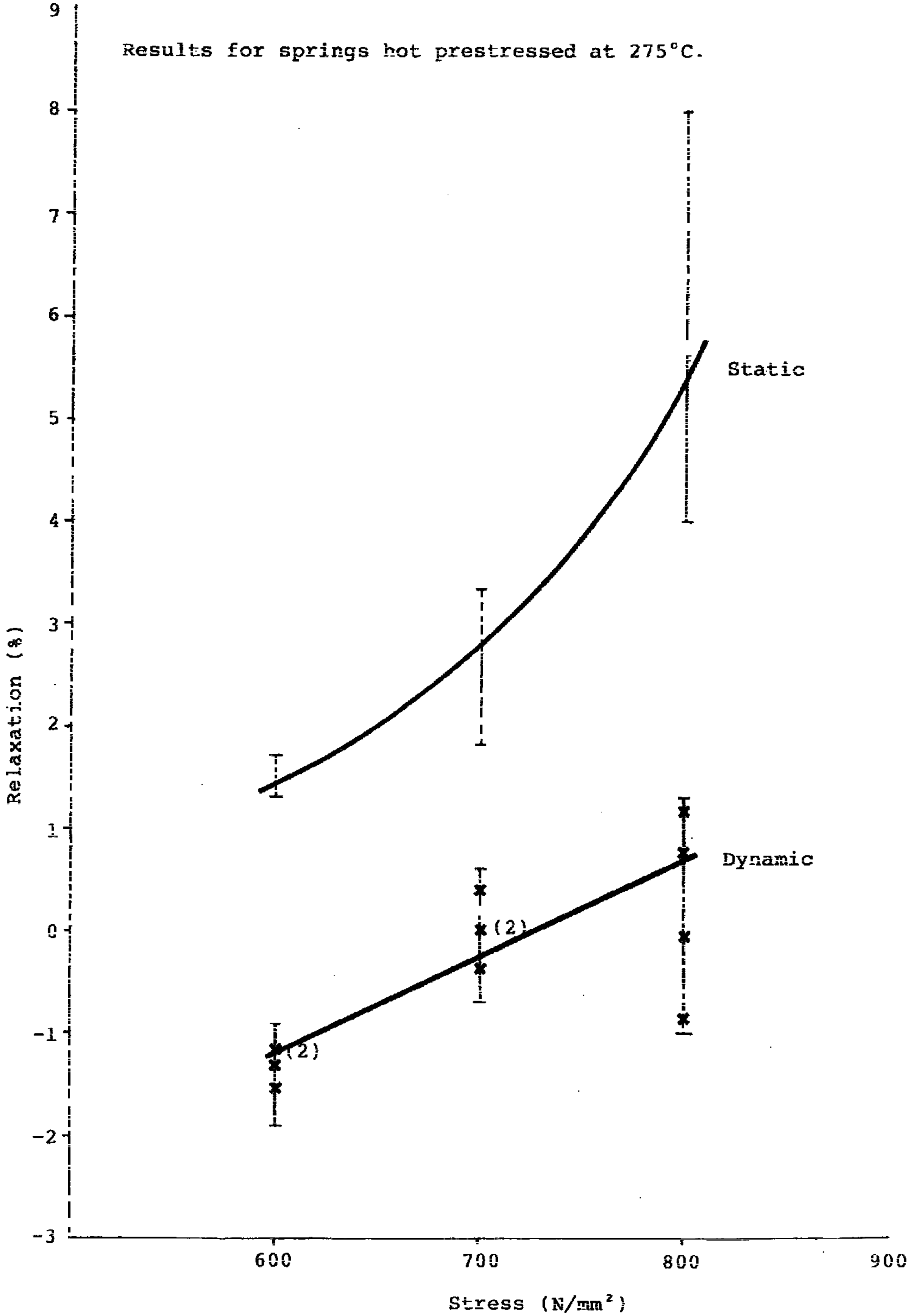

Fig 1: RELAXATION RESULTS FOR BS 5216 HD2 SPRINGS.

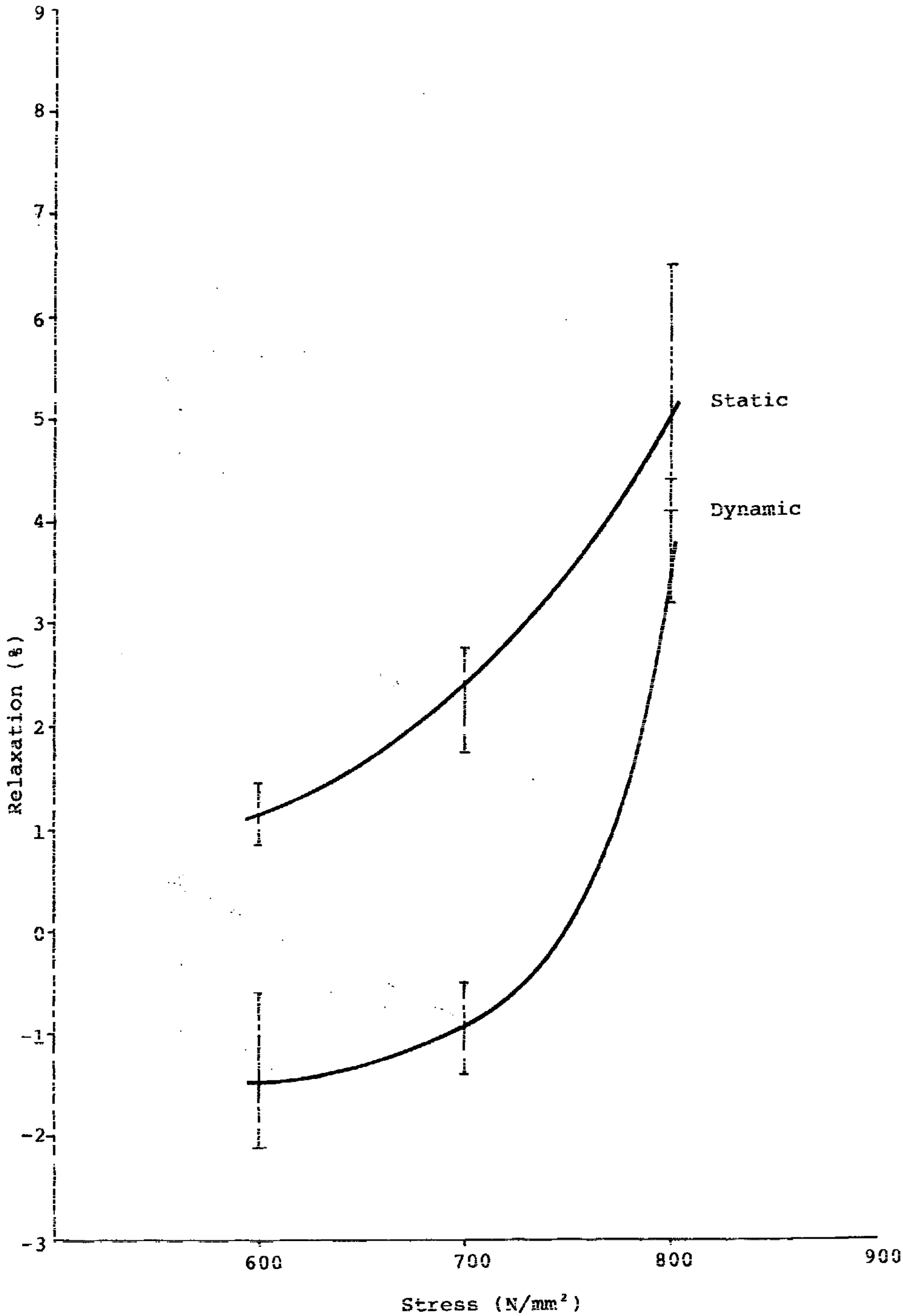

Fig 2: RELAXATION RESULTS FOR BS 2803 094 A65 SPRINGS.

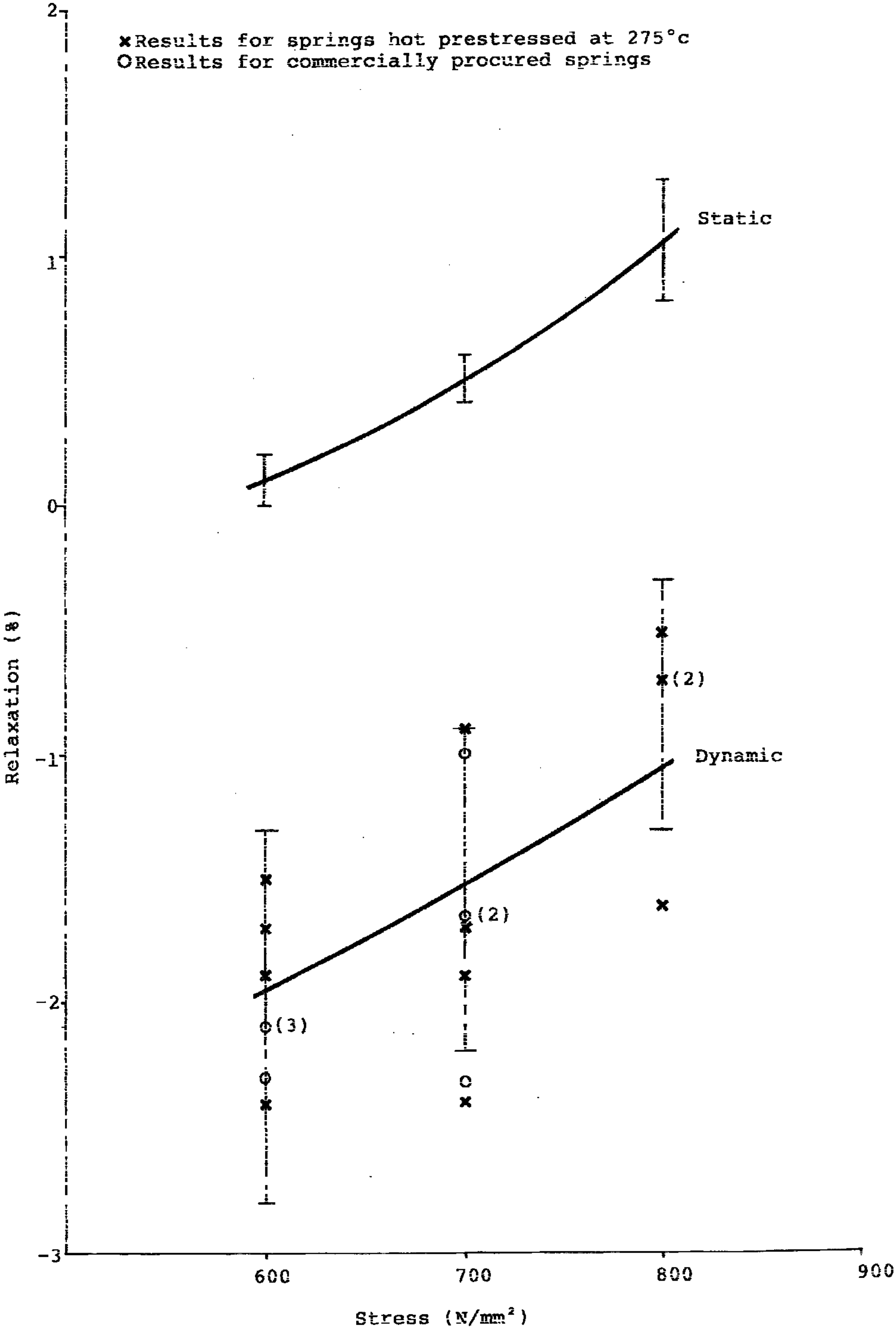

Fig 3: RELAXATION RESULTS FOR BS 2803 735A50 SPRINGS

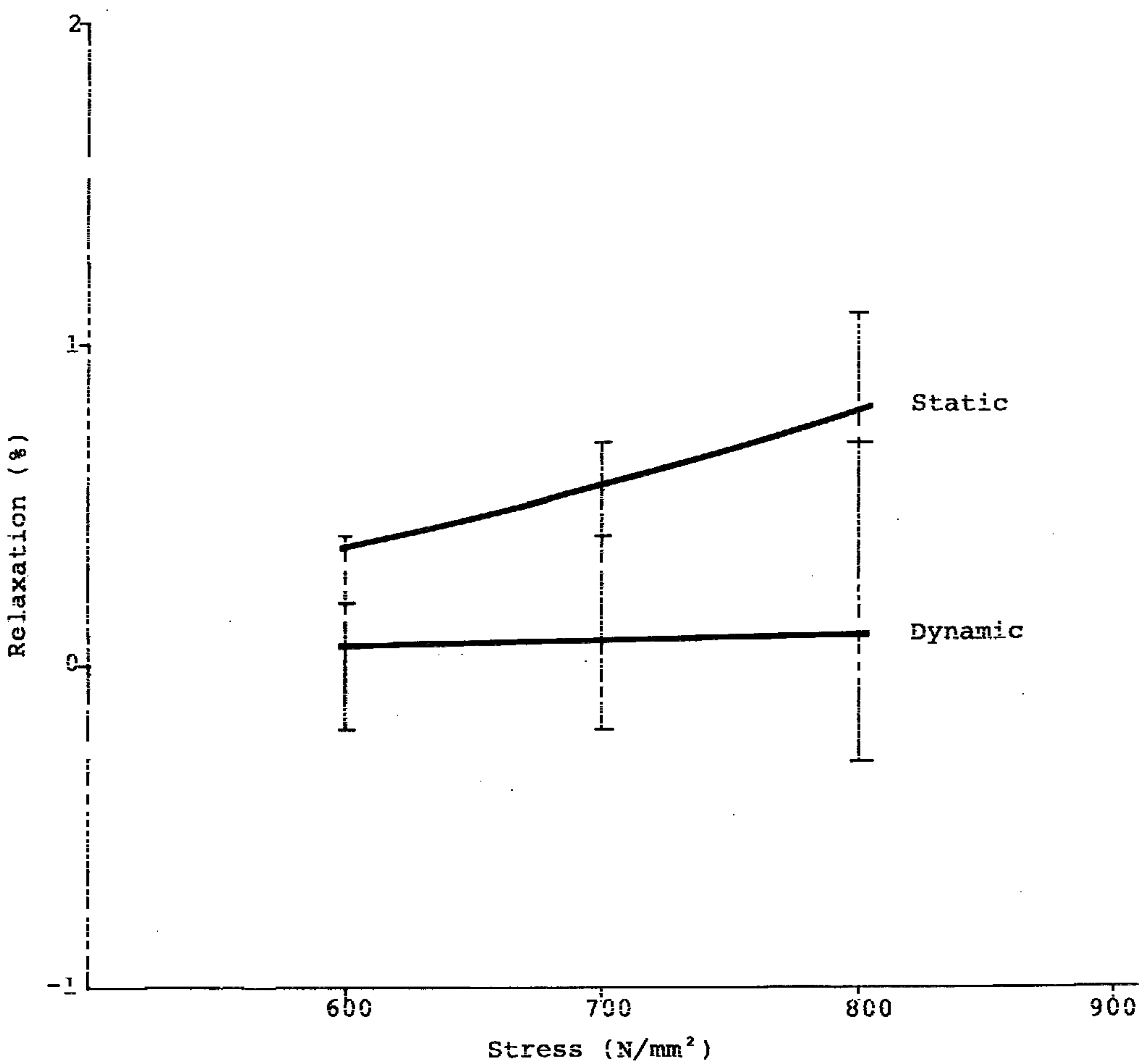

Fig 4: RELAXATION RESULTS FOR BS 2803 685A55 SPRINGS