THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

RELAXATION OF COMPRESSION SPRINGS AT 100°C

Report No 379

by

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AUGUST 1986

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SUMMARY

In order to predict accurately the relaxation likely to occur in springs operating at a particular temperature, it is necessary to have data at room temperature, the maximum operating temperature for that material and at some intermediate temperature. This report provides the required data at the intermediate temperature for all the commonly used springmaking materials, thus completing SRAMA's data bank on the relaxation behaviour of compression springs. The relative performance of springs made from hard drawn steel wires, pre-hardened and tempered carbon and low alloy steel wires, and stainless steel wires is tabulated.

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1. INTRODUCTION

The static relaxation properties of the commonly used springmaking materials have previously been evaluated at ambient temperature and elevated temperatures above 100°C. As a result, the maximum operating stress and temperatures have been determined for each material.

Since temperatures of the order of 100°C are frequently encountered by springs in engines etc. a programme of work was set up to determine relaxation at this temperature. Relaxation tests on each commonly used springmaking material were carried out for a duration of 1000 hours at three stress levels. This will enable more accurate long term relaxation predictions at intermediate temperatures.

Hot prestressing of some springs was carried out in order to determine the effect of this process on the relaxation behaviour. Springs made from dynamic quality wire were shot peened prior to hot prestressing.

2. MATERIALS INVESTIGATED

A range of materials likely to be considered for use at 100°C were selected for testing, as follows:- BS 5216 HS1, BS 5216 HS3, BS 5216 M5, BS 2803 093A65, BS 2803 685A65, BS 2803 735A50, BS 2056 302S26, BS 2056 316S42 and BS 2056 420S45. The latter two materials had not previously been tested by SRAMA.

The chemical analysis and UTS of the materials are given in Table I.

Table II lists the materials which were hot prestressed and the temperatures used for this process.

The springs were manufactured to the designs given in Table III, which also shows the stress relieving heat treatments carried out.

3. EXPERIMENT METHOD

Springs from each material were tested at three corrected stresses. The axial loads required to subject the spring to each stress was calculated from the following relationship:-

$$P = \frac{d^3}{8DK}$$

Where P = Axial load applied to spring (N)

d = wire diameter (mm)

q = torsional stress in material (N/mm^2)

D = Mean spring coil diameter (mm)

K = Sopwith curvature correction factor = C + 0.2/C - 1

C = Spring index = D/d

The springs were individually identified and load tested on SRAMA's 2000 N electronic load tester, to the loads calculated from the above relationship. The springs were tested at temperatures by the nut and bolt technique.[2]

Five springs were tested at each of three test stresses.

After a predetermined length of time in an oven at 100°C 2°C, the springs were unbolted and load tested to the original length.

The relaxation was determined from the following relationships:-

$$\% \text{ Rel} = \frac{P_0 - P_1}{P_0} \times 100$$

Where % Rel = Percent relaxation

P_0 = Original load at length L (N)

P_1 = New load at length L (N)

Tests up to 1000 hours with 10 test increments were made.

The materials in Table II were hot prestressed using SRAMA's Hot Prestressing Rig. The valve quality springs were shot peened using S330 shot. Relaxation tests were completed up to 250 hours duration. Only one test stress was used for these tests.

4. RESULTS

The result of the tests are represented graphically in figures 1-11. The results were fitted by the least squares method of regression to the following relationship:-

$$\% \text{ Rel} = a + b \log t$$

Where % Rel = Percent relaxation

t = Time of testing (hours)

a and b are regression constants

Statistical analysis of the results has enabled 95% confidence levels to be added to the regression predictions of relaxation at 100°C at 10000 and 20000 hours. Values of a, b, correlation coefficient and 95% confidence limits are given in Table IV. Figures 1-11 illustrate the mean relaxation and 95% confidence limit (---) lines.

5. DISCUSSION

The 10000 and 20000 hour predictions of relaxation for each material grade tested at 100°C are given in Table V. The 95% confidence interval included here is defined as the maximum value of relaxation that would not be exceeded by 95% of the springs tested.

The materials tested are ranked in order of resistance to relaxation at 100°C as shown in Table IV.

The stainless steel materials have the best resistance to relaxation at 100°C, - BS 2056 316S42 and 420S45 having slightly inferior resistance to the 302S26 grade. Of the hardened and tempered grades of steel to BS 2803, the SiCr grade 685A65 has the best resistance, being almost as good as the stainless grades. The CrV grade 735A50 has a slightly poorer performance than the music wire BS 5216 M5, both materials being significantly poorer than BS 2803 685A65. BS 2803 093A65 and BS 5216 HS1 and HS3 grades are somewhat poorer than all the preceeding grades and have similar relaxation properties at 100°C.

Table VII shows the effect of hot prestressing. Long term predictions of relaxation suggest a significant reduction in the relaxation expected for BS 2803 685A65 at a stress level of 1000 N/mm^2, both in the unpeened and shot peened conditions. BS 2803 735A50 also shows a large improvement, particularly where the springs are unpeened, but still has a poorer performance than BS 2803 685A65. BS 5216 M5 improves a relatively small amount with hot prestressing when stressed at 1000 N/mm^2. BS 2056 316S42 stressed at 600 N/mm^2 shows no improvement in relaxation resistance when hot prestressed.

6. CONCLUSIONS

1. Predictions of relaxation at all temperatures over a range of stresses can be made for the common springmaking materials.

2. The common springmaking materials can be ranked in order of resistance to relaxation.

3. BS 2803 685A65 springs shot peened and hot prestressed show significantly better relaxation resistance than BS 2803 735A50 springs in the same condition.

7. REFERENCES

1. G B Graves, "The Fatigue and Relaxation Resistance of Copper-Beryllium Helical Compression Springs", SRAMA report No 263.

2. G B Graves, "The Stress Temperature Relaxation Properties of Springs made from Oil Tempered and Patented Hard Drawn Wires", SRAMA report No 115.

TABLE I CHEMICAL COMPOSITION AND TENSILE STRENGTH OF MATERIALS TESTED

MATERIAL		Chemical Analysis									UTS N/mm²
		C	Si	Mn	S	P	Cr	V	Ni	Mo	
BS 5216 HS1	Specified	0.45-0.85	0.35 max	0.40-1.00	0.050 max	0.050 max	-	-	-	-	1230-1520
	Actual	0.48	0.28	0.68	0.031	0.020					1400
BS 5216 HS3	Specified	0.55-0.85	0.35 max	0.30-1.00	0.30 max	0.030 max	-	-	-	-	1670-1870
	Actual	0.84	0.20	0.59	0.024	0.017					1880
BS 5216 M5	Specified	0.70-1.00	0.35 max	0.25-0.75	0.030 max	0.030 max	-	-	-	-	2080-2230
	Actual	0.90	-	-	-	-					2151
BS 2803	Specified	0.55-0.75	0.30 max	0.60-1.20	0.030 max	0.030 max	-	-	-	-	1580-1730
	Actual	0.71	0.30	0.80	0.020	0.010					1663
BS 2803 735A50	Specified	0.46-0.54	0.10-0.35	0.10-0.35	0.60-0.90	0.035 max	0.80-1.10	0.15 min			1635-1785
	Actual	0.55	0.26	0.80	0.015	0.014	1.03	0.16			1667
BS 2803	Specified	0.50-0.60	1.20-1.60	0.50-0.80	0.025 max	0.030 max	0.50-0.80	-	-	-	1720-1870
	Actual	0.51	1.60	0.77	0.030	0.030	0.60				1792
BS 2056 302S26 Grade II	Specified	0.12 max	1.00 max	2.00 max	0.030 max	0.045 max	17.0-19.0	-	7.5-10.0	-	1570-1810
	Actual	0.5	-	-	-	-	18.1	-	11.0	0.44	1721

contd ....

TABLE I (contd)

MATERIAL		Chemical Analysis									UTS N/mm^2
		C	Si	Mn	S	P	Cr	V	Ni	Mo	
BS 2056 316S42	Specified Actual	0.07 max 0.08	1.00 max 0.72	2.00 max 1.28	0.030 max 0.010	0.045 max 0.022	16.0-18.5 17.9	-	9.50-13.50 10.4	2.00-2.50 2.59	1360-1600 1640
BS 2056 420S45*	Specified Actual	0.28-0.36 0.32	1.00 max	1.00 max	0.030 max	0.040 max	12.0-14.0 13.5	-	1.00 max	-	- 536-540 HV

* Hardness values as measured after heat treating springs as follows:- 2 minutes at 1000°C oil quench
5 minutes at 440°C water quench

TABLE II MATERIALS HOT PRESTRESSED AND TEMPERATURE USED

Material	Hot Prestressing Temperature
BS 2803 735A50 Unpeened	300°C
BS 2803 735A50 Shot Peened	300°C
BS 2803 685A65 Unpeened	300°C
BS 2803 685A65 Shot Peened	300°C
BS 5216 M5 Unpeened	200°C

TABLE III SPRING DESIGN DIMENSIONS

Material	Wire Diameter (mm)	Outside Diameter (mm)	Number of Active Coils	Free Length (mm)	Index	Corrected Solid Stress (N/mm^2)	Stress Relieving Operation
BS 5216 HS1	2.34	20.70	3½	34.0	7.85	1243	$375^{o}C$ ½ hr
BS 5216 HS3	2.62	22.46	3½	36.0	7.57	1226	$375^{o}C$ ½ hr
BS 5216 M5	2.29	20.50	3½	34.0	7.95	1250	$375^{o}C$ ½ hr
BS 2803 093A65	2.49	22.20	3½	36.0	7.92	1210	$400^{o}C$ ½ hr
BS 2803 735A55	3.17	23.56	3½	36.0	6.43	1246	$400^{o}C$ ½ hr
BS 2803 68565	3.30	23.82	3½	37.0	6.22	1310	$400^{o}C$ ½ hr
BS 2056 302S26	2.64	22.50	3½	38.0	7.52	1190	$450^{o}C$ 2 hrs
BS 2056 316S42	2.64	22.50	3½	38.0	7.52	1190	$450^{o}C$ 2 hrs
BS 2056 420S45*	2.03	14.99	3½	21.0	6.38	1047	

* See Table I for heat treatment

TABLE IV COEFFICIENTS OF THE REGRESSION LINES OF RELAXATION VERSUS LOG TIME

Material	Test Stress (N/mm^2)	$Y = a + b \log t$		Standard Error of Regression S_R	95% Confidence Increment	Correlation Coefficient r	Level of Significance %
		a	b				
BS 5216 HS1	400	0.57	0.50	0.57	0.96	0.50	1
	600	1.04	0.95	0.50	0.84	0.85	1
	800	4.89	1.89	0.58	0.97	0.94	1
BS 5216 HS3	400	0.40	0.48	0.69	1.16	0.51	1
	600	1.41	0.99	0.66	1.11	0.79	1
	800	4.53	2.13	0.57	0.96	0.95	1
BS 5216 M5	600	1.28	0.93	0.43	0.72	0.88	1
	800	2.67	1.34	0.46	0.77	0.93	1
	1000	6.44	2.00	0.66	1.11	0.93	1
BS 2803 093A65	400	2.17	0.71	0.66	1.11	0.68	1
	600	2.29	1.27	0.55	0.92	0.89	1
	800	4.81	1.88	0.47	0.79	0.96	1
BS 2803 735A50	600	1.90	0.82	0.44	0.74	0.85	1
	800	2.77	1.40	0.53	0.89	0.91	1
	1000	7.06	2.00	0.61	1.02	0.94	1
BS 2803 685A65	600	0.32	0.51	0.62	1.04	0.57	1
	800	0.87	0.91	0.53	0.89	0.83	1
	1000	4.00	1.63	0.84	0.84	0.86	1

contd ......

TABLE IV (contd)

Material	Test Stress (N/mm^2)	$Y = a + b \log t$		Standard Error of Regression S_R	95% Confidence Increment*	Correlation Coefficient r	Level of Significance %
		a	b				
BS 2056 302S26	400 600 800	0.16 0.61 0.70	0.22 0.14 0.37	0.52 0.40 0.49	0.88 0.67 0.82	0.33 0.24 0.54	5 N/S 1
BS 2056 316S42	400 600 600 800	0.61 0.61 0.62 2.85	0.05 0.14 0.55 0.72	0.64 1.15 2.08 0.90	1.08 1.93 3.50 1.65	0.06 0.10 0.22 0.50	N/S N/S N/S 1
BS 2056 420S45	400 600 800	0.05 0.22 1.86	0.11 0.25 0.53	0.73 0.62 1.30	1.22 1.04 2.18	0.13 0.32 0.33	N/S 5 5

TABLE V PREDICTED RELAXATION AFTER 10000 AND 20000 HOURS AT 100°C

Material	Stress (N/mm²)	Predicted Relaxation % after (Hours)			
		10000		20000	
		Mean	95% CL	Mean	95% CL
BS 5216 HS1	400 600 800	2.6 4.8 12.5	3.5 5.7 13.4	2.7 5.1 13.0	3.7 6.0 14.0
BS 5216 HS3	400 600 800	2.3 5.4 13.0	3.5 6.5 14.0	2.5 5.7 13.7	3.6 6.8 14.7
BS 5216 M5	600 800 1000	5.0 8.0 14.4	5.7 8.8 15.5	5.3 8.4 15.0	6.0 9.2 16.1
BS 2803 093A65 Carbon	400 600 800	5.0 7.4 12.3	6.1 8.3 13.1	5.2 7.7 12.9	6.3 8.7 13.7
BS 2803 735A50 Chrome Vanadium	600 800 1000	5.2 8.4 15.1	5.9 9.3 16.1	5.4 8.8 15.7	6.2 9.7 16.7
BS 2803 685A65 Silicon Chrome	600 800 1000	2.4 4.5 10.5	3.4 5.4 11.9	2.5 4.8 11.0	3.5 5.7 12.4
BS 2056 302S26	400 600 800	1.0 0.7 2.2	1.9 1.4 3.0	1.1 0.8 2.3	2.0 1.4 3.1
BS 2056 316S42	400 600 800	0.8 1.2 5.7	1.9 3.1 7.2	0.8 1.2 5.9	1.9 3.1 7.4
BS 2056 420S45	400 600 800	0.5 1.2 4.0	1.7 2.2 6.2	0.5 1.3 4.1	1.7 2.3 6.3

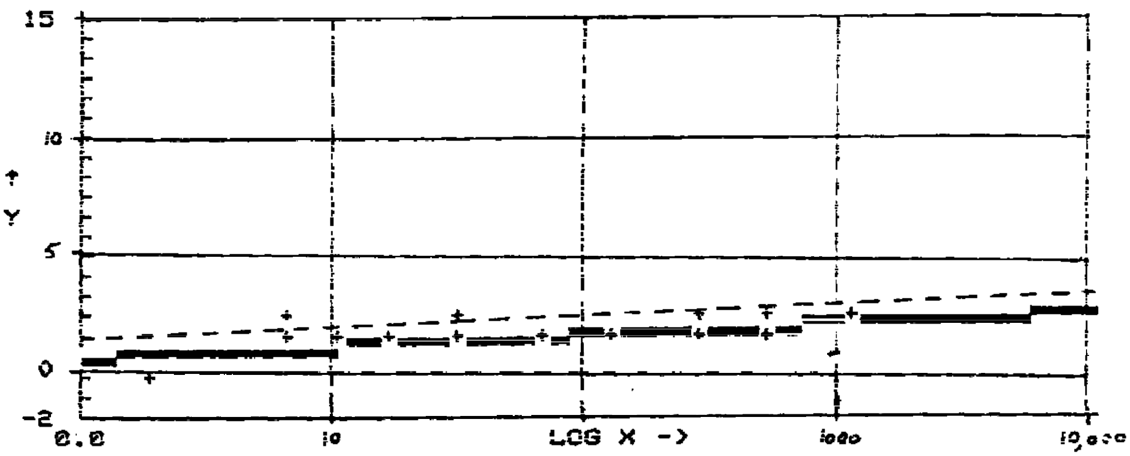
TABLE VI RANKING OF RELAXATION RESISTANCE AT 100°C

Ranking	Material
Best	BS 2056 302S26 BS 2056 420S45 BS 2056 316S42
Average	BS 2803 685A65 BS 5216 M5 BS 2803 735A50
Worst	BS 5216 HS1 and HS3 BS 2803 093A65

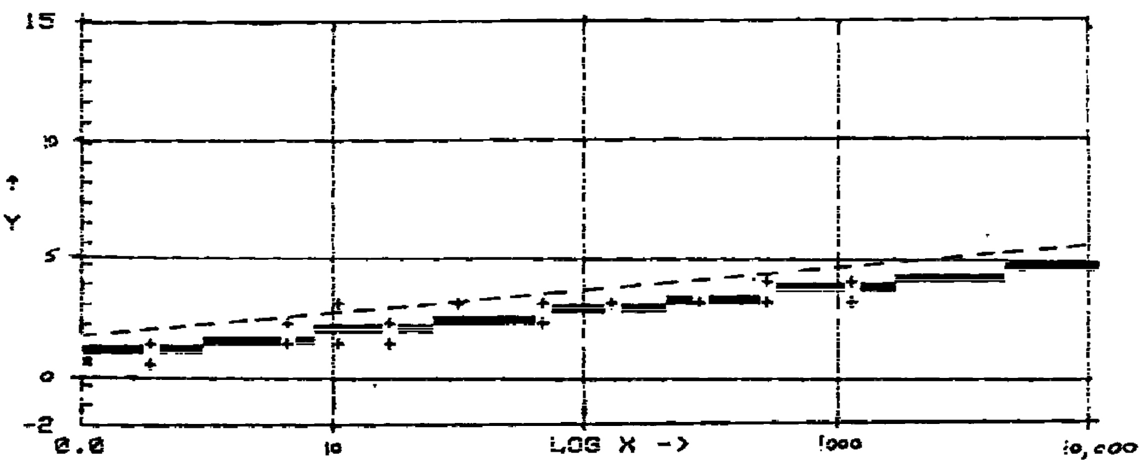
TABLE VII EFFECT OF HOT PRESTRESSING

Material	Condition	Test Stress (N/mm^2)	Regression Coefficients $R = a + b \log t$		95% Confidence Increment	Predicted % Relaxation After (Hours)			
			a	b		10000		20000	
						Mean	95%CL	Mean	95%CL
BS 2803 685A65	Shot Peened	1000	-0.27	+0.88	0.52	3.2	3.7	3.5	4.0
	Unpeened	1000	-0.28	+0.62	0-94	2.2	3.1	2.4	3.3
BS 2803 735A50	Shot Peened	1000	-0.34	+2.64	1.36	10.2	11.6	11.0	12.4
	Unpeened	1000	+0.09	+1.89	2.34	7.6	9.9	8.2	10.5
BS 5216 M5	Unpeened	1000	+1.26	+2.74	1.95	12.2	14.2	13.0	15.0

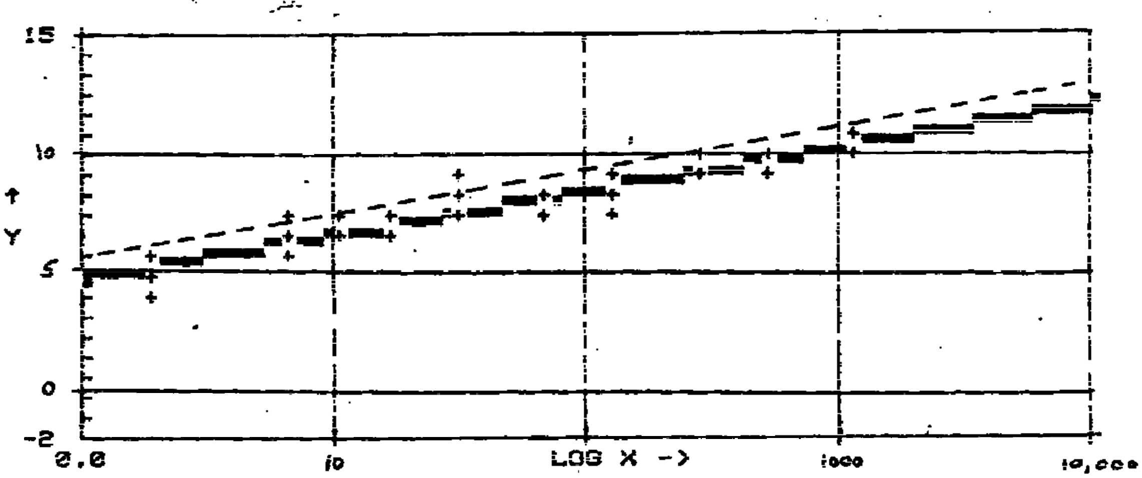
FIGURE 1 RELAXATION OF BS5216 HS1



BS5216 HS1 CORR. STRESS 400N\MM2



BS5216 HS1 CORR. STRESS 600N\MM2

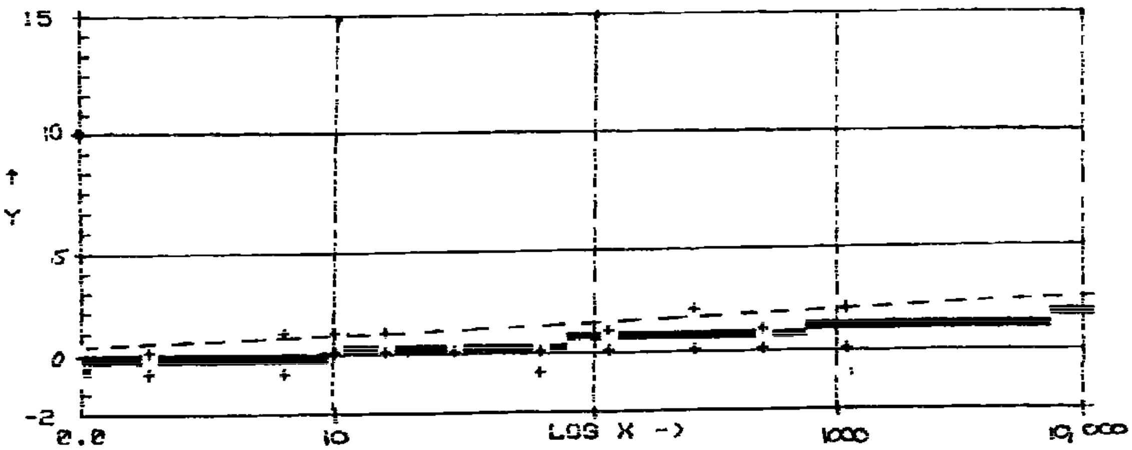


BS5216 HS1 CORR. STRESS 800N\MM2

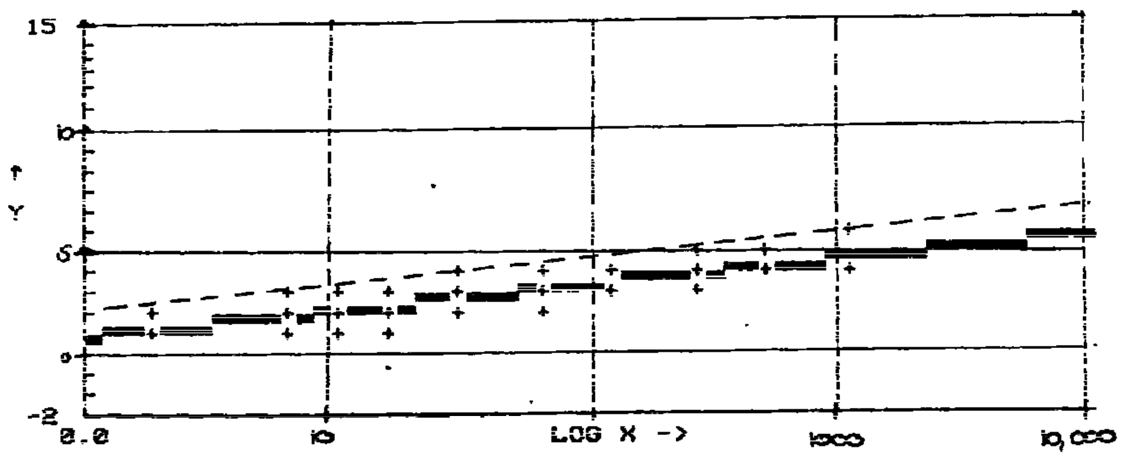
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

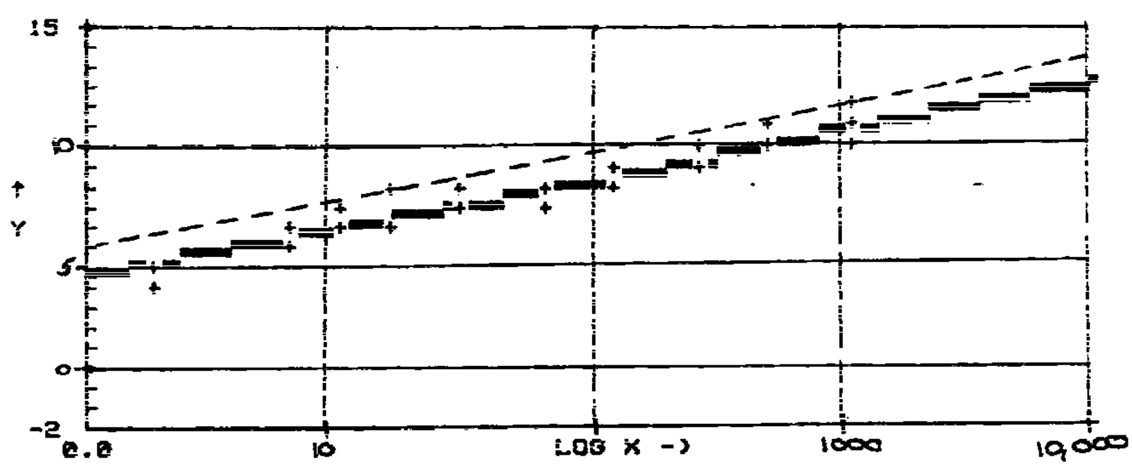
FIGURE 2 RELAXATION OF BS5216 HS3



BS5216 HS3 CORR. STRESS 400N\MM2



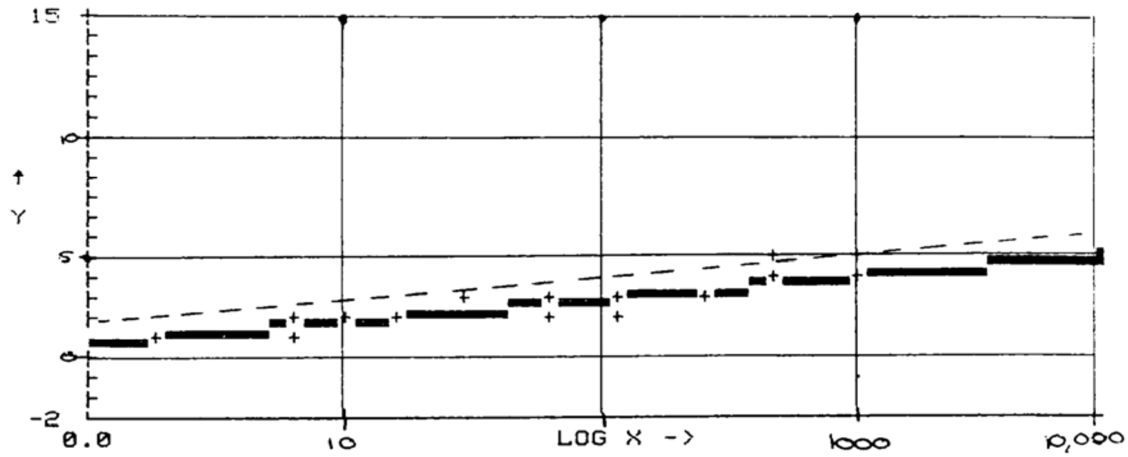
BS5216 HS3 CORR. STRESS 600N\MM2



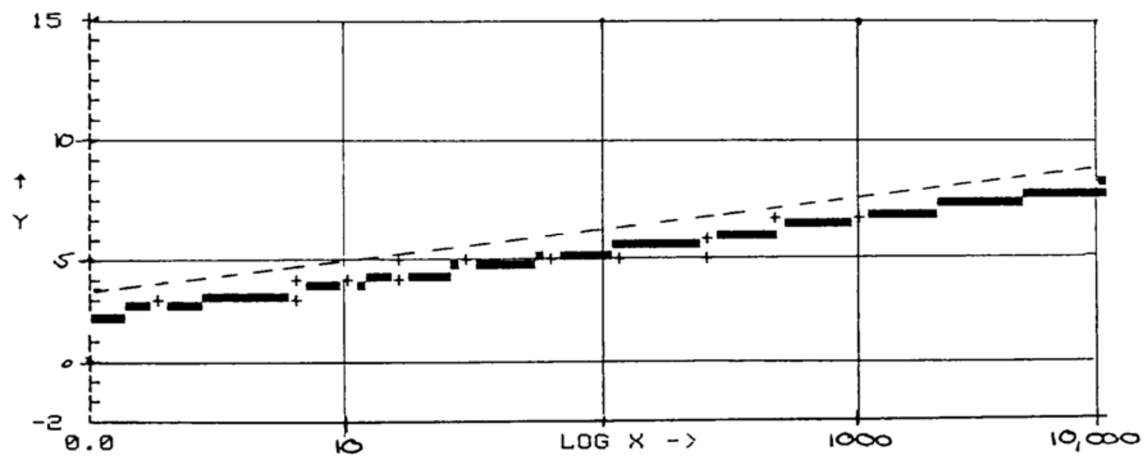
BS5216 HS3 CORR. STRESS 800N\MM2

WHERE:- X IS TIME(HOURS)
Y IS PERCENT RELAXATION

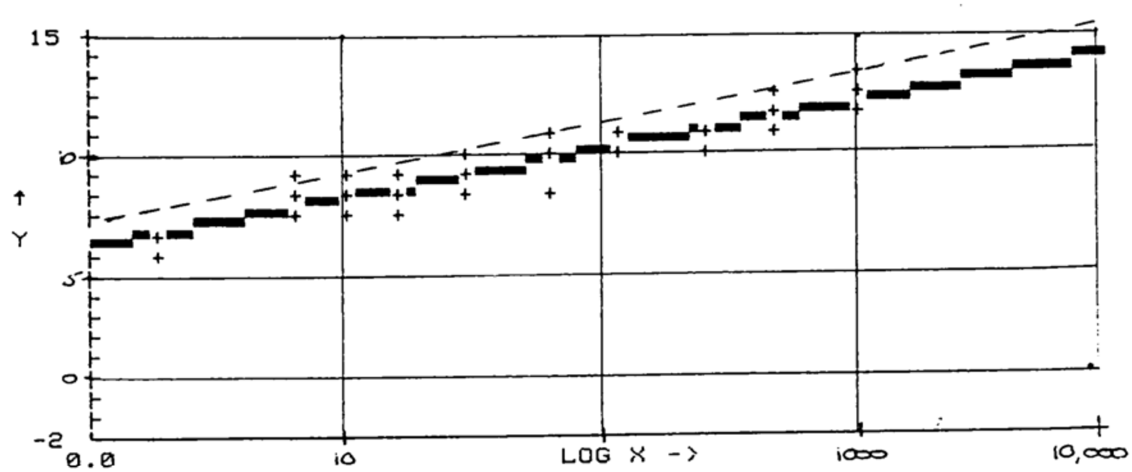
FIGURE 3 RELAXATION OF BS5216 M5



BS5216 M5 CORR. STRESS 600N\MM2



BS5216 M5 CORR. STRESS 800N\MM2

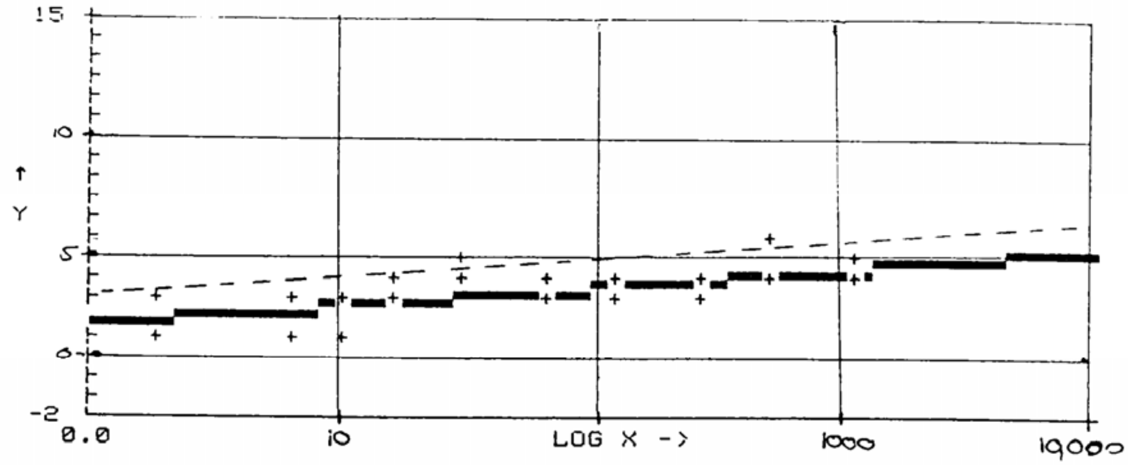


BS5216 M5 CORR. STRESS 1000N\MM2

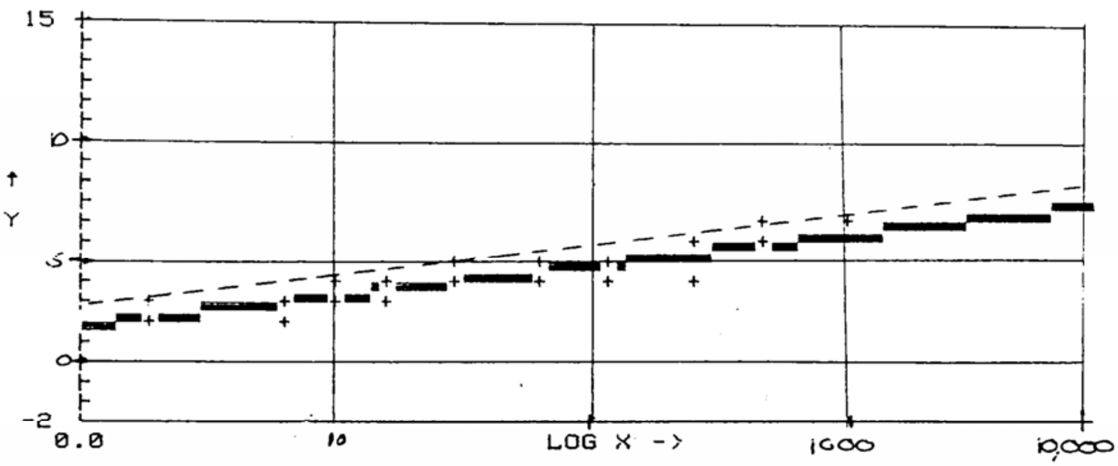
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

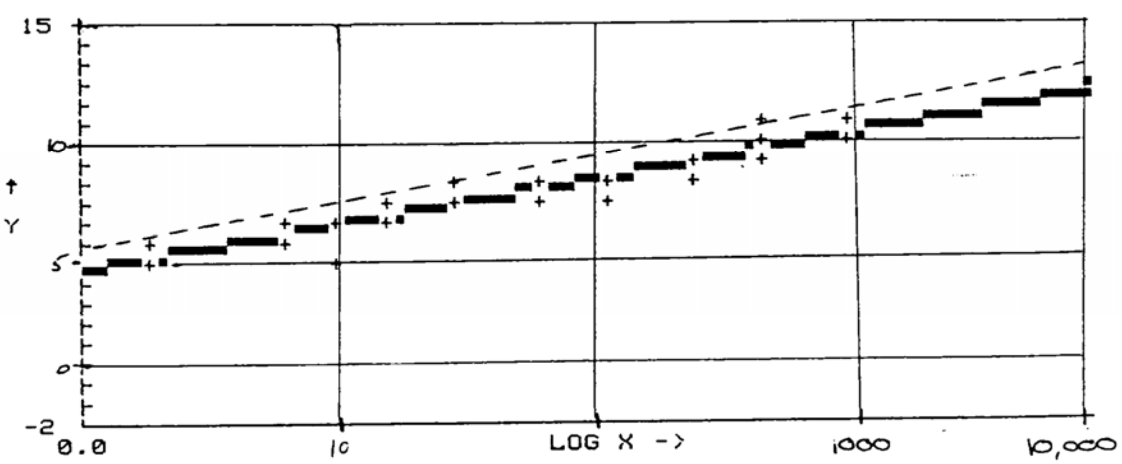
FIGURE 4 RELAXATION OF BS2803 080A65
CARBON STEEL



BS2803 CARBON CORR. STRESS 400N\MM2



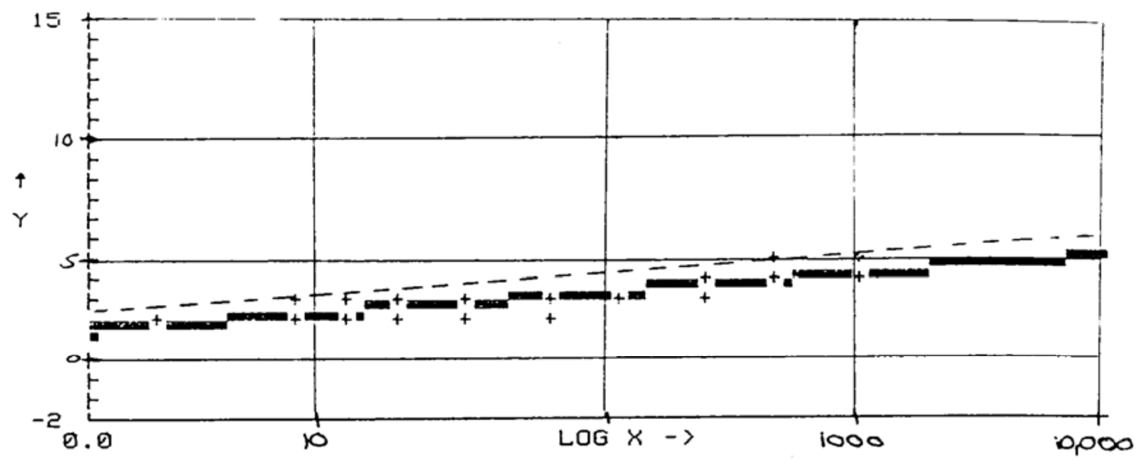
BS2803 CARBON CORR. STRESS 600N\MM2



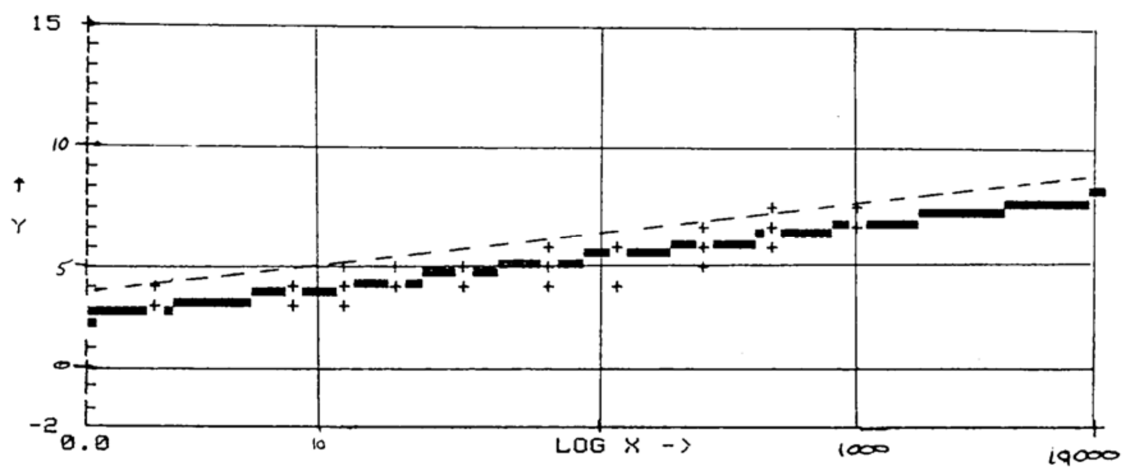
BS2803 CARBON CORR. STRESS 800N\MM2

WHERE:- X IS TIME(HOURS)
Y IS PERCENT RELAXATION

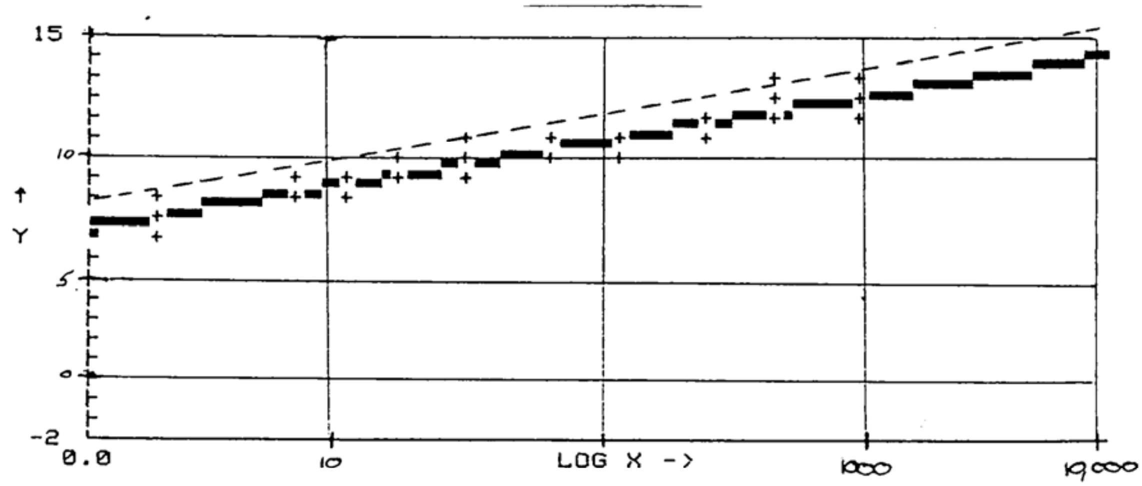
FIGURE 3 RELAXATION OF BS 2803 735A50 CHROME VANADIUM



BS2803 CRV CORR. STRESS 600N\MM2



BS2803 CRV CORR. STRESS 800N\MM2

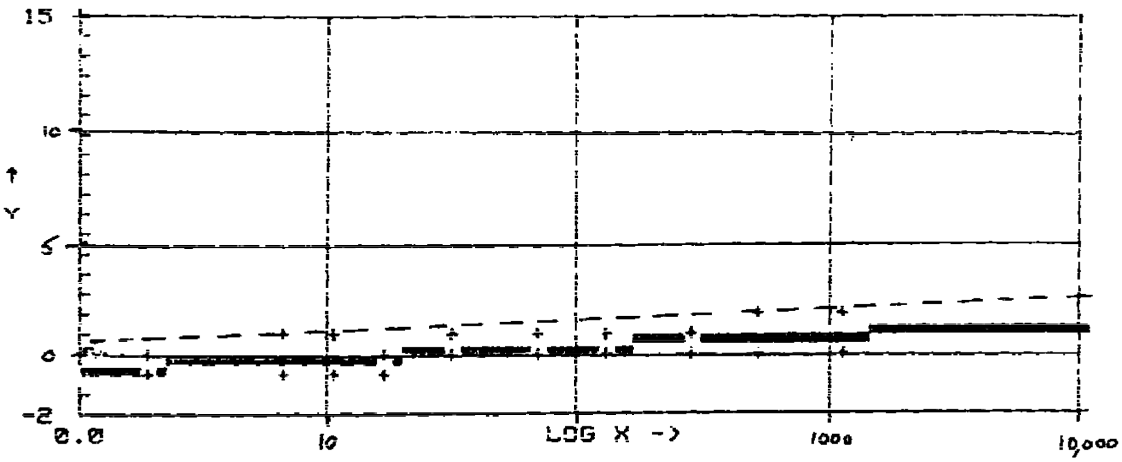


BS2803 CRV CORR. STRESS 1000N\MM2

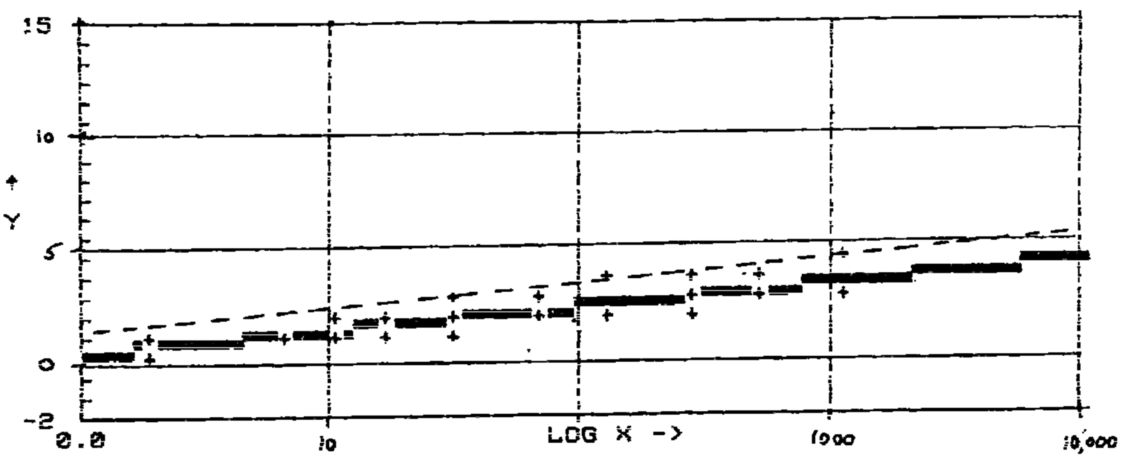
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

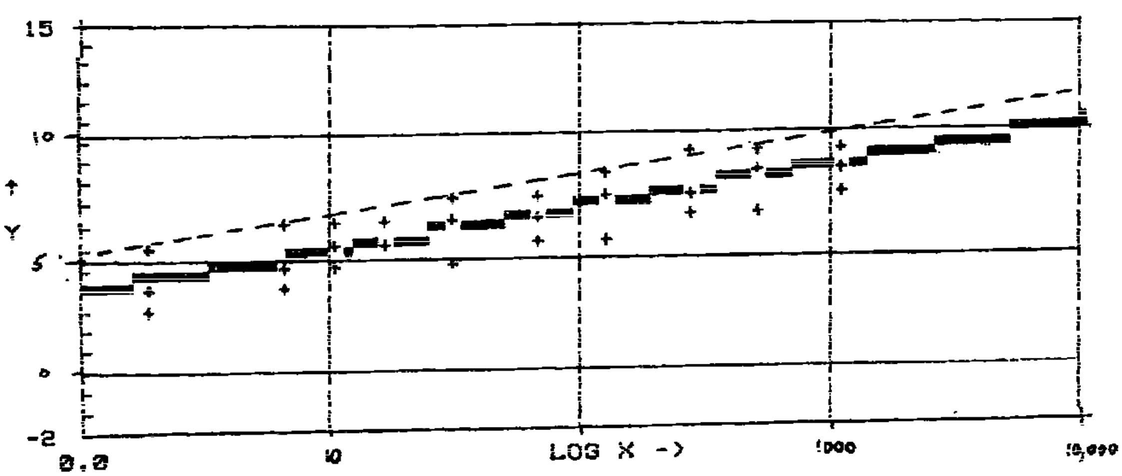
FIGURE 9 RELAXATION OF BS 2803 685A55 SILICON CHROME



BS2803 SIC CORR. STRESS 600N\MM2



BS2803 SIC CORR. STRESS 800N\MM2

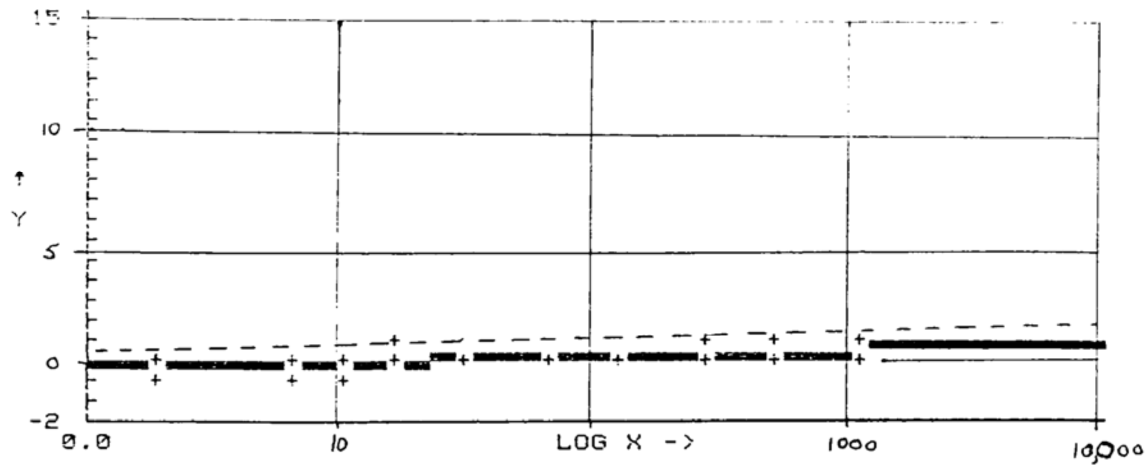


BS2803 SIC CORR. STRESS 1000N\MM2

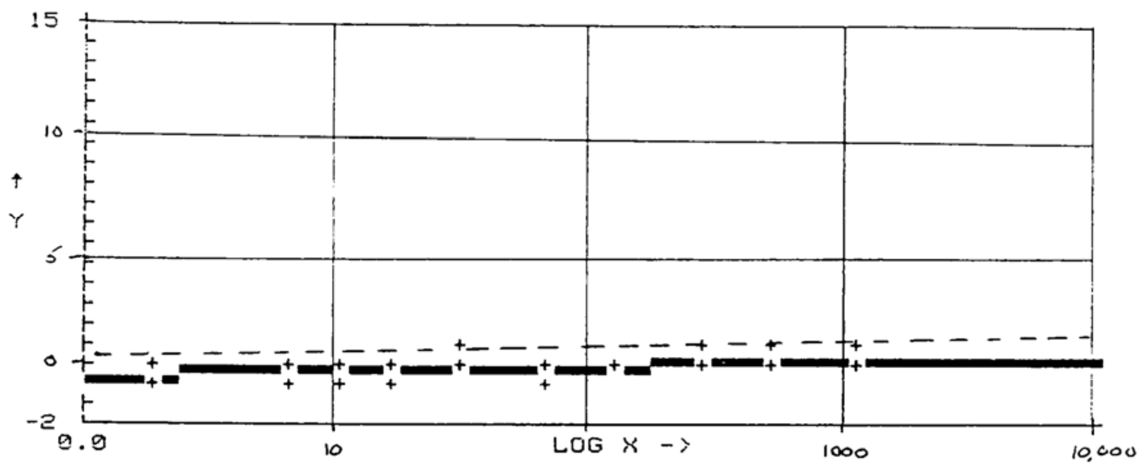
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

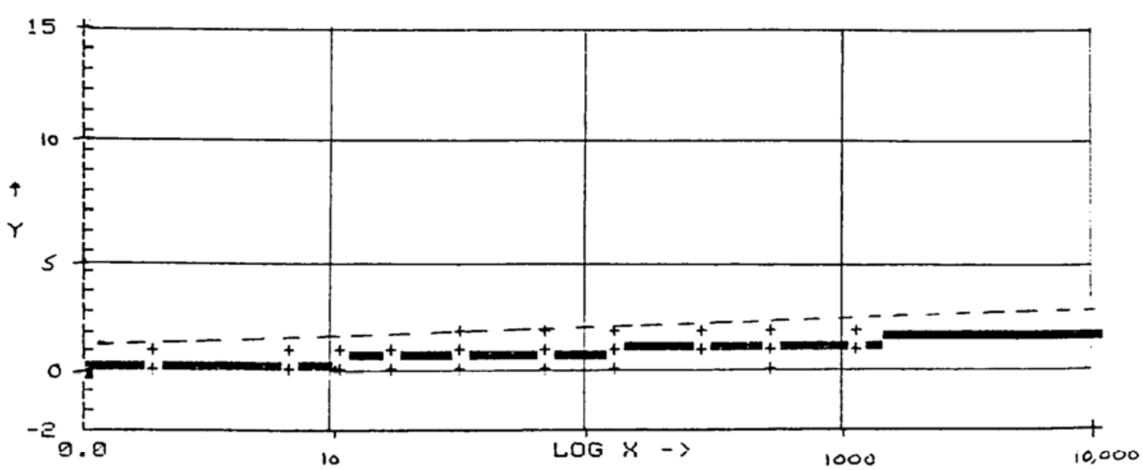
FIGURE 7 RELAXATION OF BS 2056 302S26



BS2056 302S26 CORR. STRESS 400N\MM2



BS2056 302S26 CORR. STRESS 600N\MM2

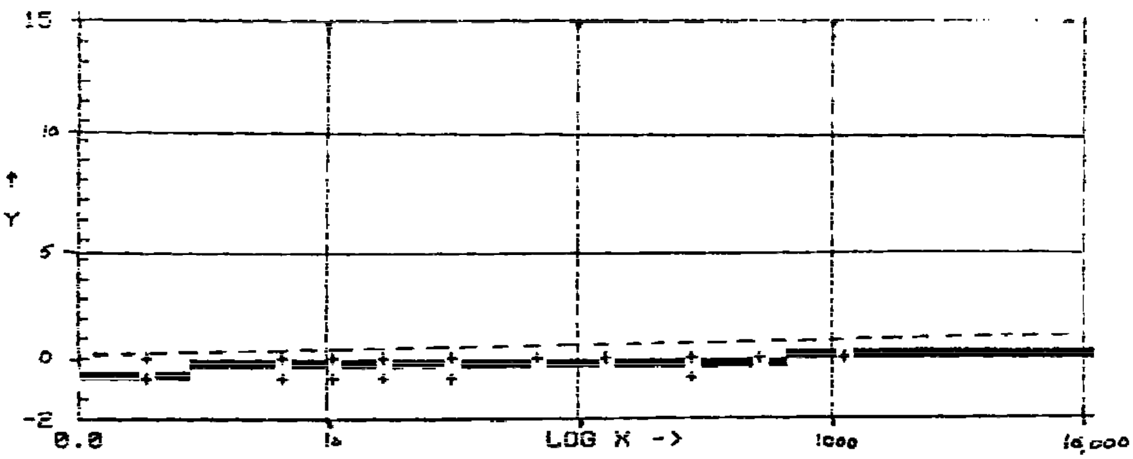


BS2056 302S26 CORR. STRESS 800N\MM2

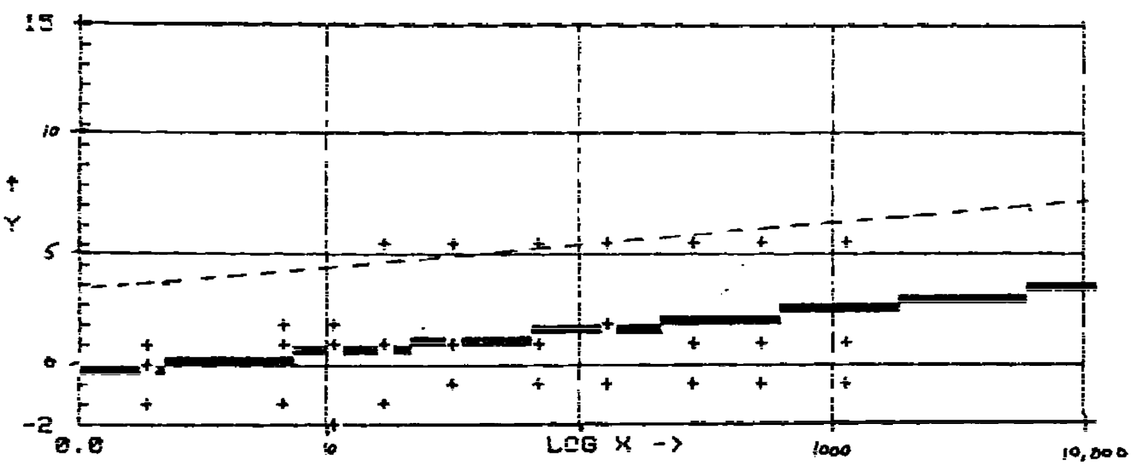
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

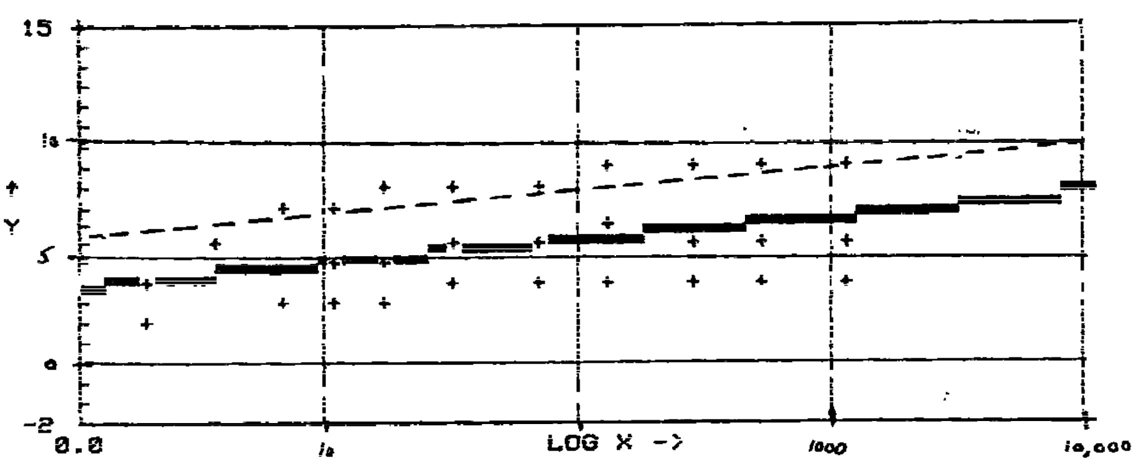
FIGURE 8 RELAXATION OF BS 2056 316S42



BS2056 316S42 CORR. STRESS 400N\MM2



BS2056 316S42 CORR. STRESS 600N\MM2

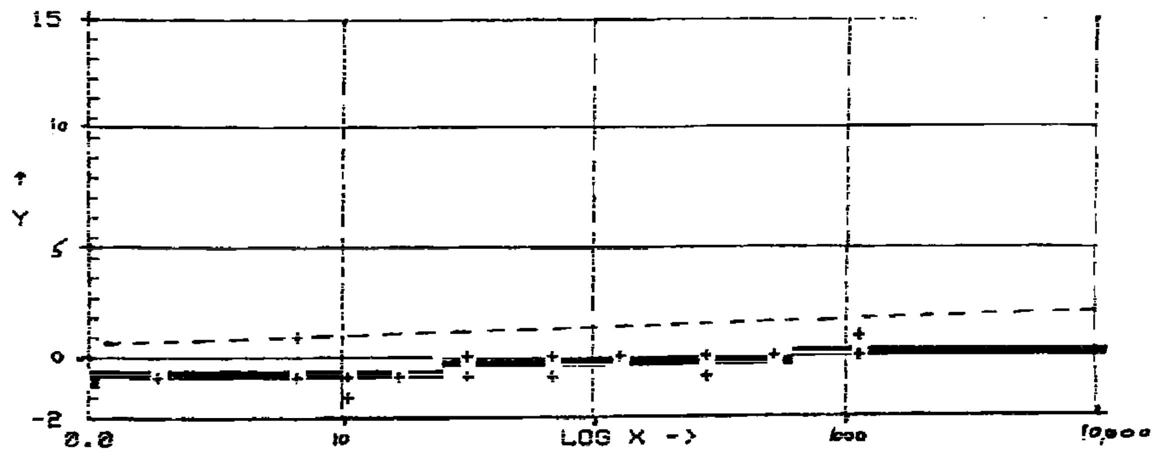


BS2056 316S42 CORR. STRESS 800N\MM2

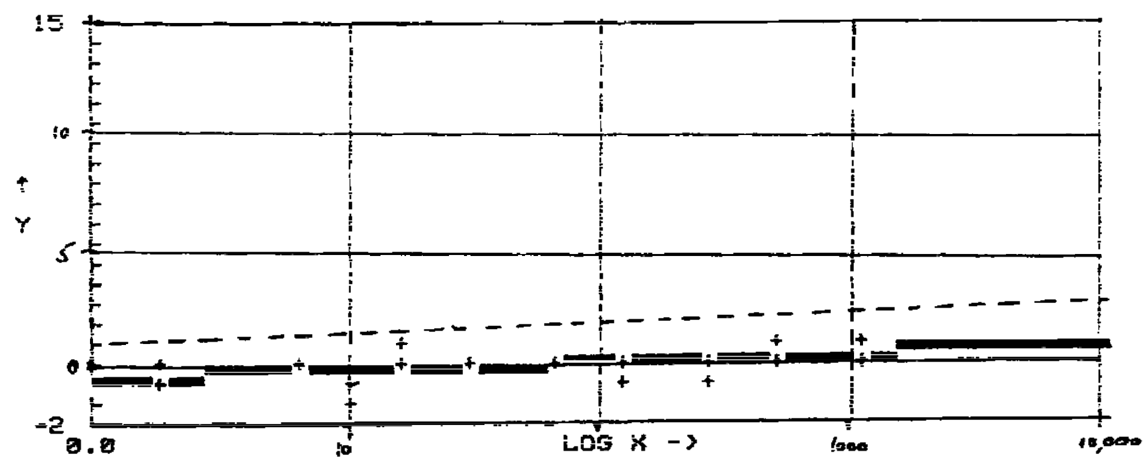
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

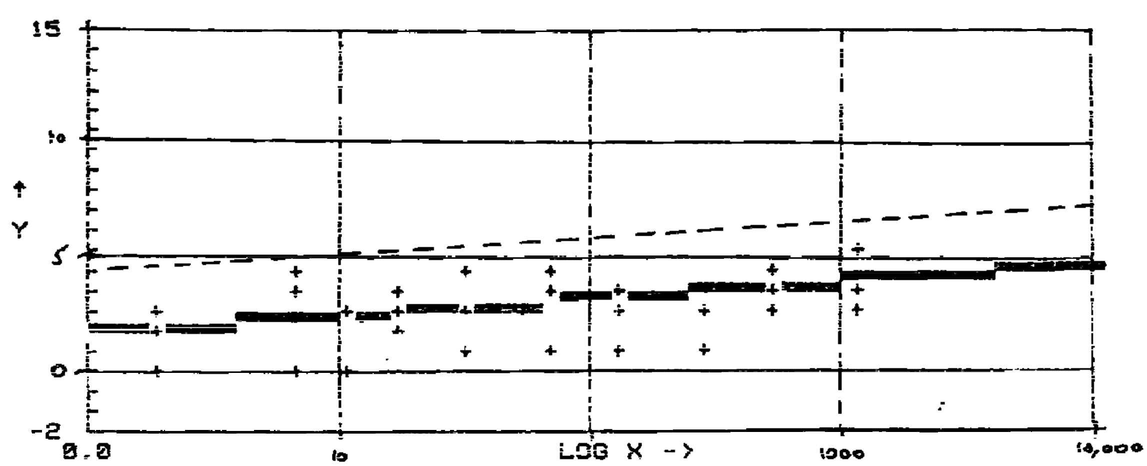
FIGURE 9 RELAXATION OF BS 2056 420S45



BS2056 420S45 CORR. STRESS 400N\MM2



BS2056 420S45 CORR. STRESS 600N\MM2

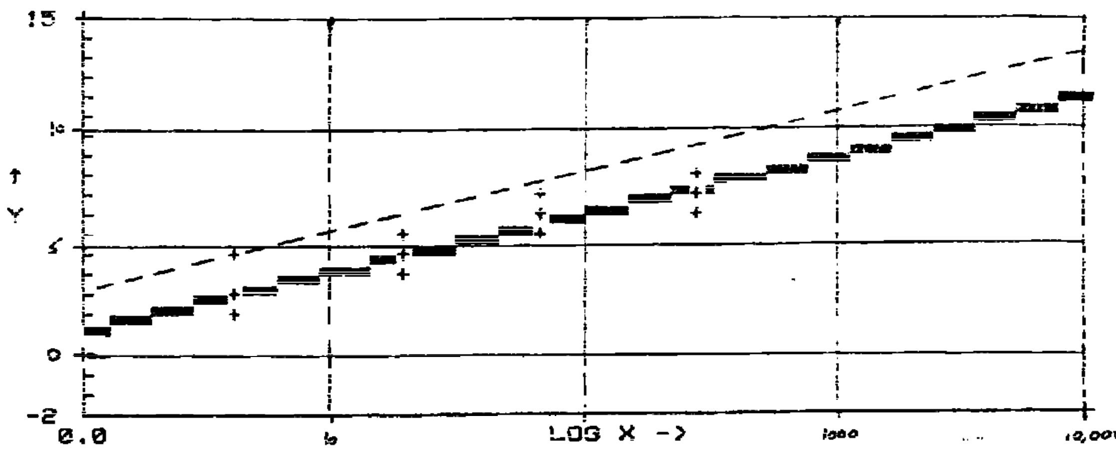


BS2056 420S45 CORR. STRESS 800N\MM2

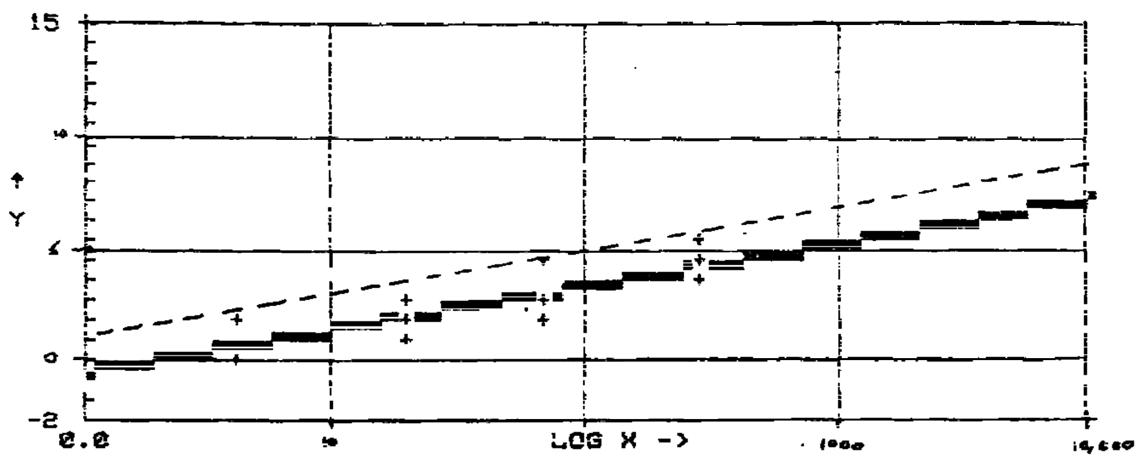
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

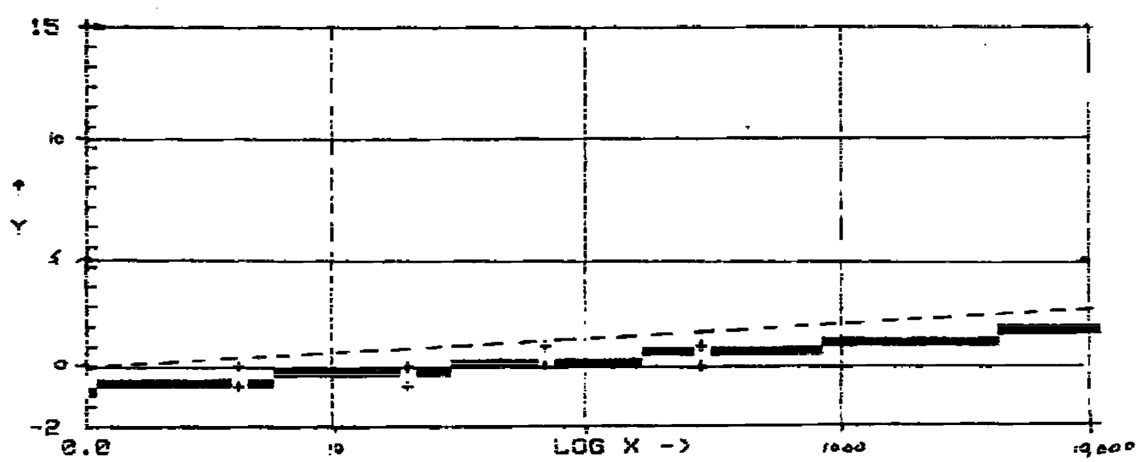
FIGURE 10 RELAXATION OF HOT PRESTRESSED UNPEENED SPRINGS



BS5216 MS CORR. STRESS 1000N\MM2



BS2803 CRV CORR. STRESS 1000N\MM2

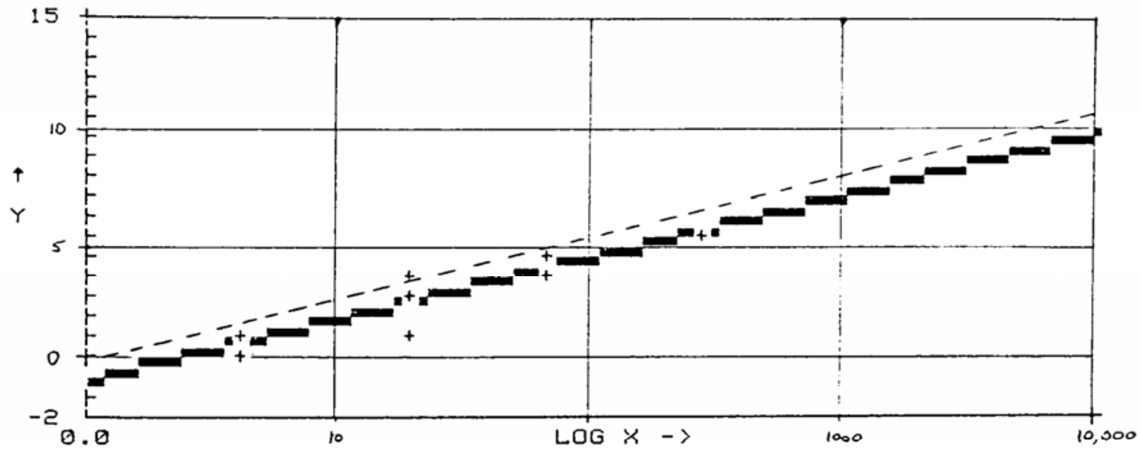


BS2803 SIC CORR. STRESS 1000N\MM2

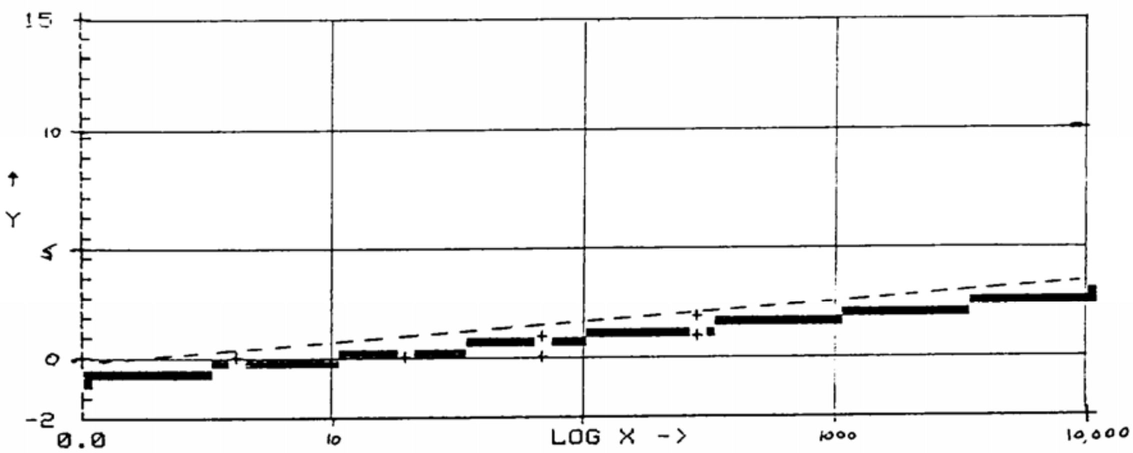
WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION

FIGURE 11 RELAXATION OF HOT PRESTRESSED SHOT PEENED SPRINGS



BS2803 CRV CORR. STRESS 1000N\MM2



BS2803 SIC CORR. STRESS 1000N\MM2

WHERE:- X IS TIME(HOURS)

Y IS PERCENT RELAXATION