THE SPRING RESEARCH AND MANUFACTURERS ASSOCIATION

THE LONG TERM RELAXATION BEHAVIOUR OF COMPRESSION SPRINGS MANUFACTURED FROM CARBON AND STAINLESS STEEL WIRES

by

M. O'Malley B.Sc.

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SUMMARY

A programme of work has been carried out to assess the long term relaxation behaviour of carbon and stainless steel springs with the intention of producing more accurate predictions of the amounts of relaxation that springs suffer after service durations. Tests have been carried out both at elevated temperatures and at room temperature, and they have continued for over 2500 hours, with the room temperature tests being allowed to continue into next year.

The results have shown that the relaxation behaviour of carbon and stainless steel springs obeys the logarithmic relaxation relationship derived by the Association very closely. The results have also shown that estimates previously made on the amounts of relaxation which springs could suffer have tended to be on the low side as springs continue to relax for a longer period of time than was previously expected, and thus during the primary stage of relaxation the spring will only suffer between 60-65% of its total possible relaxation.

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1. INTRODUCTION

During service, all compression springs are subject to relaxation. This relaxation occurs in two stages, primary or initial relaxation and secondary or steady state relaxation. Previously, it was thought that 90% of the relaxation which a spring could suffer occurred at the primary relaxation stage, with the relaxation occurring at a decelerating rate. Secondary relaxation then occurs at a constant rate and has a linear relationship with time. The time required for the primary stage of relaxation to be completed depends on the type of material from which the spring is made e.g. 72 hours is sufficient for carbon steel springs to reach the secondary relaxation stage, whereas 168 hours is required for stainless steel springs.

Most of the relaxation tests which have been carried out by the Association have been short term tests, with the springs being tested only for the length of time required to reach the secondary stage of relaxation. Only in a few cases (1,2) have these times been exceeded. In service, springs are required to operate for times far in excess of these short term tests. Thus,to predict the amount of relaxation that the springs may suffer, it has previously been the case to extrapolate the short term curves to the required length of time. This is not a very accurate method, and to get some idea of the extent to which further relaxation may occur, and to produce statistically significant relationships which could be applied to predict long term relaxation, this programme of work has been undertaken.

2. MATERIALS INVESTIGATED

Four grades of 2.8 mm diameter wire were used for this investigation. These were to BS 5216 HD3, BS 5216 M4, BS 2803 G2 and BS 2056 En58A specifications. The chemical composition of each grade of wire was obtained and this is shown in Table I along with the specified compositions. Full tensile and torsional properties were determined in the as-received condition and after the appropriate low temperature heat treatments for each type of wire, and these are shown in Table II. The BS 5216 HD3, BS 5216 M4 and BS 2803 G2 materials were heat treated at 350°C for 30 mins., and the BS 2056 En58A was heat treated at 500°C for 30 mins. Springs were produced to the dimensions listed in Table III.

3. DEVELOPMENT OF EXPERIMENTAL PROCEDURE

As a large number of springs were used for this investigation and each spring was repeatedly load tested after defined intervals of time in order to produce a time-relaxation curve, it was necessary to develop the method of relaxation testing used to reduce the amount of time and labour spent in load testing the springs. The following method was decided upon.

The springs were first load tested as in the conventional method of relaxation testing to the required load (P_o) to give the desired stress level, and the compressed length (L_o) was then measured.

The springs were then bolted down onto stainless steel bolts to this measured length (L_o). The upper washer on the bolt was a large diameter heavy duty stainless steel washer. The springs were then reload-tested using the spider attachment which fitted over the top of the bolt and rested on the stainless steel washer (See Fig. 1.). The springs were compressed to a load (P_1) which was slightly in excess of the bolted down load (P_o), and the compressed length (L_1) then measured. The springs were then placed in an oven at the appropriate temperature for a fixed length of time, removed, allowed to cool, and then reload-tested while still on the bolts using the spider attachment, by compressing to the measured length (L_1) and measuring the new load (P_2).

When relaxation occurs, the rate of the spring does not change, the spring simply loses some of its length i.e. it sets down. Thus the difference between the two loads (P_1 and P_2) will be the same as the difference in the load measured at the bolted down length. Thus the amount of relaxation suffered by the spring can be calculated from the formula:-

$$\% \text{ Rel} = \frac{P_1 - P_2}{P_o} \times 100 \quad \text{........(1)}$$

where % Rel = % relaxation
P_1 = original load at length L_1 (N)
P_2 = new load at length L_1 (N)
P_o = original load at bolted down length L_o (N)

As the springs were not removed from the bolts once the relaxation tests had been started, the errors involved in the measurement of the bolted down length which would have arisen in the conventional method of relaxation testing were thus eliminated.

4. EXPERIMENTAL METHOD

The investigation involved compression of springs made from each batch of material on stainless steel bolts at stress levels of 400, 600 and 800 N/mm^2. The load required to stress each spring to the required level was calculated using:-

$$P = \frac{\pi d^2 \tau}{8cK} \quad \text{...........(2)}$$

Where P = axial load (N) applied to the spring
τ = torsional stress (N/mm^2) due to the load P
d = diameter of wire (mm)
c = spring index
K = correction factor due to curvature

$$= \frac{c+0.2}{c-1}$$

Relaxation tests were then carried out at room temperature for all four types of spring, at 150°C for the BS 5216 HD3, BS 5216 M4 and BS 2803 G2 springs, and at 250°C for the BS 2056 En58A springs using the method described in section 3.

5. RESULTS

The results obtained from the relaxation tests are shown in Figures 2 - 9. These results were plotted using the logarithmic time relaxation relationship:-

$$\text{Rel} = a \ln t + b \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where Rel = % relaxation
t = time of test (hours)
a and b are constants

Confidence limits for the curves were determined by statistical analysis of the residuals obtained from the experimental data and the relaxation given by the regression relationships. The values for the constants a and b, and the 95% confidence interval for the curves are shown in Table IV for the room temperature test and in Table V for the elevated temperature tests.

6. DISCUSSION OF RESULTS

The materials used in the investigation complied with the appropriate British Standards with respect to both their chemical compositions, and their tensile strengths.

At every load testing stage of the investigation, one spring of each type of material was chosen at random, unbolted and load tested to the bolted down length. In each case, the value of the relaxation measured using this method was within ± 0.3% of the value obtained for that same spring when tested on the bolt using the modified method. Thus, the results obtained using the modified method, and the conclusions drawn from these results, can be considered to be a valid interpretation of the relaxation behaviour of the springs.

All the results obtained fitted the logarithmic time- relaxation relationship very closely, and all the curves gave correlations which were significant to the 99.9% level. This is shown in Figs 2-9 which have been plotted using a logarithmic time scale and the results are very close to being straight lines.

Figs. 2A and 7A which have been plotted using a linear time scale, show the two stages of relaxation very clearly. The initial curved portion represents the primary relaxation stage, and the linear portion represents the secondary relaxation stage. N.B. Figs. 2 and 7 are identical to Figs. 2A and 7A except that in Figs.2A and 7A the results have been plotted using a linear time scale, and in Figs. 2 and 7 a logarithmic time scale has been used.

The relaxation behaviour of the different types of spring in the elevated temperature tests was as expected. The stainless steel springs had better relaxation resistance than the carbon steel springs, and the oil hardened and tempered springs were more resistant to time relaxation than the patented steel springs. This is in agreement with results previously obtained (3,4). At room temperature, the stainless steel springs were more resistant to relaxation than the carbon steel springs, the oil hardened and tempered springs and the patented steel springs suffering about the same amount of relaxation.

The results show that over a long period of time (e.g. 2500 hours) springs will suffer a greater amount of relaxation than was previously expected. For example 10% relaxation was considered to be a reasonable amount of relaxation for a carbon steel spring, stressed at about 600 N/mm^2 and operating at about

150°C. The springs tested have relaxed as much as 15% after 2500 hours, and further relaxation can be expected. Similarly, spring operating at room temperature have previously only been expected to suffer a few percent relaxation. The springs tested in this investigation showed as much as 5-8% after 4000 hours.

It can be seen from the graphs and from Tables IV and V, that the rate of relaxation depends on the stress to which the spring is subjected. The rate of relaxation is greater at higher stresses than at lower stresses. The BS 2056 En 58A springs, tested at 600 N/mm^2 and 250°C showed a lower relaxation rate than those tested at the two other stresses. There does not appear to be any apparent reason as to why this has occurred.

In service, spring operating under static loading conditions are normally expected to operate for a number of years. Thus the curves obtained have been extrapolated to 10,000 and 20,000 hours to show the extent to which further relaxation may occur. The predicted relaxations thus obtained are shown in Table A below for room temperature relaxation, and in Table B for elevated temperature relaxation.

TABLE A POSSIBLE 10,000 and 20,000 HOUR RELAXATION PROJECTED 2500 HOUR TIME-RELAXATION TESTS CARRIED OUT AT ROOM TEMPERATURE

MATERIAL	PROJECTED 10,000 HOUR-RELAXATION AT STRESSES OF			PROJECTED 20,000 HOUR-RELAXATION AT STRESSES OF		
	400N/mm^2	600 N/mm^2	800 N/mm^2	400 N/mm^2	600 N/mm^2	800N/mm^2
BS 5216 HD3	5.3	5.6	6.8	6.1	6.4	7.7
BS 5216 M4	5.1	6.8	7.7	5.8	7.7	8.7
BS 2803 G2	7.3	8.4	9.4	8.2	9.4	10.5
BS 2056 En58A	2.7	3.3	4.1	3.1	3.8	4.7

TABLE B POSSIBLE 10,000 AND 20,000 HOUR RELAXATION PROJECTED 2500 HOUR TIME-RELAXATION TESTS CARRIED OUT AT ROOM TEMPERATURE

MATERIAL	TEST TEMPERATURE °C	PROJECTED 10,000 HOUR-RELAXATION AT STRESSES OF			PROJECTED 20,000 HOUR RELAXATION AT STRESSES OF		
		400 N/mm^2	600 N/mm^2	800 N/mm^2	400 N/mm^2	600 N/mm^2	800 N/mm^2
BS 5216 HD3	150	12.9	15.6	20.1	13.7	16.5	21.2
BS 5216 M4	150	13.4	13.7	17.9	14.1	14.4	18.7
BS 2803 G2	150	11.5	14.9	17.4	12.2	15.7	18.1
BS 2056 En58A	250	3.9	4.8	7.2	4.3	5.1	7.7

If the results obtained for the short term tests are expressed as a percentage of these possible long term values, then it appears that for carbon steel springs operating at 150°C 65% of the possible relaxation occurring in 10,000 hours will have occurred after 72 hours, and 90% of th relaxation will have occurred after 2,500 hours. For stainless steel springs operating at 350°C, 60% of the possible relaxation occurring in 10,000 hours will have occurred after 168 hours, and 85% will have occurred after 2,500 hours.

Zimmerli(5) has deduced from his work that 90% of the total relaxation suffered by carbon steel springs at 150°C would have occurred after 72 hours, and that 90% of the total relaxation suffered by stainless steel springs at 250°C would have occurred in 168 hours. This has now been shown to be an incorrect estimate, as although the rate of relaxation of the spring does decrease with increasing time, it does not completely stop as Zimmerli suggested. Examination of figures 2-9 clearly show that the rate of secondary relaxation is decreasing, but the curves have not yet become horizontal, at which stage there would be no further increase in relaxation.

7. CONCLUSIONS

1. The relationships which have been produced are statistically significant to the 99.99% level and can be used to predict the long term relaxation data of the types of material used in this investigation from results obtained in short term tests.

2. The amount of relaxation occurring at the primary relaxation stage,i.e. within the first 72 hours for carbon steel springs and within the first 168 hours for stainless steel springs, does not represent 90% of the total relaxation of the spring. A more conservative estimate would appear to be between 60 and 65% of the total relaxation that the spring could suffer.

3. Even at room temperature springs can suffer as much as 5-8% relaxation after fairly short periods of time when compared with service durations.

4. Stainless steel springs are more resitant to relaxation than carbon steel springs both at elevated temperatures and at room temperature.

8. AREAS OF FUTURE WORK

1. The work being carried out at room temperature will continue into next year, with the tests running for as long as possible.

2. Further long term tests should be carried out to assess the relaxation behaviour of other types of spring material, and also to assess the effect of such processes as hot prestressing on the long term relaxation behaviour of spring materials.

9. REFERENCES

1) Graves G.B. "The stress-relaxation properties of Nimonic 90 and Inconel X - 750 helical compression springs". SRAMA Report No. 152.

2) Graves G.B. "The fatigue and relaxation resistance of copper - beryllium helical compression springs". SRAMA Report No. 263.

3) Graves G.B. "The stress temperature relaxation and creep properties of some spring materials". SRAMA Report No. 143.

4) Graves G.B. "The stress temperature relaxation properties of springs made from oil tempered and patented hard drawn wires". CSFRO Report No. 115.

5) Zimmerli F.P. "Effect of temperature on coiled steel springs under various loadings". Trans ASME, 1941, 63, May p.p. 363-8.

TABLE I CHEMICAL COMPOSITION OF MATERIALS USED IN THE INVESTIGATION

Material	Element %						
	C	Mn	Si	S	P	Cr^x	Ni^x
BS 5216 HD3 Specified	0.55 0.85-	0.30 1.00-	0.35 max	0.030 max	0.030 max		
BS 5216 HD3 Actual	0.80	0.59	0.15	0.017	0.018		
BS 5216 M4 Specified	0.70 1.00-	0.25 0.75-	0.35 max	0.030 max	0.030 max		
BS 5216 M4 Actual	0.80	0.42	0.18	0.020	0.014		
BS 2803 G2 Specified	0.55 0.75-	0.60 0.90-	0.30 max	0.040 max	0.040 max		
BS 2803 G2 Actual	0.62	0.75	0.24	0.015	0.017		
BS 2056 En58A Specified	0.16 max	2.00 max	0.20 min	0.045 max	0.045 max	17.0- 20.0	7.0- 10.0
BS 2056 En58A Actual	0.078	0.68	0.50	0.003	0.028	17.5	8.4

^{x}N.B. Cr + Ni ≥ 25.0

TABLE II MECHANICAL PROPERTIES

Material and condition	Tensile Properties					Torsional Properties		
	Rm N/mm^2	L of P N/mm^2	Rp 0.05 N/mm^2	Rp 0.1 N/mm^2	Rp 0.2 N/mm^2	L of P N/mm^2	0.1% PS N/mm^2	0.2% PS N/mm^2
BS 5216 HD3 As rec'd	1735	770	1295	1465	1600	330	685	760
BS 5216 HD3 LTHT 350°C	1675	1060	1400	1450	1485	405	830	900
BS 5216 M4 As rec'd	1875	470	1265	1525	1715	440	765	885
BS 5216 M4 LTHT 350°C	1785	690	1405	1490	1530	760	960	1010
BS 2803 G2 As rec'd	1615	840	1435	1460	1475	610	920	980
BS 2803 G2 LTHT 350°C	1625	770	1455	1460	1465	805	965	1010
BS 2056 En58A As rec'd	1475	570	970	1105	1240	235	555	560
BS 2056 En58A LTHT 500°C	1575	775	1135	1255	1390	400	675	795

TABLE III SPRING DIMENSIONS

MATERIAL	WIRE DIAMETER (mm)	COIL DIAMETER (mm)	FREE LENGTH	INDEX	ACTIVE COILS	TOTAL COILS	SOLID STRESS N/mm^2	%UTS
BS 5216 HD3	2.8	19.6	20.26	7	3.5	5.5	1175	70
BS 5216 M4	2.8	19.6	21.56	7	3.5	5.5	1250	70
BS 2803 G2	2.8	19.6	19.66	7	3.5	5.5	1140	70
BS 2056 En58A	2.8	19.6	18.97	7	3.5	5.5	1100	70

TABLE IV ANALYTICAL CONSTANTS FOR LOGARITHMIC TIME RELAXATION OF SPRINGS TESTED AT ROOM TEMPERATURE FOR UP TO 4000 HOURS

Material	Initial Stress N/mm^2	Constants for Rel = a lnt+b		Increment for 95% confidence = 1.96 x S_R^*
		a	b	
BS 5216 HD3	400	1.0706	-4.5	1.4
	600	1.0707	-4.2	1.5
	800	1.2768	-4.9	1.7
BS 5216 M4	400	1.0327	-4.5	2.1
	600	1.3157	-5.4	1.6
	800	1.3829	-5.0	1.7
BS 2803 G2	400	1.2734	-4.4	1.7
	600	1.4689	-5.1	1.6
	800	1.6090	-5.4	2.1
BS 2056 En58A	400	0.5986	-2.8	1.7
	600	0.7076	-3.2	1.4
	800	0.8821	-4.0	1.6

S_R^* = Standard Deviation of the residuals derived from the difference between the experimental relaxation data and the values obtained from the analytical expression.

TABLE V ANALYTICAL CONSTANTS FOR LOGARITHMIC TIME RELAXATION OF SPRINGS TESTED AT ELEVATED TEMPERATURES FOR UP TO 2500 HOURS

Material	Test Temperature °C	Initial Stress N/mm^2	Constants for Rel = a lnt+b		Increment for 95% confidence = 1.96 S_R*
			a	b	
BS 5216 HD3	150	400	1.1373	2.5	3.2
		600	1.2999	3.6	1.5
		800	1.5239	6.1	1.9
BS 5216 M4	150	400	1.0343	3.9	2.2
		600	0.9454	5.0	2.4
		800	1.0990	7.8	1.8
BS 2803 G2	150	400	1.8911	3.3	1.3
		600	1.1166	4.6	2.7
		800	0.9768	8.4	1.5
BS 2056 En 58A	250	400	0.5230	-0.9	1.6
		600	0.4305	0.8	1.4
		800	0.7034	0.7	1.6

*S_R = Standard Deviation of the residuals derived from the difference between the experimental relaxation data and the values obtained from the analytical expression.

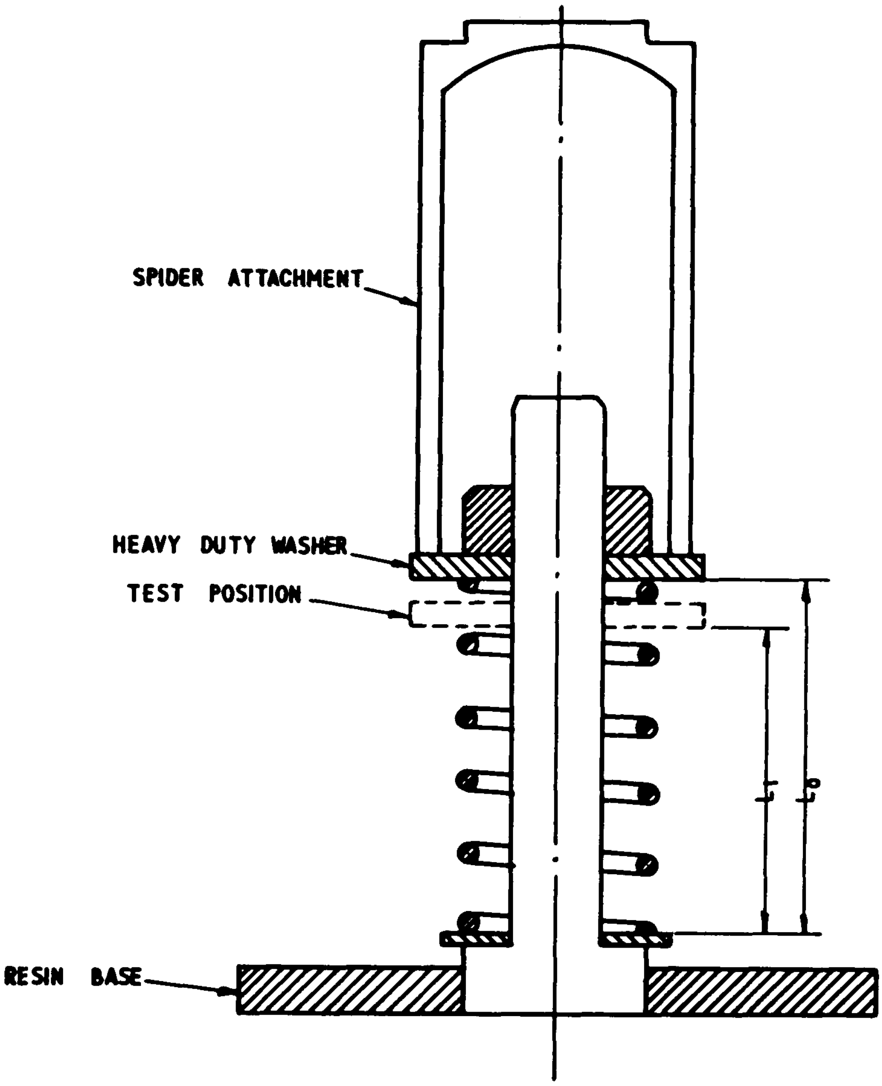

FIG. 1. STRESS-RELAXATION APPARATUS.

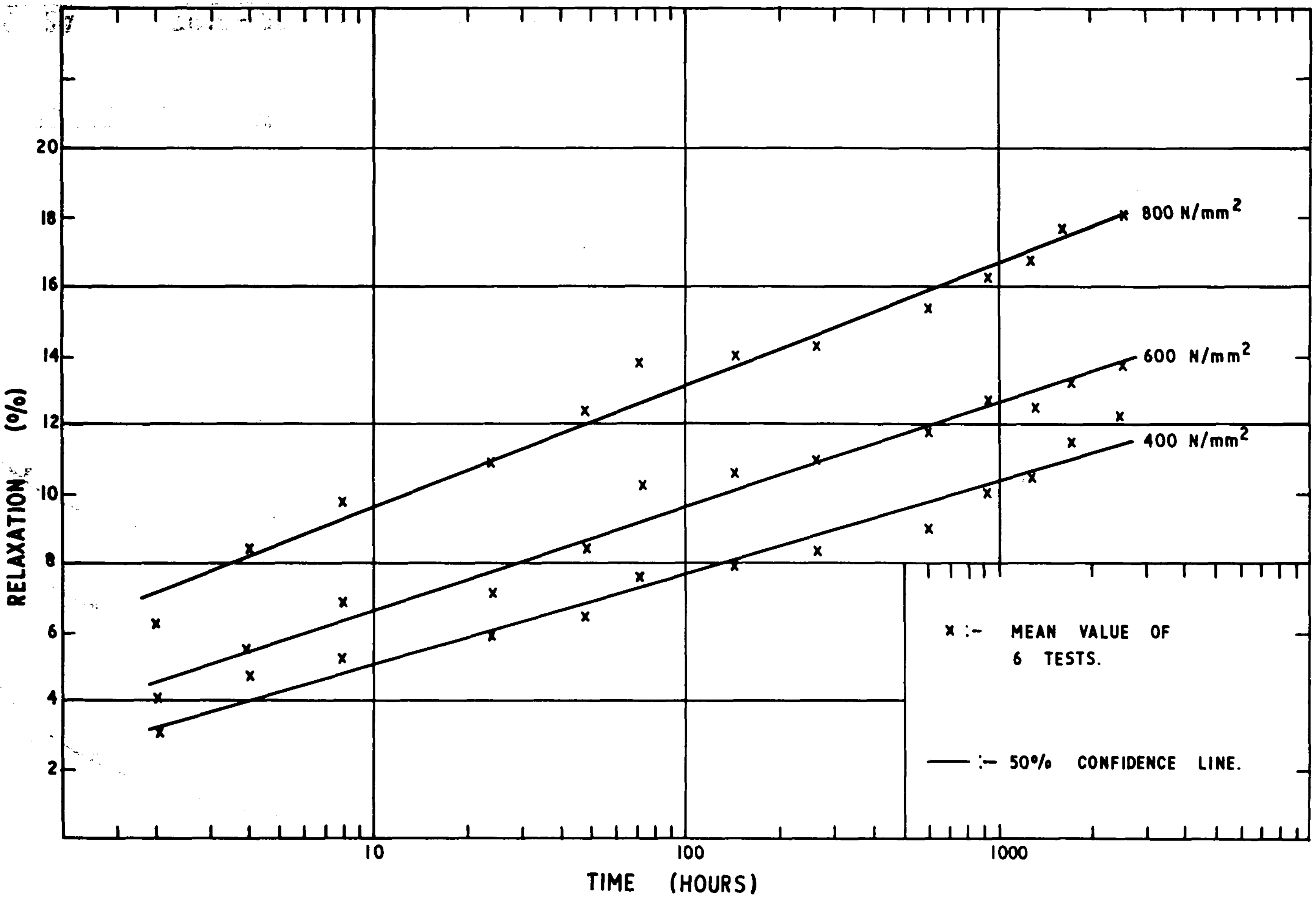

FIG. 2. TIME-RELAXATION OF BS 5216 HD 3 SPRINGS AT 150° C.

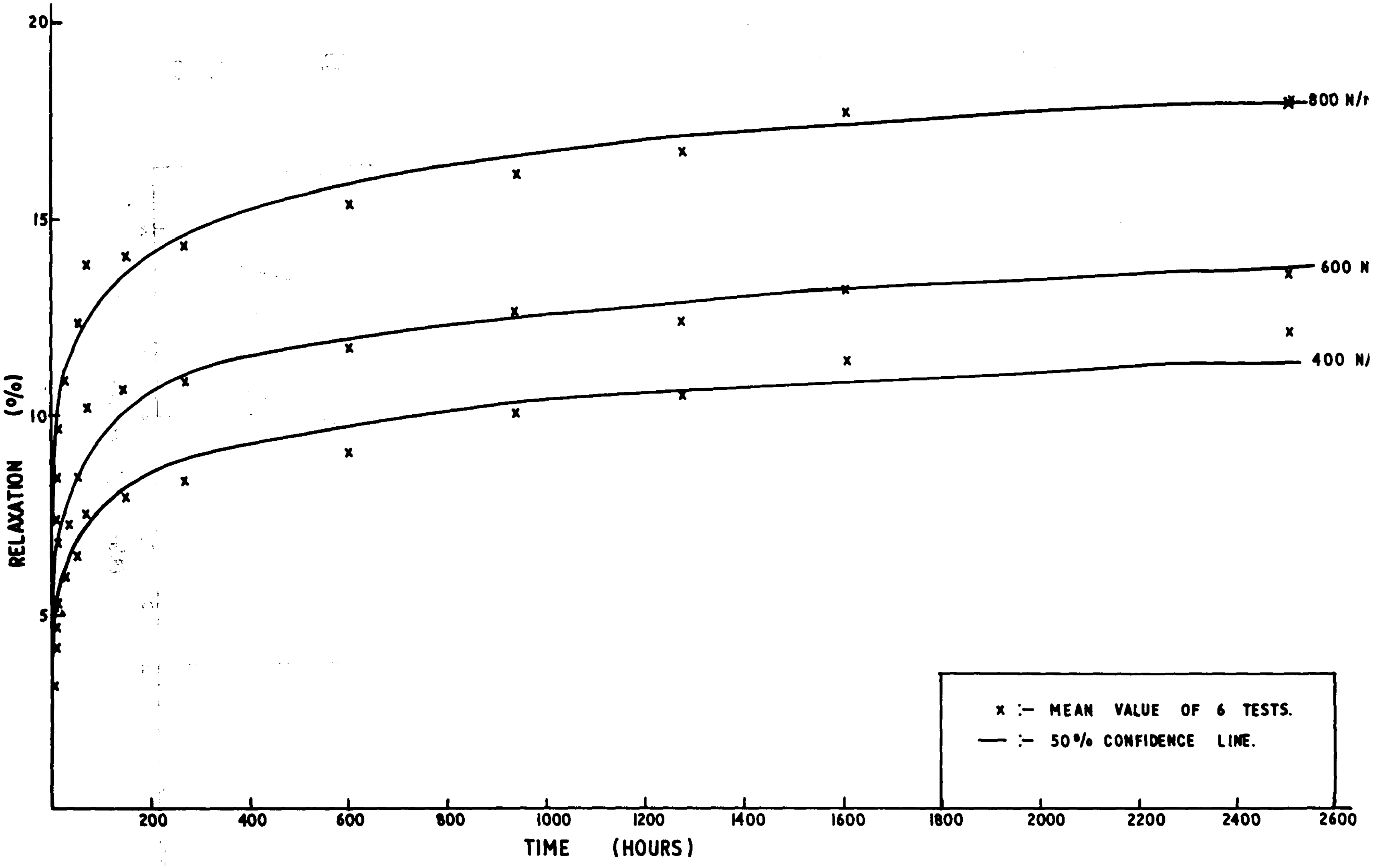

FIG. 2A. TIME-RELAXATION OF BS 5216 HD 3 SPRINGS AT 150° C.

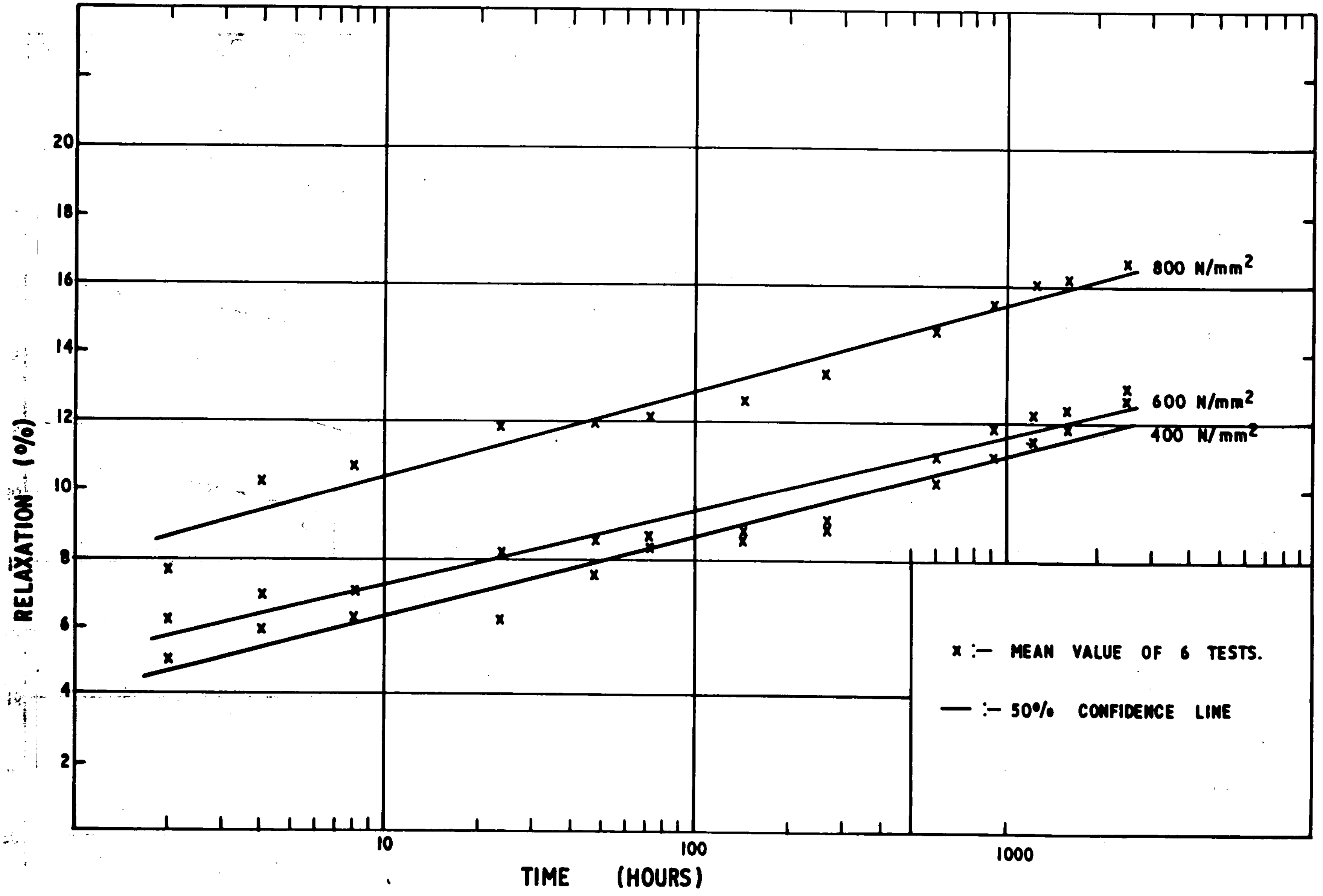

FIG. 3. TIME RELAXATION OF BS 5216 M4 SPRINGS AT 150°C.

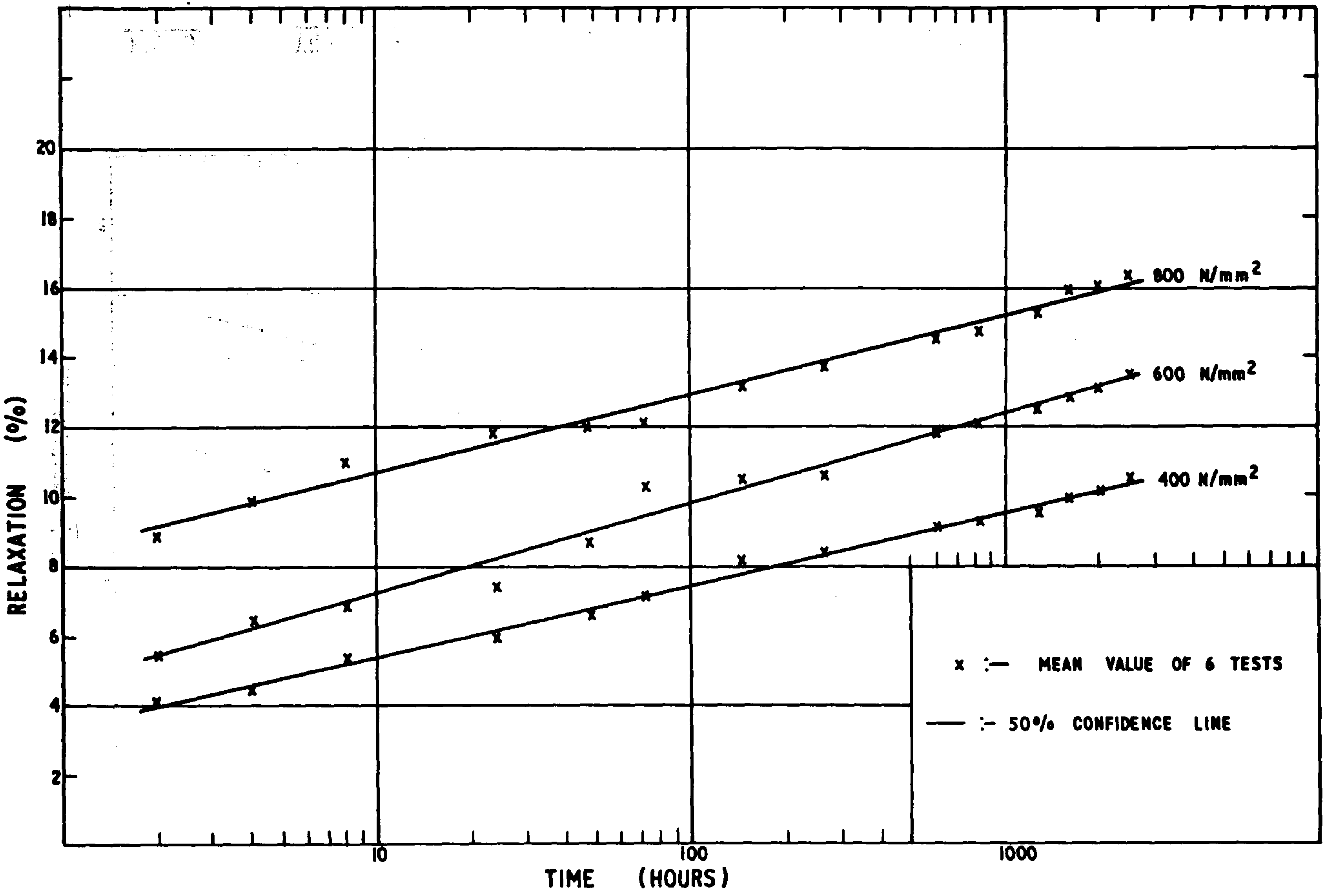

FIG. 4 TIME-RELAXATION OF BS 2803 G2 SPRINGS AT 150° C.

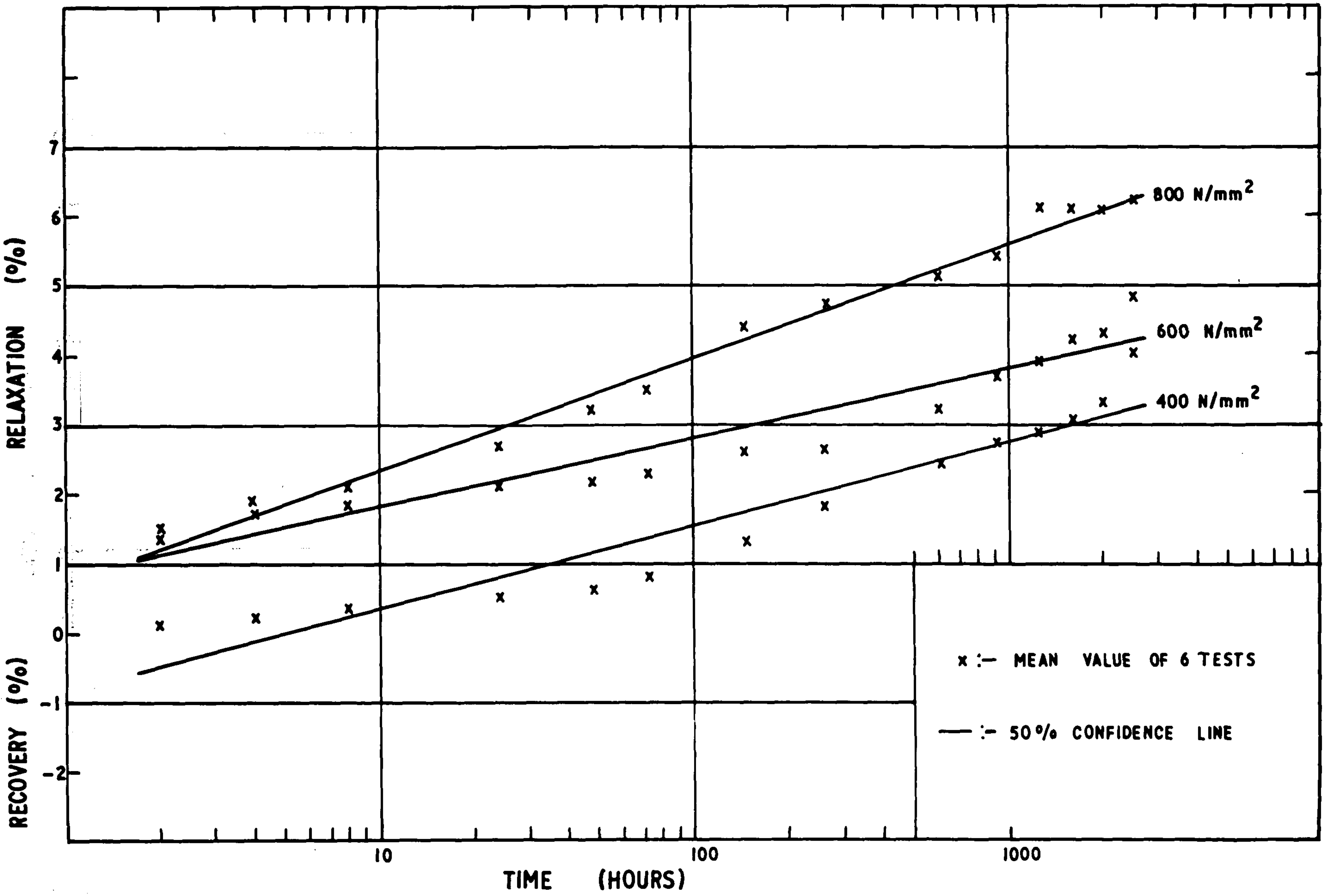

FIG. 5 TIME-RELAXATION OF BS 2056 En 58A SPRINGS AT 250° C.

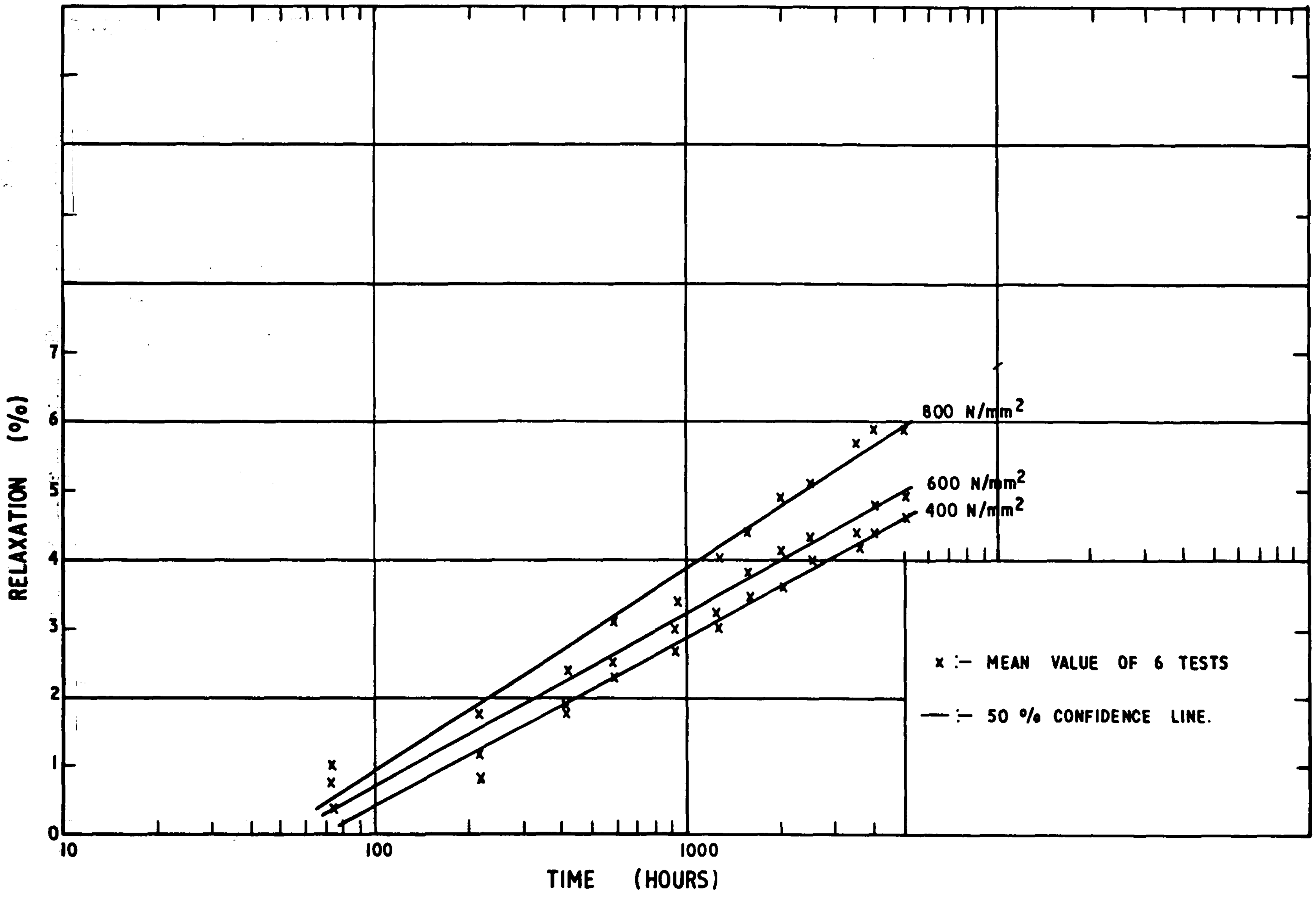

FIG. 6 TIME – RELAXATION OF BS 5216 HD3 SPRINGS AT ROOM TEMPERATURE.

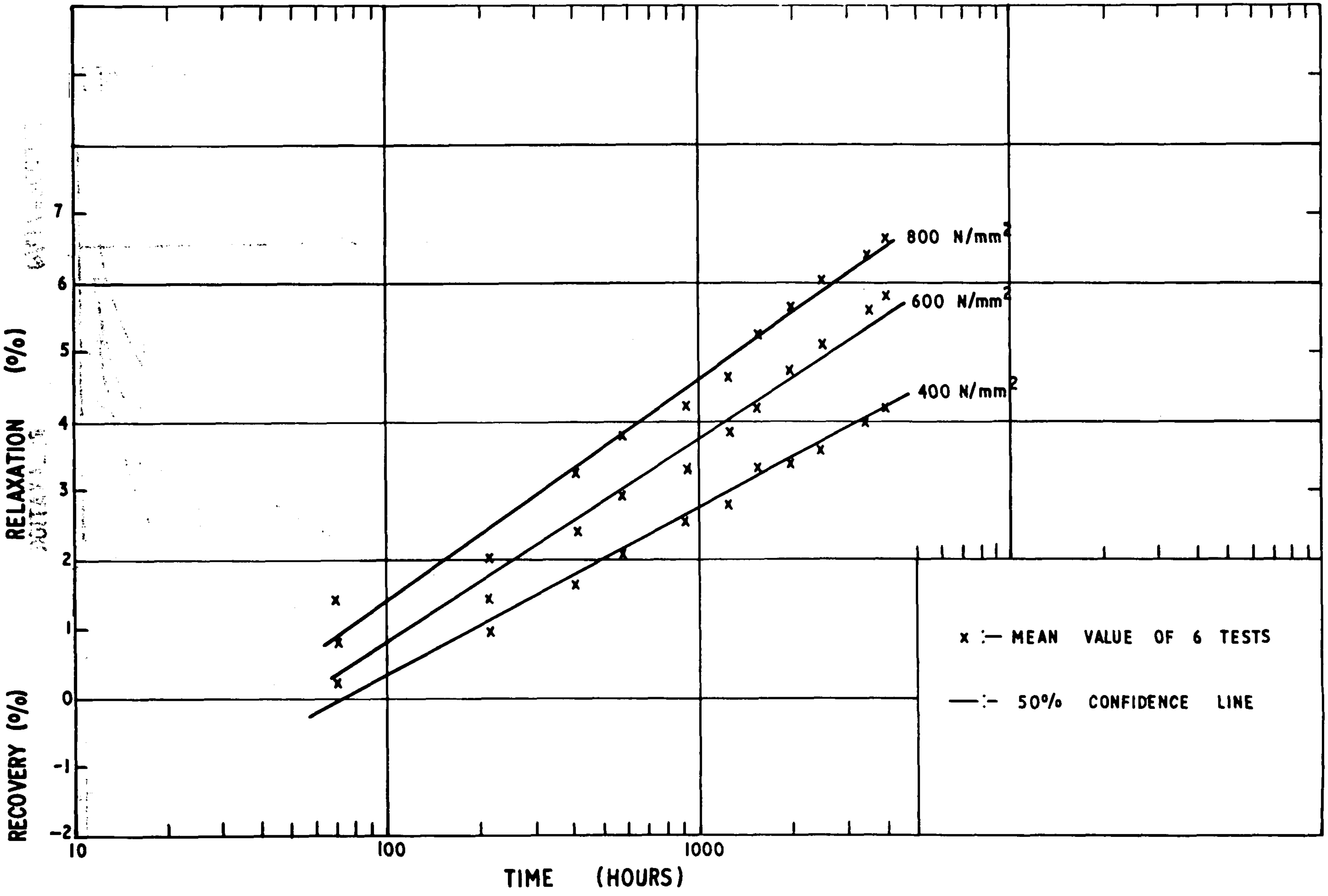

FIG. 7 TIME - RELAXATION OF BS 5216 M4 SPRINGS AT ROOM TEMPERATURE.

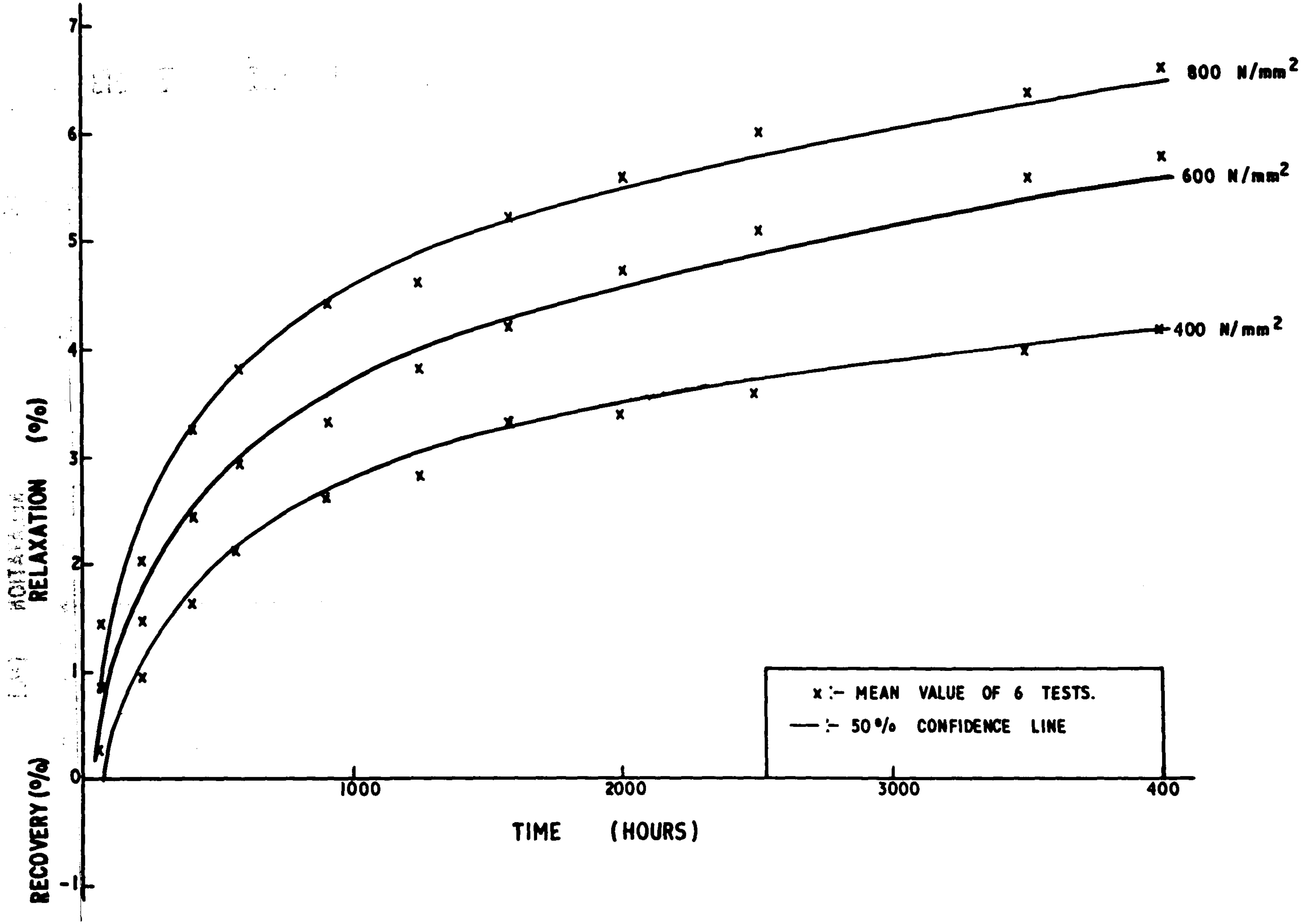

FIG. 7 A. TIME - RELAXATION OF BS 5216 M4 SPRINGS AT ROOM TEMPERATURE.

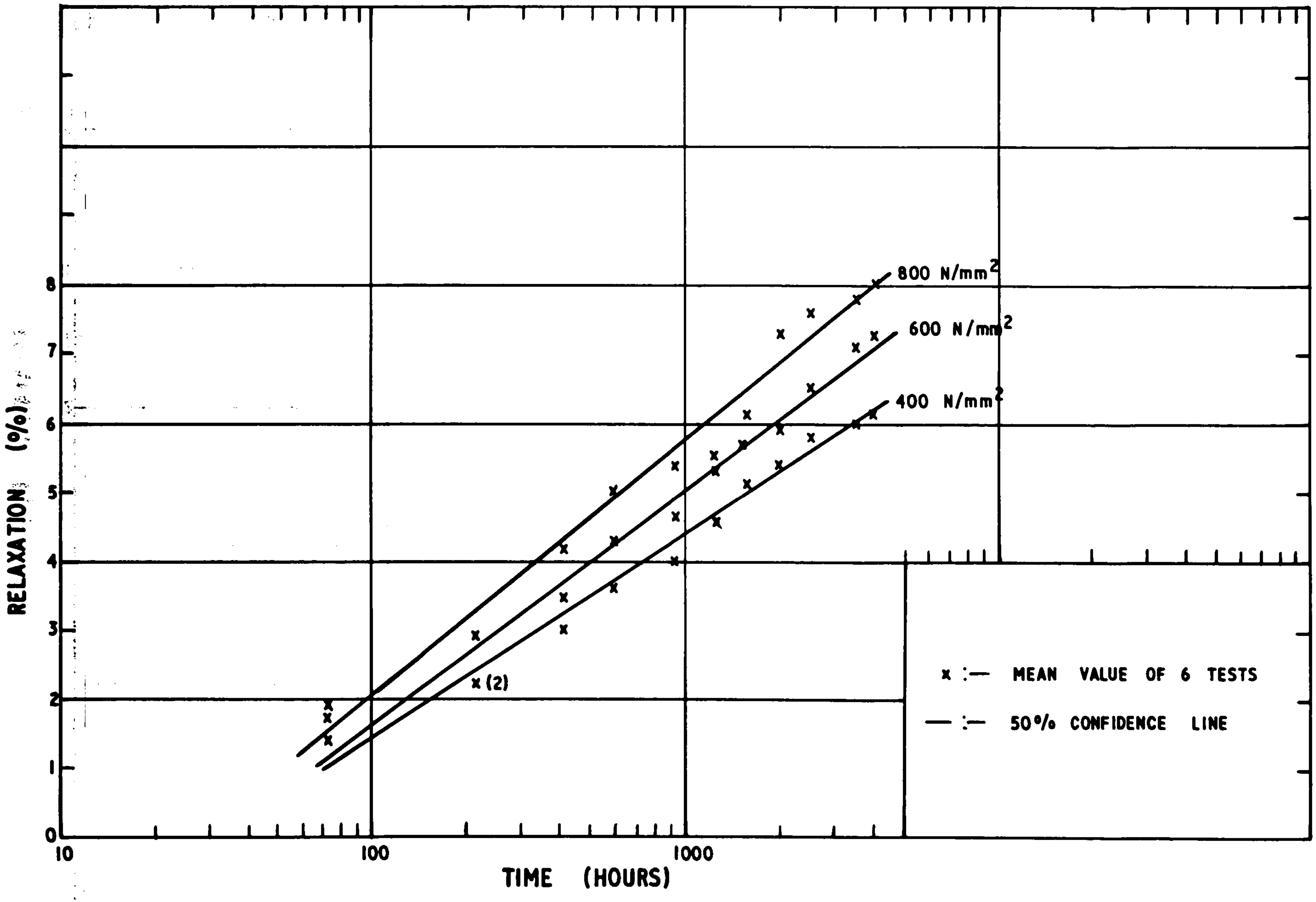

FIG. 8 TIME – RELAXATION OF BS 2803 G 2 SPRINGS AT ROOM TEMPERATURE.

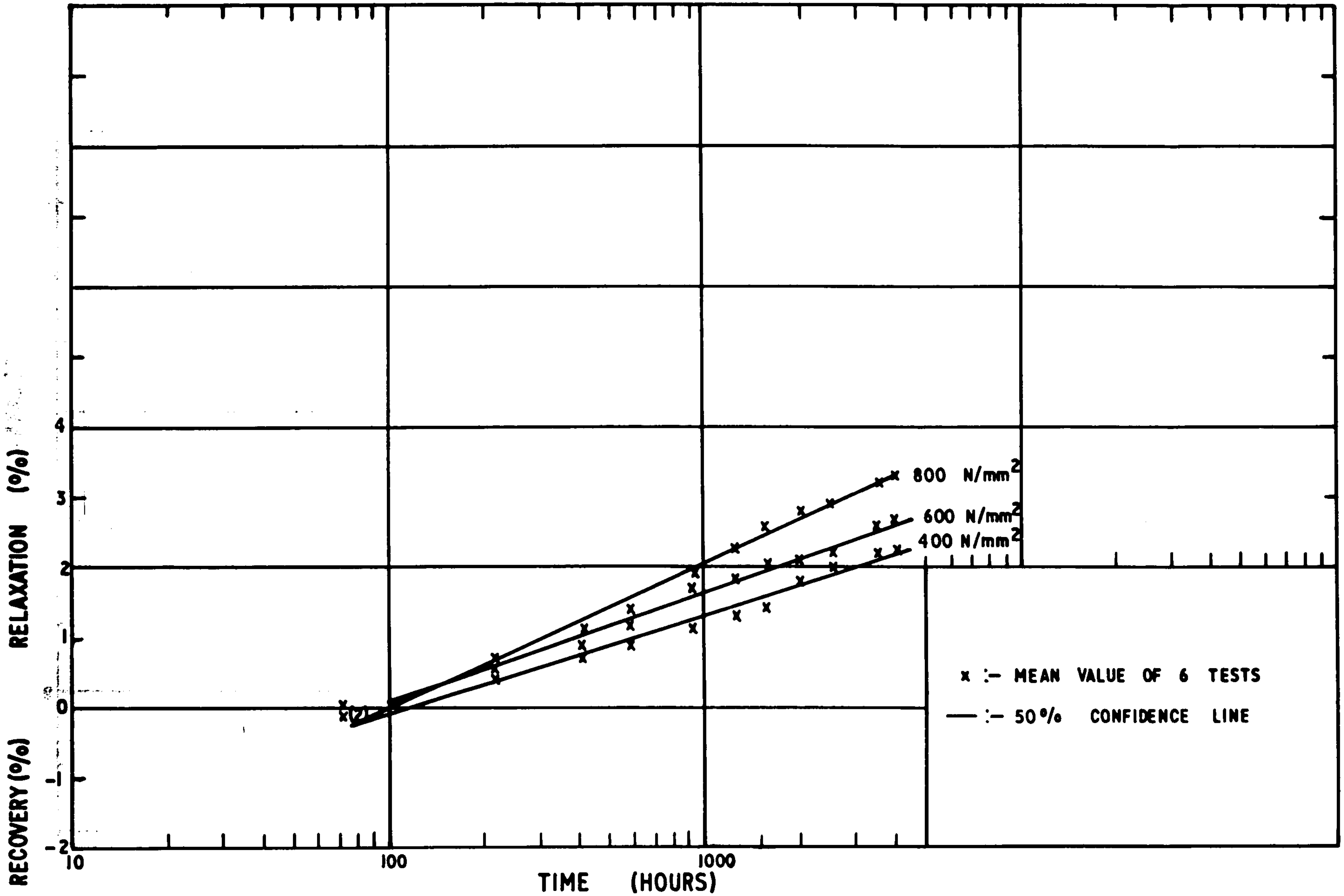

FIG. 9 TIME—RELAXATION OF BS 2056 En 58A SPRINGS AT ROOM TEMPERATURE.