THE SPRING RESEARCH AND MANUFACTURERS ASSOCIATION

THE LONG TERM RELAXATION BEHAVIOUR OF SPRING MATERIALS

2nd Progress Report

by

M. O'Malley, B.Sc.

Report No. 349

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SUMMARY

The programme of work, which was a continuation of previous work, has shown that it is possible to produce statistically significant logarithmic time relaxation relationships. Materials which have excellent ambient temperature relaxation resistance only exhibit very small amounts of relaxation and it is not always possible to produce relationships for these results. 17/7 PH has excellent relaxation resistance at both ambient and elevated temperatures. The nickel alloys tested did not have very good relaxation resistance at very high test temperatures.

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1. INTRODUCTION

A previous SRAMA report[1] gives details of the long term relaxation behaviour of certain carbon steel and stainless steel springs. In order to produce as much reliable information as possible for the spring designer and user, further tests have been carried out on a range of other spring materials.

2. MATERIALS INVESTIGATED

The work was carried out on seven materials in total. These were two patented hard drawn carbon steels to the BS 5216 specification - one a NS1 grade, the other a M5 grade; a low Chromium-Vanadium; a 17/7 PH stainless; an Inconel 600; a Monel K500 and a hard drawn and aged Copper-Beryllium.

The chemical composition, mechanical properties and spring designs for the seven materials are given in Tables I, II and III respectively.

3. EXPERIMENTAL METHOD

Relaxation tests were carried out using the standard nut and bolt technique as detailed in previous SRAMA reports[2]. The tests were carried out at elevated and ambient temperatures at stress levels of 100, 200 and 300 N/mm^2 for the copper-beryllium springs and at levels of 400, 600 and 800 N/mm^2 for the other six materials. The elevated temperatures chosen depended on the material under test, and a complete list is given below.

Material	Test Temperatures °C
BS 5216 NS1	150
BS 5216 M5	150
Low Chromium Vanadium	200
17/7 PH	250
Inconel 600	300, 400
Monel K500	200, 300
Copper-Beryllium	50, 75

4. RESULTS AND DISCUSSION

The results of the tests are plotted in Figures 1 - 17. The results were analysed using linear regression techniques to determine statistically significant relationships between time and relaxation. For the majority of the materials, the results were found to fit the logarithmic time relaxation relationship previously derived by the Association[3] :-

$$R = c \ln t + d \qquad \ldots\ldots \text{(i)}$$

Where R = % relaxation
t = time (hours)
"c" amd "d" are constants which depend on the material and test conditions.

For the materials which did fit the relationship, 95% confidence limits were determined by statistical analysis of the residuals obtained from the experimental data and the relaxation given by the regression relationships. These confidence limits together with the values for c and d are given in Table IV for the elevated temperature tests and in Table V for the ambient temperature tests. For the material results which did not fit the logarithmic time relaxation relationships (i.e. for the elevated temperature tests on the Copper-Beryllium and for the ambient temperature tests on the Inconel 600, Monel K500 and Copper-Beryllium at the two lower stress levels) analysis of variance or "Anova" tests were carried out to determine whether there was any relationship between relaxation and time.

The results of the analysis indicate that, although there might be a slight dependence of relaxation on time for the materials, the spring to spring variation for each material was so great as to overshadow any variation caused by time of testing. It was however possible in some cases to determine 95% confidence limits on the results and these have been reproduced on the graphs. A point to note is that these confidence limits only apply to the test results and cannot be extrapolated in order to predict possible relaxations for longer service durations.

It is possible to predict the possible mean levels of relaxation which would be experienced after longer service durations by the materials which do have statistically significant time relaxation relationships. The predicted levels for 10,000 hours and 20,000 hours for the various material and test conditions are given in Table VI.

A comparison can be made of the results for the four grades of patented hard drawn carbon steel materials which have been tested to date. The mean relaxation values after 2000 hours at 150°C are as follows:-

BS 5216	400 N/mm^2	600 N/mm^2	800 N/mm^2
NS 1	14.3	15.6	21.3
HD 3*	11.8	13.7	17.7
M4 *	11.3	12.3	16.4
M5	15.4	16.0	17.5

* Results from previous report(1).

For the first three materials (NS 1, HD 3, and M4) the results are consistent with those expected in that as the tensile strength is increasing, the level of relaxation experienced is decreasing. The M5 material does not, however, follow this pattern, and there is no easily available explanation for this anomaly.

For the results ~~on the~~ 17/7 PH, Inconel 600, Monel K500 ~~and~~ Copper-Beryllium, the difficulty in fitting the results to the normal logarithmic time relaxation relationships may well have occurred due to the relatively low levels of relaxation which have been experienced by the springs. For the 17/7 PH, Inconel 600 and Monel K500, these low levels have occurred due to the excellent relaxation resistance of these materials at ambient temperature. However, for the Copper-Beryllium springs, the low levels have probably occurred due to the low temperatures and stresses used for testing.

5. CONCLUSIONS

1. The relationships which were produced were significant to the 99.9% level and can be used to predict long term relaxation levels for the materials to which they relate.

2. Due to the excellent relaxation resistance of the 17/7 PH, Inconel 600 and Monel K500 springs at ambient temperatures which resulted in very low levels of relaxation being experienced, it was not possible to determine statistically significant time-relaxation relationships.

3. Even at elevated temperature the 17/7 PH springs had excellent relaxation resistance.

4. For the two nickel alloys, their relaxation resistance at the two lower elevated temperatures (300 and 200^{o}C for the Inconel 600 and Monel K500 respectively) was very good with neither material experiencing more than 8% relaxation at the highest test stress.

5. For patented hard drawn carbon steel the higher tensile strength materials exhibit better relaxation resistance under identical test conditions than the lower tensile strength materials.

6. REFERENCES

1. O'Malley, M., "The Long Term Relaxation Behaviour of Compression Springs Manufactured from Carbon and Stainless Steel Wires". SRAMA Report No. 325.

2. Graves, G. B., "The Stress Temperature Relaxation Properties of Springs made from Oil Tempered and Patented Hard Drawn Wires". C.S.F.R.O. Report No. 115.

3. Reynolds, L. F., "The Fatigue and Relaxation of High Strength Titanium 318 Alloy Springs". SRAMA Report No. 288.

TABLE I CHEMICAL COMPOSITION OF MATERIALS USED IN INVESTIGATION

Material		CHEMICAL COMPOSITION (%)													
		C	Si	Mn	Cr	Ni	Al	V	Cu	Ti	Be	Fe	S	P	Residual
BS 5216 NS 1	Specified	0.45-0.85	0.35 max.	0.4-1.0	--	--	--	-	--	--	--	Balance	0.05 max.	0.05 max.	--
	Actual	0.45	0.24	0.62	--	--	--	-	--	--	--	Balance	0.014	0.011	--
BS 5216 M5	Specified	0.7-1.0	0.35 max.	0.25 0.75	--	--	--	-	--	--	--	Balance	0.03 max.	0.03 max.	--
	Actual	0.85	0.20	0.43	--	--	--	-	--	--	--	Balance	0.014	0.011	--
Low Cr-V	Specified	0.6-0.75	0.15-0.30	0.5-0.9	0.4-0.6	--	--	0.1 min	--	--	--	Balance	0.025 max	0.03 max.	--
	Actual	0.70	0.19	0.51	0.54	--	--	0.23	--	--	--	Balance	0.015	0.016	--
17/7 PH	Specified	0.09 max.	1.0 max	1.0 max	16.0 18.0	6.5-7.75	0.75-1.5	-	--	--	--	Balance	0.025 max	0.035 max	--
	Actual	0.05	0.38	0.63	17.9	7.5	0.75	-	--	--	--	Balance	0.010	0.020	--
Inconel 600	Specified	0.15 max.	0.5 max	1.0 max	14.0-17.0	72.0 min.	--	-	0.5 max	--	--	6.0 10.0	0.015 max	--	--
	Actual	0.04	0.24	0.25	15.8	73.5	--	-	0.04	--	--	9.3	0.010	--	0.82
Monel K500	Specified	0.25 max.	1.0 max	1.5 max	--	63.0 min	2.3-3.2	-	27.0-33.0	0.35 0.85	--	2.0 max	0.010 max	--	--
	Actual	0.07	0.25	1.1	--	63.8	3.2	-	30.2	0.58	--	0.65	0.007	--	0.143
Copper-Beryllium	Specified	--	--	-	--	0.05-0.4	-	-	Balance	--	1.7-1.9	--	--	--	0.50 max.
	Actual	--	--	-	--	0.24	-	-	97.5	--	1.77	--	--	--	0.49

TABLE II MECHANICAL PROPERTIES

Material	Condition	Tensile Properties					Torsion Properties			
		R_m (N/mm^2)	L of P (N/mm^2)	R_p 0.05 (N/mm^2)	R_p 0.1 (N/mm^2)	R_p 0.2 (N/mm^2)	G (kN/mm^2)	L of P (N/mm^2)	0.1% PS (N/mm^2)	0.2% PS (N/mm^2)
BS 5216 NS1	As received	1310	580	875	980	1090	79.5	290	655	725
	LTHT 350°C for ½ hour	1335	905	1185	1235	1270	81.1	650	865	900
BS 5216 M5	As received	2145	1035	1545	1760	1935	76.3	595	915	1030
	LTHT 350°C for ½ hour	2010	1300	1620	1700	1765	79.4	780	1160	1225
Low Cr-V	As received	1780	720	1640	1690	1705	78.5	765	1050	1130
	LTHT 400°C for ½ hour	1755	960	1615	1670	1690	78.5	860	1055	1105
17/7 PH	As received	1725	800	1330	1480	1615	75.2	630	965	1060
	Aged 480°C for 1 hour	2120	1515	1910	2020	--	78.2	865	1155	1410
Inconel 600	Cold drawn 65% reduction	1200	720	1015	1100	1165	70.0	210	470	545
	Stress relieved 460°C for 3/4 hour	1360	935	1275	1300	1350	73.5	335	580	635
Monel K500	Cold drawn 65% reduction	1210	530	885	1000	1110	60.9	210	490	570
	Aged 535°C for 5 hours	1410	625	1150	1250	1340	65.7	330	605	6[illegible]
Copper Beryllium	Hard drawn	890	540	715	805	--	--	--	410	470
	Aged 335°C for 2 hours	1410	900	1140	1225	--	--	--	430	550

TABLE III SPRING DESIGNS

	BS 5216 NS1	BS 5216 M5	Low Cr-V	17/7 PH	Inconel 600	Monel K500	Copper Beryllium
Wire diameter (mm)	2.64	2.64	2.51	2.64	2.50	2.50	1.22
Mean coil diameter (mm)	18.48	18.48	17.57	18.48	22.90	22.50	8.52
Spring index	7	7	7	7	9	9	7
Active Coils	3.5	3.5	3.5	3.5	3.3	3.3	6
Total Coils	5.5	5.5	5.5	5.5	5.3	5.3	8
Free length (after end grinding and prestressing) (mm)	28.50	35.56	31.27	36.71	37.80	42.30	20.30
Solid stress (N/mm^2)	935	1410	1230	1485	965	1030	465

TABLE IV STATISTICAL CONSTANTS FOR ELEVATED TEMPERATURE TIME RELAXATION

Material	Test Temperature (^{o}C)	Duration of test (hours)	Stress Level (N/mm^2)	$R = c \ln t + d$		95% confidence increment (%)
				c	d	
BS 5216 NS1	150	2000	400	0.855	7.810	3.3
			600	0.995	7.994	2.8
			800	1.325	11.262	2.2
BS 5216 M5	150	2000	400	1.104	7.035	3.1
			600	1.114	7.513	2.3
			800	1.298	7.749	0.7
Low Cr-V	200	2000	400	1.070	8.409	5.0
			600	1.150	8.819	4.1
			800	1.396	10.622	4.3
17/7 PH	250	2000	400	0.138	0.626	1.5
			600	0.248	0.571	1.3
			800	0.280	0.564	1.6
Inconel 600	400	3000	400	1.585	0.413	1.5
			600	2.004	-0.479	1.8
			800	2.913	-1.516	2.9
Inconel 600	300	3000	400	0.139	1.763	1.3
			600	0.292	1.119	0.7
			800	0.746	1.182	1.2
Monel K500	300	3000	400	2.490	-3.481	3.5
			600	3.211	-3.419	1.4
			800	3.847	-3.021	2.9
Monel K500	200	3000	400	0.224	-0.017	1.2
			600	0.349	0.222	1.3
			800	0.566	0.247	1.5
Copper-Beryllium	75	3000	300	0.182	-0.270	0.7

TABLE V STATISTICAL CONSTANTS FOR AMBIENT TEMPERATURE TIME RELAXATION

Material	Duration of test (hours)	Stress Level (N/mm^2)	R = c lnt + d		95% confidence increment (%)
			c	d	
BS 5216 NS1	10 000	400	0.252	-0.890	1.1
		600	0.328	-0.806	0.6
		800	0.735	-1.992	1.3
BS 5216 M5	10 000	400	0.307	-1.642	1.3
		600	0.244	-0.860	0.9
		800	0.433	-1.104	0.8
Low Cr-V	10 000	400	0.199	-0.284	1.0
		600	0.272	0.126	1.2
		800	0.448	-0.350	1.5
Inconel 600	5 000	800	0.159	0.161	0.7
Monel K500	5 000	800	0.341	-0.396	1.1
Copper Beryllium	5 000	300	0.170	-0.214	0.9

TABLE VI POSSIBLE PROJECTED 10,000 and 20,000 HOUR LEVELS OF RELAXATION

Material	Temperature °C	Stress Level (N/mm^2)	Projected Relaxation (%).	
			10,000 hour	20,000 hour
BS 5216 NS1	ambient	400 600 800	--- --- ---	1.6 2.4 5.3
	150	400 600 800	15.7 17.2 23.5	16.3 17.8 24.4
BS 5216 M5	ambient	400 600 800	--- --- ---	1.4 1.6 3.2
	150	400 600 800	17.2 17.8 19.7	17.9 18.6 20.6
Low Cr-V	ambient	400 600 800	--- --- ---	1.7 2.8 4.1
	200	400 600 800	18.3 19.4 23.5	19.0 20.2 24.5
17/7 PH	250	400 600 800	1.9 2.9 3.2	2.0 3.0 3.4
Inconel 600	ambient	800	1.6	1.7
	300	400 600 800	3.1 3.8 8.1	3.2 4.0 8.6
	400	400 600 800	15.0 18.0 25.3	16.1 19.4 27.3
Monel K500	ambient	800	2.8	3.0
	200	400 600 800	2.0 3.4 5.5	2.2 3.7 5.9
	300	400 600 800	19.5 26.2 31.5	21.2 28.4 32.4
Copper-Beryllium	ambient	300	1.4	1.5
	75	300	1.4	1.5

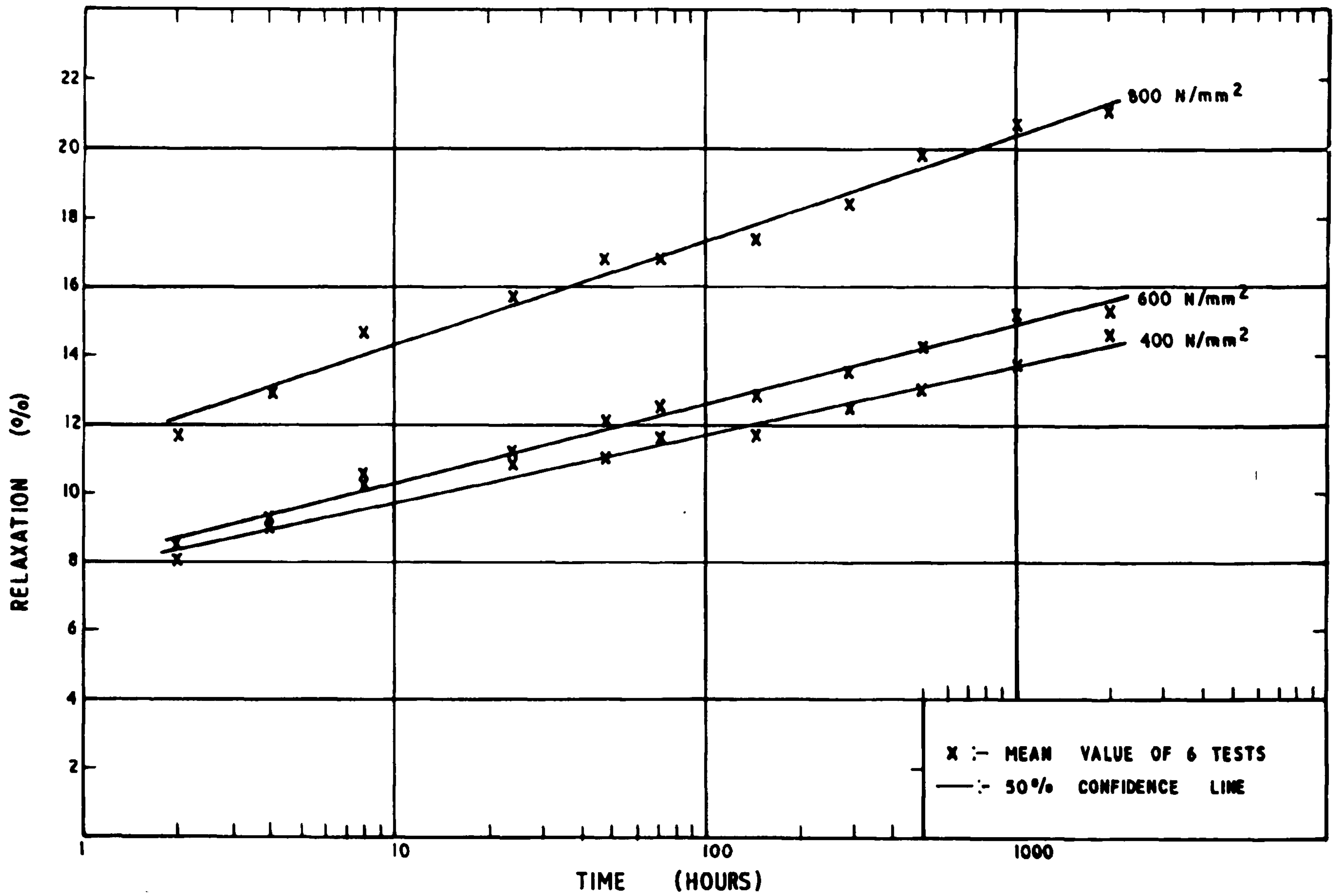

FIG. 1. TIME RELAXATION OF BS 5216 NS1 AT 150°C.

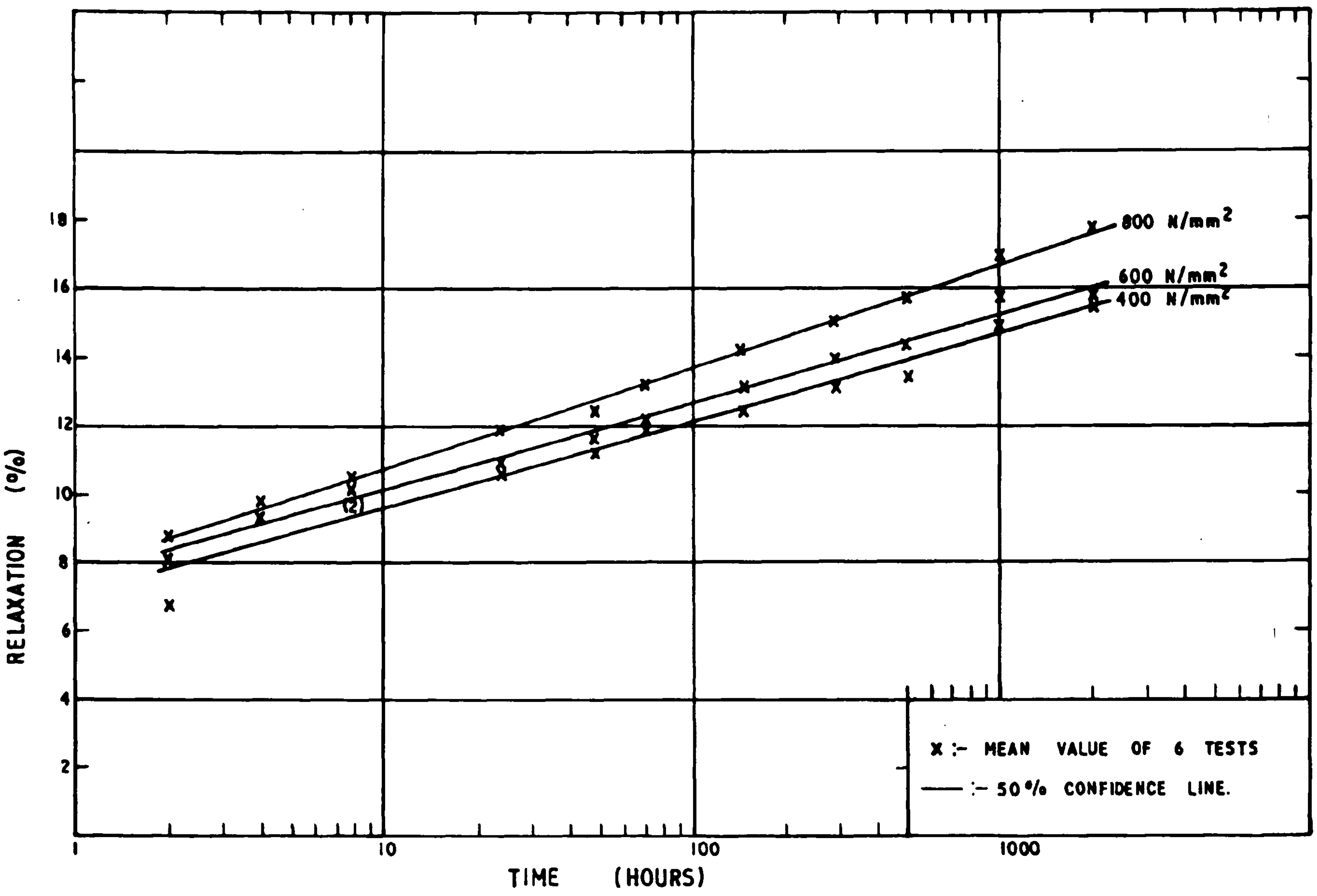

FIG. 2. TIME RELAXATION OF BS 5216 M5 AT 150°C.

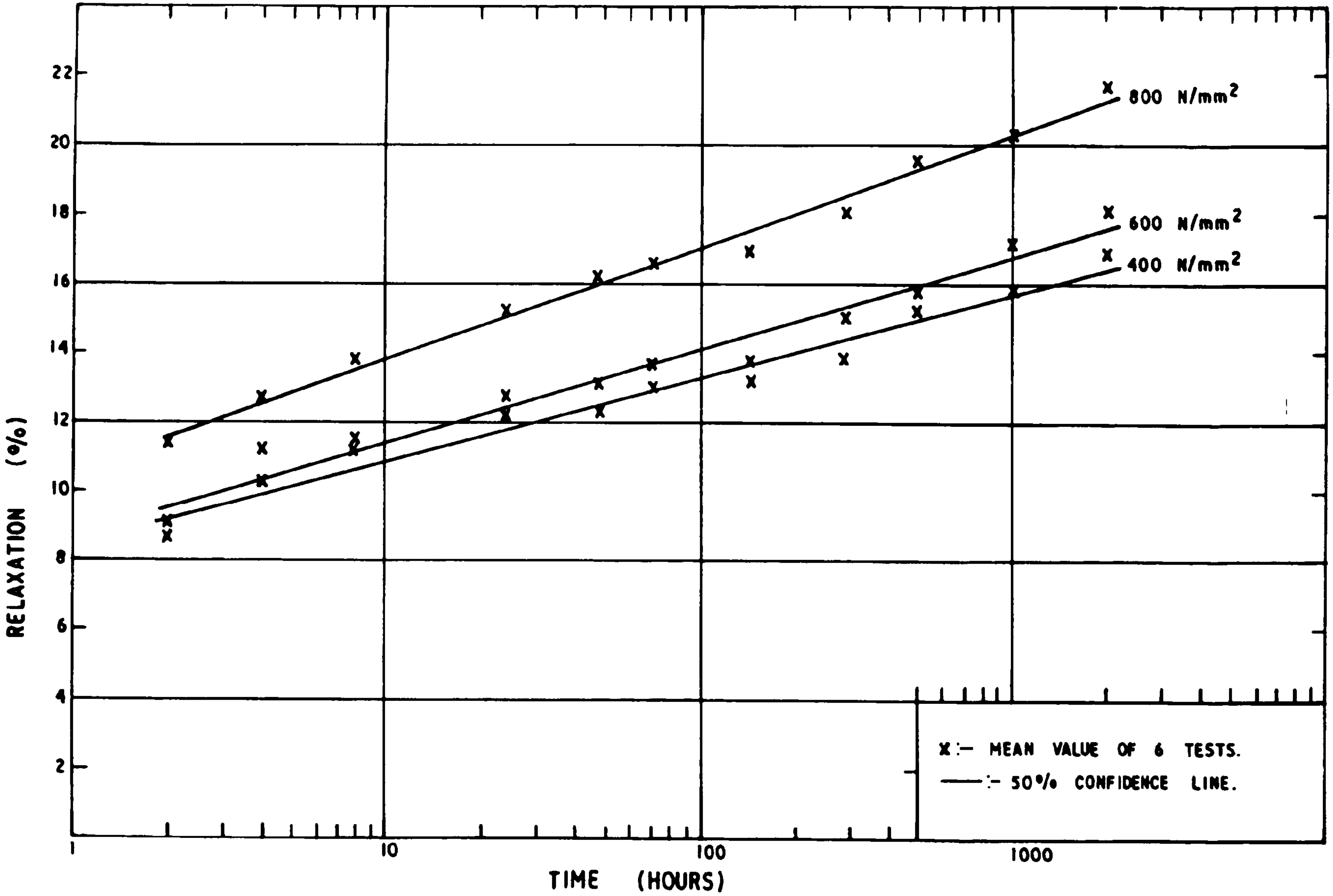

FIG. 3. TIME RELAXATION OF LOW Cr-V AT 200° C.

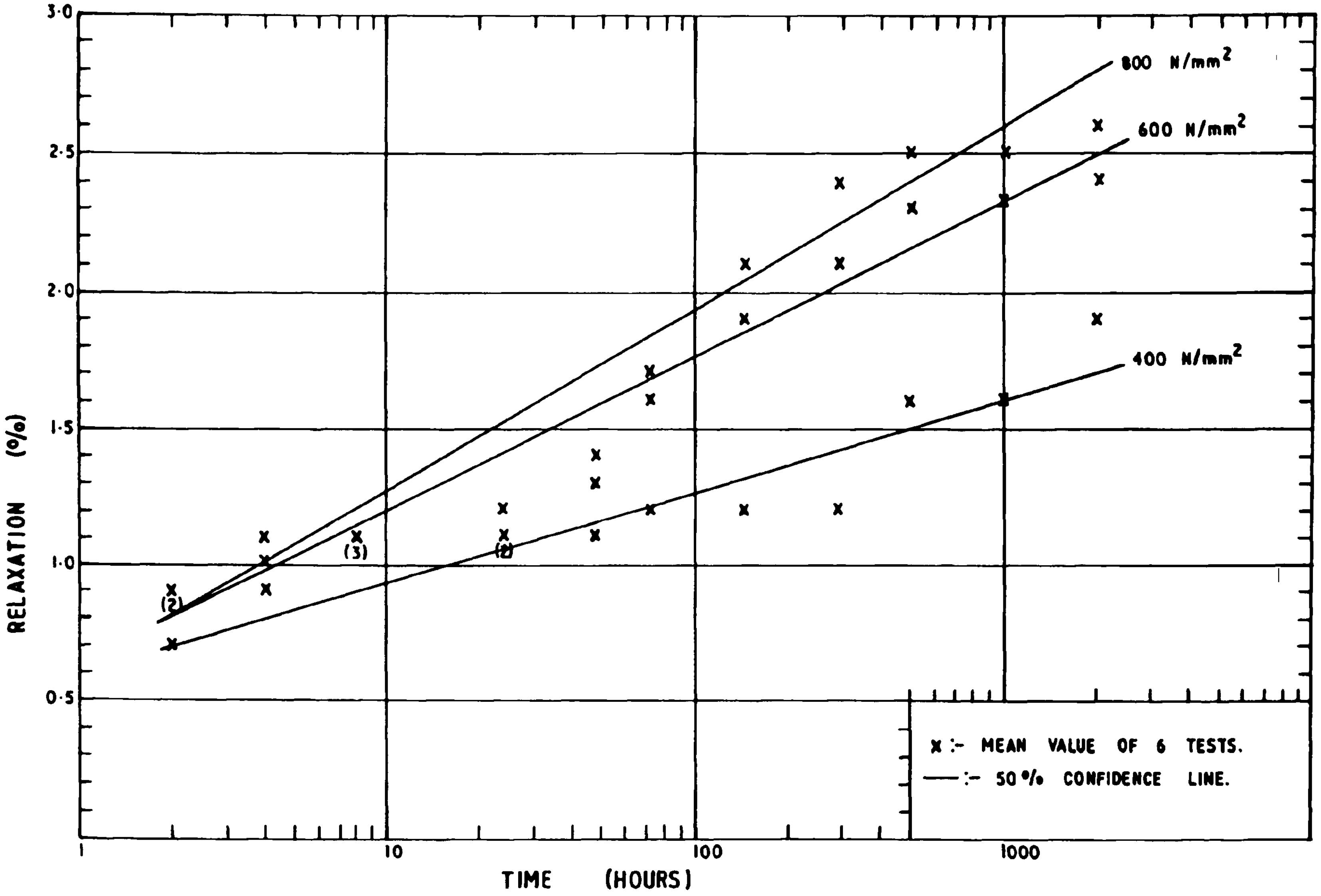

FIG. 4. TIME RELAXATION OF 17/7 PH AT 250°C.

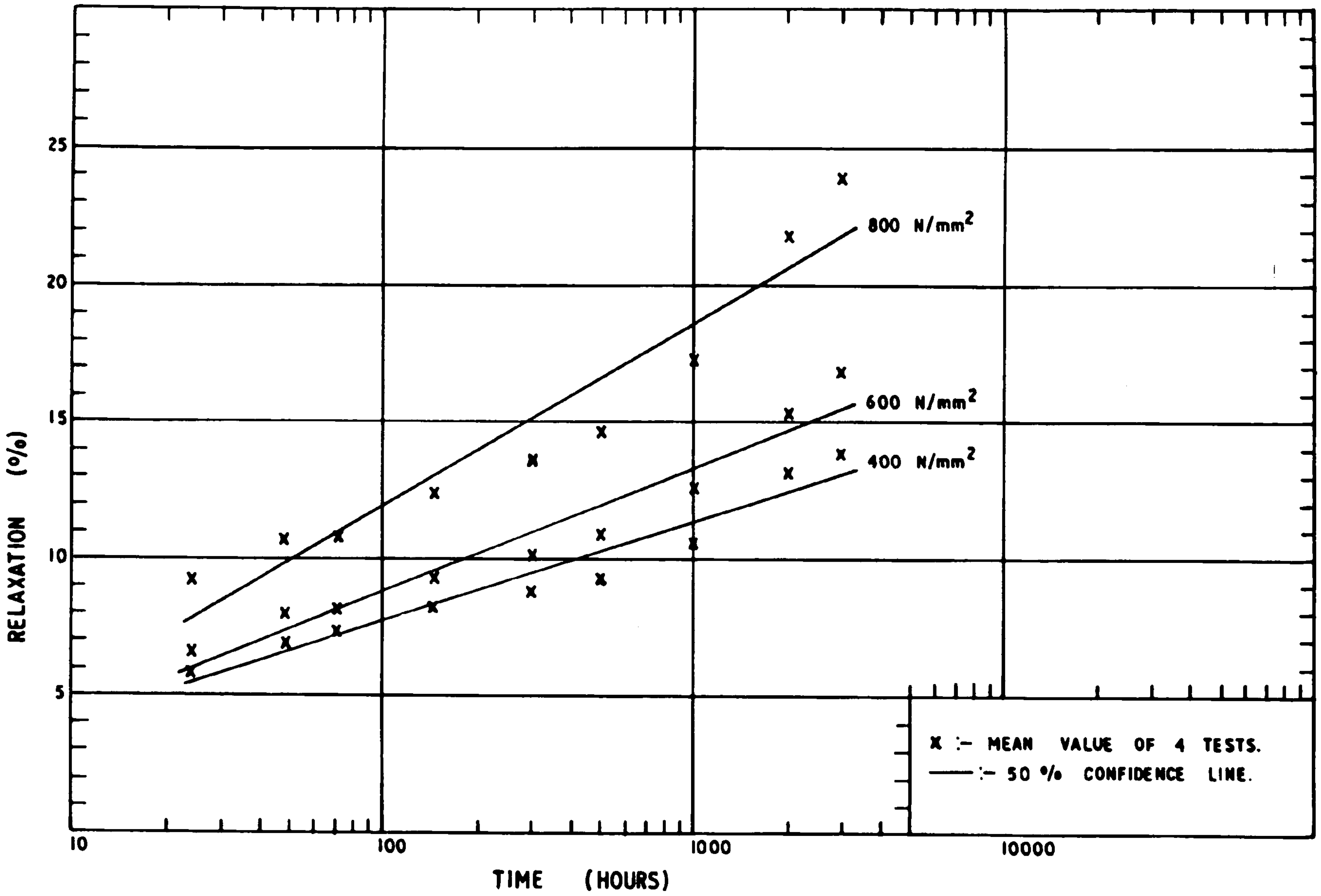

FIG. 5. TIME RELAXATION OF INCONEL 600 AT 400°C.

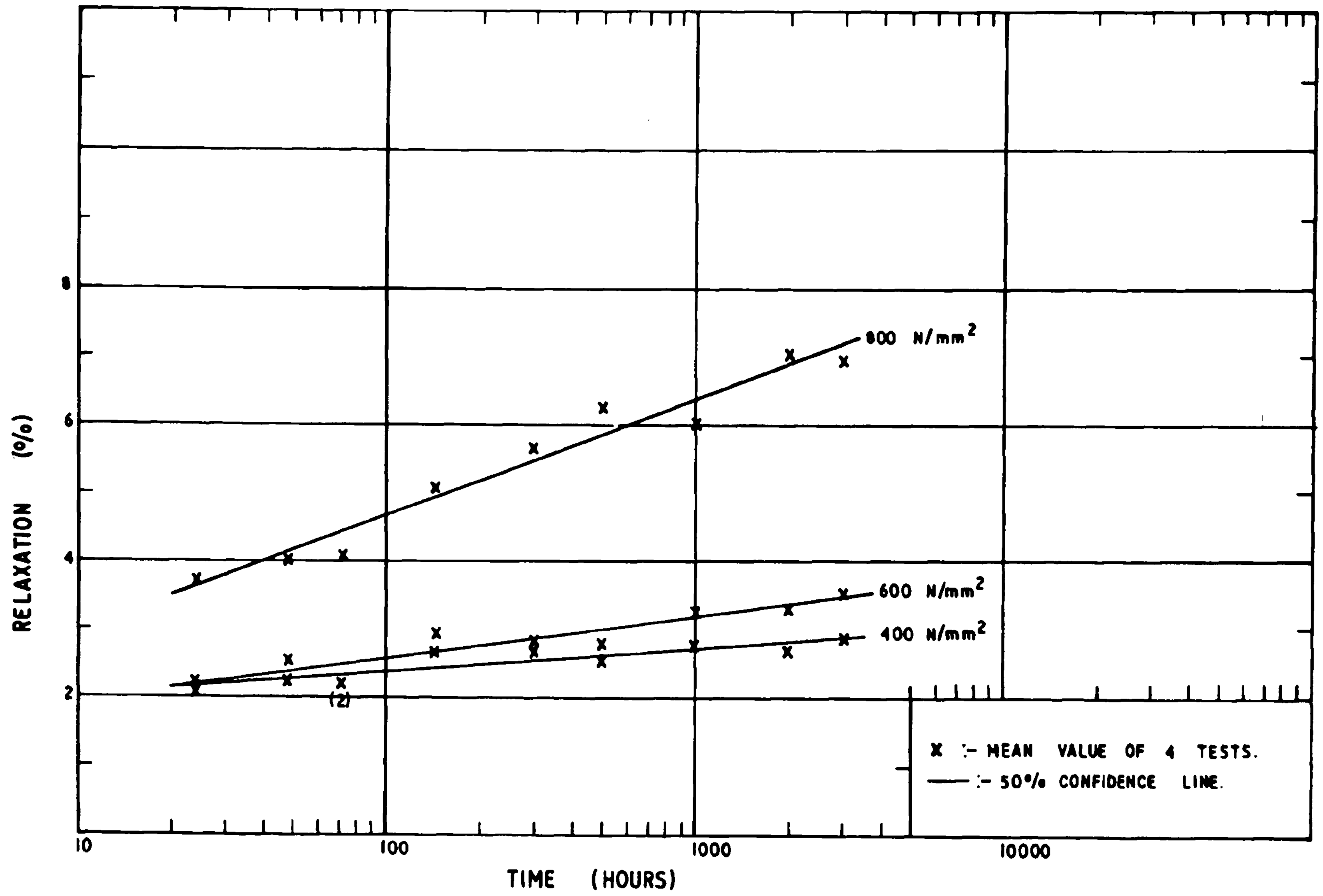

FIG. 6. TIME RELAXATION OF INCONEL 600 AT 300°C.

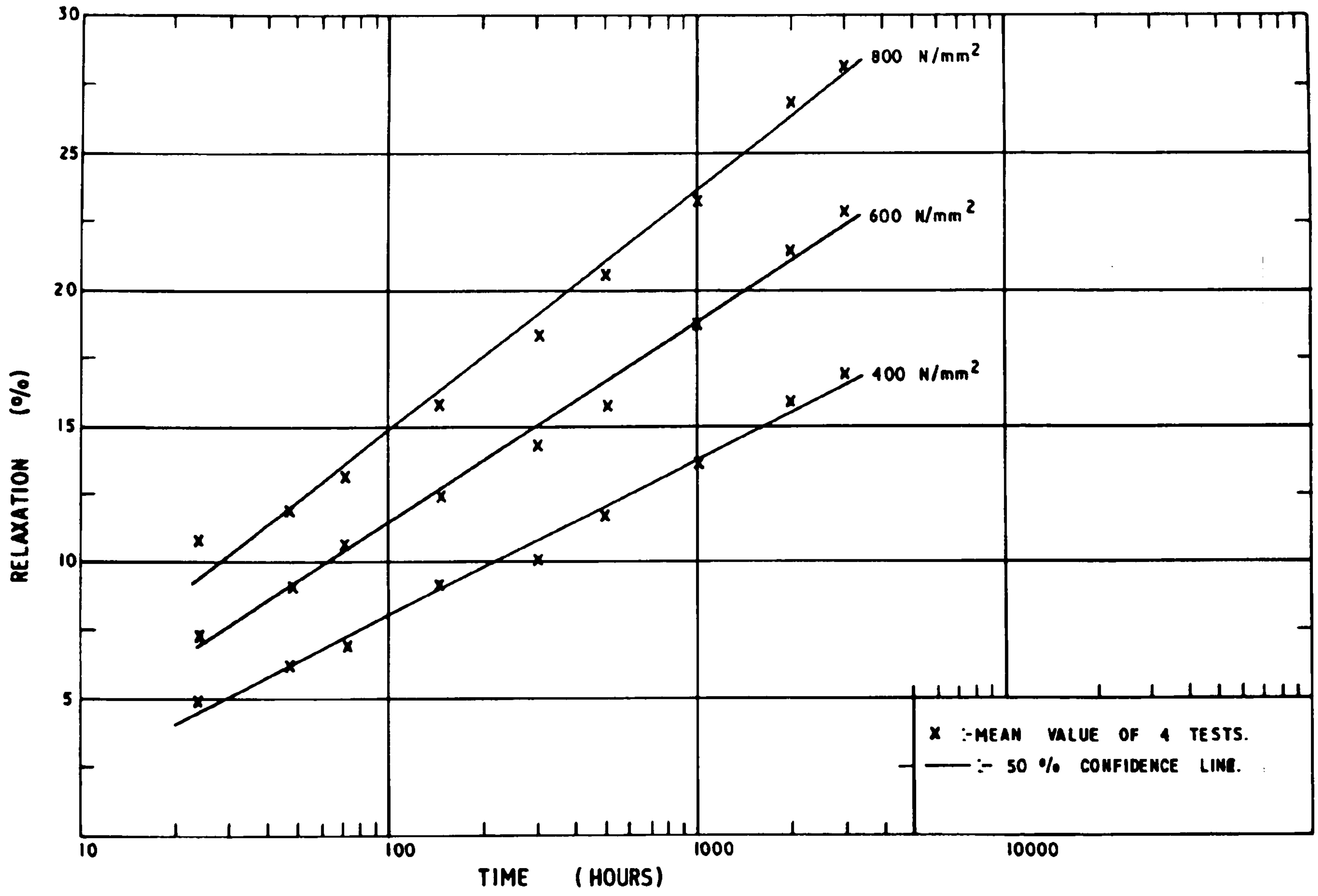

FIG. 7. TIME RELAXATION OF MONEL K500 AT 300° C.

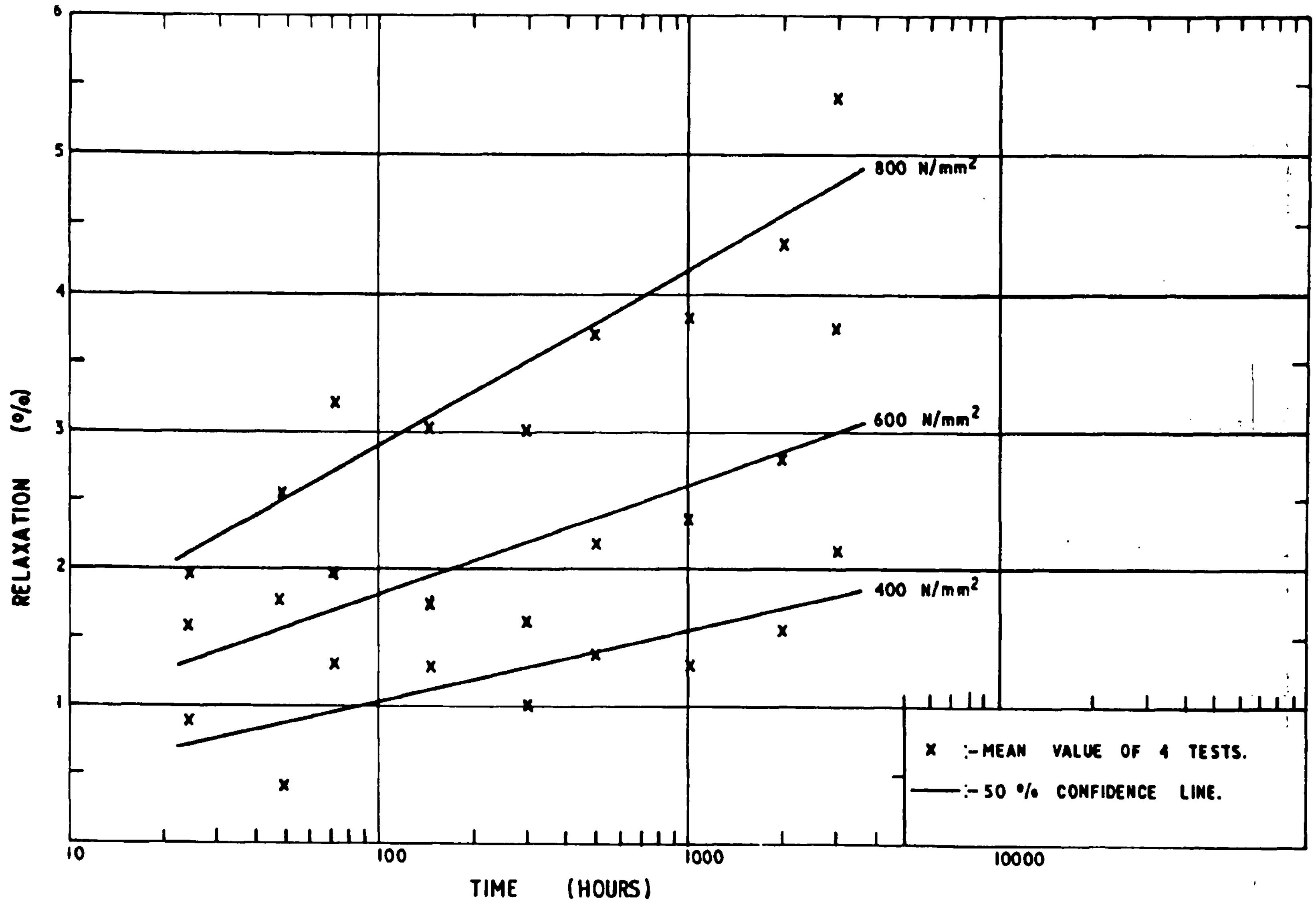

FIG. 8. TIME RELAXATION OF MONEL K500 AT 200° C.

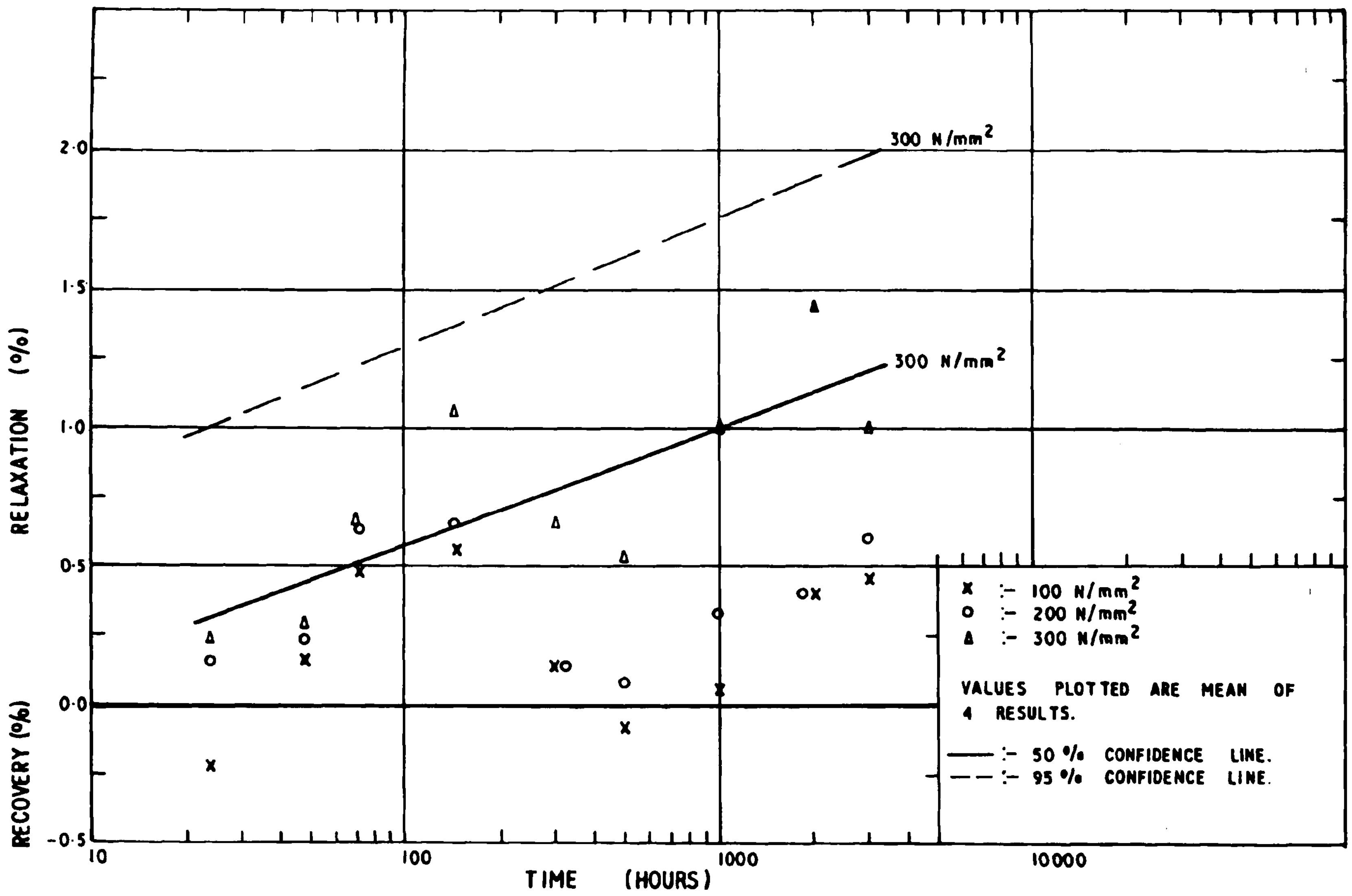

FIG. 9. TIME RELAXATION OF COPPER - BERYLLIUM AT 75°C.

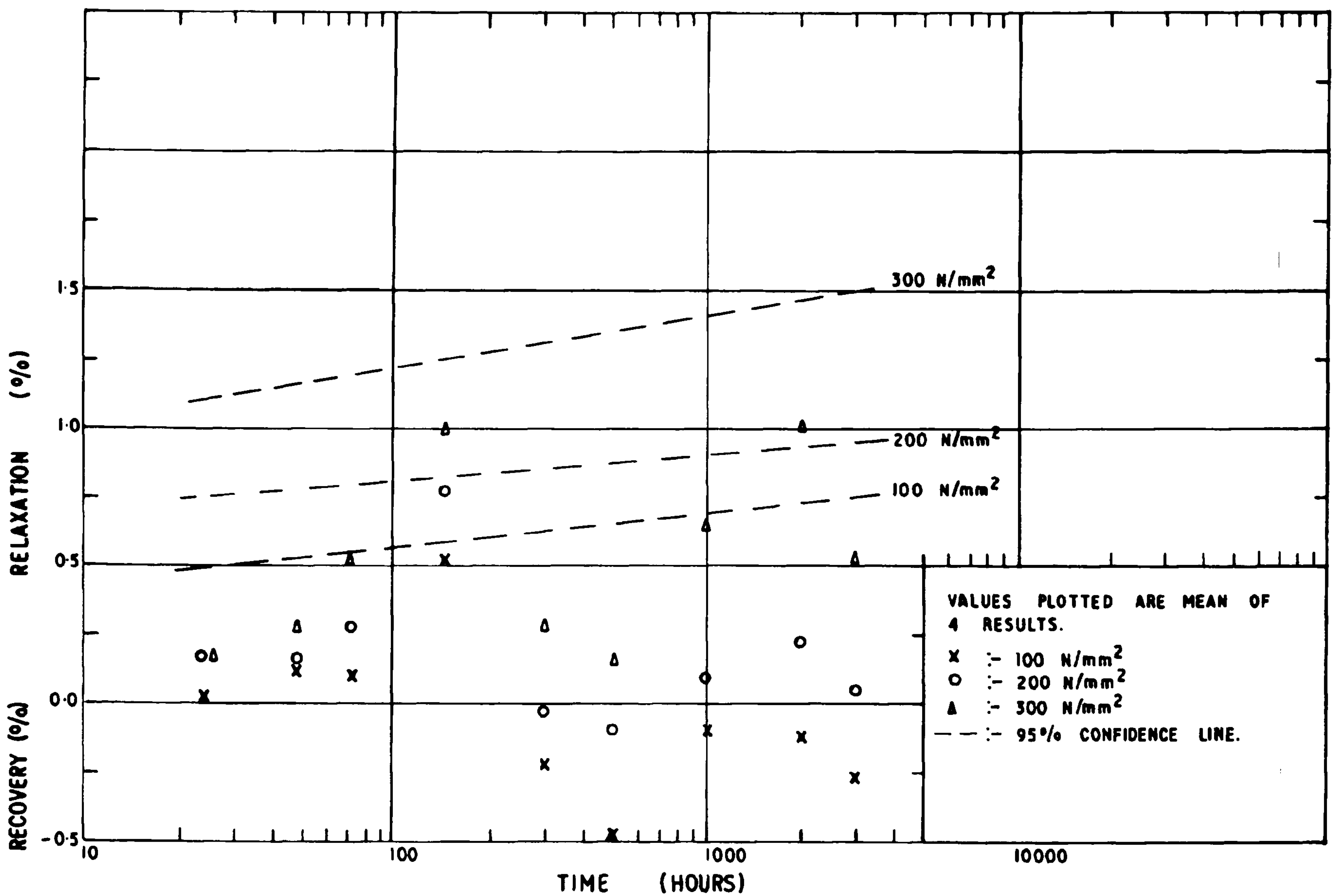

FIG. 10. TIME RELAXATION OF COPPER BERYLLIUM AT 50° C.

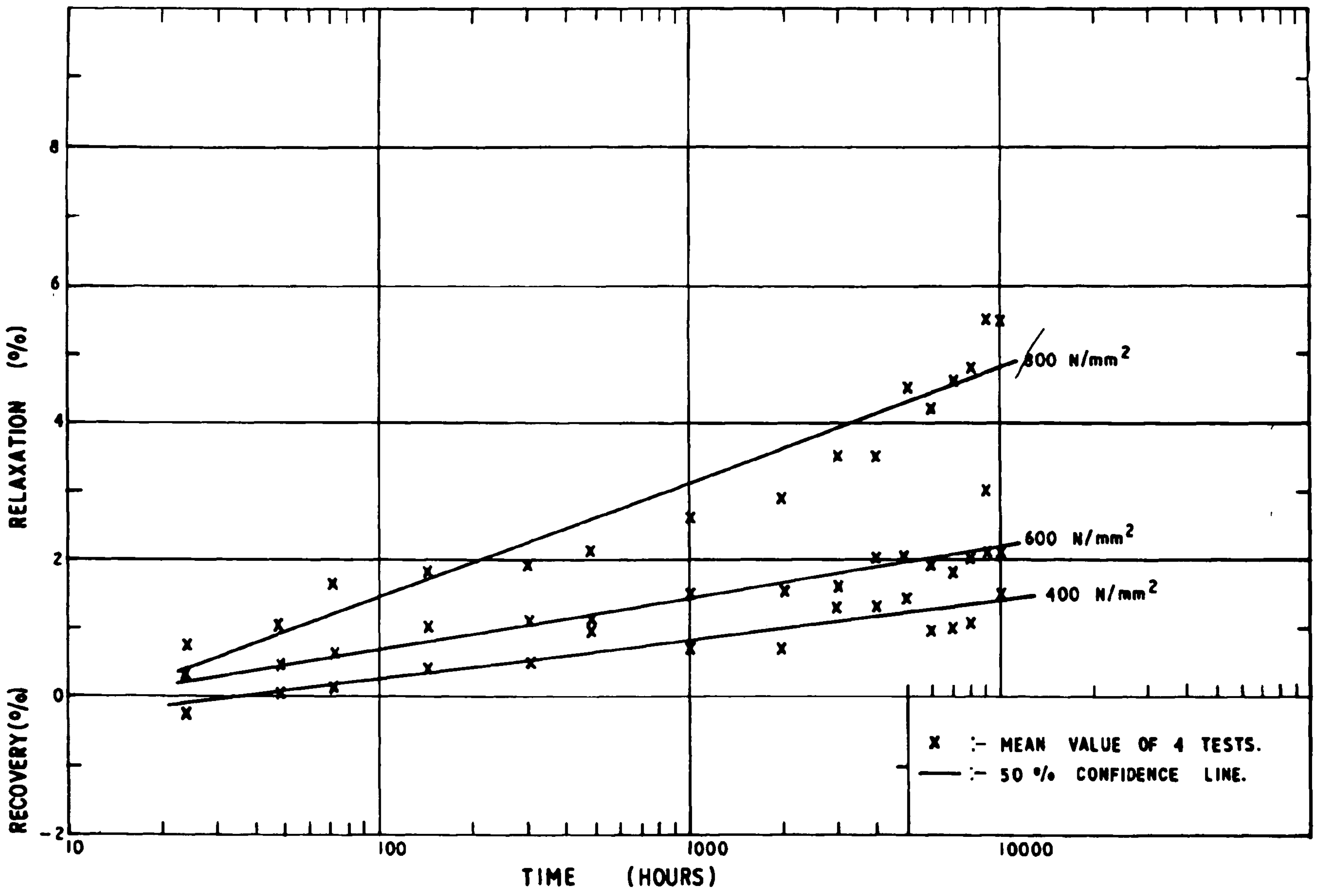

FIG. 11. TIME RELAXATION OF BS 5216 NS1 AT AMBIENT TEMPERATURE.

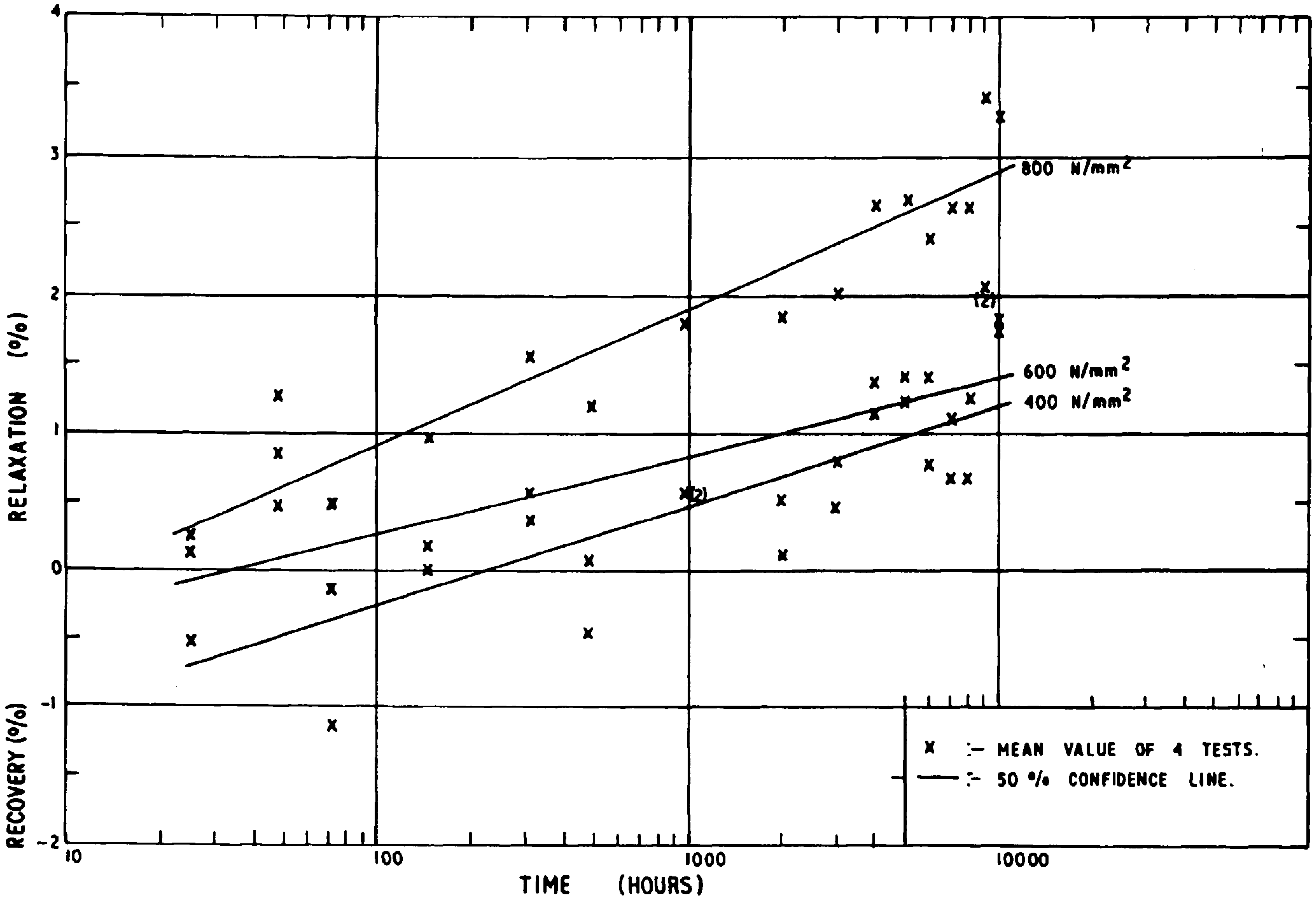

FIG. 12. TIME RELAXATION OF BS5216 M5 AT AMBIENT TEMPERATURE.

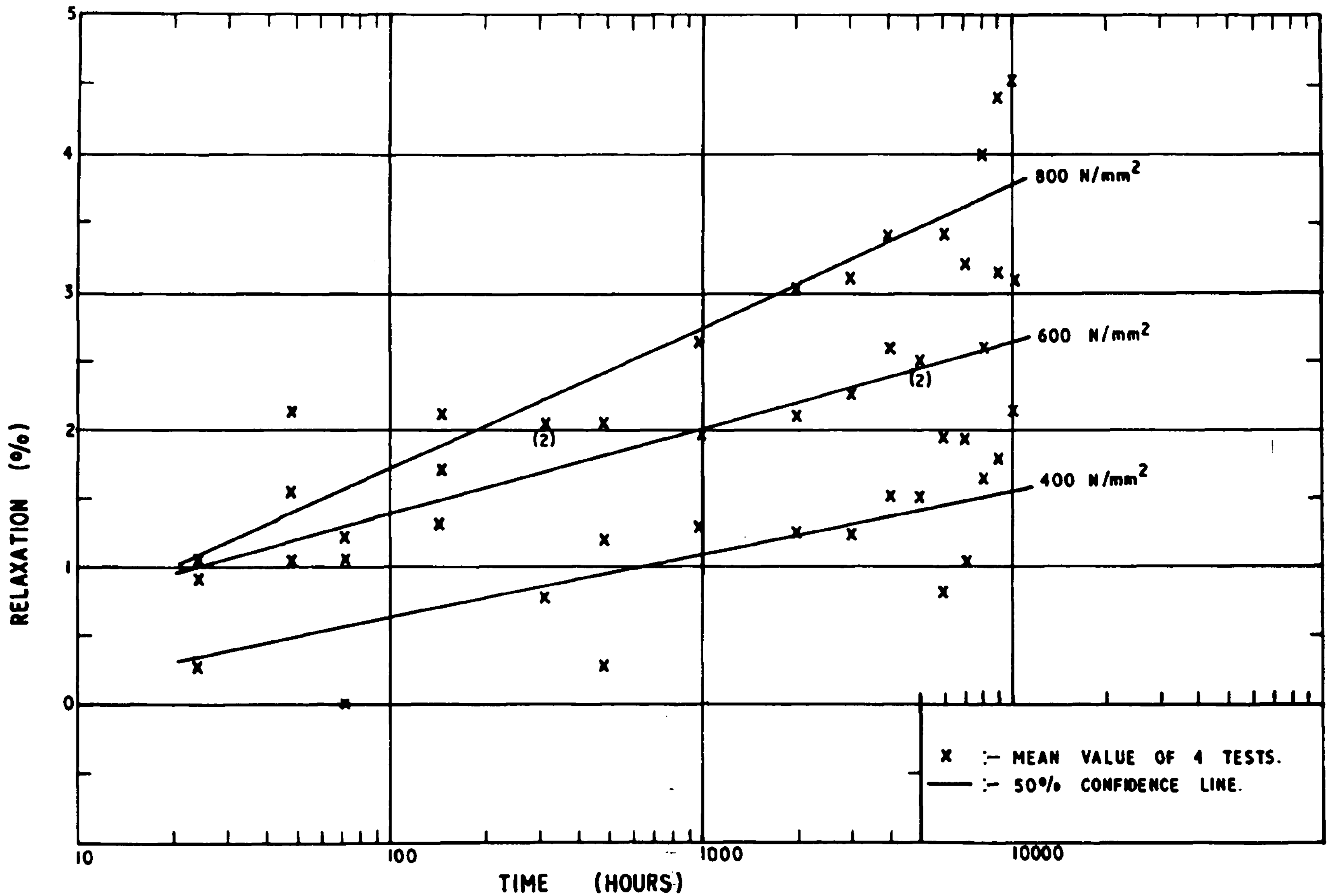

FIG. 13. TIME RELAXATION OF LOW Cr-V AT AMBIENT TEMPERATURE

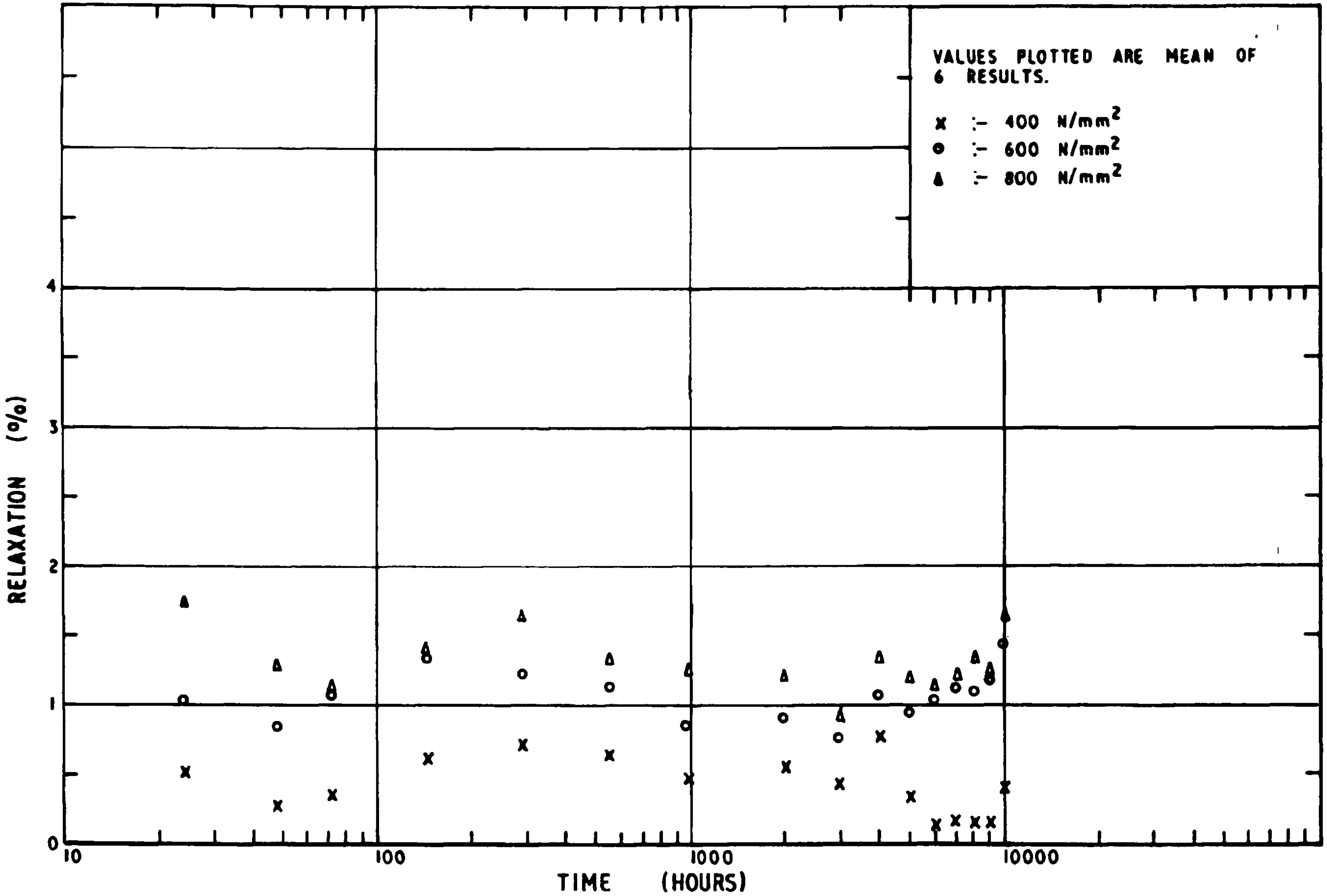

FIG. 14. TIME RELAXATION OF 17/7 PH AT AMBIENT TEMPERATURE

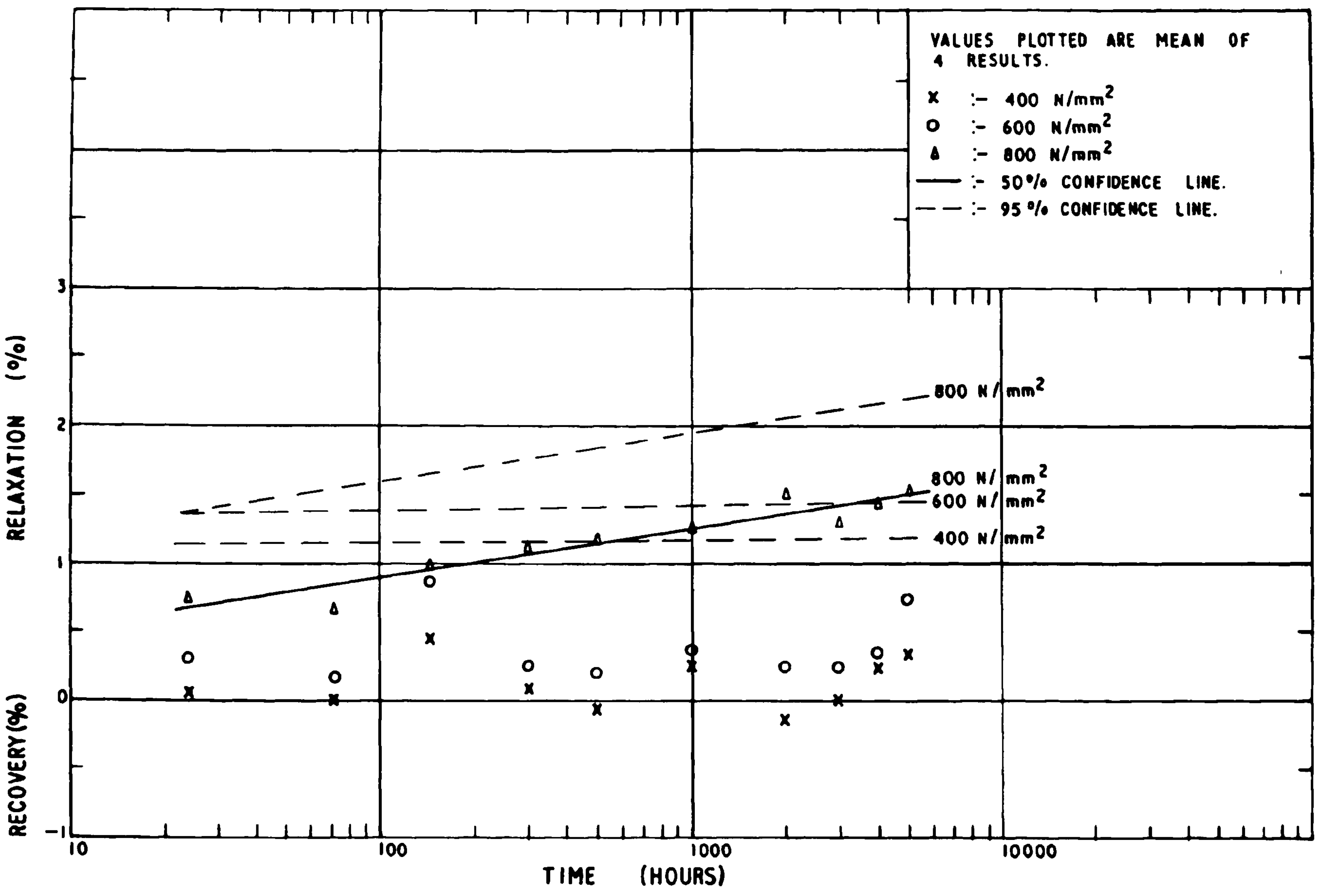

FIG. 15. TIME RELAXATION OF INCONEL 600 AT AMBIENT TEMPERATURE.

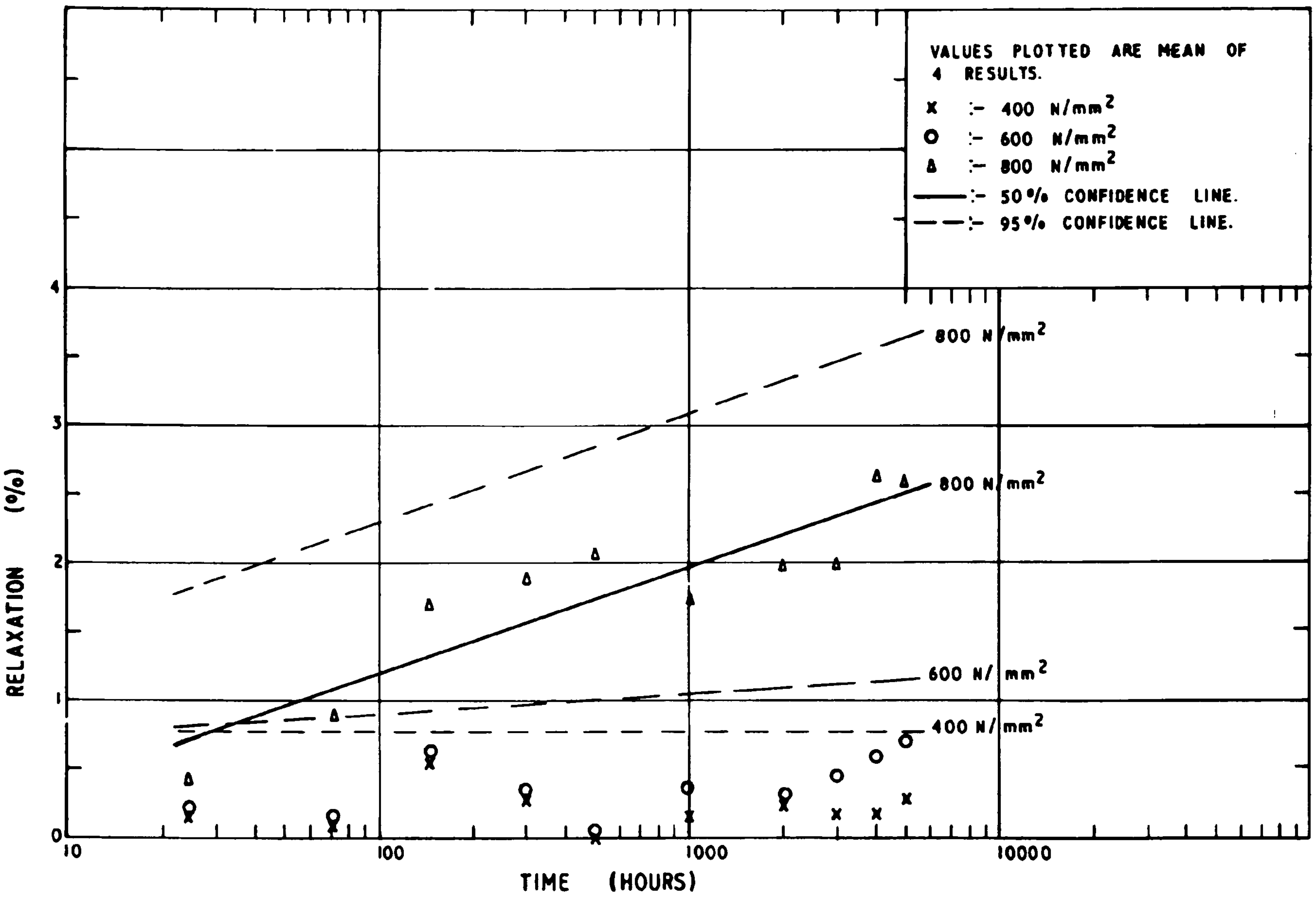

FIG. 16. TIME RELAXATION OF MONEL K500 AT AMBIENT TEMPERATURE.

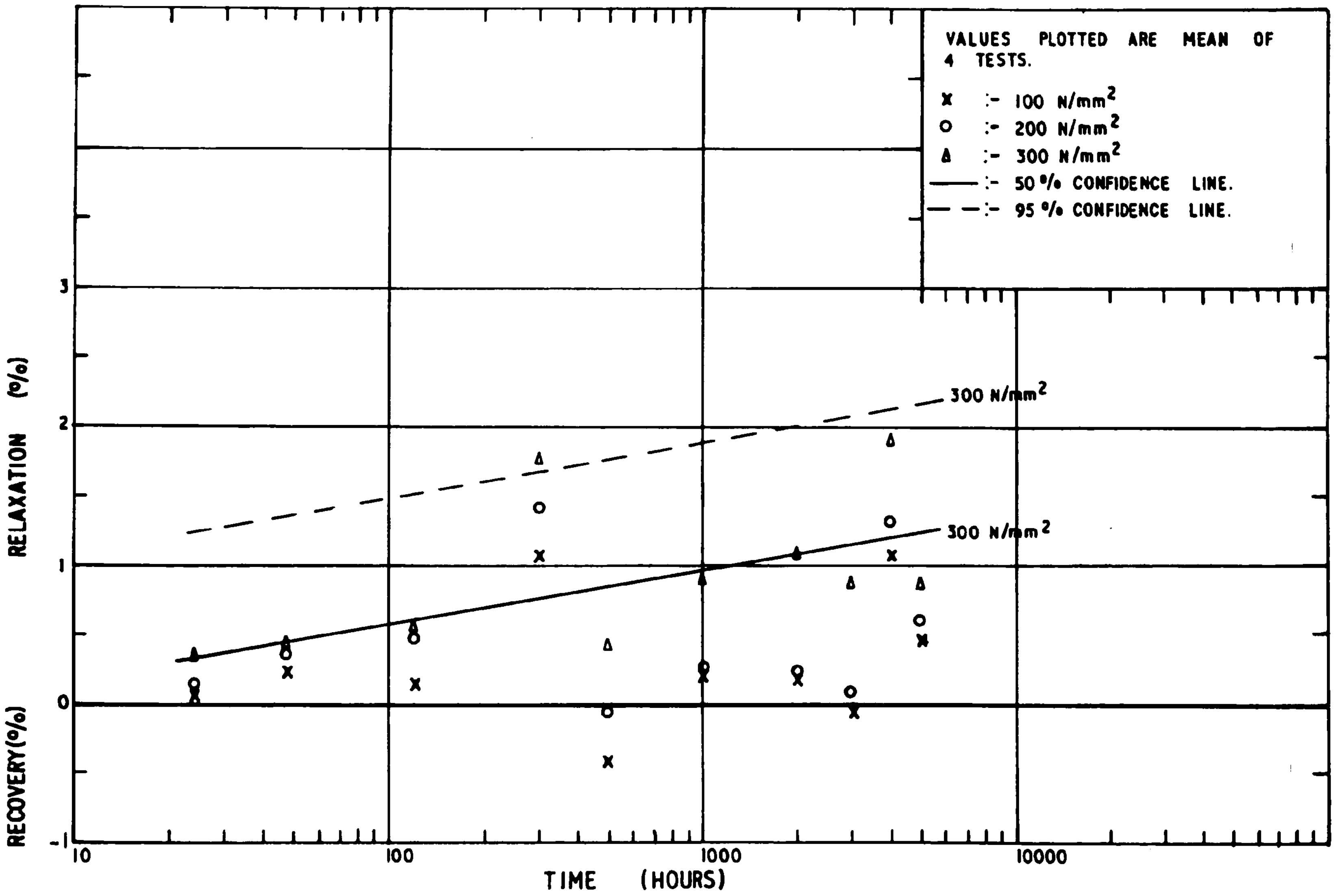

FIG. 17. TIME RELAXATION OF COPPER-BERYLLIUM AT AMBIENT TEMPERATURE.