THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE RELAXATION BEHAVIOUR OF CARBON AND STAINLESS SPRING STEELS IN BENDING

Report No 388

by

M O'Malley, B.Sc.

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SUMMARY

An investigation has been carried out to determine the stress relaxation properties of carbon and stainless spring steel materials in bending. Previous work by SRAMA [(1)] used a 4 point bending method to examine carbon steel strip, but that method had a major difficulty in that it was not possible to ensure that the strip was stressed to the required level. For the current investigation, a method was developed in which the samples were bent around the inside of circular tubes, thus ensuring that they were evenly stressed to the required level. For comparison purposes tests were also carried out on spring clip and Belleville washer components.

The test method yielded data which conformed to the established logarithmic time relaxation relationship. Relaxation data was obtained for BS 5770 302S25 and 17/7 PH grade stainless steel, and for BS 5770 CS70 and CS95 grade carbon steel. The values of relaxation obtained for these materials in bending were similar to those values recorded for the same materials in torsion.

There was no difference in performance between CS70 and CS95 carbon steel strip, but austempering may improve the relaxation resistance.

The results generated using the tube method agreed with those obtained for the components under test.

The method does not appear to be suitable for testing wires in bending, as they were not self-supporting in the tubes. Some other test method must, therefore, be devised for wire in bending, and further work is necessary examining materials not covered by this investigation.

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1. INTRODUCTION

Over recent years the Association has been building up a comprehensive data-bank on relaxation behaviour of compression springs such that it is now possible to predict the relaxation behaviour of the most commonly used spring materials at the majority of appropriate stress and temperature conditions. However, this data-bank only covers wire compression springs ie for material stressed in torsion, and very little data is available for material stressed in bending. Considering the large numbers of wire and strip components which operate in bending, eg torsion springs, wireforms, belleville washers, spring clips etc, some assessment of relaxation in bending is required. If a correlation could be made between data generated for materials in bending and existing data for compression springs of an equivalent material, it would then be possible to use the data-bank for prediction purposes for all types of spring components.

A previous investigation by SRAMA [1] assessed the relaxation of plain carbon spring steel strip in 4 point bending. The test method comprised bending the strip on a pinboard apparatus with pins spaced such that various different levels of stress were generated in the strips. A number of difficulties and limitations exist in using this test method.

Firstly, in order to reduce frictional forces on the strip round pins are used to constrain it, but as a result complex mathematical calculations must be used to determine the actual gauge length and thus the radius of curvature of the strip. Secondly, it is difficult to ensure that the strip is accurately bent to the required radius. Finally, the actual length of strip which is evenly bent to the desired radius is very short (in the order of 16 mm), subsequently the deflection of the strip is very slight and changes in this deflection due to relaxation are very small and difficult to measure.

It was, therefore, decided that another test method should be used which was capable of generating both reliable and repeatable test results. Preferably the chosen method should be suitable for testing both strip and wire materials. An assessment was carried out of the pros and cons for each test method previously used by various authors to generate strip relaxation data, and the method that was considered to be the most suitable (with a slight modification) was used for the investigation.

2. ASSESSMENT OF TEST METHODS

2.1 Mandrel Method [2]

The method comprises bending test samples around circular mandrels of sufficient diameter to produce the required stress levels in the specimens, and clamping them in place. The relaxation is determined by measuring the permanent set which occurs in the samples during testing. The advantages of this test method are that the samples are uniformly stressed along their full length (up to the position of the clamps), and it is possible to use a relatively long sample gauge length thus facilitating the measurement of permanent set as any changes in this feature will be correspondingly increased. However, at very high stresses ie with small diameter mandrels, the samples tend to bow away from the mandrel as they are not restrained on 100% of their outer surface and so are not maintained at the required stress level. Other disadvantages of this test method include alteration of the stress level on the samples at elevated temperatures due to expansion of the mandrels, the long heat up and cool down times due to the mandrel size, and the possibility of errors arising due to clamping effects.

2.2 Ring Method [3]

In this method the samples (either strip or wire) are bent around the inside of steel rings or tubes of inside diameter corresponding to the required level of stress. The relaxation is determined by measuring the change in permanent set occurring in the test specimens. The advantages of this method are that the specimens are uniformly stresed along their full lengths, they are supported on 100% of the surface and there is no change in stress due to expansion of the test apparatus. Also, as the rings or tubes are only of sufficient thickness to withstand the forces exerted by the test samples, they heat up and cool down from elevated temperatures relatively quickly. The length of specimen used for the test is of corresponding length to the inner circumference of the ring, thus the measurement of changes in permanent set is facilitated as a large gauge length can be used. However, as the test sample itself will expand when testing at elevated temperatures, the sample length must be such to accommodate this expansion and still remain in position (see Figure 1), and so the samples must be very accurately ground to length. Also, as the samples are self supporting in the tube ie with the ends butted together, it is necessary to ensure that the ends are ground square so that the samples sit squarely during testing.

The inner surface of the ring should be coated with a lubricating compound (eg graphite) to reduce friction between the sample and the test apparatus during expansion and thus eliminating the complex stress situation which can be set up.

After careful consideration of each test method, it was decided that the ring method would be the most appropriate for this investigation as:

a) it was the only method in which it was possible to ensure that the samples were maintained at the desired stress level thoughout the course of testing;

b) the samples are uniformly stressed along their full lengths;

c) by being self supporting clamping errors are eliminated;

d) the measurement of permanent set is facilitated as the samples are relatively long;

e) the test method and apparatus are simple to use.

3. MATERIALS USED IN THE INVESTIGATION

The work was carried out using 4 grades of 12.5 mm wide, 0.254 mm thick strip material (2 stainless and 2 carbon steel), 2 grades of 1.2 mm diameter spring wire (1 stainless and 1 carbon steel) and 2 types of carbon steel strip components ie a spring clip (see Figure 2) and a Belleville washer.

The strip materials consisted of a 302S25 stainless temper rolled to 380 HV minimum and stress relieved at 500°C for 2 hours, a 17/7 PH stainless in the precipitation hardened condition, a CS70 carbon steel in both the hardened and tempered and austempered condition (both to a hardness of 500 HV minimum) and a CS95 carbon steel in the hardened and tempered condition to a hardness of 500 HV minimum. The wire materials consisted of a prehardened and tempered 094A65 grade stress relieved at 350°C for half an hour, and a 302S26 stainless steel stress relieved at 500°C for 2 hours. Both strip components were manufactured from CS70 material and were in the austempered condition.

The chemical compositions and tensile properties of the strip and wire materials are given in Tables I and II respectively.

4. STRESS DETERMINATIONS AND TEST APPARATUS

4.1 Strip and Wire Materials

Materials working in bending are often stressed up to or beyond their tensile strength, so it was decided to carry out tests between nominal stresses of approximately 800 N/mm^2 and 120% of the material tensile strength. The nominal inside diameters of the tubes required for the test apparatus were calculated from bending theory using the formula:-

$$\sigma = \frac{Ey}{R} \quad .... (1)$$

Where σ = bending stress

E = Young's modulus of material

$y = \frac{t}{2}$

t = material thickness

R = radius of curvature = inside radius of tube

The nominal diameters were calculated as 63, 40 and 25 mm for nominal stresses of 800, 1300 and 2000 N/mm^2 respectively for the carbon steels for a material thickness of 0.254 mm.

Heavy gauge tube stock of suitable diameters was purchased and machined into test lengths of approximately 150 mm. The inside bore of each tube was machined to remove any irregularaties and to ensure that it was perfectly round, and was then lightly polished to remove the machining marks. The inside diameter was measured and the stress levels for each material determined using equation (1). A list of these stress levels is given in Table III.

4.2 Spring Clip Components

The components were to be relaxation tested by placing them on 37 mm diameter mandrels (see Figure 2 and section 5.3) and the greatest stress will occur in the region of the hole. This stress was calculated from bending theory using the formula:-

$$\sigma = \frac{My}{I} \times K_t \quad \ldots\ldots\ldots\ldots (2)$$

Where σ = stress

M = bending moment = P x 1

P = applied load

l = distance between point of loading and point of maximum stress

$y = t/2$

t = material thickness

I = moment of inertia of material section = $\frac{(w - a)\ t}{12}$

w = material width

a = hole diameter

K_t = stress correction factor - taken from Parrish [4]

The maximum stress was calculated as 1435 N/mm^2.

4.3 Belleville Washers

The washers were tested as a pair in series (see Figure 3 and section 5.4). The maximum tensile stress occurs at the outer lower edge of the washer and was calculated from the formula:-

$$\sigma = \frac{f}{\alpha D_a^2}\left[\beta(h - f/2) + \gamma\, s\right] \quad \ldots\ldots\ldots\ldots (3)^{(5)}$$

Where σ = stress

f = deflection of a single washer

D_a = outside diameter

h = unloaded height of a single washer

s = material thickness

α = constant depending on Di/Da ratio and E — taken from

$\beta + \gamma$ = contants depending on Di/Da ratio — Schnorr (5)

D_i = inside diameter

This stress was calculated as being of magnitude 1390 N/mm^2.

5. TEST DETAILS

5.1 Strip Testing

Prior to commencement of relaxation testing, the strips were prestressed by being repeatedly placed into and removed from the appropriate diameter tube until no further set was experienced. The strips were then numbered and the initial bow h_I of each measured over a gauge length of 75 mm using a Nikon projection microscope (see Figure 4). Five strips were placed into the tubes (the inside surface of which had been coated with a graphite suspension to reduce friction and ease removal of the strips) and placed into air circulating ovens for the test duration. The test temperatures for the 4 materials were as follows:-

TABLE A TEST CONDITIONS FOR STRIP

Material	Test Temperature (^{o}C)
Carbon Steels	Ambient, 100, 150
302S25 Stainless	Ambient, 200, 250
17/7 PH Stainless	250

After the appropriate length of time, the tubes were removed from the ovens and allowed to cool to room temperature. The strips were removed from the tubes, the new bow h_N measured and then the strips re-inserted into the tubes for a further test duration up to a maximum of 1000 hours.

Difficulties arose in testing at the highest stress level ie with the smallest tube diameter, because some of the strips did not take up an even curvature when prestressed making measurement of the bow difficult (see Figure 4). This is probably a result of the fact that, in order to place the strips in the tubes, it is necessary to bend the strips to a smaller diameter than the tube diameter, and it is not possible at this stage to ensure that the strips are evenly curved. Also, when relaxation occurred the bow of the strip was such that the distance between the ends of the strip was less than the 75 mm gauge length and thus measurement of the bow was impossible. Therefore, a number of retests were carried out using a 50 mm gauge length.

5.2 Wire Testing

As can be seen from Table III, the stress levels on the wires were exceedingly high eg approximately 200% of the tensile strength for the largest diameter tube ie the lowest stress due to the wire diameter used. It was not possible to use smaller diameter wire which would have been more lowly stressed as it was not self supporting in the tubes.

Similarly, reducing the stress level by using larger diameter tubes did not seem a feasible alternative as the test apparatus would then become cumbersome. It was, therefore, decided to limit the testing to using the large diameter tubes, and to determine a more suitable method for any future testing of wire in bending.

The test procedure is as given for the strip (see section 5.1), and the temperatures used were as follows:-

TABLE B TEST CONDITIONS FOR WIRE

Material	Test Temperature (^{o}C)
BS 2803 094A65	150
BS 2056 302A26	250

5.3 Spring Clip Components

The components were relaxation tested by placing on a suitably sized mandrel. A variety of mandrel diameters were considered, the maximum stress in the clip was calculated using the method described in section 4.2 for each mandrel and it was decided that a diameter of 37 mm was most appropriate.

The clips were prestressed by being placed on and removed from the mandrel a number of times until no further set occurred. The load exerted by the clip at the mandrel deflection was measured using the Probat 100 N electronic load tester fitted with suitable test fixtures (see Figure 2). After load testing, the clips were loaded onto the mandrels and relaxation tested at ambient and 150^{o}C for the appropriate test duration, after which the clips were reload tested to determine the load loss.

5.4 Belleville Washers

The washers were prestressed to solid a number of times and were then load tested as a pair in series (see Figure 3) at a compressed length just above solid using the Association's 40 KN electronic load tester. The washers were left in situ on the load tester at the compressed length and the reduction in load after the requisite time intervals was noted.

6. RELAXATION DETERMINATION AND RESULTS

6.1 Strip Results

The relaxation exhibited by the strips can be determined by measuring the permanent set experienced during testing as, from bending theory, the load on the strips is related to the radius of curvature which, in turn, is related to the deflection from flat (ie bow) of the strip.

Relaxation is generally calculated using the formula:-

$$\% \text{ Relaxation} = \frac{(\text{original load} - \text{load after testing})}{\text{original load}} \times 100 \qquad \ldots\ldots\ldots\ldots (4)$$

For this test method, the original load in the strip is the load due to bending from an initial radius of curvature (R_I) to the test radius (R_T) and similarly the load after testing is that due to bending from the new radius of curvature (R_N) to the test radius (R_T). From equation (1), stress, and hence load, is inversely proportional to the radius of curvature, and thus:-

$$\text{Original load} \propto {}^1/_{R_T} - {}^1/_{R_I} \qquad \ldots\ldots\ldots (5)$$

$$\text{and load after testing} \propto {}^1/_{R_T} - {}^1/_{R_N} \qquad \ldots\ldots\ldots\ldots (6)$$

Substituting (5) and (6) in equation (4) we get:-

$$\% \text{ relaxation} = \frac{{}^{1}/_{R_N} - {}^{1}/_{R_I}}{{}^{1}/_{R_T} - {}^{1}/_{R_I}} \times 100 \qquad \text{..........} \ (7)$$

The radius of curvature (R) is determined using the relationship:-

$$R = \frac{h^2 + {}^{x^2}/_4}{2h} \qquad \text{..........} \ (8)$$

Where h = bow (see Figure 4)

x = gauge length

The relaxation results for all the strip materials tested are presented in Figures 5-16. For each individual material, stress level and test temperature, the data was analysed using linear regression techniques and were found to conform to the standard logarithmic time-relaxation relationship of the form:-

$$\% \text{ Relaxation} = c \log t + d \qquad \text{..........} \ (9)$$

Where t = time in hours

c and d are constants

The values of c, d and the 95% confidence increments for the various materials and test conditions are given in Table IV.

6.2 Wire Results

The method of determination of the relaxation level was as described in section 6.1. The results obtained were:-

TABLE C RELAXATION RESULTS FOR WIRE MATERIALS

Material	Test Temperature (°C)	% Relaxation After 3 Hours
BS 2056 302S26	250	31.3-33.5
BS 2803 094A65	150	22.5-25.5

As can be seen, very high levels of relaxation were obtained after a short period of time due to the high level of stress in the material. It was, therefore, decided that testing should be discontinued.

6.3 Spring Clip Components and Belleville Washer Results

For both the spring clips and the Belleville washers, the relaxation level was calculated using equation (4); the results for the spring clip components are presented in Figure 17 and for the Belleville washers were as follows:-

% Relaxation After		
16 hrs	32 hrs	104 hrs
1.7	2.5	2.7

The results for the spring clips were analysed using linear regression techniques and were found to conform to the standard logarithmic time-relaxation relationship.

7. DISCUSSION OF RESULTS

A comparison was made between the results obtained for the strip materials after 1000 hours with existing data [6, 7] for compression springs made from corresponding materials at equivalent stress levels and temperatures. The values are presented in Table V.

As the existing data for the compression springs did not include that for the required stress levels, these values were determined using the exponential stress relaxation relationship of the form:-

$$Rel = ae^{b\tau} \quad .... \quad (10)$$

Where Rel = Relaxation (%)

τ = Stress (N/mm^2)

a and b are mathematical constants.

As can be seen, there is fairly close agreement between the compression spring results and the results obtained for the two stainless steel materials at all stress levels and for the carbon steel material at low stress levels. However, at high stress levels the actual values obtained for the carbon steel were less than the compression spring results. Thus any prediction made from existing spring data for carbon steel strip in bending would tend to be conservative.

A comparison was made between the relaxation levels obtained for the two grades of carbon steel strip in the hardened and tempered condition, and also between those obtained for the two conditions of CS70 strip. It was found that although the CS95 material generally appeared to exhibit slightly better relaxation resistance, the difference in properties between the two materials was not statistically significant so the two materials can be assumed to have the same relaxation properties. For the two conditions of CS70 strip, austempering appears to significantly improve the relaxation resistance at elevated temperature, but does not do so at ambient. This latter finding is probably a reflection of the low levels of relaxation experienced.

The results obtained for the spring clip components and for the Belleville washers correlate well with those obtained for the austempered strip indicating that the test method generates valid data which can be used for design purposes.

8. CONCLUSIONS

1. The test method provides valid design data and fulfills the requirements of being reliable and repeatable.

2. For stainless steels and for lowly stressed carbon steels in the hardened and tempered condition, there is close agreement between the relaxation of strip in bending and for relaxation of compression springs.

9. RECOMMENDATIONS FOR FURTHER WORK

As it was found that the test method was unsuitable for testing wire in bending due to the high stresses involved using the current test apparatus, some other test method must be devised to generate more meaningful data which can then be correlated with the existing relaxation data-bank. The possibilities appear to be using wire forms, torsion springs or possibly the method devised by Fox [9] where the wire is clamped into loops of varying diameters thus obtaining lower stress levels and eliminating the test apparatus.

It is also recommended that tests be carried out on other materials ie copper alloys and possibly chrome-vanadium steel, to see whether there is any correlation between the relaxation of these materials in bending and their properties as helical compression springs.

10. REFERENCES

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3. Zubov, V Ya, "Testing Spring Steel Strip for Relaxation". Zavod Lab, 1956, 22, (3), pp 329-331.

4. Parrish, A, "Mechanical Engineers' Reference Book". Newnes-Butterworths, 1973.

5. "Handbook for Schnorr Disc Springs", Adolf Schnorr KG, 8th Edition.

6. O'Malley, M, "The Long Term Relaxation Behaviour of Compression Springs Manufactured from Carbon and Stainless Steel Wires". SRAMA Report No 325, March 1980.

7. O'Malley, M, "The Long Term Relaxation Behaviour of Spring Materials Second Progress Report". SRAMA Report No 349, May 1982.

8. Fox, A, "A Simple Method for Evaluating Stress Relaxation in Bending". Materials Research and Standards, Sept 1964, 4, (8), pp 480-481.

<u>TABLE I</u> <u>CHEMICAL COMPOSITIONS OF STRIP AND WIRE MATERIALS</u>

Material		Composition (%)							
		C	Si	Mn	S	P	Cr	Ni	Al
BS 5770 CS95	Specified	0.9-1.0	0.05-0.35	0.3-0.6	0.04 max	0.04 max	-	-	-
	Actual	0.955	0.245	0.36	0.009	0.012	-	-	-
BS 5770 CS70	Specified	0.65-0.75	0.05-0.35	0.5-0.9	0.045 max	0.045 max	-	-	-
	Actual	0.695	0.304	0.62	0.012	0.012	-	-	-
BS 5770 302S25	Specified	0.12 max	0.2-1.0	0.5-2.0	0.03 max	0.045 max	17.0 19.0	8.0-11.0	-
	Actual	0.036	0.70	1.62	0.005	0.026	17.2	8.9	-
17/7 PH	Specified	0.09 max	1.0 max	1.0 max	0.03 max	0.045 max	16.0-18.0	6.5-7.75	0.75-1.5
	Actual	0.073	0.44	0.66	0.014	0.026	17.0	7.4	1.2
BS 2803 094A65	Specified	0.55-0.75	0.3 max	0.6-1.2	0.04 max	0.04 max	-	-	-
	Actual	0.62	0.24	0.75	0.015	0.017	-	-	-
BS 2056 302S26	Specified	0.12 max	1.0 max	2.0 max	0.03 max	0.045 max	17.0 19.0	7.5-10.0	-
	Actual	0.078	0.5	0.68	0.003	0.028	17.5	8.4	-

TABLE II MECHANICAL PROPERTIES OF STRIP AND WIRE MATERIALS

Material	Condition	Tensile Properties (N/mm^2)		
		Rm	L of P	$Rp_{0.5}$
BS 5770 CS95	Hardened & Tempered	1700	1120	1405
BS 5770 CS70	Hardened & Tempered	1660	1135	1455
	Austempered	1780	1130	1410
BS 2056 302S25	LTHT 500°C 2 Hrs	1430	900	1210
17/7 PH	Precipitation Hardened	1685	1120	1665
BS 2803 094A65	LTHT 350°C ½ Hr	1795	935	1395
BS 2056 302S26	LTHT 500°C ½ Hr	1545	665	1055

TABLE III TEST STRESS LEVELS

Tube Inside Diamter (mm)	Material & Form		Stress Level	
			(N/mm^2)	(% Rm)
67.9	Carbon Steel	Wire	3715	205
		Strip	775	45
	302S26	Wire	3470	225
	302S25	Strip	720	50
	17/7 PH	Strip	760	45
41.0	Carbon Steel	Wire	6155	345
		Strip	1280	75
	302S26	Wire	5745	370
	302S25	Strip	1195	85
	17/7 PH	Strip	1260	75
27.9	Carbon Steel	Wire	9045	505
		Strip	1885	110
	302S26	Wire	8440	545
	302S25	Strip	1760	125
	17/7 PH	Strip	1855	110

TABLE IV ANALYTICAL CONSTANTS FOR STRIP MATERIALS

Material & Condition	Test Temperature (^{o}C)	Stress Level (N/mm^2)	R = c log t + d		95% Confidence Increment
			c	d	
302S26	250	720 1195 1760	1.55 2.27 2.23	1.61 4.89 6.00	1.0 1.5 3.7
	200	720 1195 1760	1.41 1.15 2.29	1.06 3.05 3.69	2.1 1.2 2.7
	Ambient	720 1195 1760	0.36 0.74 1.24	0.14 0.49 2.22	0.9 1.5 3.5
17/7 PH	250	760 1260 1855	0.63 1.16 1.15	0.92 1.84 2.49	2.4 1.6 1.6
CS70 Hardened & Tempered	150	775 1280 1885	3.96 4.12 3.10	4.44 8.90 22.21	3.3 2.0 2.1
	100	775 1280	2.19 3.27	2.83 4.68	1.0 1.2
	Ambient	775 1280 1885	0.38 0.82 1.47	-0.10 -0.12 0.41	0.5 0.9 2.6
CS95 Hardened & Tempered	150	775 1280 1885	1.52 2.32 3.83	3.77 7.92 17.66	0.8 1.2 3.2
	100	775 1280	1.21 2.36	1.82 4.50	0.5 1.0
	Ambient	775 1280 1885	0.36 0.68 2.15	-0.43 0.11 4.24	0.7 0.9 8.9

TABLE IV (contd)

Material & Condition	Test Temperature (^{o}C)	Stress Level (N/mm^2)	R = c log t + d		95% Confidence Increment
			c	d	
CS70 Austempered	150	775 1280	0.92 2.18	1.98 8.26	1.8 4.1
	Ambient	775 1280	0.24 1.33	0.09 0.42	0.4 2.7

TABLE V COMPARISONS BETWEEN STRIP RELAXATION LEVELS AND COMPRESSION SPRING RELAXATION LEVELS AFTER 1000 HOURS

Material	Temperature (°C)	Stress Level (N/mm^2)	Maximum Relaxation (%)	
			For Compression Springs	For Strip in Bending
302S25[7]	250	720 1195	6.8 13.2	7.5 13.0
	Ambient	720 1195	4.0 5.4	2.0 4.5
17/7 PH[8]	250	760 1260	4.6 6.8	5.0 6.7
CS70 Hardened & Tempered[7]	150	775 1280	17.0 29.0	19.5 23.5
	Ambient	775 1280	4.0 10.1	3.0 4.2

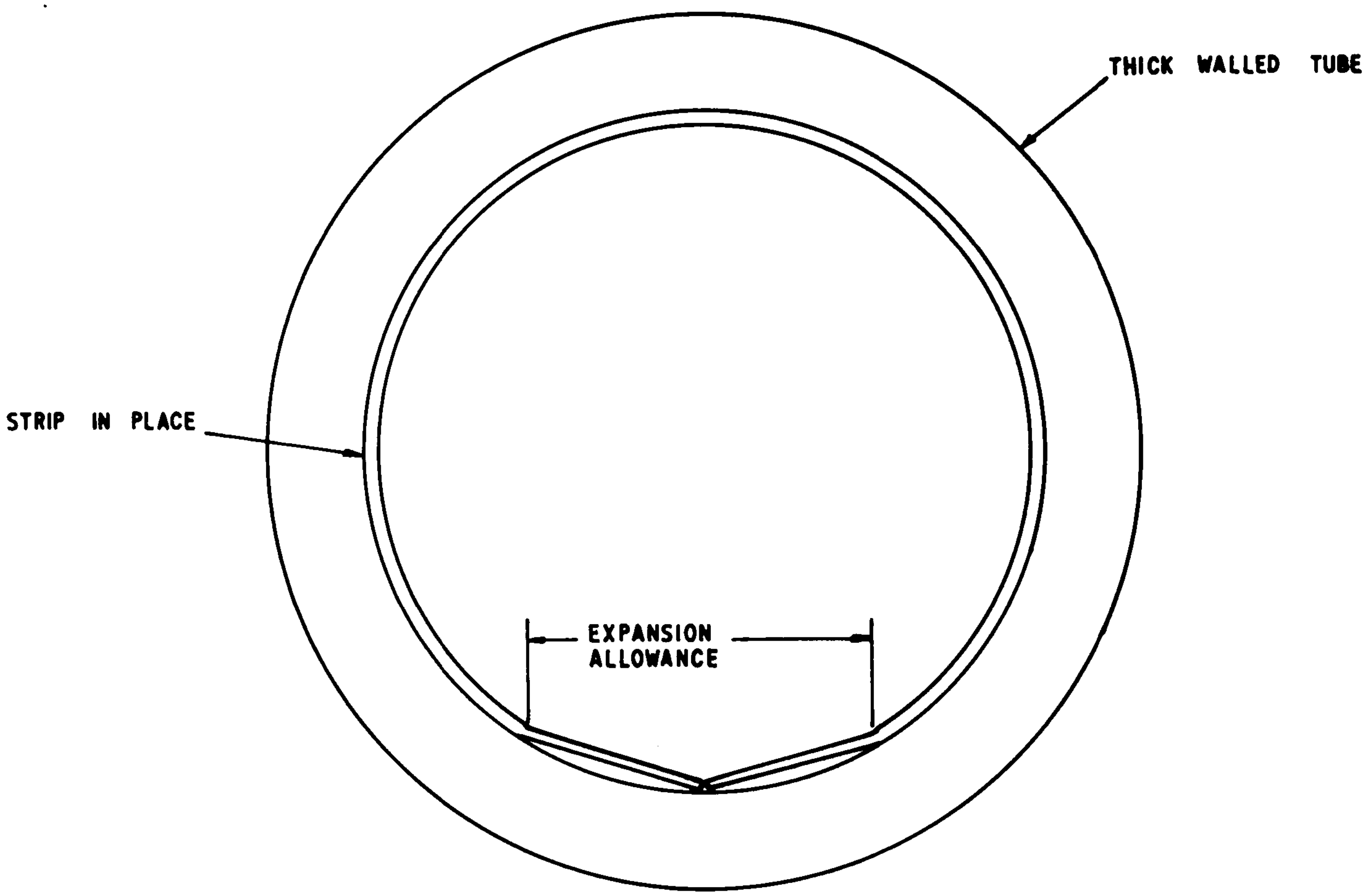
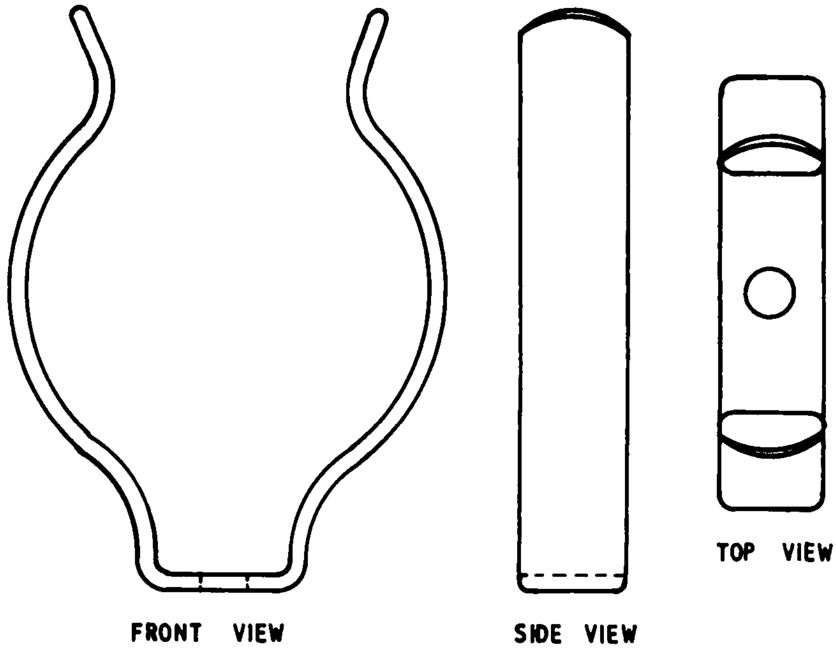
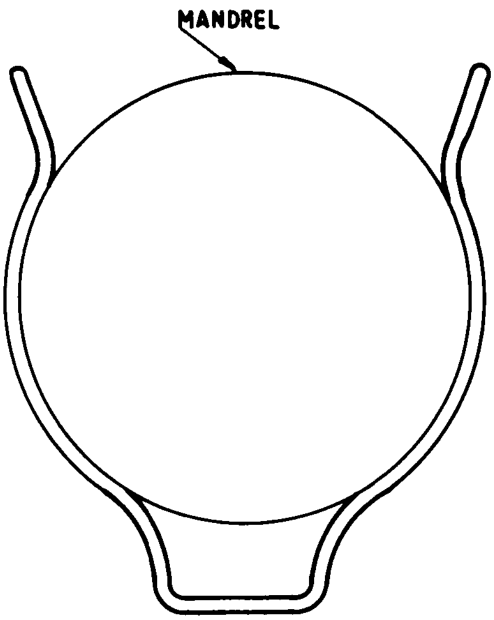


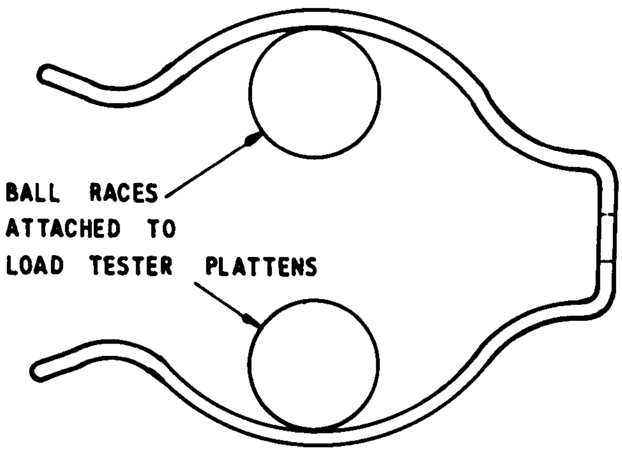
FIGURE I TEST APPARATUS FOR RELAXATION TESTING STRIP IN BENDING.



a. COMPONENT



b. TEST APPARATUS



c. LOAD TESTING APPARATUS

FIGURE 2. SPRING CLIP COMPONENT.

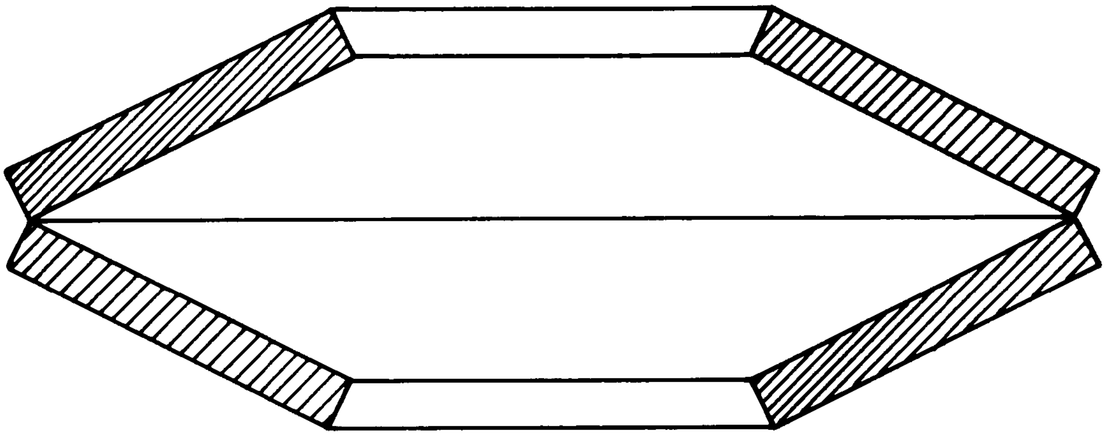


FIGURE 3. BELLEVILLE WASHERS IN SERIES.

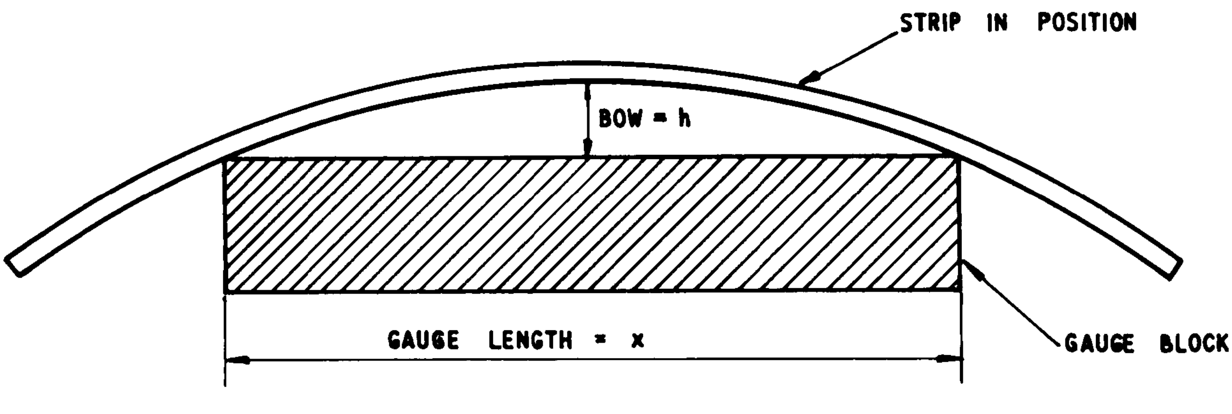


FIGURE 4. METHOD OF MEASUREMENT OF STRIP BOW.

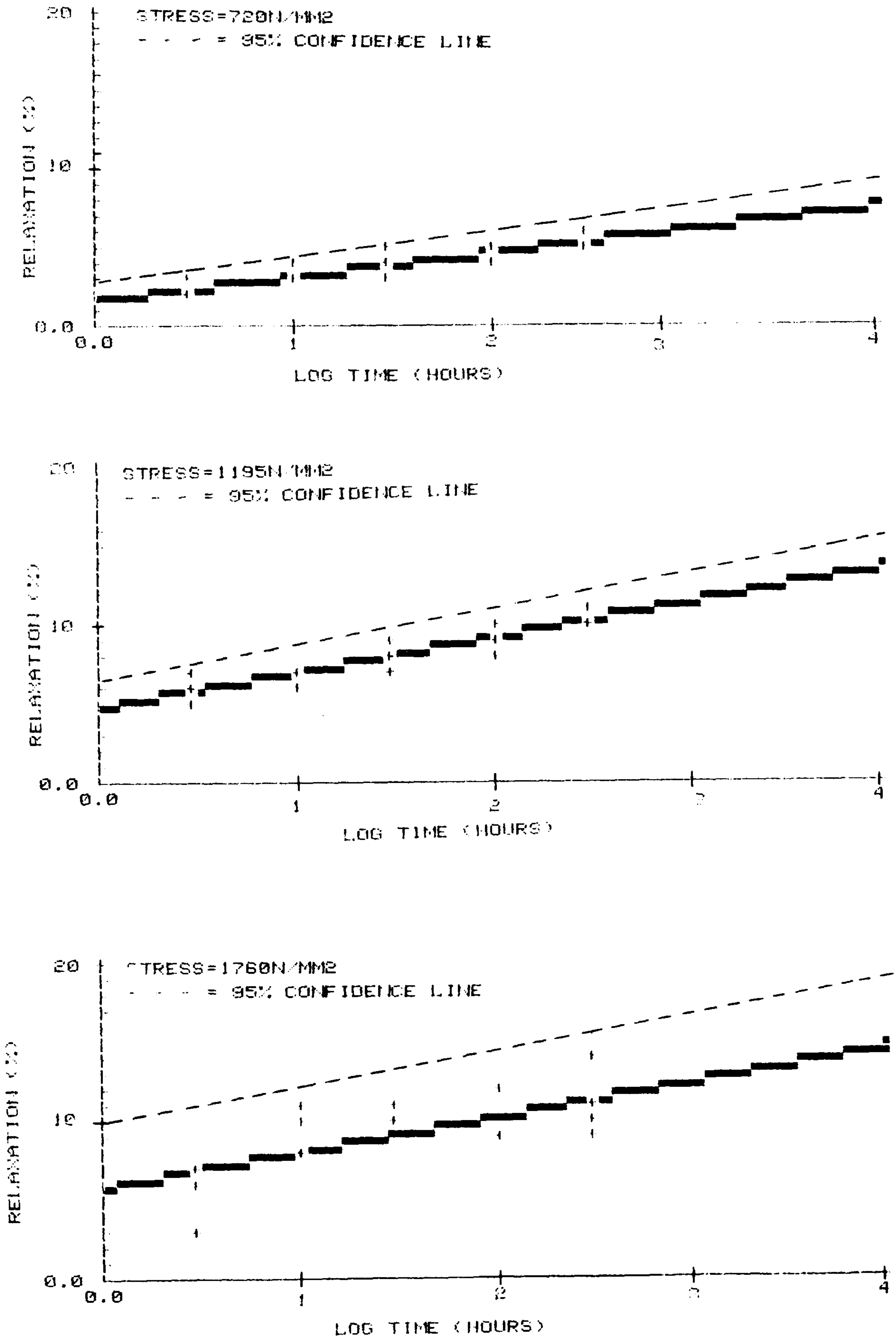


FIGURE 5 RELAXATION OF 302S25 STRIP IN BENDING AT 250 C

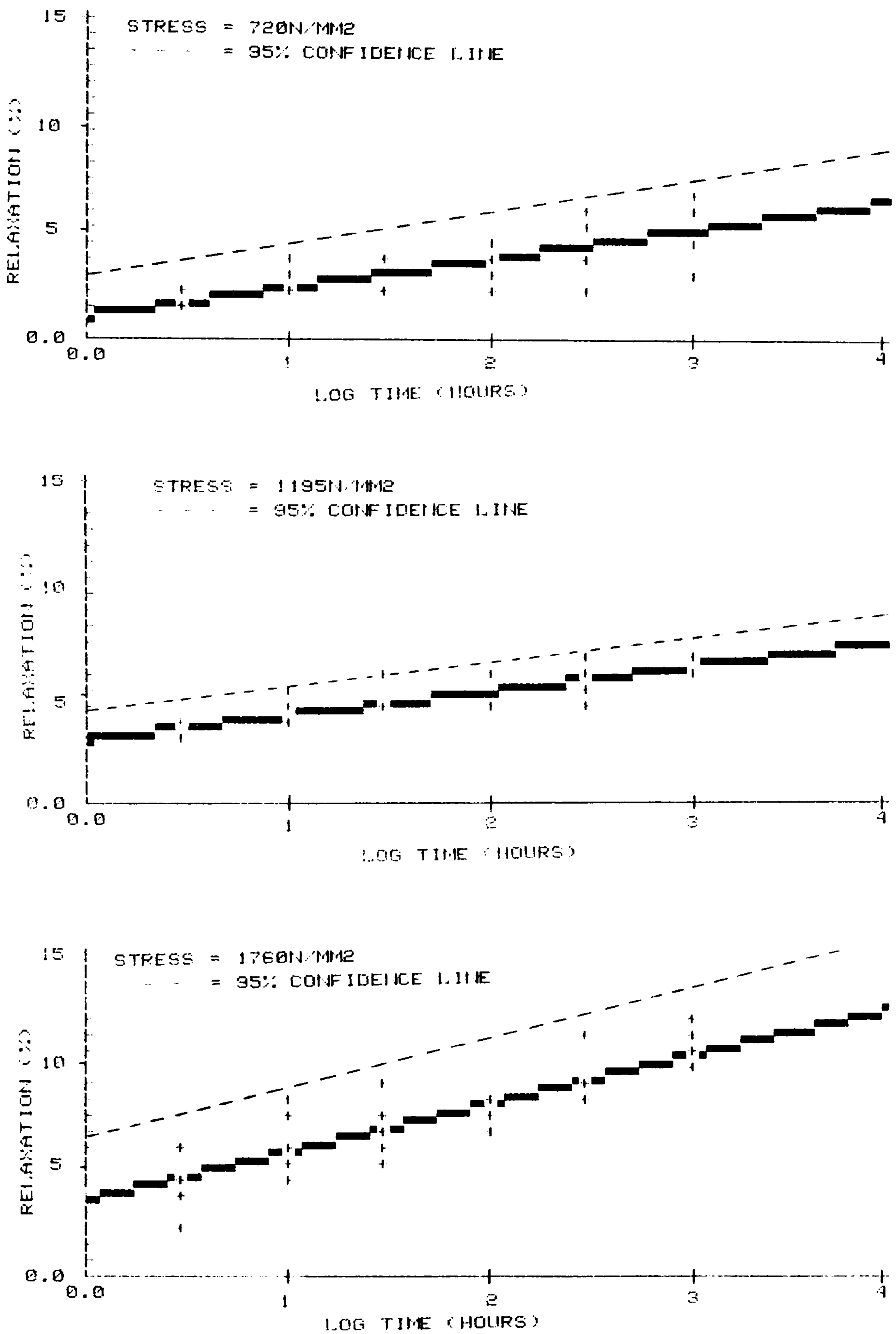
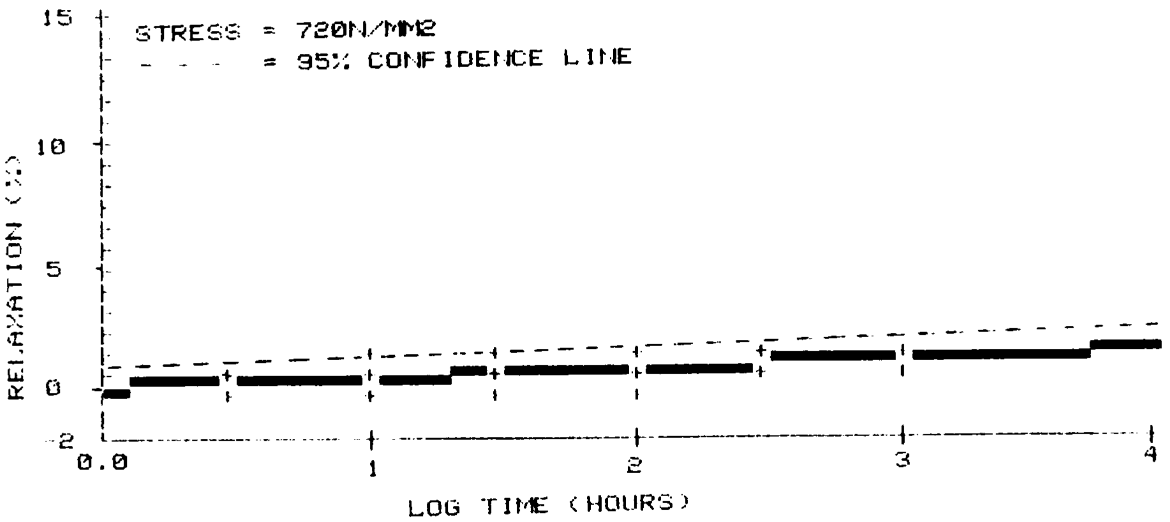
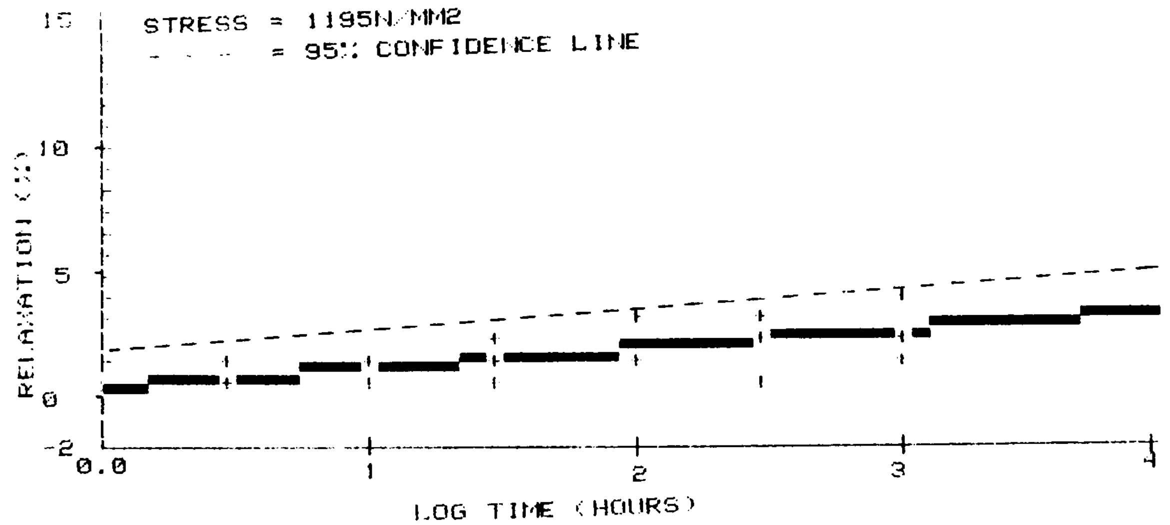


FIGURE 6 RELAXATION OF 302S25 STRIP IN BENDING AT 200 C





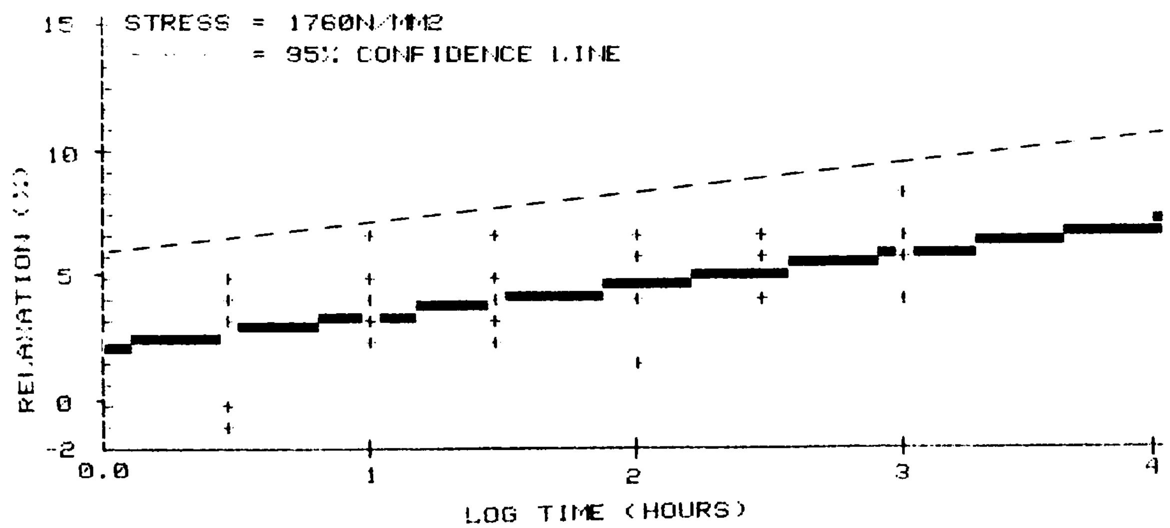


FIGURE 7 RELAXATION OF 302S25 STRIP IN BENDING AT AMBIENT TEMPERATURE

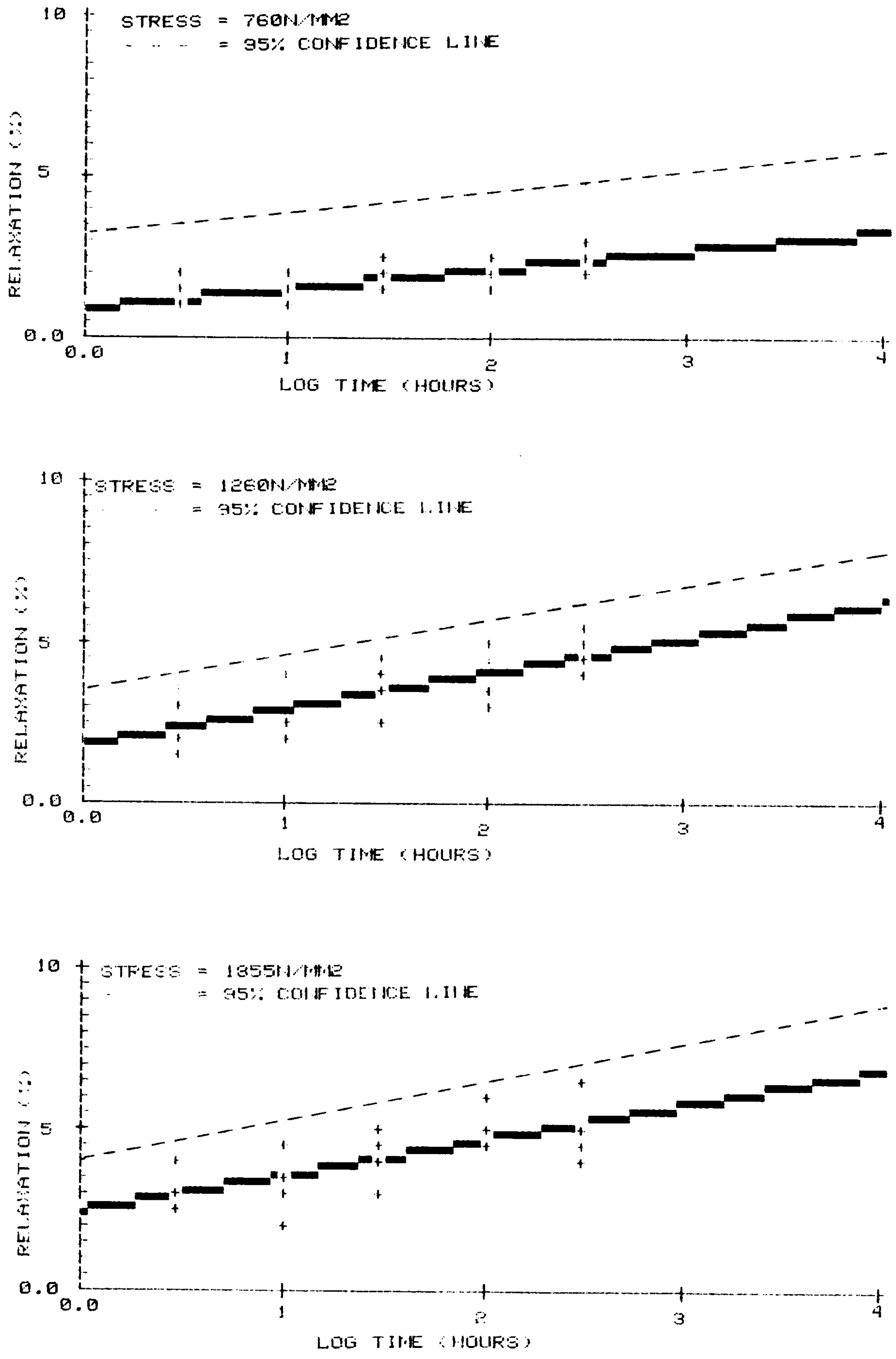


FIGURE 8 RELAXATION OF 17/7PH STRIP IN BENDING AT 250 C

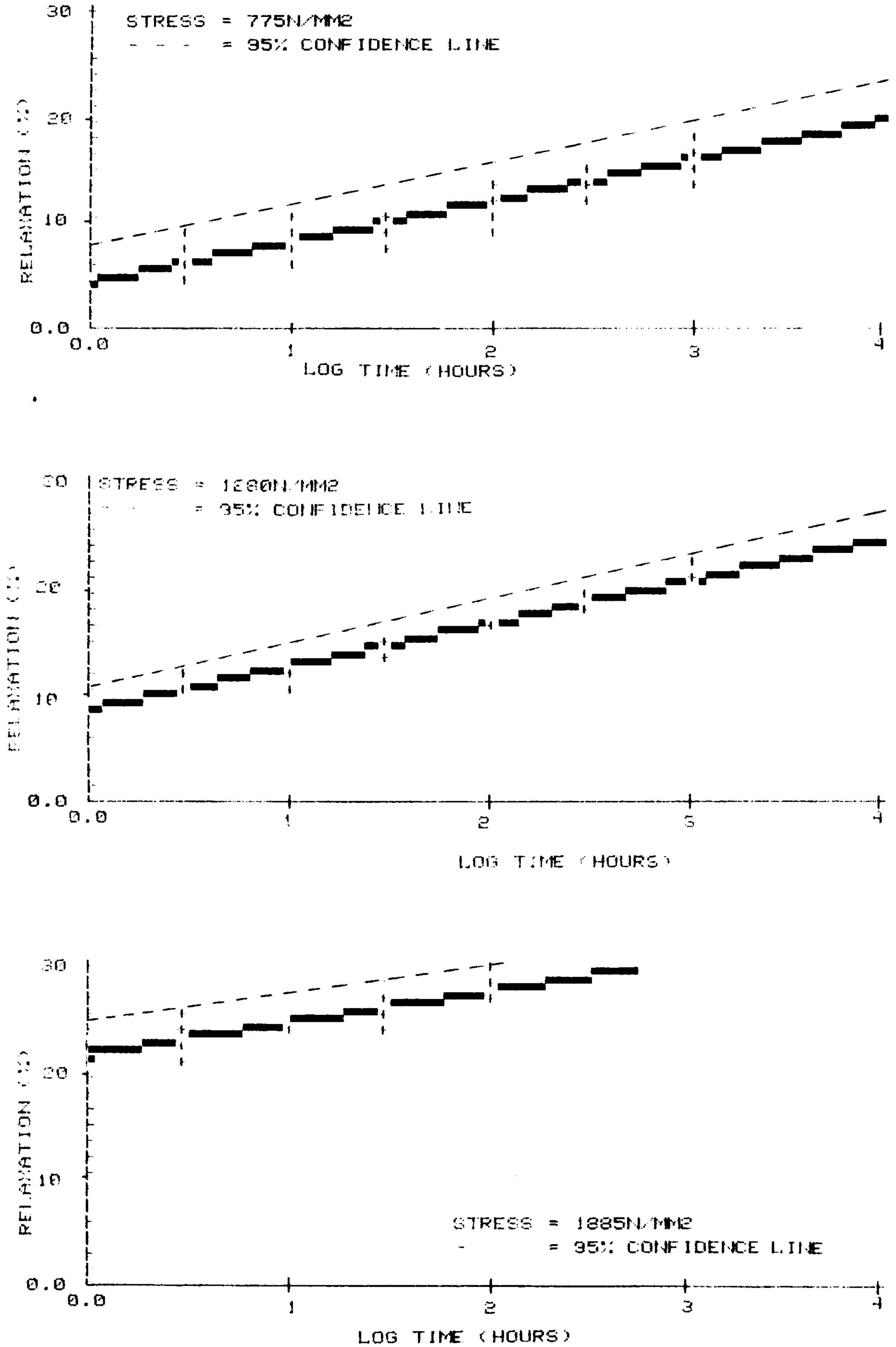
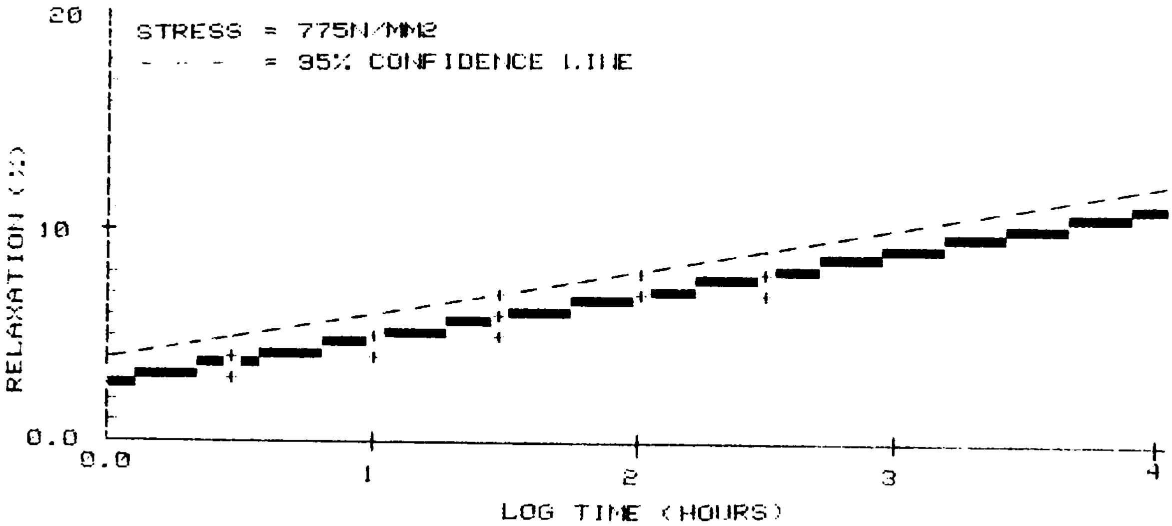


FIGURE 9 RELAXATION OF CS70 HARDENED AND TEMPERED STRIP IN BENDING AT 150 C



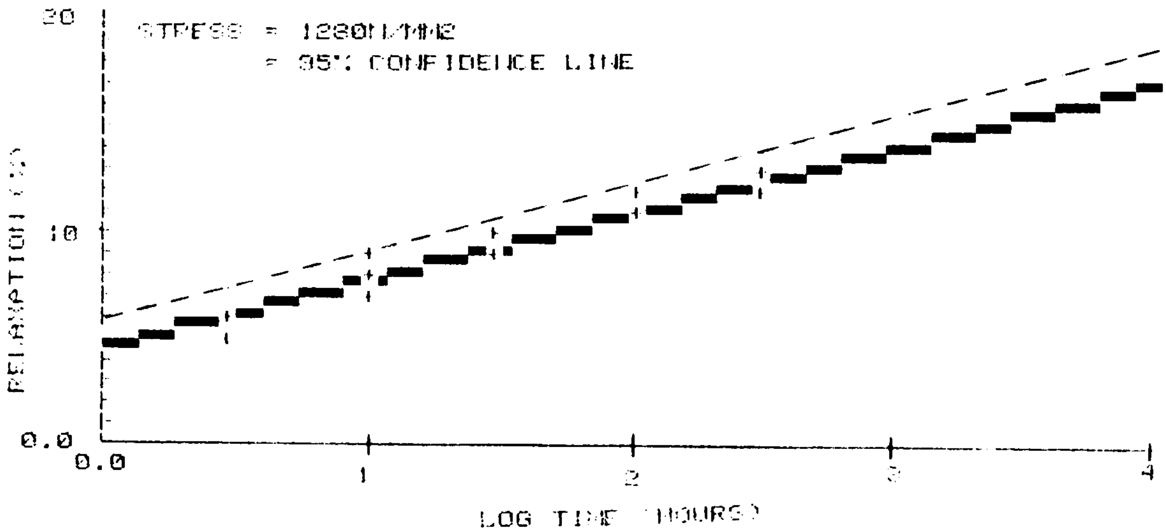
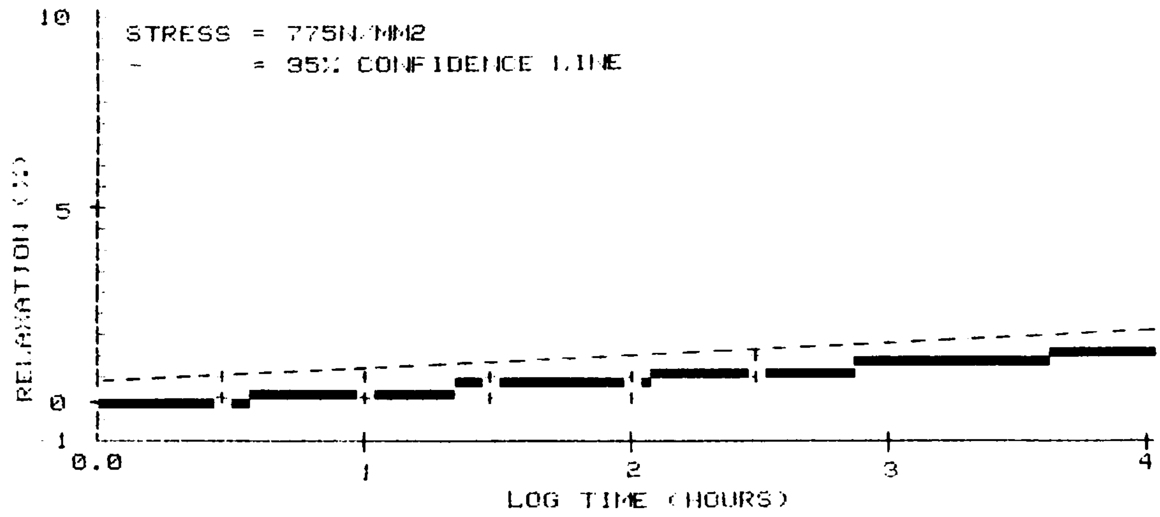
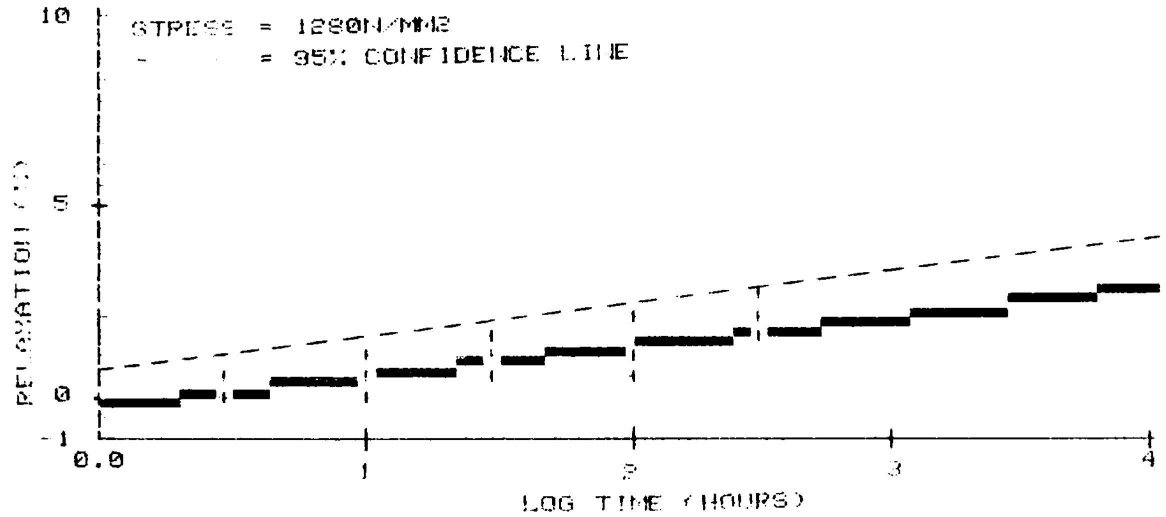


FIGURE 10 RELAXATION OF CS70 HARDENED AND TEMPERED STRIP IN BENDING AT ~~AMBIENT~~ 100°C TEMPERATURE





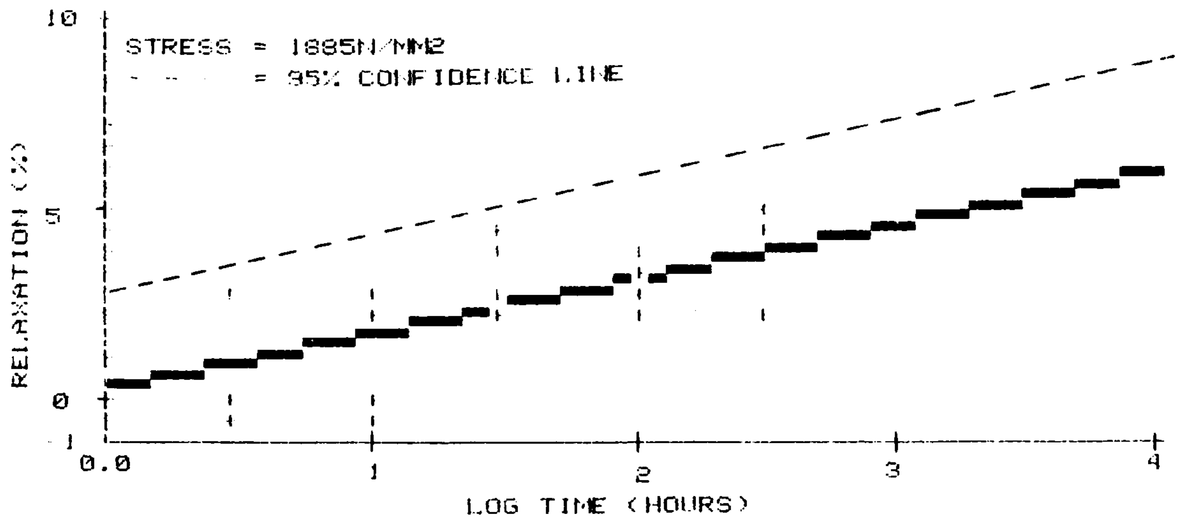


FIGURE 11 RELAXATION OF CS70 HARDENED AND TEMPERED STRIP IN BENDING AT AMBIENT TEMPERATURE

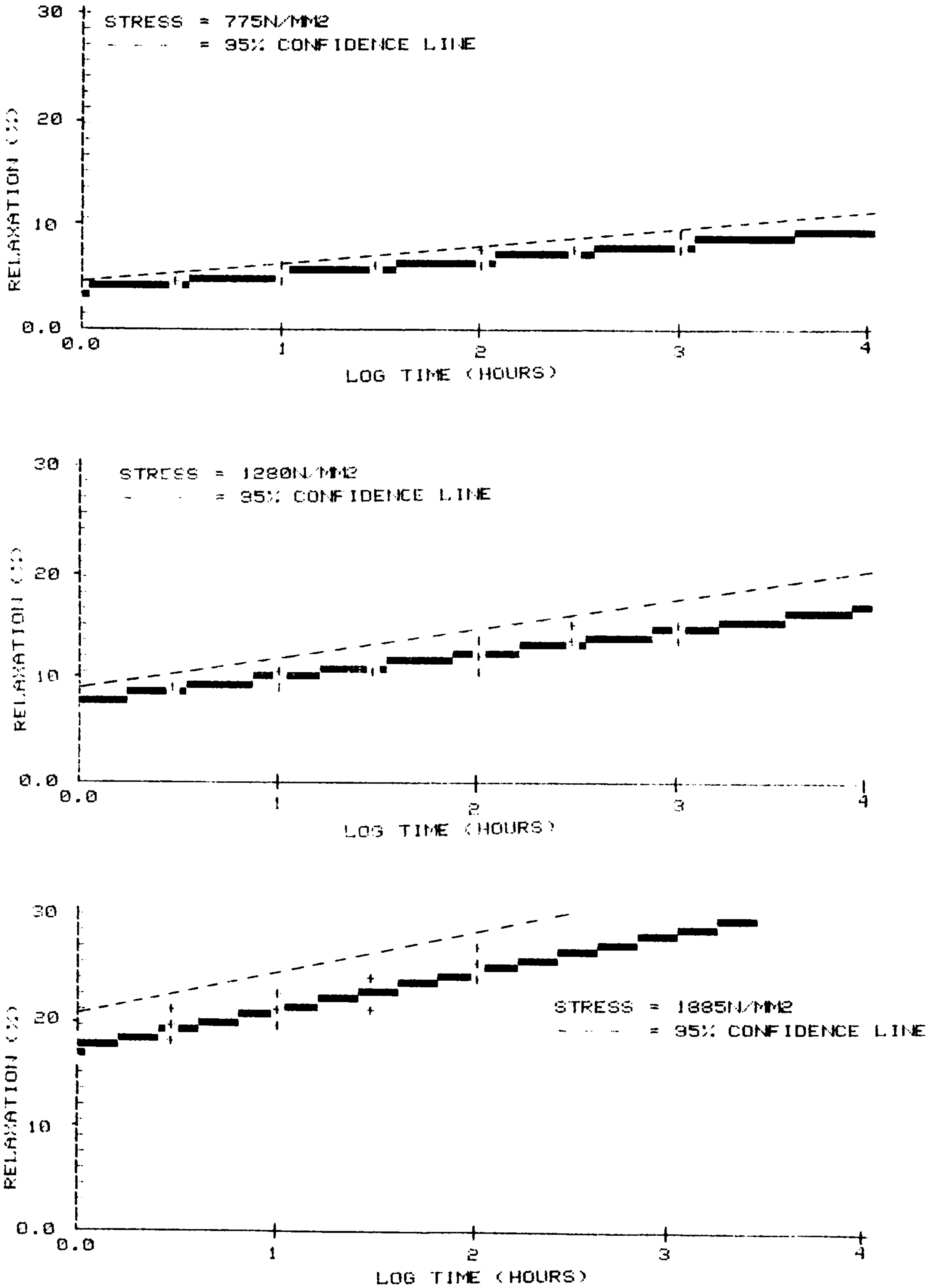
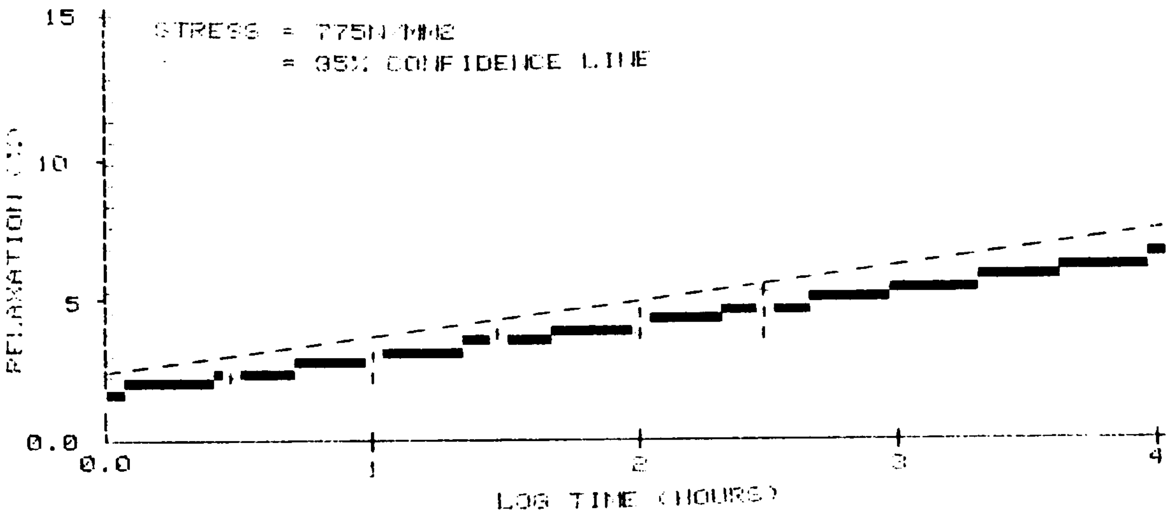


FIGURE 17 RELAXATION OF CS95 HARDENED AND TEMPERED STRIP IN BENDING AT 150 C



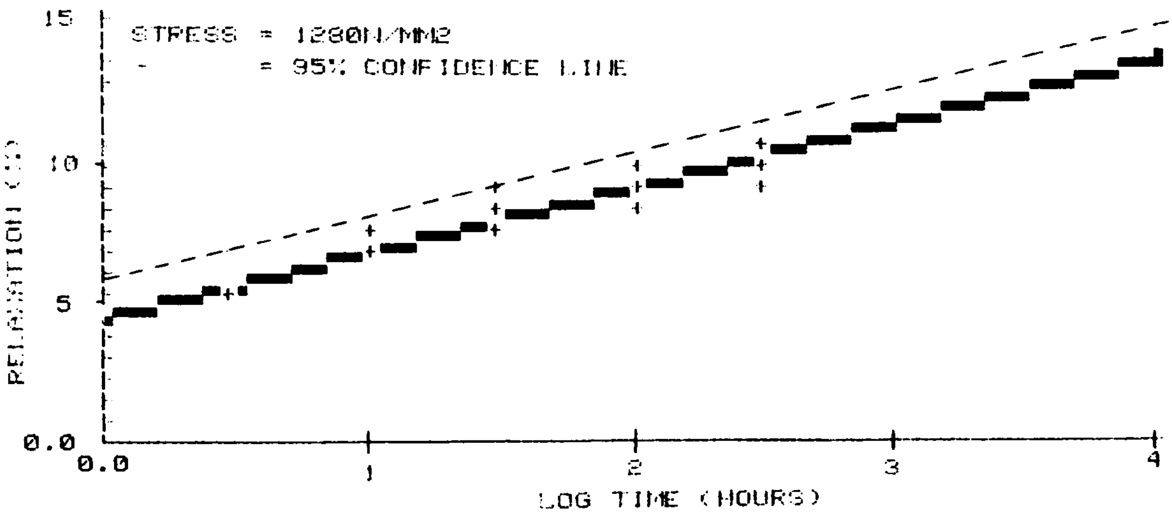


FIGURE 13 RELAXATION OF CS95 HARDENED AND TEMPERED STRIP IN BENDING ~~AT AMBIENT TEMPERATURE~~ 100°C.

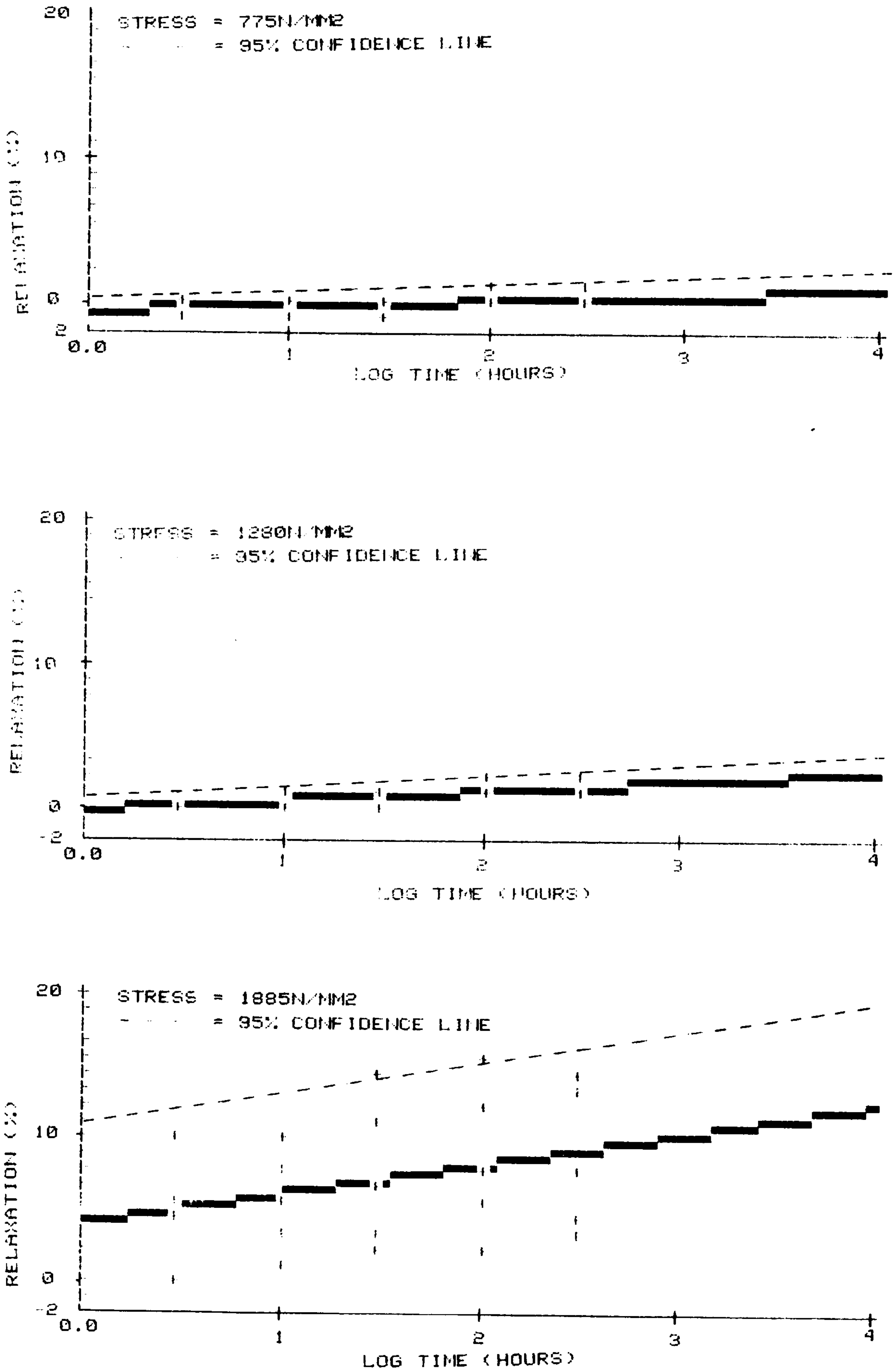
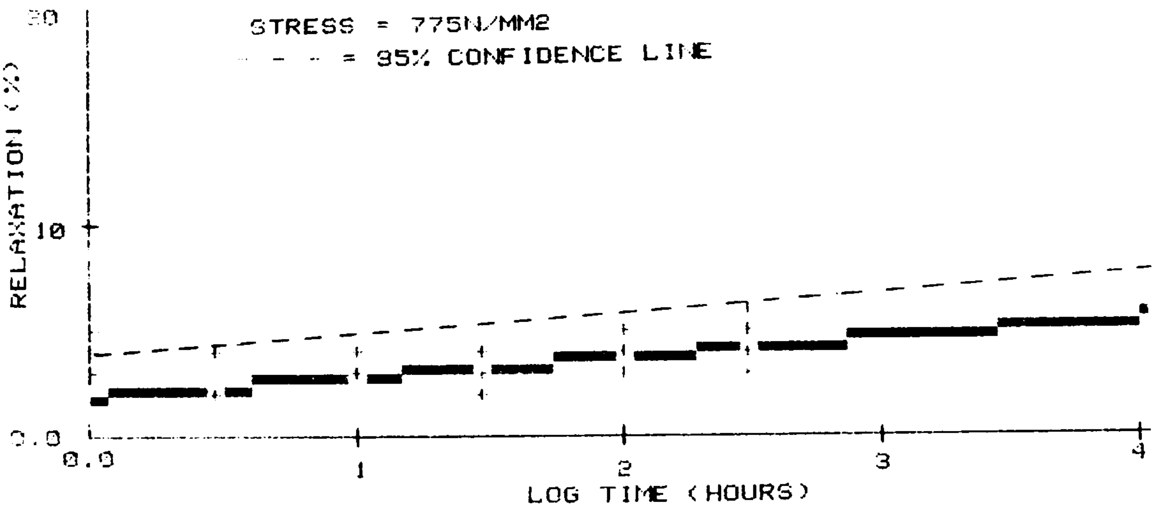


FIGURE 14 RELAXATION OF CS95 HARDENED AND TEMPERED STRIP IN BENDING AT AMBIENT TEMPERATURE



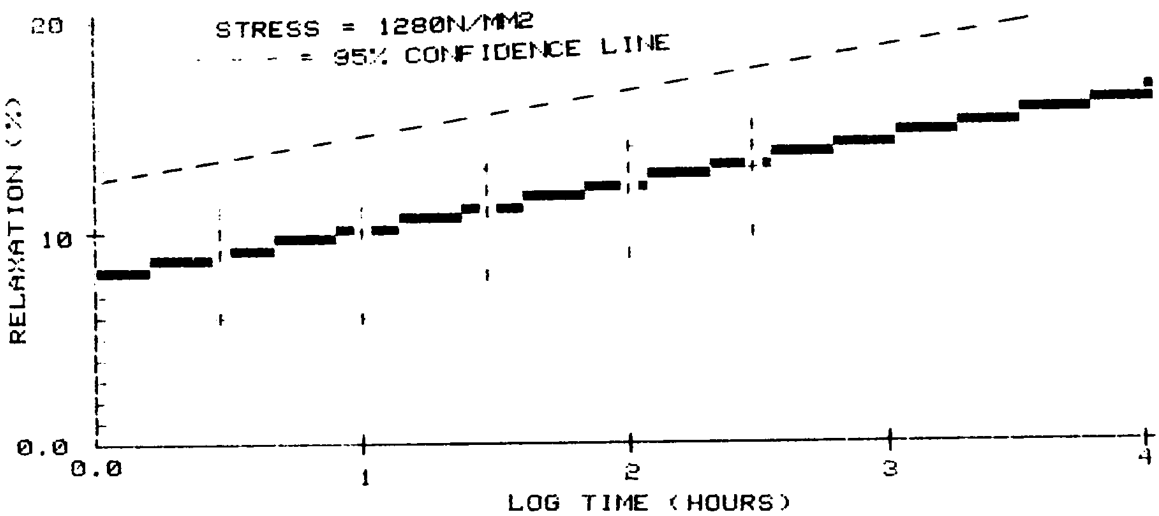
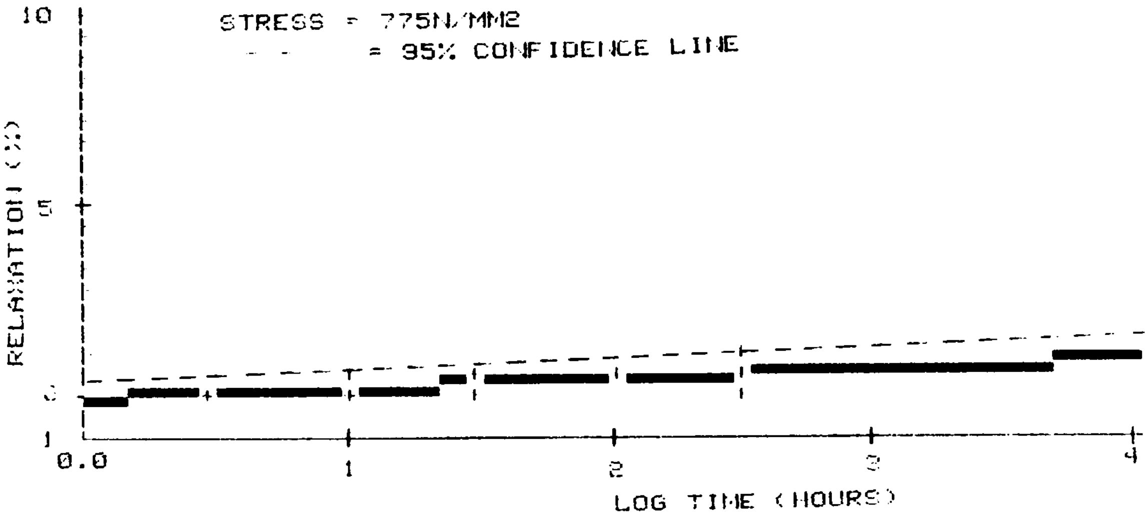


FIGURE 15 RELAXATION OF CS70 AUSTEMPERED STRIP IN BENDING AT 150 C



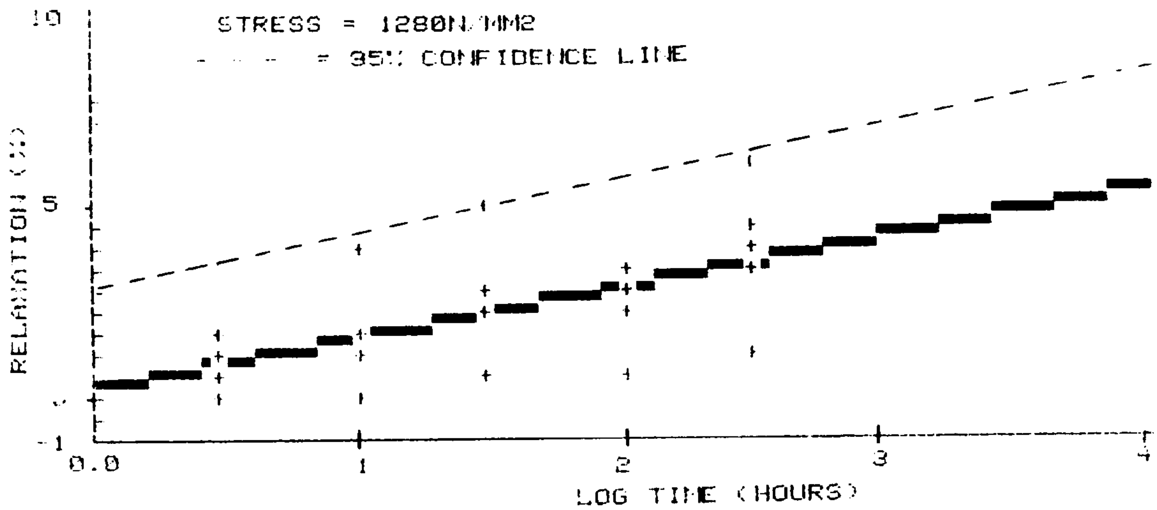
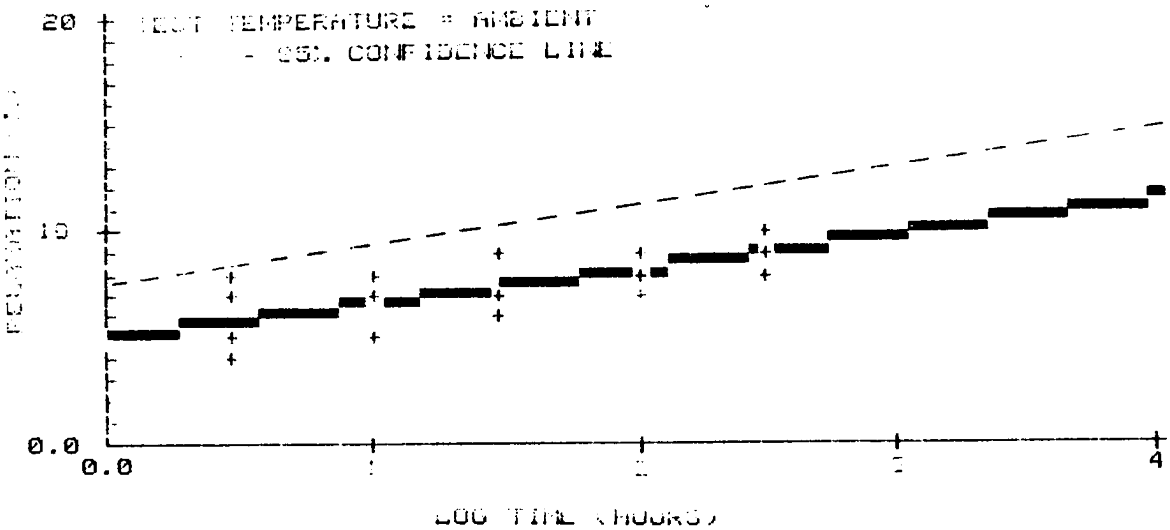


FIGURE 18 RELAXATION OF CS70 AUSTEMPERED STRIP IN BEND AT AMBIENT TEMPERATURE



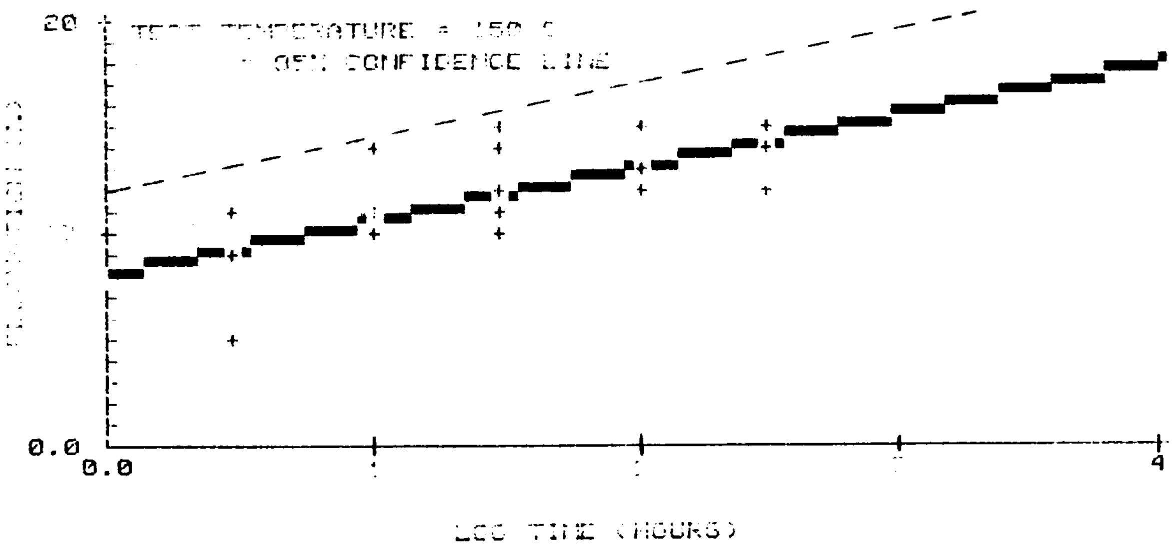


FIGURE 17 RELAXATION OF SPRING CLIP COMPONENTS MADE FROM CS70 AUSTEMPERED STEEL STRIP