THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE RELAXATION BEHAVIOUR OF COPPER ALLOY STRIP MATERIALS AND AUSTEMPERED CARBON STEEL STRIP MATERIALS IN BENDING

Report No 407

by

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THE RELAXATION BEHAVIOUR OF COPPER ALLOY STRIP MATERIALS AND AUSTEMPERED CARBON STEEL STRIP MATERIALS IN BENDING

1. INTRODUCTION

This report details the results of the concluding part of the strip relaxation data generation programme. Two previous reports (1, 2) examined hardened and tempered CS70 and CS95 steels, 302S25 grade stainless steel, 17/7 PH stainless steel, copper-beryllium and phosphor bronze. This final report covers nickel silver and austempered carbon steel strip; in addition, it examines the behaviour of a number of commercially available copper alloys which are claimed to have similar performance to copper beryllium, but have a lower cost.

In the initial strip relaxation report (1), the tests were conducted using a tube method where the materials were bent around the inside surfaces of tubes of varying diameters. This method was found to be unsuitable for the copper beryllium and phosphor bronze materials (2) which experienced excessive distortion when being inserted into the tubes. A mandrel test method was used for these materials, with the samples being bent around the outside of circular mandrels. This latter test method was used for all the materials tested in this investigation in order to avoid distortion of the soft copper alloy materials, and because dimensional restraints of the austempering process limited the maximum sample length of the carbon steel to 120 mm.

2. MATERIALS USED IN THE INVESTIGATION

2.1 Nickel Silver and Austempered Carbon Steel Material

The nickel silver strip used for the investigation was 0.55 mm thick, 15.8 mm wide NS106 EH grade material. The chemical analysis, mechanical properties and mean hardness level are presented in Tables I and II. The material was cropped into 110 mm lengths for the testing.

For the austempered material, 110 mm long samples of 0.254 mm thick, 15.8 mm wide CS80 strip were supplied to a SRAMA member for austempering. The treatments carried out and resultant hardness levels were:-

Austenitising Temperature °C	Salt Bath Temperature °C	Mean Hardness Level HV10
820	355	455
820	330	520
820	315	550

As the austempered material was to be tested using the mandrel test method (see section 3), a small number of samples of hardened and tempered CS80 material were procured for testing, so that a limited amount of testing could be carried out to ensure that the results of this testing were comparable with previous results.[1]

2.2 Copper-Beryllium Substitute Materials

A number of copper-beryllium substitute materials were identified and their manufacturers were approached for samples. Tests were conducted on:-

Delcan S18 - a copper/nickel/aluminium/silicon precipitation hardening alloy

ASTM B122 C72500 - a copper/nickel/tin alloy

Siclanic-S - a copper/nickel/silicon alloy

The Delcan was supplied in the No 3 temper grade as 0.254 mm thick strip in widths of 8 and 120 mm. Prior to testing, a hardening treatment of 375°C for 4 hours was given to promote maximum mechanical properties in the material.

The C72500 was supplied as 0.254 mm thick by 12.5 mm wide material in the spring temper condition; the Siclanic-S as 0.254 mm thick No 4 temper strip in widths of 12.5 and 110 mm. Both these materials were tested in the as received condition as no heat treatment was advised by the supplier.

The chemical compositions, mechanical properties and mean hardness levels for these materials are given in Tables I and II.

3. METHOD OF TESTING

Tests were carried out using the mandrel method as described in a previous report.[2]

The stress levels used in testing were calculated from bending theory using the formula:-

$$\sigma = \frac{Ey}{R} \qquad \ldots\ldots\ldots\ldots 1$$

Where σ = bending stress (N/mm^2)

E = Young's modulus

y = t/2

t = strip thickness (mm)

R = mandrel radius (mm)

In the previous investigations, the values of E used for the stress calculations for the various materials were the generally accepted values taken from published data. For the current investigation, it was found that there was a large variation in the published values of E for nickel silver, and no published values were available for the copper alloys. It was decided, therefore, to use the values of E calculated from the tensile test results, and these are presented in Table II.

The testing conditions used in the investigation were:-

Material	Stressing Direction	Stress Levels (N/mm^2)	Test Temperatures (^oC)
Austempered CS80	Longitudinally	685 & 835	100, 150, 200
Nickel Silver	Longitudinally	635 & 1370	Ambient, 80, 100
Delcan S18	Longitudinally & Transversely	325 & 650	150, 175, 200
C72500	Longitudinally	300 & 585	100, 150
Siclanic-S	Longitudinally & Transversely	300 & 600	100, 150, 175
Hardened & Tempered CS80	Longitudinally	710 & 870	100, 150, 200

The prestressing method and testing details were as described in a previous report.[2]

4. RELAXATION DETERMINATION AND RESULTS

The relaxation exhibited by the strips was determined by measuring the permanent set experienced during testing. A full description of this method is given in a previous report.[1]

The relaxation results for the various materials and test conditions are presented in figures 1-20. For each individual material, stressing direction, stress level and test temperature, the data were analysed using standard regression techniques, and were found to conform to the relationship:-

$$\% \text{ Relaxation} = a + b \log t + c (\log t)^2 \qquad \text{..........} \; 2$$

Where:- t = time (hours)

a, b and c are mathematical constants

The values of a, b, c and the 95% confidence increments are given for the various materials and test conditions in Tables III-VIII. Using the relationship, the predicted relaxation level after 10 years was determined for each material and test condition, and these are also given in the Tables III-VIII.

5. DISCUSSION OF RESULTS

A comparison of the results for the hardened and tempered carbon steel tested using the mandrel method with those obtained previously using the tube method[1], indicated that similar relaxation levels were obtained, so the results obtained from either method are valid and may be compared.

Comparing the results for the austempered carbon steel strip with those for the hardened and tempered strip[1] under similar testing conditions of temperature and stress, it was found that austempering substantially improves the relaxation resistance, giving up to a 50% improvement over its hardened and tempered counterpart. It was also found that the lower hardness austempered material (450 HV10) had significantly better relaxation resistance than the higher hardness material (550 HV10). The cause of this difference in performance is not known, but it may be due to some difference in the nature of the bainite of the samples which could not be determined.

The results for the austempered material indicate that the maximum practical operating temperature such that the level of relaxation over a 10 year period would not exceed 10% is 150°C.

Comparing the results for the nickel silver and copper-beryllium substitute materials with those obtained previously for copper-beryllium and phosphor-bronze[2], it is possible to produce a ranked table of relaxation performance with maximum recommended operating temperatures for a relaxation level of less than 20% over 10 years as follows:-

Delcan S18	175°C
Copper-beryllium	125°C
Siclanic-S	100°C
Nickel silver	80°C
C72500	80°C
Phosphor bronze	80°C

6. CONCLUSIONS

1. Relaxation data for austempered carbon steel, nickel silver and three commercially available copper beryllium substitute materials have been generated and are presented graphically.

2. Austempered carbon steel has significantly better relaxation resistance than its hardened and tempered counterpart, with the lower hardness material having superior relaxation performance than the higher hardness material.

3. Of the copper beryllium substitute materials, Delcan had the best performance and was the only one found to be superior to copper beryllium.

4. The maximum recommended operating temperatures for the material tested under this investigation are:-

Austempered carbon steel	150°C
Delcan	175°C
Siclanic-S	100°C
Nickel silver	80°C
C72500	80°C

7. REFERENCES

1. O'Malley, M, "The Relaxation Behaviour of Carbon and Stainless Spring Steels in Bending", SRAMA Report No 388, June 1985.

2. O'Malley, M, "The Relaxation Behaviour of Copper Alloy Strip Materials in Bending", SRAMA Report No 397, May 1986.

8. ACKNOWLEDGEMENT

We would like to thank the following companies for supplying the materials used for this investigation.

Barker and Allen, Birmingham

Comptoir Lyon-Alemand Louyot, Paris

TABLE I   CHEMICAL COMPOSITIONS OF MATERIALS USED IN THE INVESTIGATION

Material	% Cu	% Ni	% Sn	% Si	% Al	% Cr	% Zn
Nickel Silver							
Delcan S18	93.4	4.20	-	0.82	0.88	0.33	-
Siclanic-S	97.3	2.25	-	0.39	-	-	-
ASTM B122 C72500	89.1	8.75	2.01	-	-	-	-

TABLE II   MECHANICAL PROPERTIES AND HARDNESS LEVELS

Material	Hardness (HV10)	Tensile Properties			
		Rm (N/mm^2)	L of P (N/mm^2)	$Rp_{0.1}$ (N/mm^2)	E (KN/mm^2)
Austempered Steel	455	-	-	-	195
Austempered Steel	520	-	-	-	195
Austempered Steel	550	-	-	-	195
Hardened and Tempered Steel	450	-	-	-	202
Nickel Silver	220	680	315	620	135
Delcan S18	275	790	565	505	140
Siclanic-S	225	730	545	700	140
ASTM B122 C72500	220	660	270	590	130

TABLE III ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR AUSTEMPERED CS80 STRIP STRESSED LONGITUDINALLY

Material Hardness (HV10)	Stress Level (N/mm^2)	Test Temperature (°C)	Analytical Constants			95% Confidence Increment (%)	10 Year Mean Relaxation Level (%)
			a	b	c		
455	835	100 150 200	1.93 2.46 7.09	0.48 2.64 0.31	0.20 -0.27 0.61	0.9 1.0 1.0	8 9 24
455	685	100 150 200	0.25 0.53 2.57	1.02 2.82 2.52	-0.16 0.37 -0.13	0.9 1.2 1.2	2 5 12
520	835	100 150 200	2.22 2.74 8.04	0.46 2.91 0.90	0.25 -0.26 0.76	0.9 0.7 1.7	11 11 31
520	685	100 150 200	1.61 1.66 3.12	-0.25 1.98 2.84	0.30 -0.18 0.07	1.0 1.1 1.3	7 7 19
550	835	100 150 200	2.90 3.52 9.94	0.50 2.31 0.23	0.23 0.11 1.38	0.6 0.9 0.9	11 18 45
550	685	100 150 200	1.89 1.93 4.42	0.39 3.07 3.36	0.17 -0.31 0.40	0.9 1.2 1.3	8 10 31

TABLE IV ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR DELCAN S18 STRIP MATERIAL

Stressing Direction	Stress Level (N/mm^2)	Test Temperature (^oC)	Analytical Constants			95% Confidence Increment (%)	10 Year Mean Relaxation Level (%)
			a	b	c		
Transverse	650	150 175 200	1.33 3.28 4.65	2.50 1.54 1.15	-0.04 0.62 1.25	1.0 1.0 1.0	13 26 41
Transverse	325	150 175 200	-0.04 1.26 2.04	1.92 1.02 0.31	-0.14 0.36 0.88	1.1 1.1 1.3	6 15 25
Longitudinal	650	150 175 200	1.17 2.69 3.38	2.37 1.34 2.42	-0.07 0.43 0.50	1.1 0.7 0.8	11 20 28
Longitudinal	325	150 175 200	0.97 1.64 2.49	0.24 0.79 0.48	0.36 0.36 0.49	0.9 1.0 1.3	11 14 17

TABLE V ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR C72500 STRIP STRESSED LONGITUDINALLY

Stress Level (N/mm^2)	Test Temperature (^oC)	Analytical Constants			95% Confidence Increment (%)	10 Year Mean Relaxation Level (%)
		a	b	c		
585	100	12.80	5.51	-0.80	1.0	21
	150	17.59	5.98	-0.63	1.3	32
300	100	10.53	6.00	-0.89	1.3	19
	150	16.20	6.29	-0.74	1.8	29

TABLE VI ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR NICKEL SILVER STRIP STRESSED LONGITUDINALLY

Stress Level (N/mm^2)	Test Temperature (^oC)	Analytical Constants			95% Confidence Increment (%)	10 Year Mean Relaxation Level (%)
		a	b	c		
1370	Ambient	0.25	4.92	-0.71	1.4	7
	80	0.47	8.75	-1.06	1.4	18
	100	8.56	4.98	-0.59	1.6	19
685	Ambient	0.54	0.41	0.11	0.8	5
	80	-0.40	5.31	-0.51	1.1	14
	100	3.86	6.86	-0.88	1.3	16

TABLE VII ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR SICLANIC - S STRIP MATERIAL

Stressing direction	Stress level (N/mm^2)	Test temperature (^oC)	Analytical constants			95% confidence increment (%)	10 year mean relaxation level (%)
			a	b	c		
Transverse	600	100	1.75	5.91	-0.72	1.3	13
		150	6.87	6.35	-0.41	1.1	28
		175	9.81	6.78	-0.03	1.1	43
Transverse	300	100	-0.64	3.70	-0.31	1.5	10
		150	2.74	8.42	-1.00	1.4	20
		175	5.80	4.66	-0.01	1.4	29
Longitudinal	600	100	1.71	3.61	-0.31	0.9	12
		150	4.16	4.16	-0.13	1.2	22
		175	6.00	4.90	-0.14	1.1	27
Longitudinal	300	100	0.60	2.29	-0.13	0.8	9
		150	1.60	4.56	-0.61	1.4	9
		175	3.17	3.80	-0.16	1.2	18

TABLE VIII ANALYTICAL CONSTANTS, 95% CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR MEAN RELAXATION LEVEL FOR HARDENED AND TEMPERED CARBON STEEL STRIP.

Stress level (N/mm^2)	Test temperature (^oC)	Analytical constants			95% confidence increments %	10 year mean relaxation level %
		a	b	c		
710	100	0.02	3.57	-0.48	1.0	6
	150	2.08	3.80	-0.44	0.9	10
	200	4.27	5.41	-0.66	1.0	15
870	100	1.38	3.68	-0.47	0.8	8
	150	4.31	3.17	-0.29	0.9	13
	200	6.56	5.33	-0.65	1.1	18

TABLE IX SUMMARY OF RESULTS FOR COPPER ALLOYS

Material	Stress Level (N/mm^2)	Temperature (^oC)	Stressing	10 year mean relaxation level
Delcan S18	650	150	Transverse	13
		175		26
		200		41
Delcan S18	325	150	Transverse	6
		175		15
		200		25
Delcan S18	650	150	Longitudinal	11
		175		20
		200		28
Delcan S18	325	150	Longitudinal	11
		175		14
		200		17
C72500	585	100	Longitudinal	21
		150		32
C72500	300	100	Longitudinal	19
		150		29
Nickel silver	1370	20	Longitudinal	7
		80		18
		100		19
Nickel silver	685	20	Longitudinal	5
		80		14
		100		16
Siclanic-S	600	100	Transverse	13
		150		28
		175		43
Siclanic-S	300	100	Transverse	10
		150		20
		175		29
Siclanic-S	600	100	Longitudinal	12
		150		22
		175		27
Siclanic-S	300	100	Longitudinal	9
		150		9
		175		18

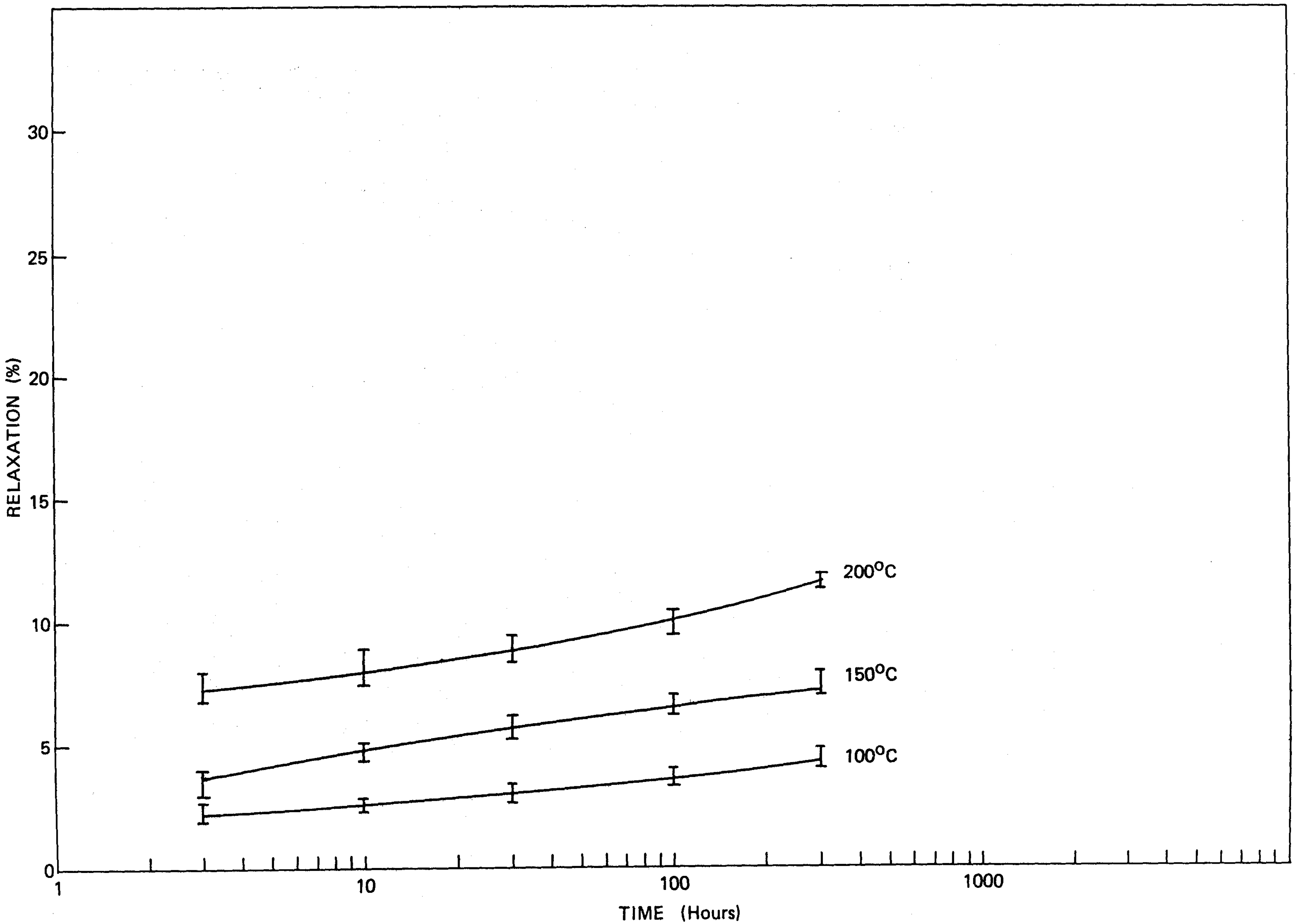

Figure 1 - Relaxation results for 455 HV_{10} austempered Carbon Steel Strip stressed at 835 N/mm^2

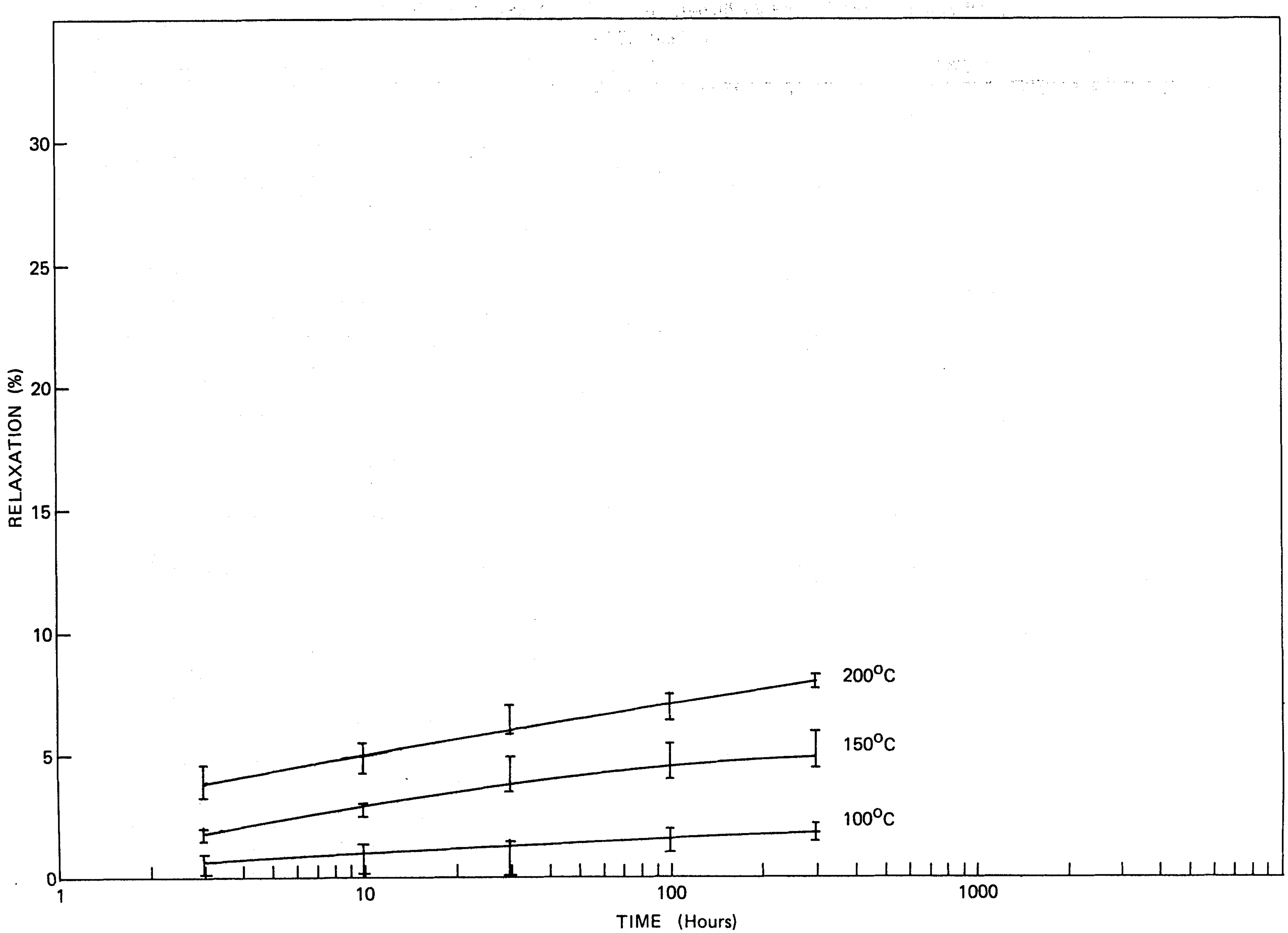

Figure 2 - Relaxation results for 455 HV_{10} austempered Carbon Steel Strip stressed at 685 N/mm^2

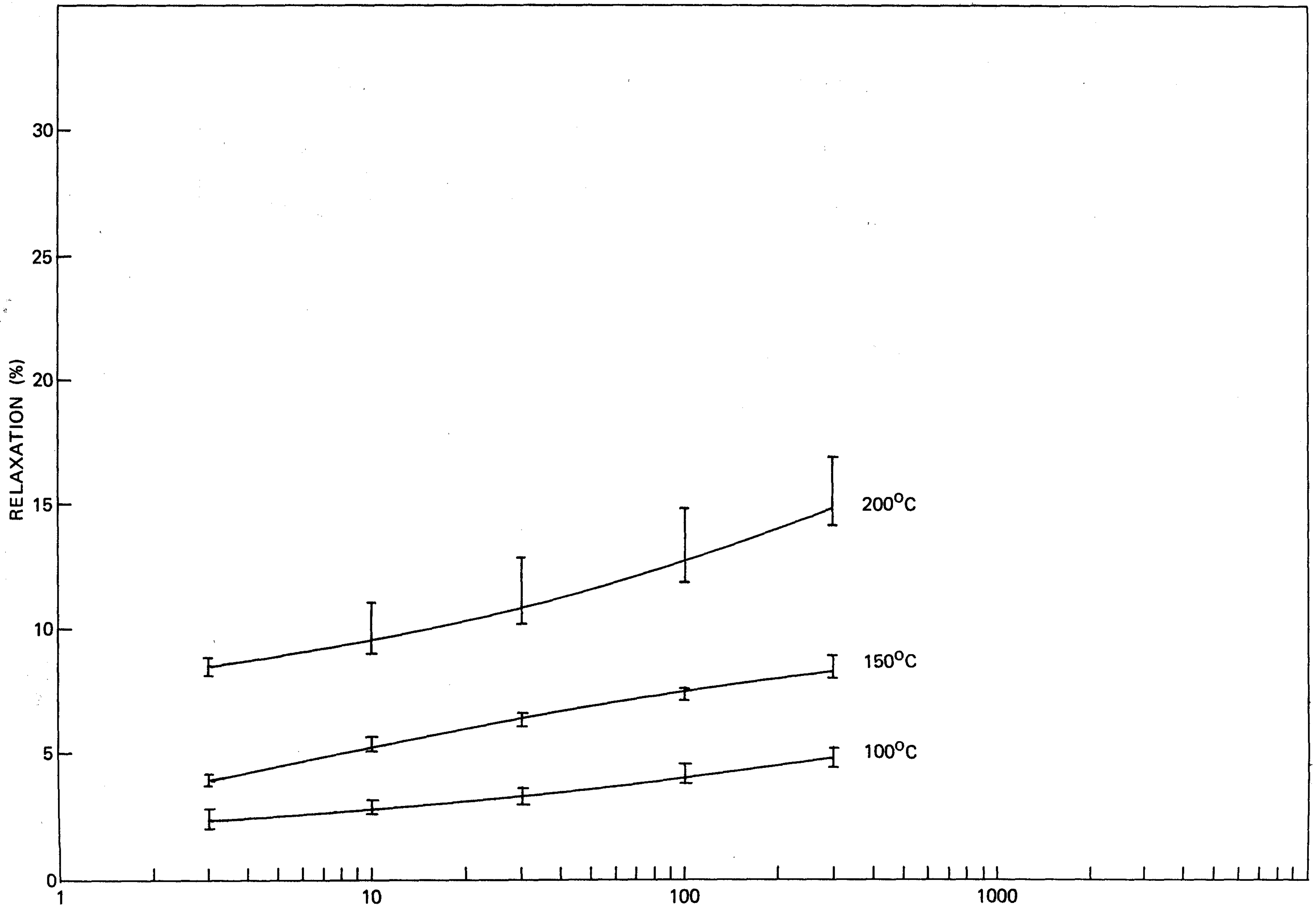

Figure 3 - Relaxation results for 520 HV_{10} austempered Carbon Steel Strip stressed at 835 N/mm^2

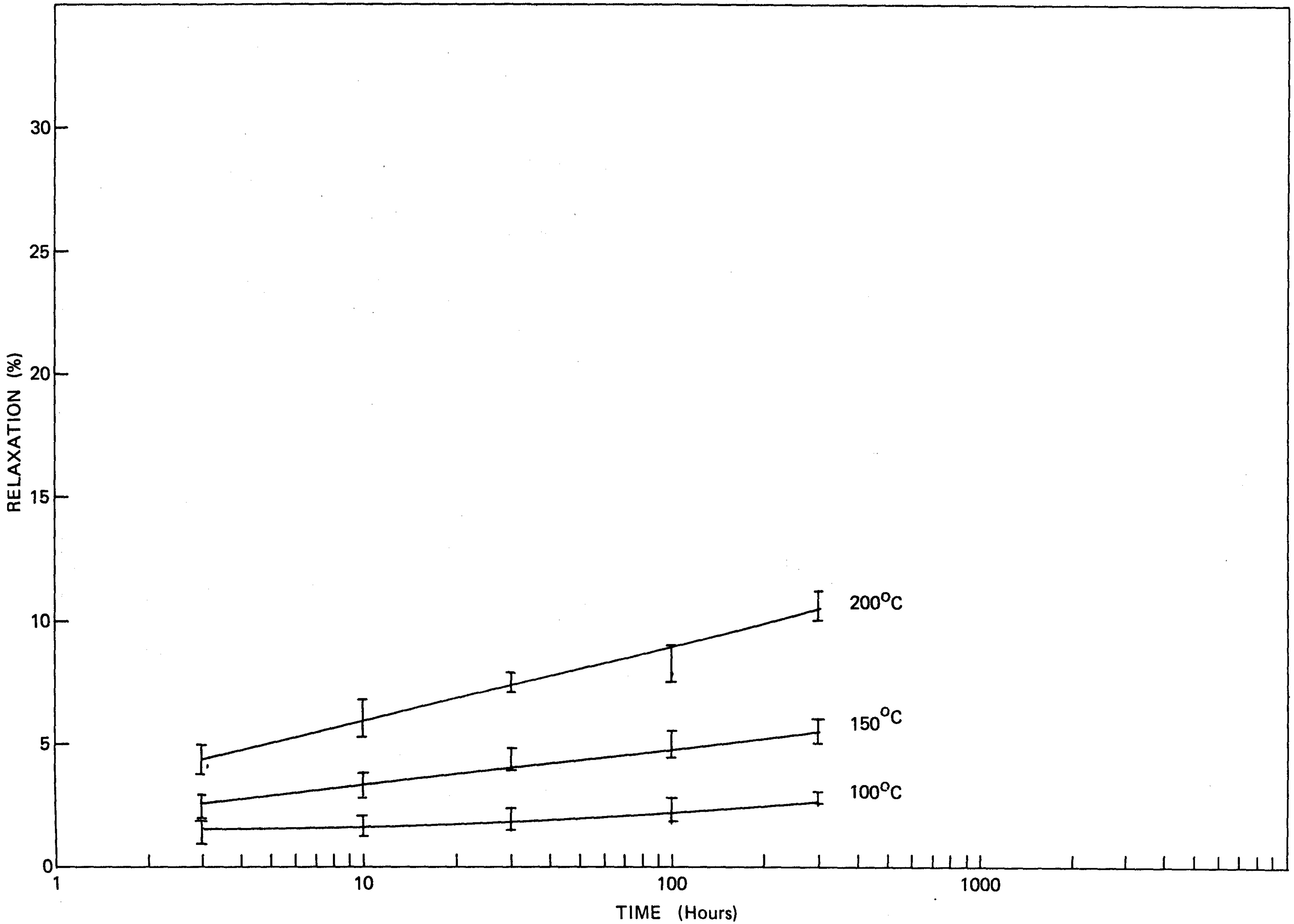

Figure 4 - Relaxation results for 520 HV_{10} austempered Carbon Steel Strip stressed at 685 N/mm^2

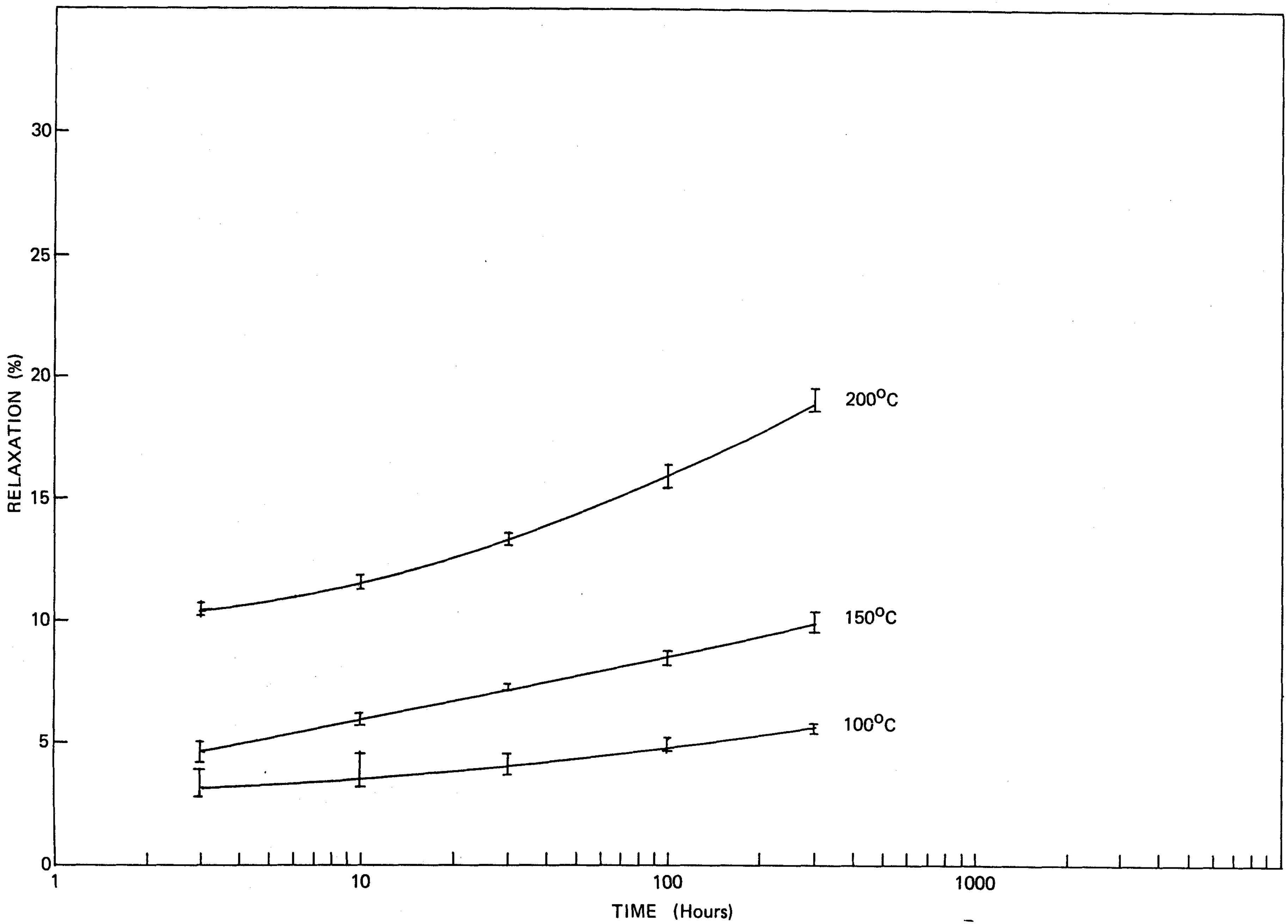

Figure 5 - Relaxation results for 550 HV_{10} austempered Carbon Steel Strip stressed at 835 N/mm^2

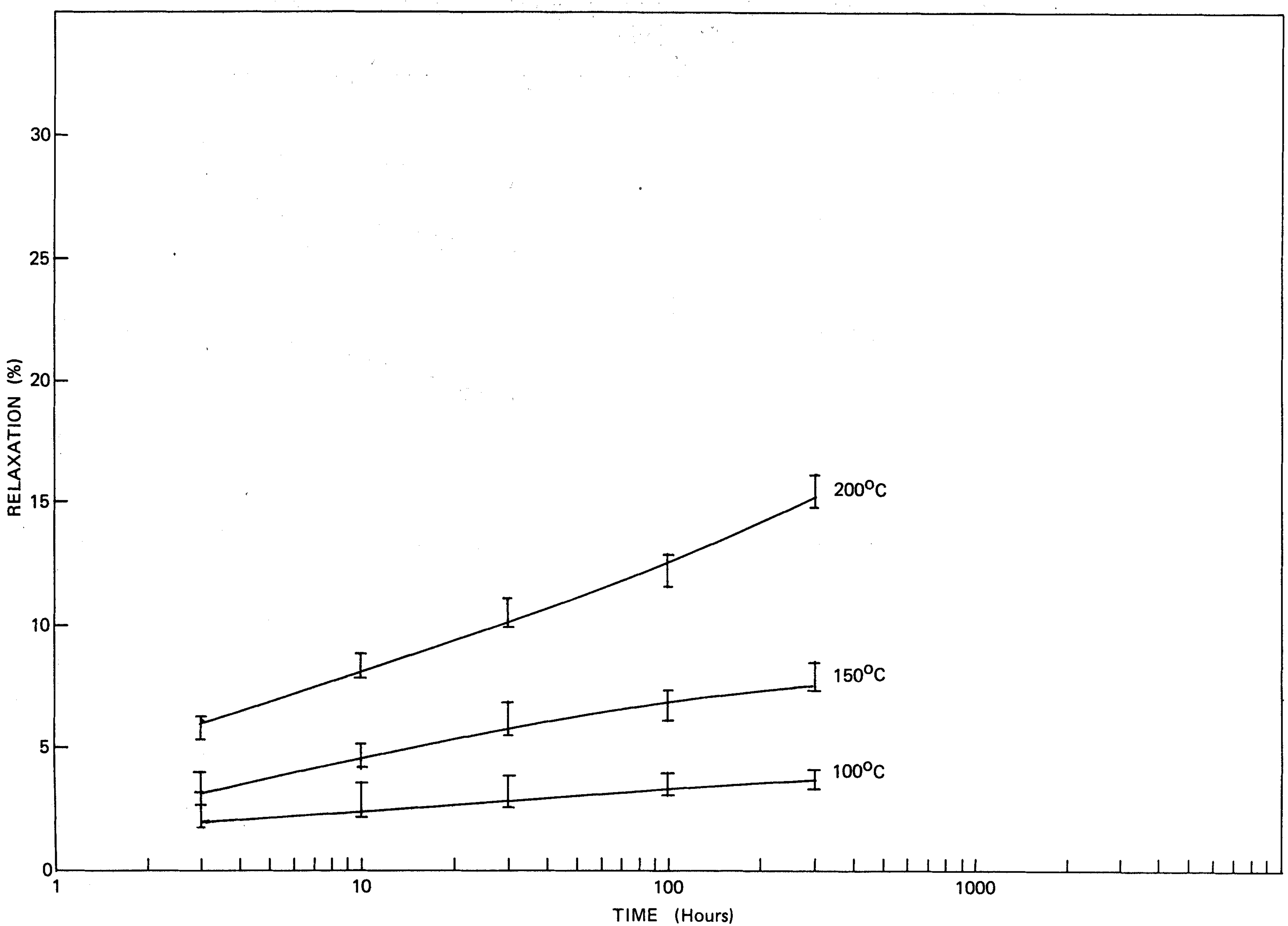

Figure 6 - Relaxation results for 550 HV_{10} austempered Carbon Steel Strip stressed at 685 N/mm^2

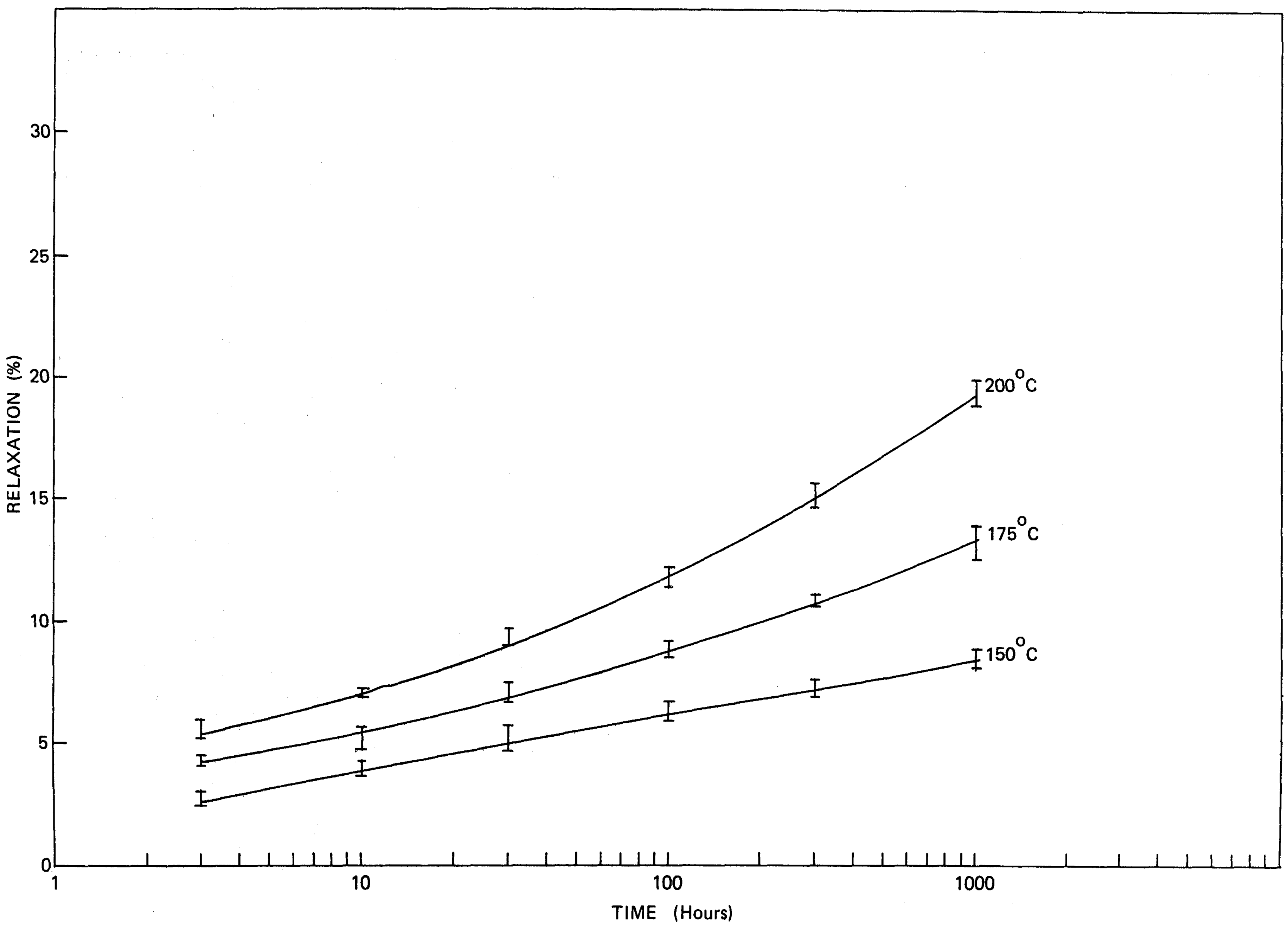

Figure 7 - Relaxation results for Delcan S18 Strip stressed transversely at 650 N/mm^2

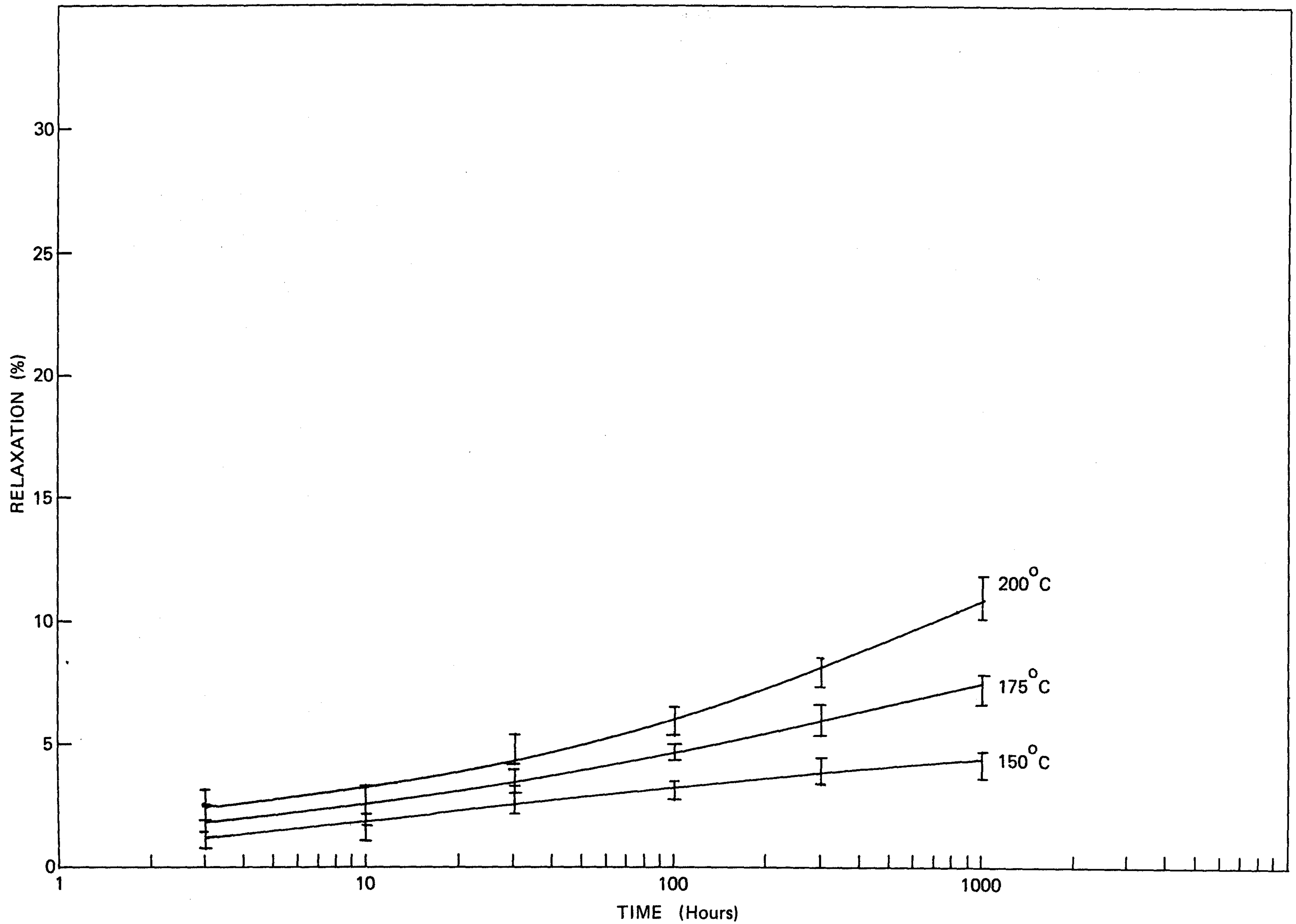

Figure 8 - Relaxation results for Delcan S18 Strip stressed transversely at 325 N/mm^2

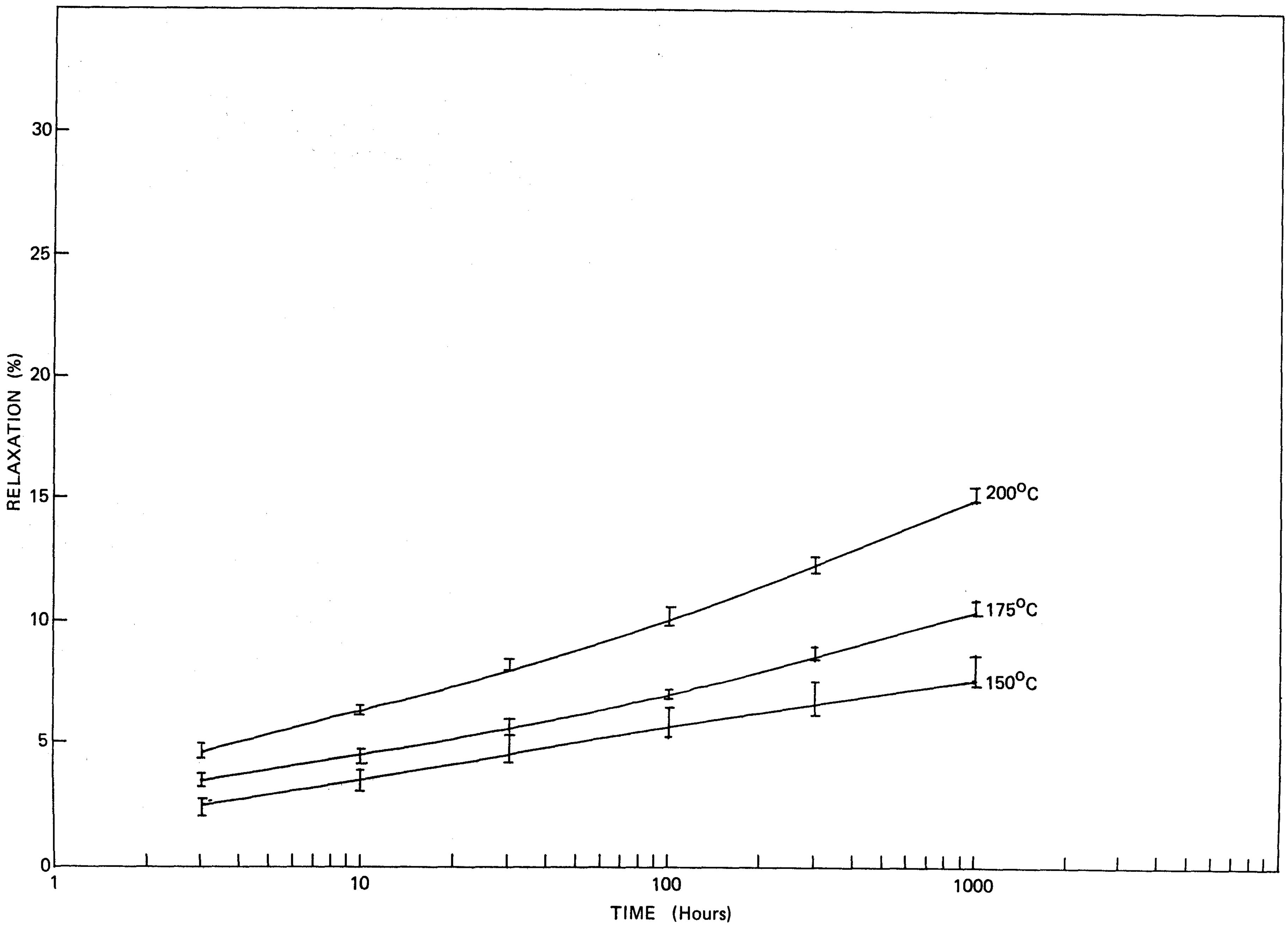

Figure 9 - Relaxation results for Delcan S18 Strip stressed longitudinally at 650 N/mm^2

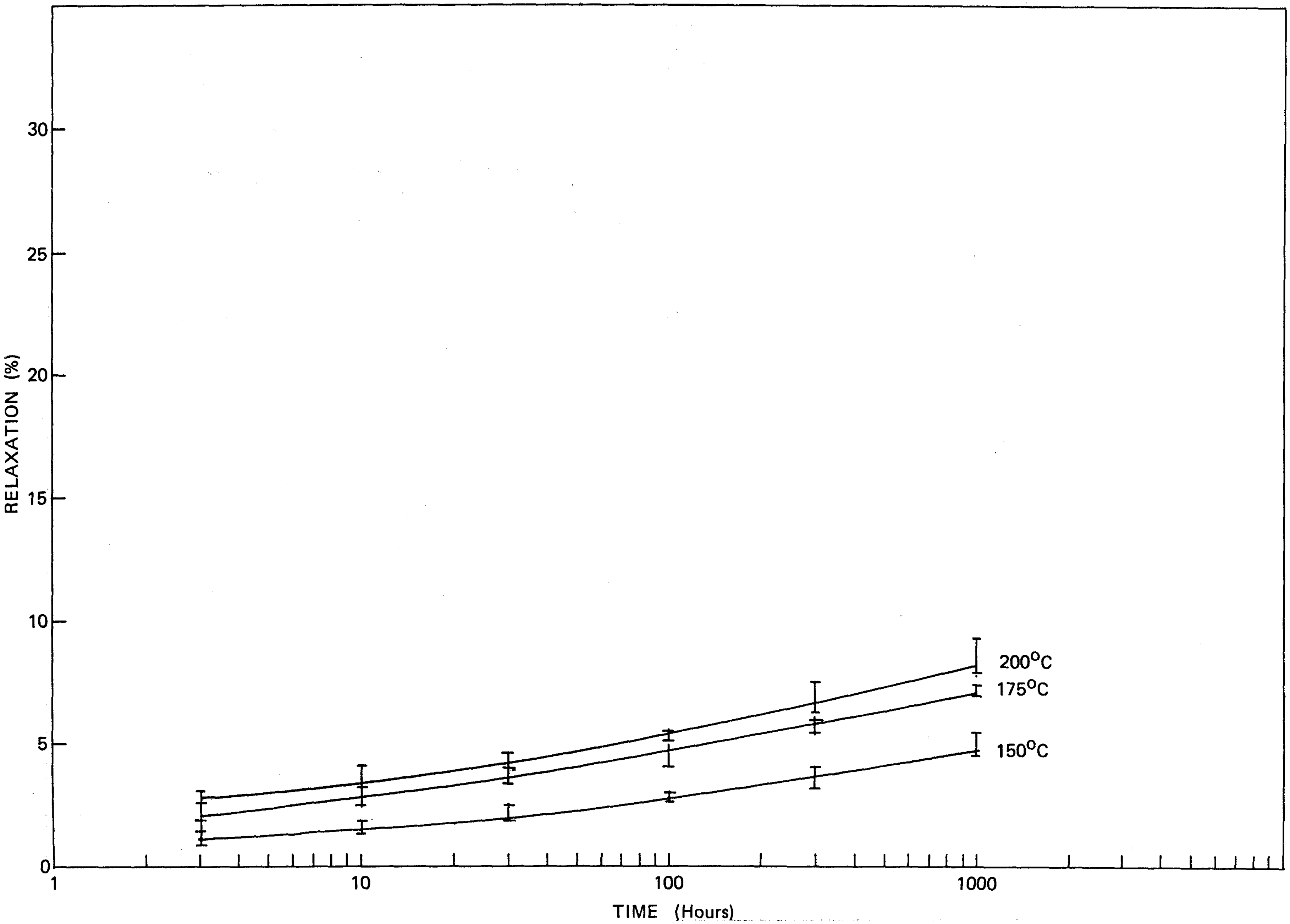

Figure 10 - Relaxation results for Delcan S18 Strip stressed longitudinally at 325 N/mm^2

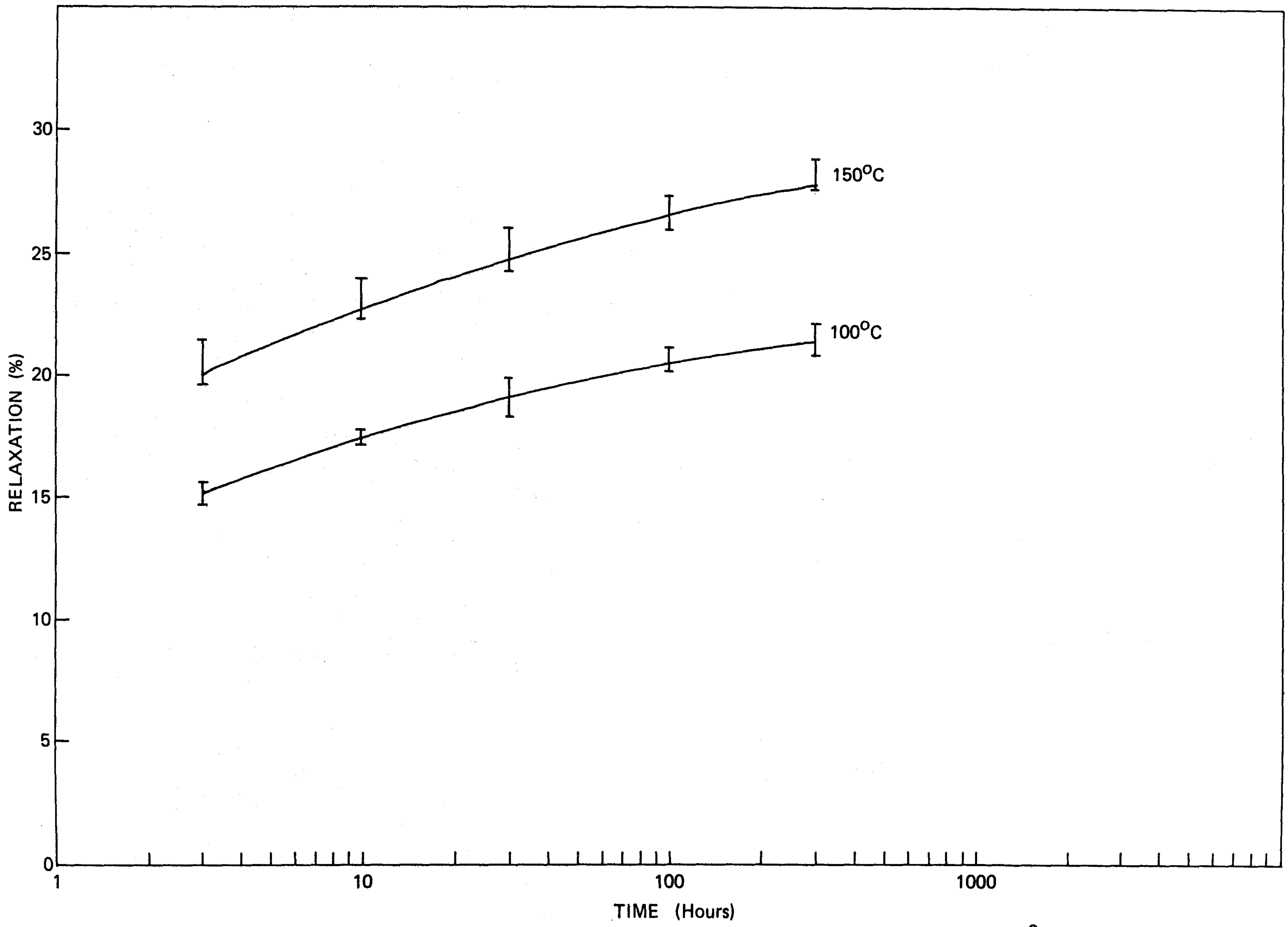

Figure 11 - Relaxation results for ASTM B122 C72500 Alloy Strip stressed at 585 N/mm^2

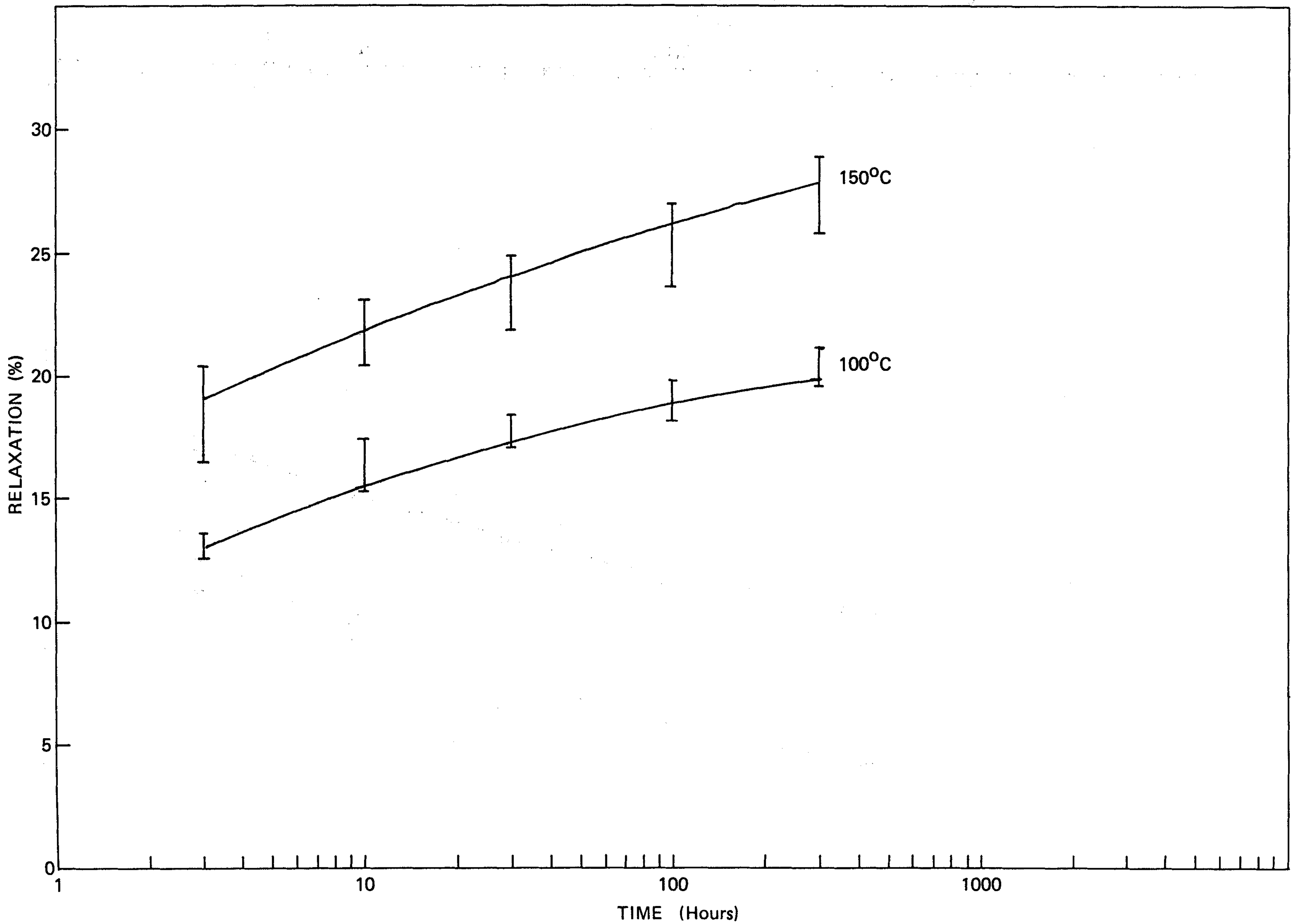

Figure 12 - Relaxation results for ASTM B122 C72500 Alloy Strip stressed at 300 N/mm^2

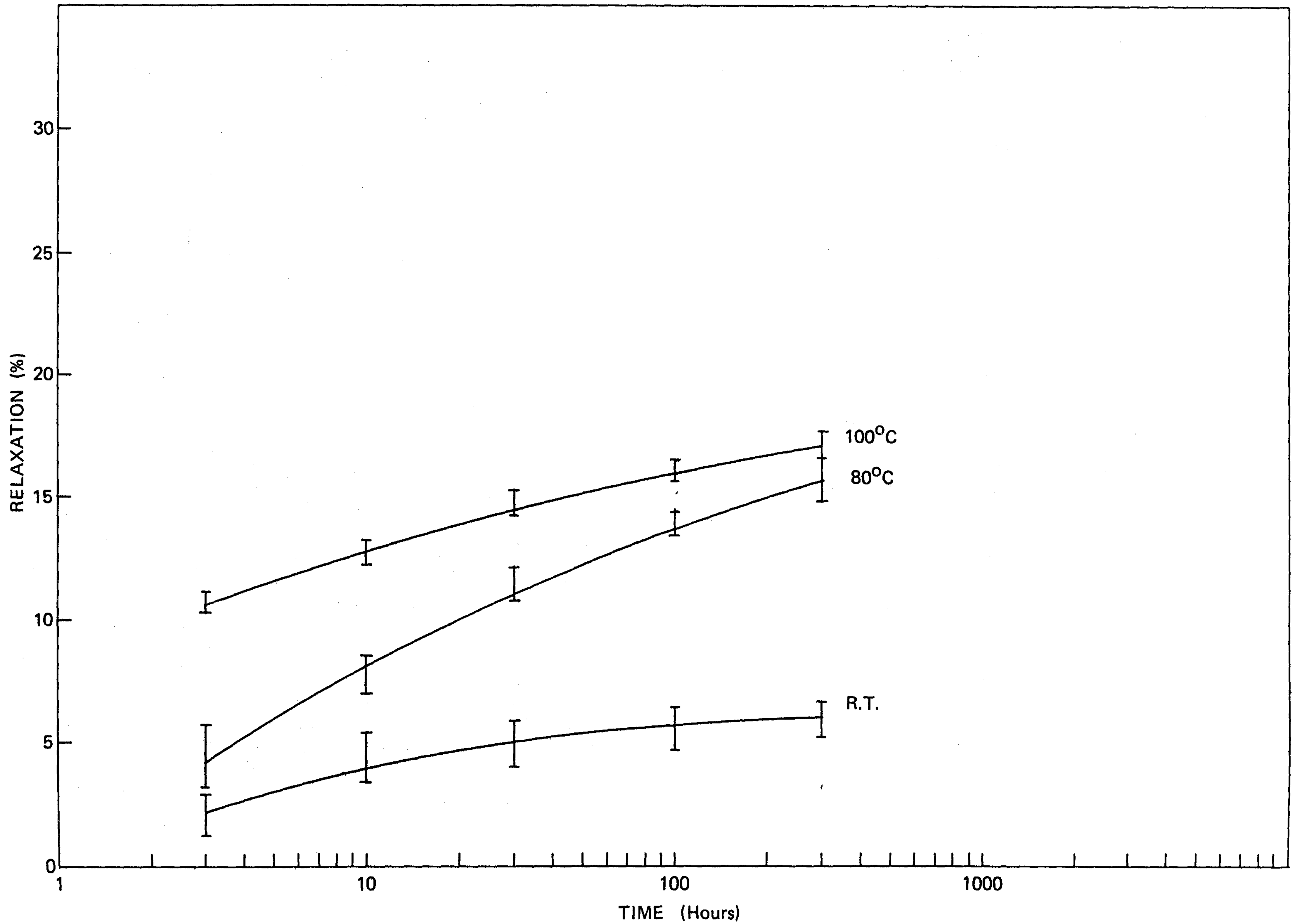

Figure 13 - Relaxation results for Nickel Silver Strip stressed at 1370 N/mm^2

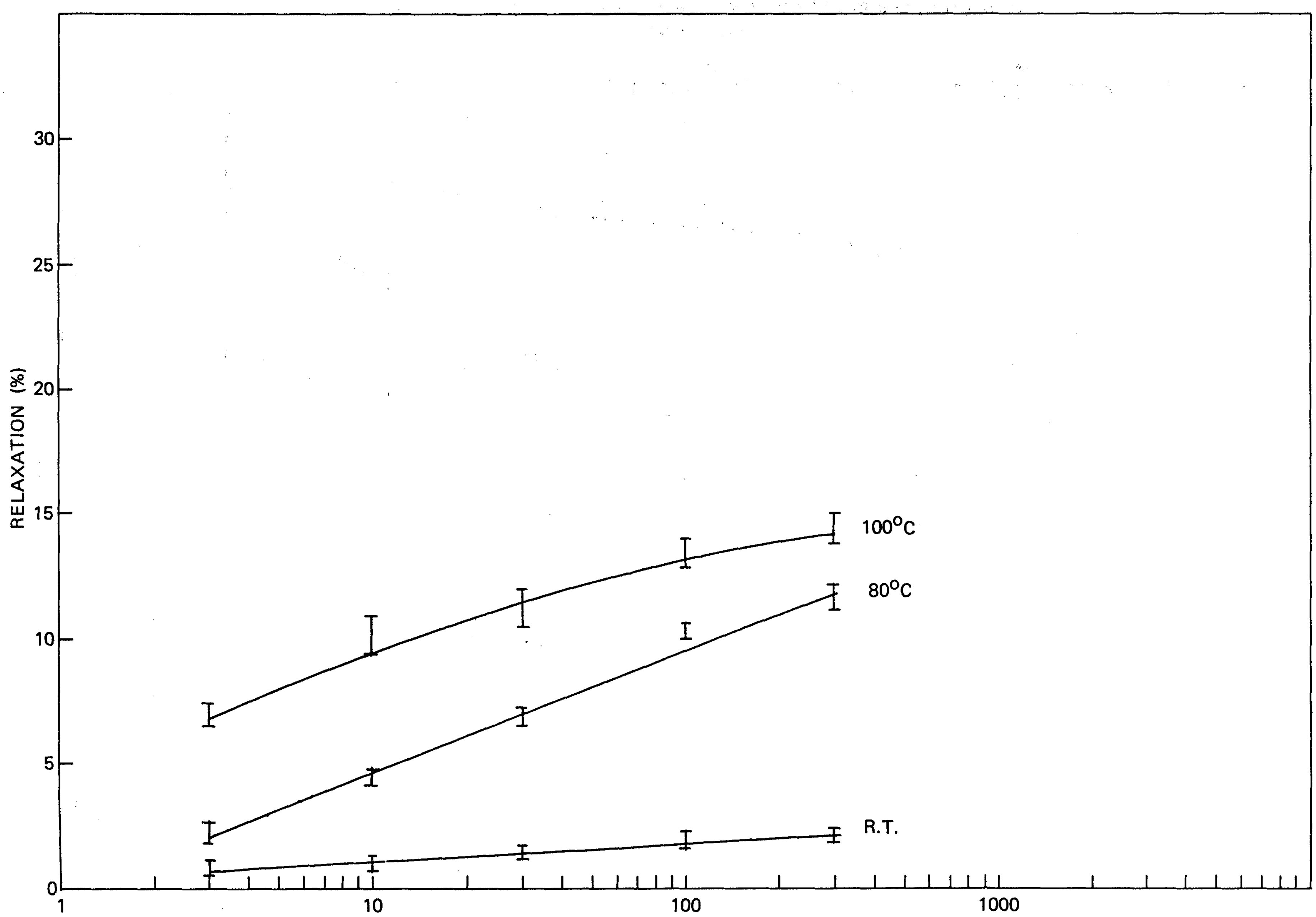

Figure 14 - Relaxation results for Nickel Silver Strip stressed at 685 N/mm^2

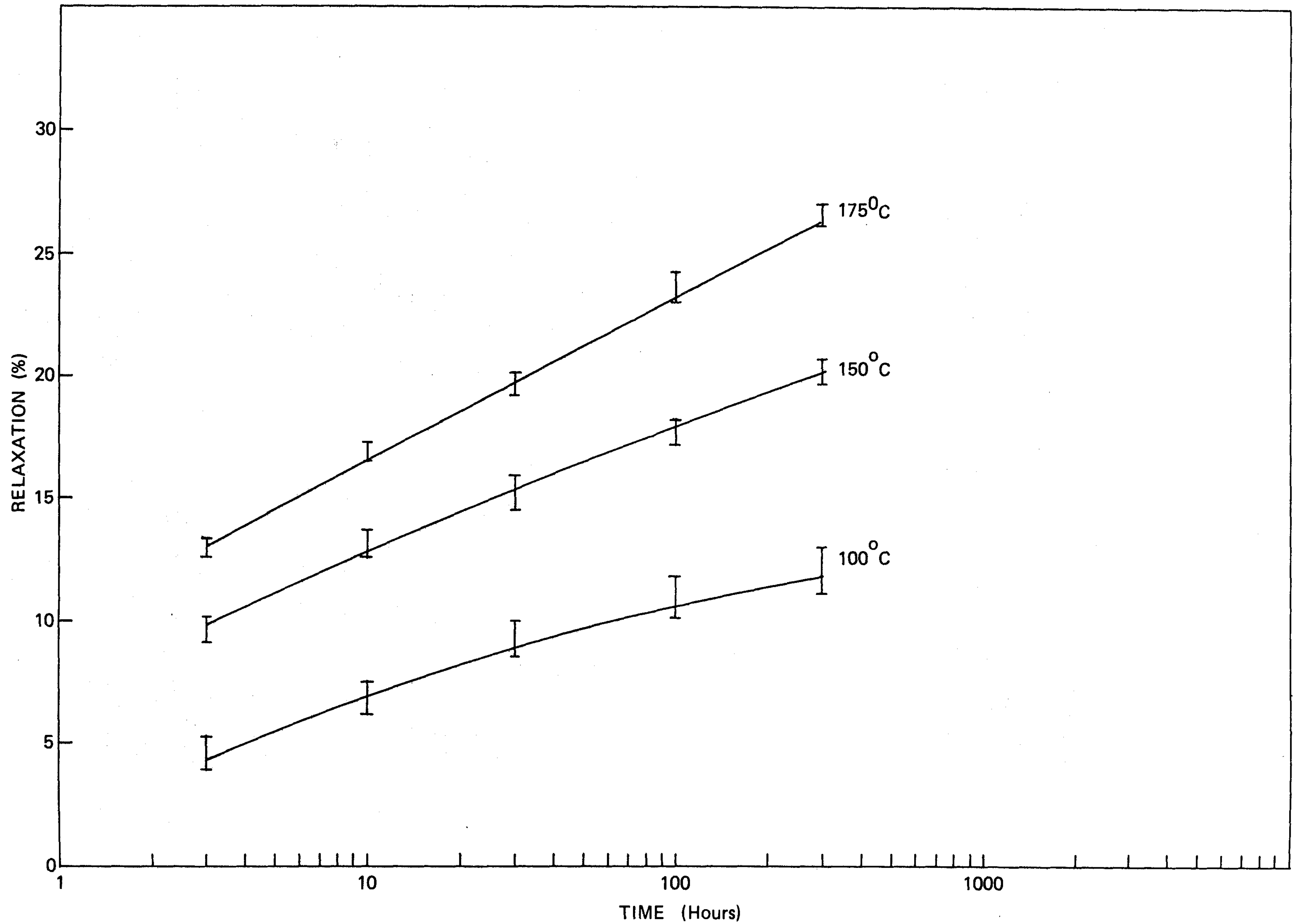

Figure 15 - Relaxation results for Siclanic - S strip stressed transversely at 600 N/mm^2

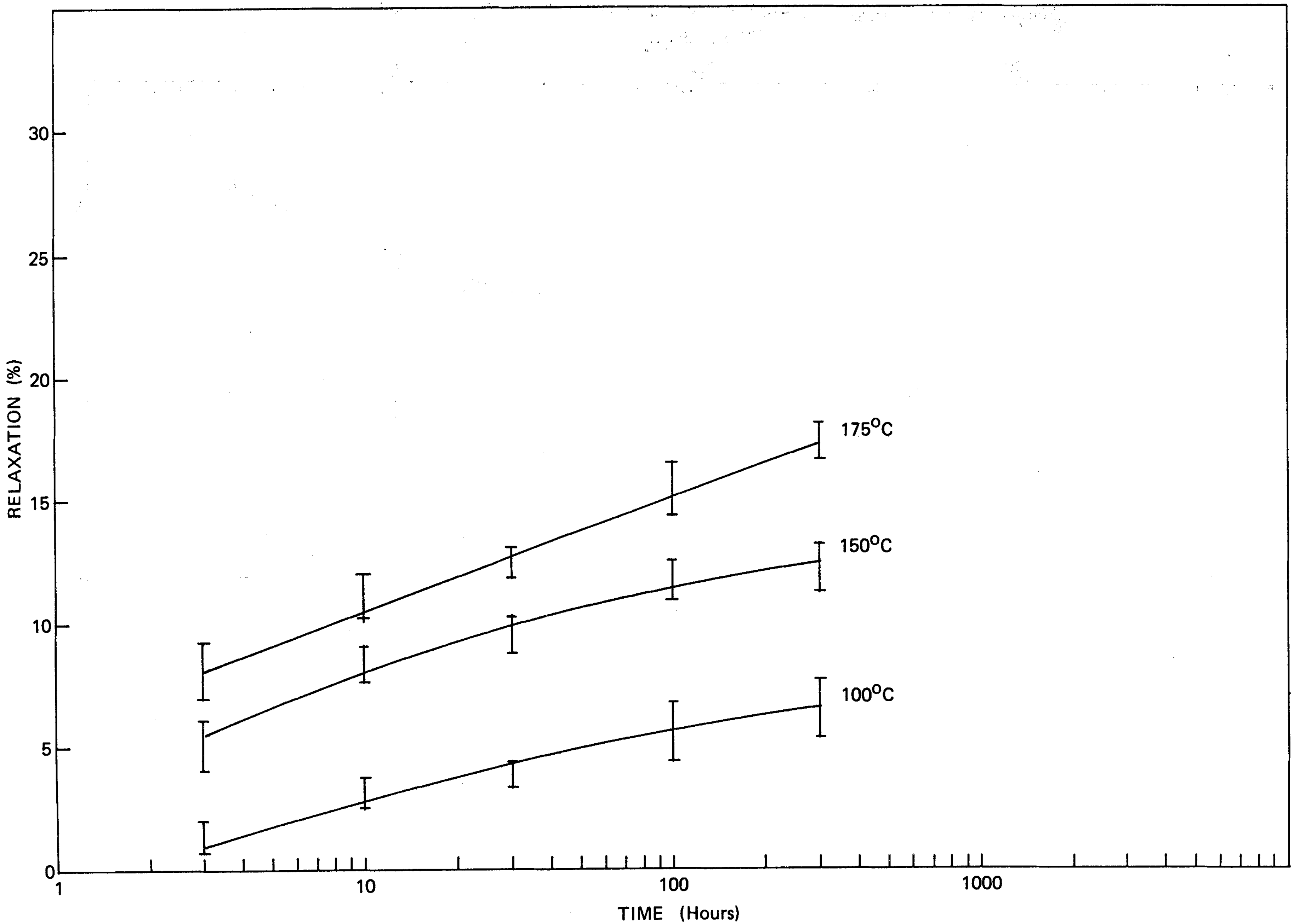

Figure 16 - Relaxation results for Siclanic - S strip stressed transversely at 300 N/mm^2

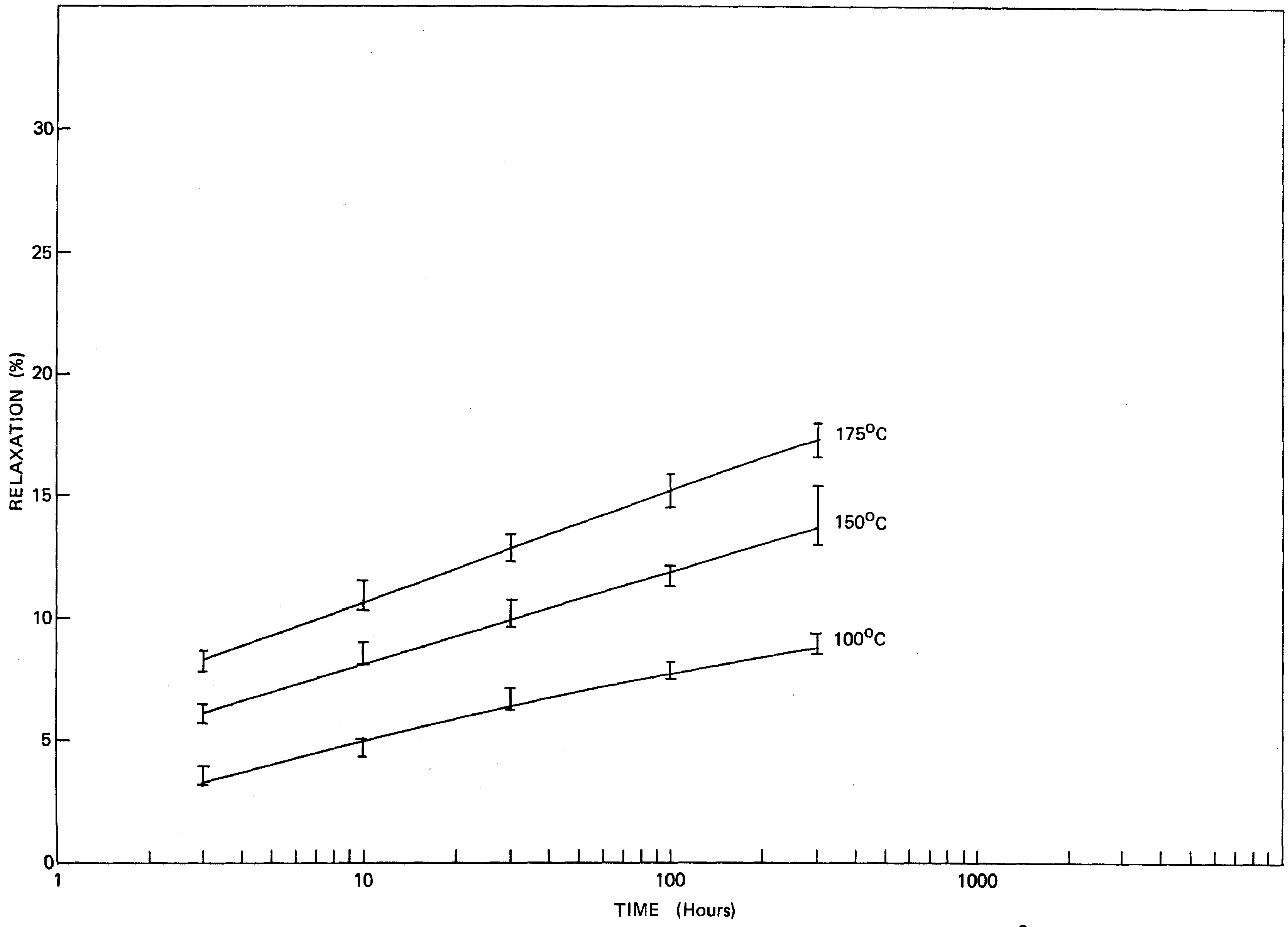

Figure 17 - Relaxation results for Siclanic - S strip stressed longitudinally at 600 N/mm^2

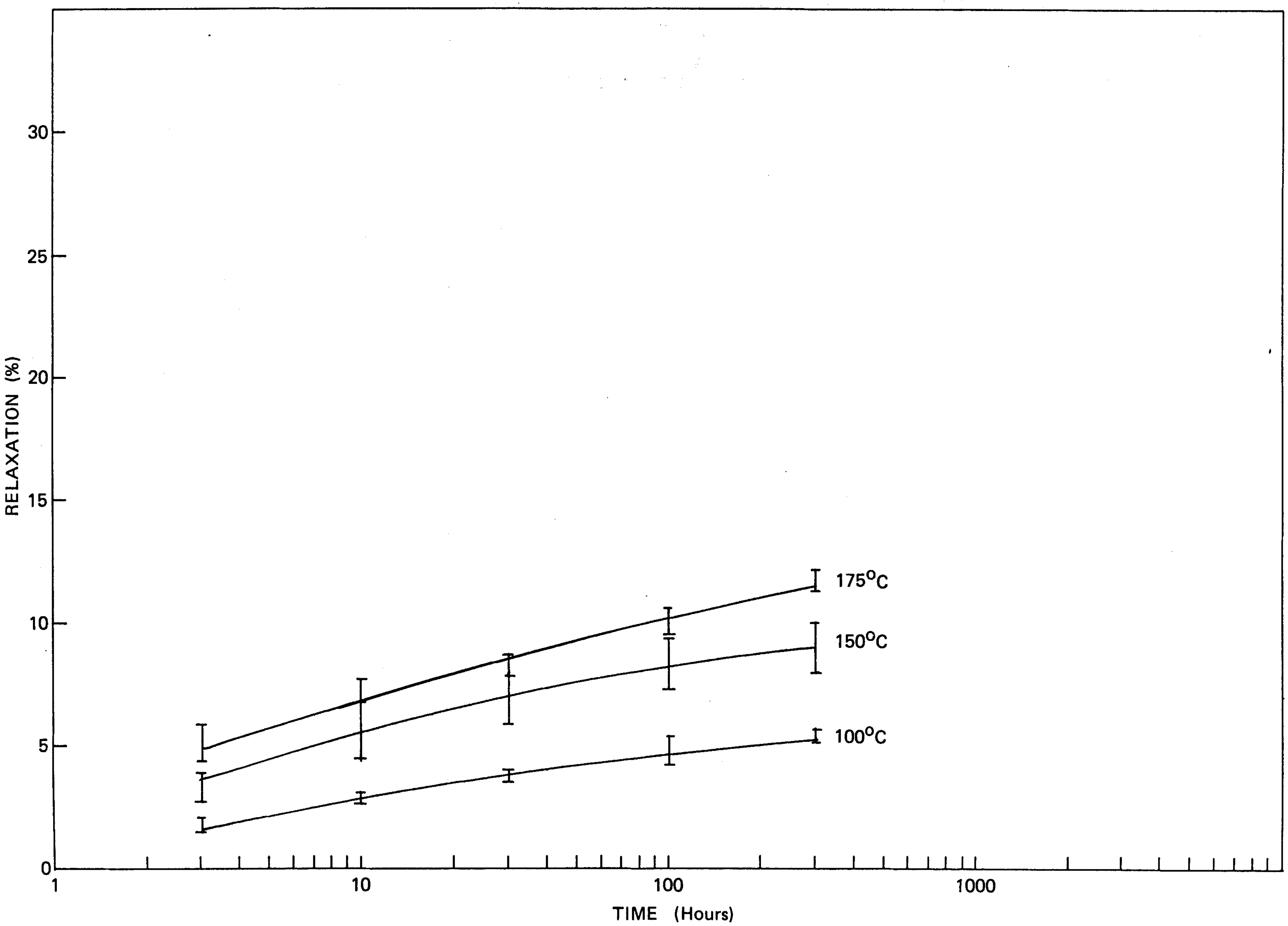

Figure 18 - Relaxation results for Siclanic - S strip stressed longitudinally at 300 N/mm^2

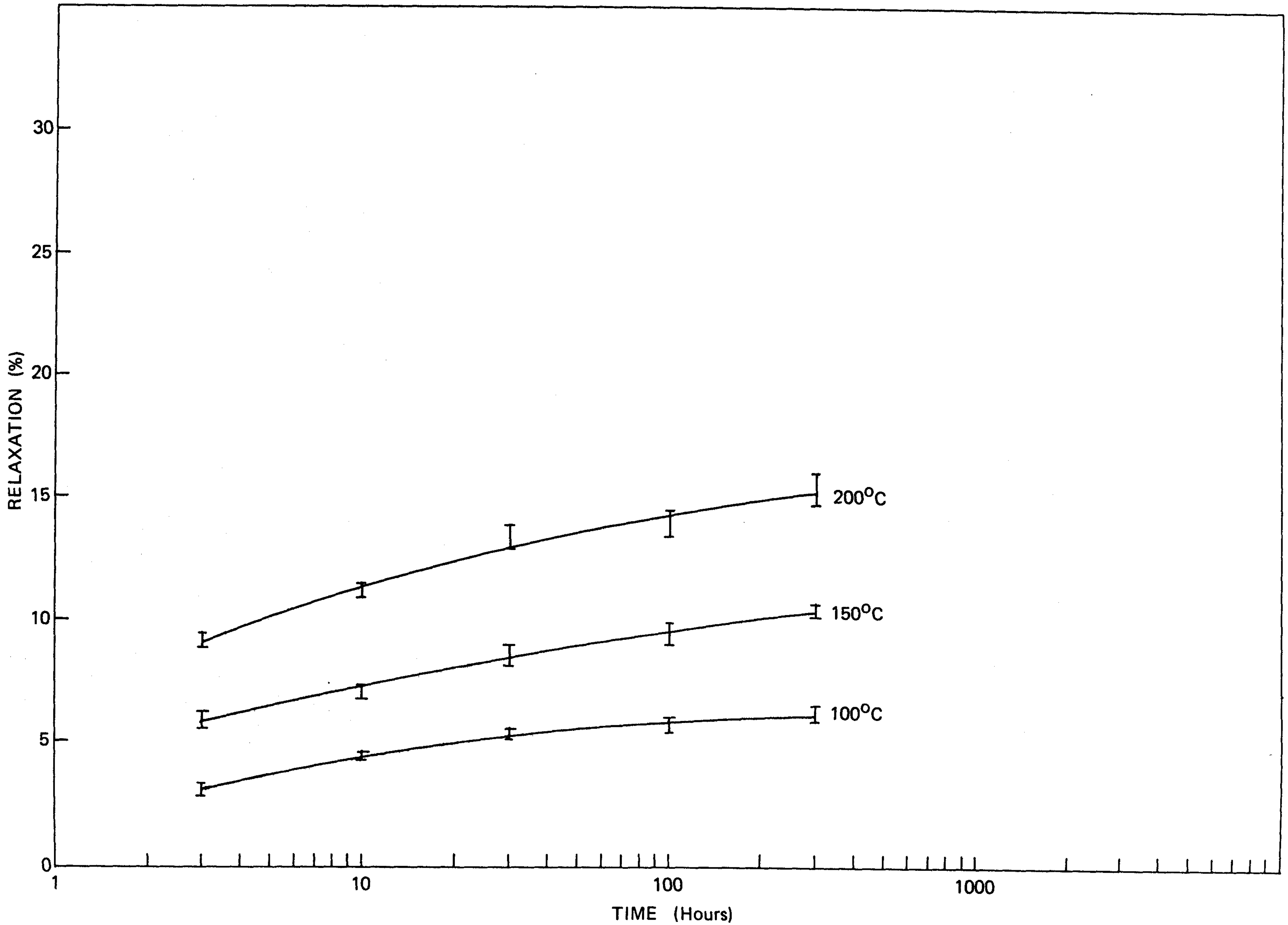

Figure 19 - Relaxation results for 450 HV_{10} hardened and tempered Carbon Steel Strip stressed at 870 N/mm^2

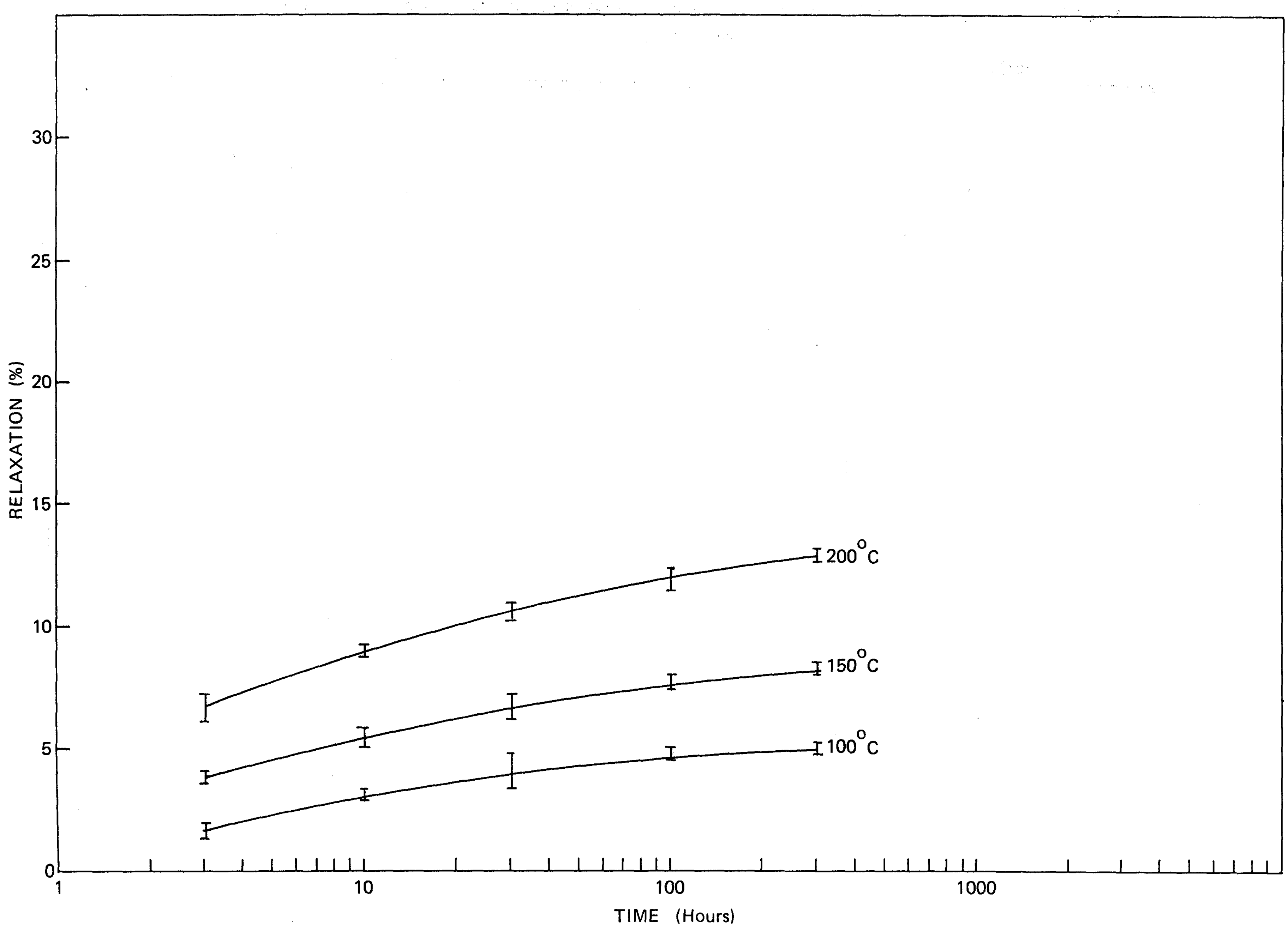

Figure 20 - Relaxation results for 450 HV_{10} hardened and tempered Carbon Steel Strip stressed at 710 N/mm^2