THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE RELAXATION BEHAVIOUR OF COPPER ALLOY STRIP MATERIALS IN BENDING

by

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SUMMARY

As a continuation of previous work, tests have been conducted examining the relaxation behaviour of beryllium copper and phosphor bronze strip material stressed in bending. The tests were carried out at a variety of appropriate stress levels and test temperatures, utilising a mandrels method of stressing.

The results indicate that the maximum recommended working temperatures are 125°C for beryllium copper and 80°C for phosphor bronze. The results also showed that the relaxation behaviour of the material was not homogeneous and that the choice of stressing direction was critical in obtaining the best performance.

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SEPTEMBER 1986

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1. INTRODUCTION

A previous report(1) examined the relaxation behaviour of carbon and stainless steel strip stressed in bending. This is a continuation of that report, examining the two copper alloy materials most widely used for electrical contact springs and similar applications, ie copper beryllium and phosphor bronze.

2. MATERIAL USED IN THE INVESTIGATION

The work was conducted using 0.254 mm thick copper beryllium and phosphor bronze strip. The copper beryllium was supplied in the mill-hardened condition to BS 2870 grade CB101 in widths of 8 mm and 203.2 mm; the phosphor bronze was supplied in the spring hard condition to BS 2870 grade PB102 in widths of 8 mm and 152.4 mm. For each material two widths were obtained as it was intended to conduct testing on materials stressed in both the transverse and the longitudinal directions.

The mechanical properties and hardness values of the two materials were determined in the as received condition and these are given in Table I. For the copper beryllium material the values obtained were low for mill-hardened material, and so an aging treatment of 335°C for two hours was carried out to bring the material into specification. The mechanical properties and hardness values of the aged material are also presented in Table I.

Test samples were cut from both materials. For the longitudinal material, samples of approximate length 100 mm were cut from the coils; for the transverse material, samples approximately 8 mm in length were sheared from the strip.

3. TEST METHOD

In the previous work on relaxation of strip[1], the testing involved bending the strips around the inside of circular tubes. However, this method was found to be unsatisfactory for the two copper alloys which experienced plastic deformation and distortion when being inserted into the tubes. A new relaxation test method was therefore investigated using a mandrel method of testing, and this method was found to give accurate and repeatable results. The method comprises bending the samples around circular mandrels of sufficient diameter to produce the desired stress levels, and clamping them in place (see Fig 1). The relaxation is determined by measuring the amount of permanent set which occurs in the test samples during testing. The diameters of the mandrels required for the test apparatus were calculated from the bending theory using the formula:

$$\sigma = \frac{Ey}{R} \qquad \text{..........} \; (1)$$

Where σ = bending stress

E = Young's modulus of material

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

t = material thickness

R = radius of curvature of mandrel

Mandrels of diameter 54, 59 and 72 mm were used for the testing. These mandrel sizes were equivalent to stress levels of 600, 550 and 450 N/mm^2 for the copper beryllium material and 485, 440 and 360 N/mm^2 for the phosphor bronze material.

Prior to commencement of relaxation testing, the strips were prestressed by being repeatedly placed into and removed from the test apparatus, until no further set was experienced. The springs were individually identified, and the initial bow of each was measured using the method described in the previous report[1]. The springs were placed in the test apparatus, locked into position and placed into air circulating ovens at the appropriate test temperature for the required test duration. After the appropriate length of time, the test apparatus was removed from the oven, allowed to cool to room temperature and the strips were then removed. The new bow was measured, the strips were re-inserted into the test apparatus for a further duration upto a maximum of 1000 hours.

A full listing of the test conditions are given in Table II.

4. RELAXATION DETERMINATION AND RESULTS

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

The relaxation results for the two materials and various test conditions (with the exception of the ambient temperature results) are presented in Figs 2-13. For each individual material, stressing direction, stress level and test temperature, the data was analysed using regression techniques.

For the phosphor bronze material the data were found to conform to a logarithmic time relaxation relationship of the form:

$$\% \text{ Relaxation} = c \log t + d \qquad \text{..........} \quad (2)$$

Where t = time in hours

c and d are mathematical constants

The values of c, d and the 95% confidence increments for the various test conditions are given in Table III. Using the logarithmic time relaxation relationship, the predicted relaxation level after 10 years was determined for each test condition and these are also given in Table III.

At ambient temperature, either very low levels of relaxation or slight recovery was experienced by the phosphor bronze. Linear regression analysis indicated that the logarithmic time relaxation relationship was not statistically significant for the results obtained for the phosphor bronze stressed transverse to a stress level of 360 N/mm^2.

For the copper beryllium mateial, the data was found to conform to a logarithmic time relaxation relationship of the form:

$$\% \text{ Relaxation} = a + b \log t + c (\log t)^2 \qquad \ldots\ldots\ldots\ldots (3)$$

Where t = time in hours

a, b and c are mathematical constants

The values of a, b and c and the 95% confidence increments are given for the various test conditions in Table IV. Using the logarithmic time relaxation relationship, the predicted relaxation level after 10 years was determined for each test condition, and these are also given in Table IV.

At ambient temperature, either very low levels of relaxation or slight recovery was experienced by the copper beryllium material under all stressing conditions.The statistical analysis indicated that the logarithmic time relaxation relationship was not significant for these results.

A comparison was made of the results for the two materials stressed in both the longitudinal and transverse directions, and it was found that, in general, the copper beryllium material stressed in the longitudinal direction had slightly superior relaxation resistance to that stressed transversely, while conversely for the phosphor bronze material that stressed transversely had superior relaxation resistance. Examples of this phenomena for both copper beryllium and phosphor bronze grades are shown in Figs 14 and 15.

It was found that, under similar test conditions of both stress and temperature, the phosphor bronze material exhibited inferior relaxation resistance to the copper beryllium. Figure 16 shows an example of this for a test temperature of 100°C and at the stress level of approximately 450 N/mm^2.

In order to limit relaxation of 20% maximum working temperatures for the copper beryllium and phosphor bronze materials are 125 and 80°C respectively.

5. CONCLUSIONS

1. Relaxation results for copper beryllium and phosphor bronze strip have been generated and are presented graphically.
2. The maximum recommended working temperatures are 125°C for copper beryllium and 80°C for phosphor bronze.
3. At ambient temperature both materials experience low levels of relaxation.
4. For copper beryllium material, material stressed in the longitudinal direction exhibited slightly superior relaxation to that stressed transversely under similar conditions of stress and temperature.
5. For phosphor bronze material, that stressed transverse exhibited slightly superior relaxation resistance to material stressed longitudinally under similar conditions of temperature and stress.

6. REFERENCES

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

TABLE I MECHANICAL PROPERTIES OF COPPER BERYLLIUM AND PHOSPHOR BRONZE STRIP

Material	Condition	Tensile Properties (N/mm^2)				Hardness HV2.5
		Rm	L of P	$Rp_{0.1}$	$Rp_{0.2}$	
CB101	As rec'd	1000	655	845	890	320
CB101	Aged 335°C	1210	820	1055	1110	390
PB102	As rec'd	675	445	630	660	220

TABLE II SUMMARY OF TEST CONDITIONS

Material	Stressing Direction	Stress Level (N/mm^2)	Temperature (°C)
CB101	Transverse and Longitudinal	600	150, 100, 20
		550	175, 150
		450	150, 100, 20
PB102	Transverse and Longitudinal	485	150, 100, 20
		440	80, 100
		360	150, 100, 20

TABLE III ANALYTICAL CONSTANTS, CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR RELAXATION LEVELS FOR PHOSPHOR BRONZE STRIP

Stressing Direction	Stress Level (N/mm^2)	Temperature (^{o}C)	c	d	95% Confidence Increment (%)	Predicted 10 Year Mean Level (%)
Longitudinal	485	150	12.53	9.48	0.9	71.4
		100	7.45	1.19	0.7	38.0
		20	0.38	0.40	0.4	2.3
Longitudinal	440	100	6.05	3.37	0.9	33.3
		80	4.83	0.83	0.5	24.7
Longitudinal	360	150	14.09	5.48	1.4	75.1
		100	7.61	-0.05	0.5	37.6
		20	0.25	0.94	0.5	2.2
Transverse	485	150	13.71	6.21	2.2	74.0
		100	5.35	2.57	0.9	29.0
		20	0.61	-0.12	0.9	2.9
Transverse	440	100	4.44	4.51	0.8	26.4
		80	3.02	3.78	0.9	18.7
Transverse	360	150	13.51	4.47	1.6	71.2
		100	5.18	2.19	1.9	27.8

TABLE IV ANALYTICAL CONSTANTS, CONFIDENCE INCREMENTS AND PREDICTED 10 YEAR RELAXATION LEVELS FOR COPPER BERYLLIUM STRIP

Stressing Direction	Stress Level (N/mm^2)	Temperature (^{o}C)	a	b	c	95% Confidence Increment (%)	Predicted 10 Year Mean Level (%)
Longitudinal	600	150	1.14	-0.86	1.66	0.5	45.8
		100	0.25	-0.58	0.39	0.5	7.0
Longitudinal	550	175	2.89	0.95	1.78	0.5	51.1
		150	1.06	0.20	1.09	0.4	28.7
Longitudinal	450	150	0.93	-1.14	1.61	0.6	34.6
		100	0.26	-0.50	0.33	0.2	5.9
Transverse	600	150	1.82	-1.22	2.08	1.0	46.7
		100	0.75	-0.83	0.54	0.8	9.8
Transverse	550	175	4.21	1.29	2.05	1.0	76.7
		150	0.34	2.87	0.46	0.8	25.7
Transverse	450	150	1.74	-1.66	2.04	1.0	43.5
		100	0.71	-0.58	0.44	0.4	8.6

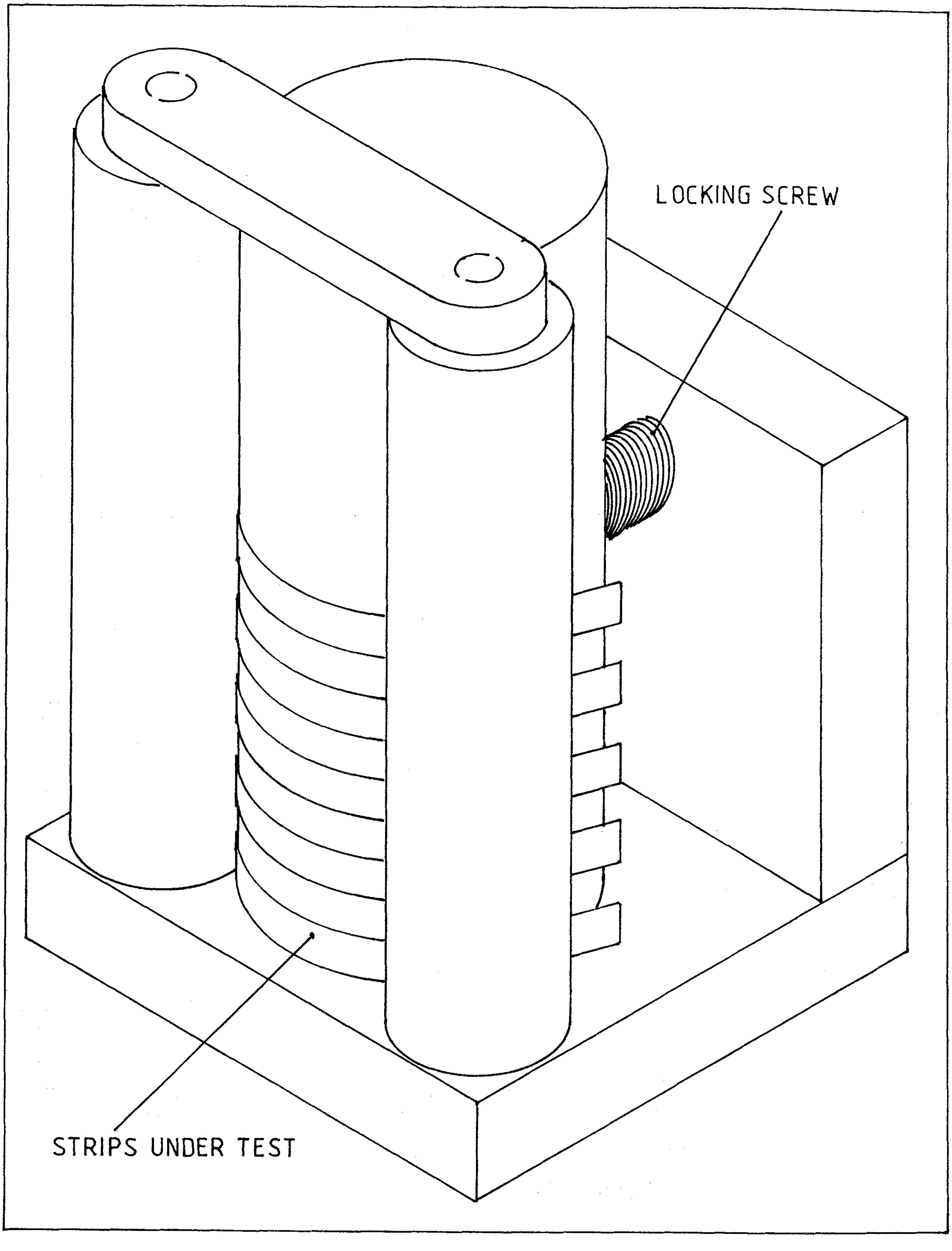

FIG.1. TEST APPARATUS

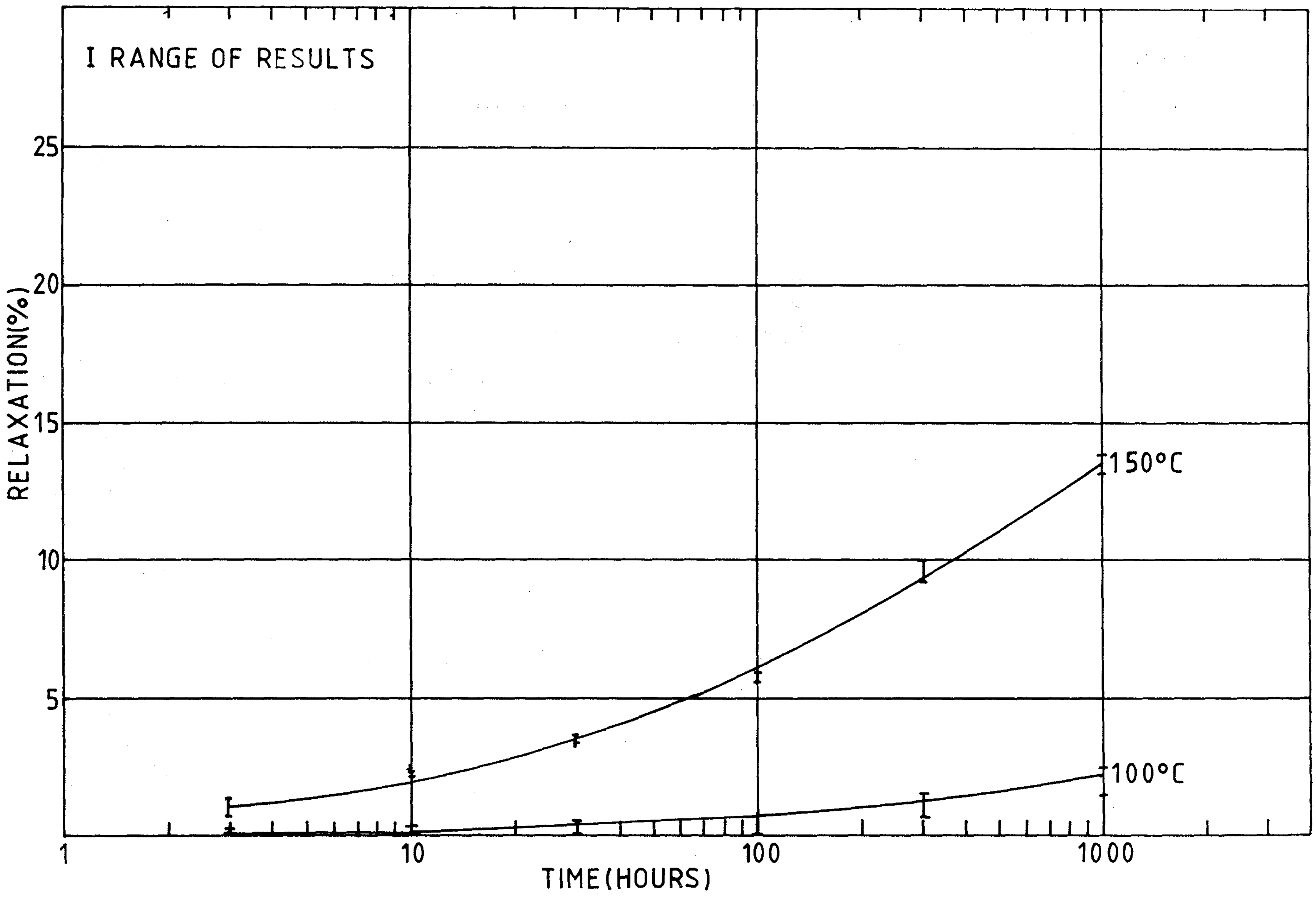

FIG. 2. MEAN RELAXATION LEVELS FOR C B 101 STRIP STRESSED LONGITUDINLLY TO 600 N/mm²

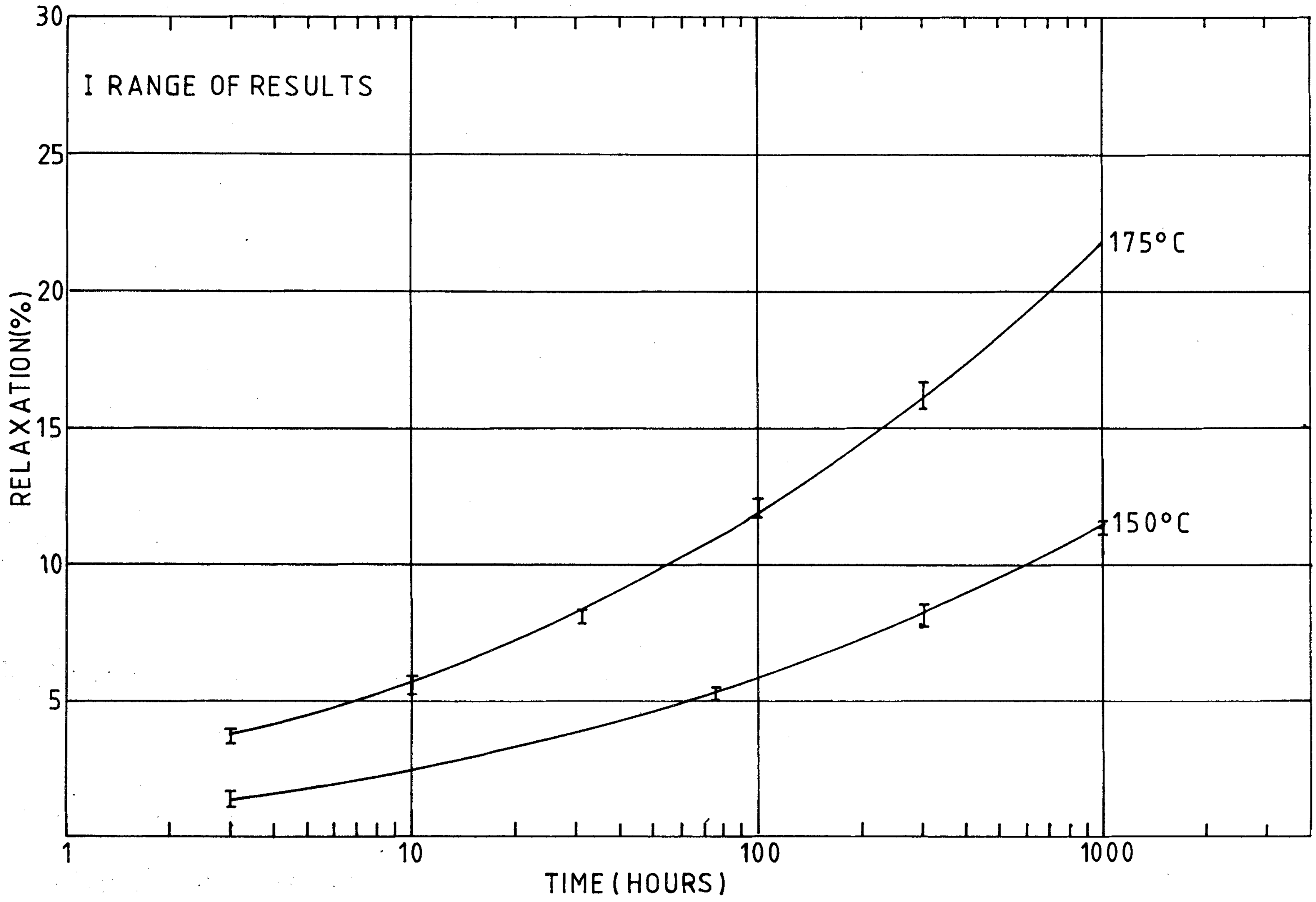

FIG. 3. MEAN RELAXATION LEVELS FOR CB 101 STRIP STRESSED LONGITUDINALLY TO 550 N/mm^2

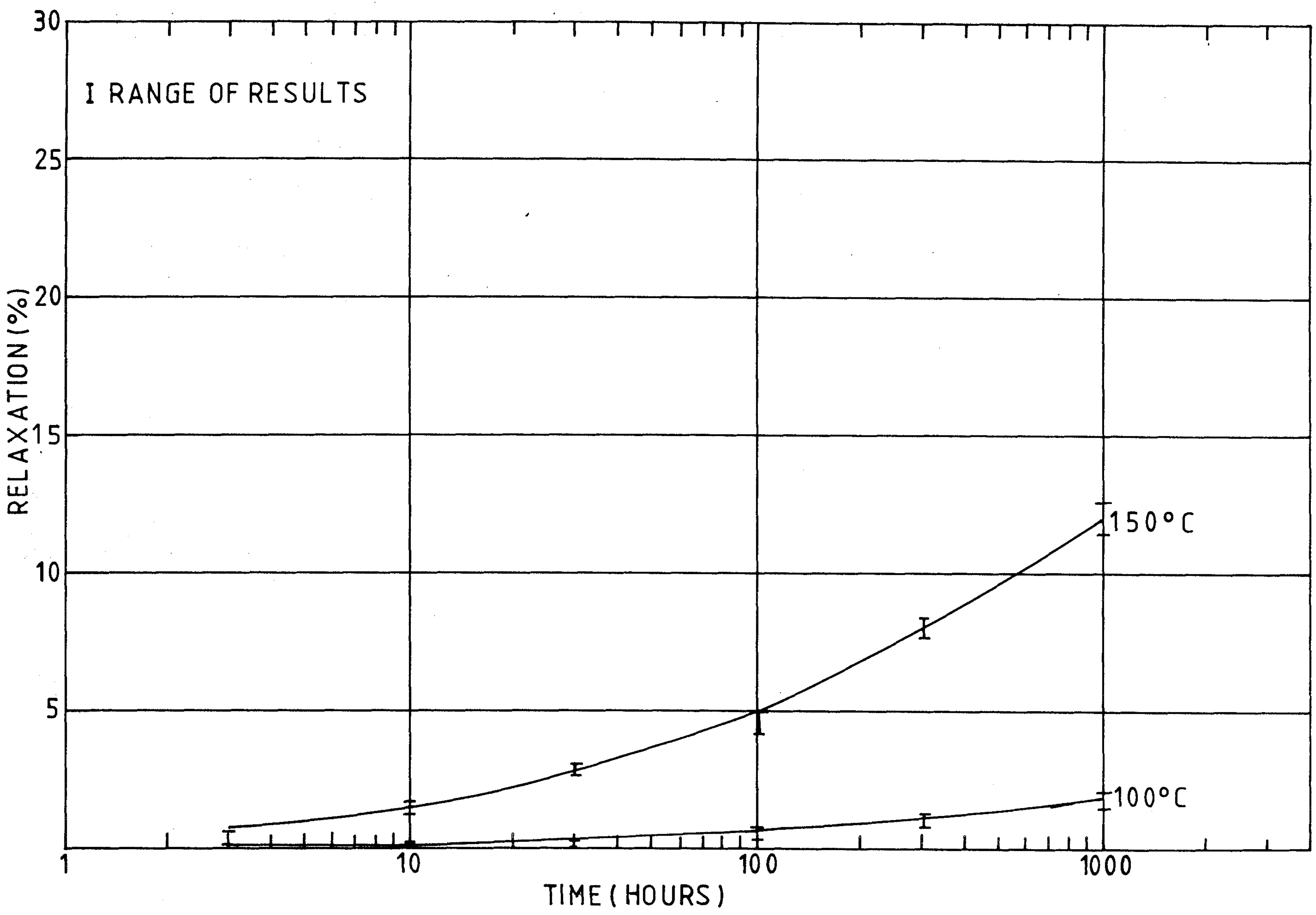

FIG. 4. MEAN RELAXATION LEVELS FOR CB101 STRIP STRESSED LONGITUDINALLY TO 450 N/mm²

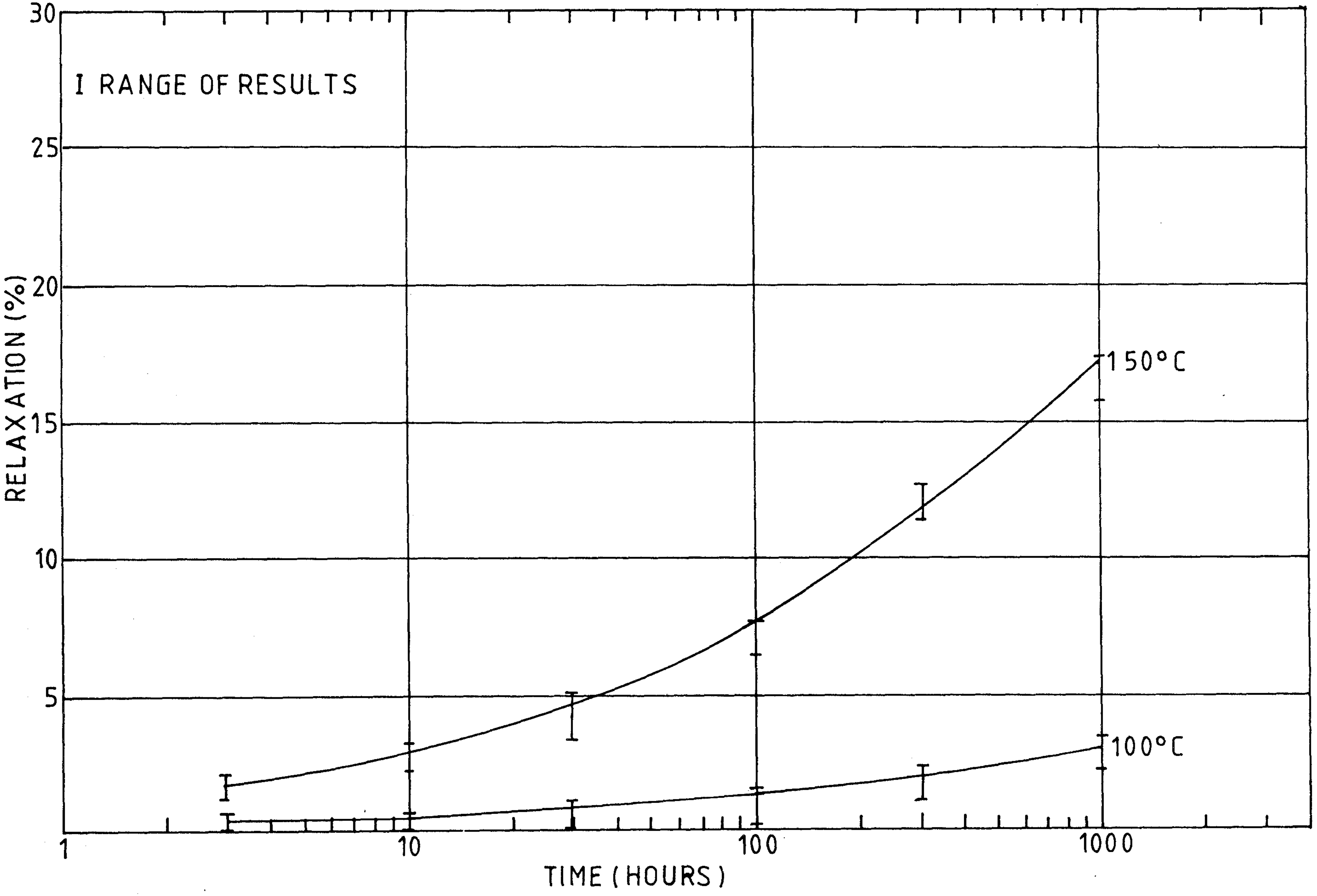

FIG. 5. MEAN RELAXATION LEVELS FOR CB 101 STRIP STRESSED TRANSVERSELY TO 600 N/mm²

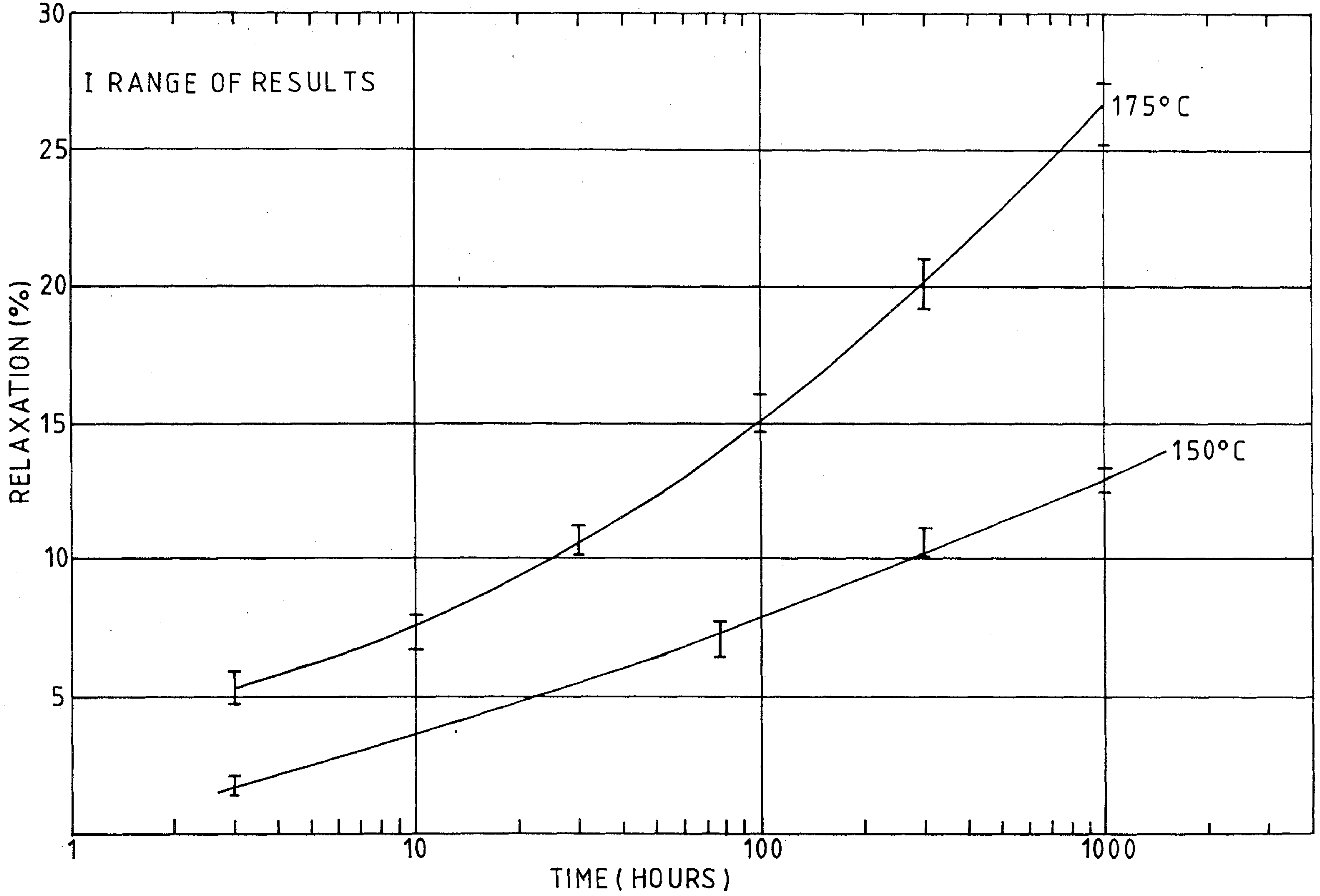

FIG. 6. MEAN RELAXATION LEVELS FOR CB 101 STRIP STRESSED TRANSVERSELY TO 550 N/mm²

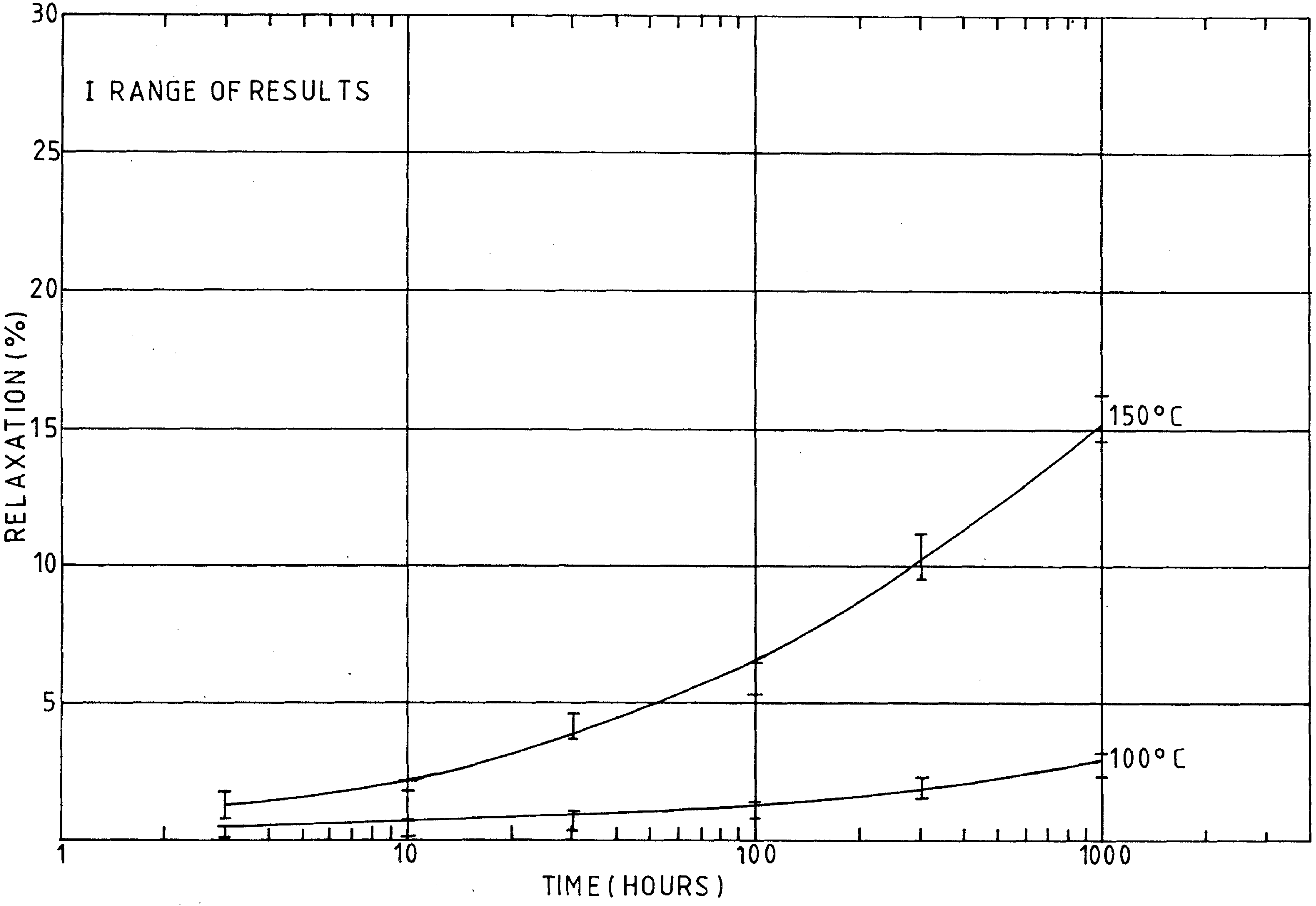

FIG. 7. MEAN RELAXATION LEVELS FOR CB101 STRIP STRESSED TRANSVERSELY TO 450 N/mm^2

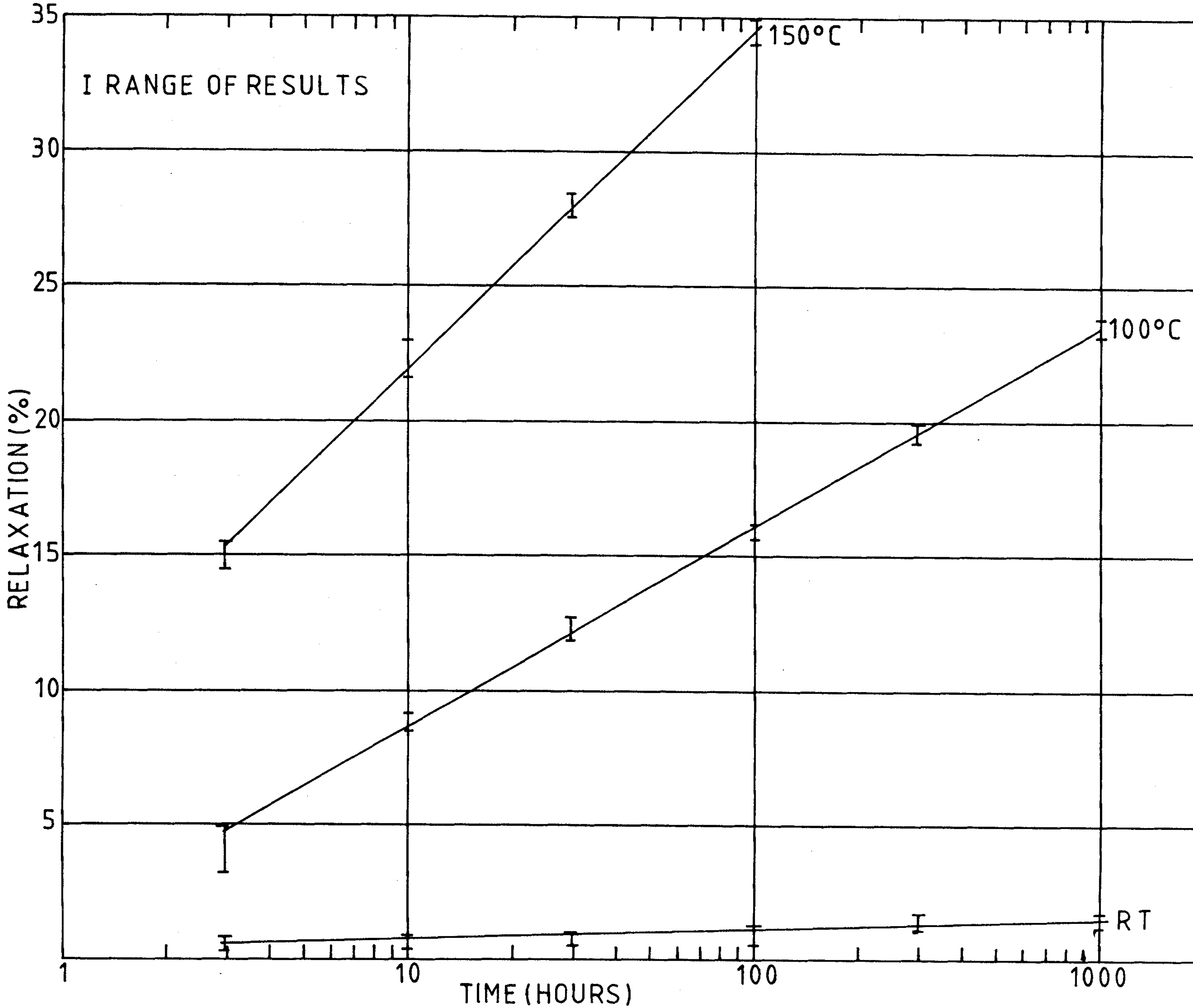

FIG. 8. MEAN RELAXATION LEVELS FOR P B 102 STRIP STRESSED LONGITUDINALLY TO 485 N/mm²

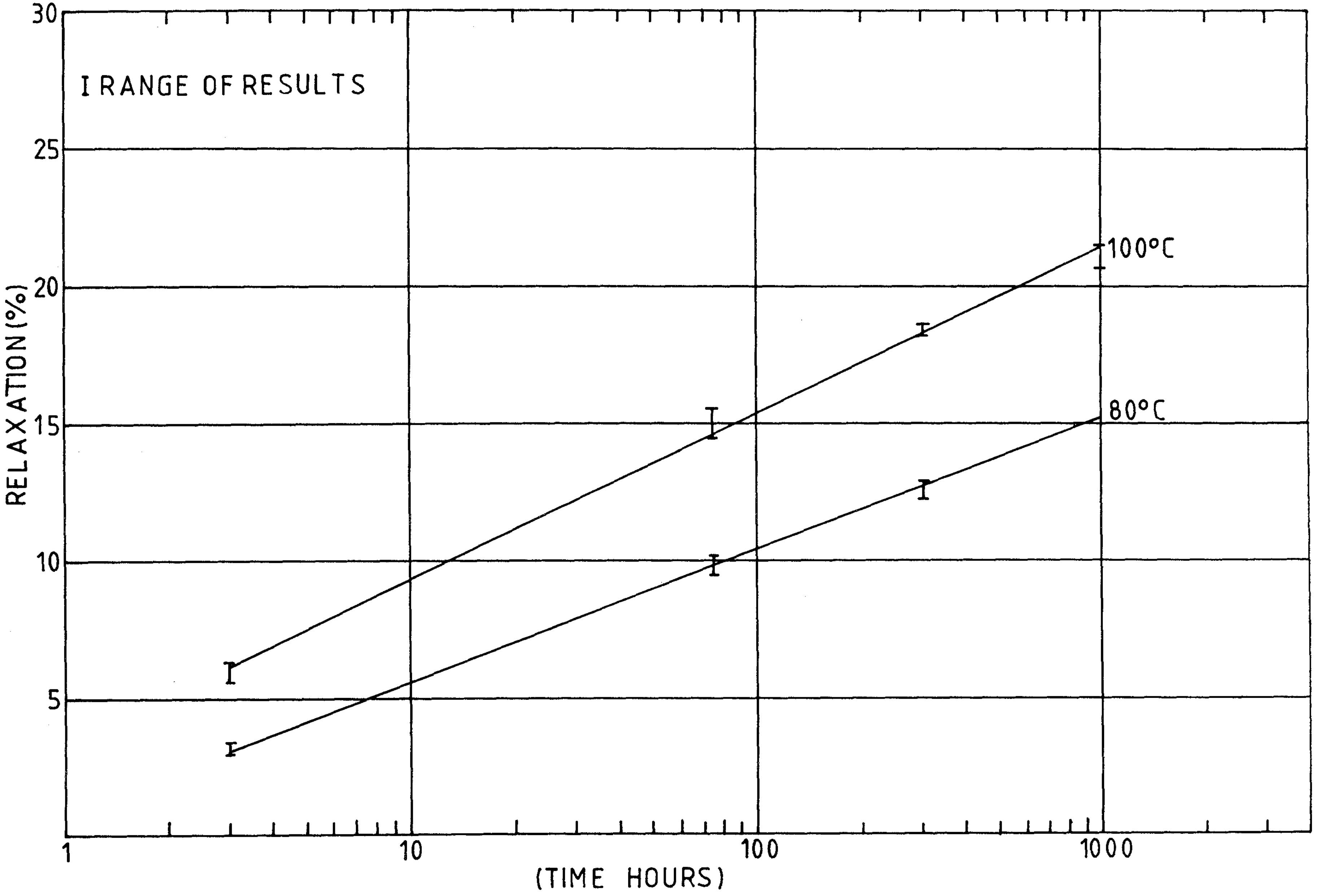

FIG. 9. MEAN RELAXATION LEVELS FOR PB 102 STRIP STRESSED LONGITUDINALLY TO 440 N/mm^2

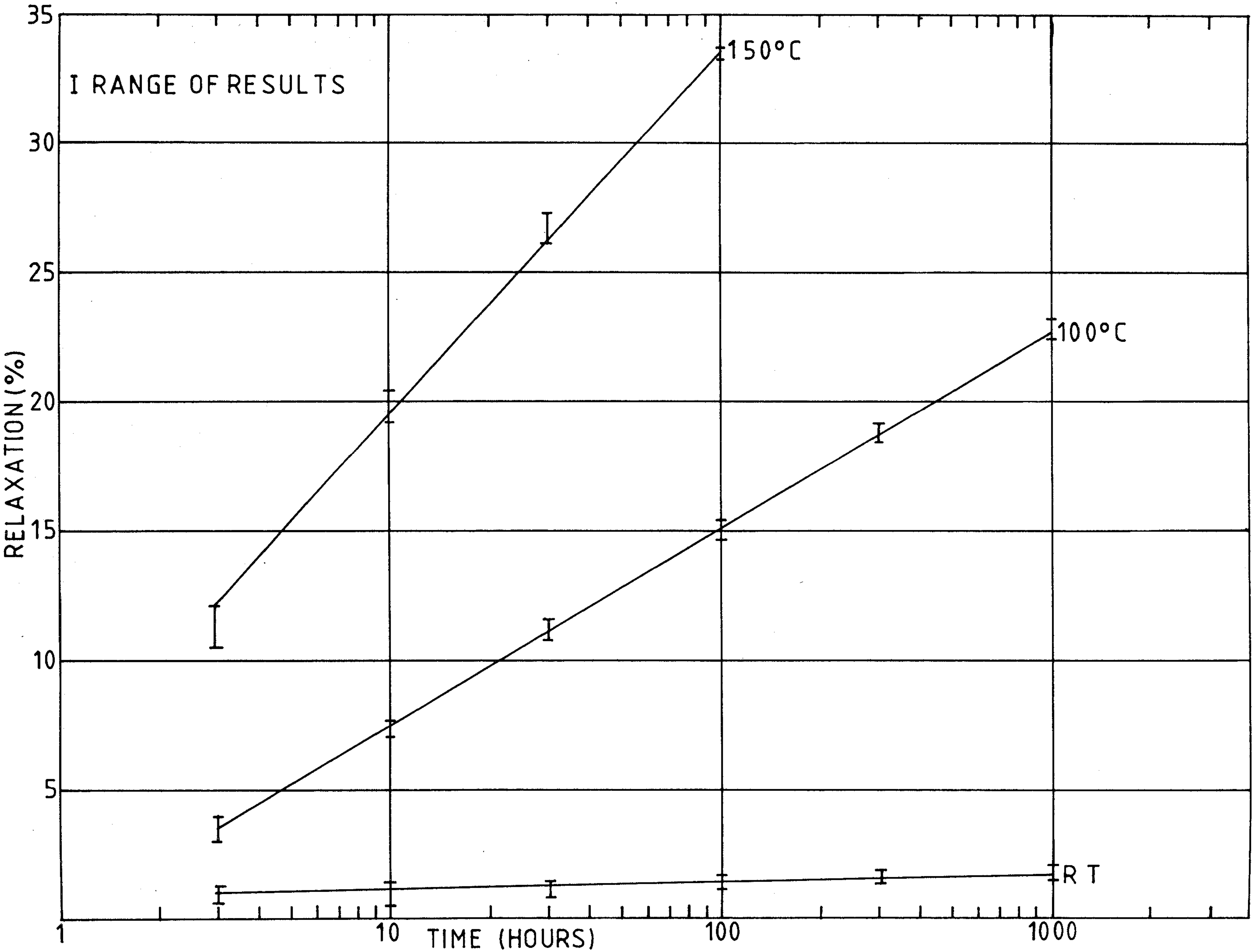

FIG.10. MEAN RELAXATION LEVELS FOR P B 102 STRIP STRESSED LONGITUDINALLY TO 360 N/mm²

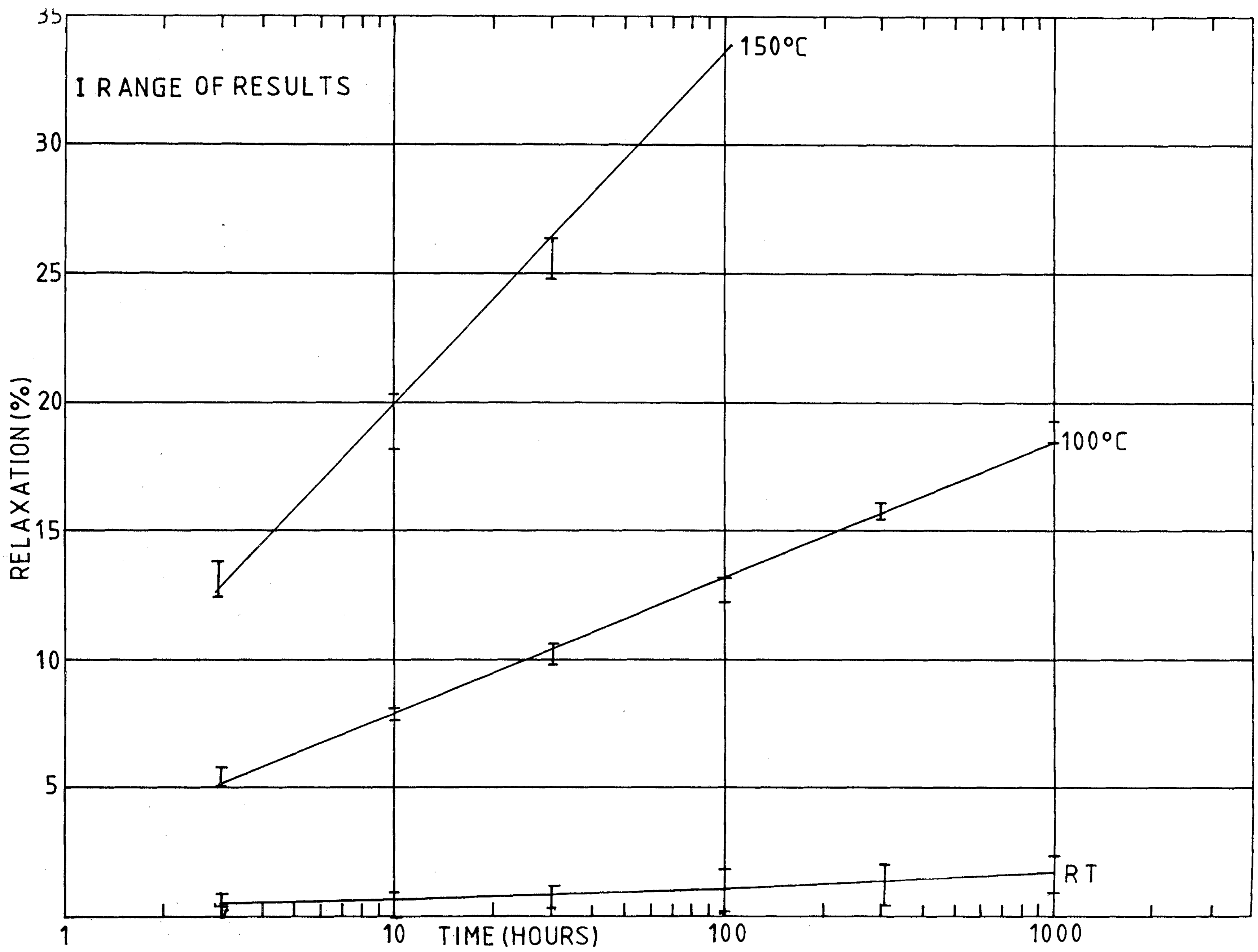

FIG. 11. MEAN RELAXATION LEVELS FOR P B 102 STRIP STRESSED TRANSVERSELY TO 485 N/mm²

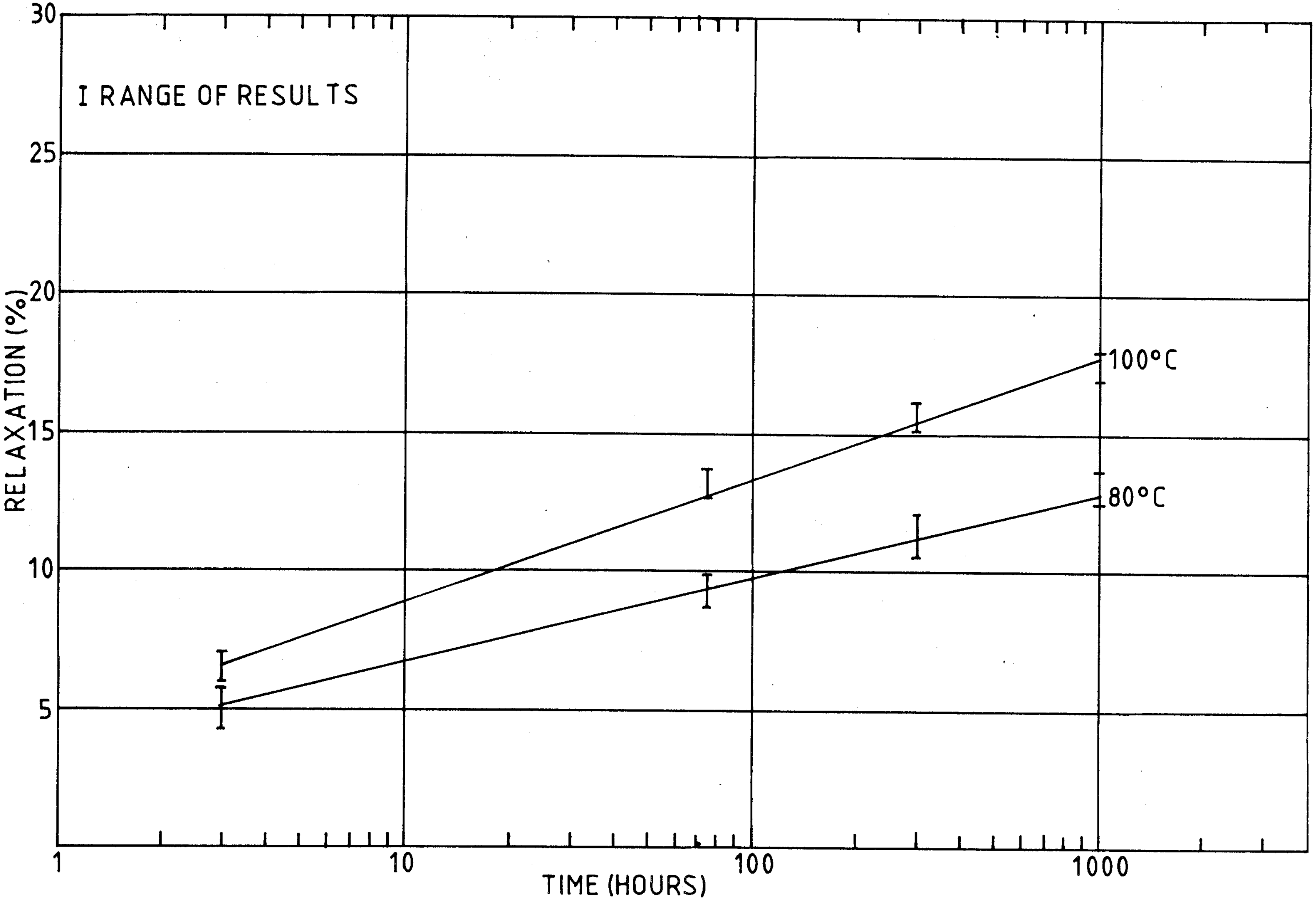

FIG.12. MEAN RELAXATION LEVELS FOR P B 102 STRIP STRESSED TRANSVERSELY TO 440 N/mm²

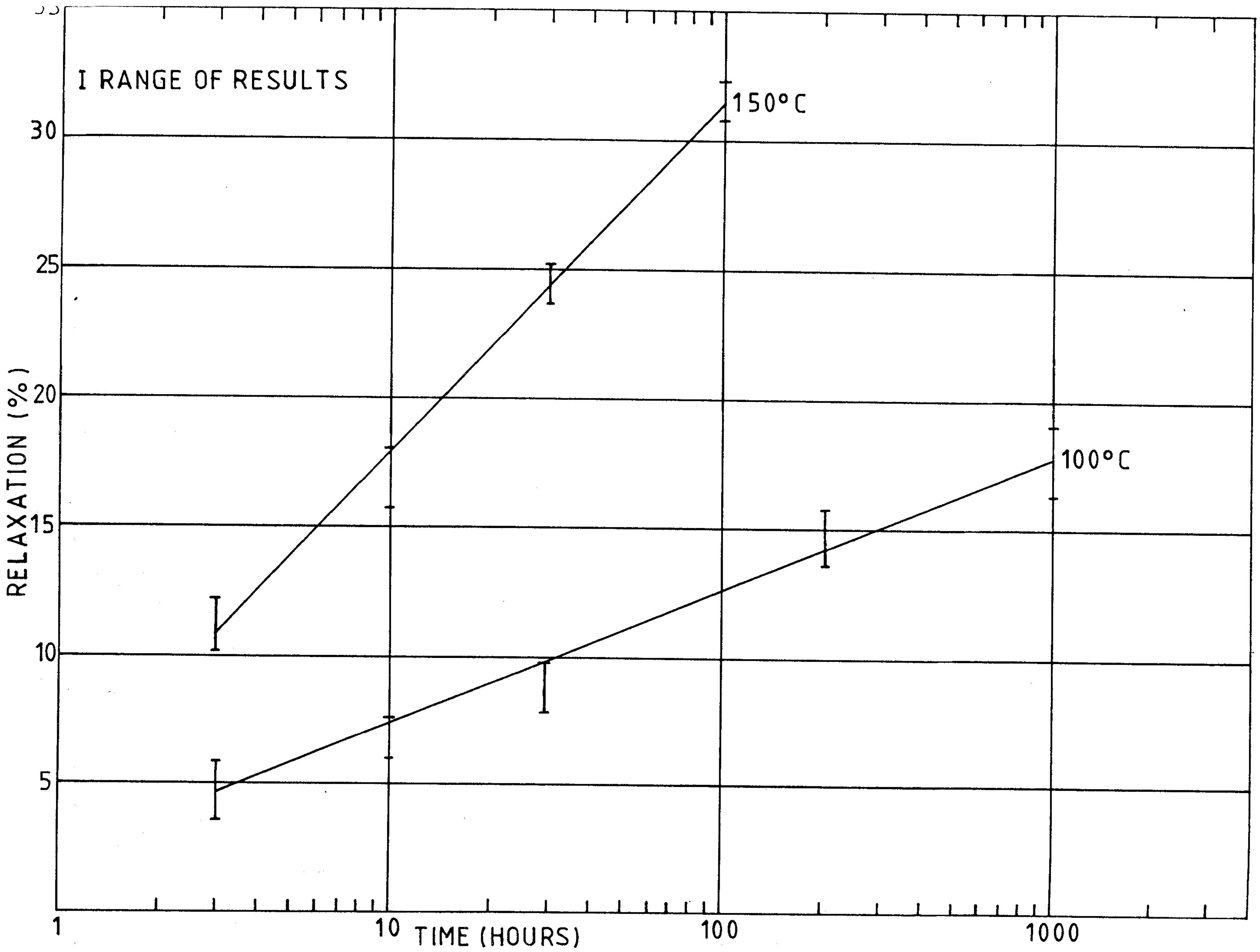

FIG.13. MEAN RELAXATION LEVELS FOR P B 102 STRIP STRESSED TRANSVERSELY TO 360 N/mm²

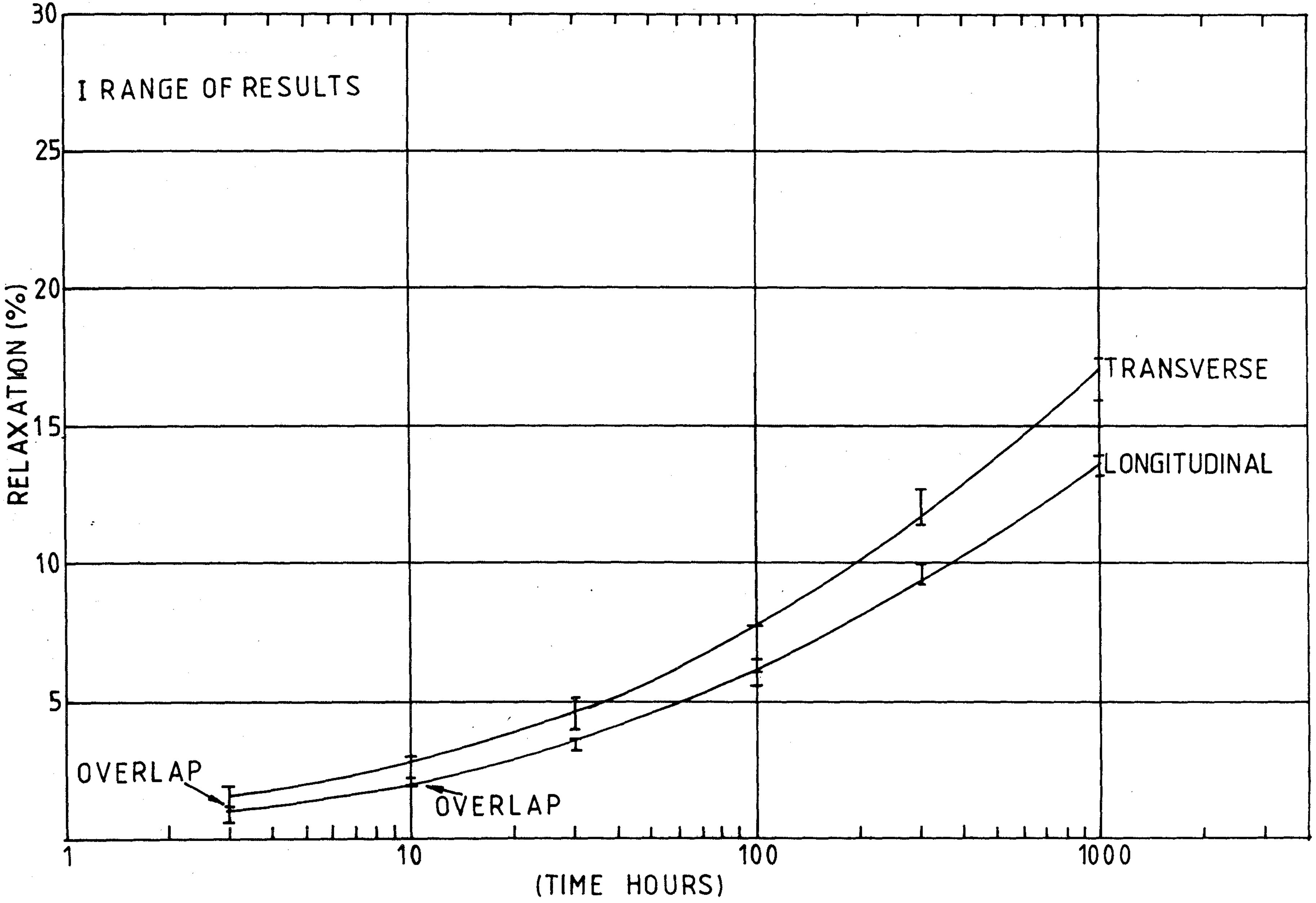

FIG.14. EFFECT OF STRESSING DIRECTION ON THE RELAXATION AT 150°C OF C B 101 STRIP STRESSED TO 600N/mm^2

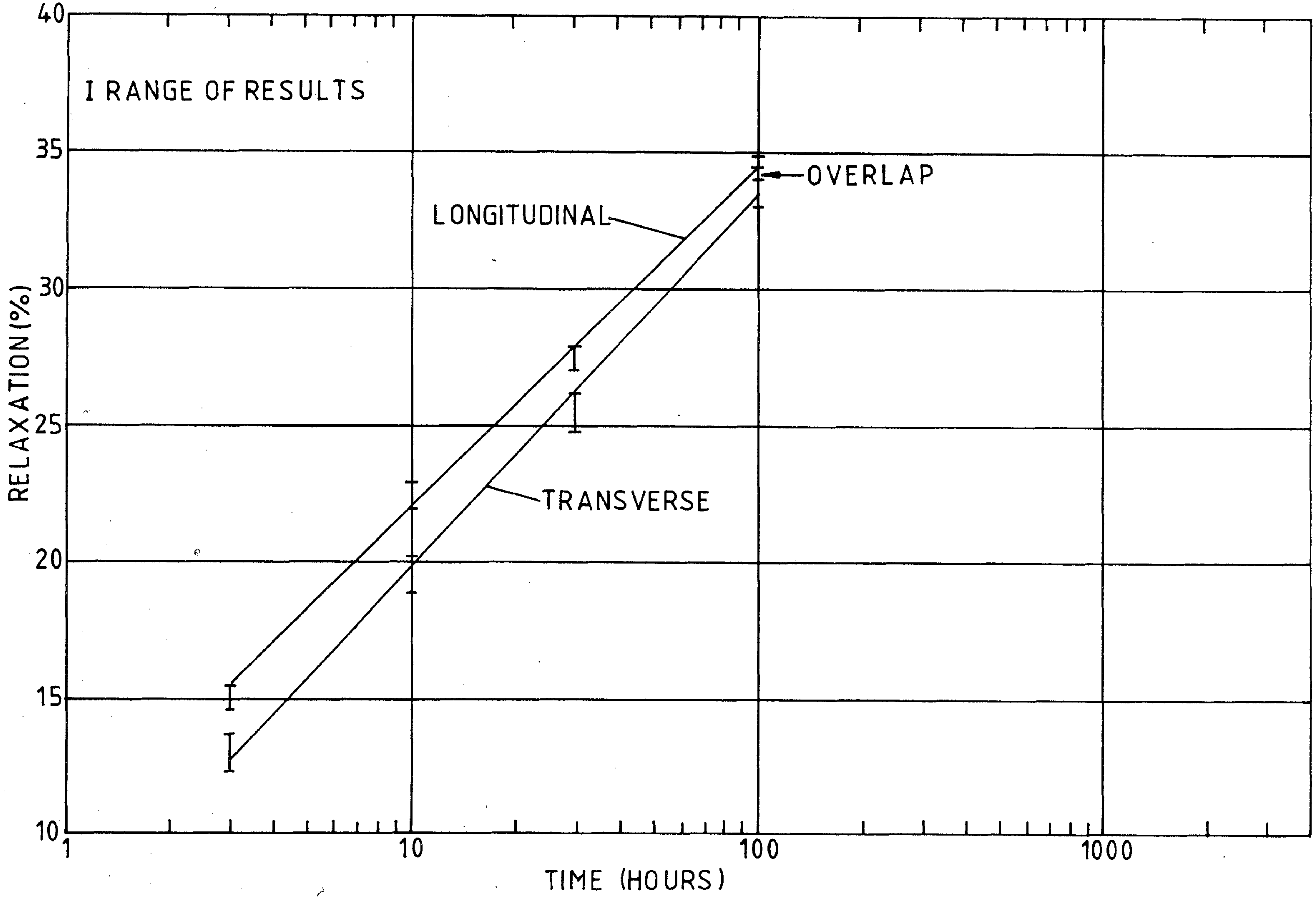

FIG.15. EFFECT OF STRESSING DIRECTION ON THE RELAXATION AT 150°C OF P B102 STRESSED TO 485 N/mm²

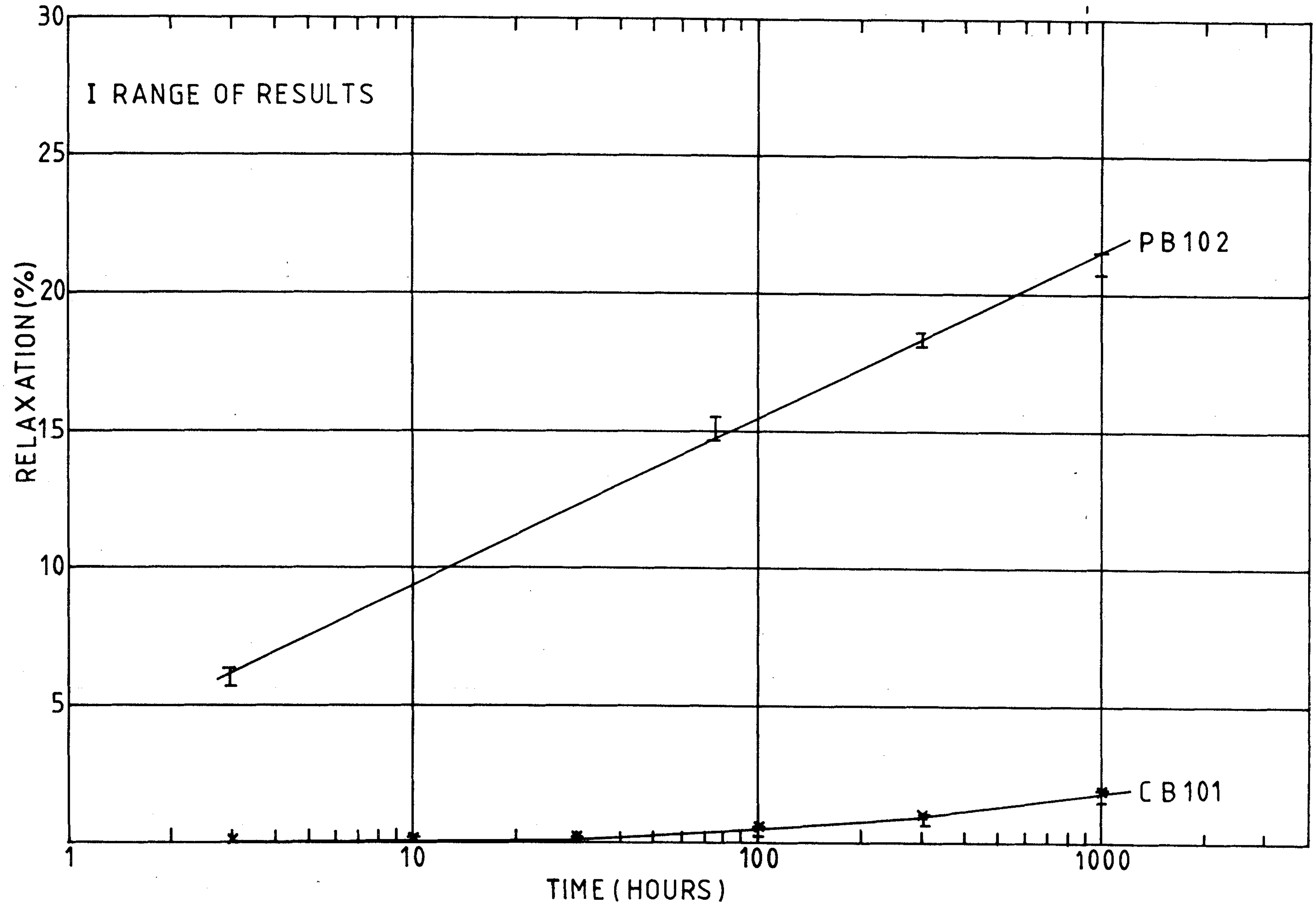

FIG.16. COMPARISON OF RELAXATION PERFORMANCE AT 100°C OF C B 101 AND P B 102 STRESSED LONGITUDINALLY TO 450 N/mm^2