THE SPRING RESEARCH ASSOCIATION

THE STRESS TEMPERATURE RELAXATION PROPERTIES OF SOME HIGH TEMPERATURE AND CORROSION RESISTANT MATERIALS

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Report No: 194

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SUMMARY

The relationships between stress, temperatures and time and their effect on the relaxation properties of helical compression springs for a number of alloys used for high temperature and corrosion resistant applications have been investigated.

The alloys were:-

18-8 Stainless Steel	air melted and vacuum melted in the peened and unpeened condition.
René 41.	A heat and corrosion resistant alloy.
A286.	A heat and corrosion resistant alloy.
M252.	A high strength nickel base forging alloy.
Waspaloy.	A heat and corrosion resistant alloy.
Elgiloy.	A heat and corrosion resistant spring alloy.
L605.	A heat and corrosion resistant alloy.

The investigation was initiated to obtain additional data on the relaxation properties of alloys used at high temperatures.

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1. INTRODUCTION

The stress temperature relaxation properties of springs manufactured from a number of steels and alloys have been dealt with in a number of published reports [1] [2] [3] [4] [5].

It was felt, however, that further work using springs could be carried out on high alloy steels intended for use where corrosion and heat resistant properties are required.

A selected number of corrosion and temperature resistant steels were used to obtain further stess relaxation data on helical compression springs, and these data are the subject of the present paper.

2. MATERIALS INVESTIGATED

A wide range of materials was selected to cover a broad analysis spectrum with the object of determining their stress temperature relaxation properties.

Table I indicates their compositions and Table II the heat treatment used.

With the exception of some springs made from 12R10 and 12R10 ~~HV~~ material all springs were tested ~~in~~ the unpeened and unscragged condition. The nominal dimensions of the springs for each quality are given in Table III.

3. EXPERIMENTAL PROCEDURE

Stress Relaxation Tests

A detailed account of the experimental method used to determine relaxation is cont ined in earlier reports. Briefly this consisted of calculating the load required to produce the desired stress within the spring using the standard stress formula and curvature correction factor. Then, by using a conventional load testing machine, the spring was compressed to the calculated load and the loaded length measured.

Each spring was fitted over a Monel bolt and by means of a nut and washers compressed to the desired length and hence the required load or stress.

After assembly the compressed springs were subjected to the desired temperature for a specified period of time, allowed to cool and unloaded. The new load at the original compressed length was measured and from these data the percentage loss in load computed. All stress calculations and load measurements were based on the ambient temperature rigidity modulus and no correction was made to the stress values quoted due to the reduction of rigidity modulus with increase in temperature. The change in modulus can, however, be obtained from Fig. 32 in which rigidity modulus curves have been compiled from various sources [(6) (7)].

4. RESULTS

4.1 12R10 Stainless Steel

The relaxation properties of this material in the peened and unpeened condition are shown in Figs. 1 to 8. Data were obtained for periods of 3, 6, 12, 24, 72, 168 and 240 hours to obtain graphs showing the effect of time on relaxation at temperatures of 200, 250 and 300°C using initial stress levels of 276, 551 and 827 N/mm^2. Curves of percentage relaxation against initial stress levels of 276, 414, 551, 690 and 827 N/mm^2 for 240 hours at temperatures of 200, 250 and 300°C were also obtained.

4.2 <u>12R10 HV Vacuum Melted Stainless Steel</u>

The same experimental procedure was followed and similar results were obtained with this material as with the normal air melted quality. A comparison of results of air melted and vacuum melted material could then be obtained. The results are shown in Figs. 9 to 16.

4.3 <u>Rene 41, M252 and Waspaloy</u>

Results were obtained on these three qualities showing the stress-temperature relaxation properties at 400, 450 and 500°C using initial stress levels of 150, 200, 300, 400 and 500 N/mm^2.

In the case of the Waspaloy alloy the number of springs available limited the tests to initial stress levels of 300, 400 and 500 N/mm^2. The curves obtained are shown in Figs. 17 to 19.

4.4 <u>A286</u>

Relaxation results were obtained for springs manufactured from cold drawn wire (30% reduction) subsequently aged after coiling. In addition springs were tested in the re-solution treated and aged condition. The results are shown in Figs. 20 to 27.

4.5 <u>Elgiloy</u>

The relaxation results for springs are shown in Figs. 28 to 31.

4.6 L605

It was shown that springs made from L605 wire subsequently aged at 815°C for 16 hours would not withstand stresses above 400 N/mm^2 (58 000 lbf/in^2) and that at temperatures above 300°C approximately 20% relaxation was common. In an endeavour to improve the relaxation resistance of this material springs were re-solution treated and aged, and further relaxation testing undertaken. Again excessive relaxation was experienced at test temperatures above 300°C.

Analysis and metallographic examinations showed that the material was within specification. It was concluded therefore that springs made from annealed wire subsequently aged after coiling were unsuitable for elevated temperature applications, possibly due to their relatively low elastic limit.

5. DISCUSSION OF RESULTS

From a study of the curves obtained it can be seen that in general relaxation of springs is time, temperature and stress dependent.

Sandvik 12R10 and 12R10 HV qualities

Both these materials are austenitic stainless steels containing approximately 18% chromium and 8% nickel. The 12R10 quality is an air melted steel similar in composition to En 58A, but with a less wide tensile strength range. The 12R10 HV, on the other hand, is a vacuum melted stainless steel for which there is no British equivalent specification. Although air melted austenitic stainless steel is widely used for springs, and relaxation data are available for this quality, little or nothing was known of the relaxation behaviour of springs made from wire produced from vacuum melted stock.

Within the temperature and stress ranges investigated the results have shown that the percentage relaxation will increase rapidly above 250°C particularly with high initial stress levels. No significant difference was noticed between springs made from commercially air melted and vacuum melted steel. (Figs. 7 and 15 and 8 and 16.)

Shot peening on the other hand adversely affected the resistance to relaxation of springs manufactured from both qualities of stainless. This is presumably due to the relief of residual peening stresses in the springs which again is dependent on the testing temperature. The relaxation results for unpeened and peened springs can be compared by referring to Figures 7 and 8, and 15 and 16.

Shot peening cannot therefore be recommended for springs made from 18-8 austenitic stainless wire if maximum resistance to relaxation at elevated temperatures is required.

From the point of view of relaxation resistance no advantage is to be gained in the use of vacuum melted stock and the less costly air melted material is recommended.

René 41, M252 and Waspaloy Springs

Due to the limited amount of material available in these three qualities the testing of springs was somewhat restricted.

Curves were obtained showing the effect of initial stress on the percentage relaxation after 240 hours for temperature levels of 450, 500 and 550°C.

It is evident that these three materials are in general suitable where resistance to stress relaxation at temperatures up to 500°C is required.

Waspaloy springs possessed slightly better relaxation resistance at 500°C than either René 41 or M252 springs. René 41 and M252 showed similar relaxation although at 550°C M252 may be slightly better.

Springs made from René 41, when subjected to temperatures of 450 and 500°C, were relatively insensitive to initial stress, therefore the use of higher initial stress levels is an attraction.

All three materials were superior to 18-8 austenitic stainless steel springs and although more costly could be employed where service conditions were too severe for the 18-8 material.

A286 Springs

The relaxation data show that springs made from cold drawn wire subsequently aged after coiling would be satisfactory for service applications up to about 400°C (Fig. 23); higher temperatures caused a marked increase in the amount of relaxation. Like many of the heat resistant alloys, A286 can be hardened by cold work and precipitation hardening and with 30% cold reduction would be expected to give tensile strengths of the order of 1390 N/mm^2 (90 $tonf/in^2$).

On the other hand, improved relaxation resistance can be obtained for higher operating temperatures by using the material in the solution treated and aged condition (Fig. 27). Such a treatment produces tensile strengths of approximately 1205 N/mm^2 (78 $tonf/in^2$), somewhat lower than the cold drawn variety but with increased resistance to relaxation at temperature. By comparing the data given in Figs. 23 and 27 an assessment of the improvement can be made. It is clearly shown that by using solution treated and aged springs the maximum operating temperature can be increased by at least 50°C to 450°C and if the operating stress is limited to about 250 N/mm^2 temperatures as high as 500°C are possible.

Attempts have been made to describe the relaxation data obtained for the various materials by means of mathematical formulae. As an example of this approach Figs. 21A and 22A for A286 springs have been constructed relating percentage relaxation to log time at temperature. Over the time periods investigated good correlation (confidence levels > 99.9%) was obtained when the data were plotted in this manner and the relationship between time and resultant relaxation could be conveniently expressed as:-

Quality	Temperature °C	Stress N/mm^2	Relationship where y = relaxation % x = time in hours
A286	450	207	$y = 4.1 \log(x-1)+4.27$
A286	450	345	$y = 4.9 \log(x-1)+3.97$
A286	450	483	$y = 6.3 \log(x-1)+4.23$
A286	500	207	$y = 4.1 \log(x-1)+10.0$
A286	500	345	$y = 5.5 \log(x-1)+12.9$
A286	500	483	$y = 7.3 \log(x-1)+13.2$

Unfortunately not all the data were amenable to this treatment due to scatter in the experimental results but nevertheless this procedure illustrates a method whereby extrapolation may be possible to extended times.

Elgiloy Springs

Elgiloy in either wire or strip form is noted for its extremely good static and dynamic properties and was originally developed for watch spring applications where cost is of secondary importance. Over the years, it has found specialist applications in other fields where full use of its excellent properties could be utilised. The optimum spring properties of wire are developed after about 45-48% cold drawing followed by a heat treatment at 525^{o}C for 5 hours. Such a treatment gives a tensile strength of about 2240 N/mm^2 (145 tonf/in^2) and yield strength of about 1450 N/mm^2 (94 tonf/in^2).

It will be seen from Table I that Elgiloy is a high cobalt nickel chromium alloy which should offer good resistance to both corrosion and temperature. The stress relaxation properties of springs produced from this material can be seen in Figs. 28 to 31 and clearly show the good elevated temperature properties. For the majority of engineering spring applications therefore Elgiloy can be used up to temperatures of 350^{o}C and perhaps 400^{o}C if relaxation of the order of 8% can be tolerated. Temperatures in excess of 400^{o}C do, however, cause a marked increase in relaxation and are not to be recommended.

Like high speed steels and Rene 41, Elgiloy is relatively insensitive to initial stress and is therefore an added attraction particularly where space limitations make the use of a relatively highly stressed spring imperative. It is suggested that this relaxation characteristic is related to the high elastic strength of the material.

6. CONCLUSIONS AND RECOMMENDATIONS

1. The austenitic stainless steel 12R10 can be used as a spring material for operating temperatures up to about 250^{o}C.

2. For elevated temperature applications shot peening of springs is not recommended since this caused an increase in load loss.

3. From the point of view of relaxation resistance no advantage is to be gained from using vacuum melted austenitic stainless steel.

4. The use of solution treated and aged A286 wire, as opposed to cold drawn and aged A286 wire, gave some improvement in relaxation resistance and springs treated in this manner were capable of withstanding temperatures up to 400°C.

5. Elgiloy springs exhibited similar properties to A286 springs when subjected to temperature and are recommended for service conditions up to 400°C.

6. The relaxation properties of springs made from René 41, M252 and Waspaloy were very similar and all were capable of resisting relaxation at temperatures up to about 500°C.

7. Both Elgiloy and René 41 springs were less sensitive to initial stress than the other qualities and could therefore find applications where space restrictions necessitate relatively highly stressed springs.

7. RECOMMENDATIONS FOR FUTURE WORK

1. Further investigation should be carried out into the effects of peening on the stress relaxation properties of other materials.

2. Investigations should be widened to include other qualities of heat and corrosion resistant alloys and steels.

3. A study of the influence of hot and cold prestressing of helical compression springs should be undertaken to determine their effect on the relaxation resistance. Such data are particularly needed for carbon and low alloy steels.

8. REFERENCES

1. G. B. Graves. 'The Relaxation and Creep of Springs at Elevated Temperatures.' SRA Report No: 113.

2. G. B. Graves. 'The Stress Temperature Relaxation Properties of Springs made from Oil Tempered and Patented Hard Drawn Wires.' SRA Report No: 115.

3. G. [illegible]. Graves. 'The Stress Relaxation Properties of Nimonic 90 and Inconel X-750 Helical Compression Springs.' SRA Report No: 152.

4. G. B. Graves 'The Stress Temperature and Creep Properties of Some Spring Materials.' SRA Report No: 143.

5. G. B. Graves 'A Note on the Effect of Heat Treatment on the Stress-Temperature Relaxation Properties of Nimonic Alloy 90 Helical Springs.' SRA Report No: 162.

6. Allegheny Ludlum Steel Corporation Data Sheets 1963

7. Inco Mond Ltd. Data Sheets.

TABLE I TYPICAL ANALYSIS OF MATERIALS

Material	%C	%Mn	%Si	%S	%Cr	%Ni	%Mo	%Ti	%Al	%Co	%Fe	%Zr	%B	Others
12R10	0.10	0.45	0.45	-	18.0	9.0	-	-	-	-	-	-	-	-
12R10 HV	0.10	0.45	0.45	-	18.0	9.0	-	-	-	-	-	-	-	-
Rene 41	0.09	-	-	-	19.0	55.4	10.0	3.0	1.5	11.0	-	-	-	-
A286	0.08 Max	1.50	0.70	-	14.25	26.0	1.25	2.0	0.03 Max	-	54.0	-	-	0.30 %V
M252	0.15	0.50 Max	0.50 Max	-	19.0	51.4	9.75	2.5	1.0	10.0	5.0 Max	0.17	.005	-
Waspaloy	0.10 Max	0.50 Max	0.75 Max	0.03 Max	19.5	54.4	4.25	3.0	1.75	13.5	2.0	0.17	.005	0.10 Max %Cu
Elgiloy	0.15	2.0	-	-	20.0	15.0	7.0	-	-	40.0	16.0	-	-	0.04 %Be
L605	0.05	1.35	0.21	.005	19.9	8.6	-	-	-	68.0	1.90	-	-	0.09 %P

TABLE II

CONDITION OF WIRE AND HEAT TREATMENT OF SPRINGS

Quality	Condition	Heat Treatment
12R10	Hard Drawn & Polished	L.T.H.T. 450°C/2 hours
12R10 HV	Hard Drawn & Polished	L.T.H.T. 450°C/2 hours
René 41	Annealed	Aged 815°C/16 hours Air cool
A286	Cold Drawn 30%	Aged 705°C/16 hours Air cool
M252	Annealed	Solution Treated 1150°C/4 hours Air cool Aged 760°C/16 hours Air cool
Waspaloy	Annealed	Solution Treated 1080°C/4 hours WQ Aged 850°C/24 hours Air cool
Elgiloy	Cold Drawn 45/49%	Aged 525°C 5 hours Air cool
L605	Annealed	Aged 815°C/16 hours Air cool

TABLE III SPRING DIMENSIONS

Material	Wire Dia mm	Mean Coil Dia mm	Free Length mm	Active Coils	Total Coils
12R10	2.64	21.59	41.66	3.5	5.5
12R10 HV	2.64	21.59	41.66	3.5	5.5
René 41	2.64	29.54	47.24	4.5	7.5
A286	2.64	29.54	51.56	4.5	7.5
M252	2.79	29.54	48.26	4.5	7.5
Waspaloy	3.50	34.92	56.64	4.5	7.5
Elgiloy	2.41	28.57	46.99	4.5	7.5
L605	2.64	29.54	47.24	4.5	7.5

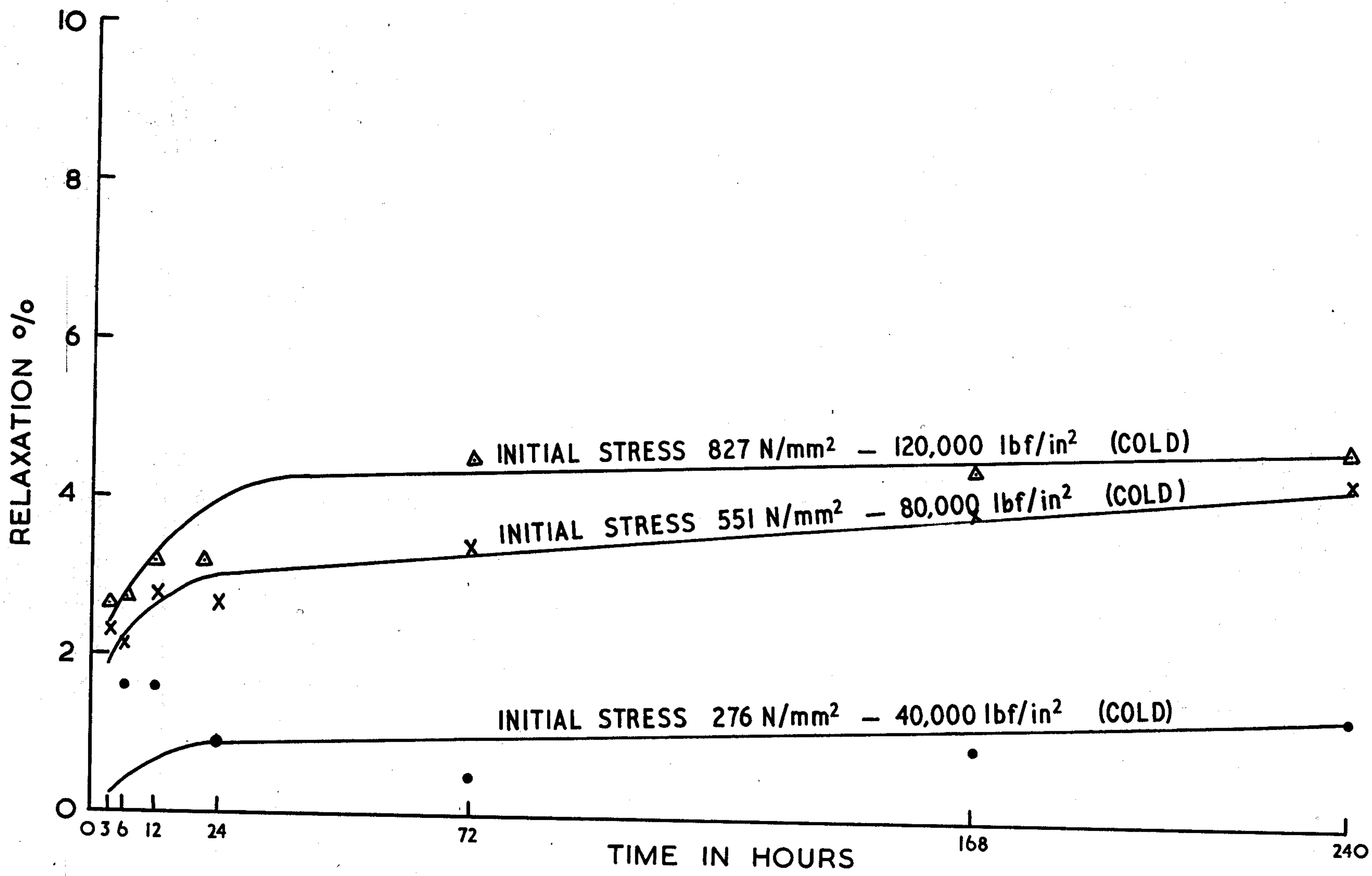

FIG. I. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 200°C UNPEENED

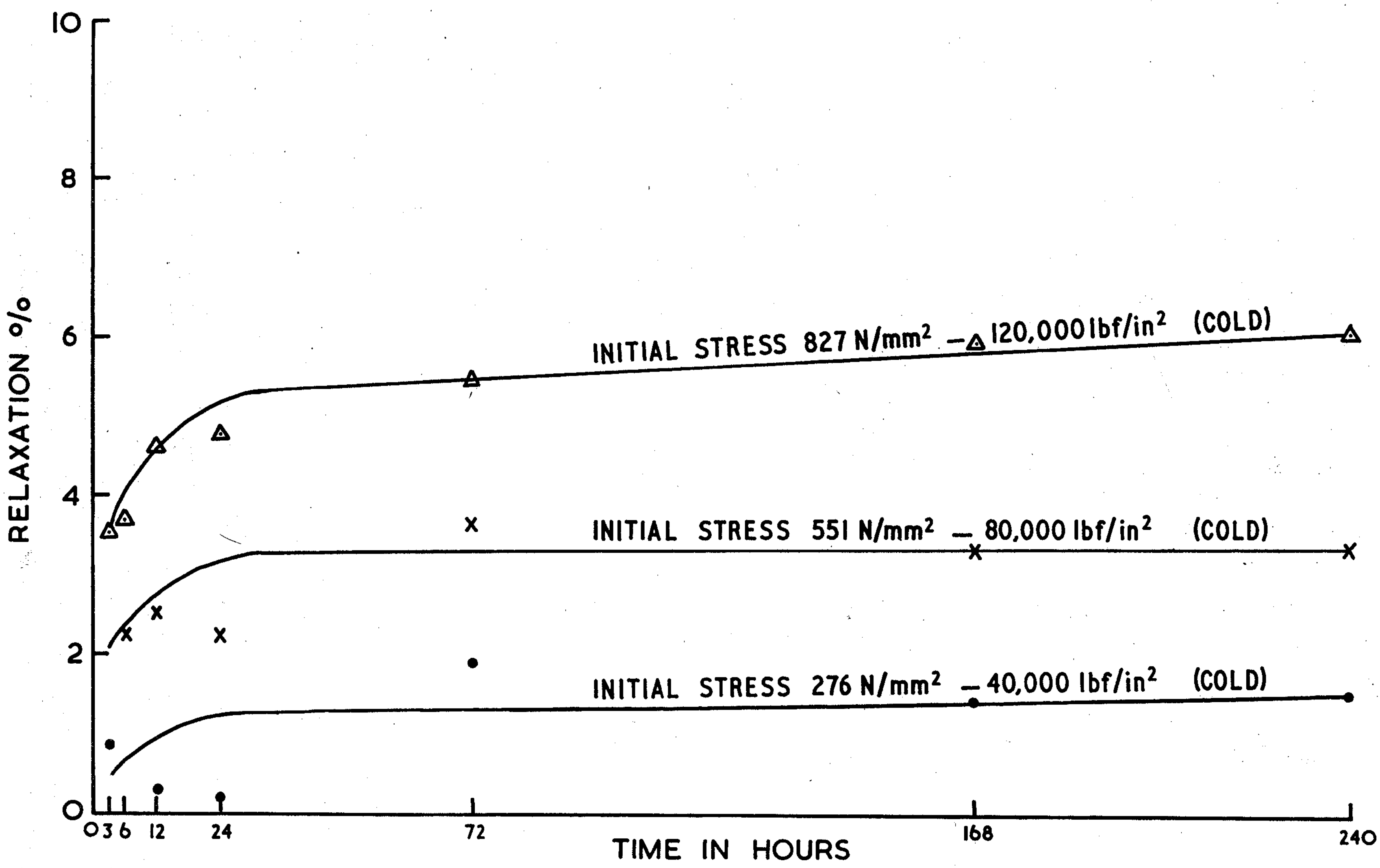

FIG. 2. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 250°C UNPEENED

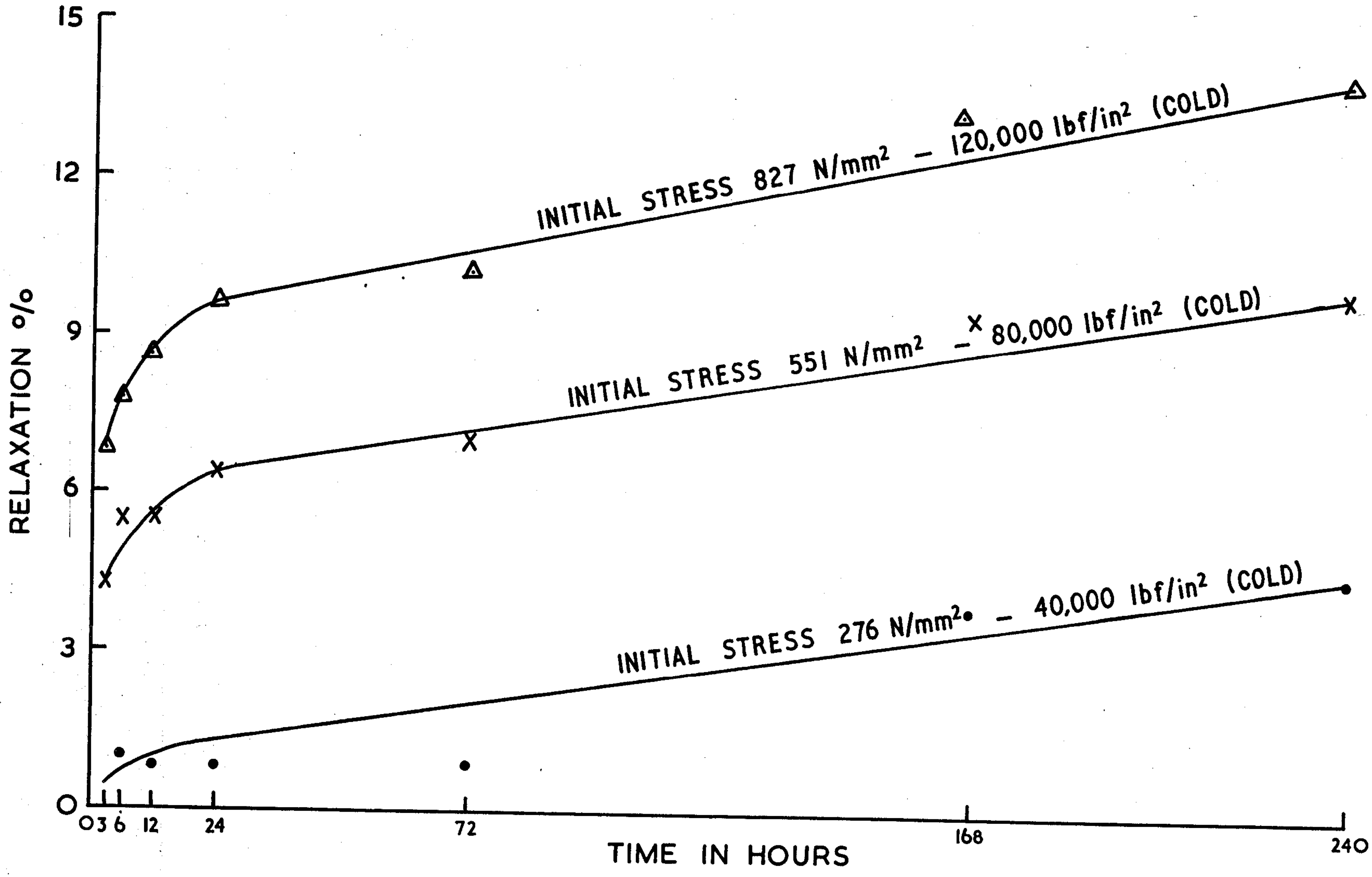

FIG. 3. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 300°C UNPEENED

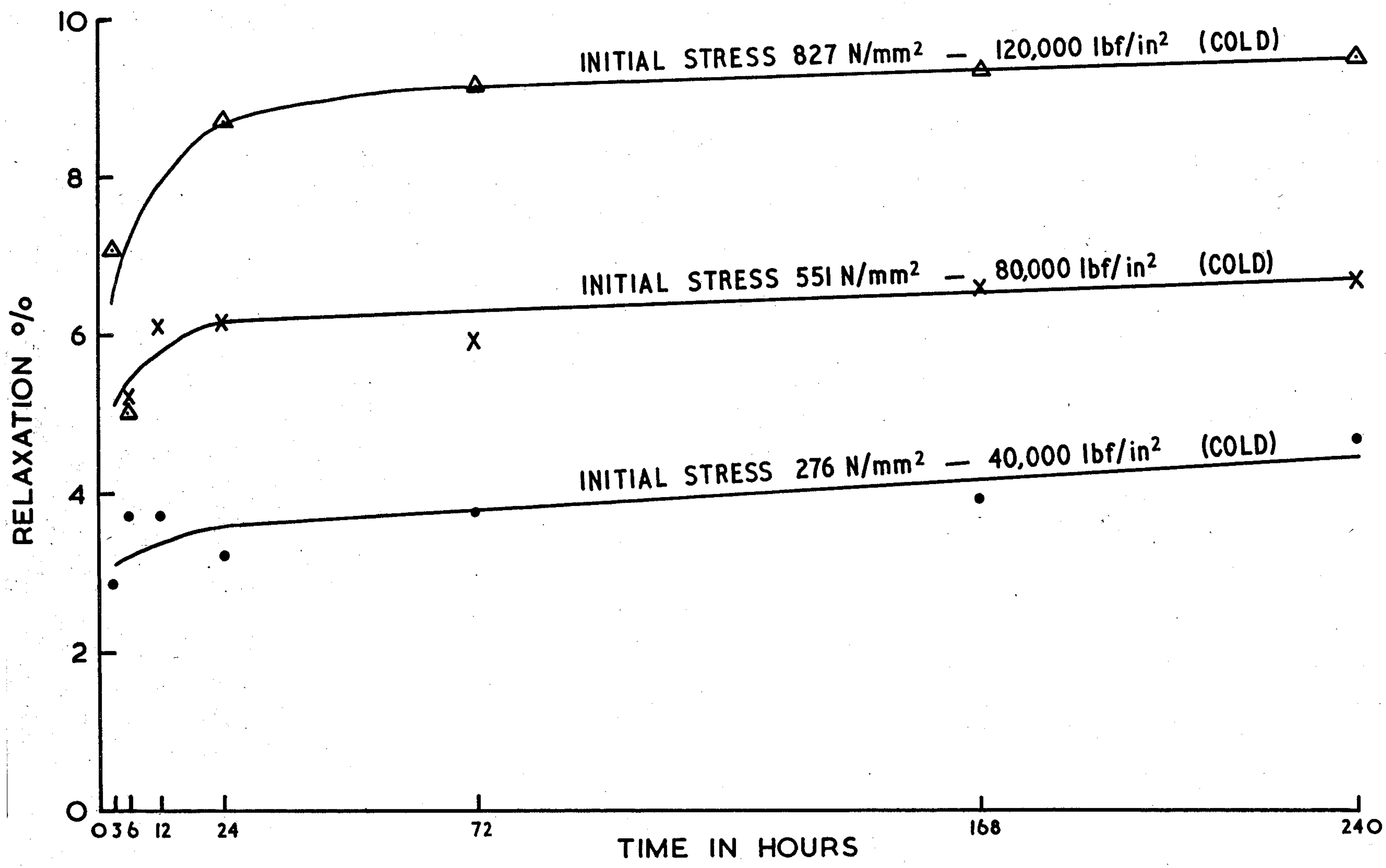

FIG. 4. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 200°C PEENED

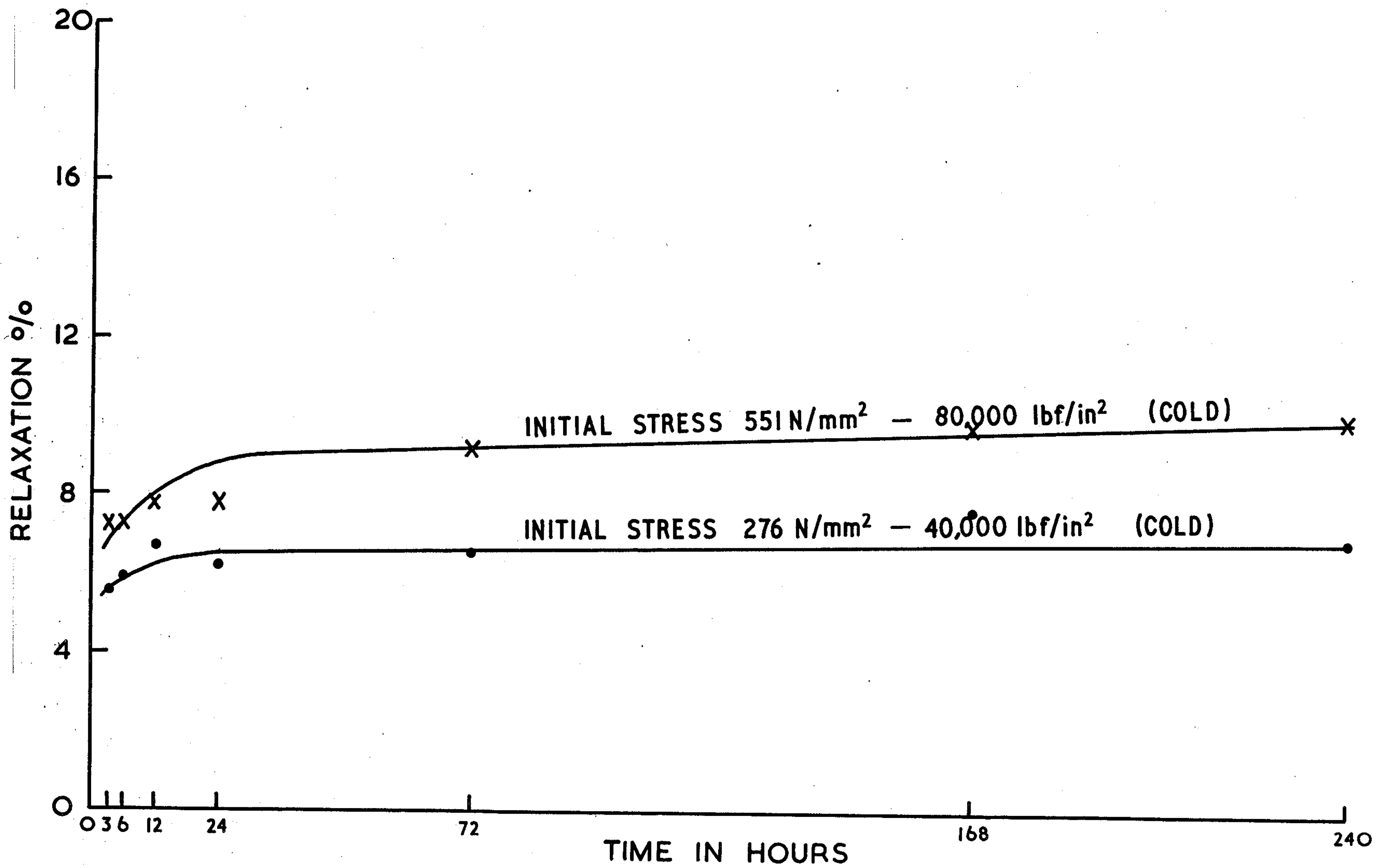

FIG. 5. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 250°C PEENED

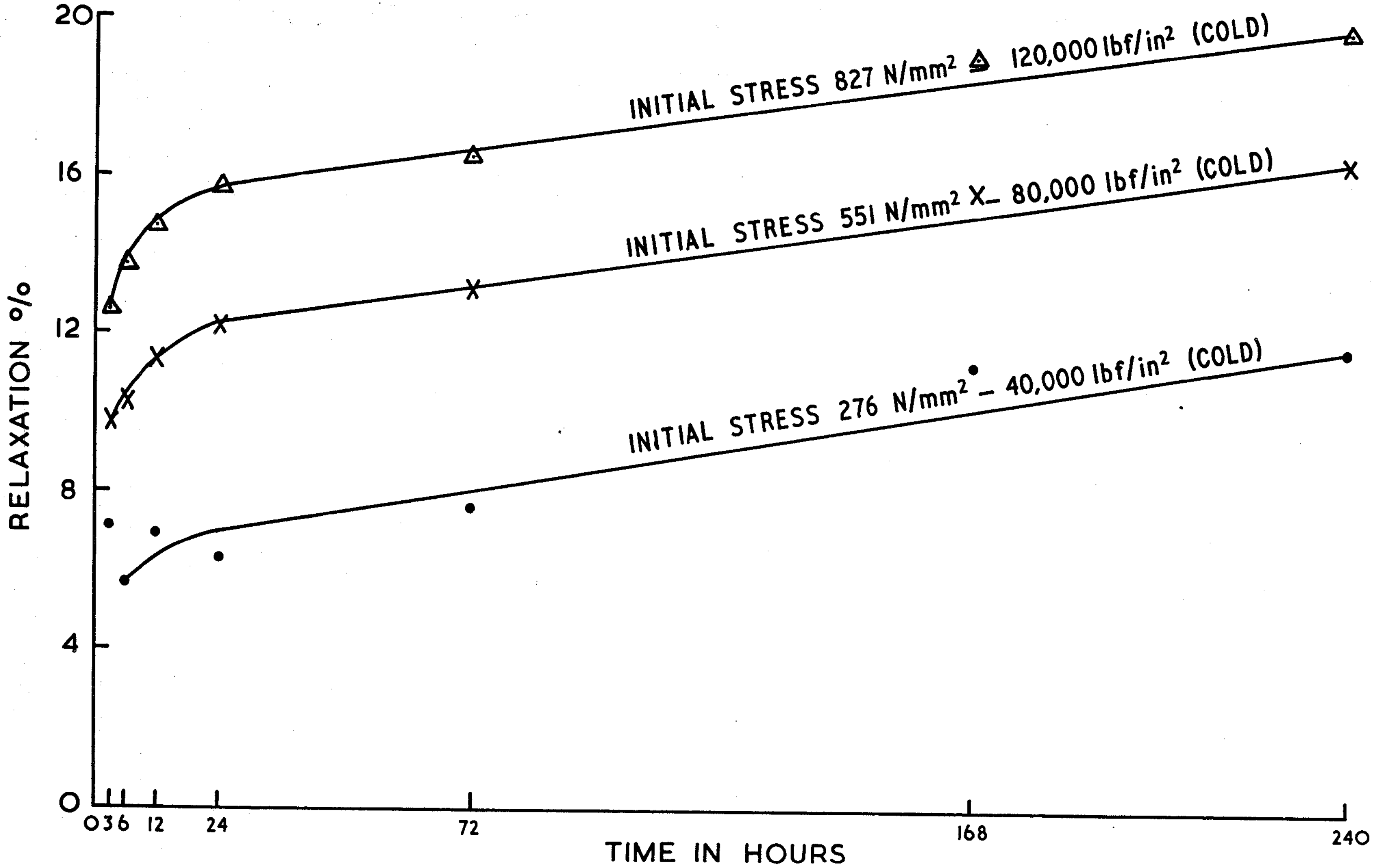

FIG. 6. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AT 300°C PEENED

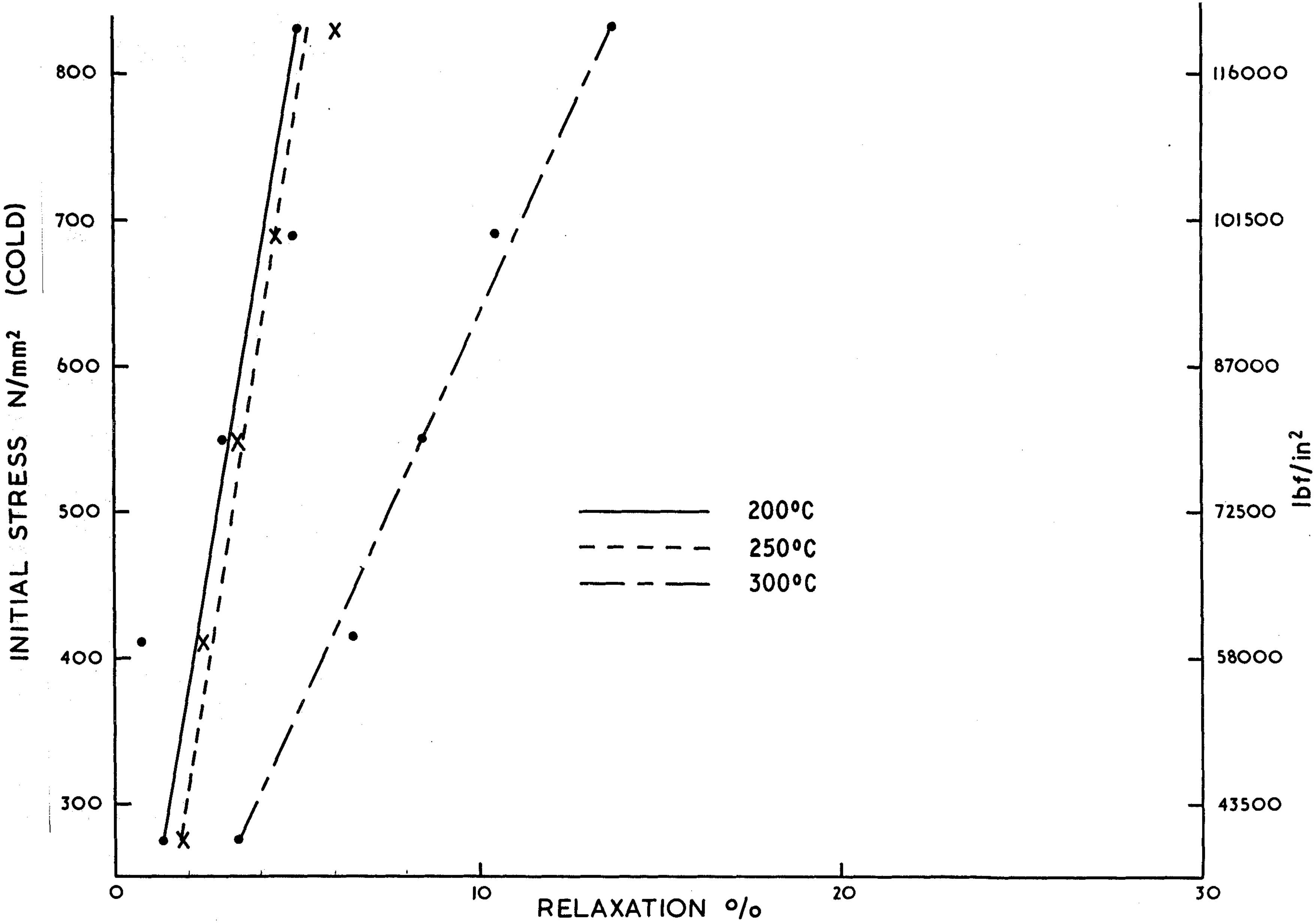

FIG. 7. STRESS TEMPERATURE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AFTER 240 HOURS UNPEENED

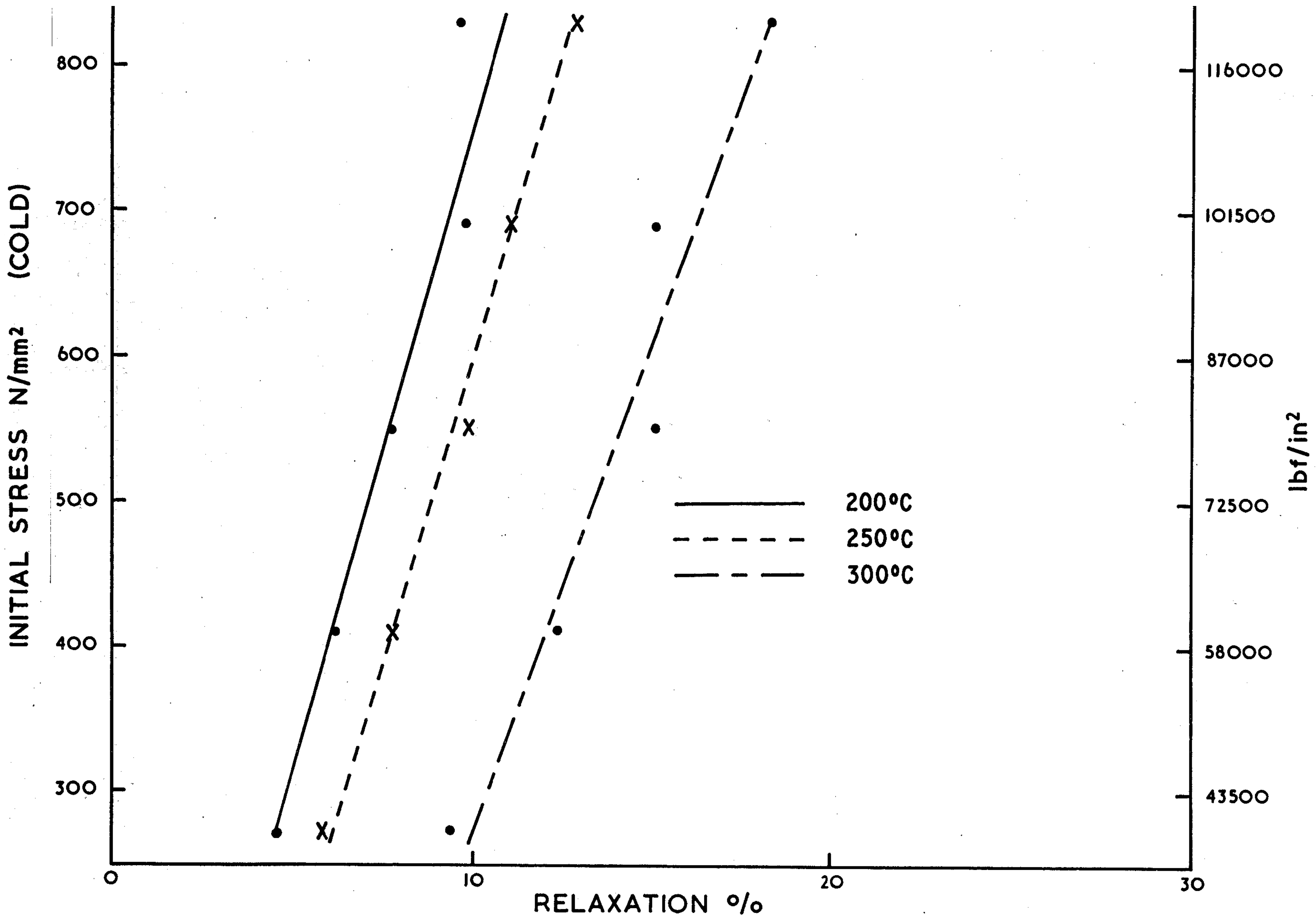

FIG. 8. STRESS TEMPERATURE RELAXATION PROPERTIES OF SANDVIK 12R10 SPRINGS AFTER 240 HOURS PEENED

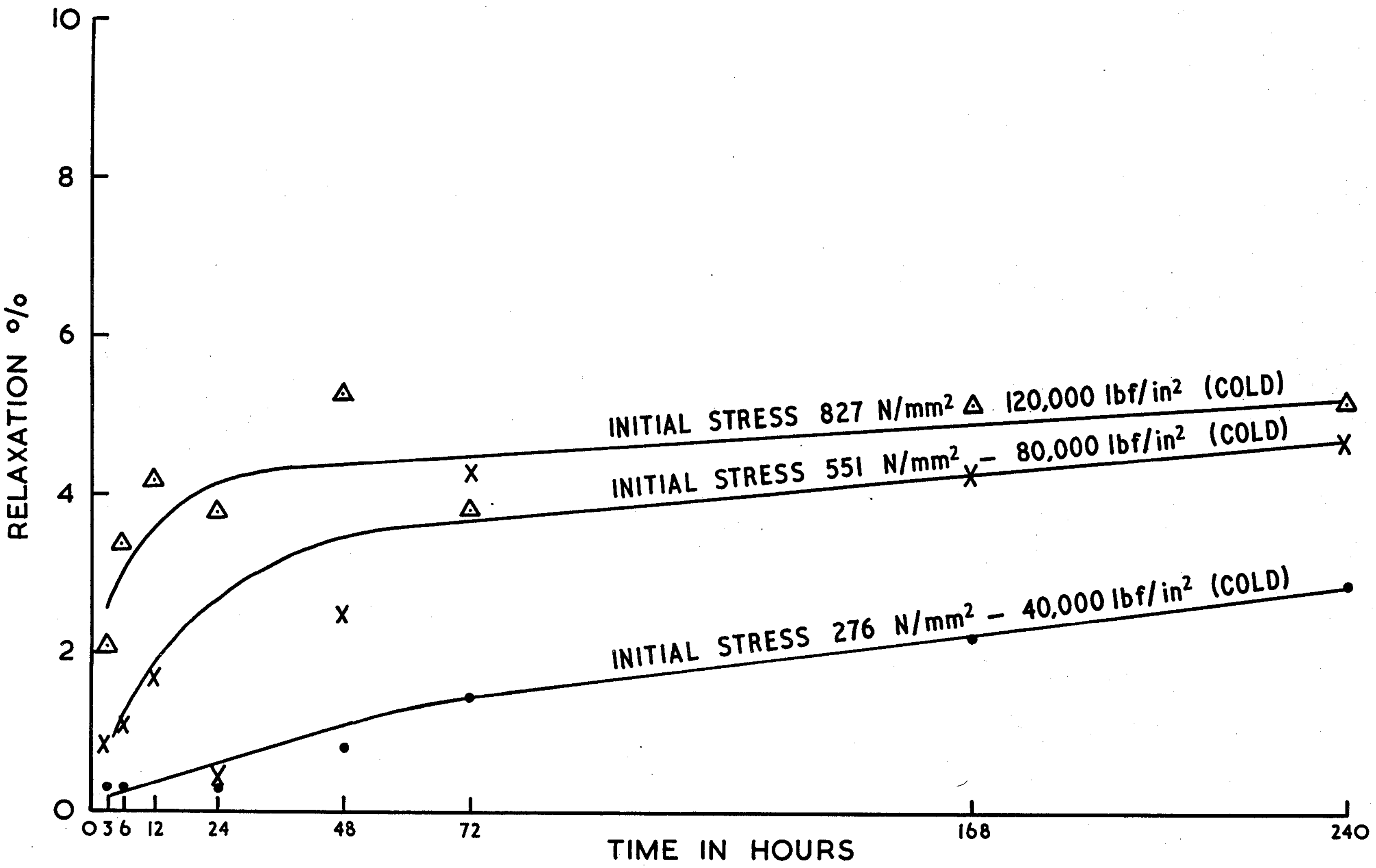

FIG. 9. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 200°C UNPEENED

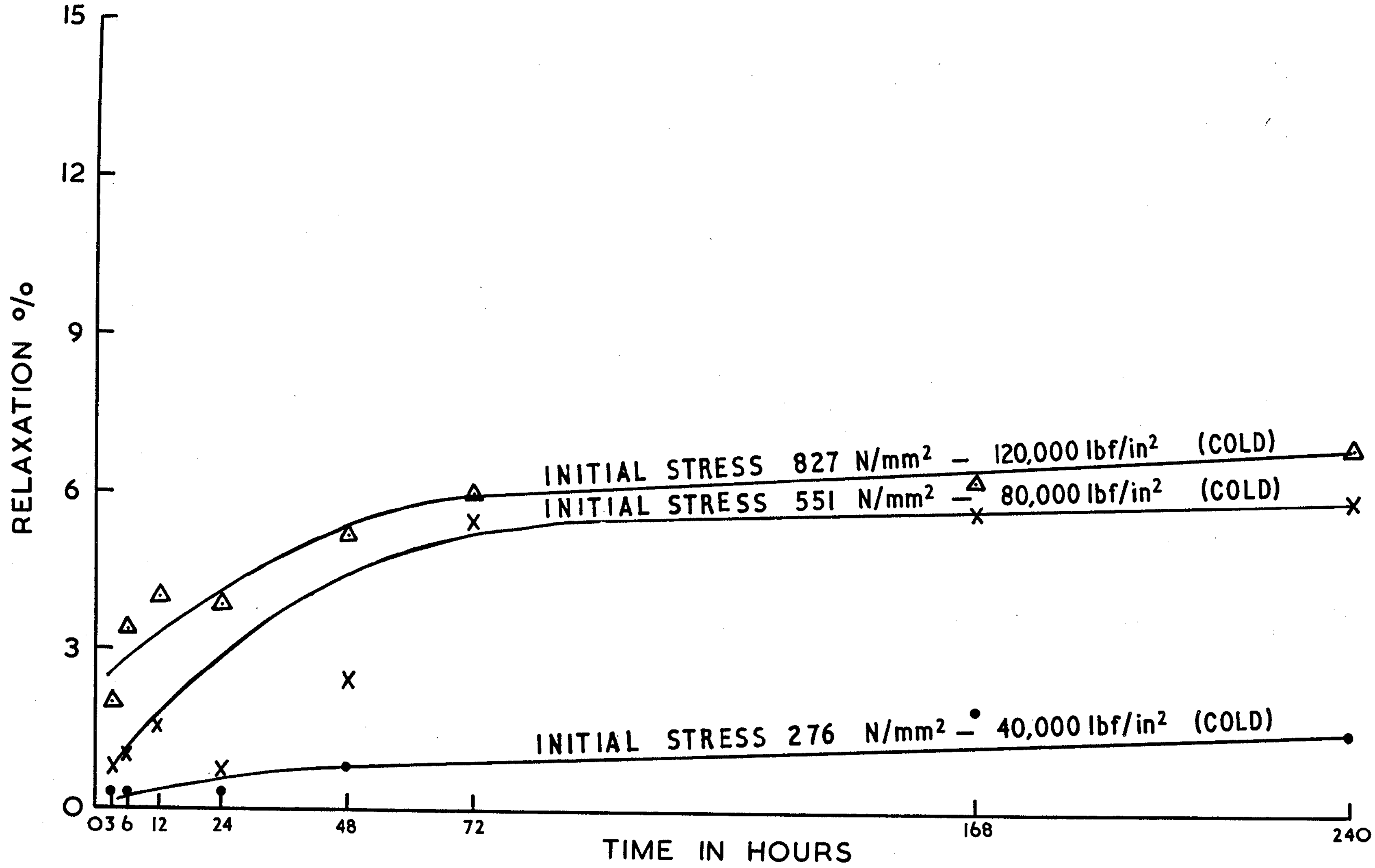

FIG. 10. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 250°C UNPEENED

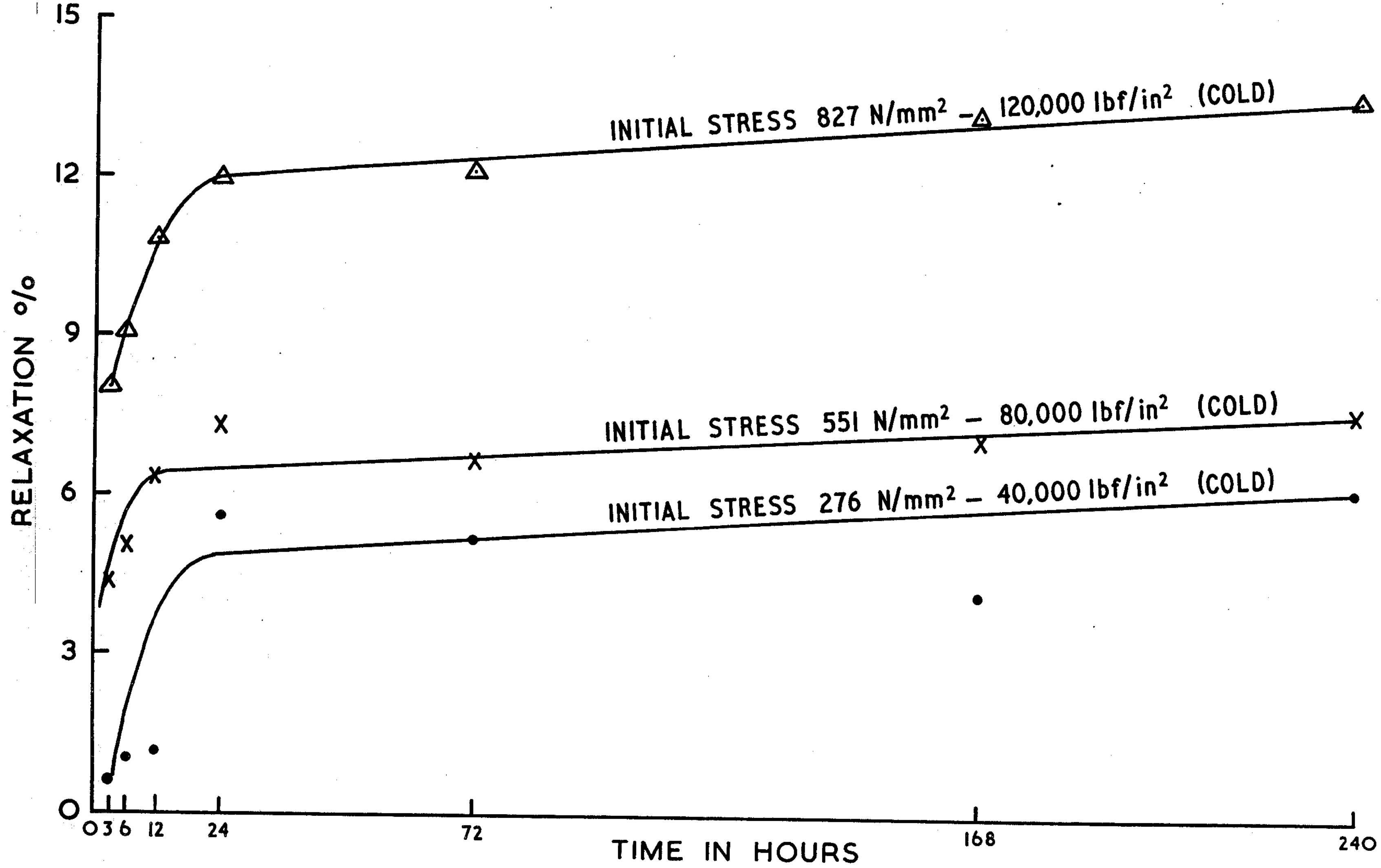

FIG. 11. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 300°C UNPEENED

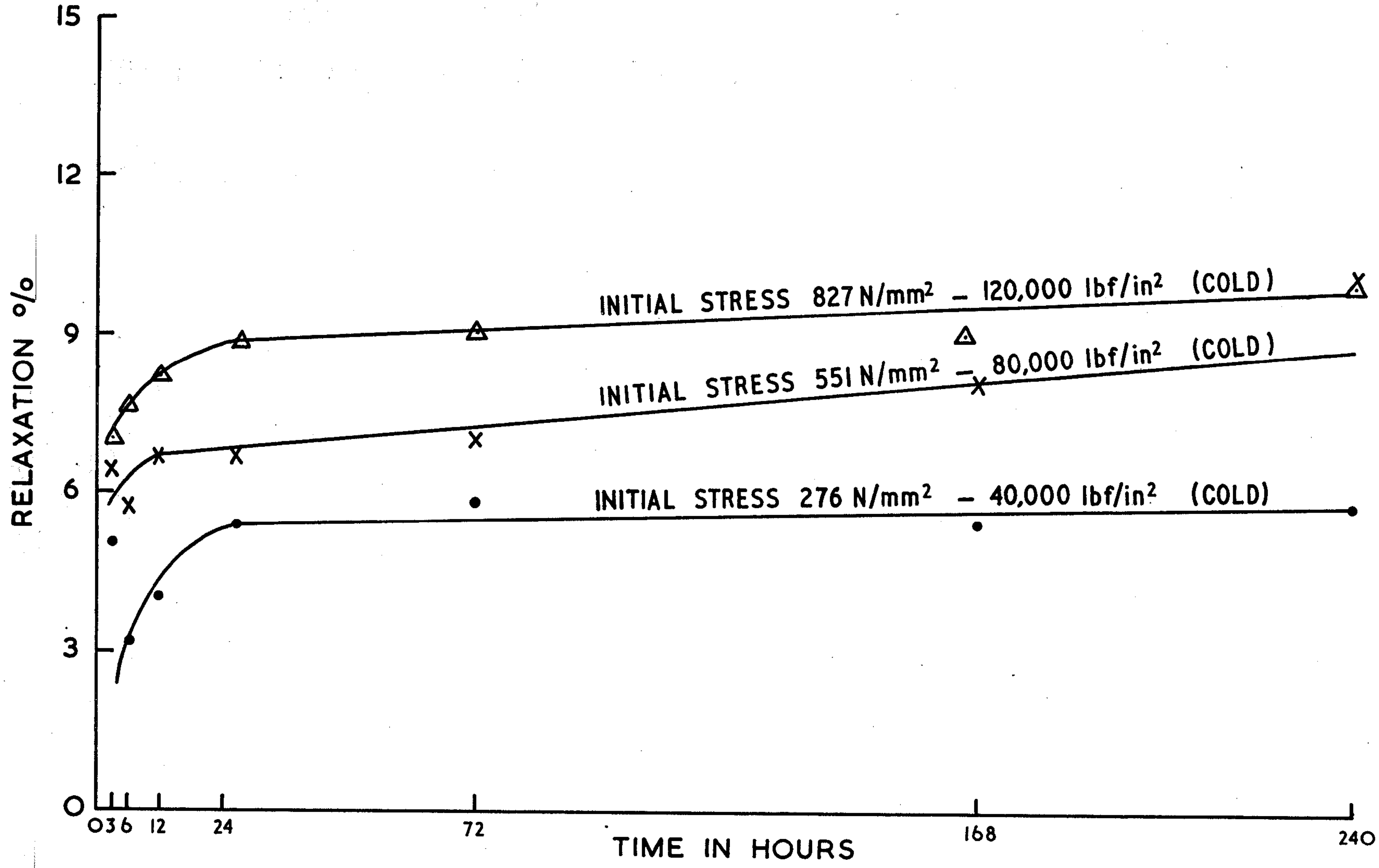

FIG. 12. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 200°C PEENED

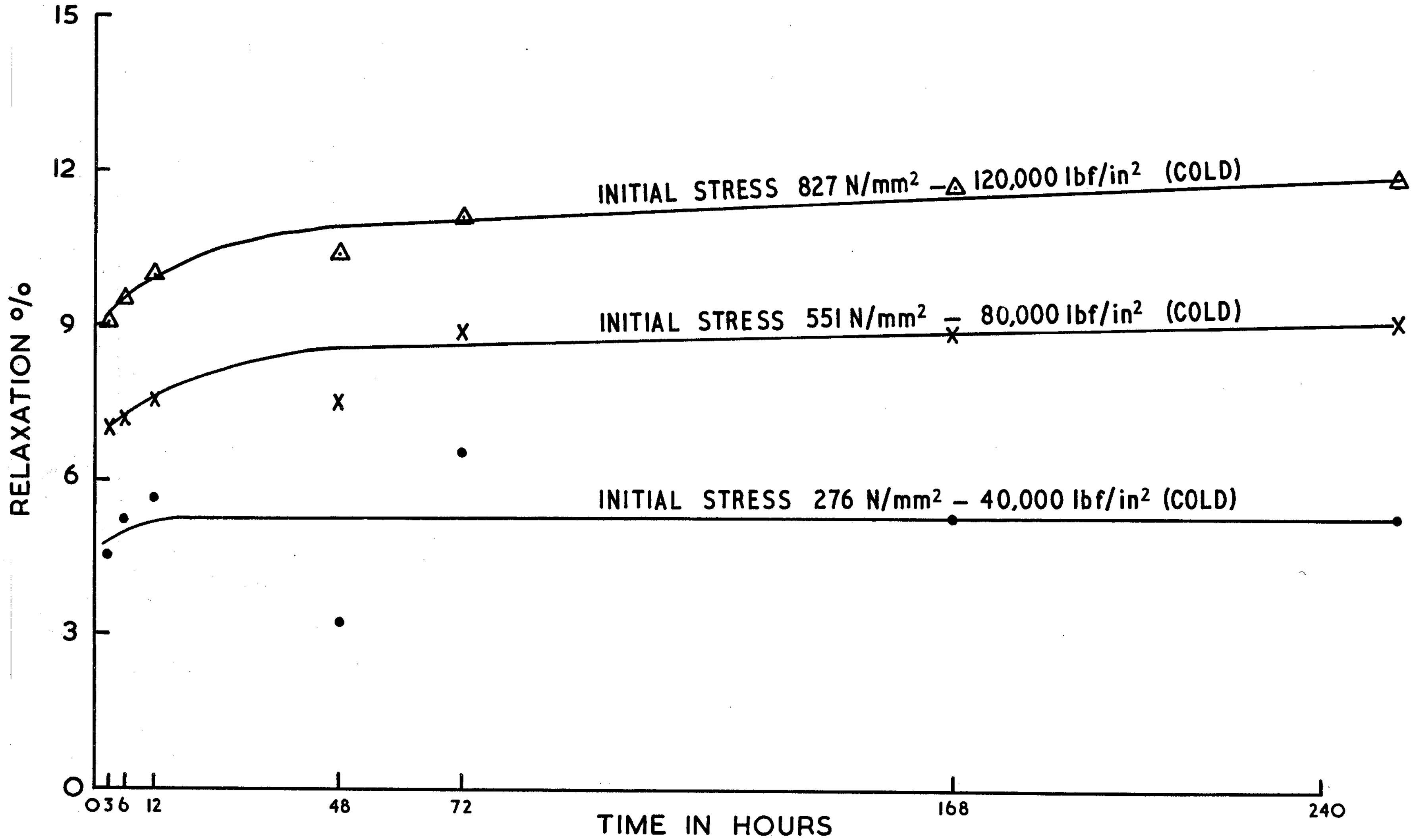

FIG. 13. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 250°C PEENED

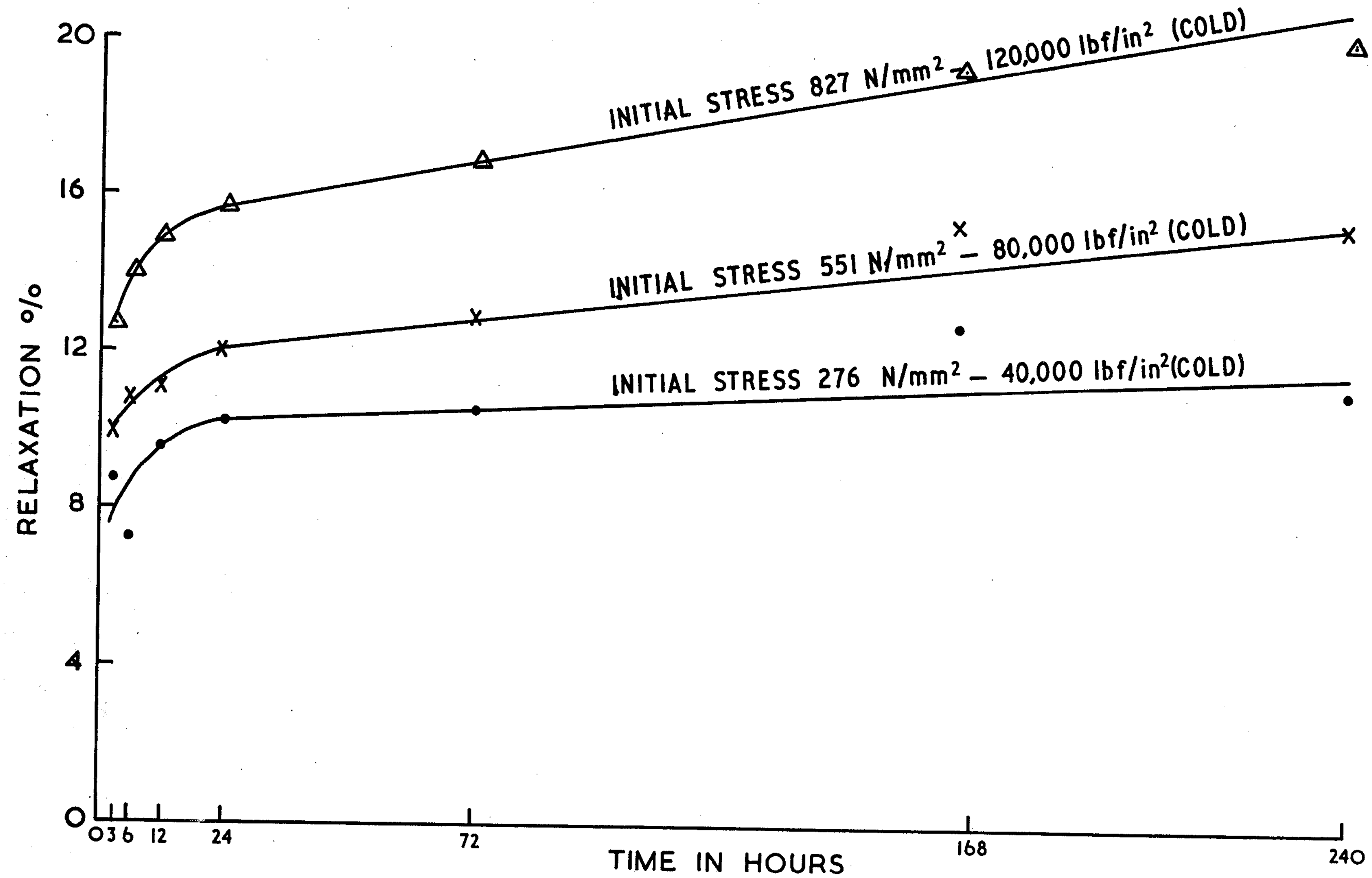

FIG. 14. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AT 300°C PEENED

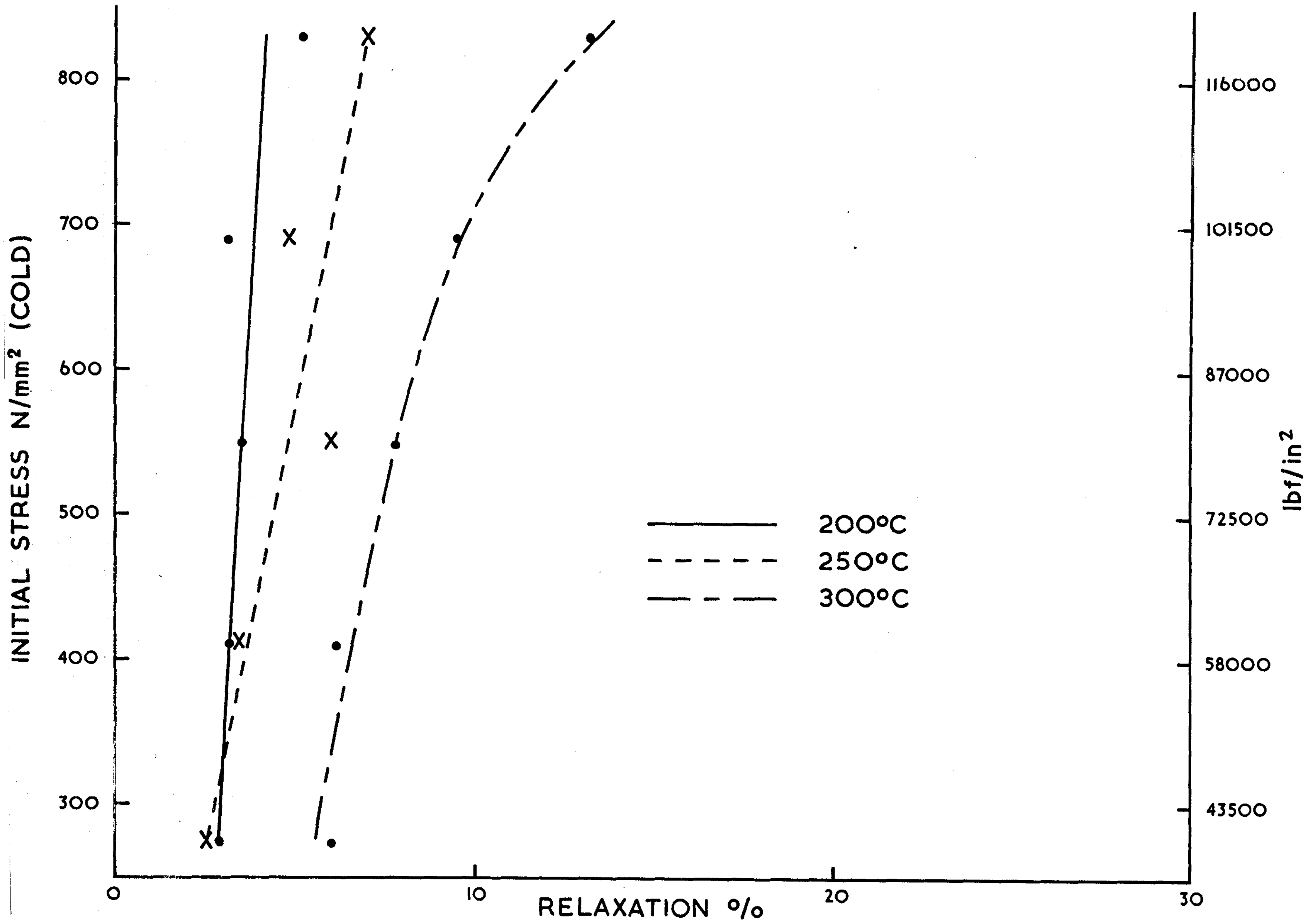

FIG. 15. STRESS TEMPERATURE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AFTER 240 HOURS UNPEENED

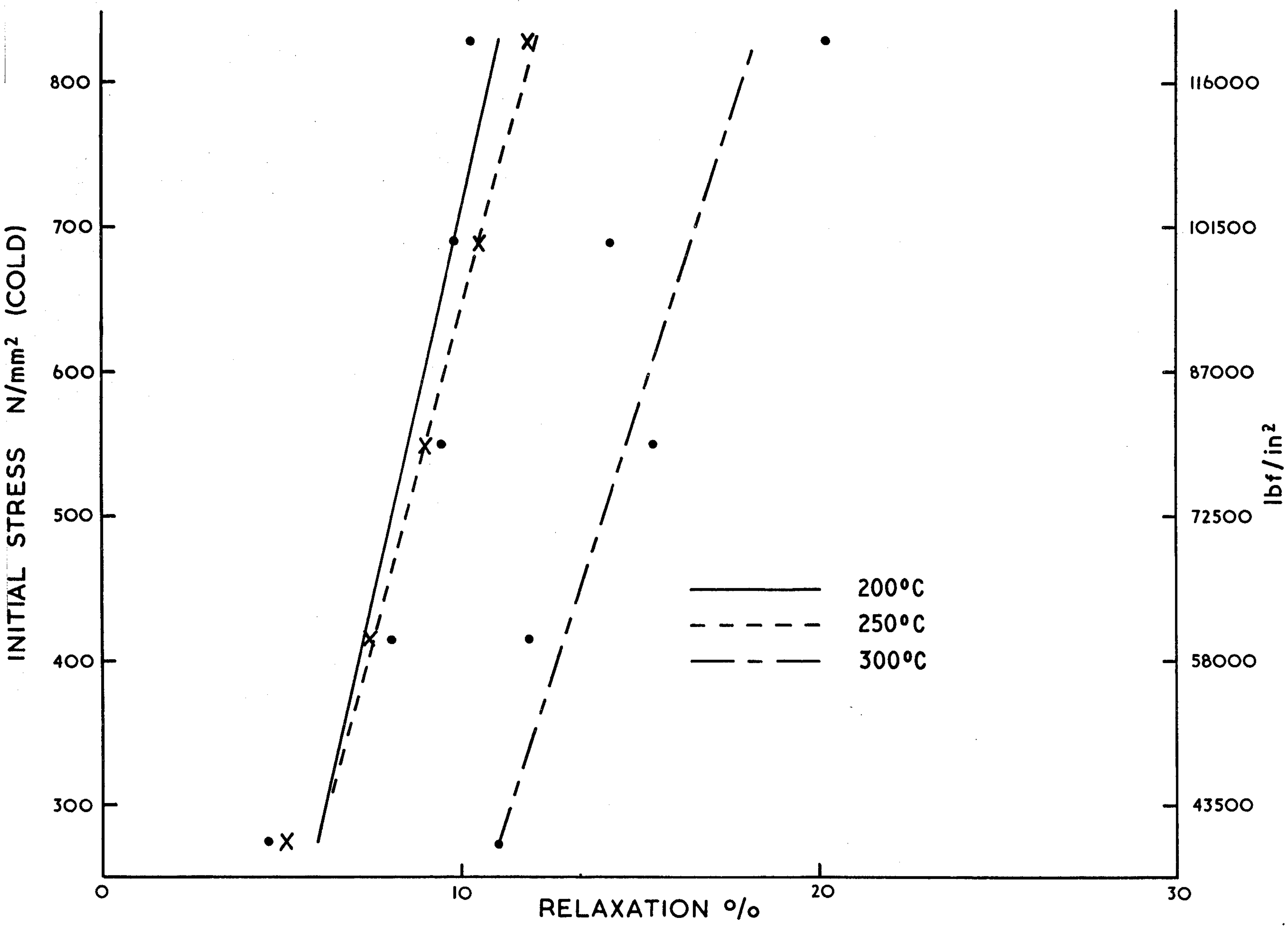

FIG. 16. STRESS TEMPERATURE RELAXATION PROPERTIES OF SANDVIK 12R10 HV SPRINGS AFTER 240 HOURS PEENED

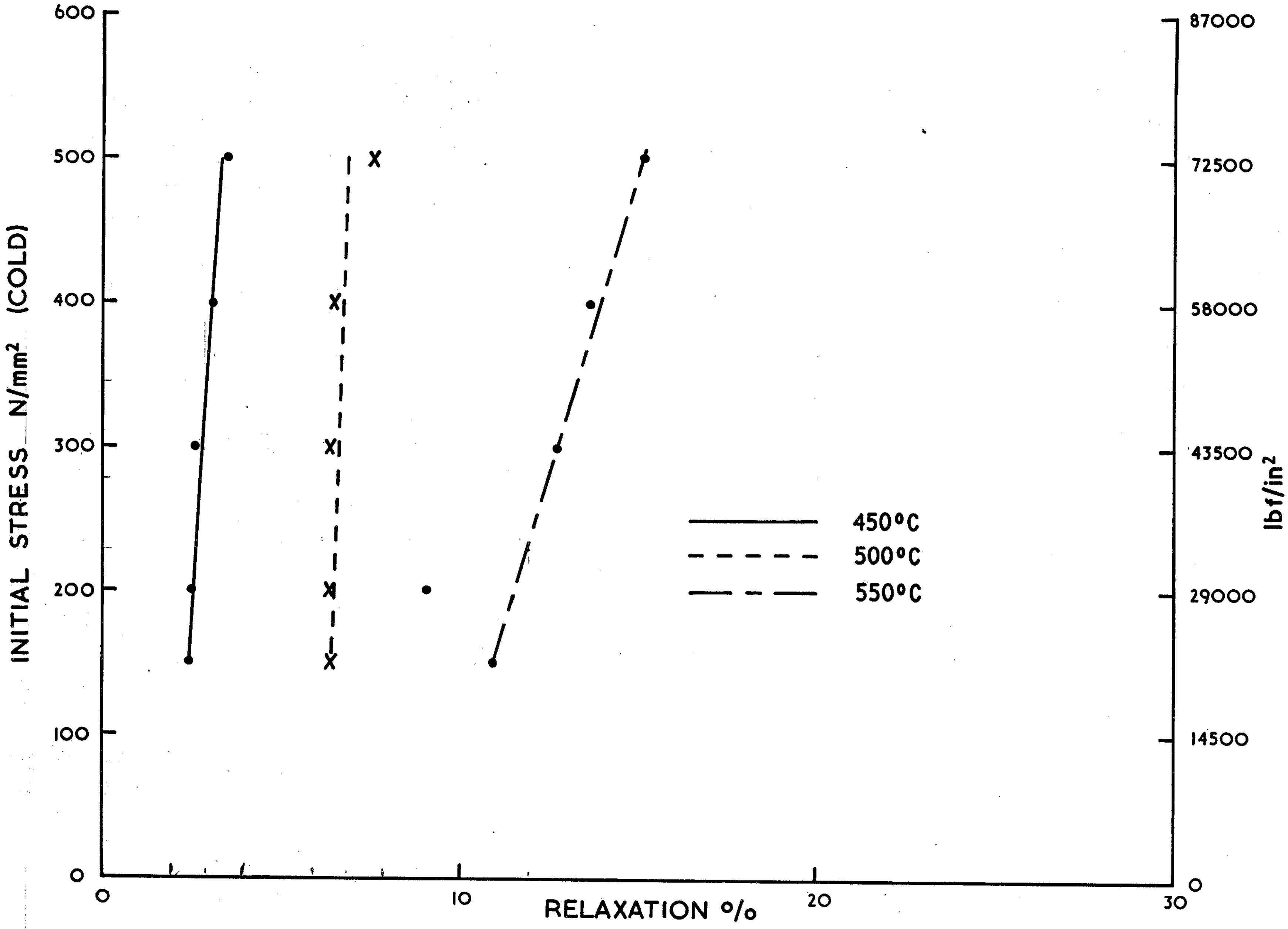

FIG. 17. STRESS TEMPERATURE RELAXATION PROPERTIES OF RENÉ 41 SPRINGS AFTER 240 HOURS UNPEENED

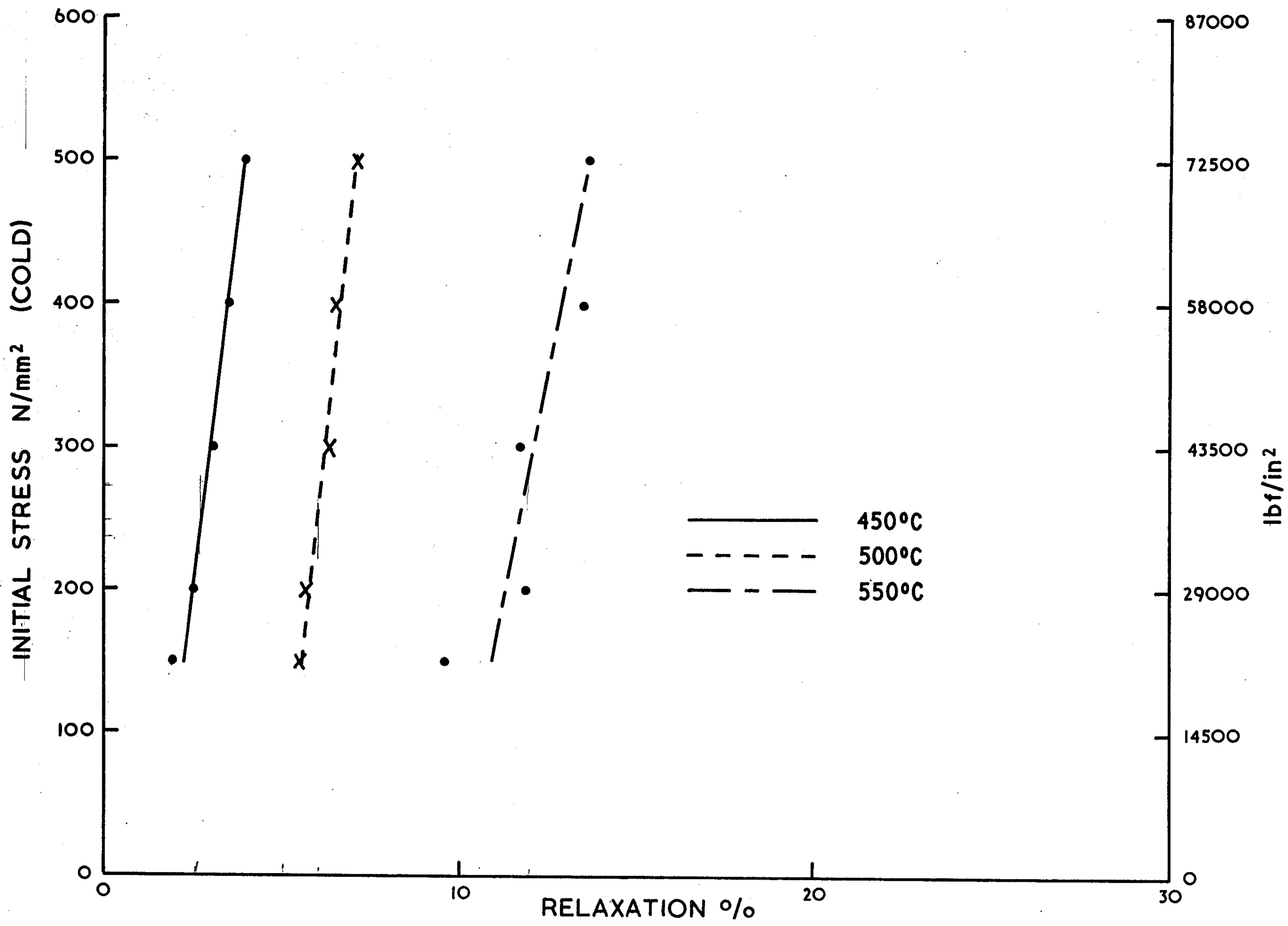

FIG. 18. STRESS TEMPERATURE RELAXATION PROPERTIES OF M 252 SPRINGS AFTER 240 HOURS UNPEENED

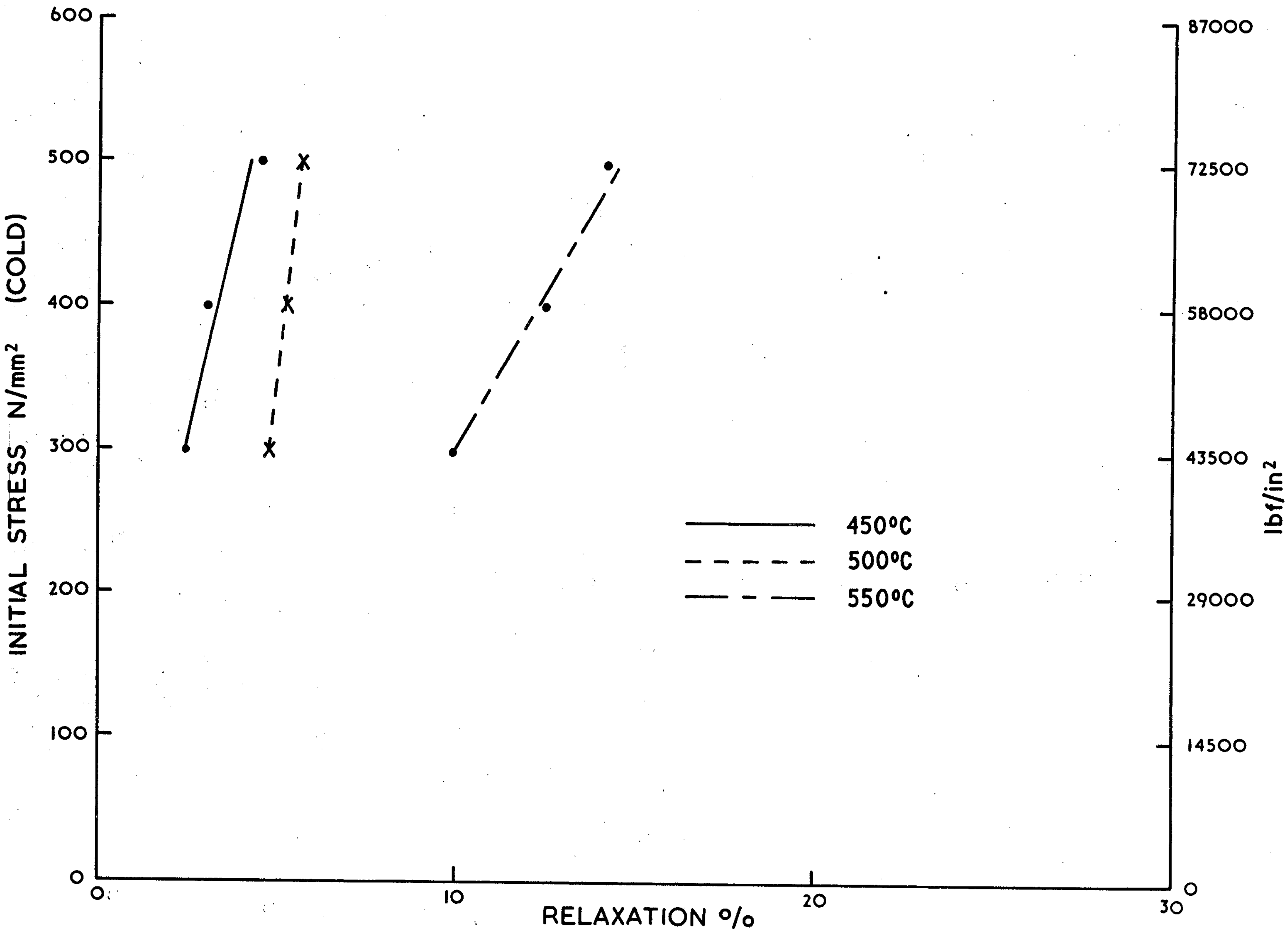

FIG. 19. STRESS TEMPERATURE RELAXATION PROPERTIES OF WASPALOY SPRINGS AFTER 240 HOURS UNPEENED

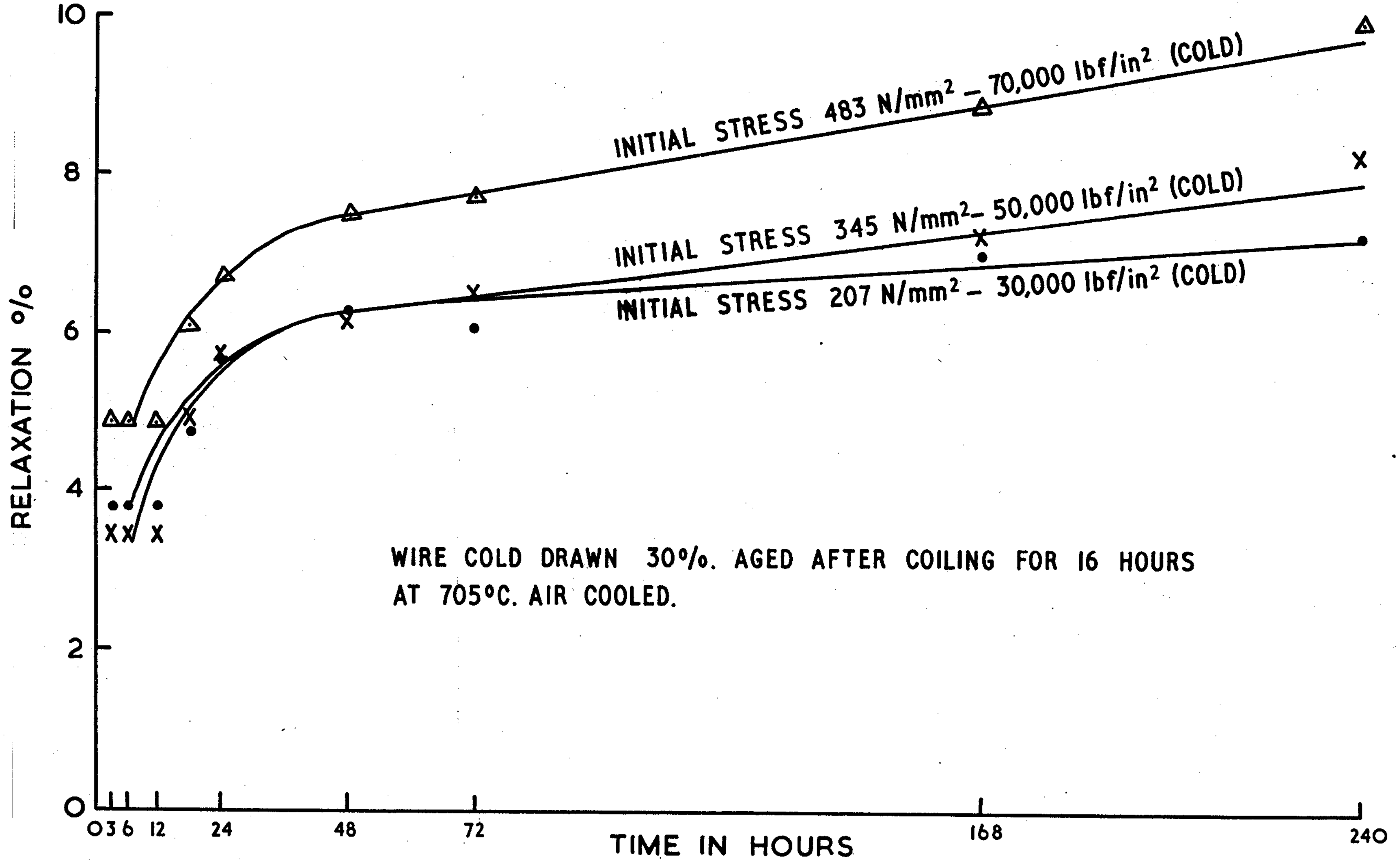

FIG. 20. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 400°C UNPEENED

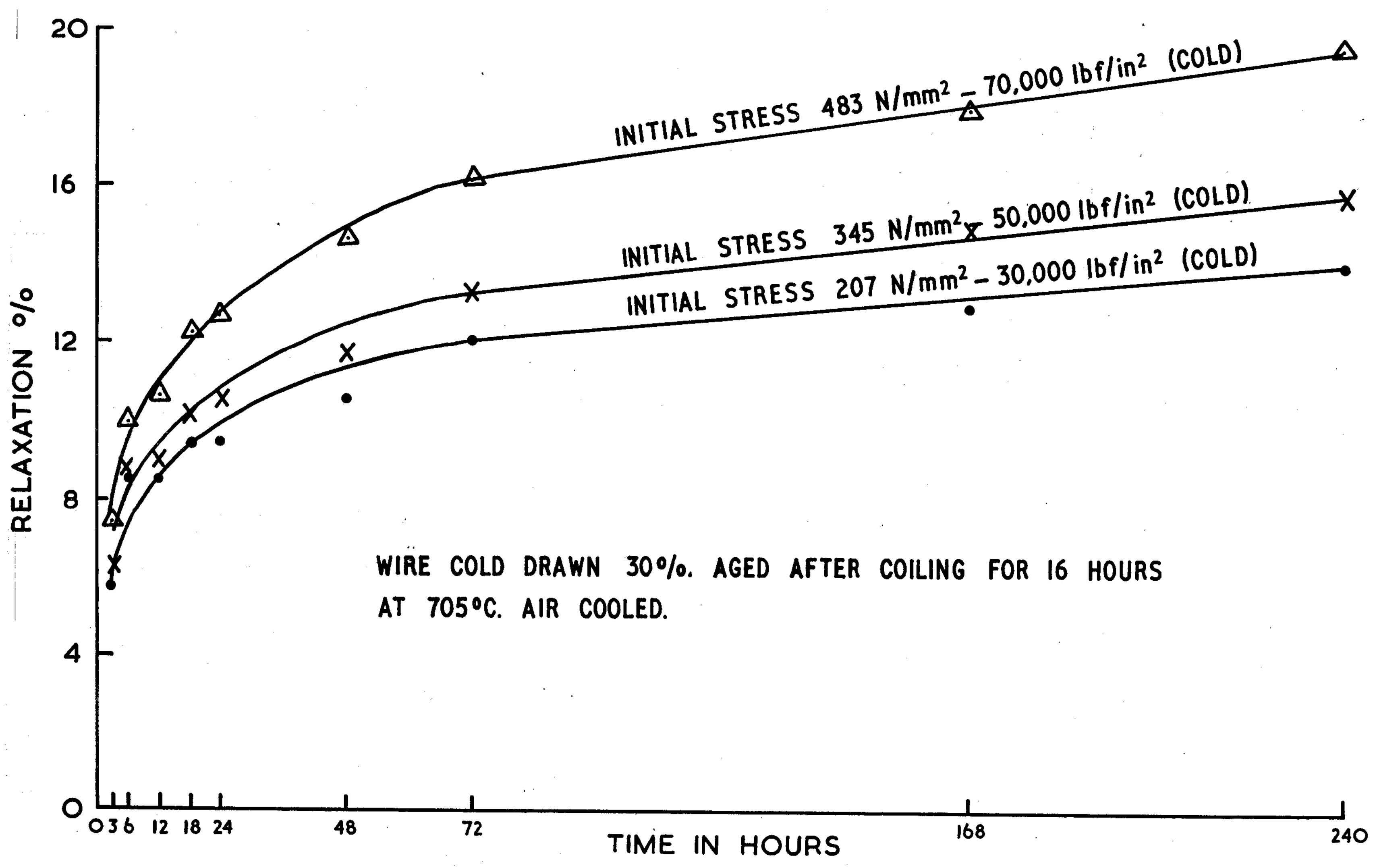

FIG. 21. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 450°C UNPEENED

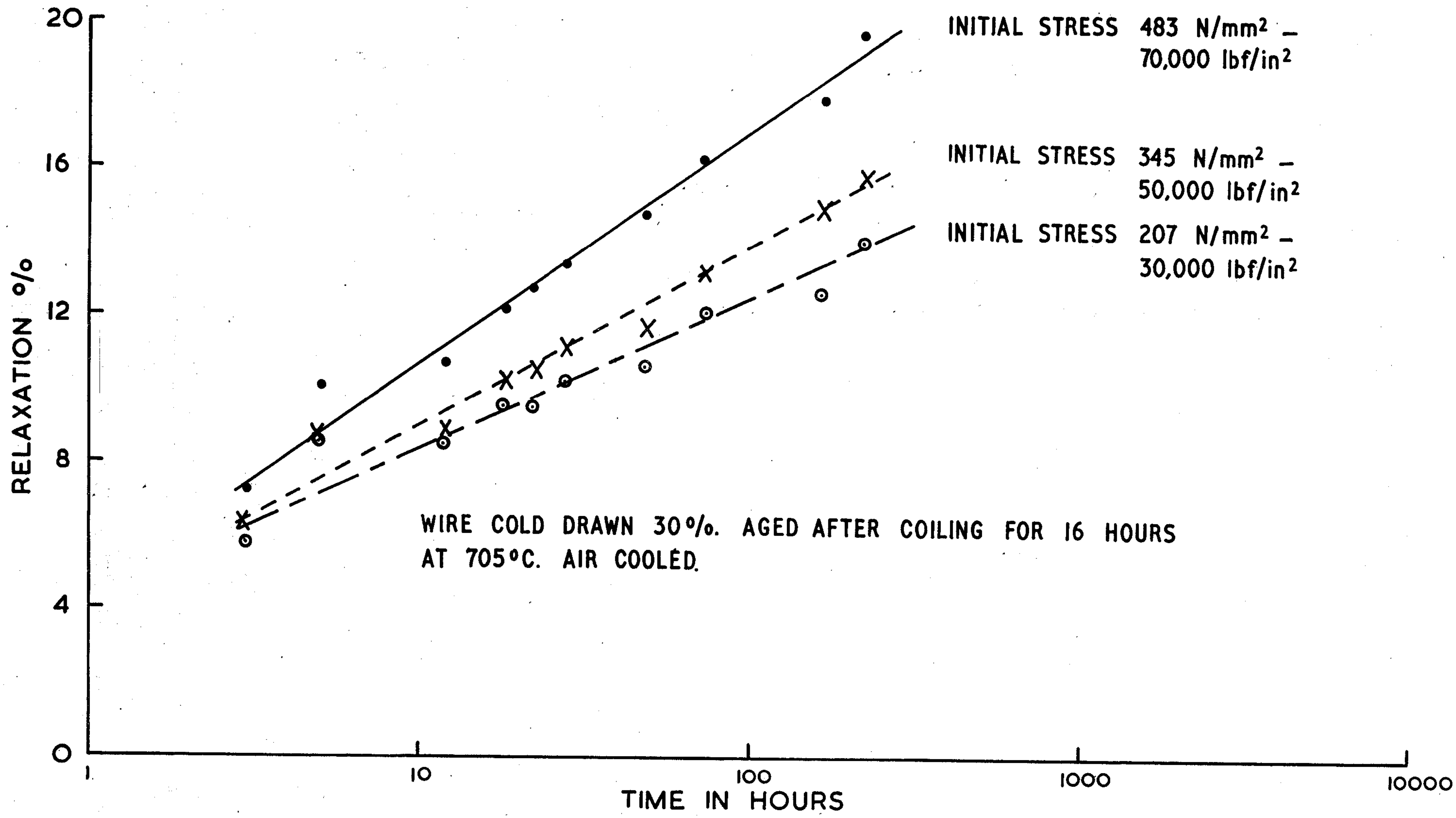

FIG. 21A. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A 286 SPRINGS AT 450°C UNPEENED

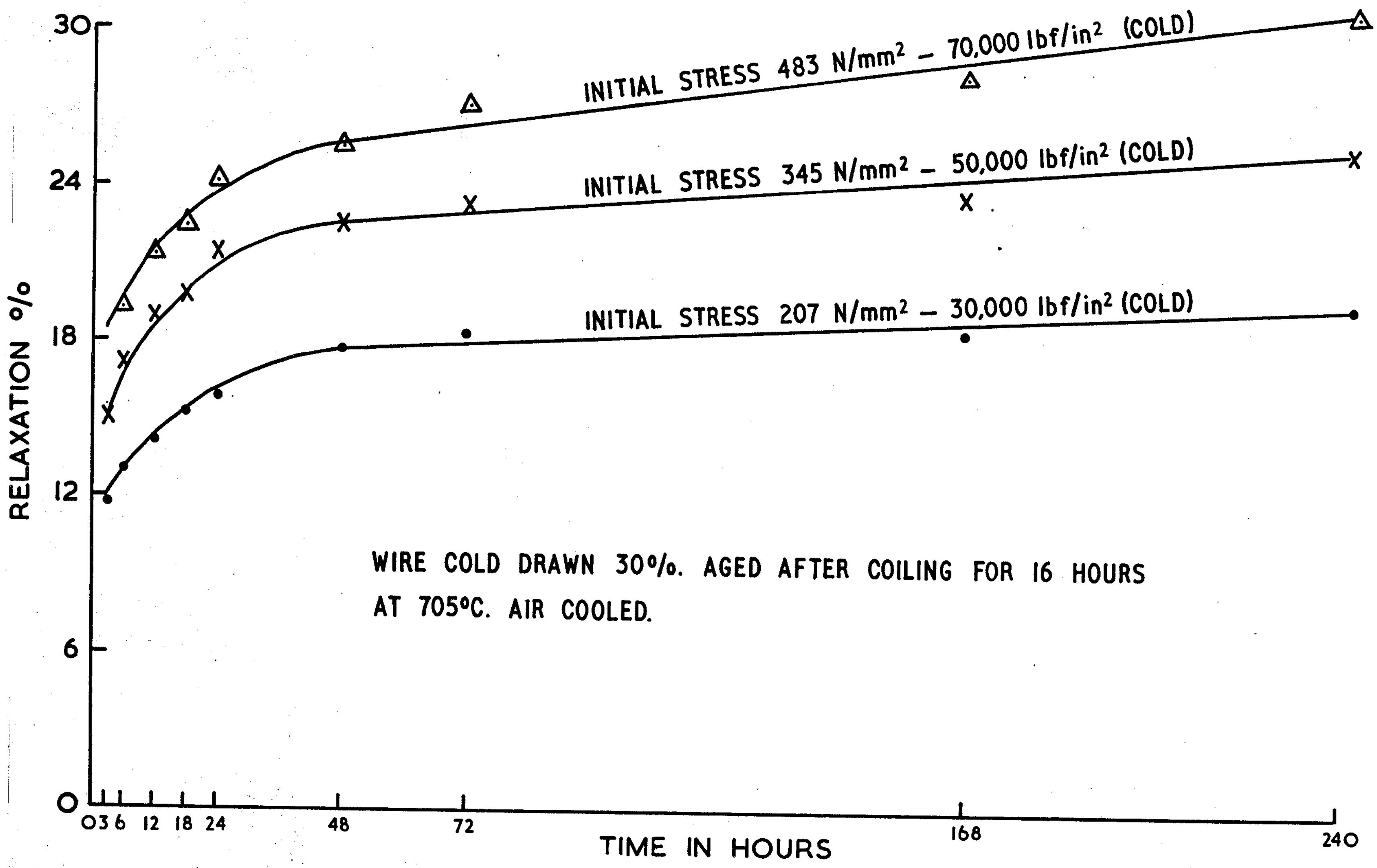

FIG. 22. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 500°C UNPEENED

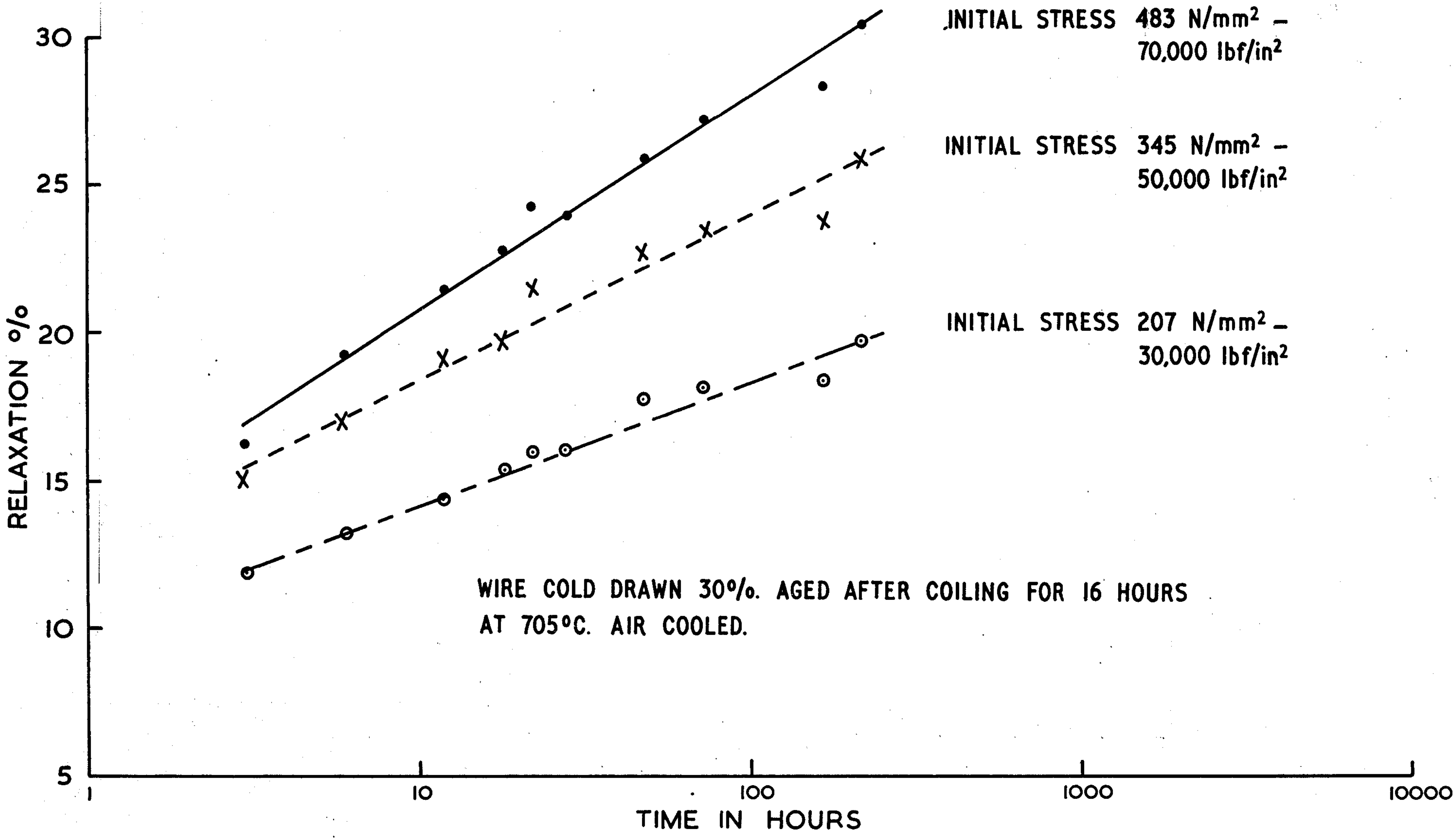

FIG. 22A. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 500°C UNPEENED

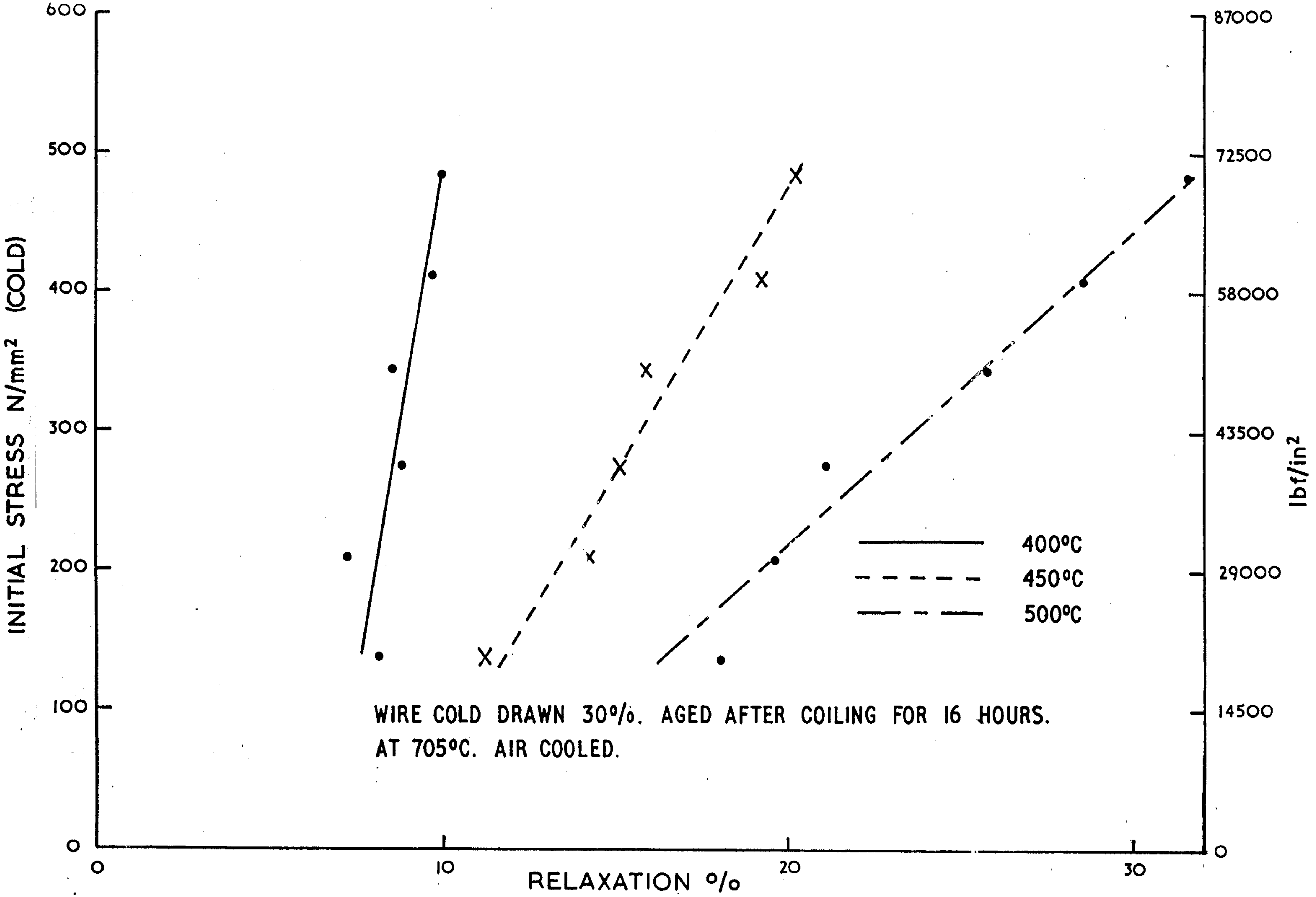

FIG. 23. STRESS TEMPERATURE RELAXATION PROPERTIES OF A286 SPRINGS AFTER 240 HOURS UNPEENED

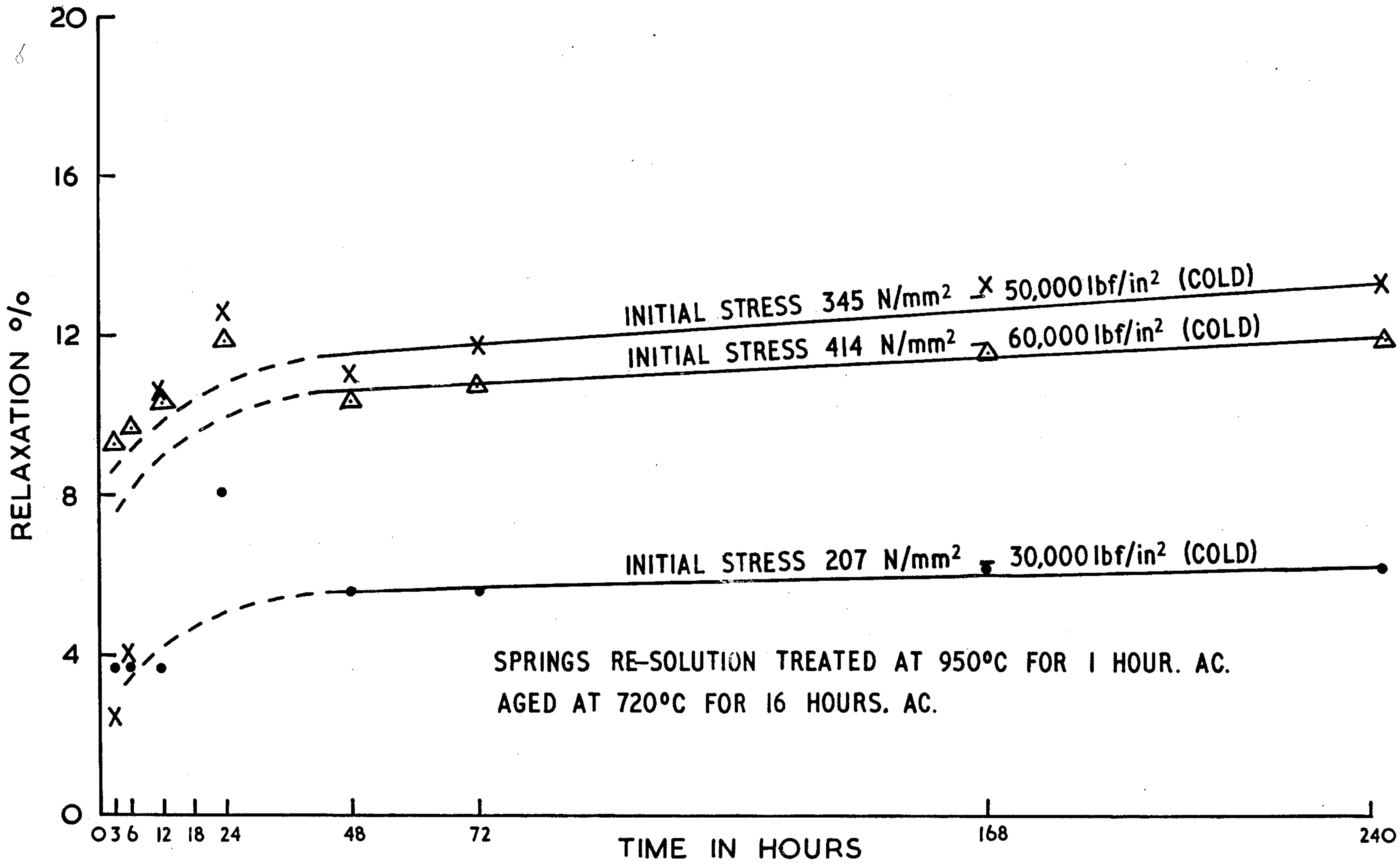

FIG. 24. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 450°C RE-SOLUTION TREATED UNPEENED

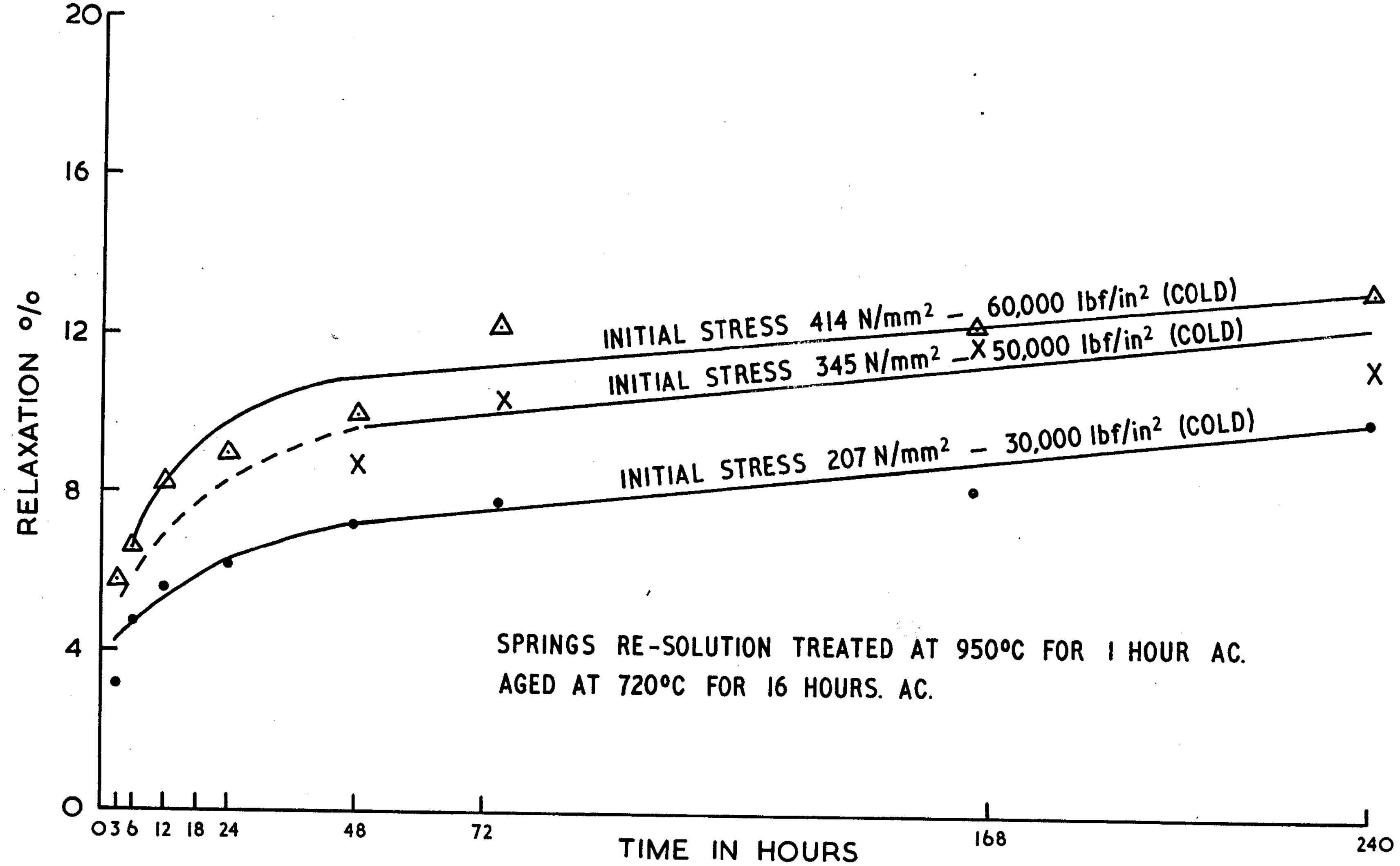

FIG. 25. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 500°C RE-SOLUTION TREATED UNPEENED

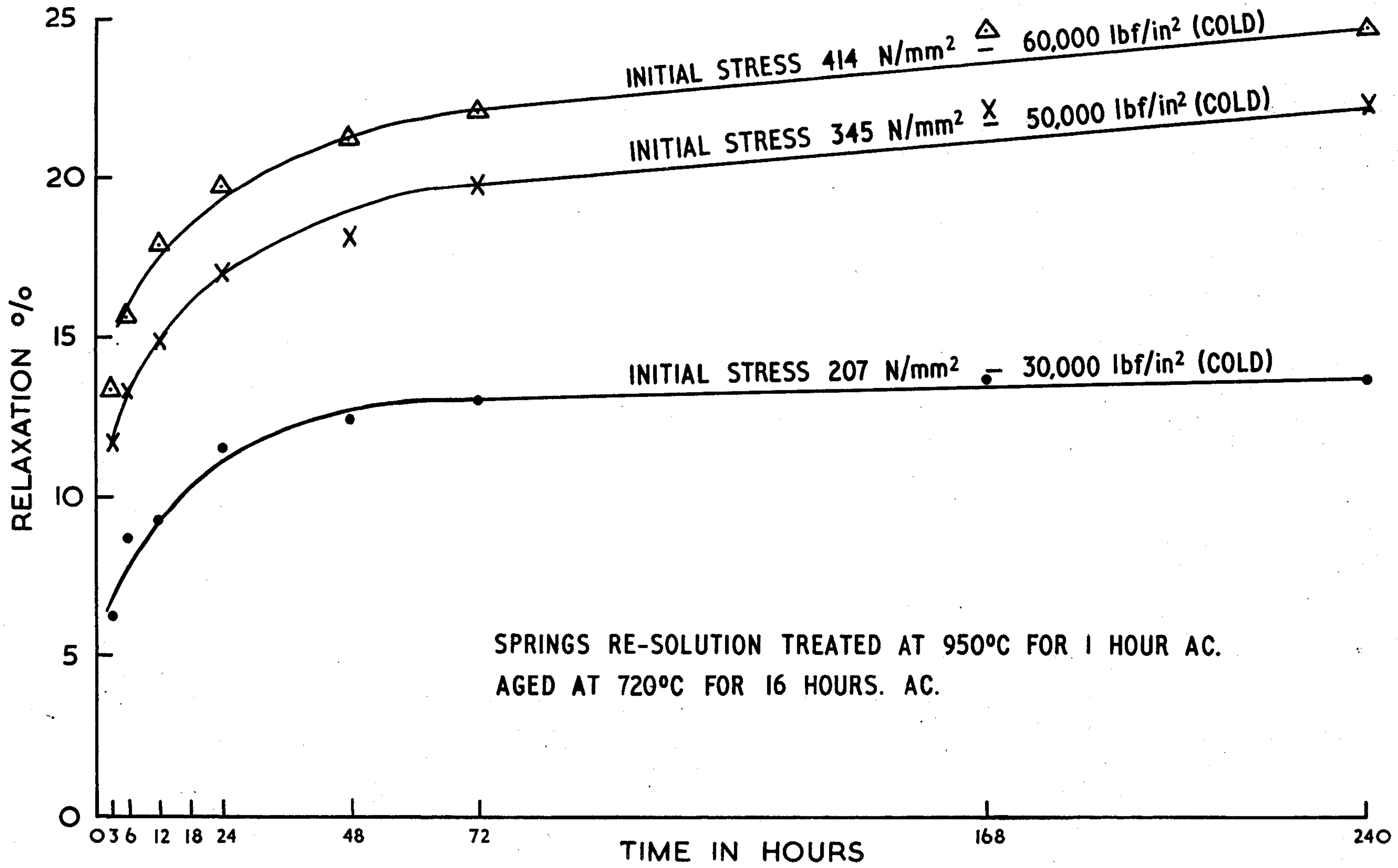

FIG. 26. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF A286 SPRINGS AT 550°C RE-SOLUTION TREATED UNPEENED

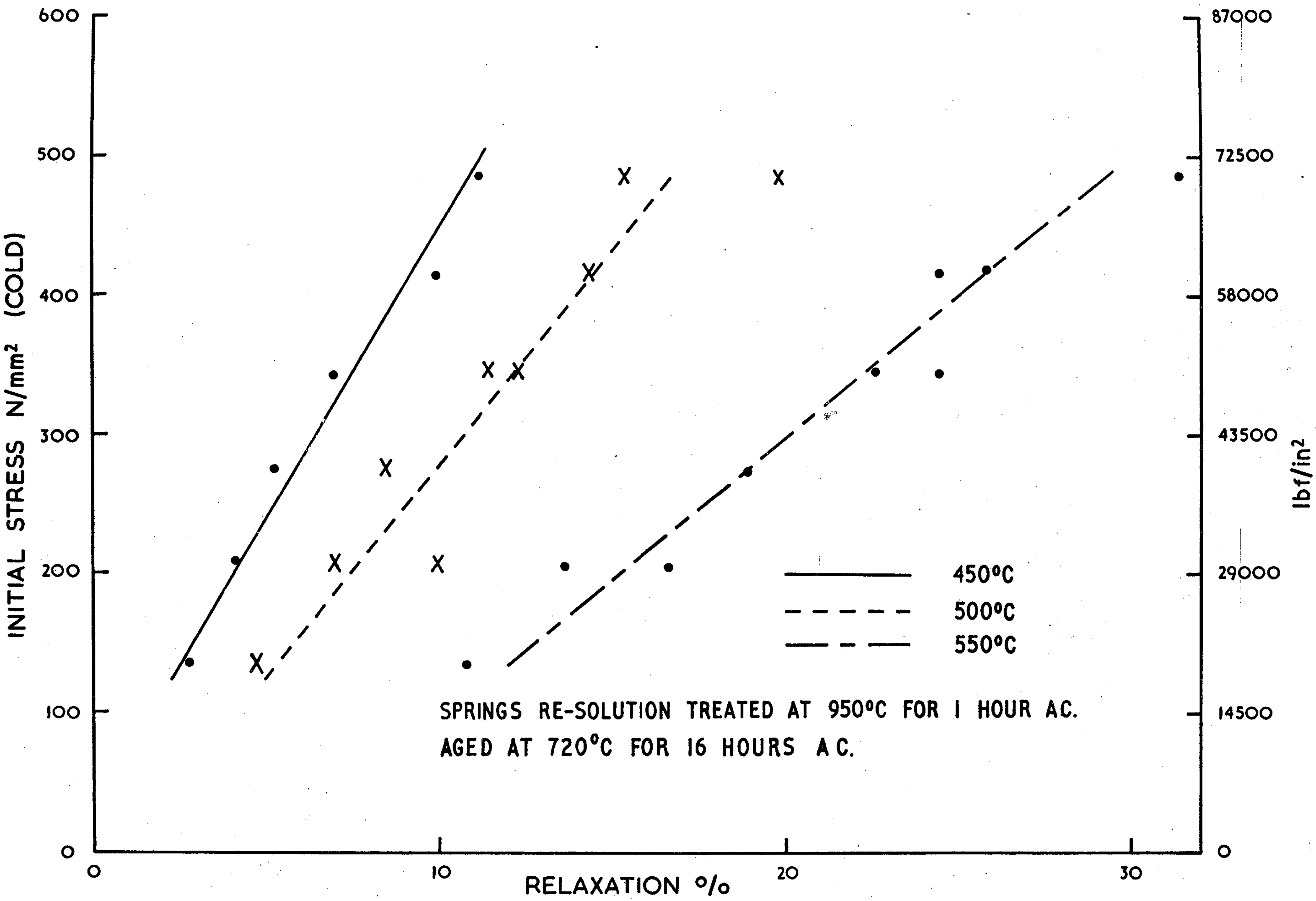

FIG. 27. STRESS TEMPERATURE RELAXATION PROPERTIES OF A286 AFTER 240 HOURS RE-SOLUTION TREATED UNPEENED

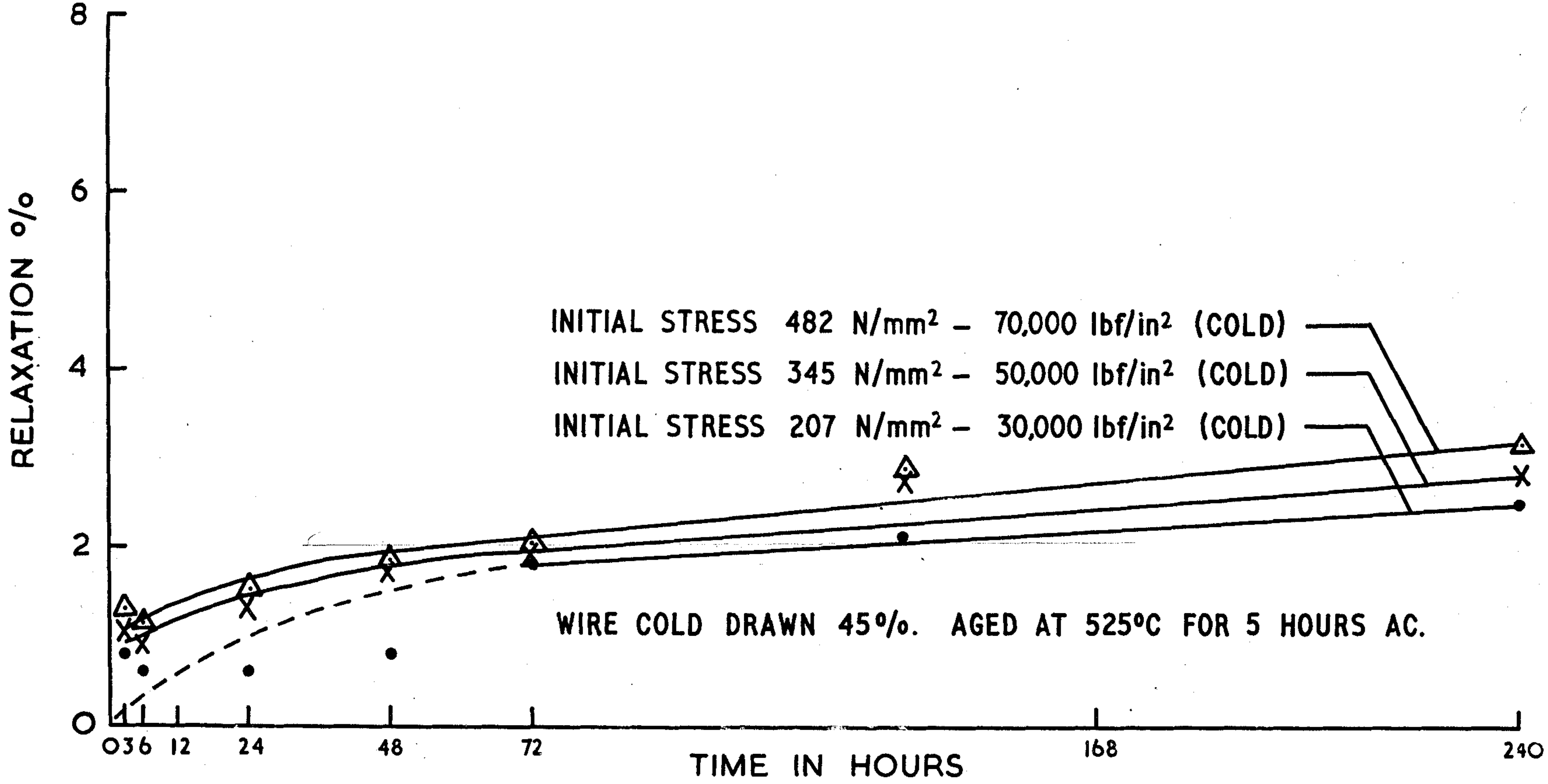

FIG. 28. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF ELGILOY SPRINGS AT 350°C UNPEENED

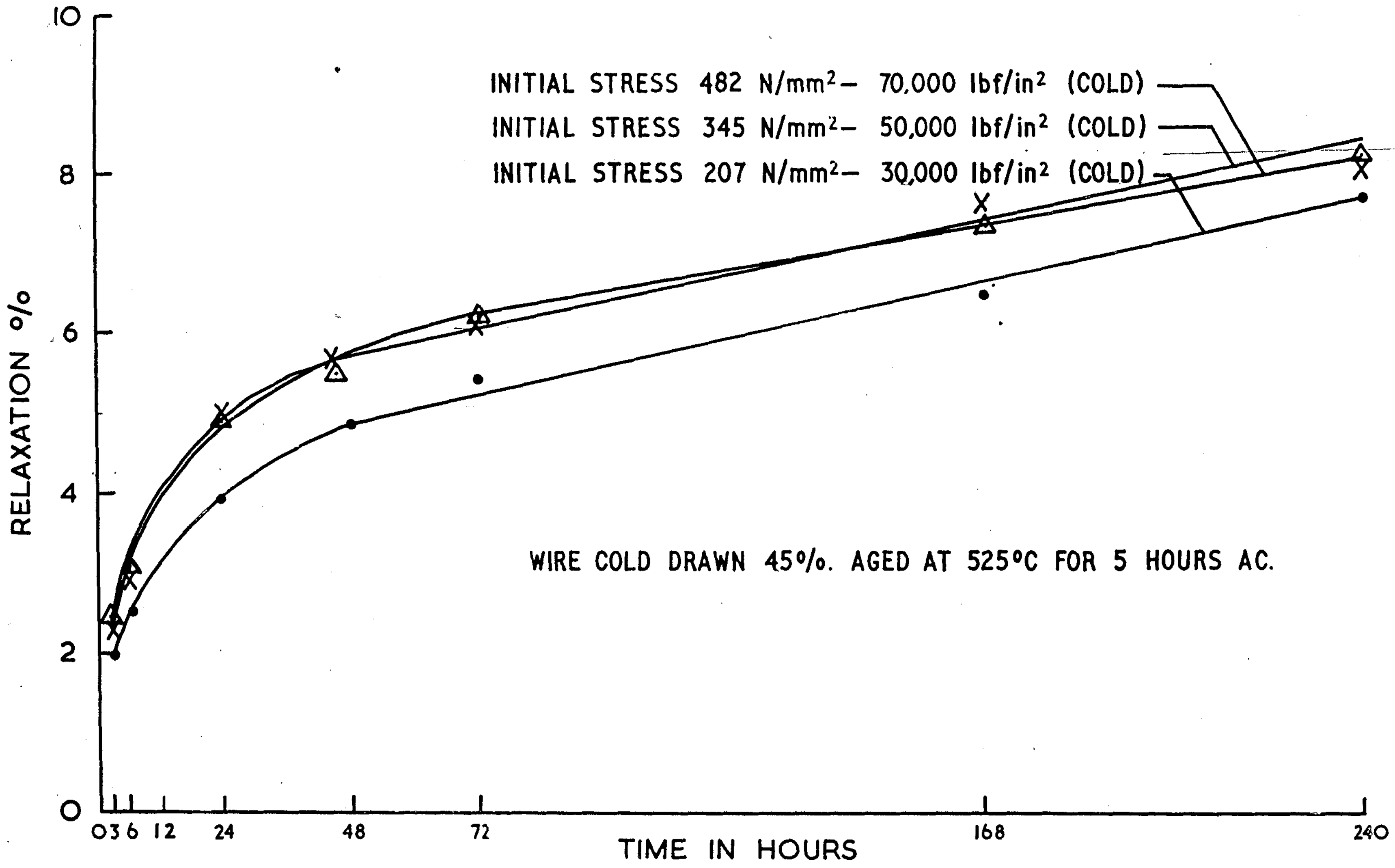

FIG. 29. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF ELGILOY SPRINGS AT 400°C UNPEENED

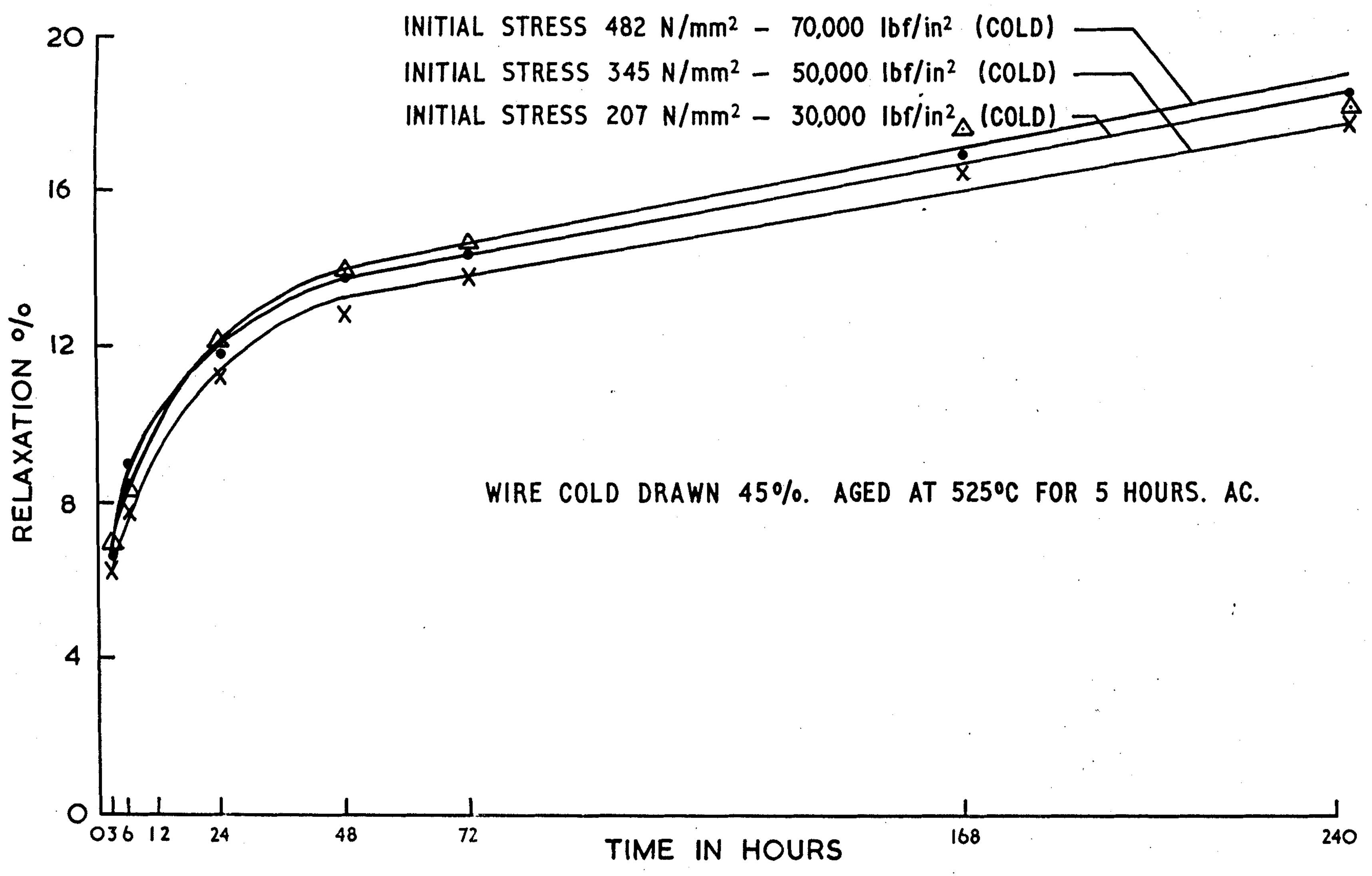

FIG. 30. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF ELGILOY SPRINGS AT 450°C UNPEENED

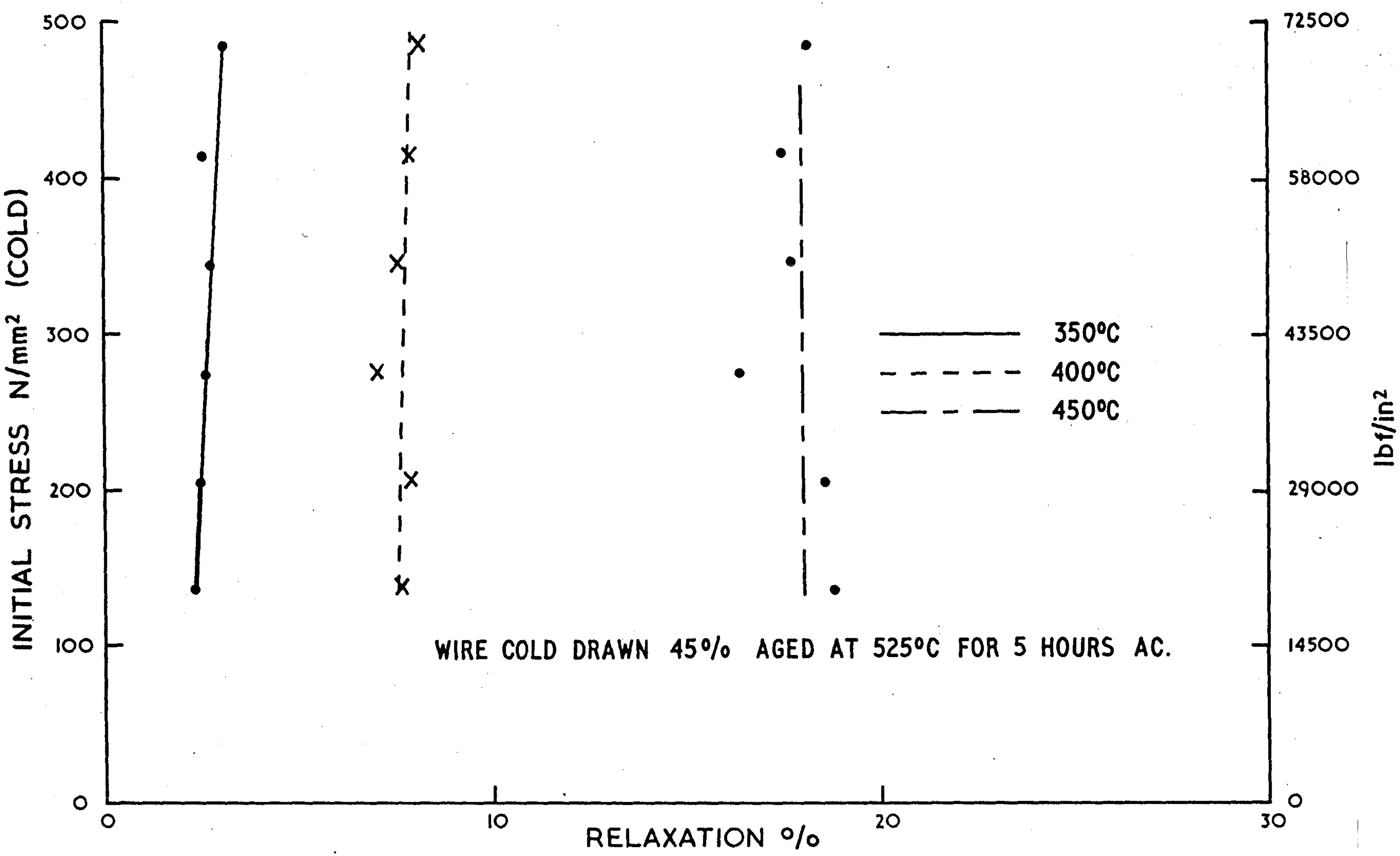

FIG. 31. STRESS TEMPERATURE RELAXATION PROPERTIES OF ELGILOY SPRINGS AFTER 240 HOURS UNPEENED

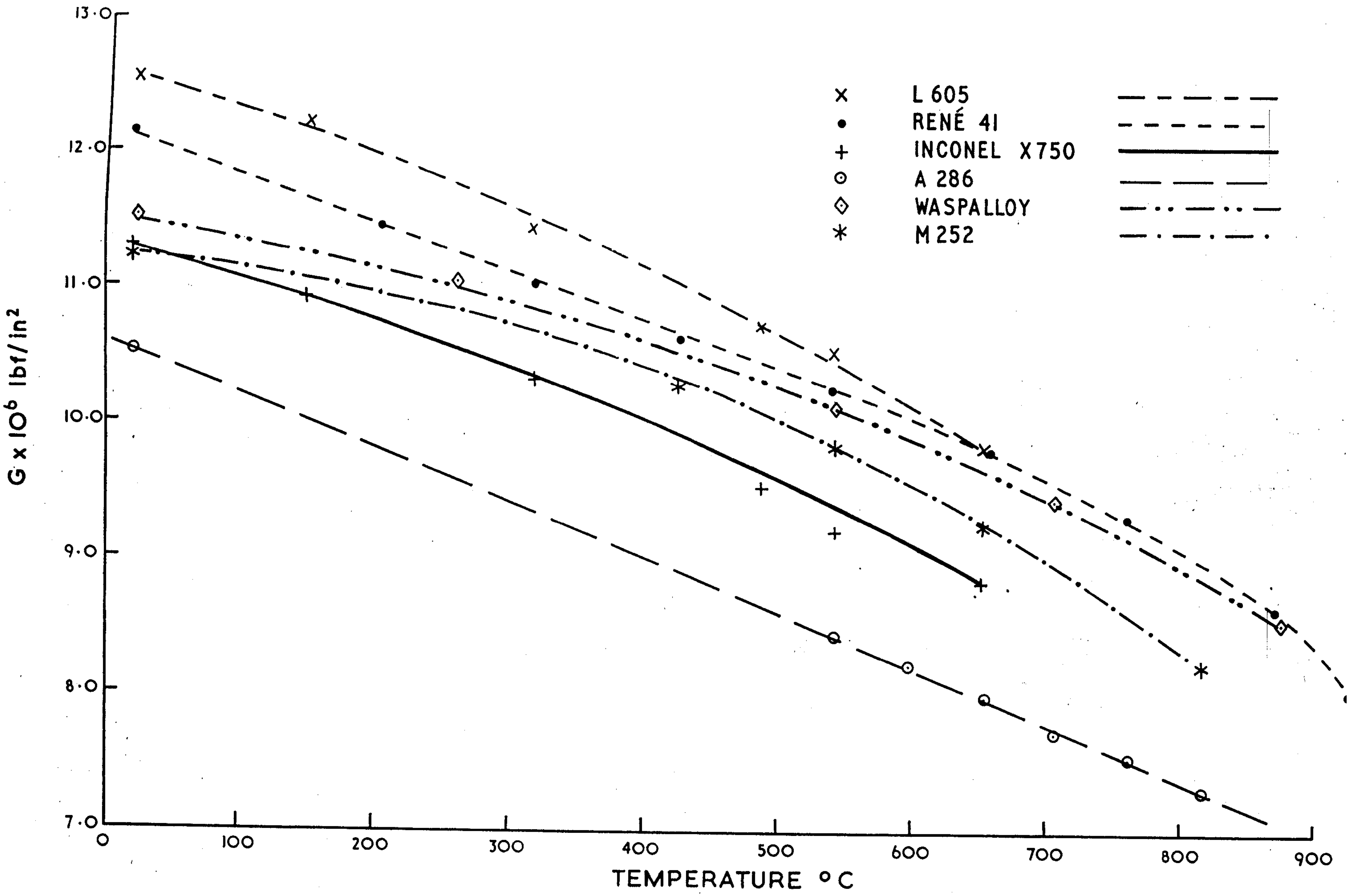

FIG. 32. CHANGE IN MODULUS OF RIGIDITY WITH TEMPERATURE (6) (7)