THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

A DESIGN GUIDE TO THE STRESS RELAXATION OF SPRING MATERIALS

by

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Report No. 330

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1. INTRODUCTION

All springs operating under static loading are prone to set down or relax, and the amount of relaxation depends on the type of material from which the springs are made, the operating temperature and the applied stress. The correct choice of spring material for the application is very important to ensure that only a minimal amount of relaxation occurs.

Over the many years that the Association has been in existence, a great deal of work has been carried out assessing the stress relaxation behaviour of the various spring materials, and the results are spread through a very large number of research reports. As an aid to the spring maker, all this information has been gathered together to produce this design guide to the relaxation of spring materials.

2. DESIGN GUIDE TO SPRING MATERIALS

The figures contained in this guide are in two forms. Figures 1 - 17 show the ISO-relaxation curves for the various spring materials examined. These curves show the combinations of stress and temperature under which the spring materials set down by 2.5, 5 and 10%. Figures 18 - 29 show the typical stress relaxation behaviour of the spring materials at temperatures ranging from 100°C to 550°C (in 50°C intervals).

The spring materials mentioned in this design guide have all been given their recommended heat-treatments, and the majority of them have been cold prestressed. These heat-treatments are described in the appropriate sections of the report.

Table I shows the maximum permissible operating temperatures for the various spring materials under static loading conditions. Tables II and III give the 99% confidence increments for the various stress relaxation curves represented in Figures 18 - 29. (N.B. The curves shown are for 50% confidence).

To use these 99% confidence increments, add the figure quoted in the appropriate table for the required temperature and material to that obtained from the graph at the required stress to give the maximum relaxation of the material. e.g. for 18Cr/8Ni stainless steels at a temperature of 250°C the 99% confidence increment (from Table II) is 1.4%, and at 300 N/mm^2 and 250°C the amount of relaxation for 18Cr/8Ni stainless steels is 2.8% (from figure 23). Thus the maximum likely amount of relaxation is (1.4 + 2.8)% = 4.2%. There would, of course, be a 1% chance of the 4.2% value quoted being exceeded.

All the stress relaxation figures in this guide have been produced from data obtained for springs in the unpeened condition. For all materials, if the springs are in the shot peened condition, then the relaxation will be greater.

The relaxation curves contained in this guide have been produced from data obtained from relatively short term tests and serve as a general guide to the selection of materials for springs operating at elevated temperatures. It should be recognized that the relaxation values quoted are likely to be exceeded where springs are subjected to extended periods of time at temperature. For instance, it has been shown that carbon and stainless steel springs experience about 60 - 70% of the possible relaxation occurring after 10,000 hours within a relatively short space of time.

2.1 Phosphor-Bronze

SRAMA Reports 243, 300
Wire Diameter 1.2 mm
LTHT of 200°C for ½ hour
Prestressed

Testing Duration 72 hours

Fig. 1 ISO-relaxation curves for 2.5, 5 and 10% relaxation

Fig. 18 Stress relaxation curves at 100°C

The maximum operating temperature of this material is approximately 80°C.

2.2 Copper-Beryllium

SRAMA Reports 143, 263.

Wire Diameter 1.2 mm

Ageing treatment of 335°C for 2 hours

Prestressed

Testing Duration 72 hours

Fig. 2 ISO-relaxation curves for 2.5 and 5% relaxation

Fig. 18 Stress relaxation curves at 100°C

Fig. 19 Stress relaxation curves at 150°C

The maximum operating temperature for this material is approximately 125°C.

2.3 Titanium Alloys

SRAMA Reports 143, 288

Range of wire diameters 2.5 to 3.3 mm

LTHT of 250°C for ½ hour

Prestressed

Testing Duration 72 hours

Fig. 3 ISO-relaxation curves for 2.5, 5 and 10% relaxation

Fig. 18 Stress relaxation curves at 100°C

Fig. 19 Stress relaxation curves at 150°C

The maximum working temperature of this material is approximately 150°C.

2.4 Carbon Steels

2.4.1 Patented material

SRAMA Reports 115, 143, 233, 266, 301, 312, 325

Range of wire diameters 2.3 to 2.8 mm

LTHT of 350°C for ½ hour

Prestressed

Testing Duration 72 hours
Fig. 4 ISO-relaxation curves for 2.5, 5 and 10% relaxation
Fig. 20 Stress relaxation curves at 100°C
Fig. 21 Stress relaxation curves at 150°C
Fig. 22 Stress relaxation curves at 200°C
The maximum working temperature for this material is approximately 150°C.

2.4.2 Music wires

SRAMA Reports 143, 301, 312, 325
Range of wire diameters 0.7 to 3.2 mm
LTHT of 350°C for ½ hour
Prestressed
Testing Duration 72 hours
Fig. 5 ISO-relaxation curves for 2.5, 5 and 10% relaxation
The maximum operating temperature for this material is approximately 150°C.

2.4.3 Oil hardened and tempered material

SRAMA Reports 115, 143, 297, 311, 312, 325
Range of wire diameters 2.5 to 4.0 mm
LTHT of 350°C for ½ hour
Prestressed
Testing Duration 72 hours
Fig. 6 ISO-relaxation curves for 2.5, 5 and 10% relaxation
Fig. 20 Stress relaxation curves at 100°C
Fig. 21 Stress relaxation curves at 150°C
Fig. 22 Stress relaxation curves at 200°C
The maximum operating temperature for this material is approximately 180°C.

2.5 Low Alloy Steels

2.5.1 Silicon-chromium material

SRAMA Reports 143, 234
Wire Diameter 4.0 mm

LTHT of 350°C for ½ hour
Prestressed
Testing Duration 72 hours
Fig. 7 ISO-relaxation curves for 2.5, 5 and 10% relaxation
Fig. 20 Stress relaxation curves at 100°C
Fig. 21 Stress relaxation curves at 150°C
Fig. 22 Stress relaxation curves at 200°C
Fig. 23 Stress relaxation curves at 250°C
The maximum working temperature for this material is approximately 270°C.

2.5.2 Chromium-vanadium materials

SRAMA Reports 143, 215, 234, 248
There are two types of chromium-vanadium spring steel used by the spring maker, a 1% chromium-vanadium (En 47) and a 0.5% chromium-vanadium. Unfortunately, there is not enough data contained in the Association's reports to draw up ISO-relaxation curves for either material.

The En 47 has better relaxation resistance than the low chromium-vanadium, which must be hot prestressed to increase its relaxation resistance. Both materials must be given a LTHT of 400°C for ½ hour after coiling, and both have a maximum operating temperature of approximately 220°C.

2.6 Stainless Steels

2.6.1 18Cr/8Ni stainless steels

SRAMA Reports 143, 194, 303, 306, 315, 325
Range of wire diameters 1.2 to 2.8 mm
LTHT of 450°C for ½ hour
Prestressed
Testing Duration 168 hours
Fig. 8 ISO-relaxation curves for 2.5, 5 and 10% relaxation
Fig. 21 Stress relaxation curves at 150°C
Fig. 22 Stress relaxation curves at 200°C
Fig. 23 Stress relaxation curves at 250°C
Fig. 23 Stress relaxation curves at 300°C

Fig. 25 Stress relaxation curves at 350°C
The maximum working temperature is 320°C approximately.

2.6.2 <u>Other stainless steels</u>

SRAMA Reports 143, 256
Materials PH 13/7 Mo
Nitronic 50
Nitronic 32
Wire Diameter 2.4 mm for all these materials
LTHT 450°C for 2 hours for Nitronic 50 and Nitronic 32
Precipitation hardened at 480°C for 1 hour for PH15/7 Mo
All these materials were prestressed
Testing Duration 168 hours
Fig. 9 ISO-relaxation curves for 2.5 and 5% relaxation for PH15/7 Mo
Fig. 10 ISO-relaxation curves for 2.5 and 5% relaxation for Nitronic 50
Fig. 11 ISO-relaxation curves for 5 and 10% relaxation for Nitronic 32.
Maximum permissible operating temperature for all three materials is approximately 320°C.
There is not enough data contained in the Association's reports to produce ISO-relaxation curves for 17/7 PH stainless steel, but this material has a maximum working temperature of 320°C.

2.7 <u>Tungsten Steels</u>

SRAMA Reports 143, 232
Wire Diameter 3.2 mm
Heat Treatment 1100°C in salt for ½ hour, oil quench, double-temper at 590°C in salt for 2 hours.
Prestressed
Testing Duration 168 hours
Fig. 12 ISO-relaxation curves for 2.5 and 5% relaxation
Fig. 23 Stress relaxation curves at 250°C
Fig. 24 Stress relaxation curves at 300°C
Fig. 25 Stress relaxation curves at 350°C
Fig. 26 Stress relaxation curves at 400°C

The maximum working temperature is 370°C approximately.

2.8 18% Ni-Co-Mo Maraging Steel

SRAMA Report 279
Wire Diameter 2.65 mm
Ageing treatment at 480°C for 3 hours
Prestressed
Testing Duration 120 hours
Fig. 13 ISO-relaxation curves for 2.5 and 5% relaxation
Fig. 24 Stress relaxation curves at 300°C
Fig. 25 Stress relaxation curves at 350°C
Fig. 26 Stress relaxation curves at 400°C
The maximum working temperature for this material is 350°C approximately.

2.9 Heat Resistant Alloys

SRAMA Reports 152, 162, 194, 314

2.9.1 Inconel 600

Wire Diameter 2.65 mm
LTHT 450°C for ¾ hour
Prestressed
Testing Duration 300 hours
Fig. 14 ISO-relaxation curves for 2.5 and 5% relaxation
Fig. 22 Stress relaxation curves at 200°C
Fig. 23 Stress relaxation curves at 250°C
Fig. 24 Stress relaxation curves at 300°C
Fig. 25 Stress relaxation curves at 350°C
Fig. 26 Stress relaxation curves at 400°C
The maximum operating temperature for Inconel 600 is 400°C approximately.

2.9.2 Inconel X-750

Wire Diameter 3.7 mm
Heat Treatment of 1150°C for 2 hours, air cool. Aged at 840°C for 24 hours, air cool, and 700°C for 20 hours, air cool.

Prestressed

Testing Duration 250 hours

Fig. 15 ISO-relaxation curves for 2.5, 5 and 10% relaxation

Fig. 27 Stress relaxation curves at 450°C

Fig. 28 Stress relaxation curves at 500°C

Fig. 29 Stress relaxation curves at 550°C

The approximate maximum operating temperature for this material is 550°C

2.9.3 <u>René 41</u>

Wire Diameter 2.64 mm

Heat treatment of 815°C for 16 hours

Prestressed

Testing Duration 240 hours

Fig. 16 ISO-relaxation curves for 5 and 10% relaxation

Fig. 27 Stress relaxation curves at 450°C

Fig. 28 Stress relaxation curves at 500°C

Fig. 29 Stress relaxation curves at 550°C

The maximum working temperature for this material is approximately 500°C.

2.9.4 <u>Waspaloy</u>

Wire Diameter 3.5 mm

Heat treatment of 1080°C for 4 hours, water quench, aged at 850°C for 24 hours.

Prestressed

Testing Duration 240 hours

Fig. 17 ISO-relaxation curves for 5 and 10% relaxation

Fig. 28 Stress relaxation curves at 500°C

Fig. 29 Stress relaxation curves at 550°C

The maximum operating temperature is approximately 500°C

2.9.5 <u>Elgiloy, A286, Nimonic 90</u>

There is not enough data to produce ISO-relaxation curves for these materials, but a few selected stress relaxation curves are included in the guide.

Wire Diameters	A286	2.64 mm
	Elgiloy	2.41 mm
	Nimonic 90	3.66 mm
Heat Treatments	A286 aged at 705°C for 16 hours Elgiloy aged at 525°C for 5 hours Nimonic 90 solution treated at 1080°C for 1 hour, air cooled aged at 750°C for 4 hours	

All materials were prestressed.

Test Durations	A286 and Elgiloy	240 hours
	Nimonic 90	250 hours

The maximum working temperatures are 400°C for the Elgiloy and A286, and 550°C for the Nimonic 90.

3. SUGGESTIONS FOR FUTURE EXAMINATION

1. Considering the large number of springs which operate statically at room temperature, there is little information available on the relaxation behaviour of springs under such conditions. Work is in hand to provide relaxation data for statically loaded springs at room temperature but is currently limited to the more common spring materials. It is suggested that this work be extended to include the full range of materials available to the spring manufacturer with the object of eventually producing a design guide to relaxation for springs operating at room temperature.

2. It is clear from the production of this guide that for certain materials only a limited amount of relaxation data is available which in turn has prevented the construction of ISO-relaxation curves of the type presented in this report. For instance, materials which are finding increasing useage as springs, such as 17/7 PH and chromium-vanadium, have insufficient related relaxation data to enable a picture of

their stress-temperature relationships to be developed. A programme of work is clearly necessary to overcome these deficiencies.

4. BIBLIOGRAPHY

Data from the following reports were used to produce this guide.

1. G.B. Graves "The stress-temperature relaxation properties of springs made from oil tempered and patented hard drawn wires". CSFRO Report No. 115 May 1960.

2. G.B. Graves "The stress-relaxation and creep properties of some spring materials". SMRA Report No. 143, April 1963.

3. G.B. Graves and J.W. Mee, "Titanium 314A wire and springs. Part I. The static and dynamic properties of 314A titanium shot peened wire and springs". SMRA No. 149 June 1964.

4. G.B. Graves "The stress relaxation properties of Nimonic 90 and Inconel X-750 helical compression springs". SMRA Report No. 152, June 1965.

5. G.B. Graves "A note on the effect of heat treatment on the stress temperature relaxation properties of Nimonic alloy 90 helical springs". SMRA Report No. 162, Feb 1967.

6. G.B. Graves and T. Key "The stress temperature relaxation properties of some high temperature and corrosion resistant materials". SRA Report No. 194 Nov. 1971.

7. S.D. Gray "The effect of hot prestressing on the relaxation properties of helical compression springs manufactured from Cr-V wire". SRA Report No. 215 May 1973.

8. S.D. Gray "The stress temperature relaxation properties of 9% tungsten hot work die steel springs". SRA report No. 232 May 1974.

9. M.R. Southward "An investigation into the effect of pre-stressing and solid stress on the relaxation behaviour of compression springs". SRA Report No. 233 May 1974.

10. S.D. Gray "The effect of hot prestressing on the fatigue and relaxation properties of helical compression springs manufactured from low alloy steel wire". SRA Report No. 234 Oct 1974.

11. P.F. Heyes "The fatigue and relaxation properties of helical compression springs made from phosphor-bronze wire". SRA Report No. 243 Mar 1975.

12. P.F. Heyes "The effects of hot and cold prestressing on the fatigue and relaxation properties of compression springs made from Cr-V steel wire". SRA Report No. 248. June 1975.

13. G.B. Graves "The fatigue and relaxation resistance of copper-beryllium helical compression springs". SRAMA Report No. 263, Sept. 1976.

14. G.C. Bird "The low temperature heat treatment of springs manufactured from patented cold drawn carbon steel wire". SRAMA Report No. 266 Nov 1976.

15. K. Brummitt "The fatigue and relaxation properties of maraging steel springs". SRAMA report No. 279 July 1977.

16. L.F. Reynolds "Fatigue and relaxation of high strength Ti318 alloy springs". SRAMA Report No. 288 Feb 1978.

17. K. Brummitt "The effect of varying hardness levels on the fatigue and relaxation properties of springs coiled from oil hardened and tempered wire". SRAMA Report No. 297 July 1978.

18. L.F. Reynolds "An assessment of the differences in static and dynamic properties of helical compression springs manufactured from two grades of phosphor-bronze wire". SRAMA Report No. 300 Jan 1979.

19. K. Brummitt "A comparison of music wires produced by British and Continental wire mills". SRMA Report No. 301 June 1979.

20. G.E. Hale "The effect of low temperature heat treatment on compression springs manufactured from En 58A hard drawn stainless steel wire". SRAMA Report No. 303 Sept. 1978.

21. G.E. Hale "The effect of hot prestressing on the relaxation behaviour of compression springs coiled from En 58A hard drawn stainless steel wire". SRAMA Report No. 306 May 1979.

22. K. Brummitt, "The effect of LTHT temperature on the fatigue and relaxation properties of springs coiled from wire manufactured to BS 2803 GII". SRAMA Report No. 311 June 1979.

23. M. O'Malley "The effect of spring index on the relaxation behaviour of hardened and tempered and hard drawn wire springs". SRAMA Report No. 312, July 1979.

24. K. Brummitt "The fatigue and relaxation properties of springs manufactured from two high nickel alloys". SRAMA Report No. 314 July 1979.

25. G.E. Hale and A.R. Hood "The fatigue and relaxation behaviour of helical compression springs coiled from type 301 hard drawn stainless steel wire". SRAMA Report No. 315 Dec. 1979.

26. M. O'Malley "The long term relaxation behaviour of compression springs manufactured from carbon and stainless steel wires". SRAMA Report No. 325 Feb 1980.

TABLE I MAXIMUM OPERATING TEMPERATURES FOR VARIOUS SPRING MATERIALS

MATERIAL	MAXIMUM OPERATION TEMPERATURE UNDER STATIC LOADING CONDITIONS /^{o}C
Phosphor-Bronze	80
Copper-Beryllium	125
Titanium Alloys	150
Patented Cold Drawn	
Carbon Steels	150
Hardened and Tempered	180
Carbon Steels	
Chrome-Vanadium	220
Silicon-Chromium	270
Stainless Steels	320
Maraging Steels	350
Tungsten Steels (High Speed Tool Steels)	370
Elgiloy, A286	400
Inconel 600,	400
Waspaloy, René 41	500
Nimonic 90, Inconel X750	550

TABLE II 99% CONFIDENCE INCREMENTS FOR THE STRESS RELAXATION CURVES (EXCEPT FOR THE NICKEL BASED MATERIALS).

MATERIAL	TEMPERATURE	99 % CONFIDENCE LIMITS
Phosphor-Bronze	100°C	2.3
Copper-Beryllium	100°C	0.6
	150°C	1.0
Titanium Alloys	100°C	3.1
	150°C	3.6
Patented Carbon Steel	100°C	3.4
	150°C	2.7
	200°C	3.9
Oil Hardened and Tempered Carbon Steel	100°C	3.3
	150°C	3.1
	200°C	3.6
Silicon-Chromium	100°C	1.8
	150°C	1.0
	200°C	1.2
	250°C	2.1
Stainless Steel	150°C	0.5
	200°C	1.2
	250°C	1.4
	300°C	2.1
	350°C	1.2
Tungsten Steel	250°C	0.4
	300°C	0.4
	350°C	0.7
	400°C	1.1
Maraging Steel	300°C	0.1
	350°C	0.1
	400°C	0.1

TABLE III 99% CONFIDENCE INCREMENTS FOR THE STRESS-RELAXATION CURVES OF THE NICKEL BASED MATERIALS

MATERIAL	TEMPERATURE	99 % CONFIDENCE LIMITS
Inconel 600	200°C	0.8
	250°C	1.9
	300°C	1.8
	350°C	0.8
	400°C	1.3
Elgiloy A286	350°C	0.1
	400°C	0.4
Inconel X 750	400°C	1.2
	450°C	0.7
	500°C	2.1
	550°C	1.4
Waspaloy	450°C	0.4
	500°C	0.6
	550°C	1.0
Rene 41	450°C	0.2
	500°C	2.0
Nimonic 90	500°C	1.3
	550°C	3.0

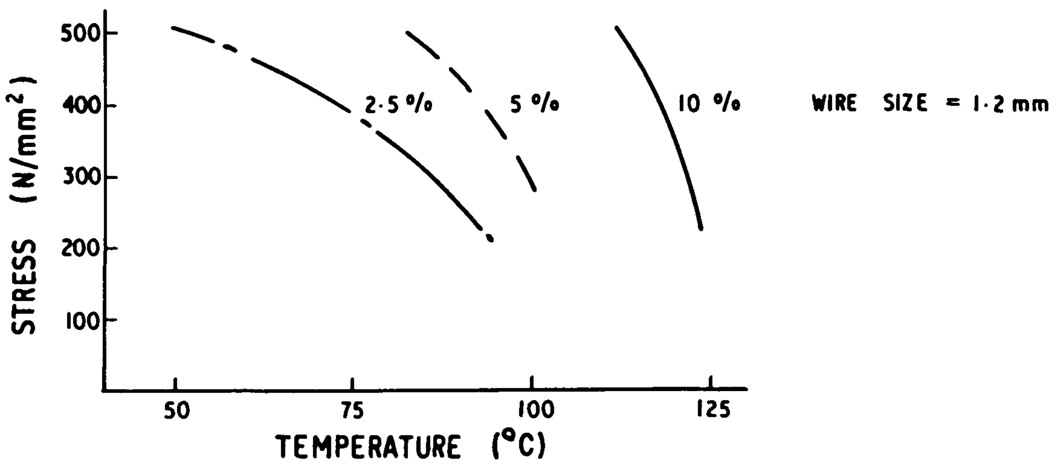

FIG. 1. ISO-RELAXATION CURVES FOR PHOSPHOR-BRONZE AFTER 72 HOURS.

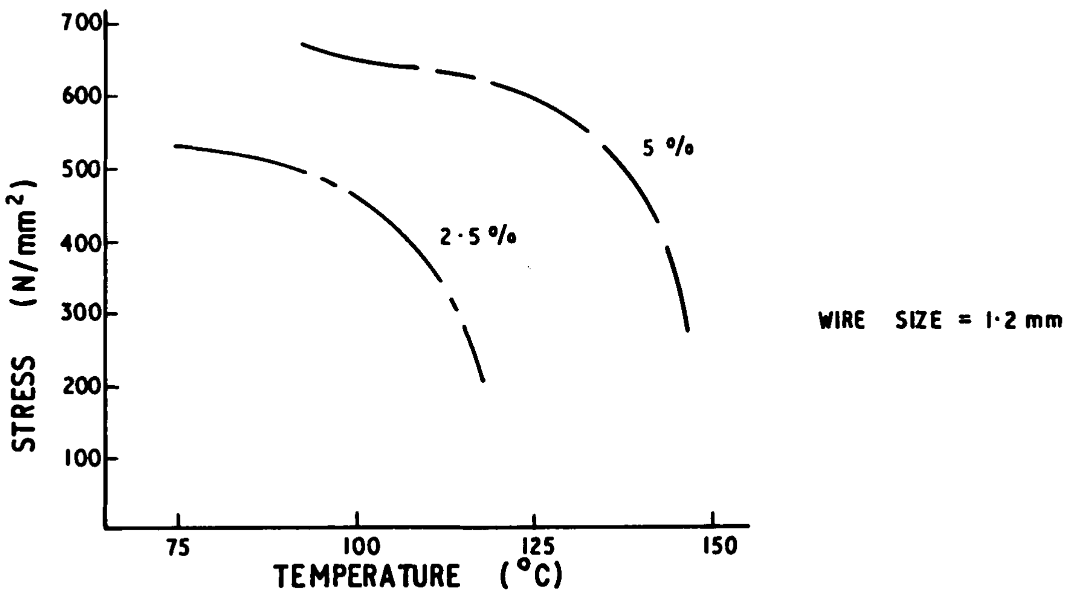

FIG. 2. ISO-RELAXATION CURVES FOR COPPER-BERYLLIUM AFTER 72 HOURS.

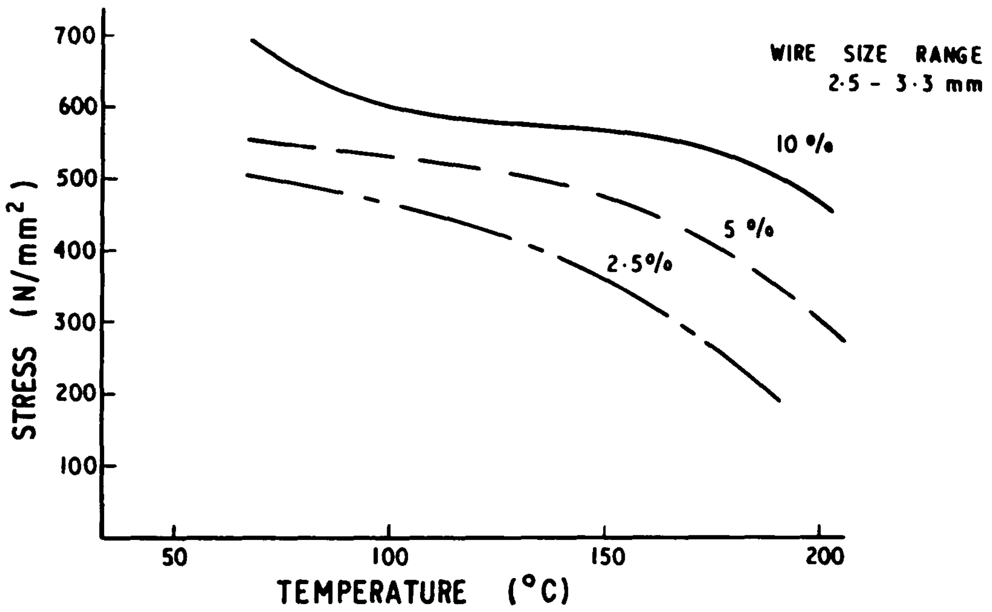

FIG. 3. ISO-RELAXATION CURVES FOR TITANIUM ALLOYS AFTER 72 HOURS.

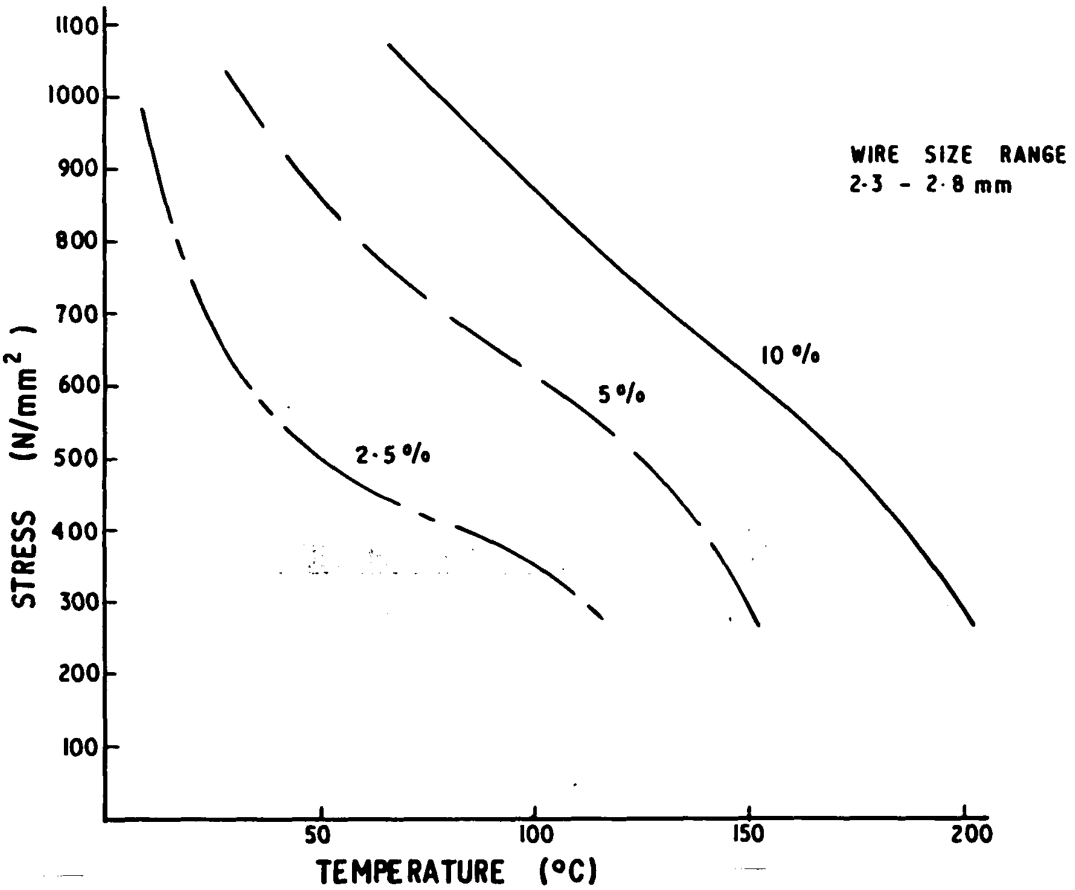

FIG. 4. ISO-RELAXATION CURVES FOR PATENTED CARBON STEELS AFTER 72 HOURS.

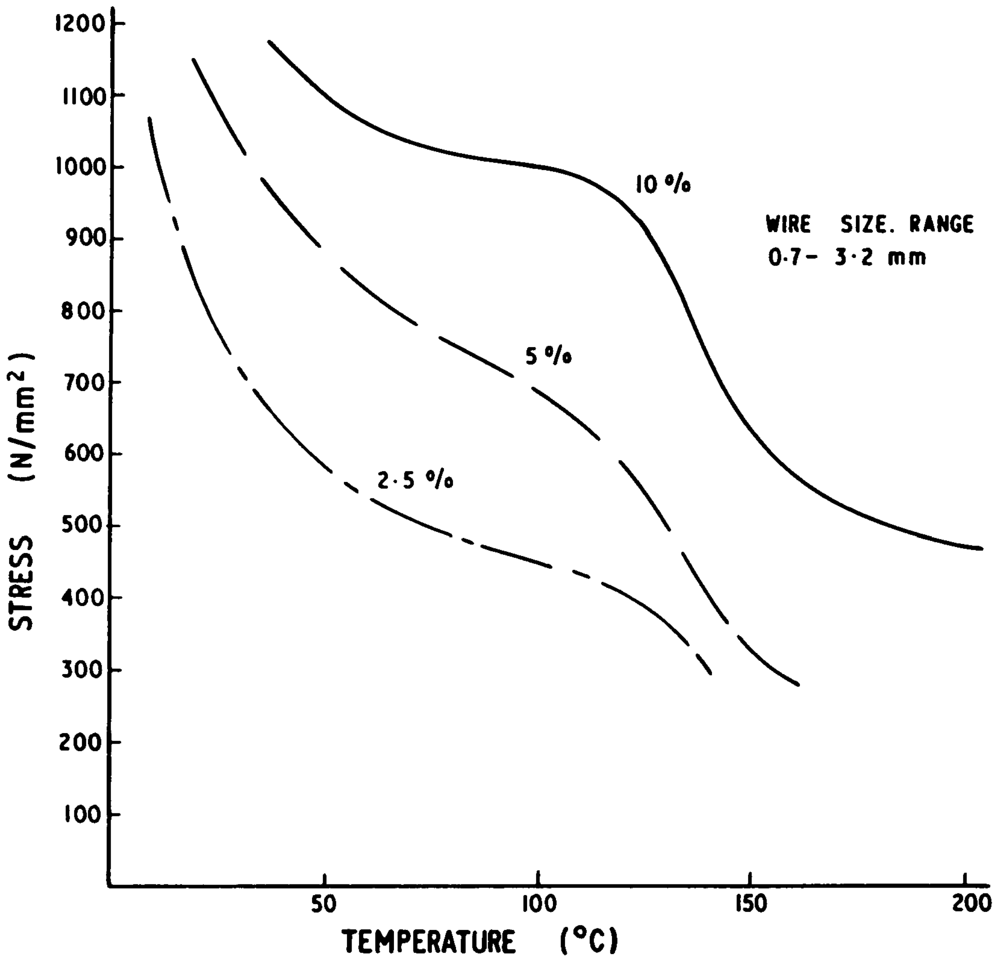

FIG. 5. ISO-RELAXATION CURVES FOR MUSIC WIRES AFTER 72 HOURS.

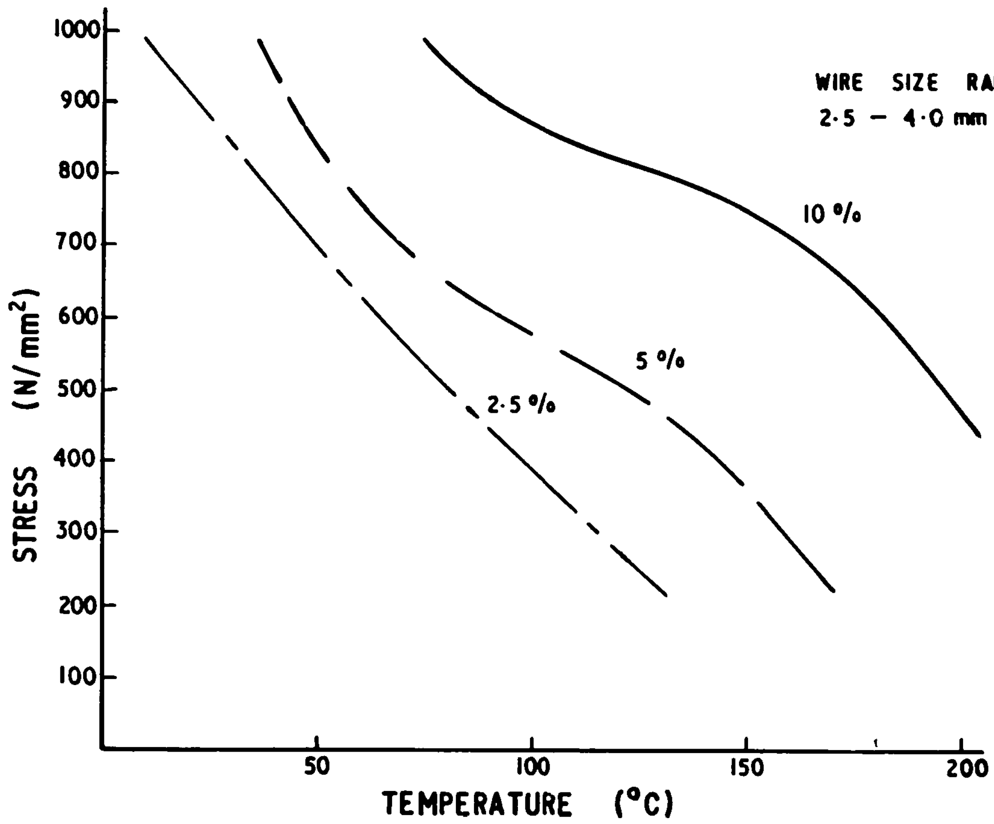

FIG. 6. ISO-RELAXATION CURVES FOR OIL-HARDENED AND TEMPERED CARBON STEELS AFTER 72 HOURS.

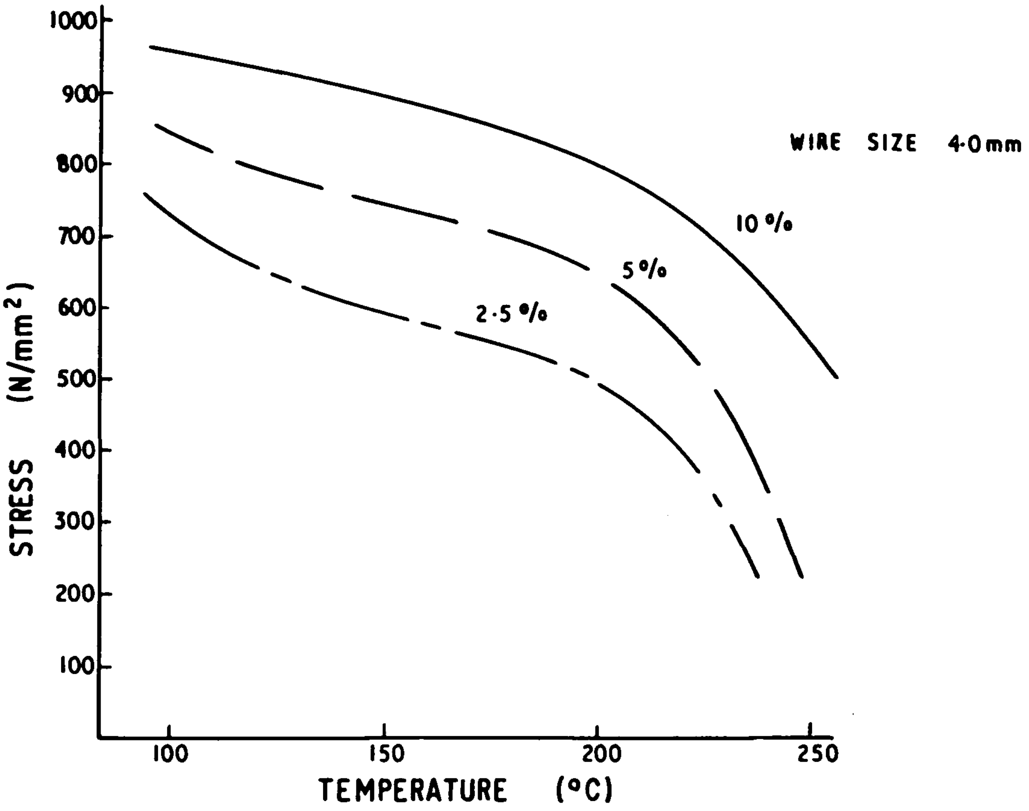

FIG. 7. ISO-RELAXATION CURVES FOR SILICON-CHROMIUM AFTER 72 HOURS.

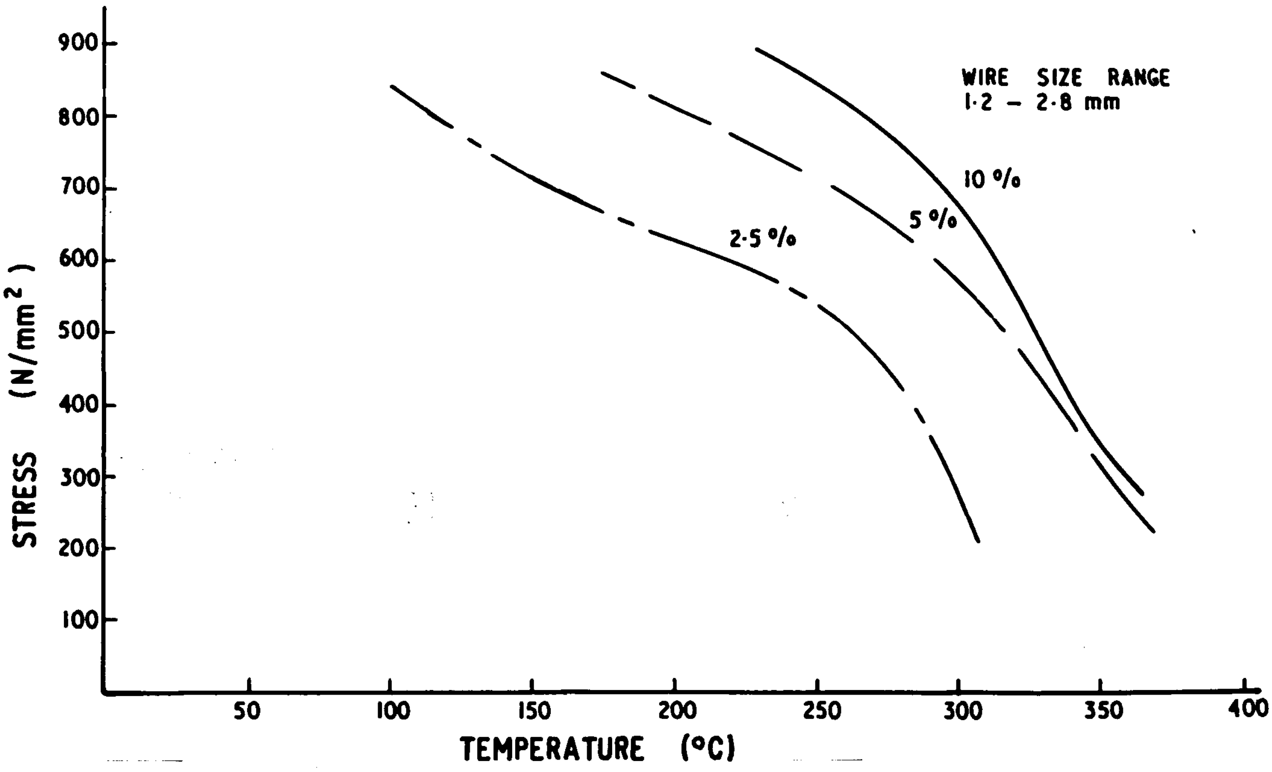

FIG. 8. ISO-RELAXATION CURVES FOR 18 Cr / 8 Ni STAINLESS STEELS AFTER 168 HOURS.

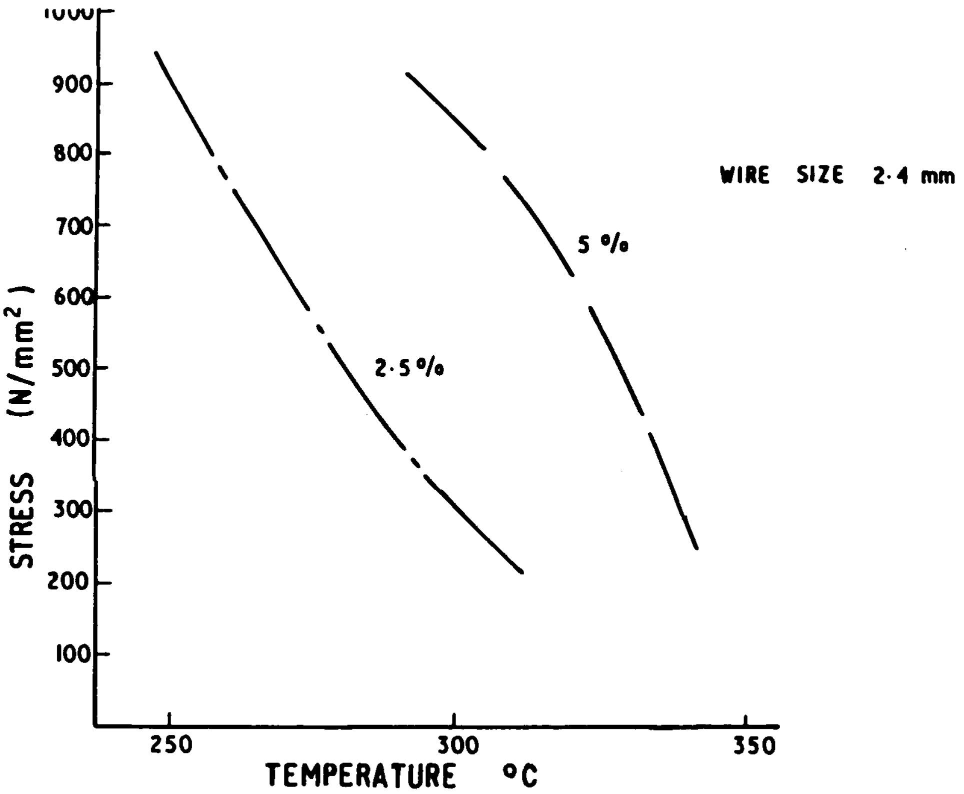

FIG. 9 ISO-RELAXATION CURVES FOR PH 15/7 Mo STAINLESS STEEL AFTER 168 HOURS.

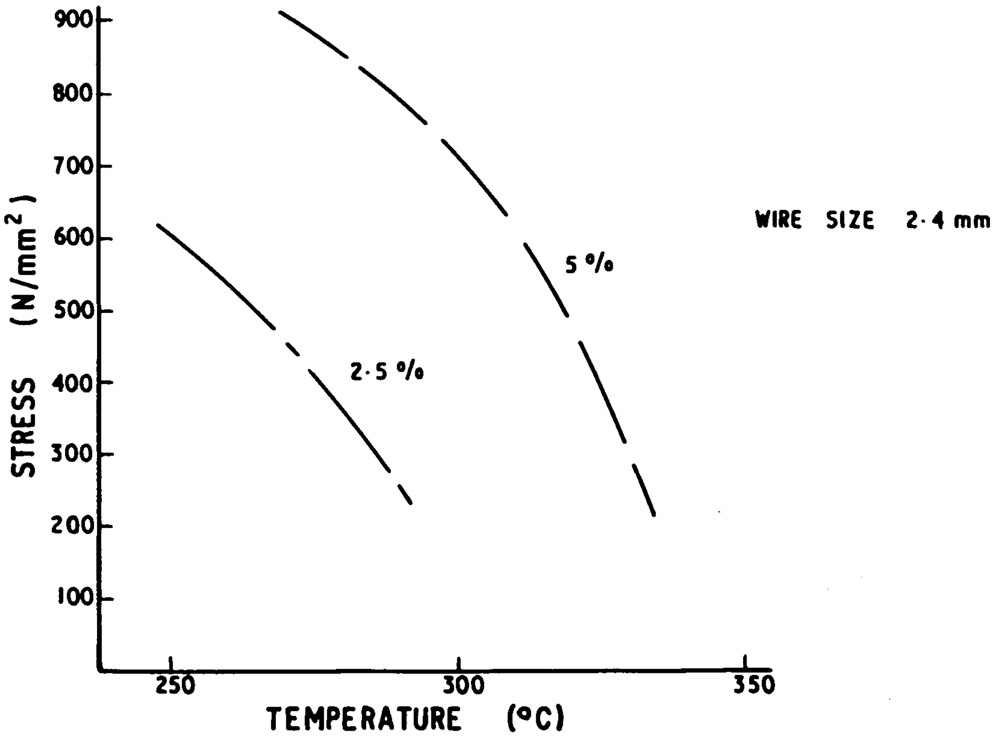

FIG. 10 ISO-RELAXATION CURVES FOR NITRONIC 50 STAINLESS STEEL AFTER 168 HOURS.

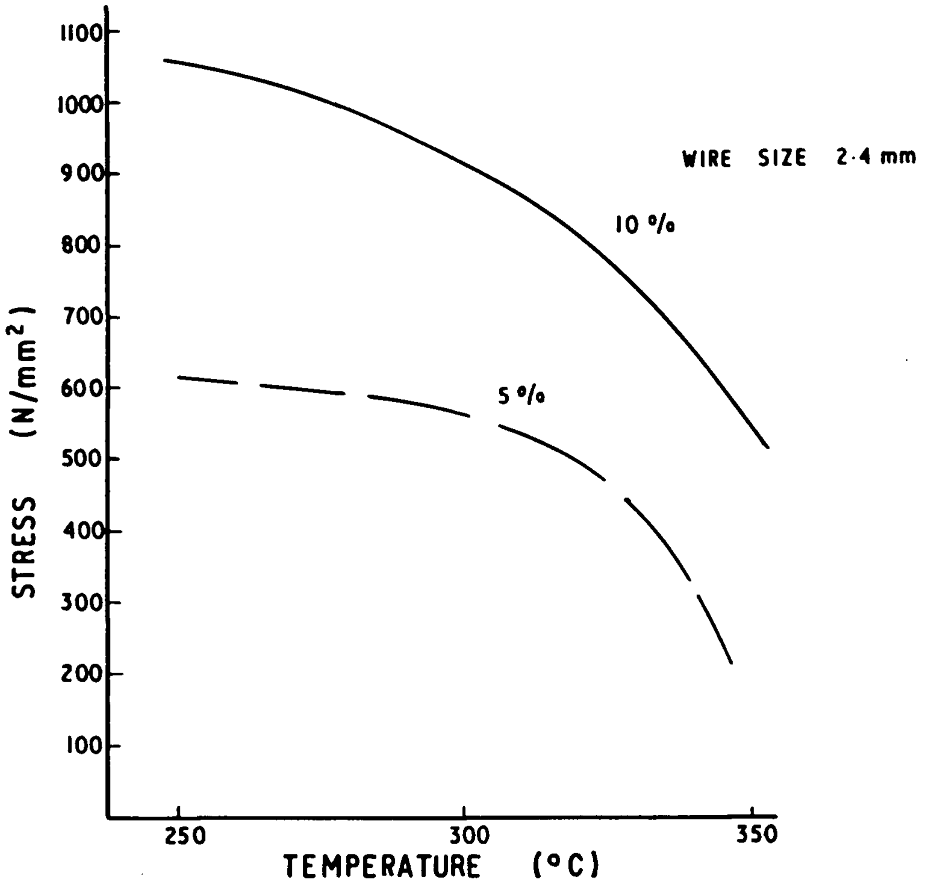

FIG. 11 ISO-RELAXATION CURVES FOR NITRONIC 32 STAINLESS STEEL AFTER 168 HOURS.

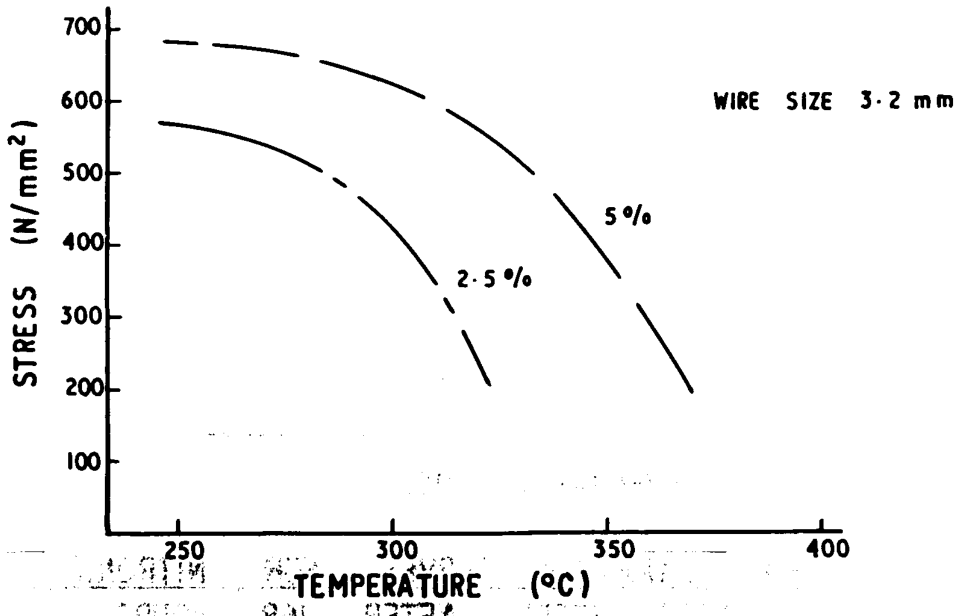

FIG. 12 ISO- RELAXATION CURVES FOR TUNGSTEN STEELS AFTER 168 HOURS.

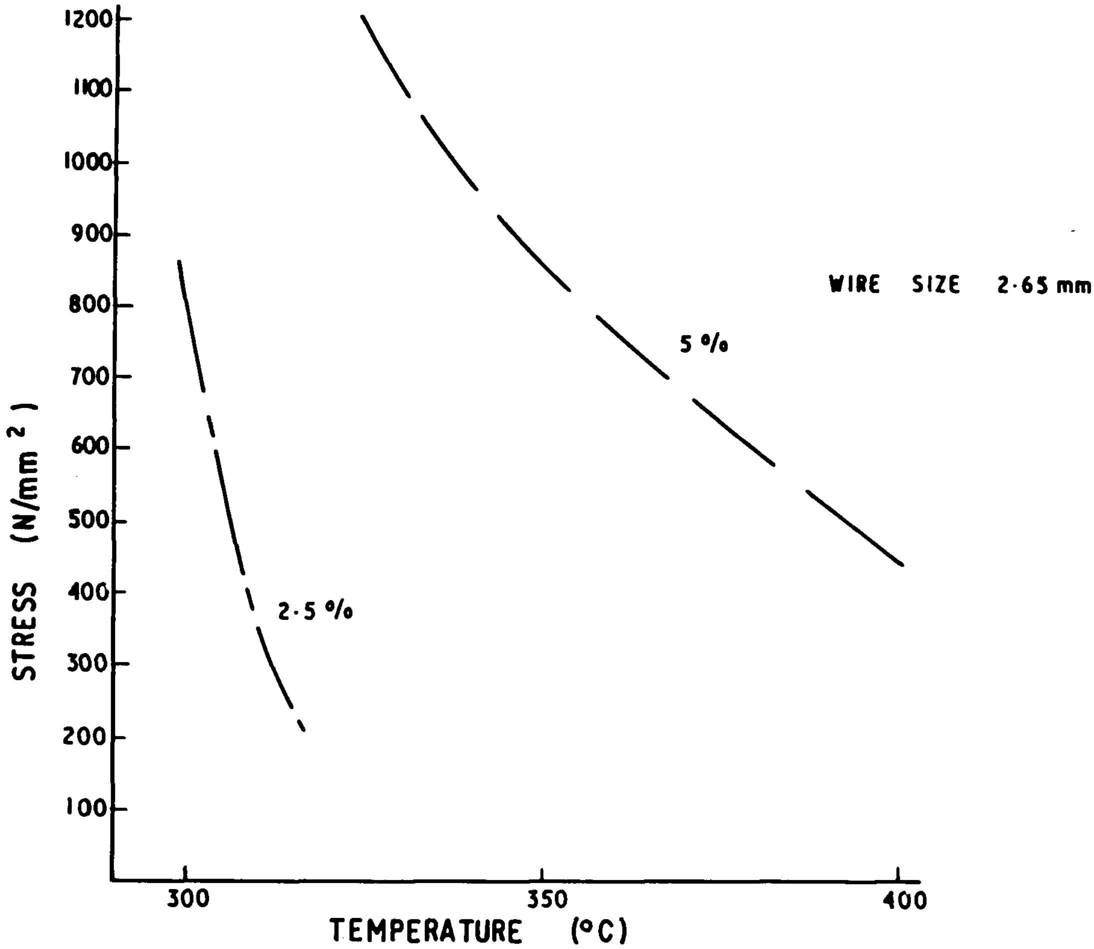

FIG. 13 ISO-RELAXATION CURVES FOR 18 % Ni-Co-Mo MARAGING STEEL AFTER 120 HOURS.

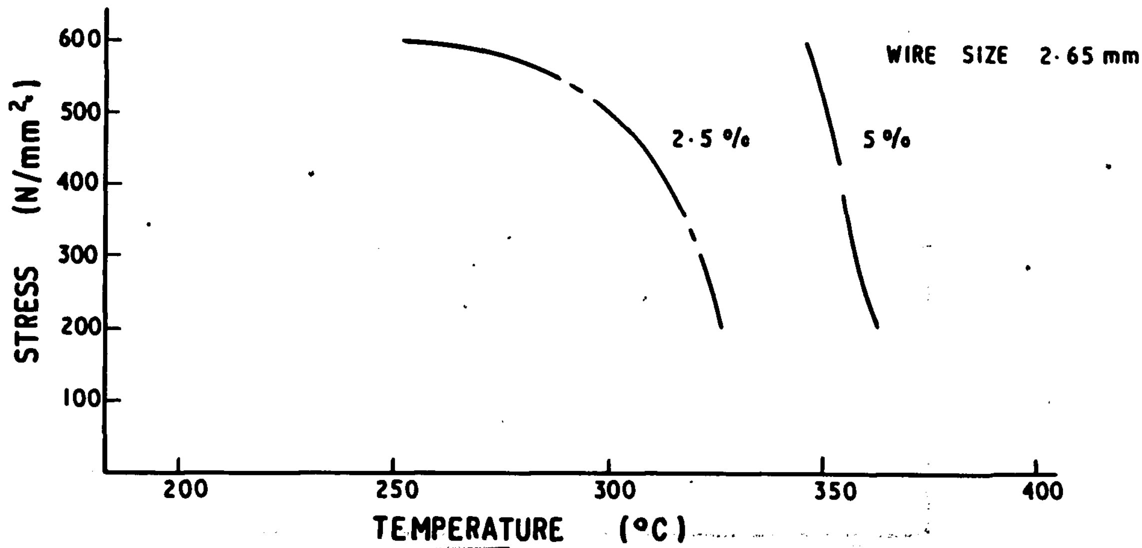

FIG. 14 ISO-RELAXATION CURVES FOR INCONEL 600 AFTER 300 HOURS.

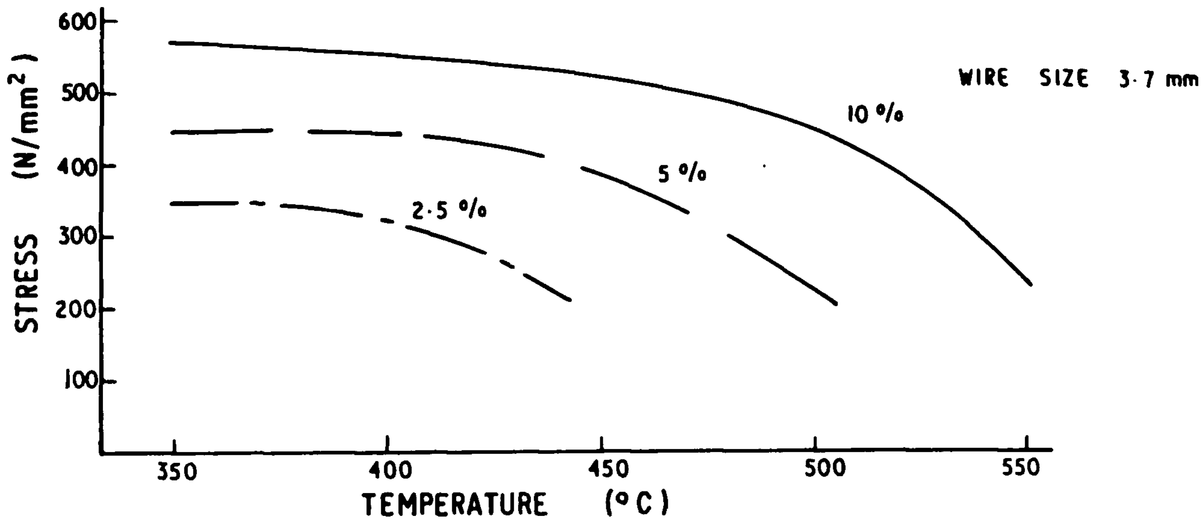

FIG. 15. ISO-RELAXATION CURVES FOR INCONEL X-750 AFTER 250 HOURS.

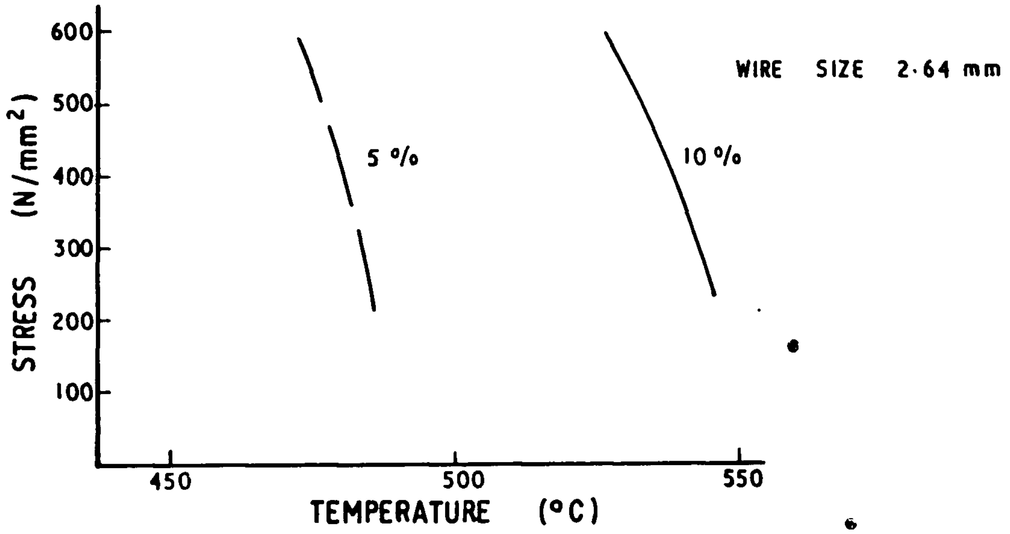

FIG. 16 ISO-RELAXATION CURVES FOR RENÉ 41 AFTER 240 HOURS.

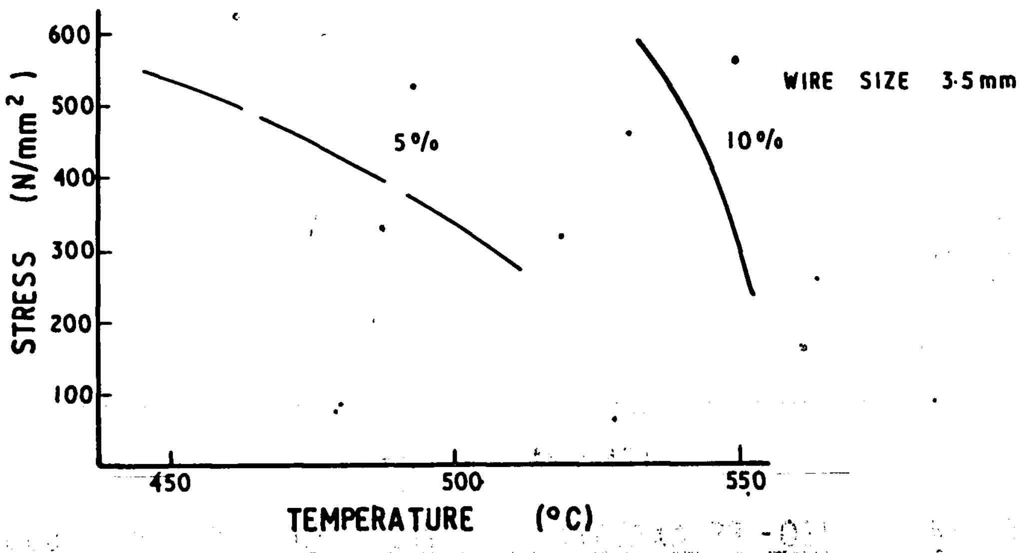

FIG. 17. ISO RELAXATION CURVES FOR WASPALOY AFTER 240 HOURS.

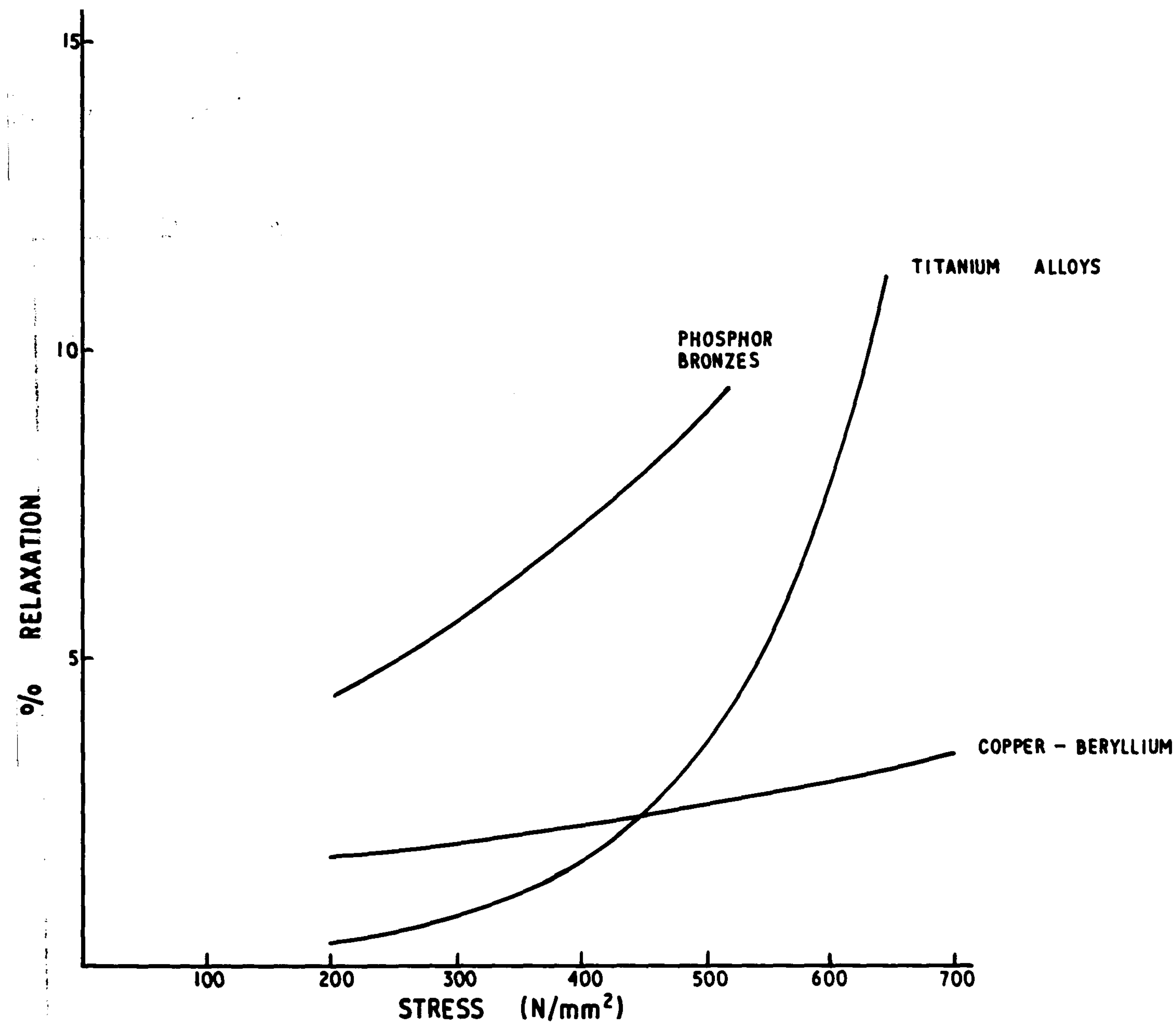

FIG. 18 STRESS RELAXATION OF NON-FERROUS SPRING MATERIALS AT 100°C.

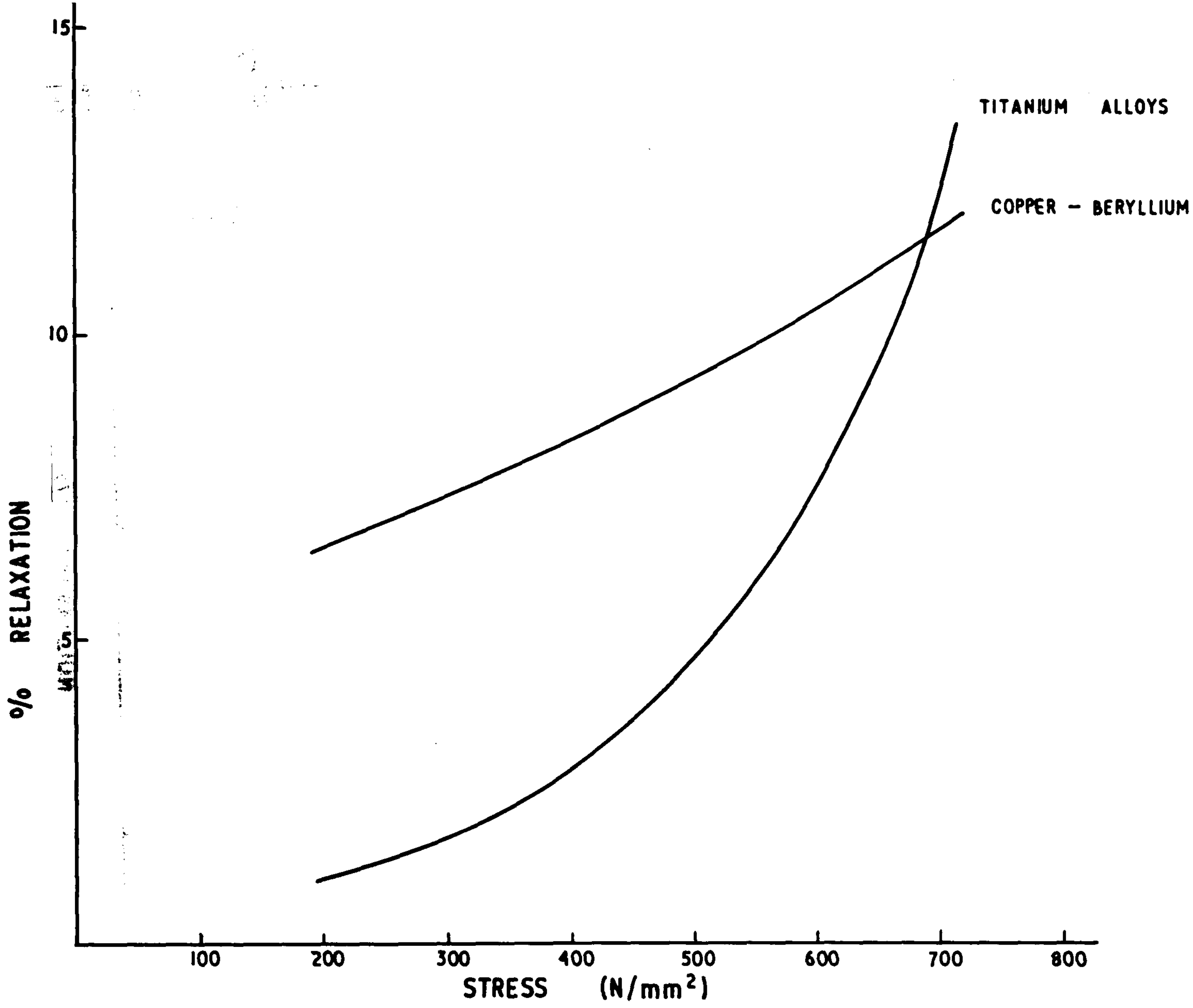

FIG. 19 STRESS RELAXATION OF NON-FERROUS SPRING MATERIALS AT 150°C.

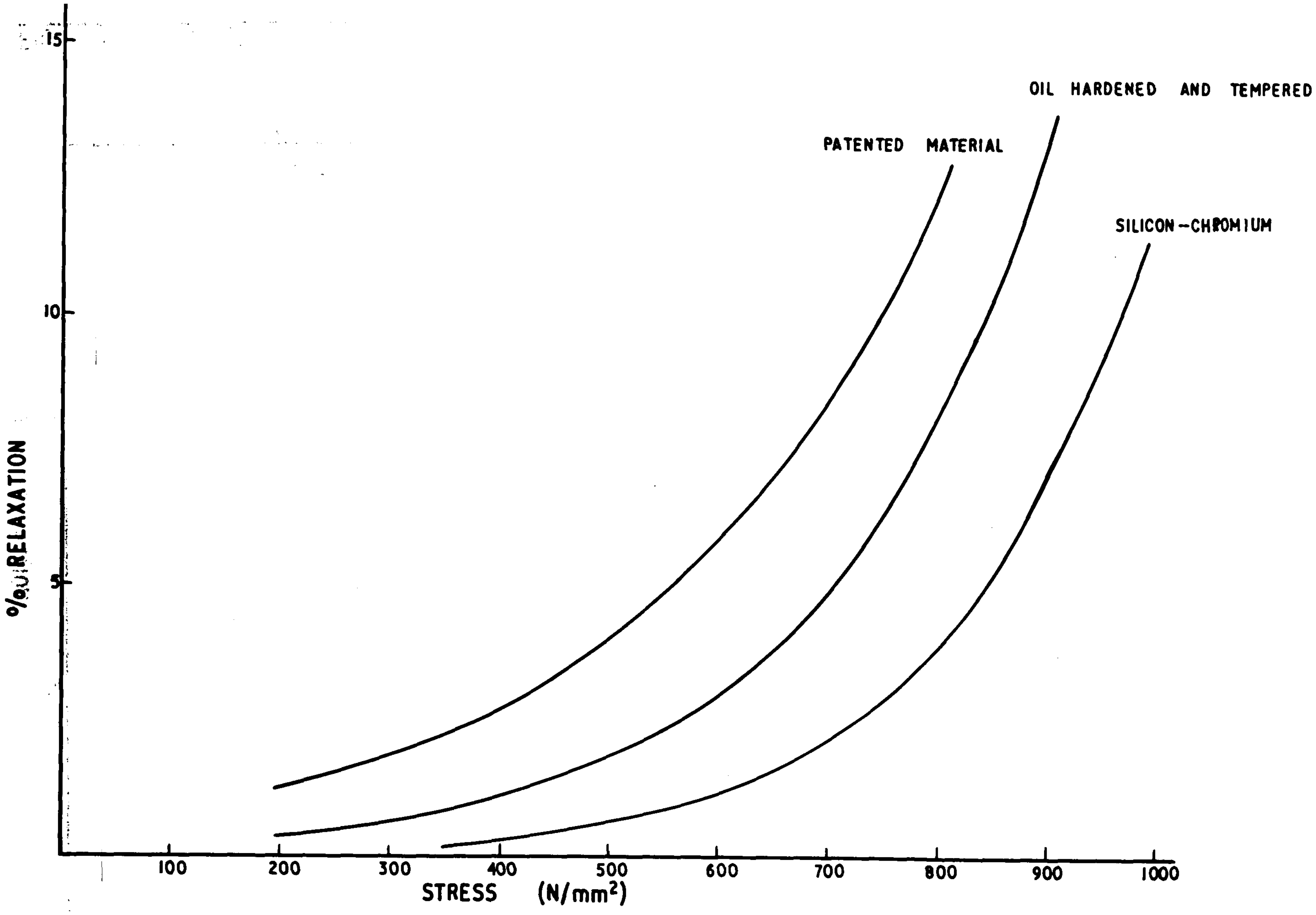

FIG. 20 STRESS-RELAXATION OF FERROUS SPRING MATERIALS AT 100°C.

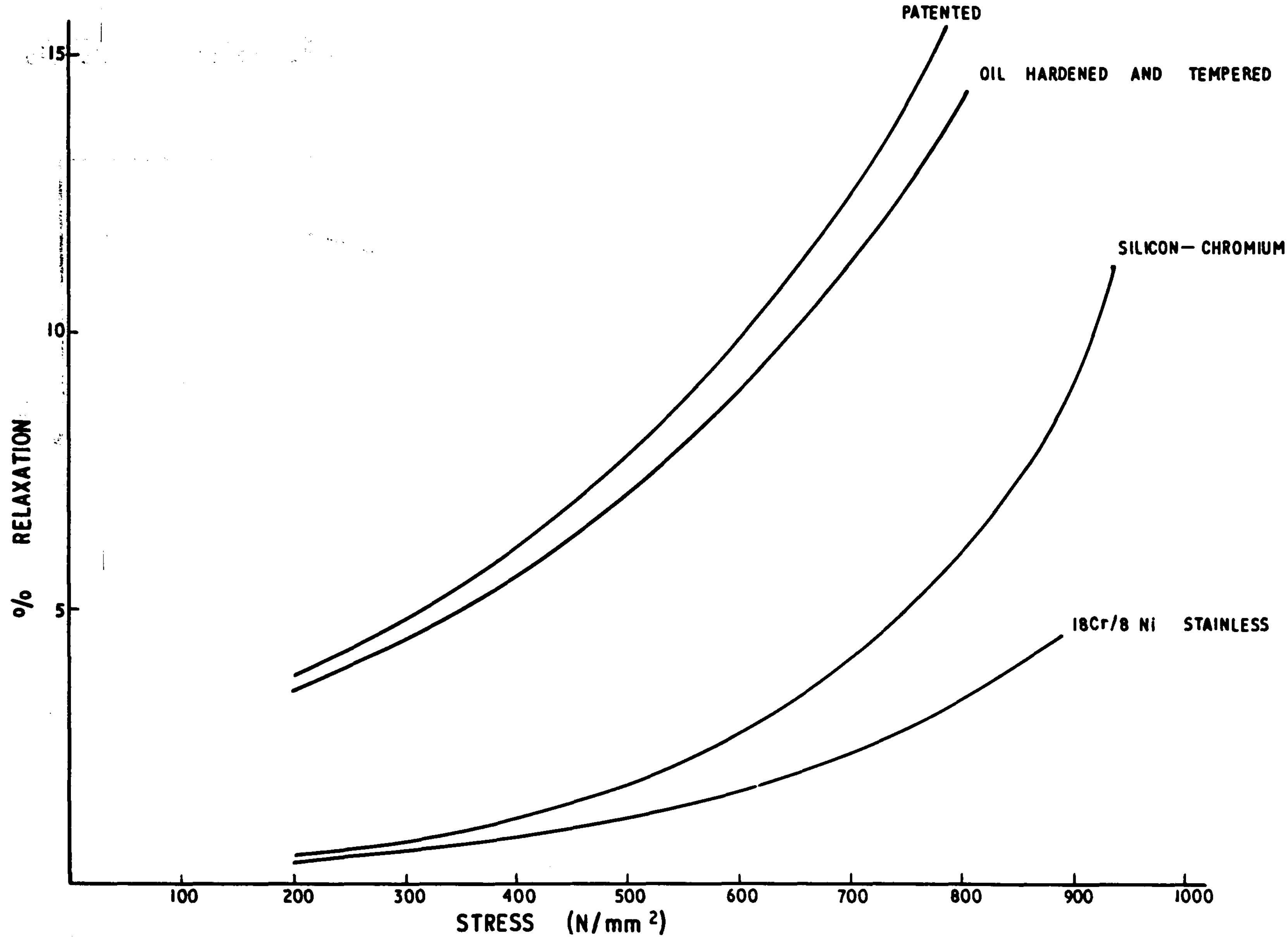

FIG. 21. STRESS RELAXATION OF FERROUS SPRING MATERIALS AT 150° C.

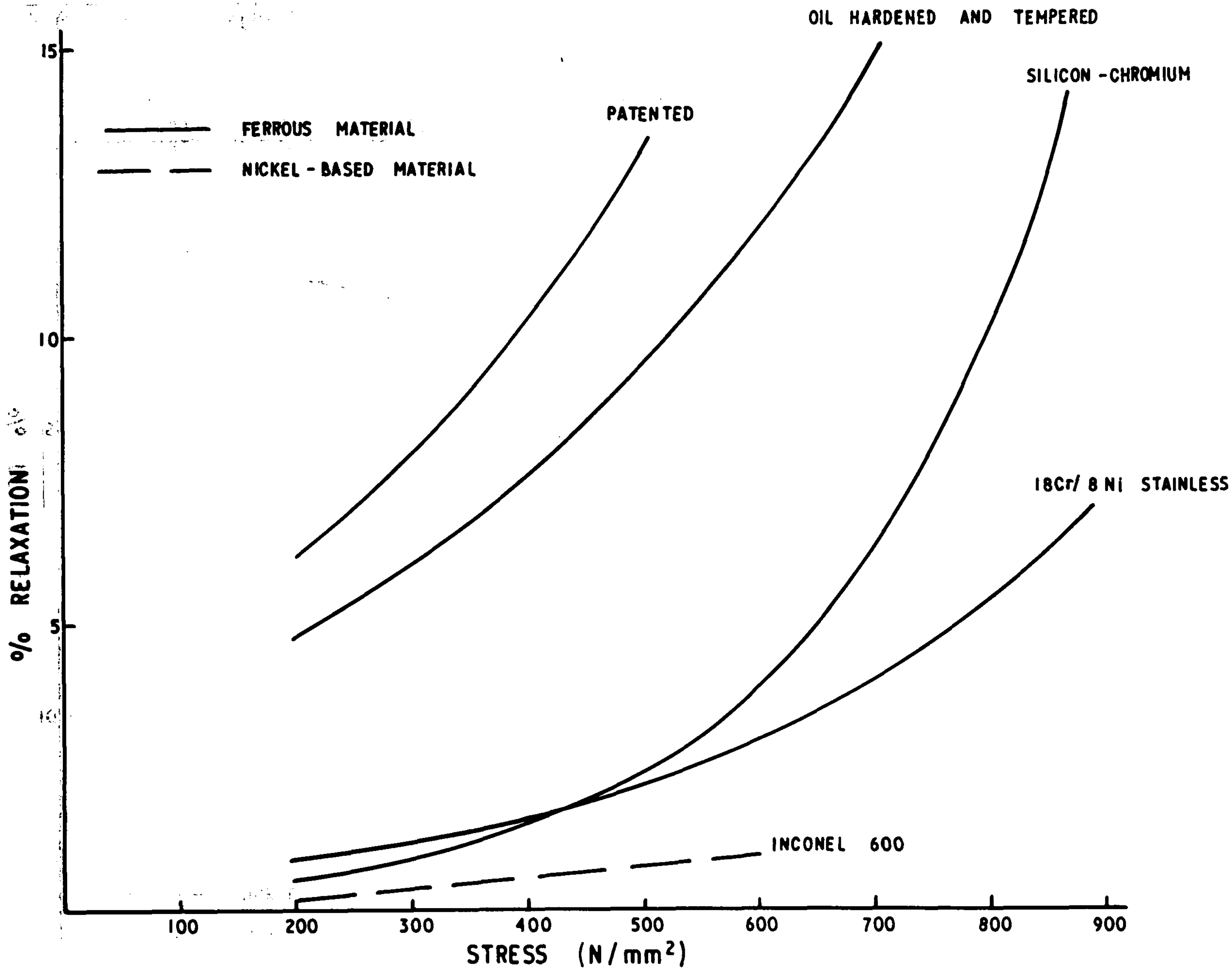

FIG. 22 STRESS RELAXATION OF VARIOUS SPRING MATERIALS AT 200°C.

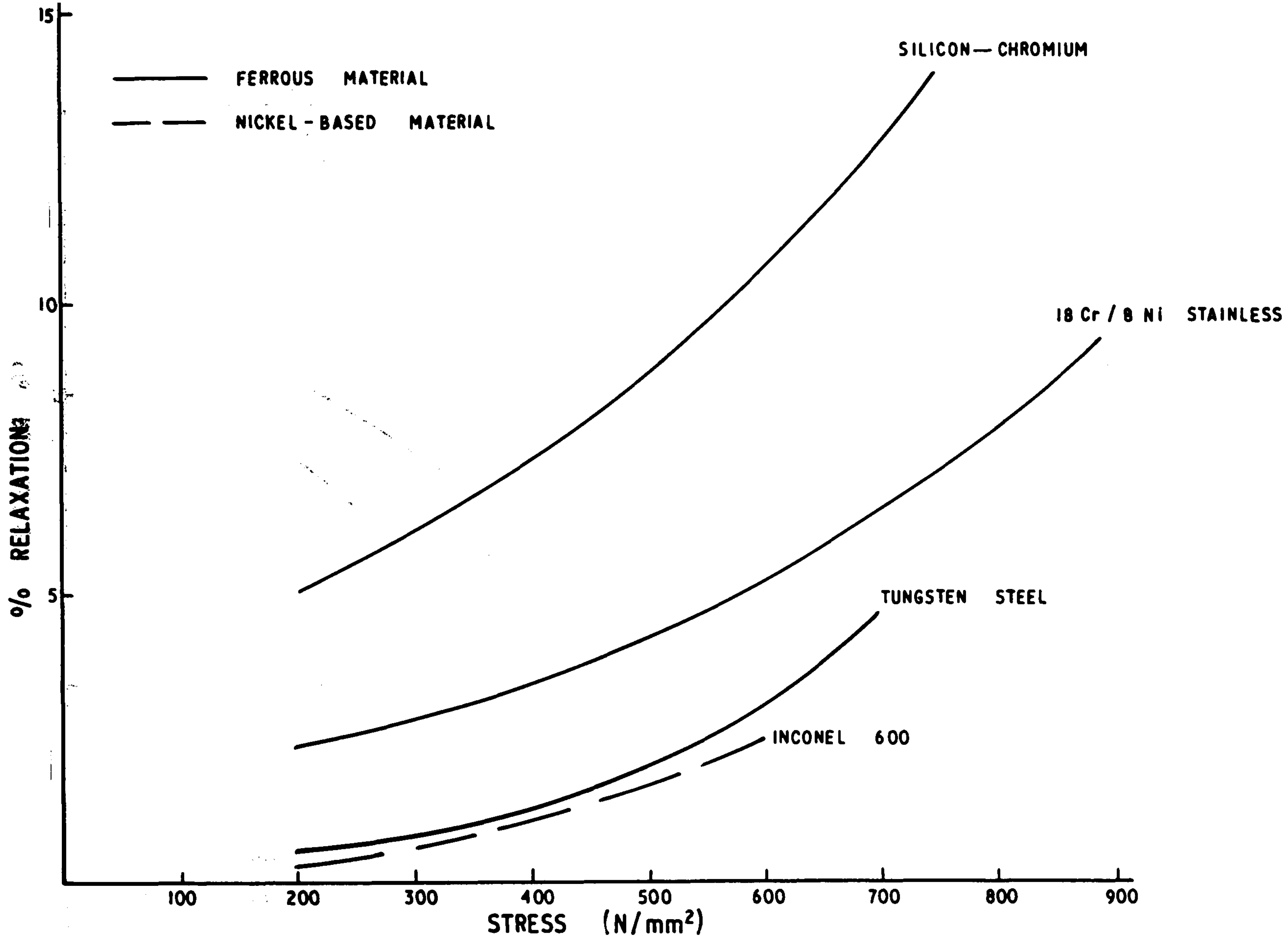

FIG. 23. STRESS RELAXATION OF VARIOUS SPRING MATERIALS AT 250°C.

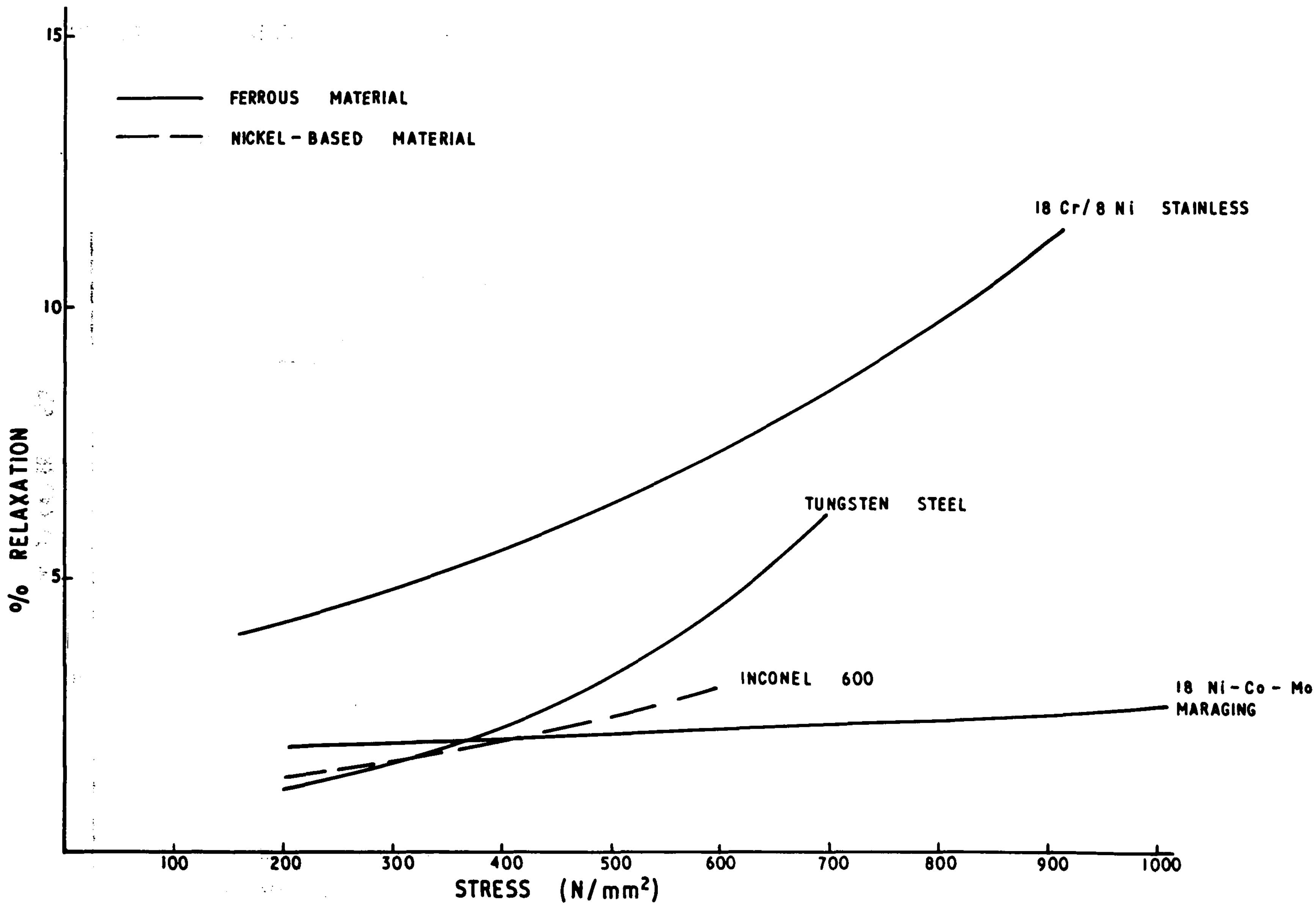

FIG. 24. STRESS - RELAXATION OF VARIOUS SPRING MATERIALS AT 300°C.

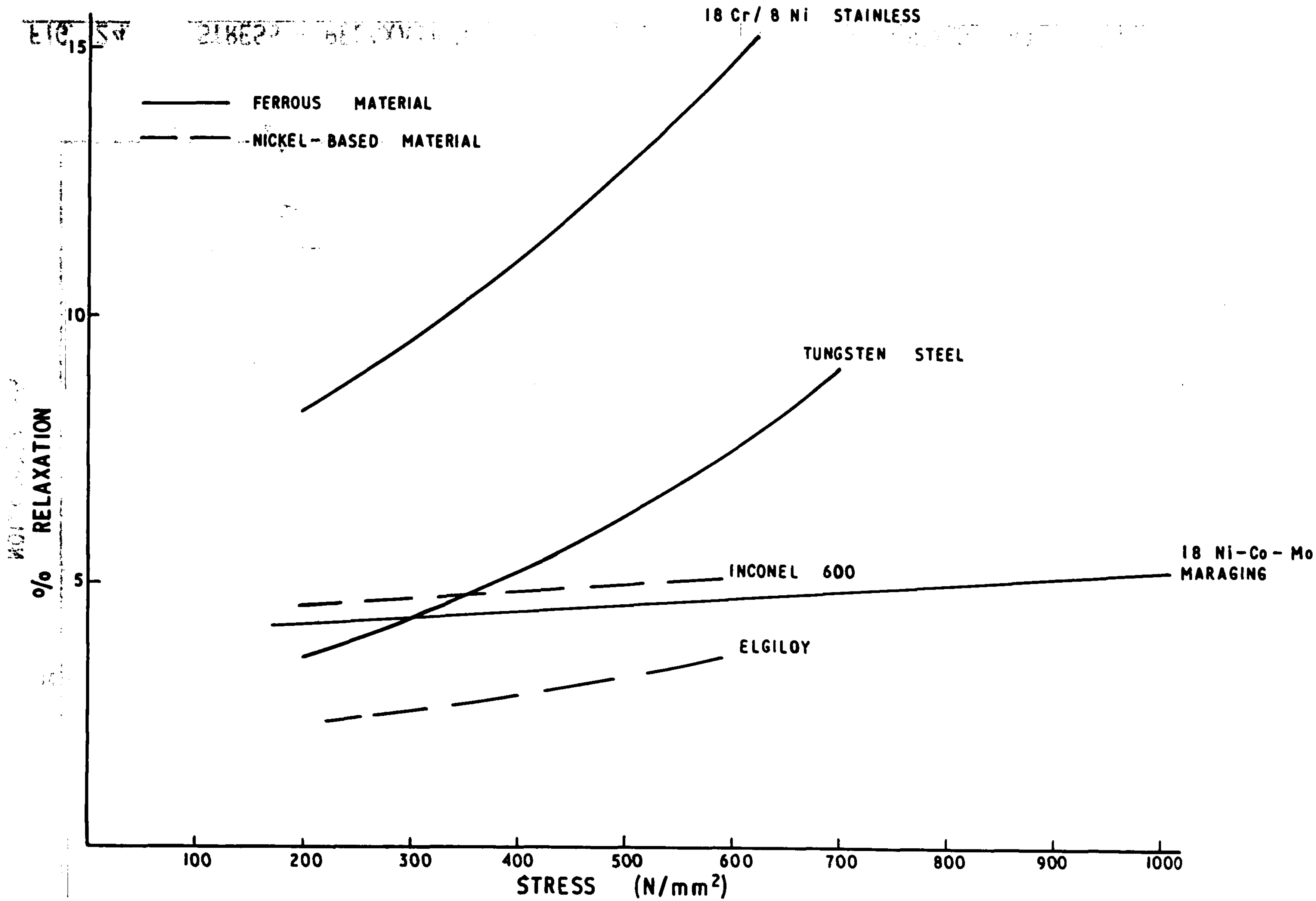

FIG. 25. STRESS RELAXATION OF VARIOUS SPRING MATERIALS AT 350°C.

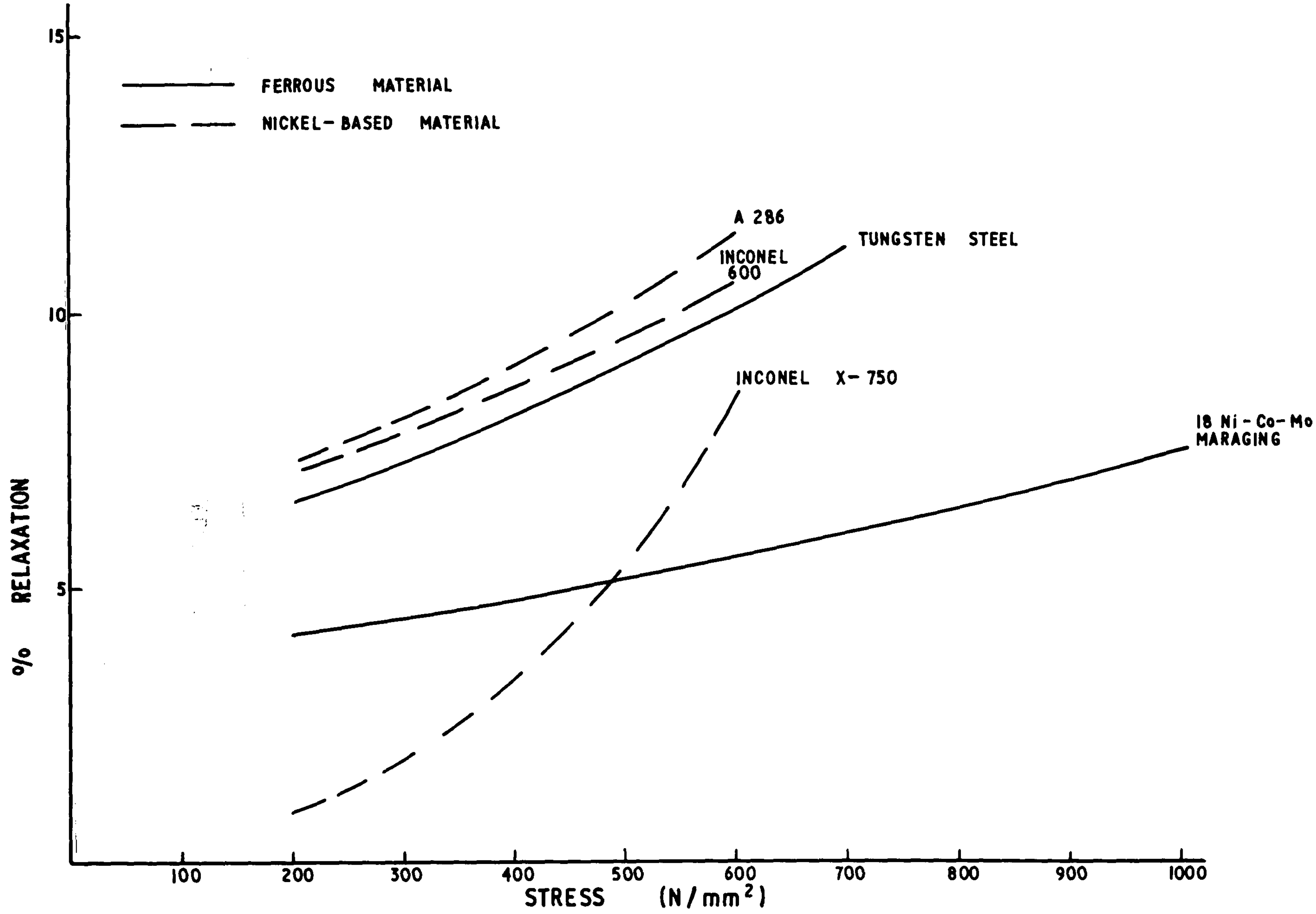

FIG. 26. STRESS RELAXATION OF VARIOUS MATERIALS AT 400° C.

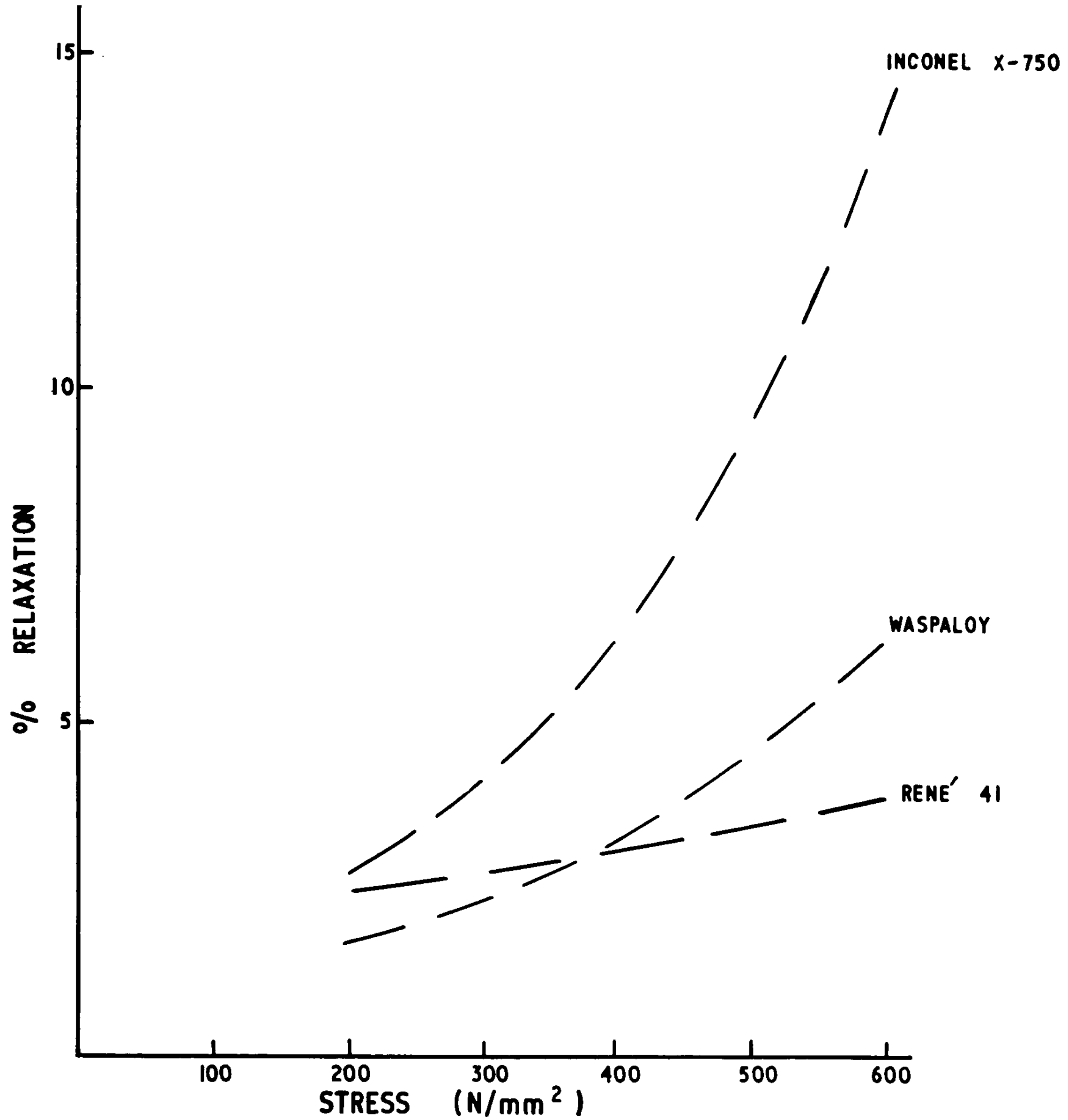

FIG. 27. STRESS RELAXATION OF NICKEL - BASED MATERIALS AT 450°C.

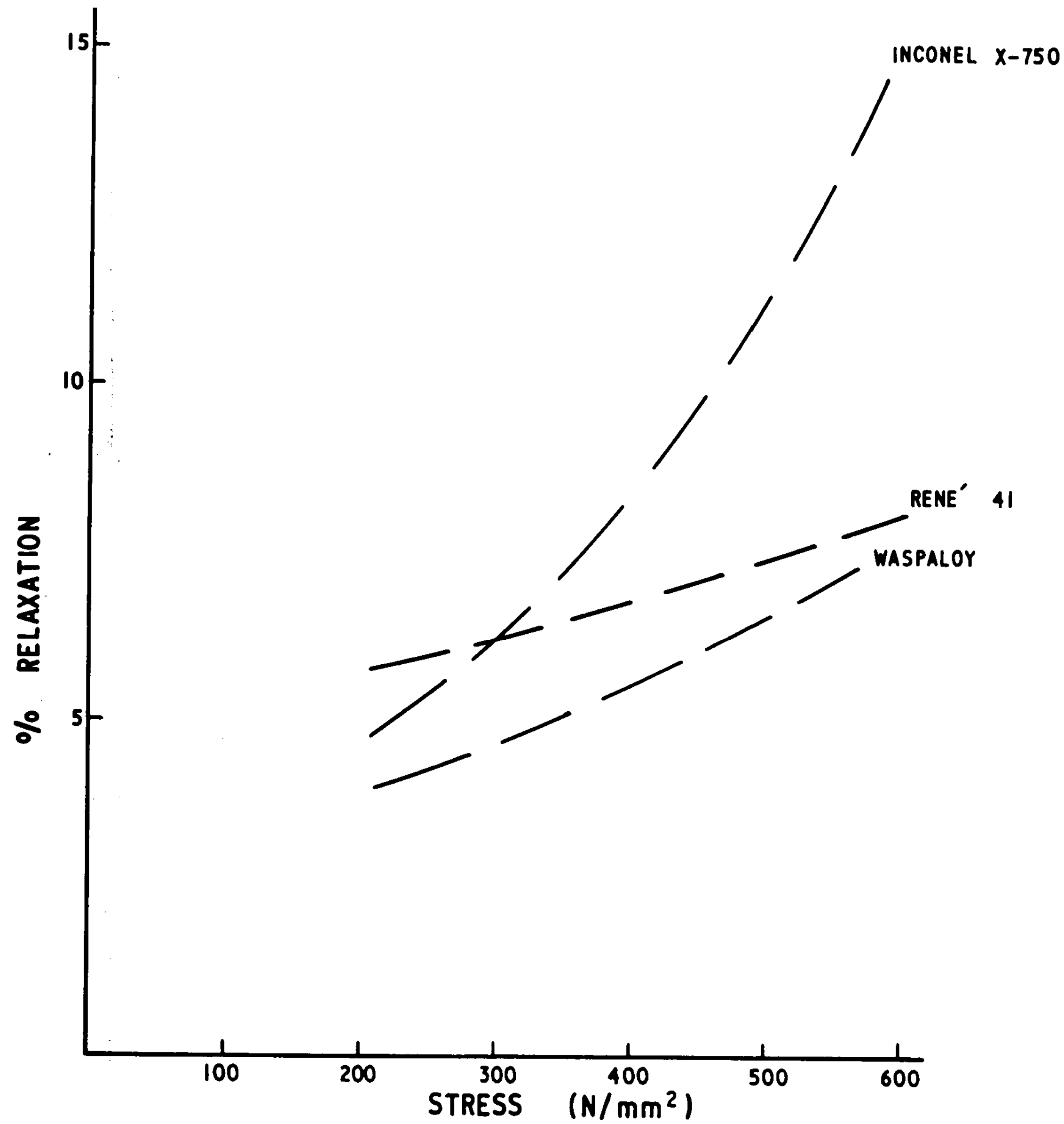

FIG. 28. STRESS RELAXATION OF NICKEL-BASED MATERIALS AT 500°C.

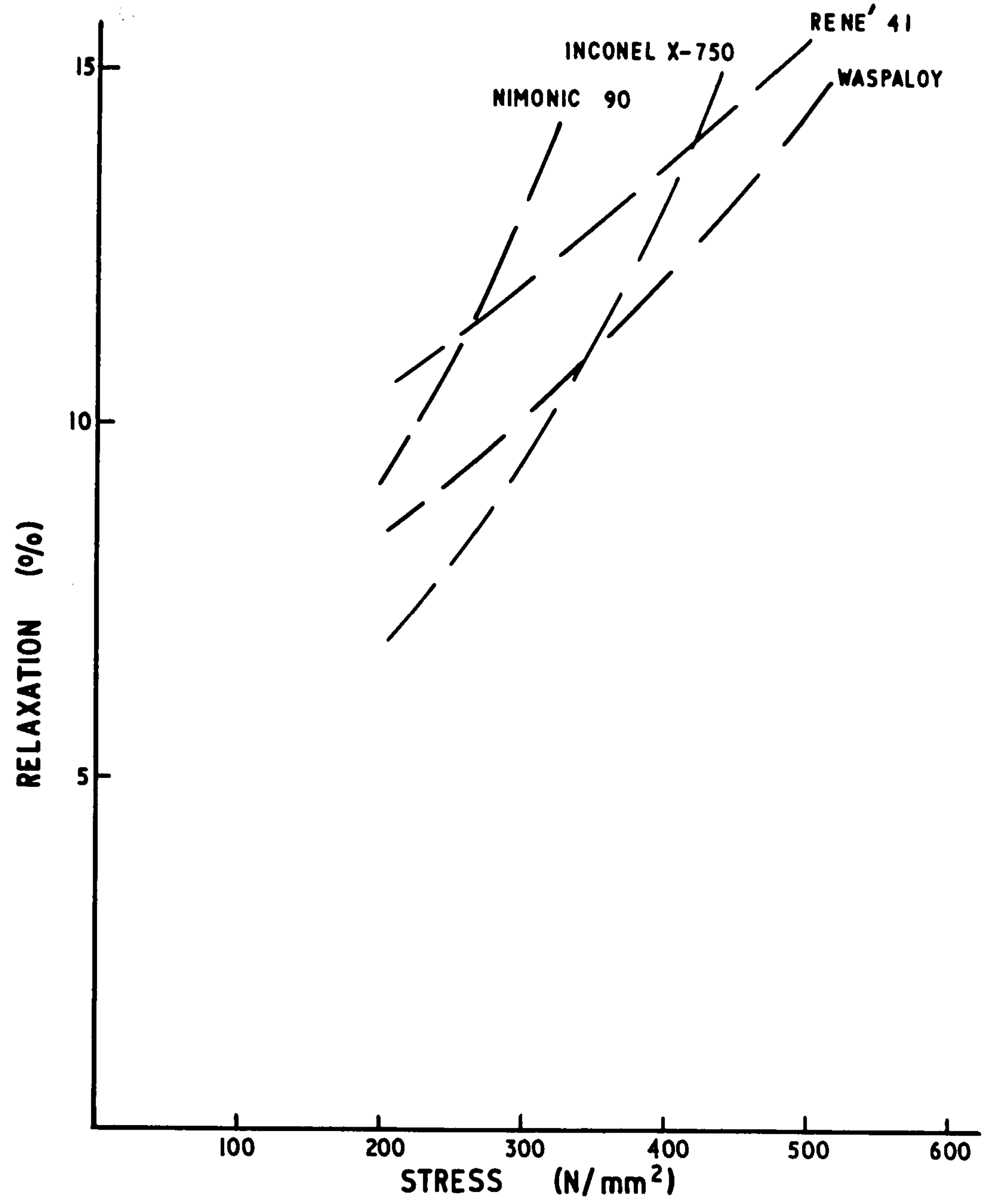

FIG. 29. STRESS RELAXATION OF NICKEL - BASED MATERIALS AT 550°C.