THE SPRING RESEARCH ASSOCIATION

THE STRESS TEMPERATURE RELAXATION PROPERTIES OF 9% TUNGSTEN HOT WORK DIE STEEL SPRINGS

by

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SUMMARY

The effect of temperature, time and stress on the relaxation properties of unpeened helical compression springs manufactured from 3.2 mm diameter, 9% tungsten hot work die steel wire, have been investigated.

The maximum permissible static operating temperature was found to vary between 350 and 400°C, dependent upon the initial stress utilised. Comparisons made with 18% tungsten high speed tool steels, showed the material under test to be slightly superior at all test temperatures and working stresses up to 600 N/mm^2.

The temperature resistant properties of 9% tungsten tool steel, are thus evident, and these together with it's relatively low cost and availability make it an attractive substitute for many other high temperature alloys, working at temperatures up to 400°C.

CONTENTS

CONTENTS (Cont.)

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1. INTRODUCTION

Investigations to correlate the effect of temperature, stress and time on the static relaxation properties of helical compression springs manufactured from a variety of spring materials have been made by the SRA.[1,2,3,4]

The results of these investigations indicate that carbon steel can be used up to a maximum operating temperature of 150°C, that stainless steel can be used up to 250°C and that René 41, Waspalloy, M 252 and Nimonic alloys at temperatures in excess of 500°C.

Previous work has also shown that A286, Elgiloy and 18% tungsten H.S.S. can be used in the temperature range 350-400°C. Of these materials A286 is not readily available and Elgiloy is prohibitively expensive for most applications, this leaves the 18% tungsten H.S.S. as the only material which has been investigated for this important temperature range. The work reported here is an investigation into the relaxation properties of 9% tungsten H.W.D.S. and a comparison of the properties of this material with those of the 18% tungsten H.S.S. which has been previously investigated.

2. MATERIAL

2.1 Wire

A nominal 9% tungsten hot work die steel wire of 3.2 mm diameter was obtained in the bright annealed condition.

The actual chemical analysis is shown in Table I.

2.2 Springs

Springs were coiled over length, such that after end grinding, heat treatment and prestressing, they complied with the design given in Table II.

3. EXPERIMENTAL PROCEDURE

3.1 Heat Treatment

Although the tungsten type tool steels are less susceptible to decarburisation than the molybdenum bearing high speed tool steels, special precautions had to be taken when heat treating the springs.

The whole consignment of springs was pre-heated in salt to 850°C, and then transferred to a salt bath at 1100°C for a minimum period of time sufficient to allow the springs to attain the above temperature and then quenched in oil. When 'hand warm', they were immediately tempered in salt at 590°C for approximately 2 hours. Following cooling they were given a second temper at the above temperature for approximately one hour, to produce a hardness of approximately 470 HV. The purpose of the double tempering operation is to relieve the internal stresses which are set up during the transformation of austenite to martensite on cooling of the steel to room temperature, and also to temper the untempered martensite produced as a result of the breakdown of retained austenite on cooling from the first temper.

3.2 Metallographic Examination

Longitudinal and transverse specimens were taken from sample springs and examined under the microscope in the unetched and etched conditions. In the polished and unetched condition no internal or surface defects could be seen.

After etching in 2% Nital for a suitable period of time, the specimens revealed a typical tool steel structure of mixed austenite grain size containing fine tempered martensite, with small carbide precipitates randomly dispersed throughout the section. Examination of the periphery of the transverse sections revealed areas of partial decarburisation, at levels below 1% of the wire diameter.

3.3 Relaxation Tests

All springs were cold prestressed prior to testing and were found to lose approximately 10.5 mm in height, an equivalent reduction in solid stress of 400 N/mm^2 (1500 to 1100 N/mm^2).

A detailed account of the experimental procedure used to determine the relaxation properties is contained in SRA report No. 115. This briefly consists of calculating the load required to produce the desired stress within the spring using the standard formula and curvature correction factor. The spring was then compressed to the predetermined load P_1, and the loaded length measured L_1.

Each was then fitted over a Monel bolt and compressed to the desired length by means of nuts and washers.

With carbon and low alloy steels the primary relaxation occurs within the first 72 hours of test, however, with materials such as austenitic, martensitic and precipitation hardening stainless steels, the primary relaxation (Logarithmic creep) occurs within the first 7 days (168h).

To establish the most suitable time period for testing, preliminary relaxation tests were carried out at 400°C for a total period of 300 hours, at three stress levels of 200, 400 and 700 N/mm^2 (Fig. 1).

After each increment of time springs were allowed to cool and unloaded. The new load P_2 at the original compressed length L_1 was measured and from these data the percentage relaxation calculated.

$$\%R = \frac{P_1 - P_2}{P_1} \times 100$$

For each test condition, three springs were used and the results averaged. All stress calculations were based on the ambient temperature rigidity modulus and no correction was made to the stress values due to the reduction of rigidity modulus with increase in temperature.

Additional springs were then subjected to temperatures between 250 and 400°C, at a stress of 200 to 700 N/mm^2 for 168 hours (Fig. 1). The test period of 168 hours was selected in order to make a direct comparison with the data previously obtained for the 18% tungsten H.S.S.

4. DISCUSSION

4.1 Relaxation Properties

The relaxation properties of the springs under investigation are tabulated in Table III and plotted graphically in Figs. 1 and 2. It can be seen that temperature, time and stress influence the relaxation properties of the springs. From Fig. 1 it can be seen that the relaxation properties obtained at each stress level follow a similar graphical relationship, although generally increased by the influence of stress. Rapid primary creep occurred during the first 50 hours of the test when the effect of stress on the relaxation properties is evident. Beyond this time the creep rate for all tests remained virtually constant up to the maximum test period of 300 hours.

The influence of stress on the relaxation properties of springs, can be also seen in Fig. 2, which indicates a similar relationship at all temperatures. The maximum tolerable relaxation in general is normally quoted as 10%, and using this value in Fig. 2, it can be seen that the maximum operating temperature is approximately 400°C, at a maximum stress level of 600 N/mm^2.

Fig. 3 gives the relaxation properties of an 18-4-1 high speed tool steel,[1] and shows how relaxation is virtually insensitive to stress. This difference in behaviour of the two tungsten tool steels may be due to the intrinsic properties of the material or it may be due to the fact that the springs in the two sets of tests, had received very different amounts of prestressing. The solid stress of the 9% tungsten H.W.D.S. after prestressing was approximately 70% of the U.T.S. of the material while in the case of the 18% tungsten H.S.S. the solid stress was only 50% of the U.T.S. of the material and the material was always stressed within its material elastic limit.

From the experimental data available it can be concluded that both the 18% tungsten H.S.S. and the 9% tungsten H.W.D.S. can be used up to a temperature of 400°C where a 10% relaxation is acceptable.

Fig. 4 compares the relaxation properties of austenitic and precipitation hardened stainless steel, and up to 300°C they appear to be similar to those for 9% tungsten steel. However, above 300°C, the mechanical properties of the stainless steels begin to deteriorate drastically, with a corresponding decrease in relaxation resistance.

It is quite clear therefore that hot worked die steels and high speed tool steels can adequately fill the temperature range between 300°C and 400°C (Table IV).

Table VI shows the approximate relative costs of the materials discussed, and it will be seen that the comparative low cost, together with its availability make 9% tungsten tool steel an attractive substitute for other high temperature materials, working at temperatures up to 400°C.

Above 400°C there is a need for greater stability which necessitates the use of heat resistant alloys such as Nimonic 90, Inconel X-750, René 41 or Waspalloy as detailed in Table V and references 3 and 4.

5. CONCLUSIONS

1. Unpeened helical compression springs manufactured from 9% tungsten hot work die steel, have a maximum static operating temperature between 350 and 400°C, dependent upon the service stress and the amount of relaxation that can be tolerated.

2. The relaxation properties of hot work die steel springs are dependent upon both temperature and stress for a given period of time at temperature.

3. 9% tungsten hot work die steel springs possess slightly superior relaxation properties to high speed tool steel springs at stresses up to 600 N/mm^2.

4. 9% tungsten die steels have similar relaxation properties to stainless steel springs up to 300°C. Above this temperature the tungsten springs possess better relaxation resistance than stainless springs.

6. REFERENCES

1. Graves G.B. "The Stress-Temperature Relaxation and Creep Properties of Some Spring Materials"

SRA Report No. 143

2. Graves G.B. "The Stress Relaxation Properties of Nimonic 90 and Inconel X-750 Helical Compression Springs"

SRA Report No. 152

3. Graves G.B. "A Note on the Effect of Heat Treatment on the Stress Temperature Relaxation Properties of Nimonic Alloy 90 Helical Springs"

SRA Report No. 162

4. Graves G.B. and Key T. "The Stress Temperature Relaxation Properties of Some High Temperature and Corrosion Resistant Materials".

SRA Report No. 194

5. The Spring Research Association. "Springs: Materials/Design/Manufacture".

TABLE I CHEMICAL COMPOSITION OF 9% W WIRE

CARBON %	CHROMIUM %	TUNGSTEN %	VANADIUM %
0.30	2.88	9.52	0.39

TABLE II SPRING DESIGN DATA

Wire Diameter	3.2 mm
Spring Mean Diameter	26 mm
No. of Active Coils	3.5
No. of Total Coils	5.5
Free Length After End Grinding and Prestressing	43.6 mm
Solid Stress After End Grinding and Prestressing	1098 N/mm^2

TABLE III   RELAXATION DATA OF 9% TUNGSTEN STEEL SPRINGS

STRESS N/mm²	% RELAXATION AFTER 168 h			
	250°C	300°C	350°C	400°C
200	0.2	1.2	3.3	7.1
300	0.7	1.7	4.5	6.9
400	1.2	2.1	5.[illegible]	7.9
500	2.0	3.3	6.1	8.7
600	3.0	4.4	7.4	10.5
700	4.6	6.5	8.8	11.2

STRESS N/mm²	TEMPERATURE °C	% RELAXATION						
		TIME (h)						
		3	9	33	48	113	200	296
200	400	1.6	5.0	6.0	6.3	6.1	7.5	8.0
400	400	5.4	6.2	6.6	7.1	7.0	8.0	9.5
700	400	8.2	9.3	10.3	10.3	10.8	11.5	12.4

TABLE IV MAXIMUM OPERATING TEMPERATURES FOR VARIOUS SPRING MATERIALS[5]

MATERIAL	APPROXIMATE MAXIMUM OPERATING TEMPERATURE °C
Waspalloy, M252, René 41 Nimonic 90, Inconel X-750	450 - 550
Hot Work Die Steel	370 - 400
Stainless Steels En 56, En 58, 17-7 PH	300
Chromium-Silicon En 48A	250
Chromium-Vanadium En 47, En 50	200
Hardened and Tempered Carbon Steel BS 2803	170
Patented and Cold Drawn Carbon Steels BS 1408	150

TABLE V THE RELAXATION PROPERTIES OF HIGH TEMPERATURE SPRING MATERIALS (250 h) (3)

MATERIAL	STRESS N/mm^2	TEMPERATURE ^oC	% RELAXATION
Nimonic 90	207	300	0.5
4h - 750°C	207	350	0.6
	207	400	0.8
	345	350	0.8
	345	400	1.0
Inconel	207	350	0.5
X 750	207	400	1.5
24h - 840°C	345	300	1.5
	345	400	2.0

TABLE VI APPROXIMATE RELATIVE COSTS OF TEMPERATURE RESISTANT MATERIALS (3 mm WIRE)

MATERIAL	£/Kilo
Elgiloy	18.50
Nimonic Alloy 90	4.00
17-7 PH	3.50
A286	2.25
18% Tungsten H.S.S.	1.70
9% Tungsten H.W.D.S.	1.30
18/8 Stainless Steel	0.75

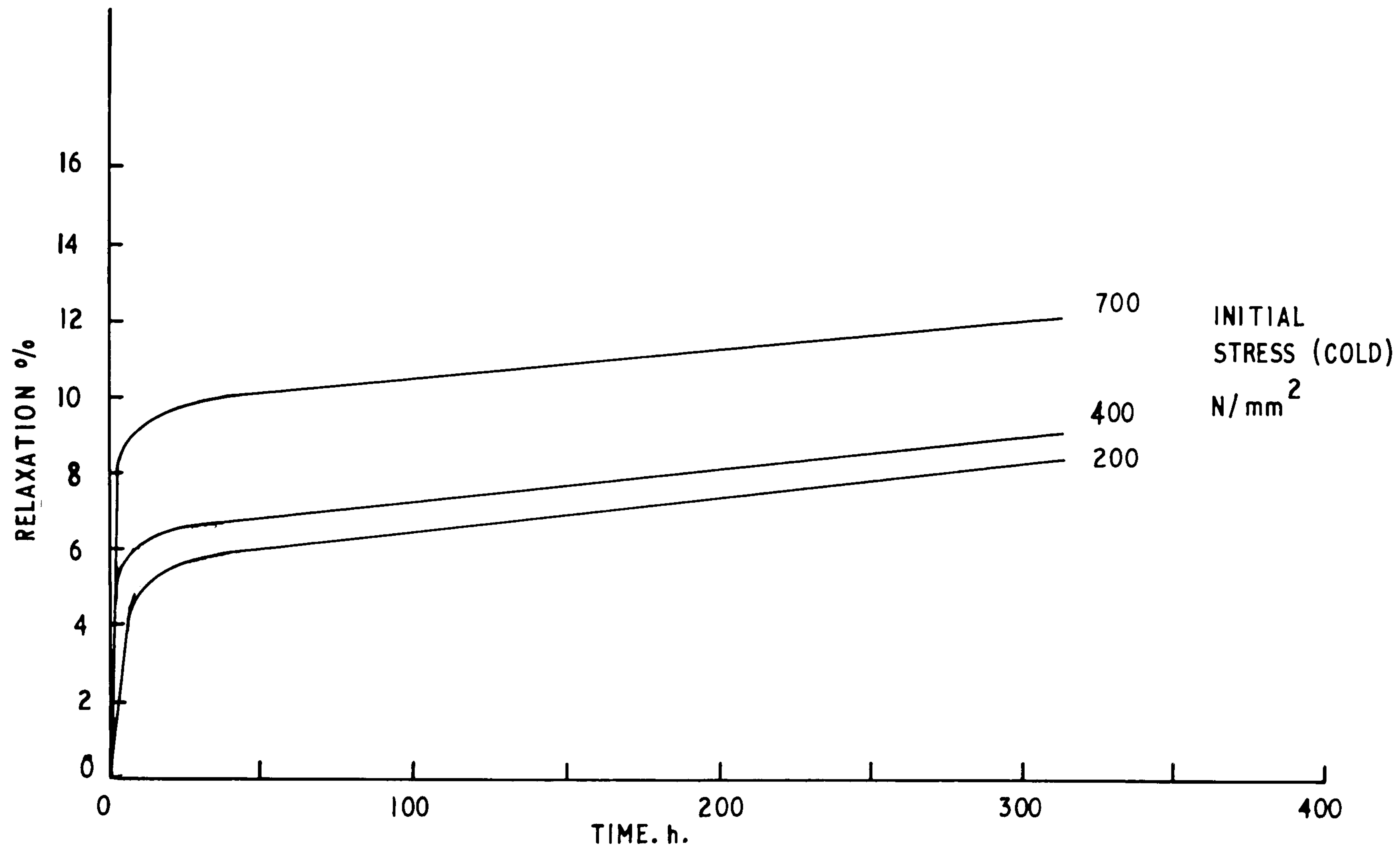

FIG 1 THE EFFECT OF TIME ON THE RELAXATION PROPERTIES OF 9% TUNGSTEN SPRINGS AT 400°C

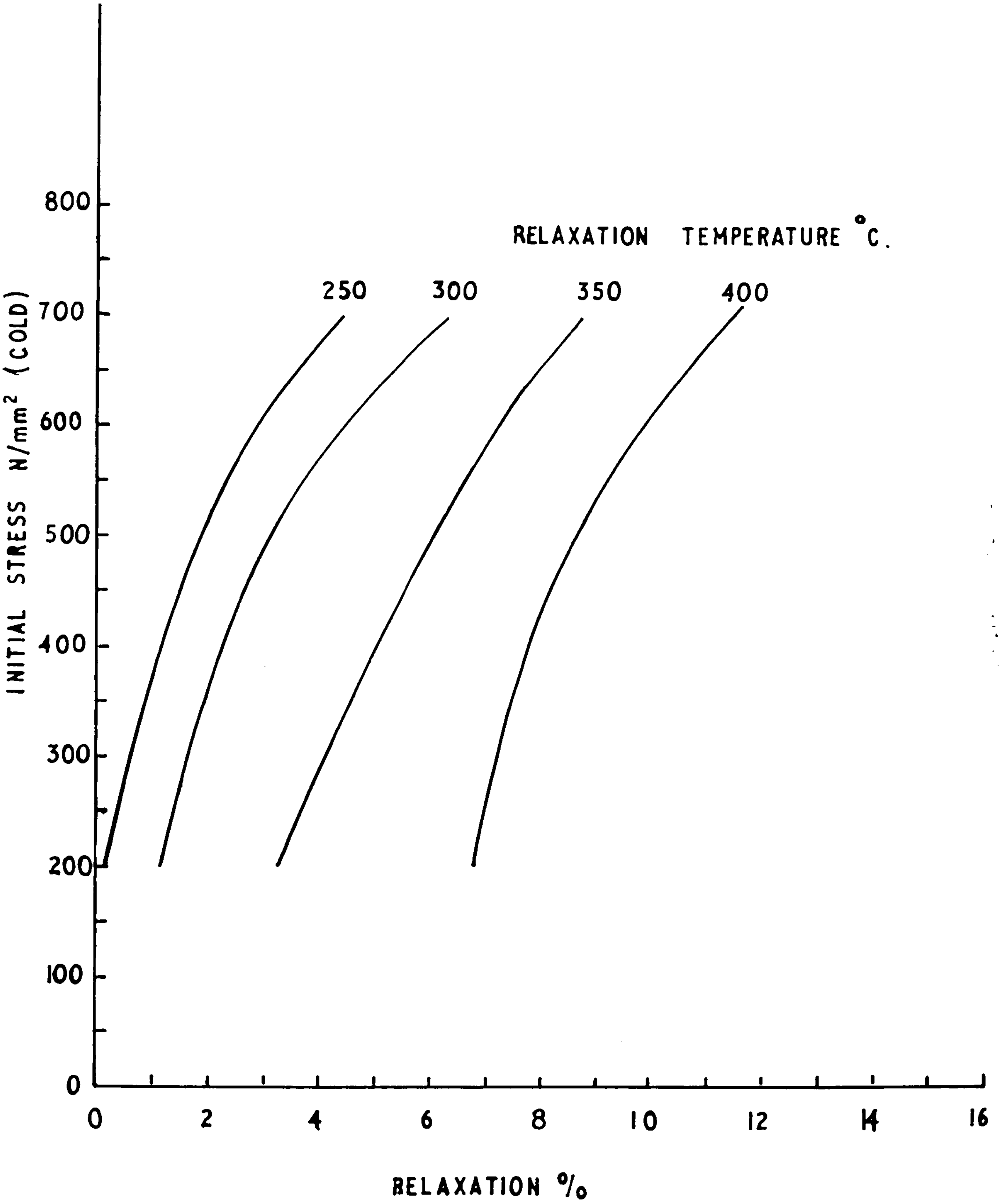

FIG. 2. STRESS TEMPERATURE RELAXATION PROPERTIES OF 9 % TUNGSTEN HOT WORK DIE STEEL SPRINGS. (168 h.)

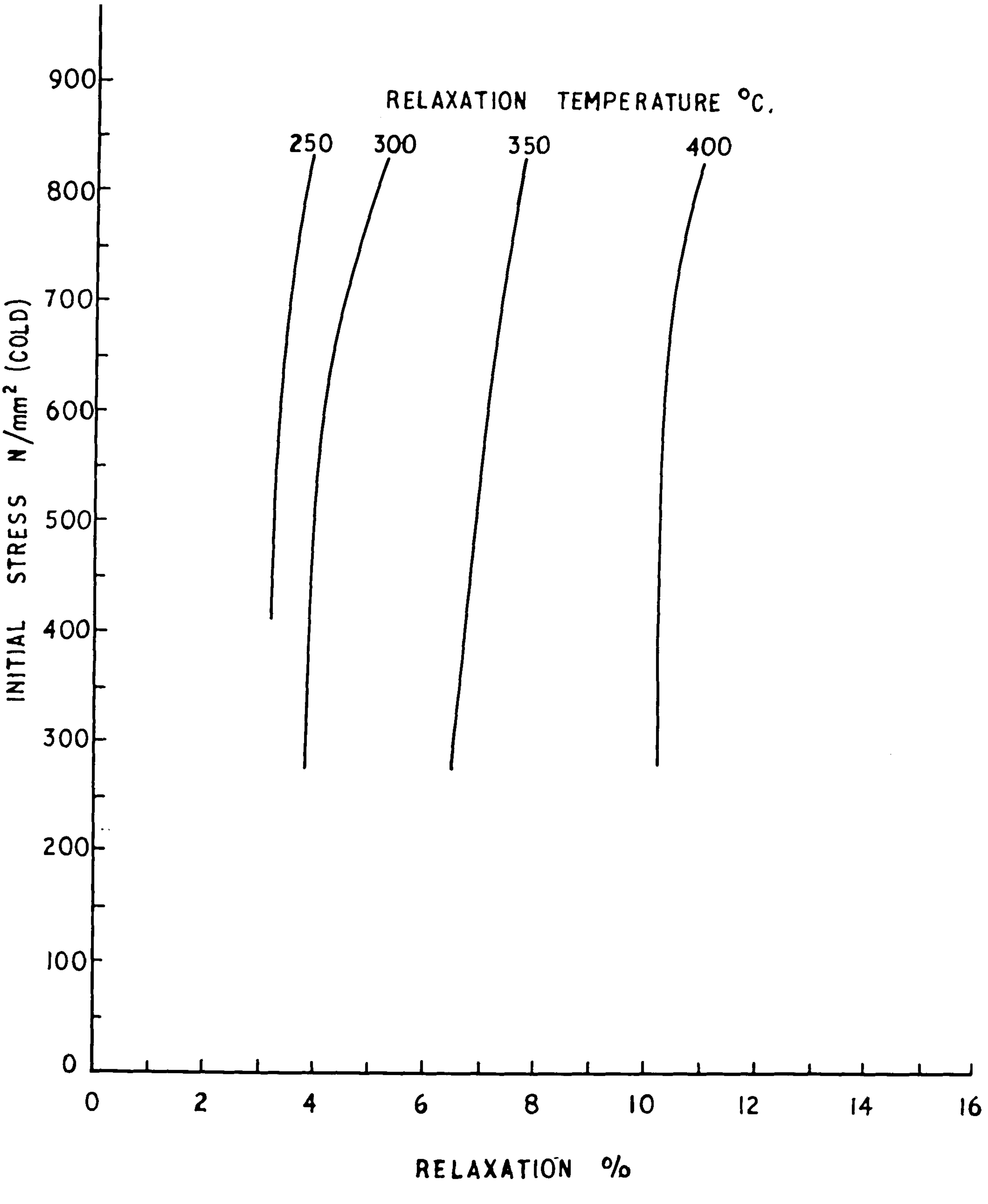

FIG. 3. STRESS TEMPERATURE RELAXATION PROPERTIES OF 18-4-1 HIGH SPEED STEEL WIRE SPRINGS (168 h)

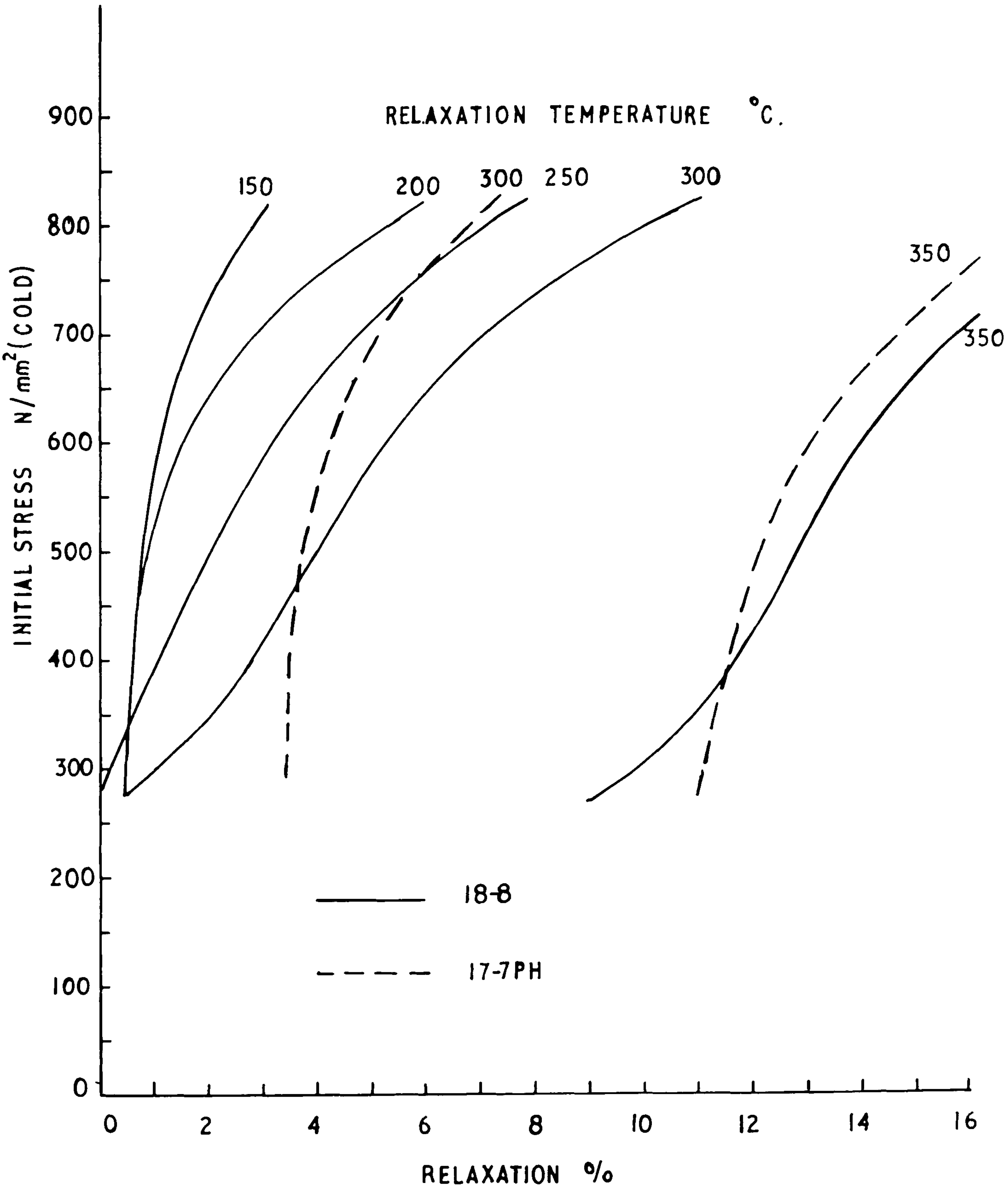

FIG 4 STRESS TEMPERATURE RELAXATION PROPERTIES OF STAINLESS STEEL SPRINGS

(168 h.)