THE SPRING MANUFACTURERS' RESEARCH ASSOCIATION

# The Stress-Temperature Relaxation and Creep of Some Spring Materials

Report No. 143

by

G.B. Graves, A.Met., A.I.M.

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### Summary

The relationships between stress, temperature and time in respect of relaxation of stress of helical compression springs made from twelve ferrous and non-ferrous materials have been determined.

In a number of cases the effects of hot setting prior to testing have been measured.

For the materials examined a stress relaxation "merit" table has been constructed.

A comparison has been made between the load loss resulting from constant deflection conditions and constant load conditions.



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# THE STRESS-TEMPERATURE RELAXATION AND CREEP PROPERTIES OF SOME SPRING MATERIALS

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## 1. INTRODUCTION

In service a spring may be required to sustain a constant load, to apply a reasonably constant force at a specific length, or may be working between two defined lengths or loads at ambient or some elevated temperature. At elevated temperatures the elastic strain in the outer fibres of a helical compression spring under load is gradually changed to plastic strain with permanent set occurring. It is usual to denote settling which occurs under constant load as "creep" and settling which occurs under constant length as "relaxation".

Under creep conditions, the load, hence the stress, remain constant throughout the service or test period whereas under fixed deflection conditions the load, hence the stress, are progressively decreased. It will be evident from this that the amount of settling which takes place under relaxation conditions is less than that which will occur under creep conditions for similar initial stresses.

Previous reports circulated by the Association have surveyed the published data(1) available on the subject of stress temperature relaxation of springs and reported the stress temperature relaxation behaviour of springs made from oil tempered and patented hard drawn wires.(2)

Further relaxation and creep investigations have been undertaken on helical compression springs made from a wide variety of spring materials and this data is the subject of the present paper.

## 2. MATERIALS INVESTIGATED

A wide range of materials were examined with the object of determining their stress-temperature relaxation characteristics. Table I indicates their compositions and Table II the heat treatments used during manufacture.

Table I

| Material | Origin of Analysis | %C | % Mn | % Si | % S | % P | Others |
|---|---|---|---|---|---|---|---|
| Music wire | Cast | 0.92 | 0.42 | 0.27 | 0.019 | 0.012 | |
| Oil tempered valve wire | Cast | 0.68 | 0.65 | 0.26 | 0.020 | 0.013 | |
| Commercial oil tempered wire | Cast | 0.64 | 0.76 | 0.21 | 0.025 | 0.025 | |
| Chromium-silicon | Cast | 0.54 | 0.62 | 1.50 | 0.014 | 0.016 | 0.62 Cr |
| D.T.D.4A (air melt) | Nominal | 0.45 | 0.60 | 0.25 | 0.02 | 0.02 | 1.25 Cr 0.20 V |
| D.T.D.4A (vac. melt) | Cast | 0.44 | 0.55 | 0.34 | 0.016 | 0.020 | 0.19 Ni 1.20 Cr 0.25 V |
| EN.49D | Cast | 0.74 | 0.48 | 0.16 | 0.015 | 0.024 | |
| EN.58A | Cast | 0.08 | 0.74 | 0.67 | 0.011 | 0.023 | 8.15 Ni 18.40 Cr |
| 17/7 PH | Cast | 0.07 | 0.77 | 0.26 | 0.008 | 0.021 | 7.25 Ni 16.97 Cr 1.24 Al |
| 18/4/1 high speed | Nominal | 0.70 | 0.30 | 0.30 | | | W 18.00 Cr 4.00 V 1.0 Mo 0.70 |
| Ti 314A | Nominal | | 4.00 | | | | 4.00 Al 92.0 Ti |
| Be-Cu | Cast | | | | | | 1.76 Be 0.11 Co 97.81 Cu |

Table II

| Material | Dia (in) | Condition(s) prior to spring making | Heat treatment after spring making | Heat treated U.T.S. ($ton/in^2$) |
|---|---|---|---|---|
| Music wire | 0.104 | patented hard drawn | L.T.H.T. 350°C | 125.8 |
| Oil tempered valve wire | 0.104 | oil tempered | L.T.H.T. 350°C | 96.5 |
| Commercial oil tempered wire | 0.104 | oil tempered | L.T.H.T. 350°C | 104.6 |
| Chromium-silicon | 0.165 | oil tempered | LTHT (i) 300°C (ii) 350°C, (iii) 400°C | (ii) 110.9 |
| D.T.D.4A (air melt) | 0.079 | annealed | 870°C O.Q. Tempered (i) 365°C, (ii) 420°C | (i) 100.0 (ii) 90.0 |
| D.T.D.4A (vac. melt) | 0.080 | annealed | 870°C O.Q. Tempered (i) 440°C, (ii) 505°C | (i) 100.0 (ii) 90.0 |
| EN.49D | 0.104 | patented, hard drawn | L.T.H.T. 350°C | 104.0 |
| EN.58A | 0.104 | hard drawn | L.T.H.T. 450°C | 104.0 |
| 17/7 PH | 0.090 | hard drawn | aged 480°C (1 hr) | 132.0 |
| 18/4/1 high speed | 0.105 | annealed | 1280°C O.Q. double temper at 540°C | 850 HV |
| Ti 314A | 0.128 | (i) Hard drawn (ii) solution treated | (i) LTHT 200°C (ii) aged at 500°C (2 hrs) | (i) 86.1 (ii) 83.4 |
| Be-Cu | 0.050 | hard drawn (62.5% R of A) | aged 315°C (2 hrs) | 99.1 |

With the exception of the high speed steel springs, all springs were prestressed during manufacture and low temperature heat treatment was carried out for a period of 30 mins. The nominal dimensions of the springs used in the investigation differed according to the wire diameters. These dimensions for each quality are given in the next table.

Table III

| Material | Wire dia (in) | Mean coil dia (in) | Free length (in) | Active coils | Total coils |
|---|---|---|---|---|---|
| Music wire | 0.104 | 0.945 | 1.65 | 3.5 | 5.5 |
| Oil tempered valve wire | 0.104 | 0.945 | 1.65 | 3.5 | 5.5 |
| Commercial oil tempered wire | 0.104 | 0.945 | 1.65 | 3.5 | 5.5 |
| Chromium-silicon | 0.165 | 1.272 | 1.90 | 3.5 | 5.5 |
| D.T.D.4A (air melt) | 0.079 | 0.85 | 1.60 | 3.5 | 5.5 |
| D.T.D.4A (vac. melt) | 0.080 | 0.85 | 1.60 | 3.5 | 5.5 |
| EN.49D | 0.104 | 0.945 | 1.65 | 3.55 | 5.55 |
| EN.58A | 0.104 | 0.900 | 1.65 | 3.5 | 5.5 |
| 17/7 PH | 0.090 | 0.875 | 1.56 | 3.5 | 5.5 |
| 18/4/1 high speed | 0.105 | 1.355 | 3.91 | 4.5 | 7.5 |
| Ti 314A | 0.128 | 0.972 | 2.60 | 4.5 | 6.5 |
| Be-Cu | 0.050 | 0.300 | 1.12 | 9.5 | 11.5 |

## 3. EXPERIMENTAL PROCEDURE

### 3.1 Stress Relaxation Tests

A detailed account of the experimental method used to determine relaxation is to be found in an earlier report.(2) Briefly, this consisted of calculating the load required to produce a stress within the spring of the desired level using the standard stress formula and curvature correction factor. Then by the use of conventional load testing machine compressing the spring to the calculated load and measuring the loaded length. 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 selected elevated temperature for a specific period of time, allowed to cool and then unloaded. The new load at the original compressed length was measured and from this data the percentage loss in stress computed. All stress calculations and load measurements were based on the ambient temperature rigidity modulus and no corrections made to the stress values quoted due to a reduction of rigidity modulus with increase in temperature.

3.2 Creep Tests

The rig used in this part of the investigation is shown schematically in Fig. 1. The spring is compressed by means of a weight of predetermined size according to the stress required. Movement of the spring at the test load and temperature was recorded by means of a dial gauge placed above the loading rod. From the dimensions of the spring the load ($P_1$) was calculated necessary to apply the selected stress. Load testing to a load of $P_1$ gave the compressed length $L_c$. The spring was then assembled in the rig without the load applied and heated to the test temperature. The spring was then loaded and the dial gauge set to zero. Readings of settling were taken, initially at short time intervals but later at longer intervals as the rate of settling decreased. After the required test period the spring was taken from the rig and when cold re-load tested by compressing to the original length $L_c$ and measuring the new equivalent load $P_2$. The percentage load loss was calculated as follows:-

$$\% \text{ Load loss} = \frac{P_1 - P_2}{P_1} \times 100$$

or since load is directly proportional to deflection the percentage load loss could be calculated from the change in length of the spring:-

$$\% \text{ Load loss} = \frac{L - L_2}{L - L_1} \times 100\%$$

where $L$ = original length of spring

$L_1$ = length of spring under load

$L_2$ = new free length of spring after creep test

With the creep test, the load calculated to give the required stress at ambient temperatures equally applied to elevated temperature conditions since the stress formula is independent of the rigidity modulus.

## 4. RESULTS

4.1 Music wire springs

The relaxation properties of this material after 72 hrs at various temperatures are shown in Fig. 2. Hot setting the springs by subjecting them to a stress 10% in excess of the test stress and a temperature 50°C in excess of the selected test temperature for 1 hour reduced the relaxation.

4.2 Oil tempered valve wire springs

In Fig. 3 the relaxation percentage after 72 hrs at each of 100, 150 or 200°C is shown for various initial stress levels. The effect of hot setting prior to testing at 150°C is demonstrated.

4.3 Commercial oil tempered wire springs

The effects of stress at temperature for a period of 72 hrs is related to percentage relaxation in Fig. 4.

4.4 Chromium-silicon wire springs

The relaxation resistance after a 72 hr test period is given in Fig. 5 for various stress and temperature levels. Fig. 6 shows the effect of three different low temperature heat treatments on the subsequent relaxation resistance and Fig. 7 the improvement in relaxation resistance due to prior hot setting the springs, 10% in excess of the test stress and $50^{\circ}C$ in excess of the test temperature.

4.5 D.T.D.4A wire springs

The relaxation resistance after 72 hrs of air and vacuum melted chromium vanadium steel both heat treated to two tensile strength levels is shown in Figs. 8 and 9 respectively.

4.6 EN.49D wire springs

The influence of time at $150^{\circ}C$ on the resultant relaxation is given for two stress levels in Fig. 10. The effect of a constant stress of 60,000 $lb/in^2$ on the settling of EN.49D springs over a time period of 450 hrs can be seen in Fig. 11.

4.7 EN.58A wire springs

Curves relating stress and temperature to relaxation after 168 hrs are given in Fig. 12.

4.8 17/7 PH wire springs

Fig. 13 shows the relationship between stress, temperature and relaxation for both non-hot set and hot set springs after 168 hrs. Selected results obtained for both EN.58A and 17/7 PH are compared in Fig. 14.

4.9 18/4/1 high speed steel wire springs

The relaxation properties of this material after 168 hrs are shown in Fig. 15.

4.10 314A Titanium wire springs

The results obtained from relaxation tests at $100^{\circ}C$ and $150^{\circ}C$ (72 hrs) for material in the hard drawn (34% reduction of area) condition and in the aged condition are given in Fig. 16. The effect of time at elevated temperatures on the percentage relaxation is shown in Figs. 17 and 18 for a different batch of 314A wire hard drawn by 30% reduction of area. The effectiveness of hot setting has been investigated and the results plotted in Fig. 17.

4.11 Copper beryllium wire springs

The relaxation resistance of springs stressed to 40,000 $lb/in^2$ at a temperature of 100°C can be seen in Fig. 19.

## 5. DISCUSSION OF RESULTS

It may be seen that in Figs. 2-9 and 12-16 the experimental curves if extrapolated would not pass through the origin. This is due to the fact that % relaxation is plotted on the x-axis and not actual stress values. In the latter case the curves would pass through the origin.

It will be appreciated that the amount of relaxation occurring in a spring subject to stress at some elevated temperature besides being stress temperature dependent is also dependent on the time period at the particular stress and temperature in question. However, it is generally accepted (1) that a test period of 72 hrs is sufficient to allow the majority of the primary relaxation to occur in the case of carbon, low alloy and non-ferrous materials and Figs. 10, 17, 18 and 19 demonstrate this point. With stainless and heat resistant materials it is necessary to increase the test period to about 168 hrs to ensure that the majority of the primary relaxation has occurred.

Within the temperature and stress ranges investigated there is little difference in the relaxation properties of music wire, commercial oil tempered and oil tempered valve wire springs. Hot setting prior to testing has been effective in reducing the amount of relaxation.

Due to the temper resistant properties of chromium silicon material, springs made from this steel resist relaxation better than carbon steel wire springs. The effects of low temperature heat treatment after coiling are demonstrated in Fig. 6 and it will be seen that an increase in L.T.H.T. temperatures results in a decrease in the amount of relaxation occurring when tested at 200°C. The benefit to be gained by L.T.H.T. at 400°C compared with 350°C is however only marginal. Again relaxation can be reduced by hot setting prior to testing as shown in Fig. 7.

A comparison has been made between the relaxation properties of air and vacuum melted chromium vanadium (DTD.4A) wire springs. Those made from vacuum melted material would appear to be slightly more resistant to relaxation. Springs made from wires having tensile strengths at the bottom and middle of the specification tensile range were tested to show what difference, if any, this variation had on the relaxation resistance. Fig. 8 shows that with air melted material, springs made from the lower tensile wire had better resistance to relaxation due presumably to the fact that a higher tempering temperature was necessary to obtain the lower tensile. However, this idea was not borne out by the results obtained from the vacuum melted wire springs where the higher tensile springs would appear to possess the better resistance to relaxation. Comparing the DTD.4A relaxation results with the chromium-silicon results it is clear that the latter has superior resistance at 200°C.

Previously[2] the relaxation properties of EN.49D have been reported for a range of stresses and temperatures after a test period of 72 hrs. Fig. 10 has been produced to show how the process of relaxation is time dependent. Initially rapid relaxation occurs but with increasing time the rate of relaxation becomes progressively slower. An interesting comparison can be made between Fig. 10 (constant deflection conditions) and the results obtained from EN.49D (Fig. 11) under constant load conditions (creep). The creep or loss in free length if the spring has been indicated for any particular time interval and from this the percentage loss in load calculated from the various spring lengths:-

| Type of test | % load loss after | | |
|---|---|---|---|
| | 24 hrs | 72 hrs | 120 hrs |
| Relaxation | 3.8 | 5.0 | 5.3 |
| Creep | 8.6 | 12.0 | 14.0 |

It should be remembered however, that the relaxation results were obtained from springs initially stressed cold to 60,000 lb/in$^2$ but at the test temperature of 150°C the stress would have decreased by about 4% due to a similar decrease in rigidity modulus. Nevertheless, it will be evident that there is a marked difference between the load loss experienced with constant length (decreasing stress) and constant load conditions and that this should always be realised when using such data for practical spring applications.

The relaxation properties of EN.58A springs have been determined and follow the usual pattern relating stress to relaxation for one particular temperature. Up to 300°C the relaxation is relatively small but tests carried out at 350°C show a marked increase in the percentage load loss. Hot setting experiments carried out on 17/7 PH springs followed by testing at 300°C and 350°C (Fig. 13) have reduced the amount of relaxation by approximately half due in the main to the elimination of the primary relaxation. Fig. 14 compares the relaxation proerties of EN.58A and 17/7 PH springs, at the higher stress levels the 17/7 PH would appear to be somewhat superior.

The stress temperature properties of 18/4/1 high speed steel wire springs show superior relaxation resistance to any other material reported in this paper. It will be noted that the amount of relaxation is only slightly affected by increase in stress and should therefore find use at elevated temperatures where the stress conditions are rather high.

Alloys of titanium have found applications in the aircraft industry where a light highly corrosion resistant and moderately heat resistant material is required. The relaxation properties of two different melts of 314A titanium have been evaluated and the results shown in Figs. 16, 17 and 18. A comparison has been made (Fig. 16) between material from the same melt drawn 34% reduction of area and material solution treated and aged. Testing had to be restricted to a stress value of 90,000 lb/in$^2$ as this was virtually the torsional elastic limit of the material. For the two temperatures investigated, in general the aged wire springs were more resistant to relaxation than the drawn wire springs. It was noticed during the experimental work that the springs tended to be dimensionally unstable in that they changed their free length overnight when left standing at room temperature. It is thought that this feature would contribute to the recovery shown for the lower stressed springs even though a precise measure of free length was made immediately prior to loading.

Figs. 17 and 18 relate to the second melt and show how time at temperatures of 100 and 150$^\circ$C affect the relaxation. Hot setting again would appear beneficial (Fig. 17) reducing the load loss from approximately 5% to a recovery of about 1% for springs initially stressed to 40,000 lb/in$^2$ and from approximately 8% to zero for springs stressed at 80,000 lb/in$^2$ at a temperature of 100$^\circ$C. Comparing the drawn conditions a considerable difference in the amount of relaxation is apparent between the two melts. It seems unlikely that this difference can be accounted for by a small difference in final reduction of area on drawing i.e. 30% and 34%, it might however be due to the instability of the of the material from which Fig. 16 was produced causing an increase in length of the springs which would be recorded as recovery in the case of lowly stressed springs or smaller percentage load losses in the case of more highly stressed springs.

The behaviour of copper beryllium springs stressed initially to 40,000 lb/in$^2$ and tested at 100$^\circ$C can be seen in Fig. 19, the normal rapid relaxation occurred in the first 20 hrs after which relaxation continued at a decreasing rate. The enlarged scale for relaxation tends to give the impression of scatter but this is no greater than that experienced with other materials.

## 6. CONCLUSIONS

1. From the data reported in this paper a general grading of spring materials suitable for elevated temperature service conditions can be drawn up. Many of the materials have similar resistance to relaxation and in these cases other operational requirements would be the deciding factors on ultimate choice of material. Based on the qualities examined a table of descending merit is presented as follows:-

(i) 18/4/1 high speed steel
(ii) EN.58A and 17/7 PH
(iii) Chromium silicon
(iv) Chromium vanadium
(v) Oil tempered wires, EN.49D and music wire
(vi) Copper Beryllium, 314A Titanium

Recommended maximum service temperatures for the above materials have not been given as these will vary with the applied stress and also with the degree of relaxation which is permissible in service.

2. Hot setting markedly reduced the subsequent amount of relaxation which occurred when springs were stressed at temperatures above ambient.

3. It would appear from the results that it is not possible to predict the creep performance of springs working under constant load conditions from relaxation data.

## 7. RECOMMENDATIONS FOR FUTURE WORK

1. Further investigations into the technique of hot setting and measurement of its effects on relaxation properties should be undertaken.

2. A programme of longer term relaxation testing, at least to 1000 hrs, should be instituted with the object of determining the secondary relaxation characteristics of the most promising of the conventional spring materials. From such work it should be possible to provide a more accurate estimate of the relaxation behaviour of springs operating at elevated temperatures for extended periods of time.

3. A study of the relaxation properties of springs made from high nickel heat resistant alloys is at present being carried out and when complete will form the subject of a separate paper.

## 8. REFERENCES

1. G.B. Graves "The Relaxation and Creep of Springs at Elevated Temperatures" C.S.F.R.O. Report No. 113

2. G.B. Graves "The Stress-Temperature Relaxation Properties of Springs made from Oil Tempered and Patented Hard Drawn Wires" C.S.F.R.O. Report No. 115

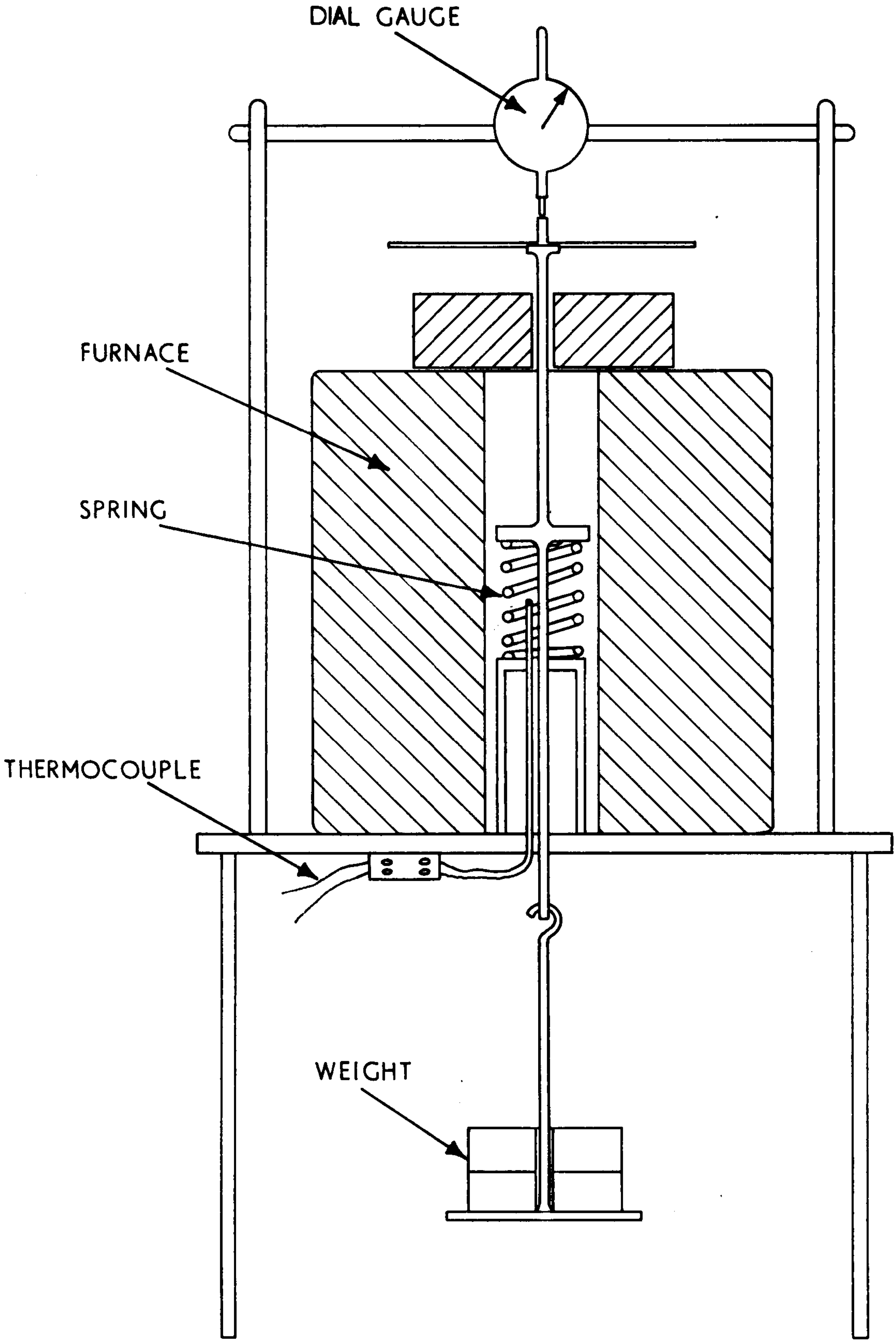



FIG. 1. SPRING CREEP TESTING RIG.

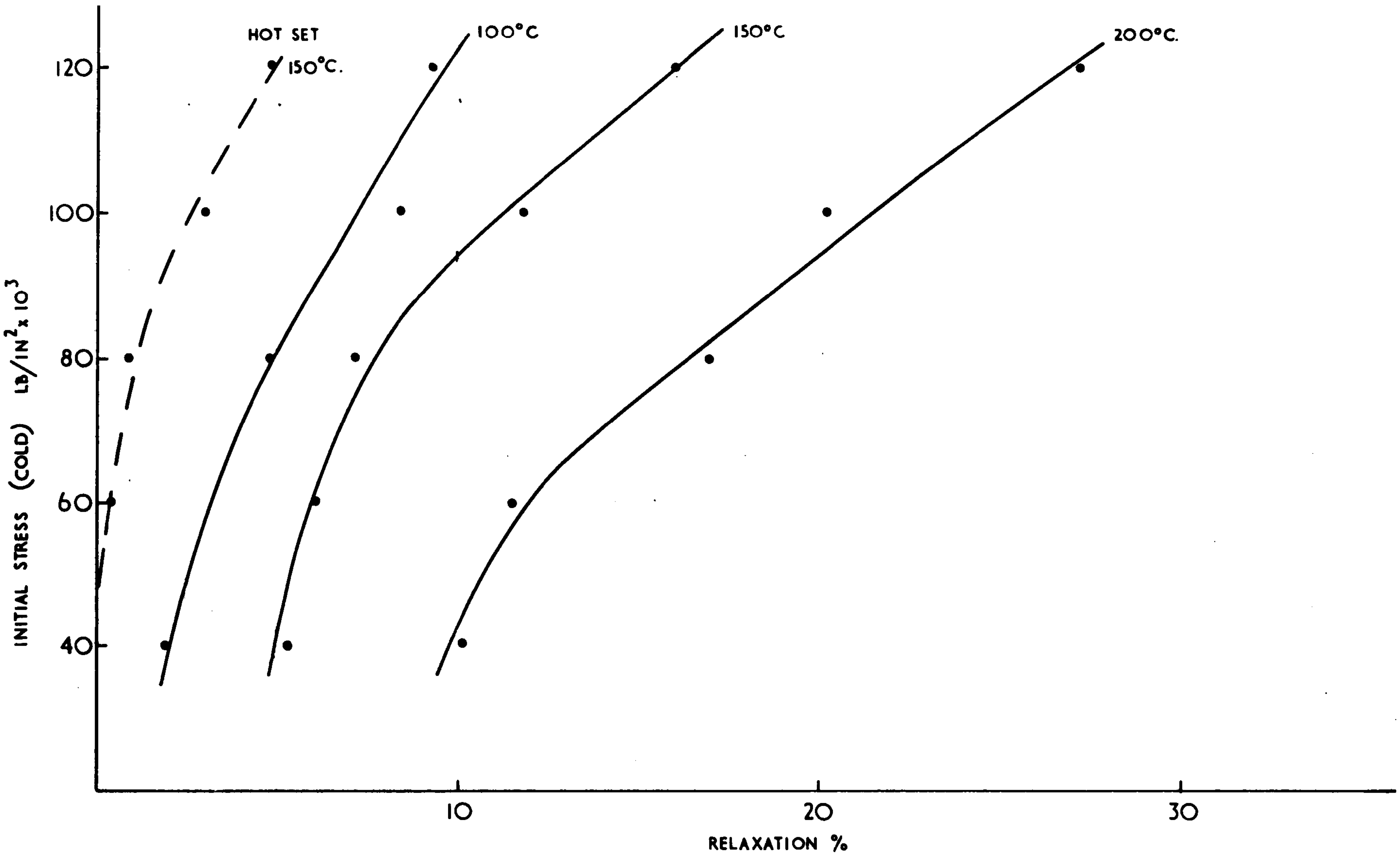



FIG. 2. STRESS TEMPERATURE RELAXATION PROPERTIES OF CONTINENTAL MUSIC WIRE SPRINGS.

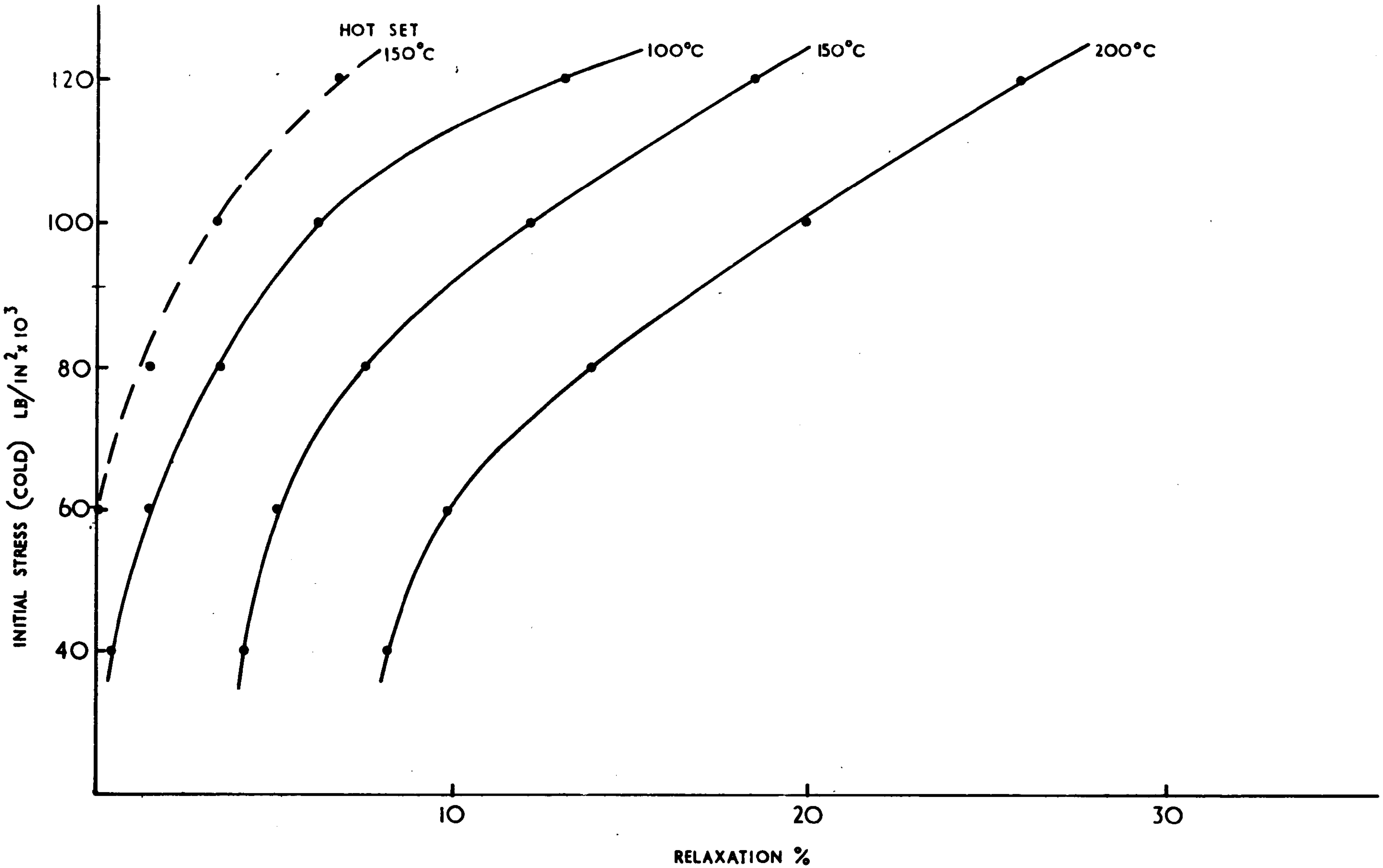



FIG. 3. STRESS TEMPERATURE RELAXATION PROPERTIES OF CONTINENTAL OIL TEMPERED VALVE SPRING QUALITY WIRE SPRINGS

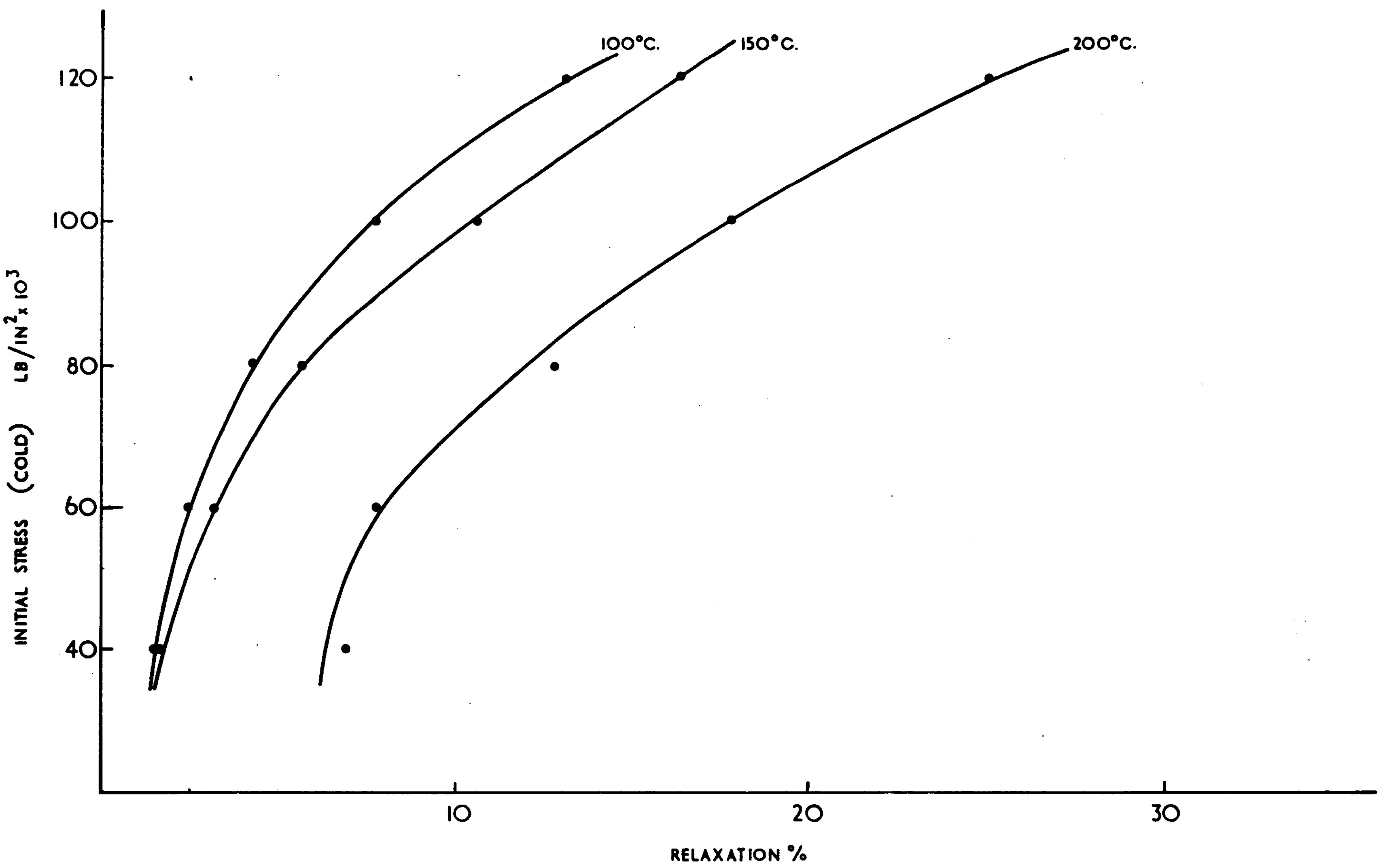



FIG. 4. STRESS TEMPERATURE RELAXATION PROPERTIES OF CONTINENTAL COMMERCIAL OIL TEMPERED WIRE SPRINGS

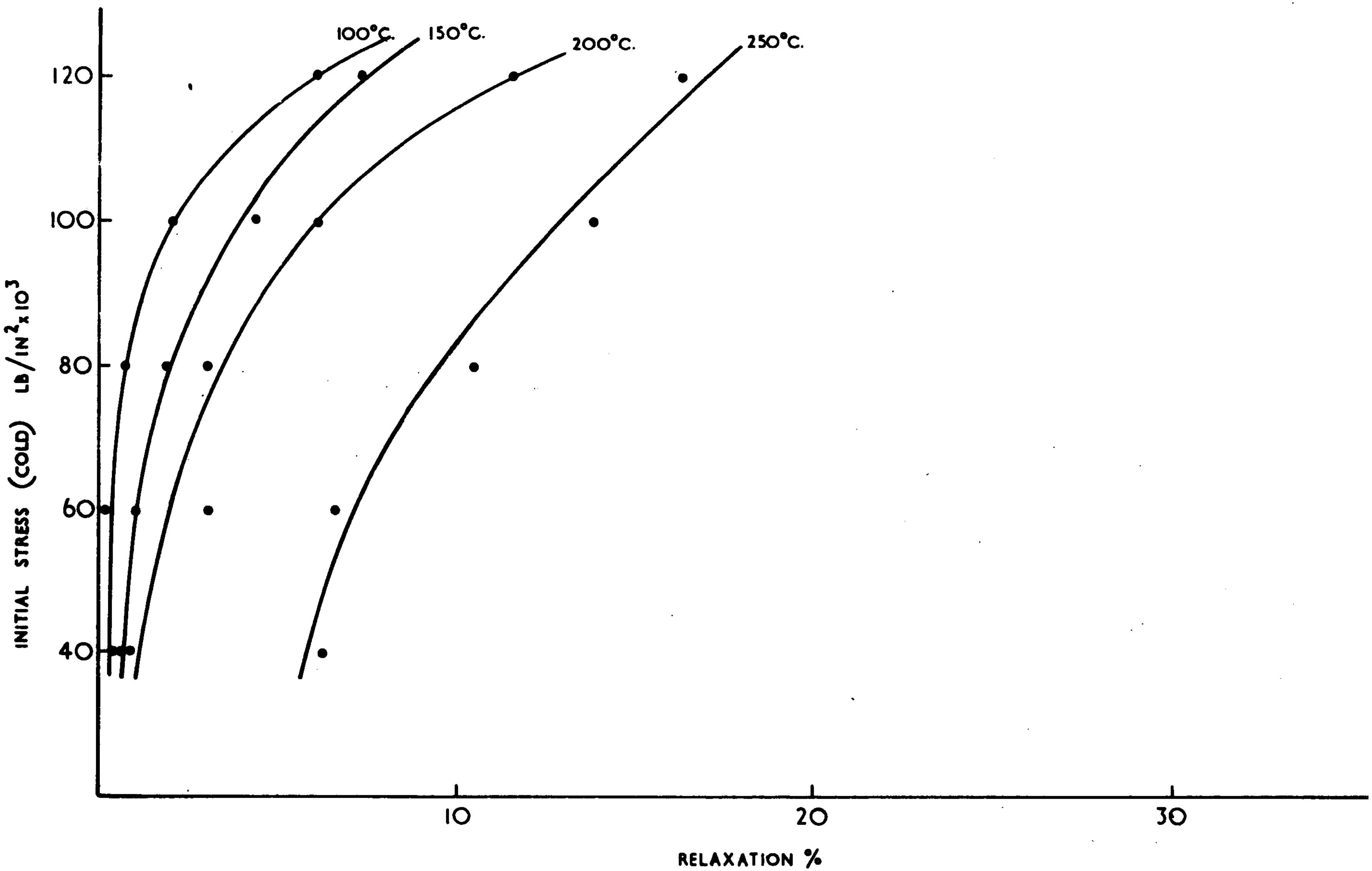



FIG. 5. STRESS TEMPERATURE RELAXATION PROPERTIES OF CONTINENTAL Cr.-Si. STEEL WIRE SPRINGS L.T.H.T. AT 350°C

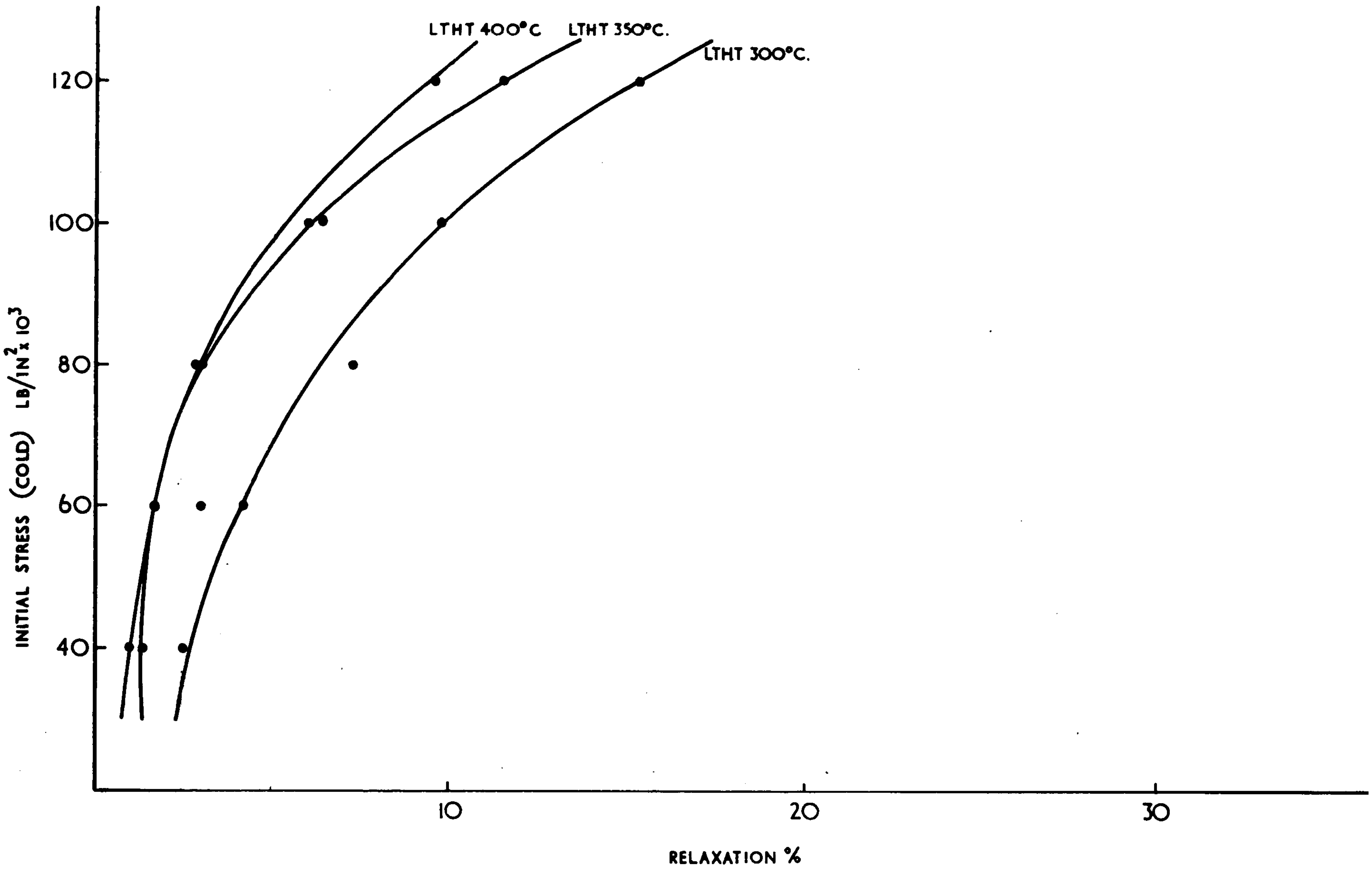



FIG. 6. STRESS TEMPERATURE RELAXATION PROPERTIES OF Cr.-Si. STEEL WIRE SPRINGS AT 200°C SHOWING THE EFFECTS OF LOW TEMPERATURE HEAT TREATMENT

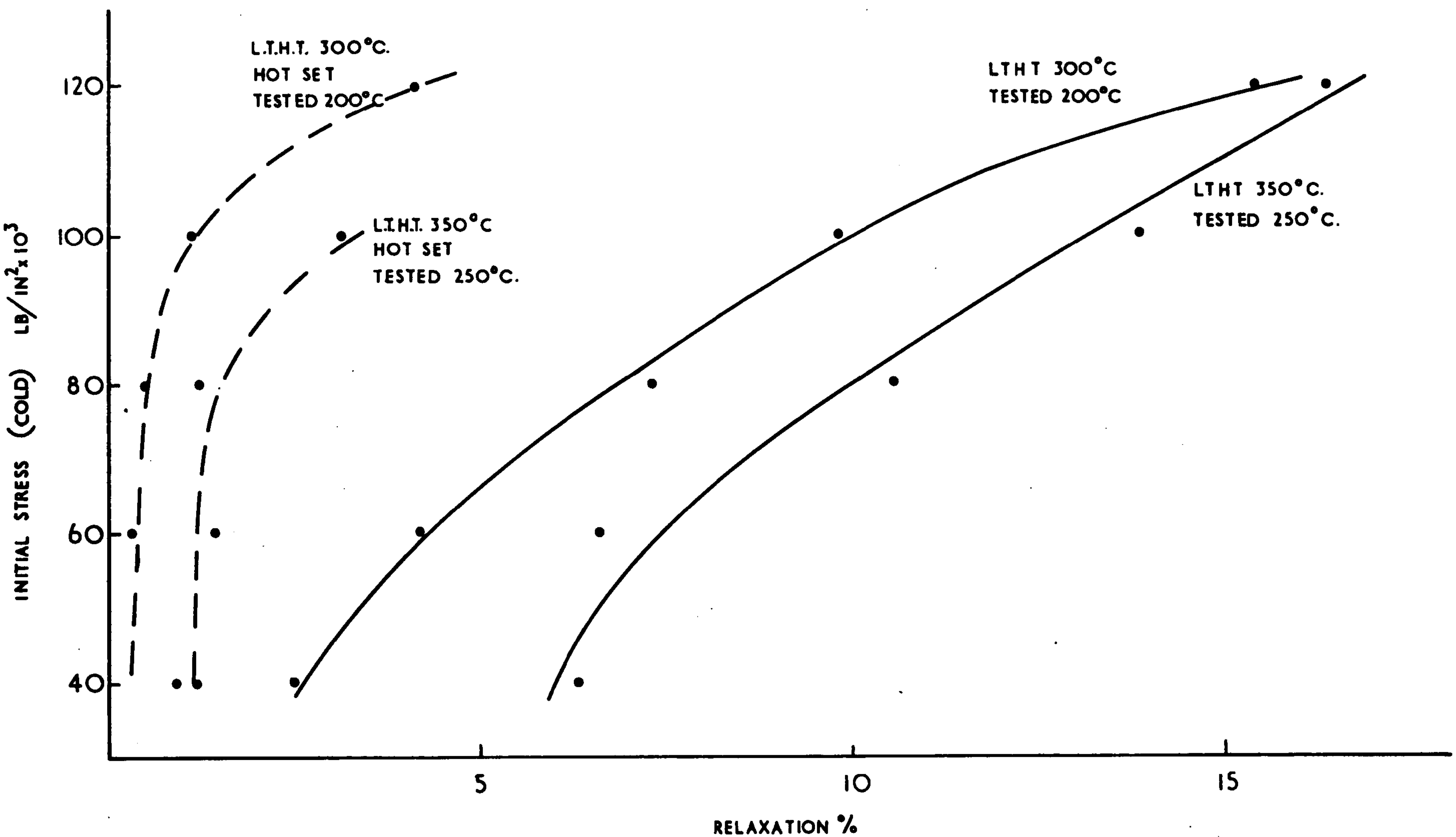



FIG. 7. STRESS TEMPERATURE RELAXATION PROPERTIES OF Cr.-Si. SPRINGS SHOWING THE EFFECTS OF HOT SETTING

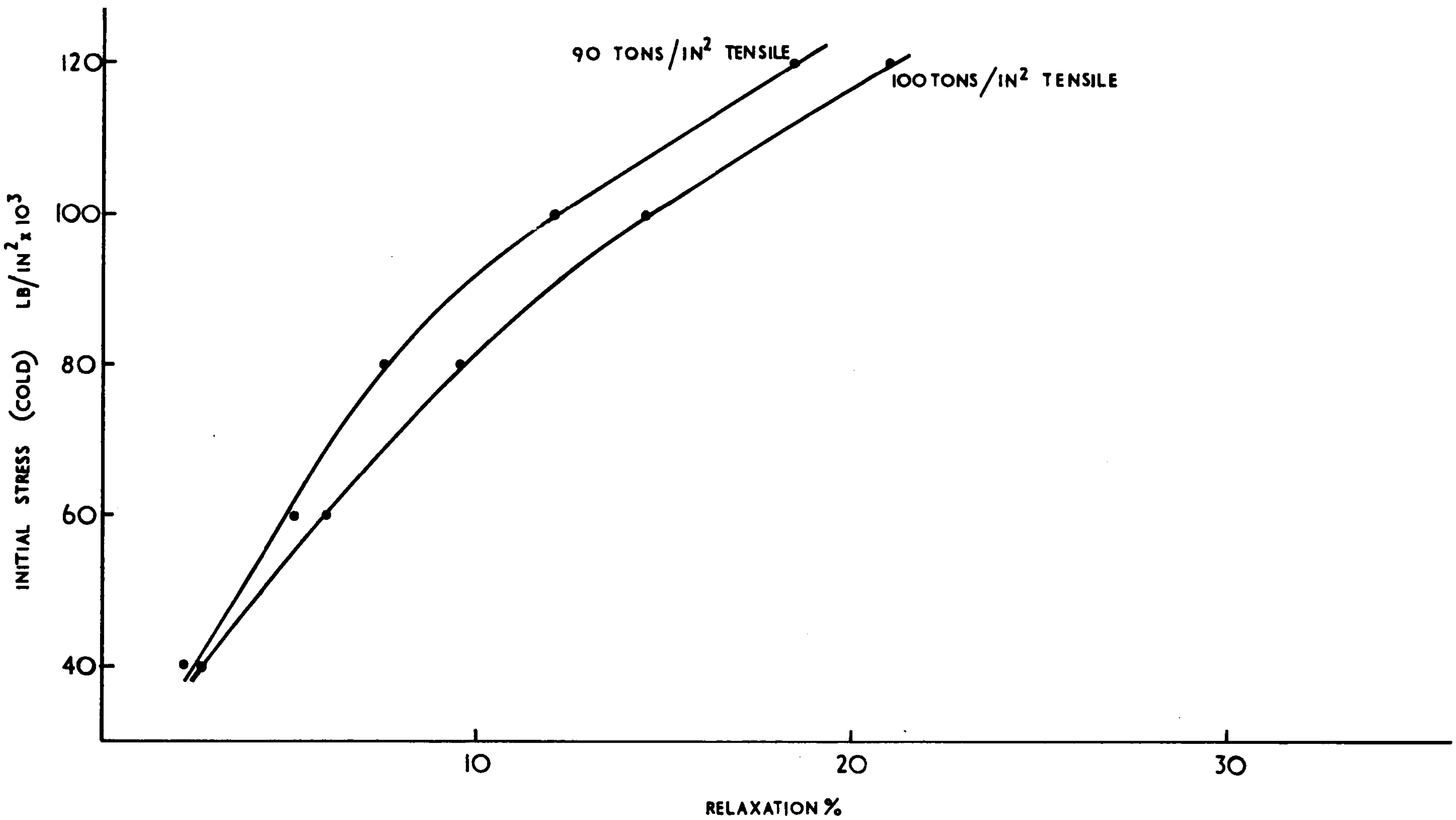



FIG. 8. STRESS TEMPERATURE RELAXATION PROPERTIES OF AIR MELTED D.T.D. 4A SPRINGS. MADE FROM WIRE OF TWO TENSILE STRENGTHS AND TESTED AT 200°C.

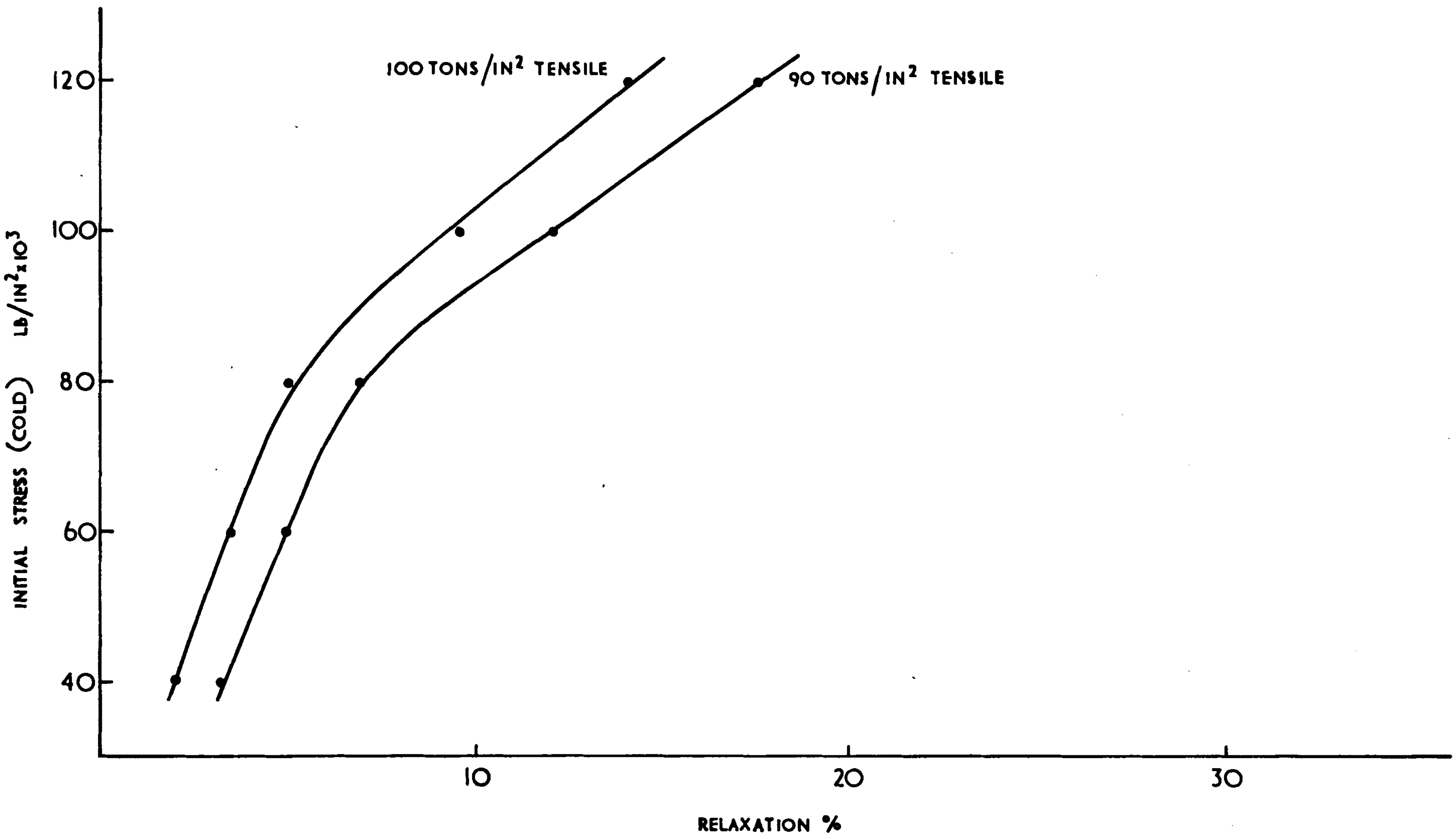



FIG. 9. STRESS TEMPERATURE RELAXATION PROPERTIES OF VACUUM MELTED D.T.D. 4A SPRINGS MADE FROM WIRE OF TWO TENSILE STRENGTHS AND TESTED AT 200°C.

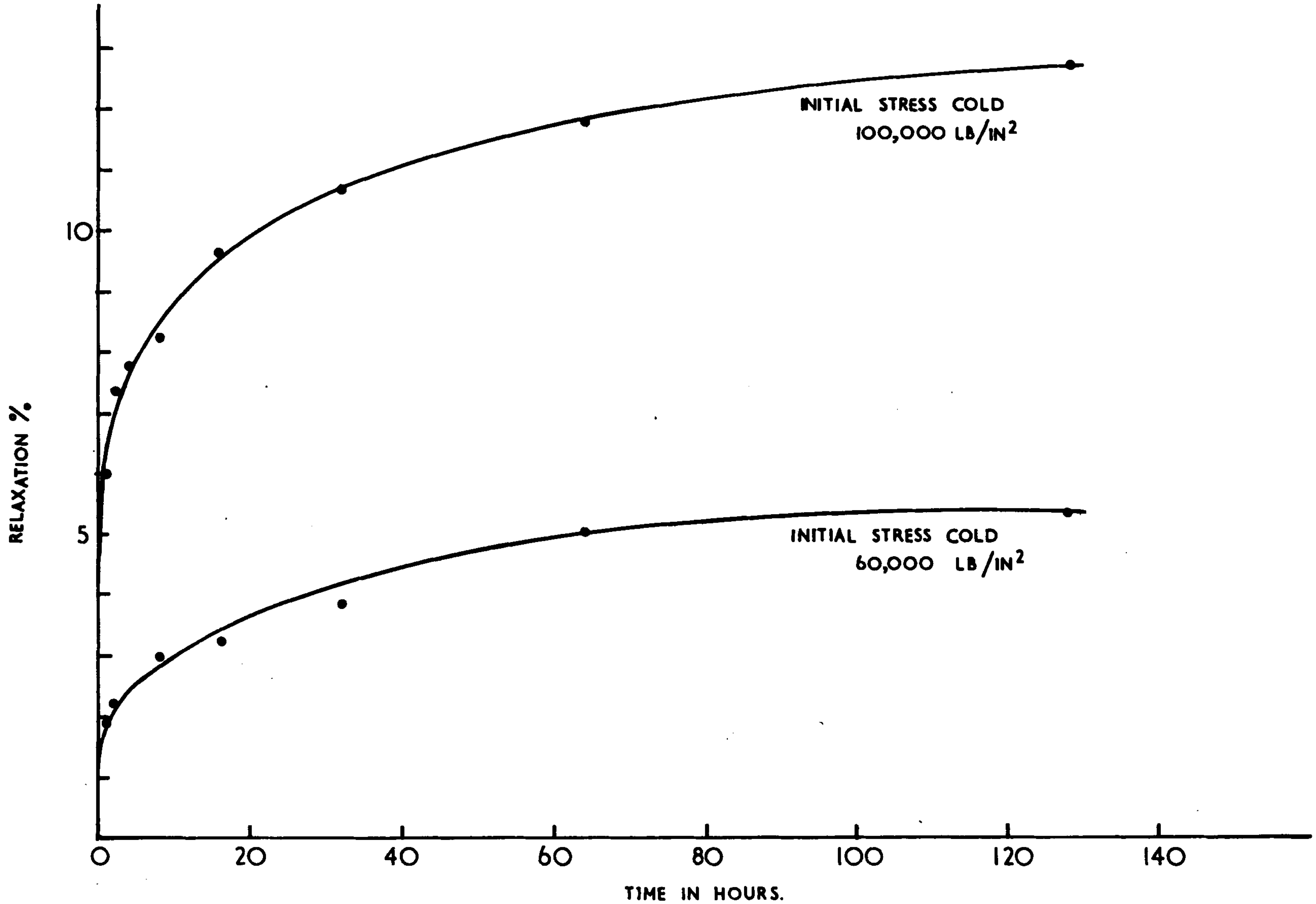



FIG 10 EFFECT OF TIME ON THE RELAXATION PROPERTIES OF EN49D SPRINGS AT 150°C.

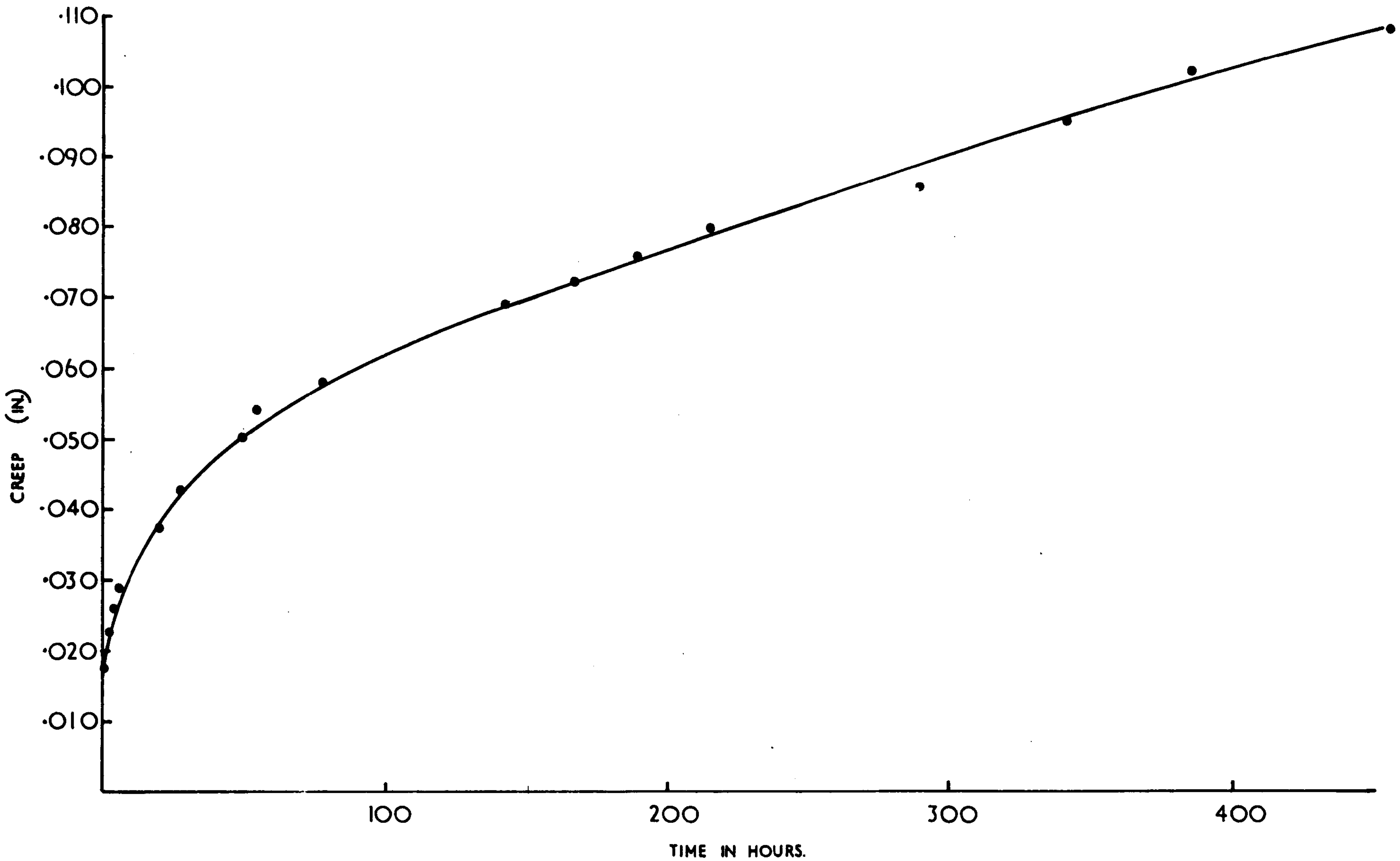



FIG. 11. EFFECT OF TIME ON THE LOSS IN LENGTH OF EN 49D SPRINGS WHEN STRESSED TO 60,000 LB/IN$^2$ AT 150°C.

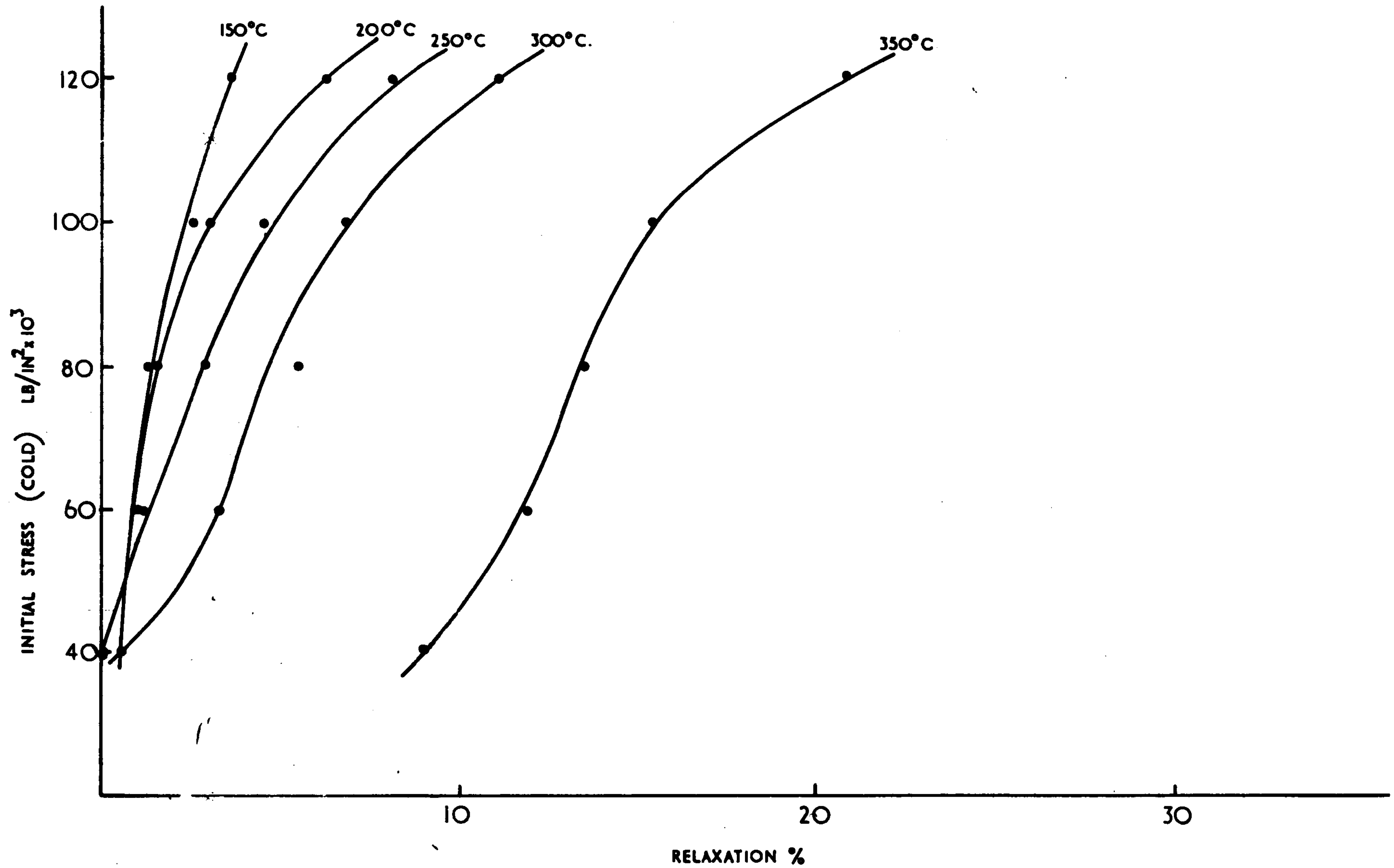



FIG. 12. STRESS TEMPERATURE RELAXATION PROPERTIES OF EN 58A WIRE SPRINGS

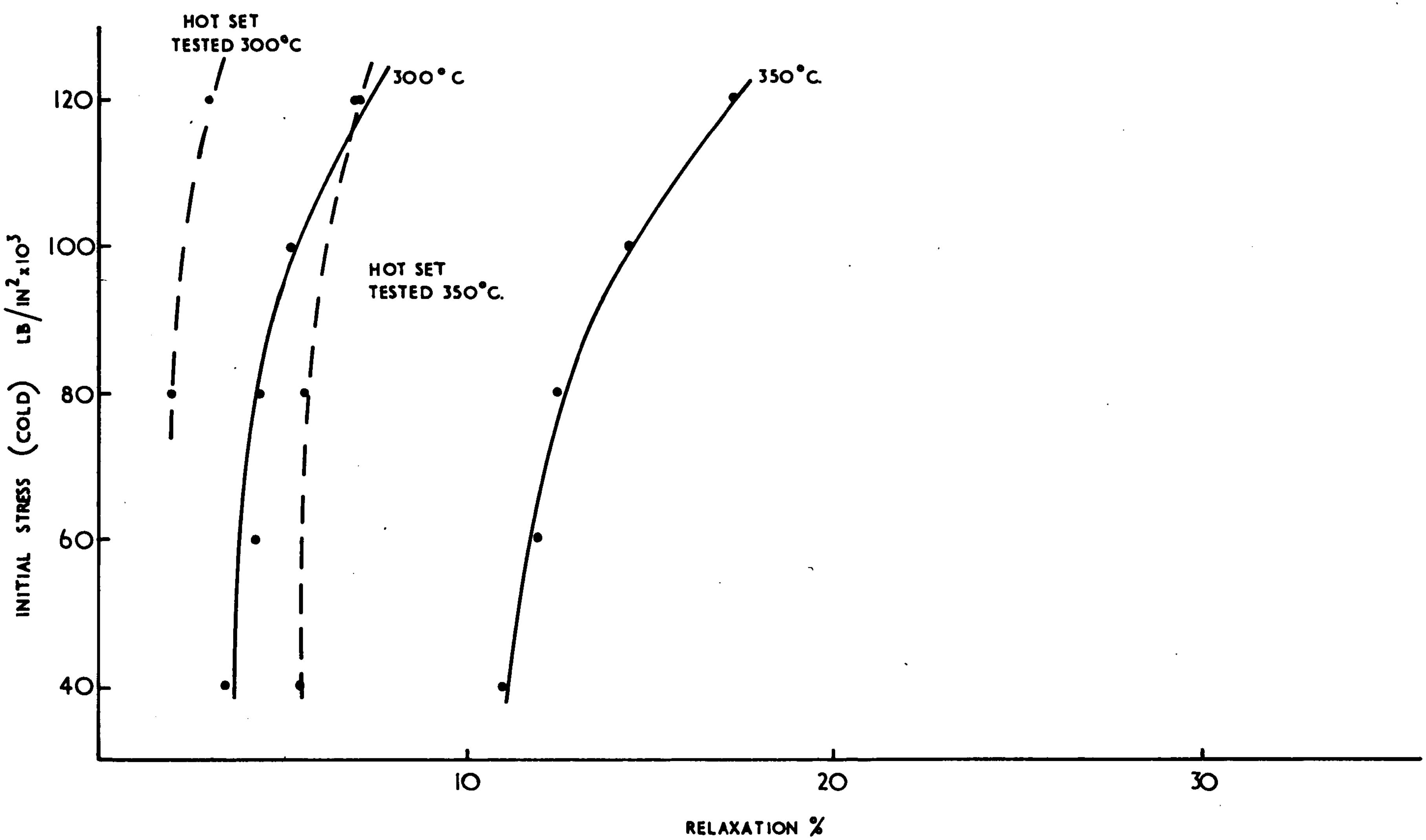



FIG.13. STRESS TEMPERATURE RELAXATION PROPERTIES OF 17/7 P.H. WIRE SPRINGS

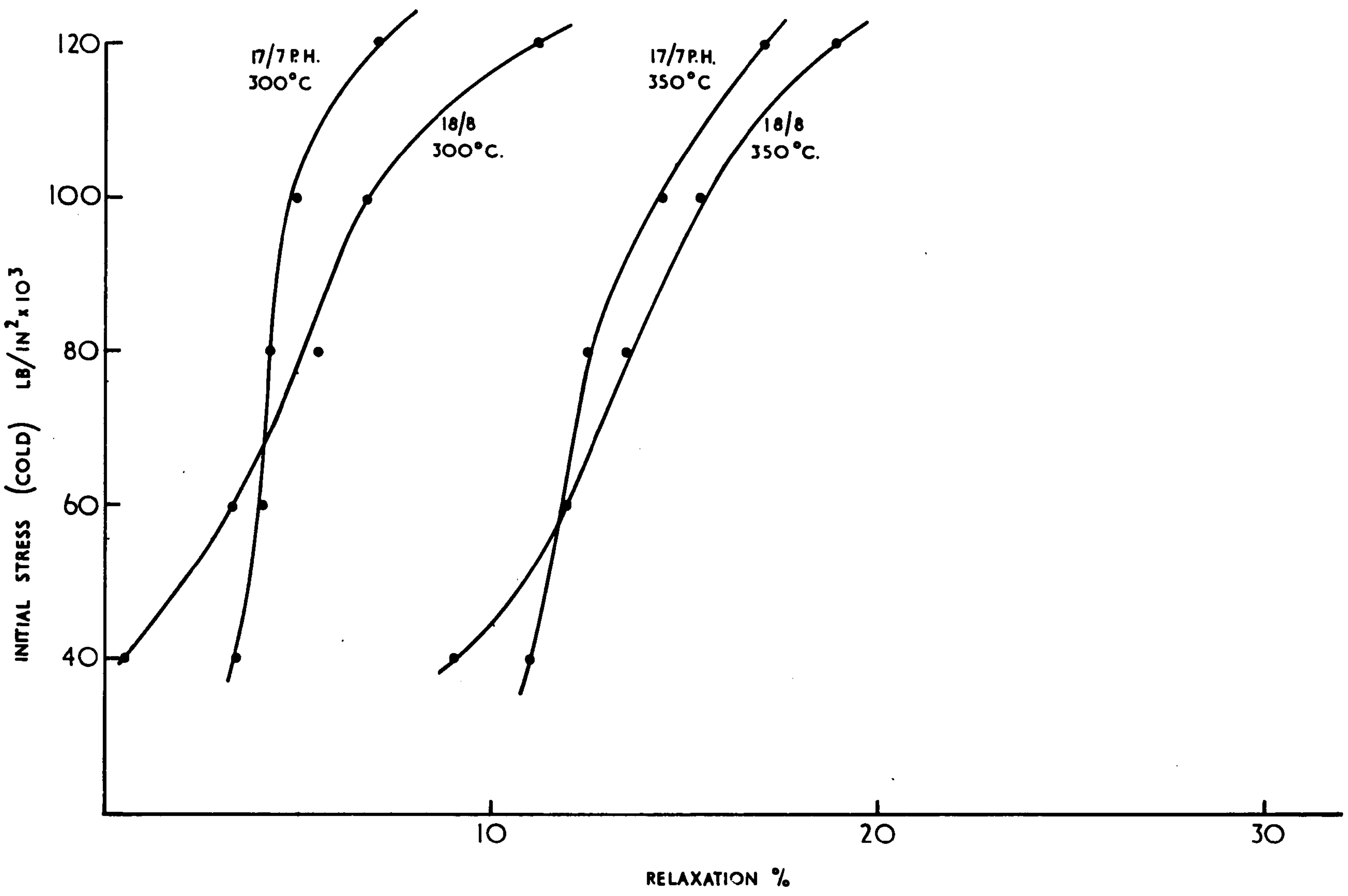
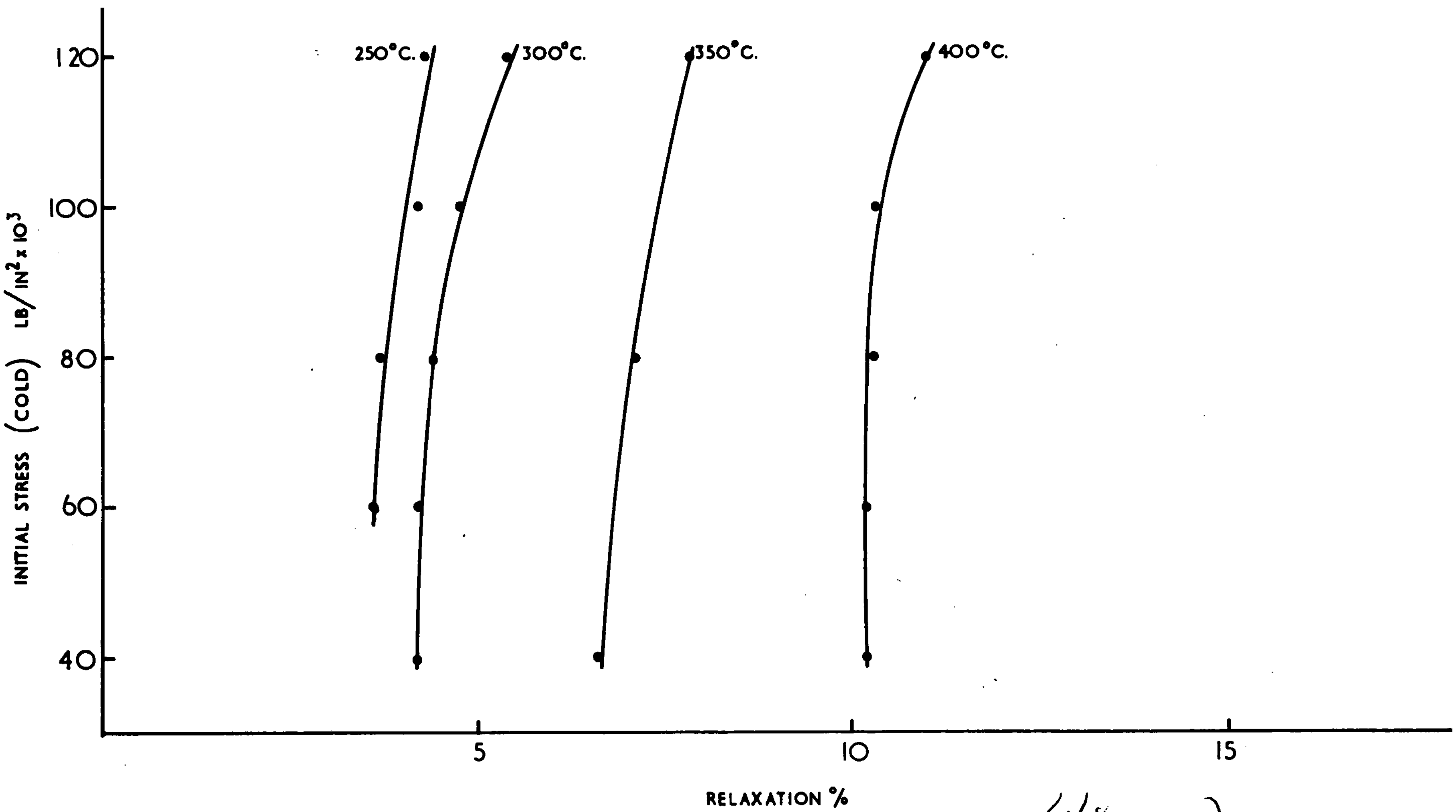



FIG. 14. STRESS TEMPERATURE RELAXATION PROPERTIES OF 18/8 AND 17/7 P.H. WIRE SPRINGS.




(168 HOURS)

FIG. 15. STRESS TEMPERATURE RELAXATION PROPERTIES OF 18/4/1 HIGH SPEED STEEL WIRE SPRINGS

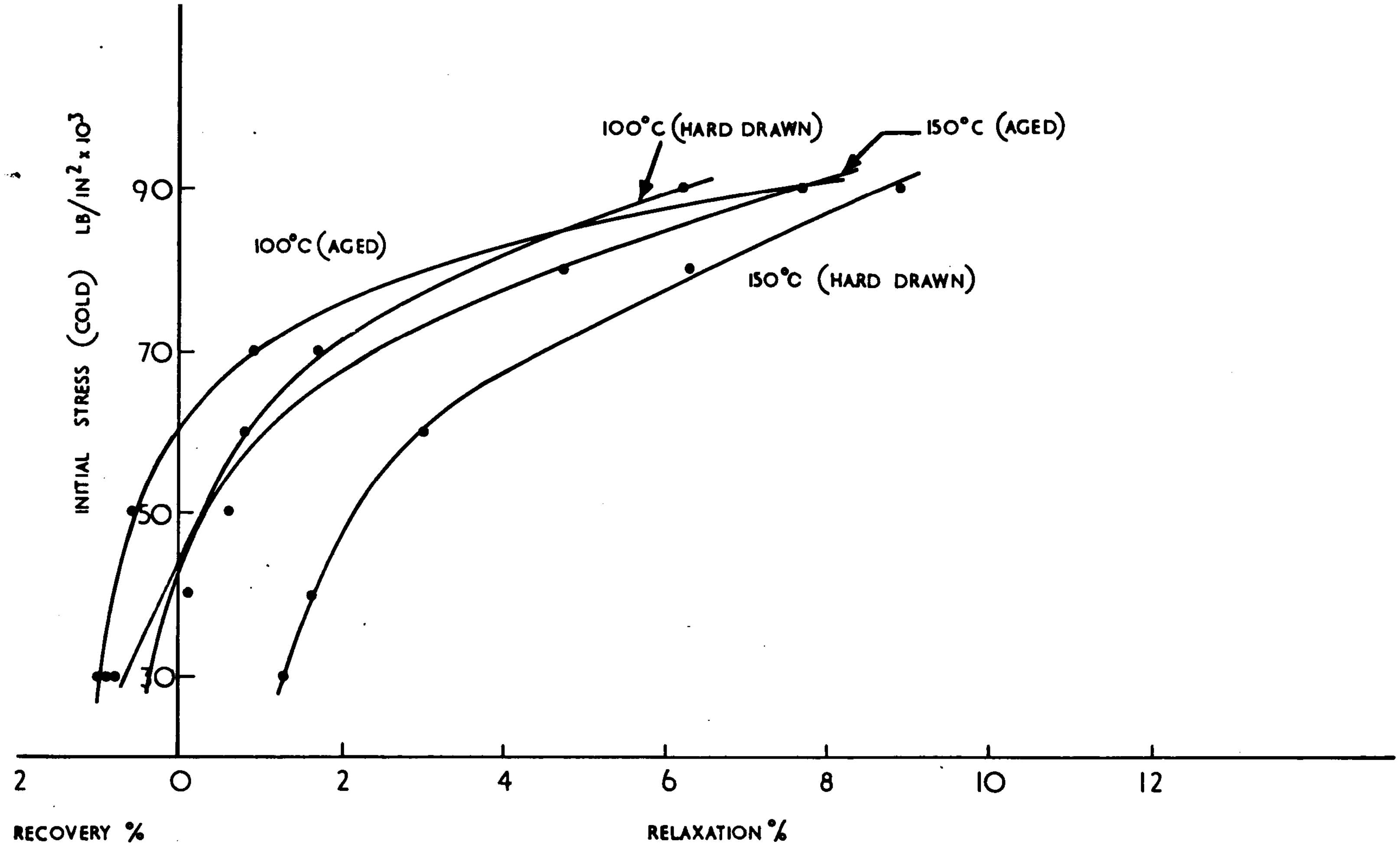



FIG. 16. STRESS TEMPERATURE RELAXATION PROPERTIES OF 314 A TITANIUM SPRINGS IN THE 34% HARD DRAWN CONDITION AND ALSO IN THE AGED CONDITION

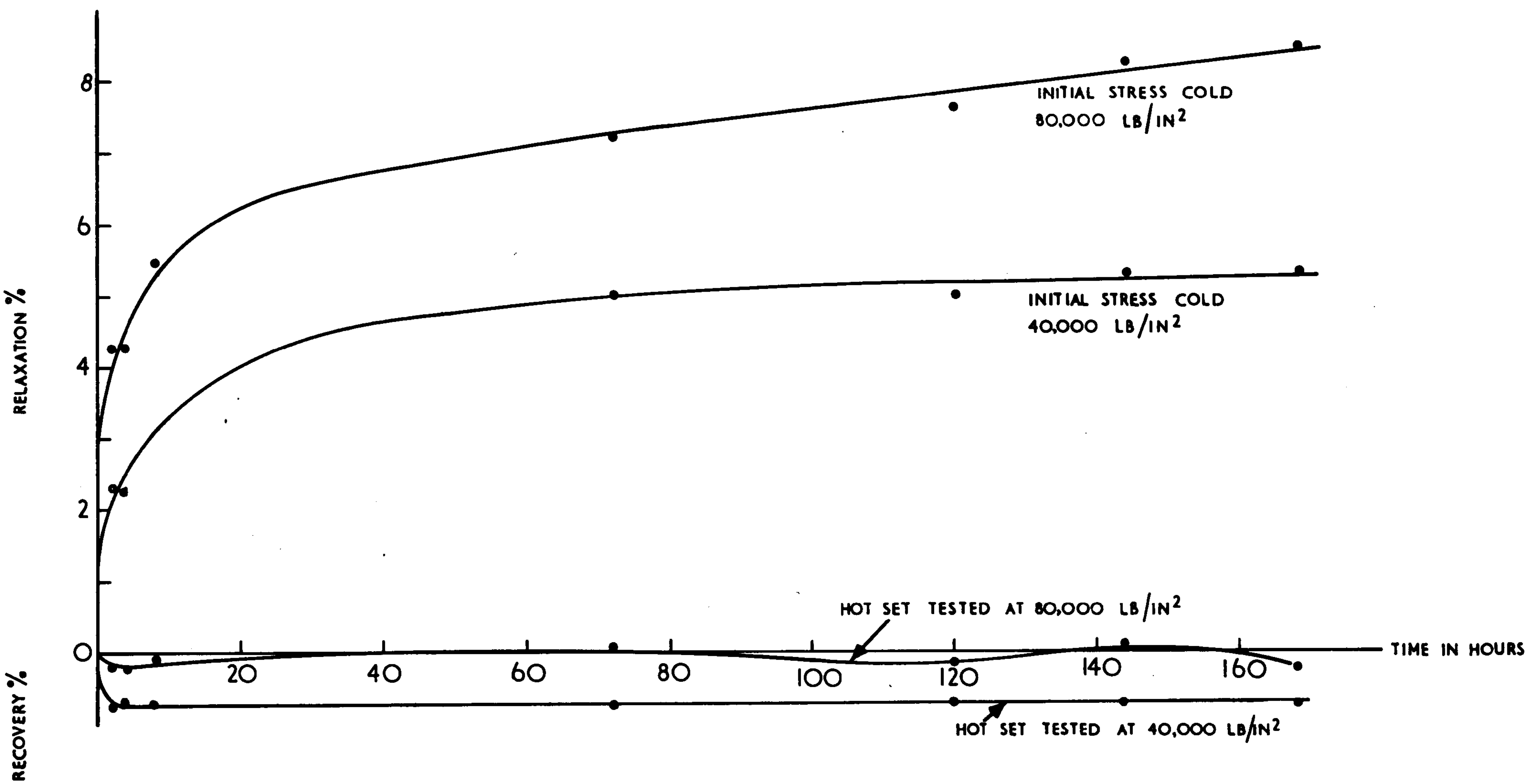



FIG.17. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF 314 A TITANIUM SPRINGS AT 100°C MADE FROM WIRE DRAWN 30% REDUCTION OF AREA

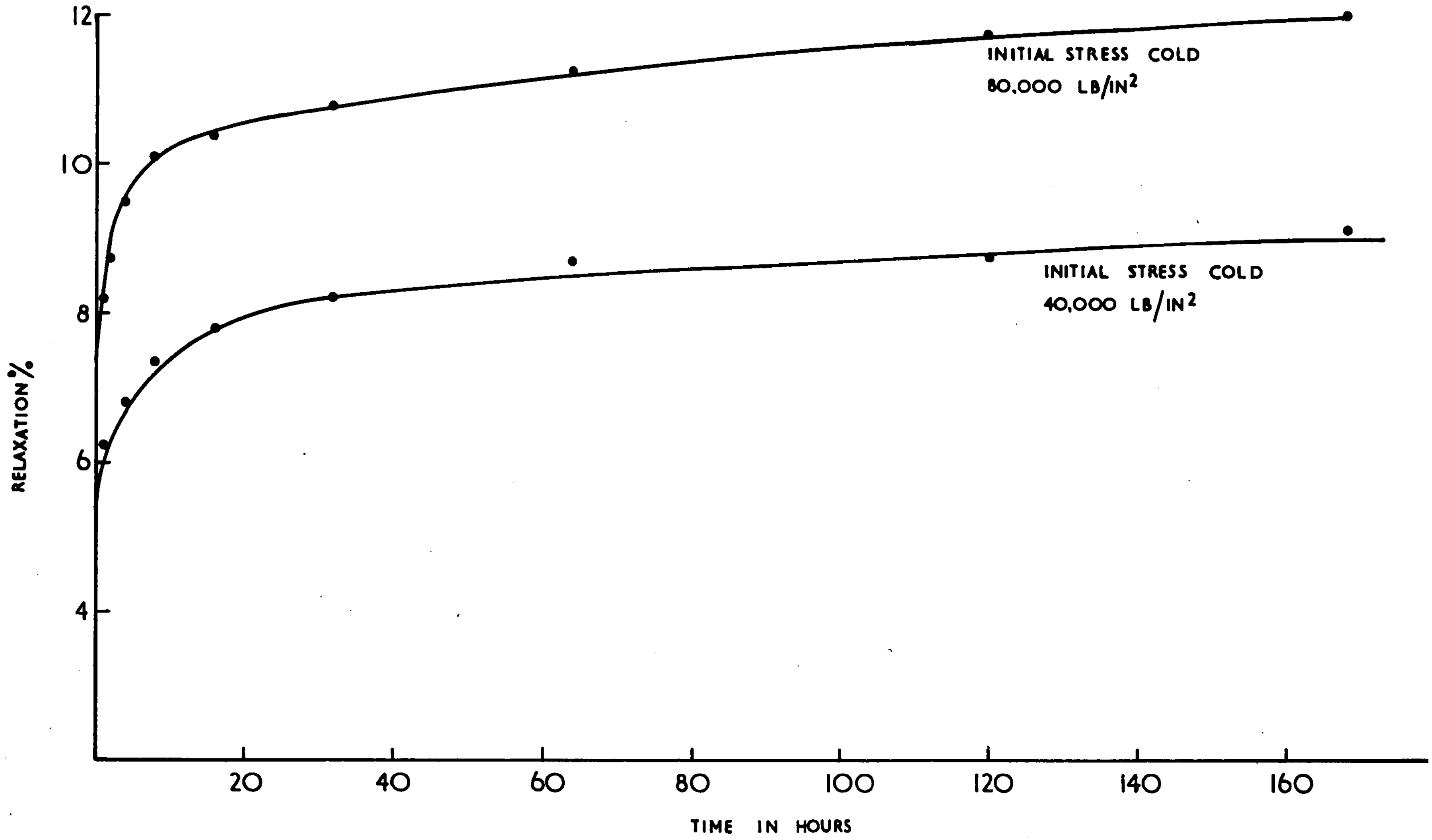



FIG 18 EFFECT OF TIME ON THE RELAXATION PROPERTIES OF 314A TITANIUM SPRINGS AT 150°C MADE FROM WIRE DRAWN 30% REDUCTION OF AREA

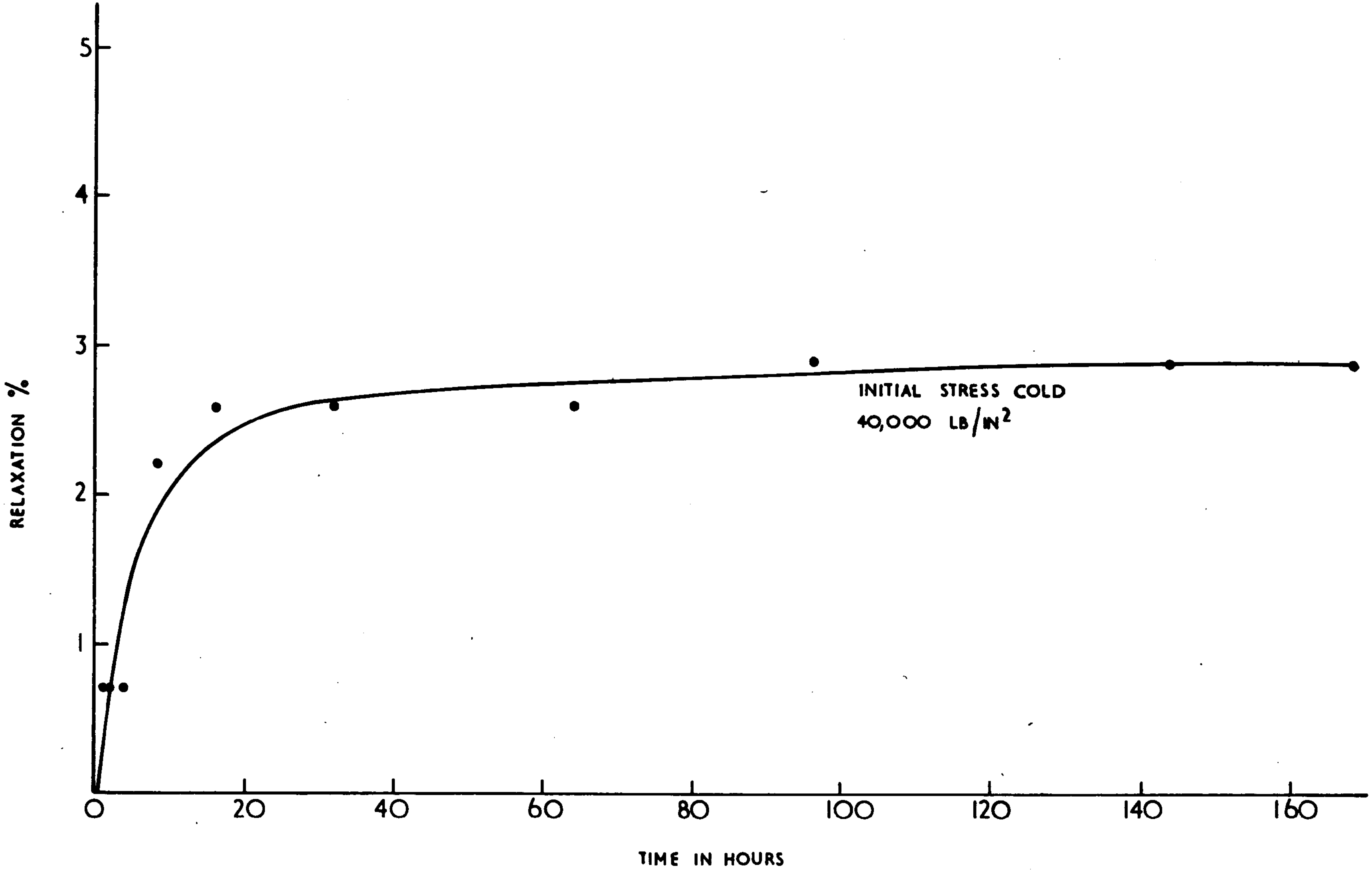



FIG. 19. EFFECT OF TIME ON THE RELAXATION PROPERTIES OF COPPER BERYLLIUM WIRE SPRINGS AT 100°C.