THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE COILABILITY OF PATENTED HARD DRAWN CARBON STEEL SPRING WIRE.

Final Progress Report

The Effects of Short Time Ageing upon the Elastic and Plastic Properties of Spring Wire, and their Significance with respect to Coilability

by

L. F. Reynolds, M.Sc.Tech., C.Eng., M.I.M.

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SUMMARY

The elastic and plastic properties of patented hard drawn carbon steel wire have been investigated in detail both before and after experimental ageing at temperatures of 160°C., 175°C., 200°C. and 300°C.

It has been demonstrated that the stress/strain characteristics displayed by "poor" coilability wire can be duplicated in the laboratory.

The work has indicated that the variability of elastic properties increases significantly upon ageing at 175-200°C., but that the variability is much less after ageing at 150-160°C. It is suggested that "poor" coilability of these spring wires may arise as a result of temperatures within the range 175-200°C., introduced during wire drawing, and that the problem of "poor" coilability may be alleviated to some extent by heat treating the wire at 150-160°C. prior to coiling.

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1. INTRODUCTION

Previous work at SRAMA has shown that "poor" coilability of patented hard drawn carbon steel spring wires was associated with increases in both the proportional limit of the wire and the degree of scatter associated with spring back tests(1,2).

During the course of the statistical analyses necessary for the determination of the true proportional limit, it became apparent that poor coilability also appeared to be associated with a reduction of the work hardening coefficients which described the behaviour of the wires during plastic deformation. A more complete analysis was therefore undertaken of the true stress/true strain data obtained during the previous work, to characterise the behaviour of "good" and "poor" coilability wires during plastic deformation.

A limited number of short time ageing experiments were subsequently carried out at various temperatures, using wire which was known to exhibit the low proportional limits apparently associated with "good" coilability. These experiments were initiated in an attempt to reproduce the conditions of increased proportional limit and reduced work hardening coefficients which were representative of wires exhibiting "poor" coilability.

The significance of these experiments lies in the findings by Cahill and Jones, and by Phillips et al, that dwell times as short as 10 - 30 seconds at temperatures in excess of 160 - 180°C., could induce strain ageing during the drawing of high carbon steel wire, with a resultant deterioration in the ductility of the "as drawn" wire(3,4).

2. MATERIALS AND EXPERIMENTAL/ANALYTICAL TECHNIQUES

The identification of the materials of "good" and "poor" coilability is shown summarised in Table I taken from the earlier report(1). The report also included a detailed description of the analytical techniques employed for the determination of the true proportional limit, σ_p, and the apparent work hardening exponent, N_a, from the true stress/true strain curves established by tensile tests carried out on the wires. During the present work, similar measurements and analyses were conducted to determine the true proportional limits and apparent work hardening exponents of 2.03 mm BS 5216 HS3 wire both in the unaged condition and after ageing at 160°C/2½ mins., 175°C/2½ mins., 200°C/2½ mins. and 300°C/15 mins.

The Coefficient of Variation was employed as a measure of the scatter of the true proportional limits resulting from the appropriate ageing treatments.

This parameter is defined as:

$$(\%)\ \text{Coeff. of Var.} = \frac{Sx}{\bar{x}} \times 100 \qquad \text{.......( )}$$

Where S_x = Standard Deviation of Samples

$\bar{x}$ = Sample mean

The coefficient is a dimensionless measure of scatter which can prove useful for comparing the variations displayed by different distributions of the same general form.

The relationship between true stress and true strain can be described, within the region of uniform plastic deformation, by the expression(5):-

$$\sigma_T = A\,\varepsilon_T^{\,N_a} \qquad \text{......(2)}$$

Where σ_T = True stress, N/mm^2

ε_T = True strain

A = Constant

N_a = Apparent work hardening exponent.

Once this relationship has been established, by Log/Linear regression techniques, from the true stress/true strain curve, the rate of work hardening within the region of uniform plastic deformation, $d\sigma_T/d\varepsilon_T$, can be represented by the simplified expression

$$\frac{d\sigma_T}{d\varepsilon_T} = N_a \frac{\sigma_T}{\varepsilon_T} \qquad \text{......(3)}$$

The considerable amount of data analysis required during this work was carried out using a Commodore PET 4032 microcomputer with appropriate line printer/data storage facilities, using appropriate statistical software.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The results of the stress/strain analyses for the seven wires originally employed in the investigation are shown in Table II, whilst the work hardening rates for the appropriate combinations of "good" and "poor" coilability wires are compared in Figs 1 - 4. It is apparent from these results that the proportional limits of the "poor" coilability wires were consistently higher, whilst the work hardening rates were consistently lower, than the equivalent properties for the wires of "good" coilability.

The elastic and plastic deformation characteristics of the BS 5216 HS3 wires used in the ageing experiments are shown in Tables III and IV respectively.

The effect of ageing temperature upon the elastic properties of the wires, and their scatter, is shown plotted in Fig. 5. For ease of comparison this diagram also includes data derived from free length measurements made at SRAMA upon springs which were warm coiled at temperatures between 150 - 200°C(6,7).

It is apparent that, for both the true proportional limit of wires and the free length of warm coiled springs, the coefficient of variation was at a distinct minimum when the materials were heated to a maximum temperature of 150 - 160°C, but rapidly increased as the ageing temperature increased to 175 - 200°C. Furthermore, the diagram indicates that the true proportional limit started to increase in value within the temperature range 175 - 200°C. reaching a maximum value after ageing at 300°C., at which treatment the scatter of results as represented by the coefficient of variation, was reduced once again to 1 - 2%

Such results would suggest that the onset of ageing was accompanied by a significant increase in the variability of wire properties, but that ageing susbstantially to completion at 300°C produced more uniform properties.

The low degree of variability observed after ageing at 150 - 160°C., is interesting, in that there is evidence that the susceptibility of steel to ageing may be influenced more by the nitrogen content of the steels than by the dissolved carbon at temperatures below about 200°C(8,9). This aspect of low variability after ageing at 150 - 160°C may merit further investigation.

The work hardening rate, $d\sigma_T/d\ \varepsilon_T$, for the wires aged in the laboratory during the present work are presented in Fig. 6, from which it can be seen that $d\sigma_T/d\varepsilon_T$ showed a slight decrease from the unaged values after ageing at 160°C/2½ mins. The decrease in work hardening rate was much more marked after ageing at 175 - 200°C/2½ mins., however, and was particularly apparent after an ageing treatment of 300°C./15 mins.

The reductions in $d\sigma_T/d\varepsilon_T$ observed after ageing at 175 - 200°C. showed a marked resemblance to those observed for the wires of "poor" coilability depicted in Figs. 1 - 4. Furthermore, the behaviour after ageing at 300°C./15 mins. displayed a strong similarity to that observed by Evans et al in their work on the influence of warm straining on the physical properties of a lead patented, hard drawn entectoid carbon steel wire(10). They found that warm straining of the hard drawn material by 1-2% in tension at a temperature of 300°C. resulted in a signficant increase in the elastic properties, which they attributed to a process of dynamic strain ageing.

Subsequent analysis of their published data at SRAMA has shown that warm straining increased the true proportional limit, σ_p, from its initial value of 990 N/mm^2 to a final value of 1370 N/mm^2, as depicted in Fig. 7.

Calculation of the work hardening rates, using the data of Evans et al, gave the results shown in Fig. 8, from which it can be seen that warm straining also produced very marked reductions in $d\sigma_T/d\varepsilon_T$, to a degree which bore a strong resemblance to the reductions observed in the present work after ageing at 300°C/15 mins.

When viewed in this context, therefore, the inference of the present work is that the increases in proportional limit and reduction in work hardening rates, observed in wires of "poor" coilability, may be associated with the processes of dynamic strain ageing resulting from increases in wire temperature during the drawing operation. In particular significant increases in the variation of elastic properties were observed at ageing temperatures of 175 - 200°C. This observation suggests that the sequentially random variation in elastic properties along the length of the wire related to "poor" coilability, may be associated with wire temperatures within the approximate range 175 - 200°C during the drawing operation.

The finding that the coefficient of variation, for both the proportional limit and the free length of warm coiled springs, was a minimum at a wire temperature of 150 - 160°C may be significant, since it could imply that the variability in properties associated with "poor" coilability would be reduced by applying a 150 - 160°C. ageing treatment to the wire prior to coiling. It is possible for example, that such an effect could result from a differential ageing phenomenon of low intensity along the wire length, and/or from preferential relief of residual stresses associated with the wire cast.

4. CONCLUSIONS AND RECOMMENDATIONS

1. Experimental ageing, for short times, of hard drawn carbon steel spring wire at 175 - 200°C has reproduced the increased proportional limits and reduced work hardening rates associated with wires of "poor" coilability, thus implying that some problems of "poor" coilability may be the result of strain ageing during the wire drawing operation.

2. The variation in elastic properties was greatest within the temperature range 175 - 200°C., suggesting that these temperatures may be particularly significant with respect to the rapid changes in sequential elastic properties associated with "poor" coilability wire.

3. There were some indications that a low temperature heat treatment of 150 - 160°C could significantly improve the coilability of patented hard drawn carbon steel spring wire. This aspect of the work may merit more detailed investigation in the future, particularly with respect to improvements in the performance of wires previously established to possess "poor" coilability characteristics.

5. REFERENCES

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TABLE I WIRES INITIALLY INVESTIGATED AND ASSESSMENT OF COILABILITY*

Wire Quality	Nominal wire size, mm	Wire No.	Springmakers assessment of coilability
BS 1408 R3	0.71 dia.	1	G = Good
		2	P = Poor (variable free length)
		3	P = Poor (variable free length)
BS 1408 M2	0.76 dia.	4	G = Good
		5	P = Poor (variable free length)
BS 1408 R1	2.5 x 1.6 flattened wire	6	G = Good
		7	P = Poor (variable coil diameter)

* From Ref. 1.

TABLE II ELASTIC/PLASTIC PROPERTIES OF "GOOD" AND "POOR" COILABILITY HARD DRAWN CARBON STEEL WIRES INITIALLY INVESTIGATED.

Wire No.	Coilability Characteristics	True Proportional Limit* σ_p N/mm^2	Coefficients for relationship $\sigma_T = A\varepsilon_T^{N_a}$	
			A N/mm^2	N_a
1	GOOD	916	127907	0.910
2	POOR	1115	106141	0.865
3	POOR	1097	94733	0.836
4	GOOD	1178	112393	0.879
5	POOR	1329	109196	0.874
6	GOOD	817	40851	0.706
7	POOR	893	31602	0.654

* From Ref. 1

TABLE III ELASTIC PROPERTIES OF 2.03 MM BS 5216 HS3 WIRES BEFORE AND AFTER AGEING

Condition of Wire	True Proportional Limit, σ_p N/mm^2.		Coefficient of Variation, %
	Mean	Standard Deviation	
Unaged	1146	147	12.8
Aged 160°C/2½ mins.	1131	15	1.3
Aged 175°C/2½ mins.	1143	100	8.7
Aged 200°C/2½ mins.	1254	217	17.3
Aged 300°C/15 mins.	1736	19	1.1

TABLE IV PLASTIC DEFORMATION PROPERTIES OF 2.03 MM BS 5216 HS3 WIRES BEFORE AND AFTER AGEING.

Condition of Wire	Coefficients for relationship $\sigma_T = A\epsilon_T^{N_a}$	
	A N/mm^2	N_a
Unaged	28178	0.613
Aged 160°C/2½ mins.	25593	0.590
Aged 175°C/2½ mins.	21726	0.561
Aged 200°C/2½ mins.	18907	0.518
Aged 300°C/15 mins.	12212	0.403

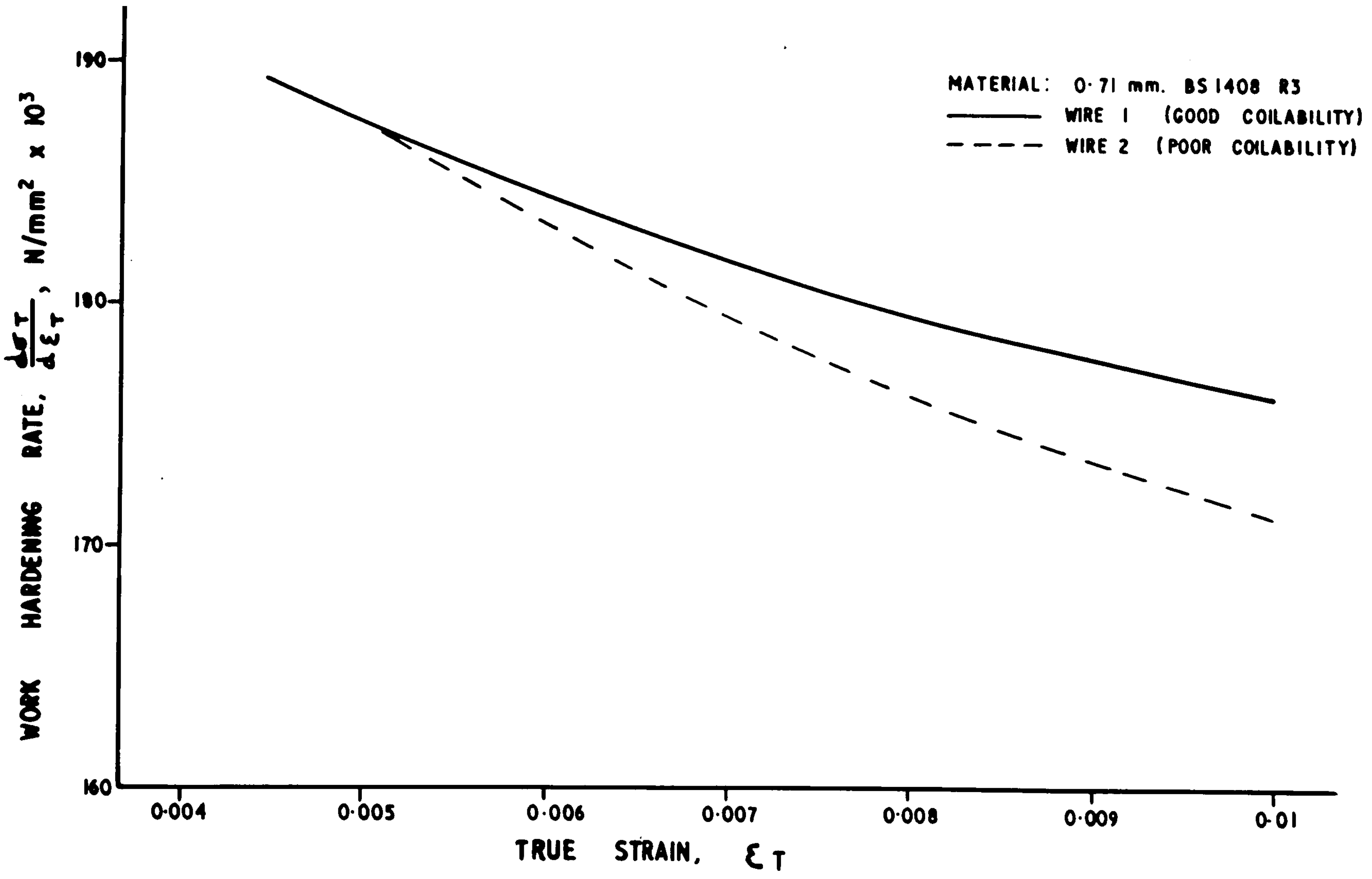

FIG. I. WORK HARDENING RATES OF CARBON STEEL WIRES 1 AND 2.

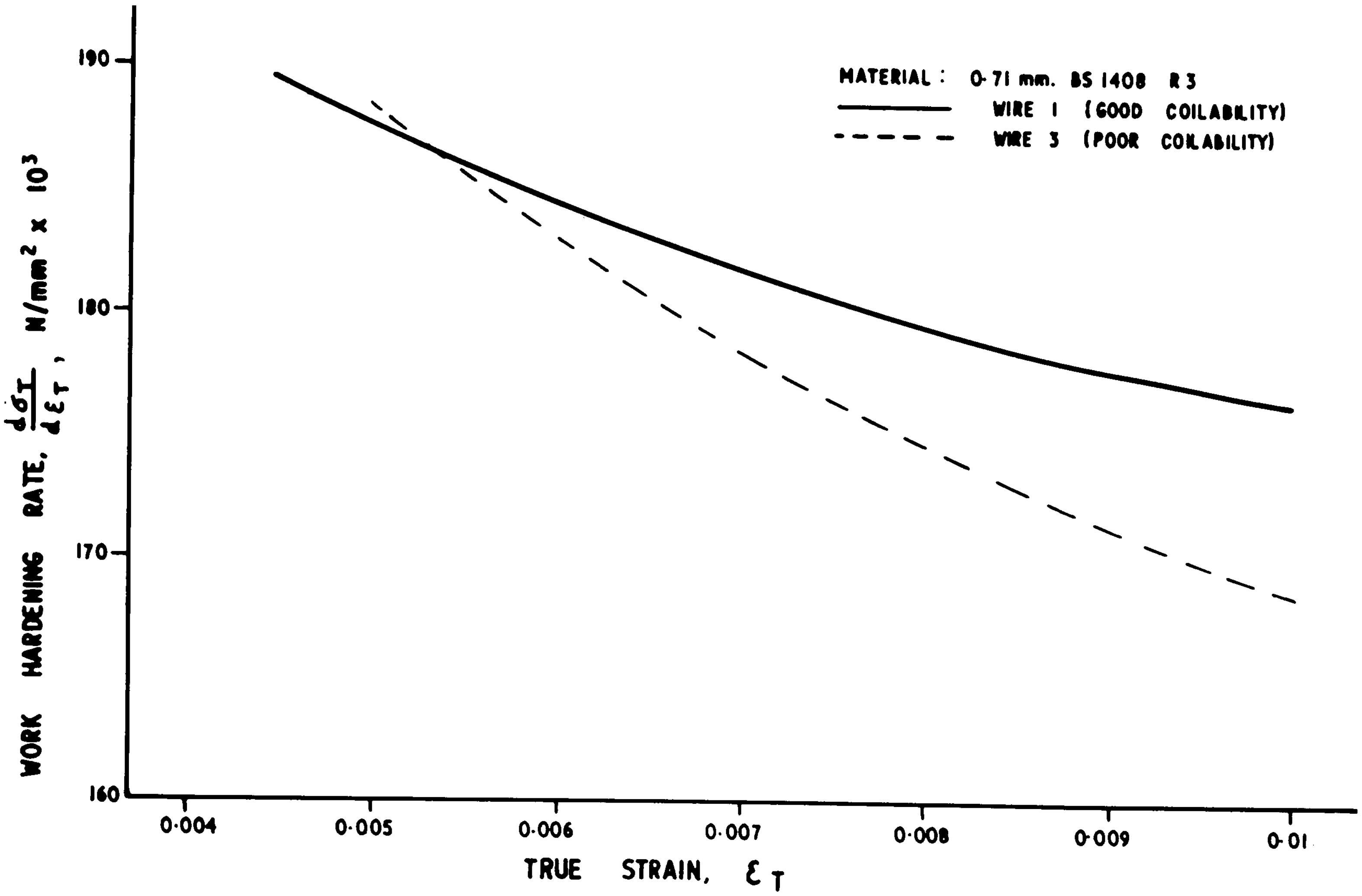

FIG. 2. WORK HARDENING RATES OF CARBON STEEL WIRES 1 AND 3.

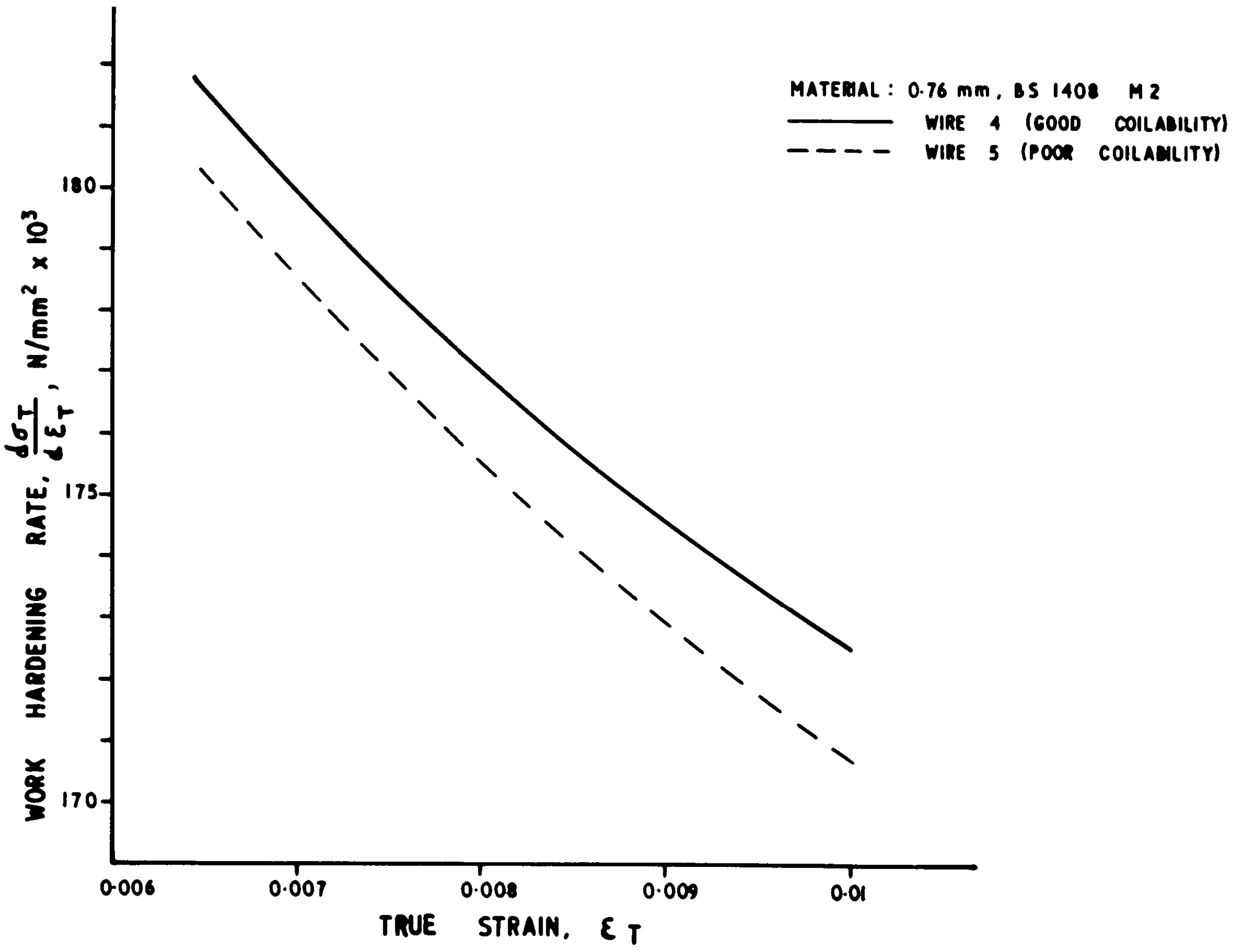

FIG. 3. WORK HARDENING RATES OF CARBON STEEL WIRES 4 AND 5.

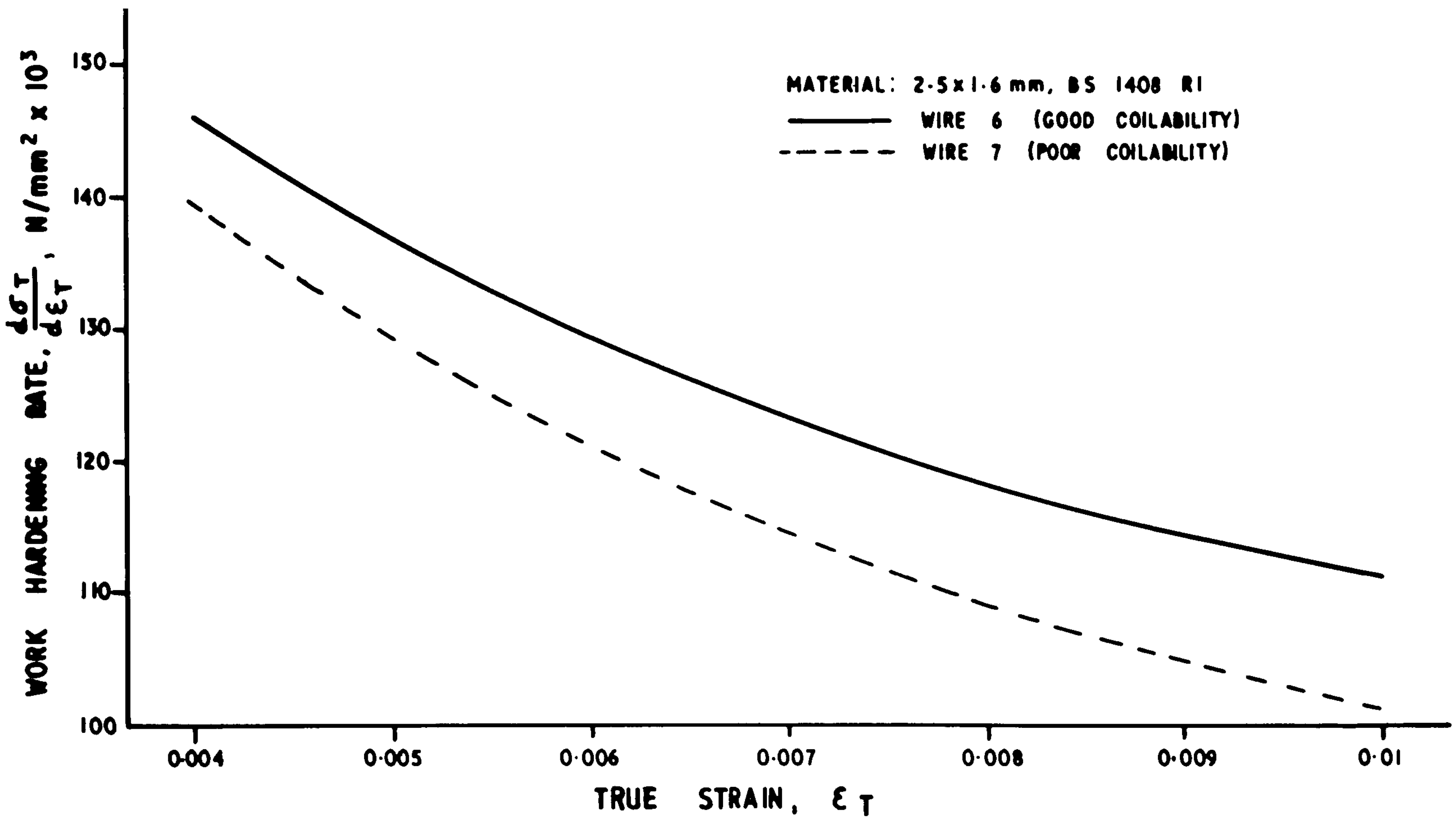

FIG. 4. WORK HARDENING RATES OF CARBON STEEL WIRES 6 AND 7.

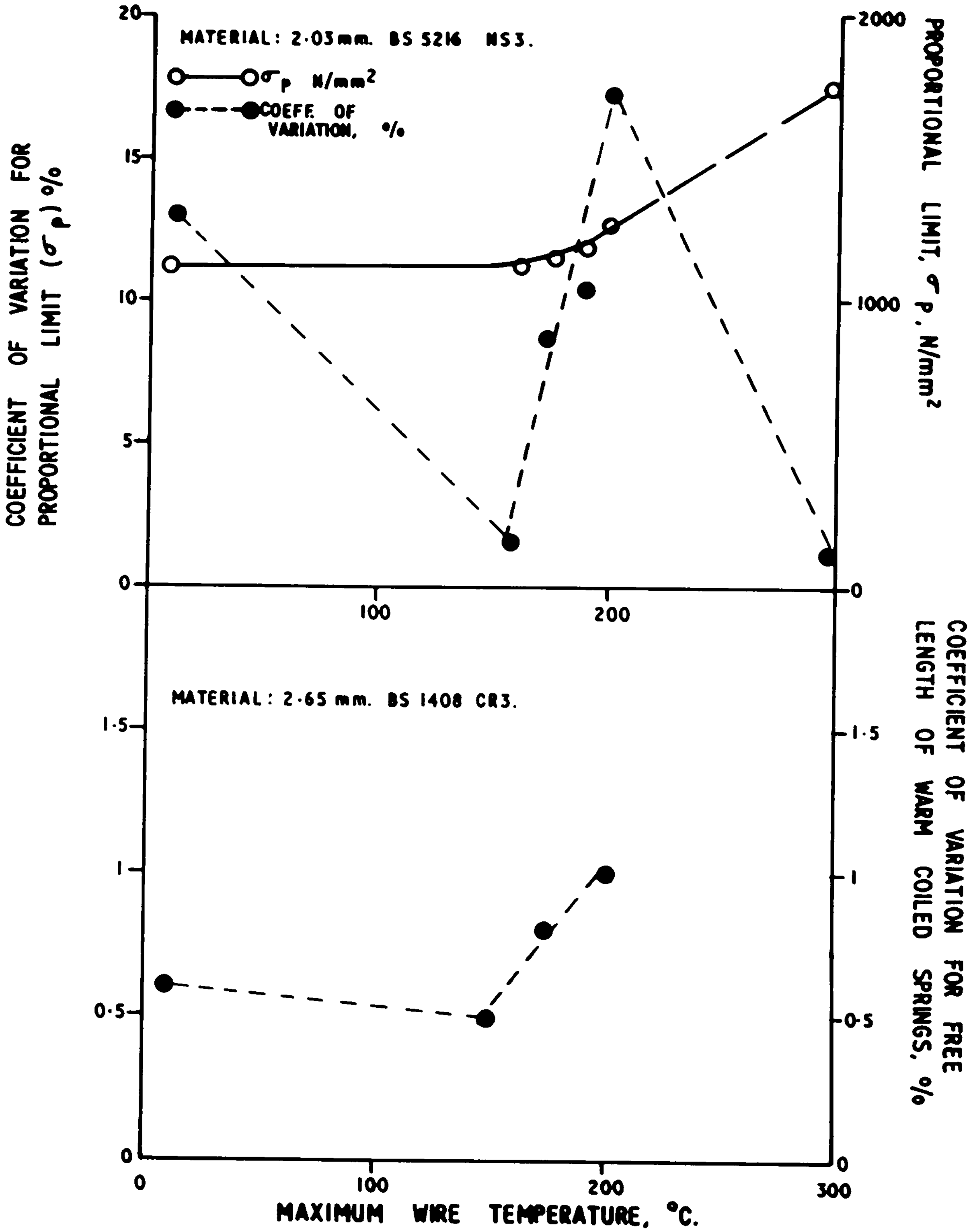

FIG. 5. VARIATION OF PROPORTIONAL LIMIT AND FREE LENGTH VARIABILITY OF WARM COILED SPRINGS WITH MAXIMUM WIRE TEMPERATURE FOR CARBON STEEL WIRE.

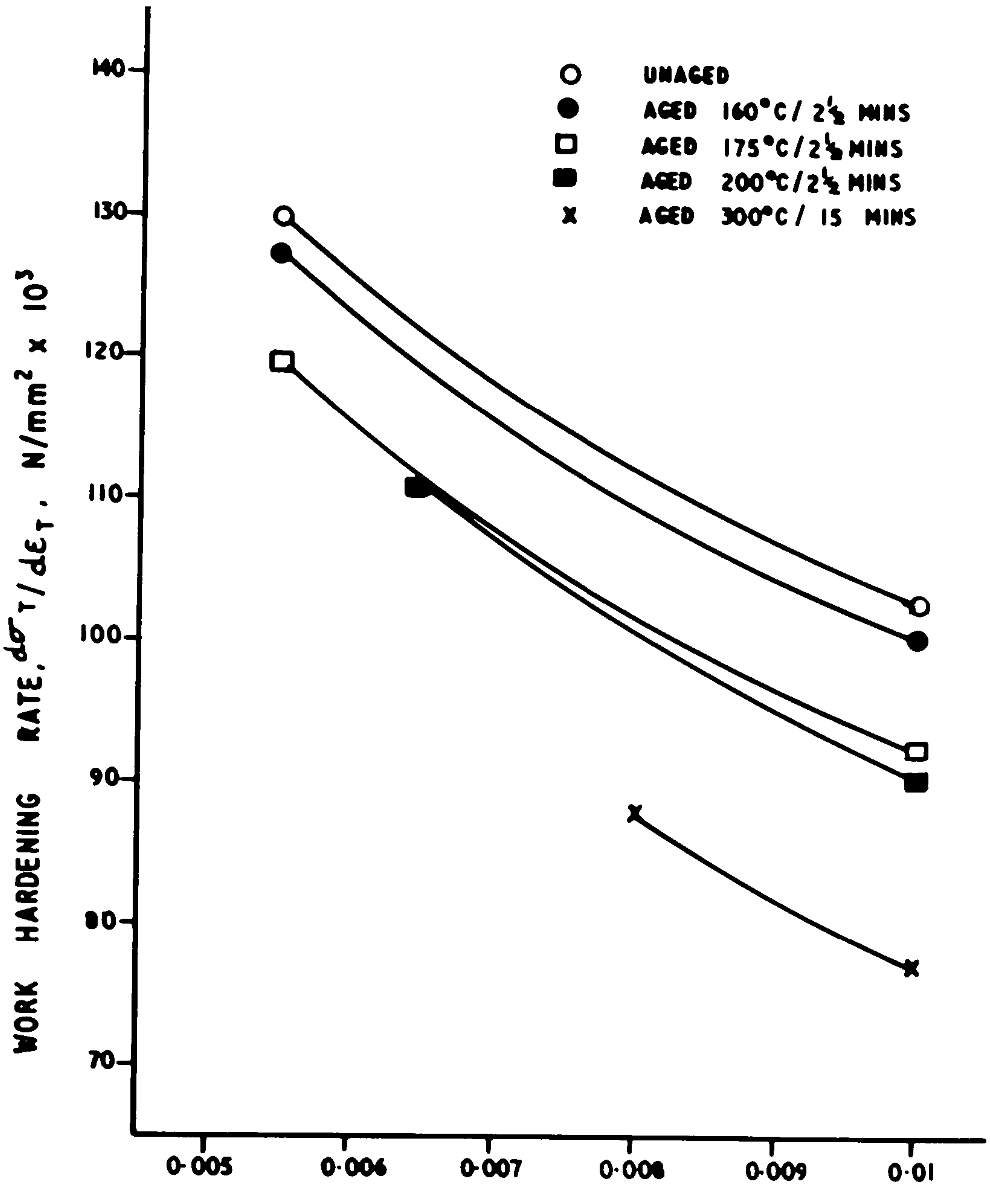

FIG. 6 EFFECT OF MAXIMUM WIRE TEMPERATURE UPON THE WORK HARDENING RATE OF 2·03 mm, BS 5216 NS 3 WIRE.

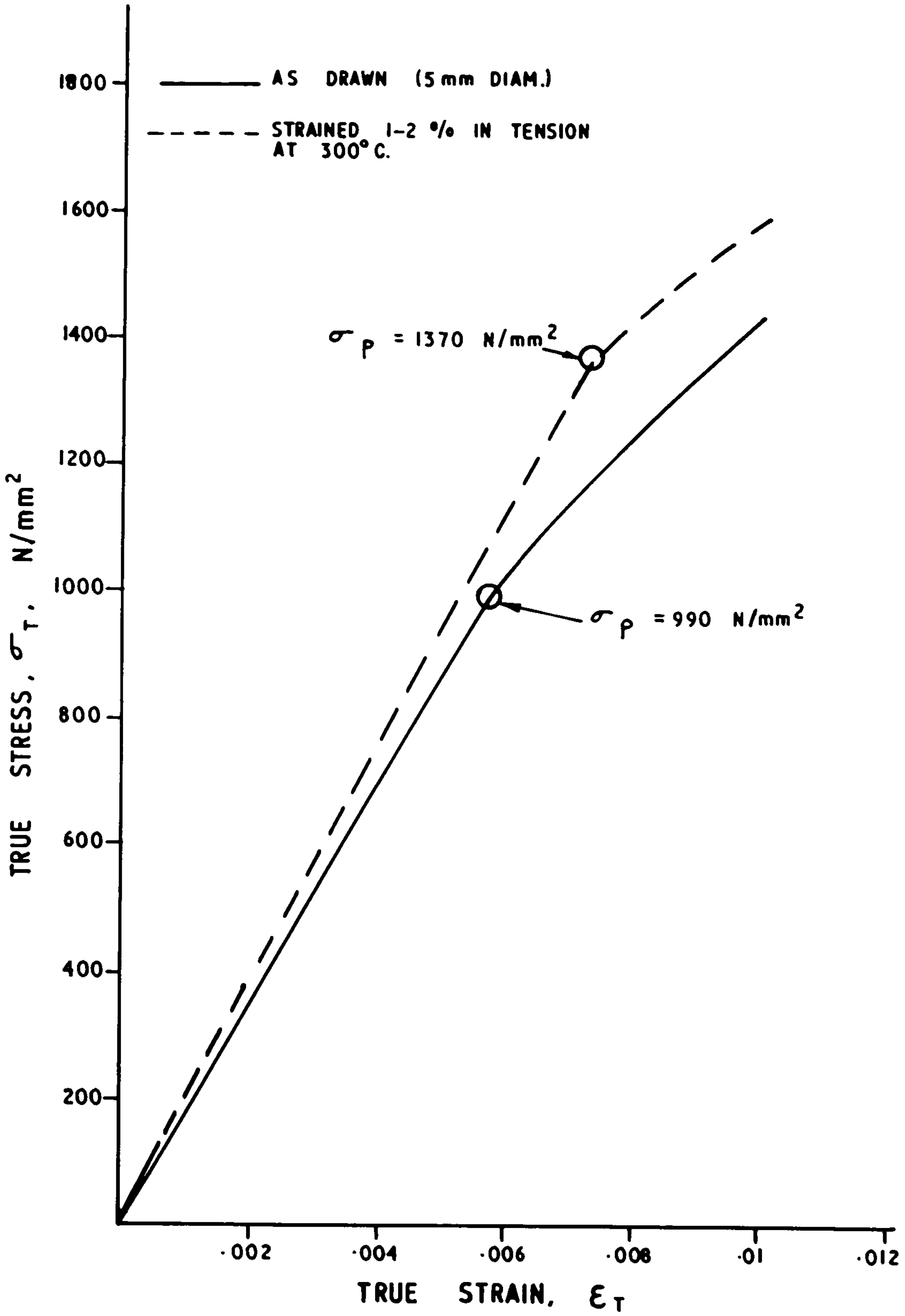

FIG. 7. EFFECT OF DYNAMIC STRAIN AGEING ON TENSILE ELASTIC PROPERTIES OF PATENTED CARBON STEEL WIRE. (FROM REF. 10.)

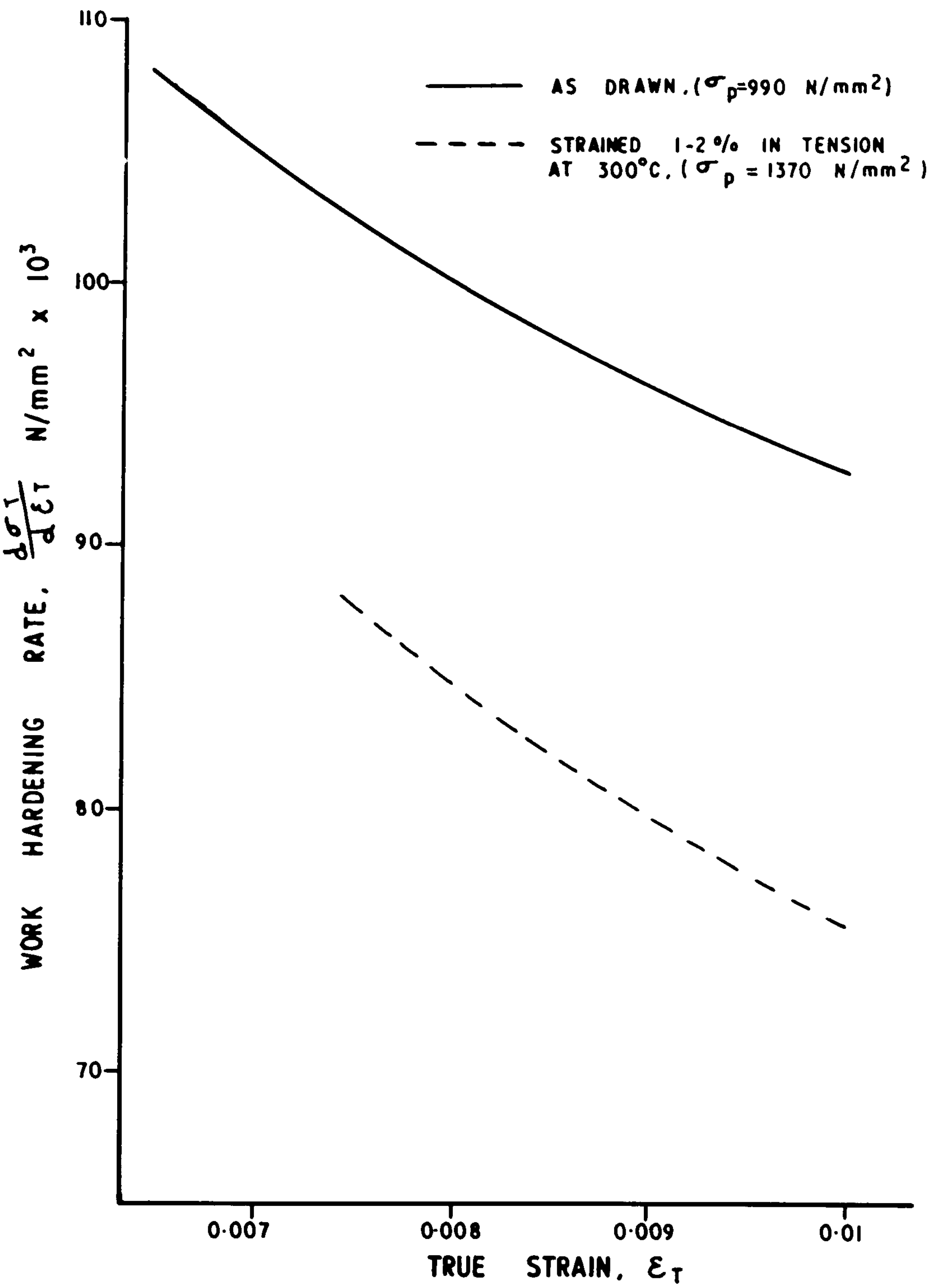

FIG. 8. EFFECT OF DYNAMIC STRAIN AGEING ON WORK HARDENING RATE OF PATENTED CARBON STEEL WIRE. (FROM REF 10.)