SPRING MANUFACTURERS' RESEARCH ASSOCIATION

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Summary

The effect of low temperature heat treatment on 0.048 in. diameter and 0.104 in. diameter EN.49C and EN.49D spring wire has been investigated. Static tensile and torsional tests on wires low temperature heat treated over the range 150°C - 350°C have shown that the maximum elevation in properties occurs when the wires are heat treated in the temperature range 200°C - 250°C. Prestressing caused no significant change in the optimum low temperature heat treatment temperature.

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THE EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE STATIC MECHANICAL PROPERTIES OF SOME BRITISH SPRING WIRES

by G.B. Graves, A.Met., A.I.M. and R.A. Varo, A.I.M.

1. INTRODUCTION

High tensile steel wires produced by a process of cold deformation possess relatively low elastic properties, in fact it has been stated that such wires possess no "elasticity".[1] In spring manufacture it is necessary to increase the elastic properties of the coiled spring by a suitable treatment and this is achieved by both thermal and mechanical means.

The present paper deals with the effects of L.T.H.T. on the static mechanical properties of some standard British hard drawn spring wires. Later it is intended to investigate whether coiling stresses result in a different L.T.H.T. to produce maximum elevation of the elastic limit.

2. MATERIALS

The specification, composition and size of the wires investigated are given in Table I.

Table I Composition and size of wires

Specification	Wire Size (in)	Cast Analysis %				
		C	Mn	Si	S	P
B.S.1408 EN.49D Range 2	0.104	0.78	0.60	0.24	0.024	0.016
B.S.1408 EN.49D Range 2	0.048	0.79	0.66	0.20	0.018	0.018
B.S.1408 EN.49C Range 2	0.104	0.79	0.60	0.21	0.021	0.016
B.S.1408 EN.49C Range 2	0.048	0.79	0.66	0.20	0.018	0.018

3. EXPERIMENTAL PROCEDURE

Random samples for heat treatment and testing were taken from each coil of wire. As the wire was "dead" in the coil it was necessary to straighten very carefully the cut samples by hand. Previous experience had shown that by this method the minimum amount of residual stress is introduced into the specimen. Duplicate mechanical tests in tension and in torsion were undertaken on material which had been heat treated over the temperature range 150°C to 350°C. The effect of prior low temperature heat treatment on the elastic limit in torsion after prestressing has also been studied.

The heat treatment of the straight sample lengths was carried out in an air circulating oven having an accuracy of ± 2°C. Previous work[2] had shown that there was little advantage to be gained from heat treatment times greater than 30 mins, consequently the time of 30 mins was adopted throughout this investigation.

4. MECHANICAL TESTING

4.1 Tensile Properties

All tensile tests were carried out on a grade A universal testing machine, the load range being selected according to the wire diameter such that at least 75% of the full scale deflection was utilised during the test.

4.2 Torsional Properties

The torsional properties were determined on a machine having a maximum capacity of 50 lb.in. using specimens having a gauge length 100 times the wire diameter. The maximum shear stress, elastic limit, and maximum elastic limit after prestressing were determined for wires in various conditions of low temperature heat treatment. In view of hysteresis of some of the stress-strain curves a true limit of proportionality could not be obtained and the elastic limit was therefore determined, this was taken as the point at which the first perceptible sign of permanent set took place.

The method of prestressing used was based on two distinct experiments. Namely, (a) subjecting the wire to a very small increment of stress above the natural elastic limit of the material, removing this stress and then repeating the load application a further five times. This procedure was then repeated for a higher level of stress and the process continued until a stage was reached when the repeated application of a given stress resulted in plastic deformation still occurring on the sixth application. The stress value below this increment at which no plastic deformation occurred on the sixth repeated application was taken as the maximum prestressed elastic limit. (b) Subjecting the wire to some arbitrary torsional stress value for six repeated stress applications well in excess of the prestressed elastic limit determined in (a). Subsequent stress applications to successively reduced stress levels were then made until a stress value was obtained at which further plastic deformation did not occur. This value of stress was taken as the maximum prestressed elastic limit. With both these methods of prestressing the maximum prestressed elastic limit proved to be the same. Method (b) is less time consuming and more convenient and was therefore adopted during the present work as the standard method of determining the maximum level of prestressing.

All torsional stress calculations were based on the formula

$S = \frac{16T}{\pi d^3}$ where T = torque in lb.in. and d = wire diameter in inches.

5. RESULTS

The effect of temperature on the static tensile and torsional properties of 0.048 in. dia. and 0.104 in. diameter EN.49C and EN.49D wire is shown in Figs. 1 - 4 and Table 2.

6. DISCUSSION OF RESULTS

Fig. 1 shows the effect of low temperature heat treatment on the elastic limit in torsion with and without prestressing for 0.104 in. and 0.048 in. diameter EN.49C range 2 material. This shows that for both wire sizes the maximum elevation in these two properties occurred after a L.T.H.T. at 250°C. It will be noticed that before prestressing the lower tensile strength 0.104 in. diameter had superior elastic properties to the 0.048 in. diameter wire, when both were heat treated above 175°C.

The U.T.S. of spring wire is invariably quoted in specifications owing to the relative simplicity of the test. However as such figures are of little value where the material is to work in torsion, it is necessary to know the relationship between the U.T.S. and torsional properties. The effect of L.T.H.T. on mechanical properties and the relationship between U.T.S., maximum shear strength and number of twists to failure are shown in Fig. 2 and can be compared with the torsional elastic properties given in Fig. 1. The initial tensile strengths of both wires met the B.S.1408 range 2 specification. The optimum L.T.H.T. for both maximum elevation of U.T.S. and shear strength was 250°C for the 0.104 in. diameter wire. It showed good ductility as measured by twists to fracture and gave clean 90° shear fractures in all cases. For the 0.048 in. diameter wire, however, the optimum L.T.H.T. was 200°C for U.T.S. and 175°C for maximum shear strength and although again showing a high number of twists to failure it gave unsatisfactory fractures after L.T.H.T. at 175°C.

The effect of L.T.H.T. on the elastic properties of 0.104 in. and 0.048 in. diameter EN.49D range 2 wires is illustrated in Fig. 3. As was the case for EN.49C material, the maximum elevation of elastic properties of the 0.104" diameter EN.49D wire, both before and after prestressing, occurred after a heat treatment at 200°C. The elastic limit of the 0.048 in. diameter wire reached a maximum value after a treatment at 250°C and the elastic limit after prestressing a maximum after a 200°C treatment.

Fig. 4 shows the relationship between L.T.H.T. and U.T.S., maximum shear stress and number of twists to failure for the same wires, In this case, for the 0.104 in. diameter material the optimum L.T.H.T. was 175°C for the U.T.S. and 200°C for maximum shear strength. The number of twists to failure was high after all heat treatments and showed ductile 90° shear fractures, except in one case where an unsatisfactory type was obtained after the 175° treatment. The 0.048 in. diameter wire showed a peak U.T.S. after a 200°C treatment and a peak for maximum shear strength after the 250°C treatment. With the exception of the material L.T.H.T. at 175°C all the specimens fractured in a 90° ductile manner giving a high number of twists to failure.

Due to the general flatness of the curves obtained over the temperature range 175 - 250°C it seems reasonable to assume that they might be used with confidence for other spring wires manufactured to the same specification. With temperatures in the region of 175°C however, some difficulty may arise due to embrittlement which it is suspected may result from strain age-hardening. It would therefore seem reasonable to avoid treatments around this temperature. At temperatures of approximately 350°C softening commenced. However, where maximum resistance to stress-relaxation is required these higher temperatures are known to be advantageous.

The ratios of the maximum shear strength and natural and prestressed torsional elastic limits to the "as drawn" U.T.S. for no low temperature heat treatment and for the optimum heat treatment are given in Table II.

7. CONCLUSIONS

1. The optimum L.T.H.T. for the various mechanical properties of the wires tested was in the range 200° - 250°C and the change in mechanical properties was small over this range.

2. Differences in size and initial strength of the wires tested caused no significant change in the range of temperatures where maximum elevation of properties occurred.

3. Rather surprisingly, the torsional elastic properties of the 0.104 in. diameter wires were generally higher than those of the 0.048 in. diameter wires, this was true even after the same L.T.H.T. Prestressing, however, reversed the position.

4. Although there was considerable variation in the torsional elastic limit/U.T.S. ratio according to wire size, type of material and L.T.H.T. the effect of prestressing was both to elevate and stabilise this ratio so that it finally lay approximately between the values 0.6 - 0.7.

5. This information relates directly to wire. Further work is required to study what effect, if any, the stresses introduced on coiling will have on the elastic limit after L.T.H.T.

8. REFERENCES

1. R.S. Brown. Journal of the Iron & Steel Institute, June, 1949, "Plastic strain and hysteresis in drawn steel wire".

2. C.W. Barson and G.B. Toyne. Coil Spring Journal, March 1953, No. 30, p.10. "Static torsional properties of cold drawn spring wires".

Table II Ratios of torsional properties to U.T.S.

Wire Quality	Size (in)	As received U.T.S. tons/sq.in.	L.T.H.T. Temp. °C	Max. Shear Stress tons/sq.in.	Natural Elastic Limit tons/sq.in.	Prestressed Elastic Limit tons/sq.in.	Max. Shear Stress / U.T.S.	Natural Elastic Limit / U.T.S.	Prestressed Elastic Limit / U.T.S.
EN.49C	0.048	121.1	20	98.0	20.4	75.6	0.81	0.17	0.62
"	"	121.1	250	102.2	42.8	84.8	0.84	0.35	0.70
"	0.104	105.3	20	89.7	15.9	66.7	0.85	0.15	0.63
"	"	105.3	250	96.6	63.7	75.7	0.92	0.60	0.72
EN.49D	0.048	120.6	20	97.0	17.2	73.0	0.81	0.14	0.61
"	"	120.6	200	99.5	39.6	82.0	0.83	0.33	0.68
"	0.104	105.2	20	84.0	21.5	62.0	0.80	0.21	0.59
"	"	105.2	200	88.0	49.0	75.0	0.84	0.47	0.71

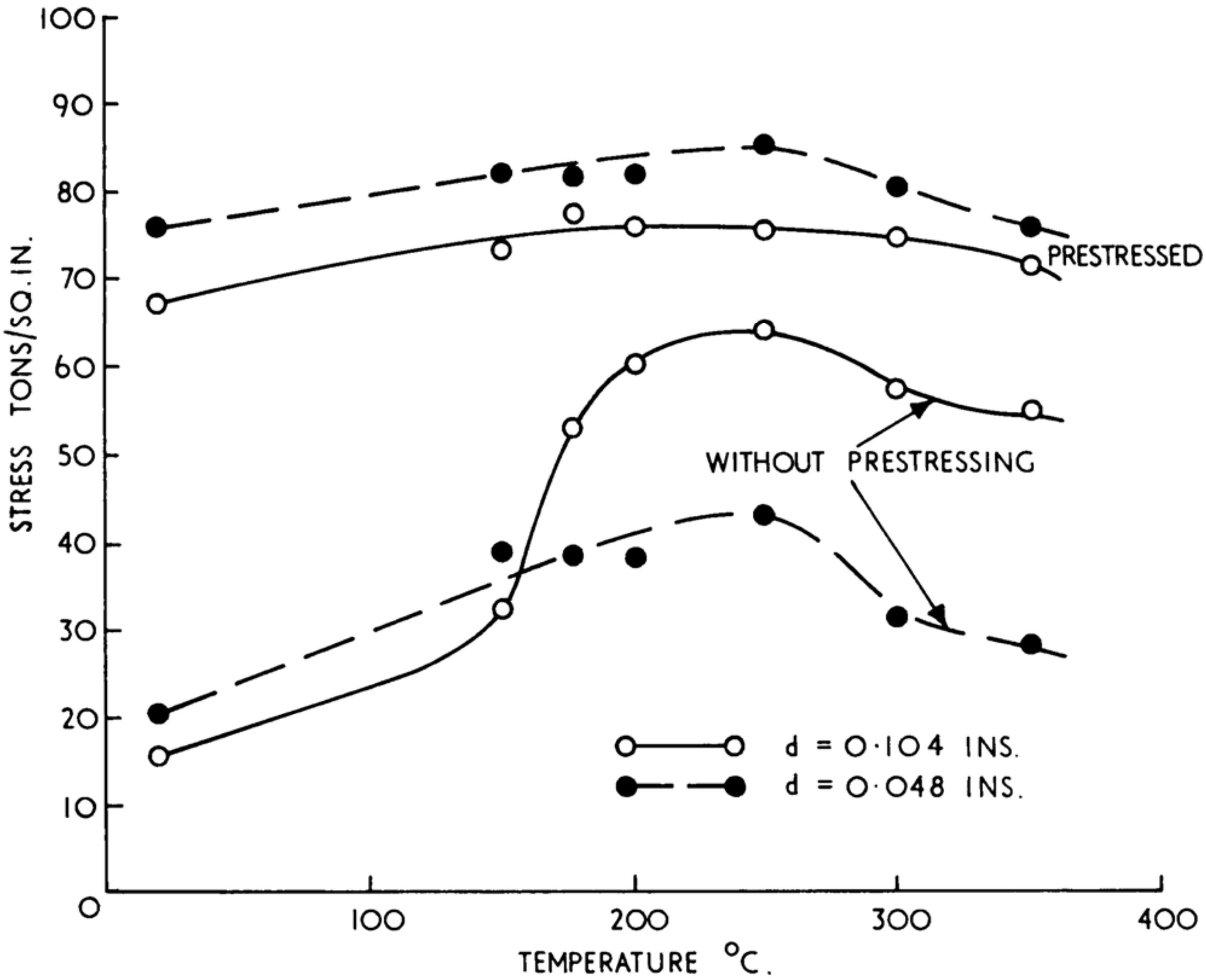

FIG. I.

EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE ELASTIC LIMIT IN TORSION OF EN 49 C STEEL WIRE WITH AND WITHOUT PRESTRESSING.

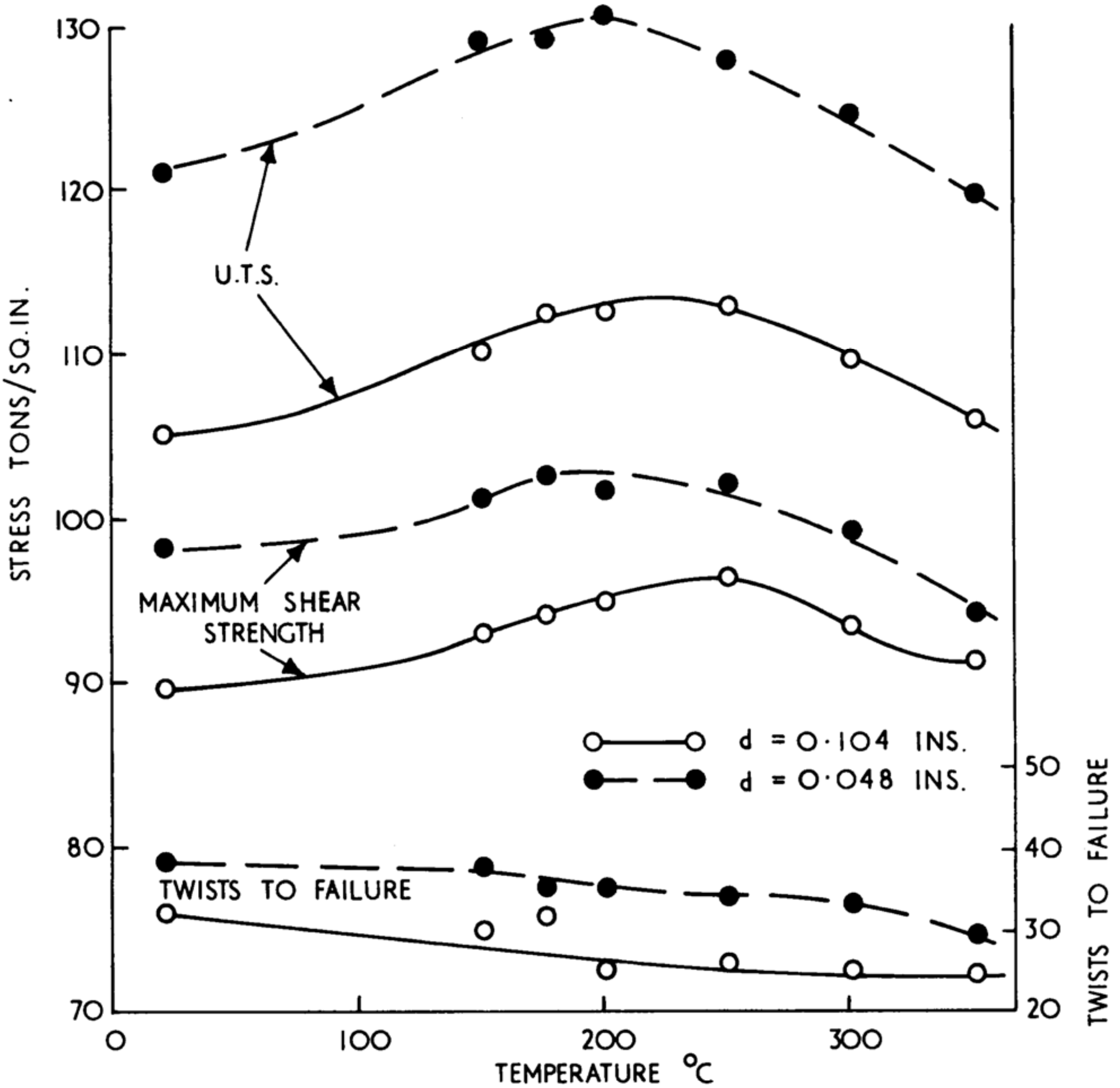

FIG.2.

EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE ULTIMATE TENSILE STRENGTH, MAXIMUM SHEAR STRENGTH AND NUMBER OF TWISTS TO FAILURE OF EN49 C STEEL WIRE.

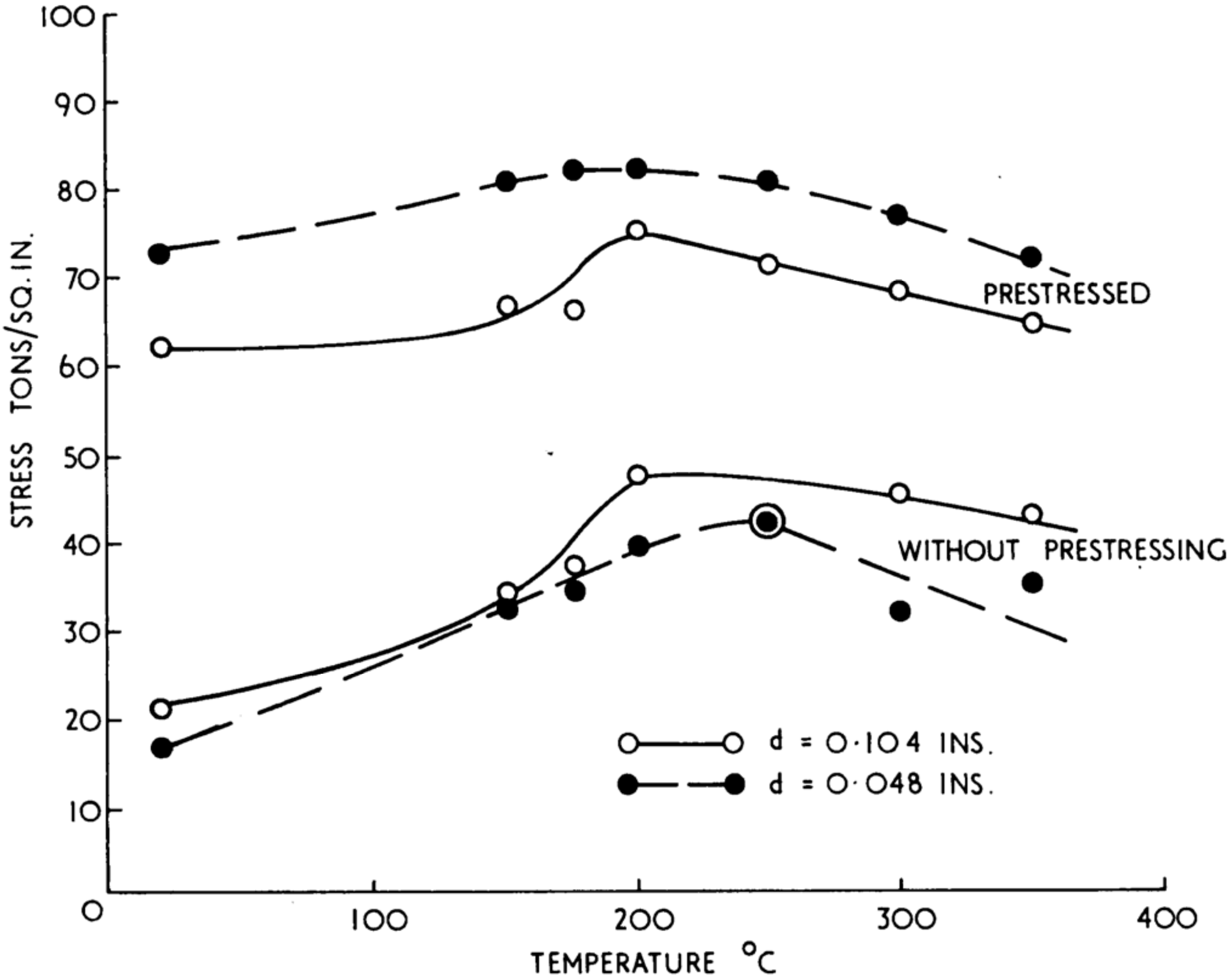

FIG.3.

EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE ELASTIC LIMIT IN TORSION OF EN 49 D STEEL WIRE WITH AND WITHOUT PRESTRESSING.

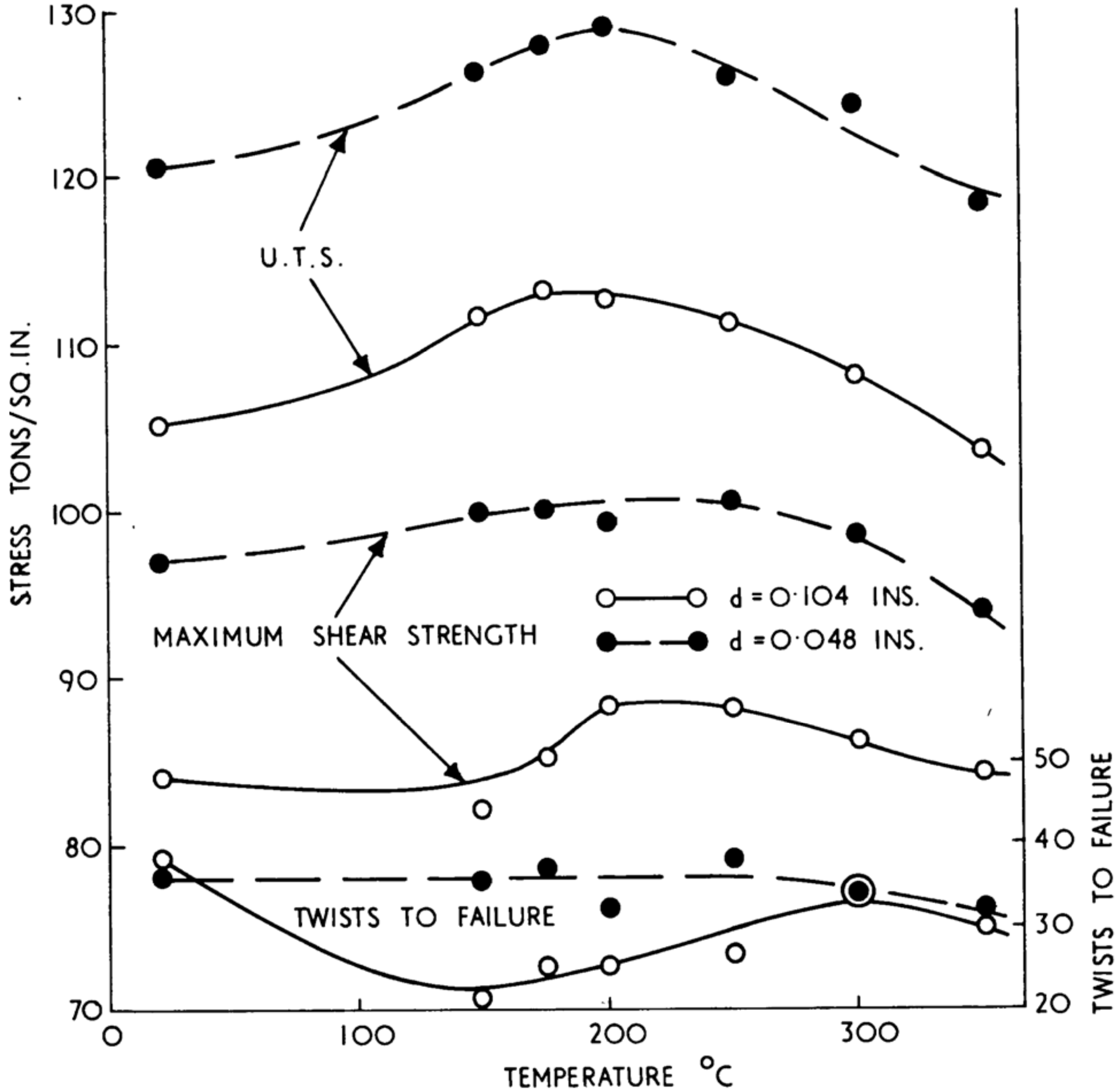

FIG. 4.

EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE ULTIMATE TENSILE STRENGTH, MAXIMUM SHEAR STRENGTH AND NUMBER OF TWISTS TO FAILURE OF EN 49 D STEEL WIRE.