THE SPRING MANUFACTURERS' RESEARCH ASSOCIATION

The Evaluation of D.T.D. Spring Materials (Static Mechanical Properties)

Report No. 158

by

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

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(Static Mechanical Properties)

(Contract No. KS/1/033)

Summary

The influence of low temperature heat treatment on the torsional limit of proportionality has been determined using two sizes of wire in D.T.D.5B, D.T.D.5006 and D.T.D.239B qualities.
Torsional prestressing raised the elastic limit of each of the materials investigated but did not increase the proportional limit to the same extent. Altering the straining rate from 10°/min. to 100°/min. had no effect on the resultant torsion properties.
Torsional prestressing had little effect on the ultimate tensile strength. The proportional limit values were affected erratically, in some cases increasing whilst in others decreasing after prestress.

(June, 1966)

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1. INTRODUCTION

The J.A.C. Metallic Materials Sub-committee of the Ministry of Aviation asked the S.M.R.A. to undertake experimental work on D.T.D. spring materials with the object of obtaining data for both wire and springs. It is the intention that information shall be provided to enable designers and manufacturers to obtain the best possible performance from springs made from the various D.T.D. spring wires. The work has included the effects of low temperature heat treatment on the torsional limit of proportionality, the effects of prestressing wire which had received the optimum low temperature heat treatment and the influence of straining rate used during testing on the resultant torque - angular twist curves. The tensile properties of each quality and size have been determined after various treatments designed to simulate the production sequence used when making springs.

2. MATERIALS

The investigations were undertaken on 0.064 in diameter and 0.160 in diameter wire each to the following D.T.D. specifications, namely:

Patented hard drawn carbon steel	D.T.D.5B
Cold drawn 18/8 Cr-Ni steel	D.T.D.5006
Hardened and tempered carbon steel	D.T.D.239B

Details regarding the composition of the wires are given in Table I.

3. EXPERIMENTAL PROCEDURE

3.1 Sample preparation and heat treatment

Samples for heat treatment and testing were taken from each 56 lb coil of wire having mean coil diameters of 22 inches. As the wire was 'dead' in the coil it was necessary to straighten out the cut lengths very carefully by hand. Previous experience had shown that by this method the minimum amount of residual stress is introduced into the specimen. In order to facilitate gripping in the torsion testing machine, it was necessary to bend 2 in of wire at each end of the specimen to form an angle of 90°.

Unlike the hard drawn wires D.T.D.5B and D.T.D.5006, the D.T.D.239B material needed hardening and tempering prior to testing, to meet the tensile strength laid down in the specification. Heating for hardening was done in an electrical muffle furnace having an atmosphere of raw town's gas and tempering was carried out in an air circulating furnace. The 0.064 in diameter wire was austenitised at 840°C and hardened by quenching into oil and then tempered for 1h at 350°C to produce a U.T.S. of 109 tonf/in^2. The larger size 0.160 in diameter received 840°C O.Q. and was tempered 1h at 400°C, resulting in a U.T.S. of 100 tonf/in^2.

After specimen preparation low temperature heat treatment was undertaken using an air circulating furnace controlled within ± 5°C. The D.T.D. 5B was heat treated over a temperature range 100°C to 400°C, the D.T.D.5006 wire over a range 100°C to 500°C and the D.T.D.239B wire over a temperature range of 100°C to 475°C. A number of samples were tested in the "as drawn" or hardened and tempered condition without subsequent low temperature heat treatment.

3.2 Torsion tests

All torsion testing was carried out on a Tinius Olsen torsion testing machine, the torque - angular twist characteristics being automatically recorded. For the purpose of determining the relationship of limit of proportionality to low temperature heat treatment all samples had a nominal gauge length of 100 times the wire diameter and were tested at a straining rate of 100° of angular twist per minute. Triplicate tests were undertaken for each condition of heat treatment and the limit of proportionality determined from each torque-twist curve. All torsional stress calculations were based on the formula:

$$q = \frac{16T}{\pi d^3 2240}$$

where: q = shear stress in tonf/in^2

d = wire diameter in inches

T = torque in lbf/in

It is well known that the elastic properties of spring materials can be increased by subjecting a wire or spring to controlled plastic deformation, such an operation is known as prestressing or scragging. To establish the maximum level to which the materials under investigation would prestress the following experimental method was employed using straight wire specimens. The wire was subjected to a very small increment of stress above the natural elastic limit of the material, the stress removed and any set resulting noted, the load application and removal was repeated 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.

Previous work by the S.M.R.A. (1) has shown that in order to obtain the maximum lift in elastic properties on prestressing it is only necessary to carry it out on specimens which have previously received the optimum low temperature heat treatment to give maximum elastic properties. For each quality and wire size, the optimum low temperature heat treatment was selected from Figs. 1 to 6 and applied to wire samples prior to the determination of the maximum prestressed elastic limit. Triplicate samples were used to produce torque - angular twist curves using a testing straining rate of 100° of angular twist per minute and the limit of proportionality, 0.5% proof stress and rigidity modulus determined.

The effects of the straining speed used during torsion testing on the torsional properties have been evaluated using wires which had been low temperature heat treated and prestressed and tested at speeds of 10° and 100° per minute.

3.3 Tensile tests

Some aircraft springs made from non-corrosion resistant materials such as D.T.D.5B and D.T.D.239B are protected against corrosion by a suitable coating such as electrodeposited cadmium. Tensile property data have therefore been obtained from wires which had purposely received various process treatments intended to simulate the normal spring production procedure. Tensile tests were carried out on wires in the following conditions:

(a) after optimum low temperature heat treatment
(b) after L.T.H.T. and prestressing
(c) after L.T.H.T., cadmium plating, baking and prestressing

Specimens produced from the rust resisting quality D.T.D.5006 were not plated.

The load-extension curves were obtained using a Grade A Amsler tensile testing machine using load scales of 1 ton and 3 tons for the 0.064 in diameter and 0.160 in diameter wires respectively. Strain was measured using a mechanical extensometer measuring to 0.00005 in on a 2 in gauge length. From the load-extension curve for each specimen the U.T.S., limit of proportionality, 0.1% proof stress, 0.2% proof stress, 0.5% proof stress and Young's Modulus were determined. In certain cases, however, it was not always possible to obtain the 0.2% P.S. and 0.5% P.S. due to the attendant danger of damage to the extensometer since these values were very close to the U.T.S.

3.4 Plating

All tensile specimens were treated in accordance with the Ministry of Aviation Specifications D.T.D.904C and D.T.D.934.

Specimens having a tensile strength less than 120 tonf/in^2 (i.e. D.T.D.5B 0.160 in diameter, D.T.D.239B 0.064 and 0.160 in diameters) were cleaned and plated to the following schedule:

(a) degreased in an organic solvent

(b) anodically pickled in a proprietary acid cleaner for 5 minutes

(c) plated in "Zonax" cadmium cyanide solution for 45 minutes using a current density of 10 amp/ft^2

(d) de-embrittled by baking at 200°C for 18 hours

Wire samples prepared from 0.064 in diameter D.T.D.5B had a tensile strength in excess of 120 tonf/in^2 and it was therefore necessary to use a modified plating procedure, namely:

(a) degreased using an organic solvent

(b) anodically cleaned using a proprietary hot alkali at 90°C for 15 minutes

(c) plated in "Zonax" cadmium solution for 45 minutes at a current density of 10 amp/ft^2

(d) de-embrittled by baking for 24 hours at 200°C

The plating thickness was determined by the strip and weigh method for average thickness and by a dip test for local thickness. The average thickness of the plate was maintained at 0.0008 in throughout.

4. RESULTS

The individual torsional limit of proportionality determinations after various low temperature heat treatments are given in tabular form in Table II, III and IV, for each of the three materials and two wire sizes investigated. The relationship between the limit of proportionality and low temperature heat treatment is shown graphically in Figs. 1 and 2 for 0.064 in diameter and 0.160 in diameter D.T.D.5B wires, in Figs. 3 and 4 for D.T.D.5006 wires and in Figs. 5 and 6 for D.T.D.239B wires.

The torsional properties of the various wire qualities and sizes determined after each had received the optimum low temperature heat treatment and prestressing are given in Tables V, VI and VII. The effect of straining rate on the resultant torsional properties after prestressing is also shown in these tables.

Tensile data obtained from the three materials in various metallurgical conditions have been tabulated and are reported in Tables VIII to X.

5. DISCUSSION OF RESULTS

5.1 Torsional properties and L.T.H.T.

The effect of low temperature heat treatment on the torsional limit of proprtionality values is shown in Figs. 1 to 6. An increase in the temperature of treatment caused a progressive increase in the L. of P. values until some optimum temperature is reached, treatment temperatures above the optimum caused in most cases, a rapid fall off of the proportional limit.

With the hard drawn materials, D.T.D.5B and D.T.D.5006, there was a marked elevation of the L. of P. values. The 0.064 in D.T.D.5B wire showed a maximum elevation of 61 tonf/in^2 after a L.T.H.T. of 200°C for 30 minutes and the 0.160 in wire to 42.8 tonf/in^2 after 175°C, but in this case treatment temperatures above 175°C did not result in a rapid fall off in L. of P. In fact, the L. of P. was still above 40 tonf/in^2 even after an L.T.H.T. of 400°C.

The behaviour of hard drawn wires in resisting softening at temperatures above that to produce the optimum lift in the proportional limit have been previously observed on 0.104 in diameter En 49D wire to B.S.1408(2).

The hard drawn stainless steel wires, D.T.D.5006, showed a similar behaviour when low temperature heat treated, maximum increase in L. of P. to 47.7 tonf/in^2 occurred after heat treatment in the temperature range 400°C - 450°C for the smaller 0.064 in diameter wire and to 30 tonf/in^2 after treatment in the range 375°C - 425°C for the larger 0.160 in wire. Higher temperatures resulted in a rapid falling off in the value of the limit of proportionality.

The hardened and tempered 0.064 in D.T.D.239B wire also unexpectedly responded to low temperature heat treatment increasing from the as hardened and tempered L. of P. of 38 tonf/in^2 to 48.5 tonf/in^2 after a subsequent heat treatment of 325°C. At temperatures above the original tempering temperature of 350°C, there was a decline in L. of P. properties, presumably due to further tempering of the structure. With hardened and tempered structures such as this strain age hardening and/or preferential relief of undesirable textural stresses would not normally occur. However, considerable distortion was experienced during hardening and tempering, due to the slender nature of the torsion samples, with the result that, after hardening and tempering the specimens had to be hand straightened prior to low temperature heat treatment. It is suggested that the response shown in this curve (Fig. 5) might be due to the introduction of residual stress which on low temperature heat treatment caused either strain age hardening or preferential stress relief with a consequent lift in the L. of P. values.

The form of the L. of P. and L.T.H.T. curve for 0.160 in diameter D.T.D.239B wire (Fig. 6) is normal. It did not show any marked response to low temperature heat treatment, the L. of P. increasing only slightly from 38.5 tonf/in^2 to 42 tonf/in^2 after L.T.H.T. at 400°C. When the original tempering temperature of 400°C was exceeded general softening commenced.

5.2 <u>Torsional prestressing</u>

Prestressing in every case elevated the limit of proportionality values, the effect being greater with the smaller 0.064 in diameter wires than with the larger 0.160 in diameter wires.

The 0.064 in diameter D.T.D.5B when prestressed to a maximum elastic limit value of 87 tonf/in^2 resulted in an L. of P. of 65 tonf/in^2 and 0.5% P.S. of 90 tonf/in^2, these values being respectively 68.5%, 51% and 71% of the U.T.S. after low temperature heat treatment. The larger 0.160 in diameter D.T.D.5B was capable of being prestressed to a maximum elastic limit of 73 tonf/in^2 again 68% of the U.T.S., giving an L. of P. of 45.8 to 50.0 tonf/in^2 (about 45% of the U.T.S.) and 0.5% P.S. of 77 to 79 tonf/in^2 (73% of the U.T.S.)

With the 0.064 in diameter D.T.D.5006 quality, prestressing was possible to an elastic limit of 91 tonf/in^2 (74% of the U.T.S.), slightly higher than with a similar sized D.T.D.5B wire, resulting in an L. of P. of between 63.5 and 73 tonf/in^2 (51% - 59% of the U.T.S.)and a 0.5% P.S. of 93.7 to 96.9 tonf/in^2 (76% - 78% of the U.T.S.) The L. of P. for prestressed 0.160 in diameter D.T.D.5006 was appreciably lower, at 31.5 to 35.7 tonf/in^2 (about 34% of the U.T.S.), than that for the other two qualities after prestressing to an elastic limit level of 68.9 tonf/in^2 (68.9% of the U.T.S.) The 0.5% P.S. at 75 tonf/in^2 (75% of the U.T.S.) is comparable with 0.160 in diameter D.T.D.5B and D.T.D.239B wires.

Comparing the properties of 0.064 in diameter D.T.D.239B with the other materials of similar size, it will be seen that this did not prestress to such a high elastic limit, nevertheless at 81.3 tonf/in^2 this was 75% of the U.T.S., which was the highest percentage of the U.T.S. recorded. The L. of P. and 0.5% P.S. values were in keeping with the other 0.064 in diameter wires at 63.5 tonf/in^2 (59% of the U.T.S.) and between 82.6 and 88.9 tonf/in^2 (76% - 82% of the U.T.S.) respectively. Prestressing 0.160 in diameter D.T.D.239B caused an elevation in the elastic limit to 64.3 tonf/in^2 (64.3% of the U.T.S.), a proportional limit of 45 tonf/in^2 (45% of the U.T.S.) and a 0.5% P.S. of 70.3 to 71.6 tonf/in^2 (70.3 to 71.6% of the U.T.S.)

From this data, it is evident that although the elastic limit can be raised considerably by prestressing, the materials are all exhibiting non-proportional elastic deformation at stress levels below the prestressed elastic limit. Such a feature would be expected to affect the rate characteristics of prestressed springs, but it may be that its effect is relatively small and is swamped by other parameters which also affect spring rate.

Various workers(3 - 5) have shown that a low temperature heat treatment after prestressing could be usefully employed to raise the L. of P. value still further. However, the application of low temperature heat treatments after prestressing is not normally employed during spring manufacture but such a procedure would appear to be worthy of further investigation.

Comparing the data given in Tables V, VI and VII, differences in the straining rate used during testing at 10°/min. and 100°/min. had no effect on the resultant properties.

5.3 Tensile properties

Very little difference in the ultimate tensile strength of D.T.D. 5B, D.T.D.5006 and D.T.D.239B was recorded between the three metallurgical conditions investigated. The tensile L. of P. results obtained after torsional prestressing were quite erratic, showing considerable scatter, in some instances the tensile L. of P. appeared to have been raised by torsional prestressing whilst in others the reverse was the case.

Considering the properties of both sizes of D.T.D.239B, the tensile L. of P. values in the prestressed condition were much lower than either the unprestressed or the plated, prestressed conditions. This difference gradually disappears if a comparison is made at the progressively higher proof strains.

On the other hand, a study of the tensile L. of P. values obtained from 0.064 in diameter D.T.D.5B wire indicates higher L. of P. properties for both the prestressed and plated, prestressed conditions compared with the results for unprestressed wire. These differences are not substantiated by the 0.1% and 0.2% proof stress results where the proof stresses are lower for the torsionally prestressed wires. The trend for higher tensile L. of P. properties after torsionally prestressing is not supported by the results obtained from the 0.160 in diameter wires.

In view of the rust resistant nature of D.T.D.5006 plating was not carried out, therefore only the effects of torsional prestressing on the tensile properties could be assessed for this quality. In the case of the 0.064 in diameter wire prestressing in torsion lowered both the tensile limit of proportionality and the 0.1% proof stress. Little difference was observed between the values of tensile L. of P. and proof stress for unprestressed and prestressed 0.160 in diameter wire, although there was a slight tendency towards a lowering of these properties with prestressing.

Young's modulus determinations have supported previous findings of a lower modulus figure for 18/8 stainless steel compared with carbon steels.

6. CONCLUSIONS

1. Low temperature heat treatment of the hard drawn spring steel wires, D.T.D.5B and D.T.D.5006, resulted in a considerable increase in the torsional limit of proportionality compared with the "as drawn" values.

(a) Maximum elevation of the limit of proportionality occurred with treatments of 200°C for 0.064 in diameter D.T.D.5B wire and 175°C - 350°C for 0.160 in diameter D.T.D.5B wire.

(b) Maximum elevation of the limit of proportionality for D.T.D. 5006 occurred after treatments of 400°C - 450°C for 0.064 in diameter and 375°C - 425°C for 0.160 in diameter.

(c) Some lift in the L. of P. properties of hardened and tempered 0.064 in diameter D.T.D.239B was obtained by low temperature heat treatment; the optimum temperature range for treatment was 100°C - 350°C for 0.064 in diameter and 100°C - 400°C for 0.160 in diameter wire.

2. Torsional prestressing after low temperature heat treatment raised the elastic limit of the 0.064 in diameter D.T.D.5B, D.T.D.5006 and D.T.D. 239B wires to 68.5%, 74% and 75% of the U.T.S. respectively and the elastic limit of the 0.160 in diameter D.T.D.5B, D.T.D.5006 and D.T.D.239B wires to 68%, 68.9% and 64% of the U.T.S. respectively. Non-proportional elastic deformation occurred below the prestressed elastic limit.

3. The rate of straining during torsion testing, as shown by using rates of 10°/min. and 100°/min. had no effect on the resultant torsion properties.

4. Torsional prestressing had little effect on the U.T.S. properties of D.T.D.5B, D.T.D.5006 and D.T.D.239B. The tensile proportional limits were affected in an erratic manner by torsional prestressing, in some cases they were increased whilst in others they were decreased. The tensile proof stress values were less influenced by torsional prestressing.

7. REFERENCES

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(3) Greaves, R.H. "Overstrain and Elastic Recovery in Relation to Prestressing" Coil Spring Journal No. 10, March, 1948.

(4) Pope, J.A. and Andrews, J.E. "Report on the Prestressing of Springs" Coil Spring Journal No.10, March, 1948 and No. 14, March, 1949.

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TABLE I COMPOSITION OF D.T.D. WIRES

Quality	Cast No.	Nominal Size (in)	%C	%Si	%Mn	% S	% P	%Cr	%Ni	%Ti
DTD.5B	P.6494	0.064	0.73	0.19	0.52	0.015	0.018			
DTD.5B	KA.9679	0.160	0.73	0.19	0.57	0.012	0.018			
DTD.5006	2105 FR	0.064	0.06	0.60	1.11	0.010	0.017	18.20	9.20	0.40
DTD.5006	2105 FR	0.160	0.06	0.60	1.11	0.010	0.017	18.20	9.20	0.40
DTD.239B	J.10590	0.064	0.75	0.25	0.65	0.012	0.015			
DTD.239B	J.10590	0.160	0.75	0.25	0.65	0.012	0.015			

TABLE II TORSIONAL PROPERTIES OF
D.T.D.5B SPRING WIRE (NOT PRESTRESSED)

Condition	Size (in)	L. of P. tonf/in^2		
		Test 1	Test 2	Test 3
As rec'd	0.0639	34.3	34.3	36.0
100°C/½h	"	42.5	42.5	40.9
150°C/½h	"	52.3	50.7	50.7
175°C/½h	"	58.8	58.8	55.6
200°C/½h	"	62.1	62.1	58.8
225°C/½h	"	58.8	62.1	58.8
250°C/½h	"	58.8	60.5	58.8
275°C/½h	"	60.5	58.8	55.6
300°C/½h	"	58.8	55.6	55.6
350°C/½h	"	52.3	52.3	52.3
400°C/½h	"	49.0	49.0	49.0

Condition	Size (in)	L. of P. tonf/in^2		
		Test 1	Test 2	Test 3
As rec'd	0.160	23.3	22.5	25.0
100°C/½h	"	25.0	25.0	25.0
150°C/½h	"	36.6	36.6	36.6
175°C/½h	"	45.0	41.7	41.7
200°C/½h	"	41.7	41.7	41.7
225°C/½h	"	40.0	41.7	41.7
250°C/½h	"	41.7	41.7	41.7
275°C/½h	"	41.7	41.7	41.7
300°C/½h	"	41.7	41.7	41.7
350°C/½h	"	41.7	41.7	41.7
400°C/½h	"	40.0	41.7	40.8

TABLE III TORSIONAL PROPERTIES OF D.T.D.5006 SPRING WIRE (NOT PRESTRESSED)

Condition	Size (in)	L.of P. tonf/in^2		
		Test 1	Test 2	Test 3
As rec'd	0.0645	31.8	31.8	31.8
100°C/2h	"	34.9	34.9	38.1
200°C/2h	"	38.1	38.1	38.1
300°C/2h	"	46.1	41.3	47.7
375°C/2h	"	44.5	47.7	47.7
400°C/2h	"	47.7	47.7	47.7
425°C/2h	"	47.7	47.7	47.7
450°C/2h	"	47.7	47.7	47.7
475°C/2h	"	46.0	46.0	47.7
500°C/2h	"	41.3	44.5	41.3

Condition	Size (in)	L.of P. tonf/in^2		
		Test 1	Test 2	Test 3
As rec'd	0.160	10.5	10.9	12.5
100°C/2h	"	15.8	15.8	14.2
200°C/2h	"	22.5	22.5	22.5
300°C/2h	"	29.2	29.2	25.0
375°C/2h	"	30.9	29.2	29.2
400°C/2h	"	29.2	29.2	29.2
425°C/2h	"	30.0	30.0	30.0
450°C/2h	"	26.7	26.7	25.8
475°C/2h	"	25.0	25.0	25.0
500°C/2h	"	25.0	26.7	25.0

TABLE IV TORSIONAL PROPERTIES OF

D.T.D.239B SPRING WIRE (NOT PRESTRESSED)

Condition	Size (in)	L.of P. tonf/in^2		
		Test 1	Test 2	Test 3
As H & T	0.0645	38.1	38.1	38.1
100°C/½h	"	47.7	44.5	47.7
200°C/½h	"	47.7	47.7	47.7
300°C/½h	"	49.3	46.1	49.3
325°C/½h	"	50.8	47.7	47.7
350°C/½h	"	47.7	47.7	47.7
375°C/½h	"	44.5	41.3	44.5
400°C/½h	"	31.8	33.4	38.1
425°C/½h	"	31.8	31.8	31.8
450°C/½h	"	31.8	31.8	31.8

Condition	Size (in)	L.of P. tonf/in^2		
		Test 1	Test 2	Test 3
As H & T	0.161	34.7	40.9	40.1
100°C/½h	"	40.9	40.1	40.1
200°C/½h	"	40.1	40.9	40.9
300°C/½h	"	40.9	40.9	40.1
350°C/½h	"	39.3	40.9	40.9
375°C/½h	"	43.0	42.6	39.7
400°C/½h	"	43.0	42.2	40.9
425°C/½h	"	34.7	32.7	40.9
450°C/½h	"	32.7	32.7	39.7
475°C/½h	"	25.8	32.7	28.7

TABLE V TORSIONAL PROPERTIES OF PRESTRESSED D.T.D.5B SPRING WIRE

Condition	Prestressed tonf/in²	Dia. (in)	G.L. (in)	Straining Rate	L.of P. tonf/in²	0.5% P.S. tonf/in²	G x 10⁶ lbf/in²
200°C/½h	87.2	0.0639	50d	100°/min.	65.4	94.8	10.94
"	"	"	"	"	65.4	88.2	10.94
"	"	"	"	"	65.4	89.8	11.23
"	"	"	"	10°/min.	65.4	89.8	10.94
"	"	"	"	"	65.4	89.8	11.04
"	"	"	"	"	65.4	89.8	10.94

Condition	Prestressed tonf/in²	Dia. (in)	G.L. (in)	Straining Rate	L.of P. tonf/in²	0.5% P.S. tonf/in²	G x 10⁶ lbf/in²
200°C/½h	73.3	0.160	50d	100°/min.	45.8	78.7	10.97
"	"	"	"	"	50.0	78.7	11.05
"	"	"	"	"	50.0	79.1	10.87
"	"	"	"	10°/min.	45.8	77.9	10.93
"	"	"	"	"	45.8	77.1	11.45
"	"	"	"	"	45.8	77.1	11.45

TABLE VI TORSIONAL PROPERTIES OF PRESTRESSED D.T.D.5006 SPRING WIRE

Condition	Prestressed $tonf/in^2$	Dia. (in)	G.L. (in)	Straining Rate	L.of P. $tonf/in^2$	0.5% P.S. $tonf/in^2$	$G \times 10^6$ lbf/in^2
425°C/2h	91.5	0.0645	50d	100°/min.	63.5	95.3	10.00
"	"	"	"	"	63.5	93.7	10.17
"	"	"	"	"	63.5	95.3	10.17
"	"	"	"	10°/min.	69.9	95.3	10.17
"	"	"	"	"	73.0	96.9	10.17
"	"	"	"	"	69.9	95.3	9.85

Condition	Prestressed $tonf/in^2$	Dia. (in)	G.L. (in)	Straining Rate	L.of P. $tonf/in^2$	0.5% P.S. $tonf/in^2$	$G \times 10^6$ lbf/in^2
425°C/2h	68.9	0.160	50d	100°/min.	34.8	75.5	10.01
"	"	"	"	"	35.7	75.5	9.95
"	"	"	"	"	31.5	75.3	10.08
"	"	"	"	10°/min.	32.4	75.3	9.83
"	"	"	"	"	35.7	75.5	9.89
"	"	"	"	"	31.5	74.7	10.08

TABLE VII TORSIONAL PROPERTIES OF PRESTRESSED D.T.D.239B SPRING WIRE

Condition	Prestressed tonf/in^2	Dia. (in)	G.L. (in)	Straining Rate	L.of P. tonf/in^2	0.5% P.S. tonf/in^2	G x 10^6 lbf/in^2
350°C/½h	81.3	0.0645	50d	100°/min.	63.5	88.9	10.92
"	"	"	"	"	63.5	88.9	10.54
"	"	"	"	"	63.5	82.6	10.54
"	"	"	"	10°/min.	63.5	85.7	10.92
"	"	"	"	"	63.5	82.6	10.54
"	"	"	"	"	63.5	82.6	10.73

Condition	Prestressed tonf/in^2	Dia. (in)	G.L. (in)	Straining Rate	L.of P. tonf/in^2	0.5% P.S. tonf/in^2	G x 10^6 lbf/in^2
400°C/½h	64.3	0.161	50d	100°/min.	45.0	70.8	11.14
"	"	"	"	"	45.0	71.1	10.87
"	"	"	"	"	45.0	70.3	11.14
"	"	"	"	10°/min.	45.0	71.1	11.14
"	"	"	"	"	45.0	70.3	10.97
"	"	"	"	"	44.9	71.6	10.96

TABLE VIII TENSILE PROPERTIES OF D.T.D.5B SPRING WIRE

Condition		Torsional Prestress $tonf/in^2$	Size (in)	U.T.S. $tonf/in^2$	L.of P. $tonf/in^2$	0.1% P.S. $tonf/in^2$	0.2% P.S. $tonf/in^2$	0.5% P.S. $tonf/in^2$	Young's Modulus $lbf/in^2 \times 10^6$
L.T.H.T.	Cadmium Plated								
200°C/½h	No	No	0.0639	127.2	68.6	122.6	125.7	-	27.93
"	No	No	"	126.9	65.5	119.5	124.7	-	29.79
"	No	87.2	"	126.3	74.8	107.0	115.3	123.1	25.98
"	No	87.2	"	127.2	74.8	111.3	116.2	125.8	27.93
"	No	87.2	"	126.3	77.9	110.1	117.6	124.7	27.46
"	Yes	87.2	"	125.2	96.7	115.4	120.1	123.8	28.73
"	Yes	87.2	"	126.3	99.8	116.3	120.4	124.0	29.03
"	Yes	87.2	"	125.5	89.5	114.8	120.1	124.0	28.58
200°C/½h	No	No	0.160	107.1	74.6	97.3	101.0	-	27.60
"	No	No	"	106.7	67.2	96.3	100.5	-	27.40
"	No	73.3	"	107.7	62.2	97.0	101.1	104.5	27.85
"	No	73.3	"	106.4	47.3	87.9	96.2	102.0	26.74
"	No	73.3	"	108.4	64.7	97.0	102.5	107.0	28.16
"	Yes	73.3	"	105.9	64.7	91.2	97.0	102.8	27.52
"	Yes	73.3	"	105.2	57.2	91.2	96.2	101.1	27.52
"	Yes	73.3	"	105.5	69.6	92.8	97.0	101.1	27.31

TABLE IX TENSILE PROPERTIES OF D.T.D.5006 SPRING WIRE

Condition		Torsional Prestress tonf/in^2	Size (in)	U.T.S. tonf/in^2	L.of P. tonf/in^2	0.1% P.S. tonf/in^2	0.2% P.S. tonf/in^2	0.5% P.S. tonf/in^2	Young's Modulus lbf/in^2 x 10^6
L.T.H.T.	Cadmium Plated								
425°C/2h	No	No	0.0645	124.8	88.7	122.5	-	-	23.82
"	No	No	"	123.3	74.5	120.9	-	-	23.82
"	No	91.5	"	119.3	71.9	114.1	-	-	24.37
"	No	91.5	"	119.3	62.7	110.5	-	-	25.22
"	No	91.5	"	119.0	70.4	110.2	-	-	24.93
"	No	91.5	"	121.7	58.2	110.2	-	-	25.22
"	No	91.5	"	122.1	73.5	114.4	-	-	24.50
"	No	91.5	"	122.1	73.5	111.0	-	-	24.33
425°C/2h	No	No	0.160	100.2	52.9	82.1	91.0	-	21.61
"	No	No	"	100.7	51.9	85.5	92.0	-	21.61
"	No	68.9	"	100.9	51.9	83.0	91.0	-	21.88
"	No	68.9	"	101.7	49.0	77.6	85.1	-	20.61
"	No	68.9	"	101.2	49.5	81.1	91.5	-	21.51
"	No	68.9	"	100.2	47.0	75.6	86.5	-	23.03
"	No	68.9	"	101.5	49.5	78.6	89.0	-	22.87
"	No	68.9	"	100.9	45.7	80.1	90.0	-	22.87

TABLE X TENSILE PROPERTIES OF D.T.D.239B SPRING WIRE

Condition		Torsional Prestress tonf/in²	Size (in)	U.T.S. tonf/in²	L.of P. tonf/in²	0.1%P.S. tonf/in²	0.2%P.S. tonf/in²	0.5%P.S. tonf/in²	Young's Modulus lbf/in² x 10⁶
L.T.H.T.	Cadmium Plated								
350°C/½h	No	No	0.0645	109.2	76.5	95.8	98.0	105.1	28.13
"	No	No	"	108.5	76.5	94.9	98.0	101.0	26.72
"	No	81.3	"	107.4	58.2	82.6	88.7	98.0	26.84
"	No	81.3	"	107.4	58.2	88.7	91.8	98.7	26.75
"	No	81.3	"	107.4	58.2	89.7	94.9	100.9	25.30
"	Yes	81.3	"	107.1	73.4	91.8	96.9	100.9	27.38
"	Yes	81.3	"	107.4	73.4	94.9	97.9	100.9	27.12
"	Yes	81.3	"	107.1	70.4	91.8	94.9	99.9	27.32
400°C/½h	No	No	0.161	100.1	71.7	86.5	89.0	92.3	26.05
"	No	No	"	100.6	72.2	86.3	89.5	93.8	27.59
"	No	64.3	"	100.5	41.8	85.0	89.3	92.5	29.86
"	No	64.3	"	99.7	56.7	86.6	89.3	93.4	28.16
"	No	64.3	"	95.9	47.0	79.9	84.3	90.5	29.34
"	Yes	64.3	"	100.2	66.3	86.8	89.3	93.4	27.31
"	Yes	64.3	"	100.7	68.8	88.4	90.9	93.4	28.34
"	Yes	64.3	"	100.2	63.9	86.8	89.3	91.7	28.73

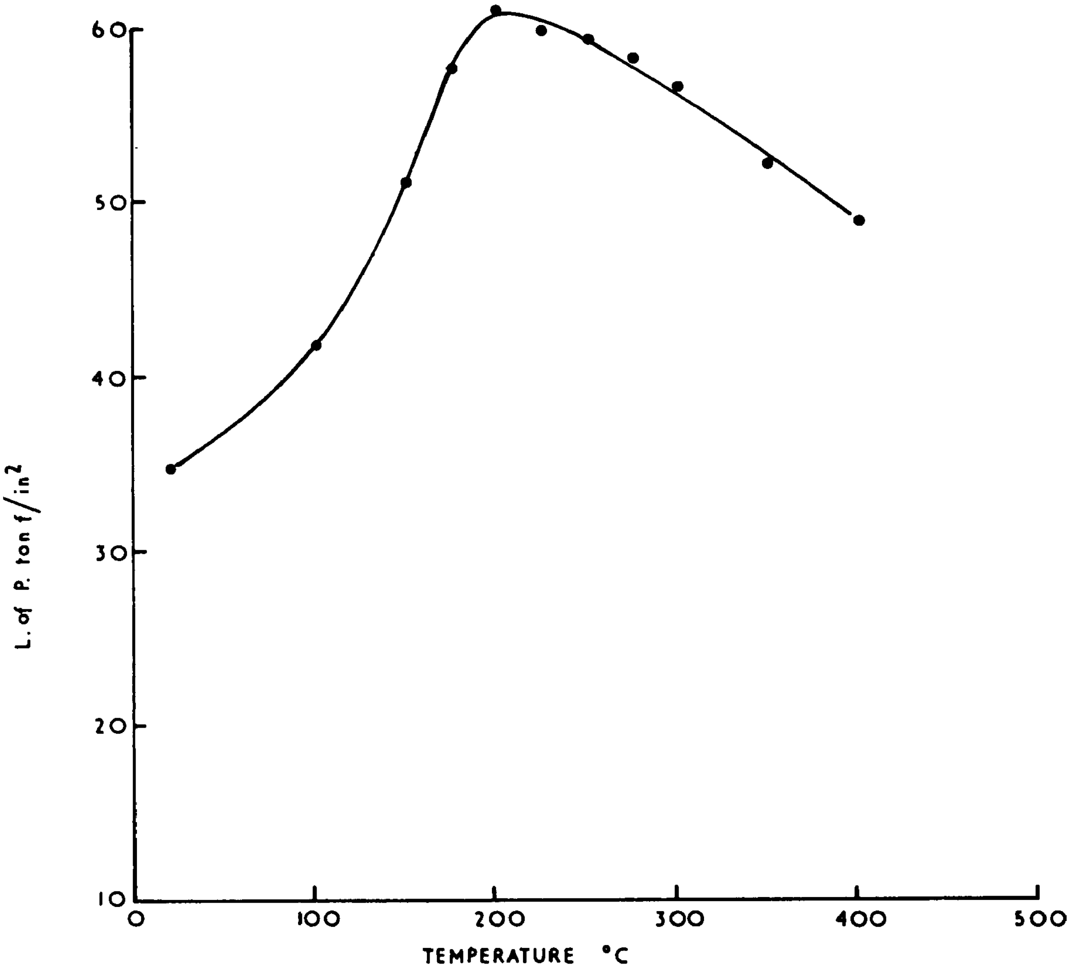

FIG. 1. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·0639" DIA. DTD 5B WIRE.

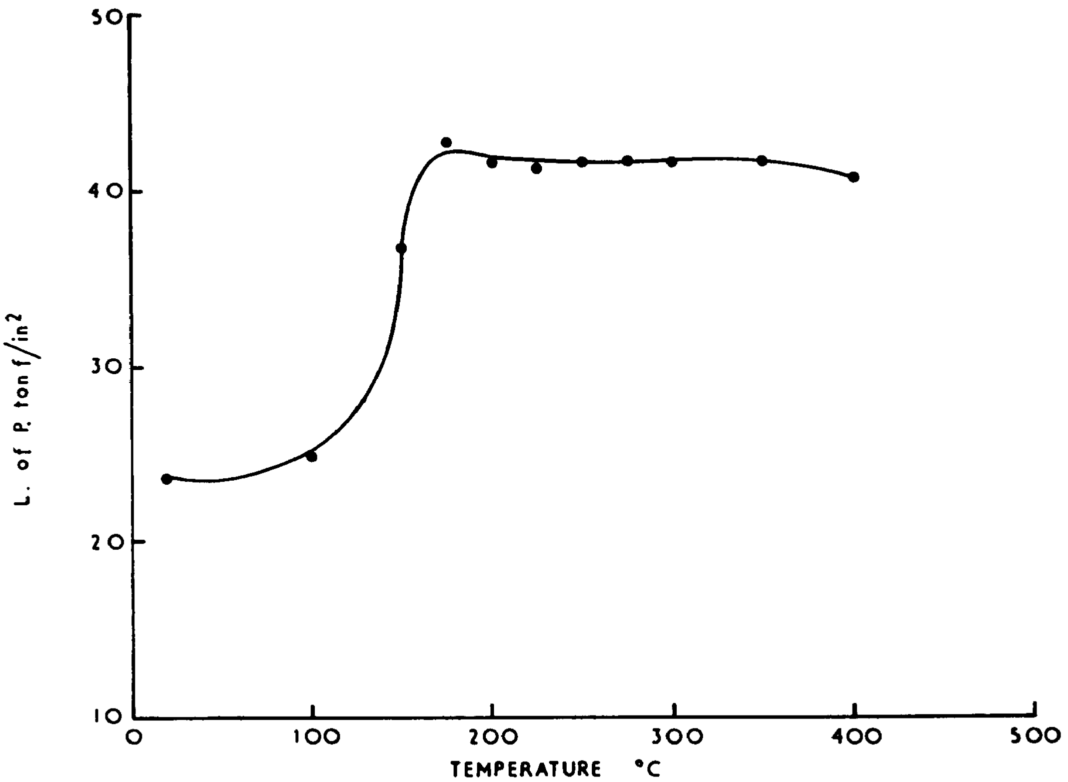

FIG. 2. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·160" DIA. DTD 5B WIRE.

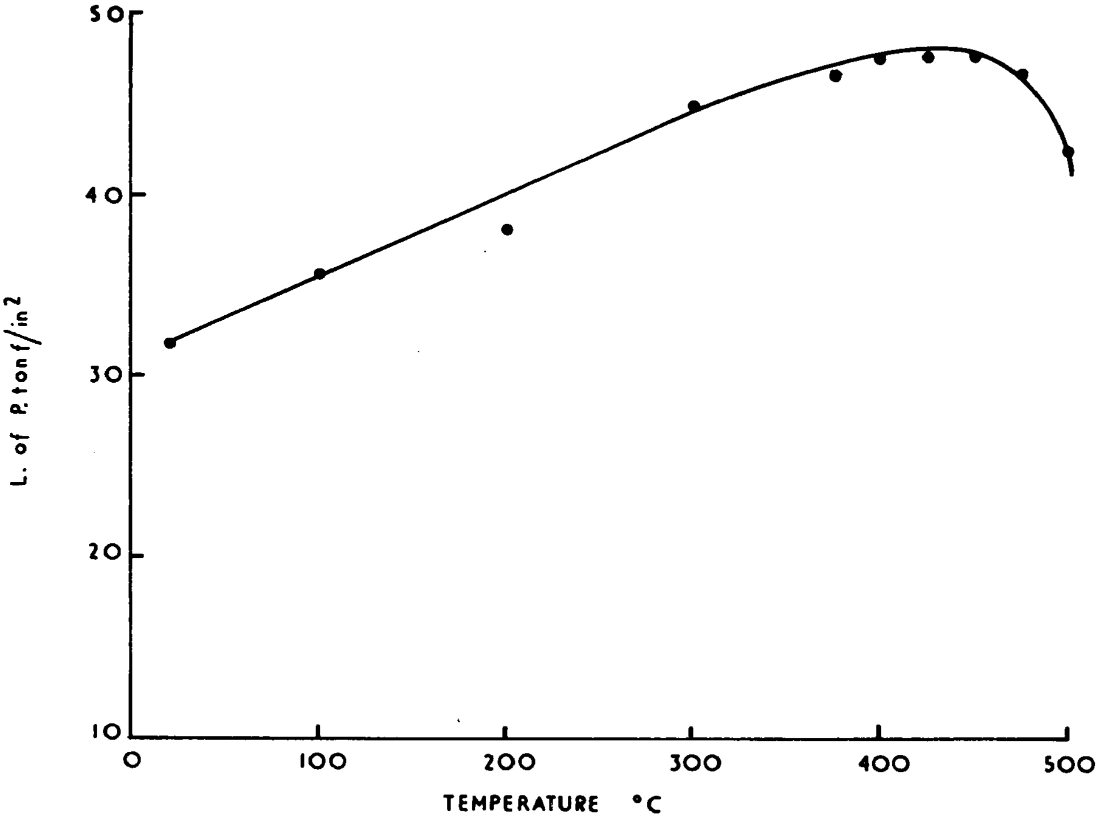

FIG. 3. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·0645" DIAMETER DTD 5006 WIRE.

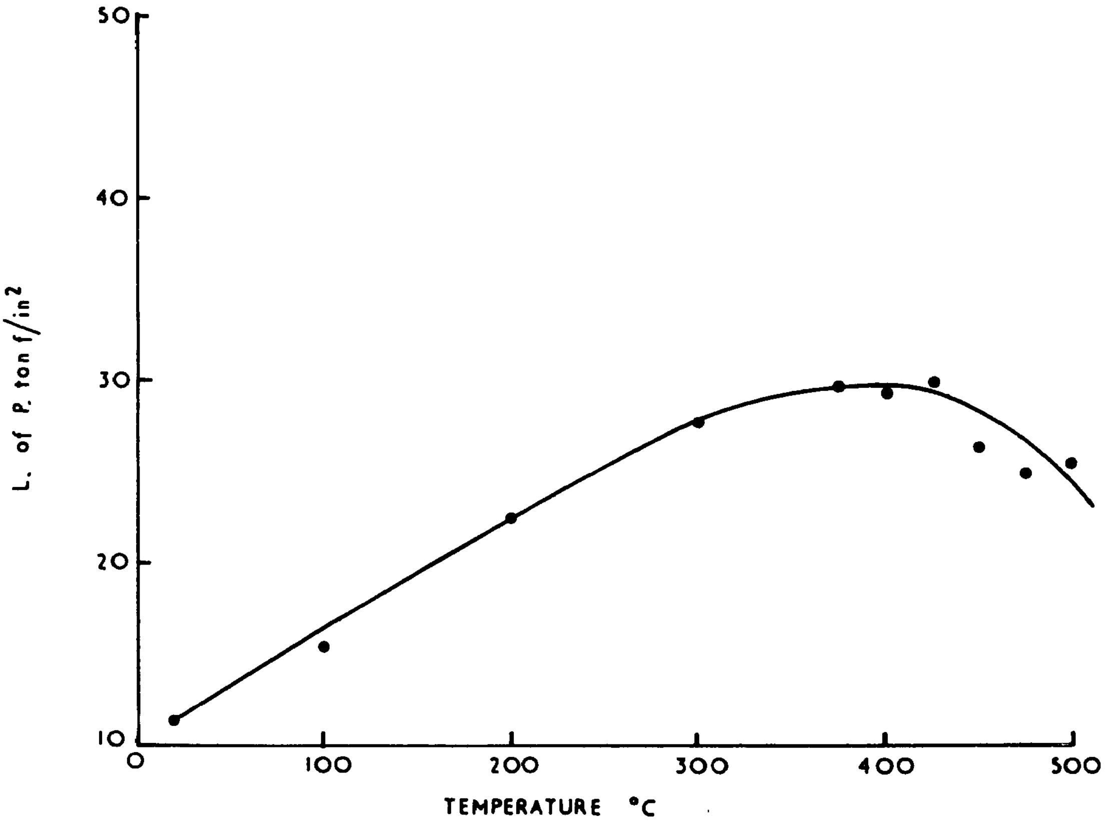

FIG. 4. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·160" DIAMETER DTD 5006 WIRE.

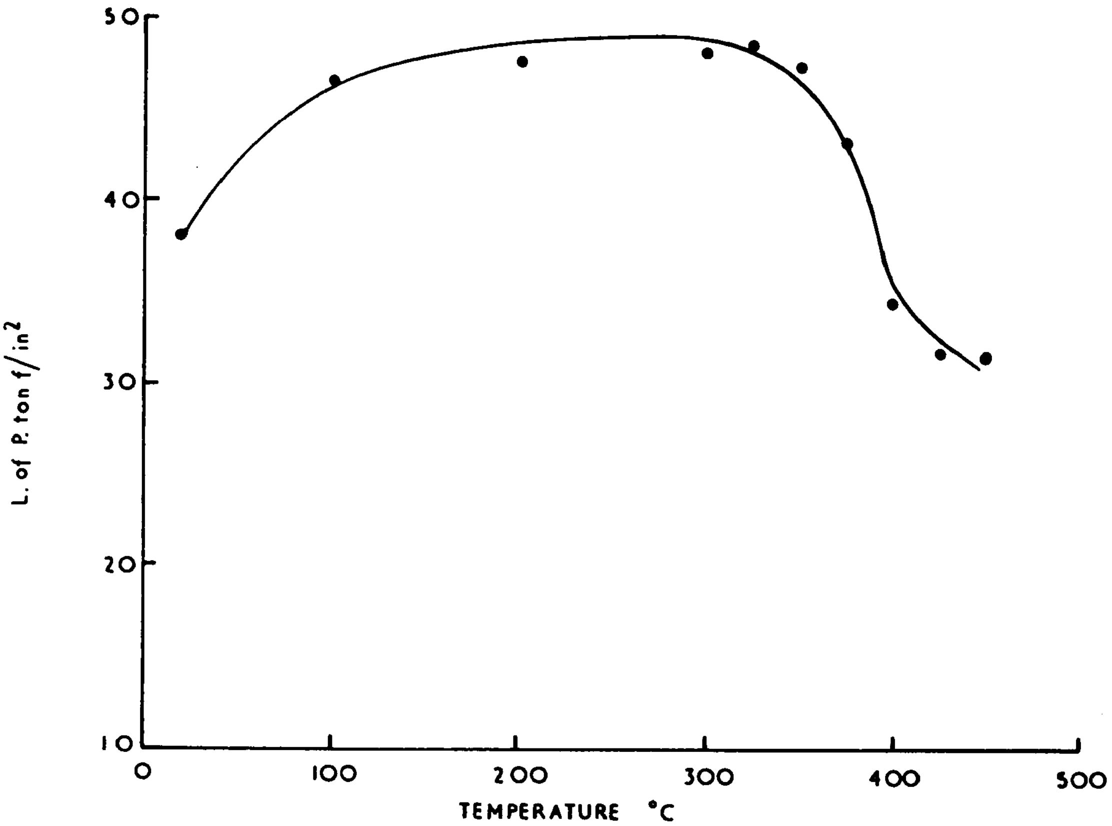

FIG. 5. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·0645" DIAMETER DTD 239B WIRE.

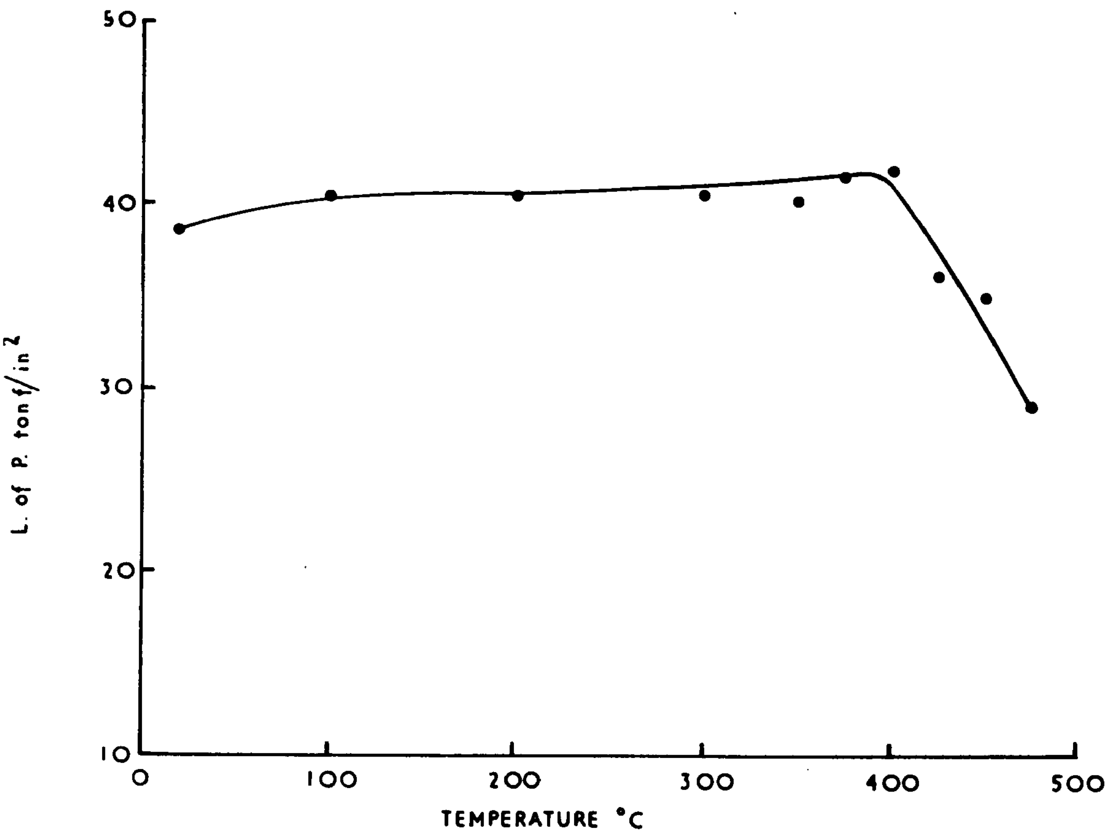

FIG. 6. EFFECT OF LOW TEMPERATURE HEAT TREATMENT ON THE LIMIT OF PROPORTIONALITY IN TORSION OF 0·161" DIAMETER DTD 239B WIRE.