THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE LOW TEMPERATURE HEAT TREATMENT OF SPRINGS MANUFACTURED FROM PATENTED COLD DRAWN CARBON STEEL WIRE

by

G.C. Bird, B.Sc.

Report No. 266

November 1976

THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

Report No. 266

THE LOW TEMPERATURE HEAT TREATMENT OF SPRINGS MANUFACTURED FROM PATENTED COLD DRAWN CARBON STEEL WIRE

SUMMARY

In this programme of work, the effect has been examined of the low temperature heat treatments carried out after coiling and shot peening on the dimensions, fatigue and stress-temperature relaxation properties of springs made from 2.65 mm diameter, cold drawn spring steel wire to BS 5216:HD3.

A low temperature heat treatment of 250°C - 275°C after coiling was found to give the least amount of permanent set on prestressing; the amount of relaxation at elevated temperatures could, however, be minimised by stress relieving at 350°C. A low temperature heat treatment after coiling improved the fatigue properties of unpeened springs but varying the heat treatment temperature between 250°C and 400°C did not have any noticeable effect.

Stress relieving shot peened springs after peening reduced the stress-temperature relaxation and enabled the maximum solid stress to be achieved, A temperature of between 200°C and 250°C was found to give the best overall performance, as temperatures above this caused a reduction in the fatigue properties of the springs.

November 1976

CONTENTS

		Page No.
1.	INTRODUCTION	1
2.	SPRING DESIGN AND MANUFACTURE	1
3.	MECHANICAL AND PHYSICAL PROPERTIES OF WIRE	2
4.	LOW TEMPERATURE HEAT TREATMENT OF UNPEENED SPRINGS	2
	4.1 Spring Dimensions	2
	4.2 Stress Relaxation Properties	3
	4.3 Fatigue Performance	3
5.	STRESS RELIEVING AFTER SHOT PEENING	4
6.	DISCUSSION OF RESULTS	4
	6.1 Mechanical Properties	4
	6.2 Unpeened Springs	5
	6.2.1 Spring Dimensions	5
	6.2.2 Stress Relaxation Properties	6
	6.2.3 Fatigue Behaviour	7
	6.3 Shot Peened Springs	7
	6.3.1 Spring Dimensions	7
	6.3.2 Stress Relaxation Properties	8
	6.3.3 Fatigue Behaviour	8
	6.4 General Discussion	9
7.	CONCLUSIONS	10
8.	REFERENCES	11
9.	TABLES	
	I Chemical Composition of Wire	
	II Mechanical Properties of 2.65 mm Dia. Wire to BS 5216:HD3	
10.	FIGURES	
	1. Effect of L.T.H.T. on Mechanical Properties of 2.65 mm Wire to BS 5216:HD3	

CONTENTS (Cont.)

2. Effect of L.T.H.T. on Wind Up of Springs

3. Effect of L.T.H.T. on Free Length of Springs

4. Effect of L.T.H.T. on the Stress Relaxation of Unpeened Springs at Various Stress Levels

5. The effect of L.T.H.T. on Parameters of Unpeened Springs

6. Effect of L.T.H.T. on Relaxation of Shot Peened Springs at Various Stress Levels

7. Effect of L.T.H.T. on Solid Stress and Fatigue Limit of Shot Peened Springs

THE LOW TEMPERATURE HEAT TREATMENT OF SPRINGS MANUFACTURED FROM PATENTED COLD DRAWN CARBON STEEL WIRE

by

G.C. Bird, B.Sc.

1. INTRODUCTION

Most compression springs made from patented cold drawn wire are given a low temperature heat treatment after coiling in order to improve the elastic properties of the wire and reduce detrimental stresses induced during coiling. The time for which the springs are heat treated is usually between 20 and 30 minutes depending on the batch size; the temperature at which the springs are maintained may vary from 200°C to 400°C depending upon the service for which the spring is designed. With springs that have been shot peened, it is recommended that a further stress relieving treatment be given.

The object of this programme of work was to examine the effect of the low temperature heat treatments carried out after coiling and shot peening on the dimensions, fatigue and stress-temperature relaxation properties of springs made from cold drawn spring steel wire. The effect of various heat treatment temperatures on the mechanical properties of the material were also examined.

2. SPRING DESIGN AND MANUFACTURE

The material used was 2.65 mm diameter, high duty dynamic (HD) wire to the new specification BS 5216 Grade 3, which is similar in tensile strength and surface quality to the superseded specification BS 1408D Range 3. The springs were coiled on a Torrington 115A coiling machine to the design given below:-

Wire diameter:	2.65 mm
Mean diameter:	21.7 mm
Total coils:	5.5
Active coils:	3.5
Free length (after grinding):	47.5 mm

After coiling, the springs were ground on a Bennett SG1-14 grinding machine. Although not usual practice, springs were ground before heat treatment so that the free length after each subsequent process could be measured more easily. Batches of springs were then heat treated, at temperatures of 200°C, 250°C, 275°C, 300°C, 350°C, 400°C and 450°C in an air circulating furnace for half an hour. After removal from the furnace, sample springs from the batch were subjected to the various tests described in Section 4.

3. MECHANICAL AND PHYSICAL PROPERTIES OF WIRE

The wire used was examined and found to be free from decarburisation and surface defects. A sample of the wire was analysed and was found to conform to the specification in respect of chemical composition (see Table I).

The tensile properties and twists-to-failure of the wire were established in the 'as received' condition and after heat treatment at temperatures between 100°C and 450°C. The results are given in Table II and are shown graphically in Fig. 1.

4. LOW TEMPERATURE HEAT TREATMENT OF UNPEENED SPRINGS

4.1 Spring Dimensions

After coiling and grinding, the springs to be tested in the unpeened condition were divided into seven batches, which were heat treated at temperatures between 200°C and 450°C for half an hour. Before heat treatment, ten sample springs were taken from each batch; their free length was measured and the angular relation of the ends noted. The same measurements were taken after these springs had been heat treated and also after they had been prestressed. The effect of temperature on the 'wind up' of the springs, in terms of the average increase in coils is shown in Fig. 2. Fig. 3 shows the variation in free length after prestressing according to the stress relieving temperature.

4.2 Stress Relaxation Properties

To examine the effect of stress relieving temperature on the subsequent stress relaxation behaviour, springs were load tested and compressed on stainless steel bolts to stress levels of 300, 500, 700 and 900 N/mm^2. They were then placed in an air circulating furnace at a temperature of 125°C for 72 hours, after which they were again load tested to determine the loss in load, and hence the relaxation, that had occurred. The results are shown in Fig. 4, which indicates how the relaxation at a particular stress level varies with the stress relieving temperature.

4.3 Fatigue Performance

To establish the effect of stress relieving temperature on the fatigue properties, springs which had been heat treated at the various temperatures were fatigue tested on the Association's forced motion machines. From the results, the fatigue limit for an initial stress of 100 N/mm^2 was determined together with that for springs which had not been stress relieved.

Although all the springs had been fully prestressed before fatigue testing, they were removed after 50 000 cylces and the load at the minimum compressed length re-measured, in order to measure any relaxation that had occurred during fatigue testing. The springs were then replaced in the fatigue testing machine at their original settings. Those springs which survived 10 million cycles were also removed and load tested again.

5. STRESS RELIEVING AFTER SHOT PEENING

A batch of springs which had been given a low temperature heat treatment of 350°C for half an hour was shot peened, using S230 cast steel shot, to an Almen arc rise of 0.015 A2. These were then divided into seven groups, six of which were given a stress relieving treatment at temperatures of 150°C, 200°C, 250°C, 300°C and 400°C for half an hour, the one remaining group receiving no heat treatment at all. The springs were then prestressed and subjected to similar stress relaxation and fatigue tests as the unpeened springs. The results of the stress relaxation tests are shown in Fig. 6 and of the fatigue tests in Fig. 7.

6. DISCUSSION OF RESULTS

6.1 Mechanical Properties

The tensile and torsion tests, and a decarburisation check on the material, were carried out before the springs were manufactured. The tensile strength was found to be 1750 N/mm^2 in the 'as received' condition, the specified range being 1690 - 1890 N/mm^2, and the number of twists-to-failure 36, the specification calling for a minimum of 15.

The response of both the tensile strength and the tensile elastic properties to low temperature heat treatment can be seen in Fig. 1. Through age hardening, the properties improved rapidly at temperatures above 100°C, reaching a maximum between 200°C and 225°C. As the heat treatment temperature was raised beyond this level, the tensile properties decreased until, at 450°C, the tensile strength was considerably lower than in the 'as received' condition. The 0.1% and 0.05% proof stress values, however, both remained higher than originally.

It can also be seen that a drop occurred in the torsional properties near the temperature of maximum elevation of tensile properties, which was not fully recovered by increasing the heat treatment temperature. This ductility trough is not so marked in this wire as on other cold drawn wires investigated[1,2] previously, where twists-to-failure were a minimum of 7 and 3 respectively. These wires were, however, of a higher tensile strength than the material being investigated here; the different drawing history of the wire may account for the differences.

6.2 Unpeened Springs

6.2.1 Spring dimensions

Stress relieving causes a carbon steel spring to 'wind up', decreasing its diameter, increasing the number of coils and reducing the free length. The change in free length varied only slightly according to the heat treatment temperature; the wind up behaviour of the spring, however, measured in degrees per coil, increased as the heat treatment temperature increased, as shown in Fig. 2. These parameters were also measured after prestressing, which, as Fig. 2 also shows, reduced the amount of wind up that had taken place after heat treatment.

The springs were all ground to a length of 47.5 mm. After being stress releived at the appropriate temperature, the springs were prestressed until the free length was stable. The average free length of each batch of springs varied slightly, as shown in Fig. 3, from which the amount of permanent set occurring in each batch on prestressing can also be seen. As the elastic properties of the wire are increased by the heat treatment, so the loss in height on prestressing decreases. Without any heat treatment, the average free length after prestressing was 36.4 mm, whilst with a stress relieving temperature between 250°C and 275°C, the free length was at a maximum, about 43.0 mm. As the elastic properties of the wire fall, so the free length also falls. The relationship between the tensile strength and the solid stress of the spring can be seen in Fig. 5, the two parameters being plotted on the same graph. It is noticeable that the maximum solid stress occurred with a stress relieving temperature higher than that which gave the maximum increase in tensile elastic properties; the reason for this may be that the torsional properties, on which the amount of permanent set depends, exhibit a slightly different reaction than the tensile properties.

The advantage of heat treating the springs at the temperature which causes the least reduction in height is that the desired solid stress can be achieved with the minimum amount of distortion. The optimum heat treatment temperature, from static considerations, for this wire would appear to be about 250 - 275°C; only at temperatures above 350°C, however, was there an appreciable loss in solid stress.

6.2.2 Stress relaxation properties

The effect of the low temperature heat treatment on the stress relaxation properties of the unpeened springs at various stress levels can be seen in Fig. 4. Here, as the stress relieving temperature increases, the relaxation at the two lower stress levels decreases. Thus, if the spring is held at a stress level of 500 N/mm^2, the relaxation can be reduced from 9% to 4.3% by increasing the L.T.H.T. temperature from 200°C to 350°C and still further to 3.5% by stress relieving at 450°C. As the stress level is increased, however, a different pattern emerges. At a stress of 900 N/mm^2, the relaxation is reduced from 16% to 10.8% by increasing the L.T.H.T. temperature from 200°C to 350°C but any further increase in temperature causes the relaxation to rise again, to 15.5% at 450°C. The probable reason for this behaviour is that the low temperature heat treatment reduces the residual stress and hence the amount of relaxation but also reduces the elastic limit of the material. At the higher working stresses, therefore, the test stress could be close to, or even exceed, the torisonal elastic limit and hence produce a greater degree of relaxation. It would appear, therefore, that the most suitable stress relieving temperatures for springs which are to be statically loaded at working temperatures above ambient is about 350°C.

6.2.3 Fatigue behaviour

It was found that the overall fatigue performance for springs which had been prestressed but which had received no low temperature heat treatment was poorer, the fatigue strength at 10^7 cycles being about 100 N/mm^2 lower than for the stress relieved springs. This effect can be seen in Fig. 5, in which the fatigue limit is plotted against stress relieving temperature. The values for 200°C and 450°C temperatures are slightly lower than for the other stress relieving temperatures and more scatter was encountered with these particular springs.

Previously[(3)], fatigue data have been produced on springs from the same diameter wire to BS 1408D Range 3, the equivalent equivalent specification in terms of surface condition and tensile strength. Here, the fatigue limit of springs which had been low temperature heat treated at 350°C for 30 minutes was 752 N/mm^2 with an initial stress of 77 N/mm^2, which is equivalent to 775 N/mm^2 with an initial stress of 100 N/mm^2. The fatigue properties of the BS 5216 wire are, therefore, very similar to those obtained previously.

The dynamic relaxation was measured after the springs had completed 50 000 reversals and on those springs which survived 10^7 cycles. The only springs to show any appreciable relaxation after 50 000 cycles were those tested at maximum stresses above 950 N/mm^2. Here, a drop in load of about 20 - 25% was recorded in most cases. Since the life of these springs was only between 90 000 and 150 000 cycles, however, it is possible that the loss in load was caused by the presence of a crack which subsequently propagated to cause failure.

Of the springs to survive 10 million cycles, the only ones to show any consistent amount of relaxation were those which had received no heat treatment after coiling. The average amount was 3% and the points on the S/N curve have been adjusted accordingly.

6.3 Shot Peened Springs

6.3.1 Spring dimensions

Because the springs had already been stabilized by a heat treatment at 350°C for half an hour, the heat treatment after shot peening had little additional effect other than on the free length after prestressing. The shot peening process, which induces a residual compressive stress near the surface of the spring, also depresses the elastic limit of the wire in this region, the amount depending on the size of shot (depth of residual stress pattern) and the diameter of the wire. For the springs used in this investigation, the lowering of the elastic limit is reflected in the lower solid stress of those springs that were shot peened and then prestressed without any further L.T.H.T. If the spring is stress relieved at temperatures between 200°C and 300°C, a change in the stress pattern occurs and the elastic limit is restored so that, as can be seen from Fig. 7, the solid stress after prestressing is the same as that of the unpeened springs. In the same way as with the unpeened springs, stress relieving at 350°C and 400°C reduces the solid stress of the spring.

6.3.2 Stress relaxation properties

The shot peened springs were subjected to similar stress relaxation tests to the unpeened springs, being held at stress levels of 500 N/mm^2, 700 N/mm^2 and 900 N/mm^2 for 72 hours at 125°C. The results of the tests, illustrated in Fig. 6, show that the stress relieving treatment after shot peening reduces the amount of relaxation. Because of the residual stress induced by the peening, however, the shot peened springs always exhibited greater relaxation than unpeened ones at the same stress level.

6.3.3 Fatigue performance

The shot peened springs were fatigue tested in a similar fashion to the unpeened ones and the fatigue limits obtained can be seen in Fig. 7. There was much greater scatter in the fatigue data for shot peened than for the unpeened springs but the fatigue limit of 920 N/mm^2 is about 21% higher. As the stress relieving temperature is increased above 250°C, the fatigue performance began to fall. This is illustrated in Fig. 7 where, with a stress relieving temperature of 400°C, the residual stresses induced by the peening had been relieved completely and the fatigue performance was no better than that of the unpeened springs.

This effect has been noticed previously (4), where carbon steel valve springs of 4 mm wire diameter were heat treated at temperatures between 175°C and 450°C after shot peening. The springs were then fatigue tested with an initial stress of 140 N/mm^2 to determine the fatigue limit for each condition. At temperatures of 175°C and 260°C, this was 930 N/mm^2; increasing the temperature to 350°C and 400°C reduced the fatigue limit to 830 N/mm^2 and 760 N/mm^2 respectively. When the springs were stress relieved at 450°C after shot peening the fatigue limit was 655 N/mm^2, the same as for the springs which had not been shot peened. In this work it was also observed that re-opening reproduced the same high fatigue resistance.

The dynamic relaxation of the shot peened springs, which was measured for all those which survived 10^7 cycles, was found to be slightly greater for the non-stress relieved springs (0.8%) than for those which had been stress relieved at 200°C and 250°C (0.3%).

6.4 General Discussion

The wire used for the manufacture of the springs conformed in all respects to the specification and responded significantly to a low temperature heat treatment, the tensile strength being increased by a maximum of 13% and the 0.05% proof stress by a maximum of 90%, at temperatures between 200°C and 225°C.

When low temperature heat treated after coiling, the springs 'wound up', reducing the diameter and the free length of the spring, and increasing the number of coils; the higher the temperature, the greater the amount of movement. The minumum loss in height on prestressing unpeened springs occurred when they had been heat treated at about 250 - 275°C, a temperature range which would appear to be the best for springs working at ambient temperatures. For springs operating at temperatures above ambient, however, the amount of relaxation can be reduced by increasing the stress relieving temperature. A temerature of 350°C was found to give the best relaxation performance for a wide range of working stresses.

The stress relieving treatment improved the fatigue performance of the unpeened springs but little difference was noted as the temperature was increased from 250°C through to 400°C. Since springs subject to fatigue often operate at temperatures higher than ambient, treatment at 350°C would seem the most suitable to minimise any relaxation. Stress relief of the springs after shot peening enables the maximum solid stress to be achieved and reduces the amount of stress-temperature relaxation. It has little effect on the fatigue performance except that, if the treatment is carried out a temperatures of 300°C and above, the residual stresses are gradually removed. The optimum temperature for stress relieving springs after peening would appear to be between 200 and 250°C.

7. CONCLUSIONS

1. A low temperature heat treatment after coiling of 250 - 275°C reduces to a minimum the amount of permanent set on prestressing unpeened springs.

2. The lowest stress-temperature relaxation of unpeened springs is obtained with a L.T.H.T. of 350°C after coiling.

3. A L.T.H.T. after coiling improves the fatigue properties of unpeened springs; variation in temperature between 250°C and 400°C does not, however, have a noticeable effect.

4. Shot peened springs which are stress relieved between 200°C and 300°C after peening do not suffer any greater loss in height than unpeened springs on prestressing.

5. If springs are stress relieved after shot peening the stress-temperature relaxation is reduced but is still always greater than for similar unpeened springs.

6. The fatigue properties of shot peened springs are not improved by a low temperature heat treatment after peening and a L.T.H.T. above 250°C has a detrimental effect on the fatigue performance.

8. REFERENCES

1. GRAVES G.B. and GRAY S.D. "The Properties of BS 1408M R1 and R2 Wires and Springs". SRA Report No. 246.

2. GRAVES G.B. and GRAY S.D. "The Properties of Ultra High Strength Carbon Steel Wire and Springs". SRA Report No. 245.

3. MEE J.W. "The Fatigue Properties of Springs made from Patented Cold Drawn Wire to BS 1408C and BS 1408D in 3 Ranges of Tensile Strength". SRA Report No. 164.

4. ZIMMERLI F.P. "Shot Blasting and its Effect on Fatigue Life". A.S.M. Surface Treatment of Metals Symposium 1940.

TABLE I CHEMICAL COMPOSITION OF WIRE

Element	Specified (%)	Actual (%)
Carbon	0.55 - 0.85	0.76
Manganese	0.3 - 1.0	0.57
Silicon	0.35 Max.	0.30
Sulphur	0.030 Max.	0.016
Phosphorus	0.030 Max.	0.010

TABLE II MECHANICAL PROPERTIES OF 2.65 mm DIA, WIRE TO BS 5216:HD3

LTHT °C	Tensile Strength (R_m) N/mm^2	Proof Stresses N/mm^2		Elastic Limit N/mm^2	Twists to Failure
		0.1%	0.05%		
20	1750	1150	940	580	37,34
100	1810	1195	1010	620	36,34
150	1925	1615	1440	965	34,34
175	1960	1800	1650	1225	28,27
200	1975	1865	1770	1440	26,24
225	1935	1885	1780	1465	30,28
250	1910	1820	1730	-	29,27
275	1895	1780	1680	1377	-
300	1880	1700	1615	1275	29,28
350	1825	1550	1485	1240	28,28
400	1675	1440	1405	1185	28,27
450	1465	1295	1220	990	27,27

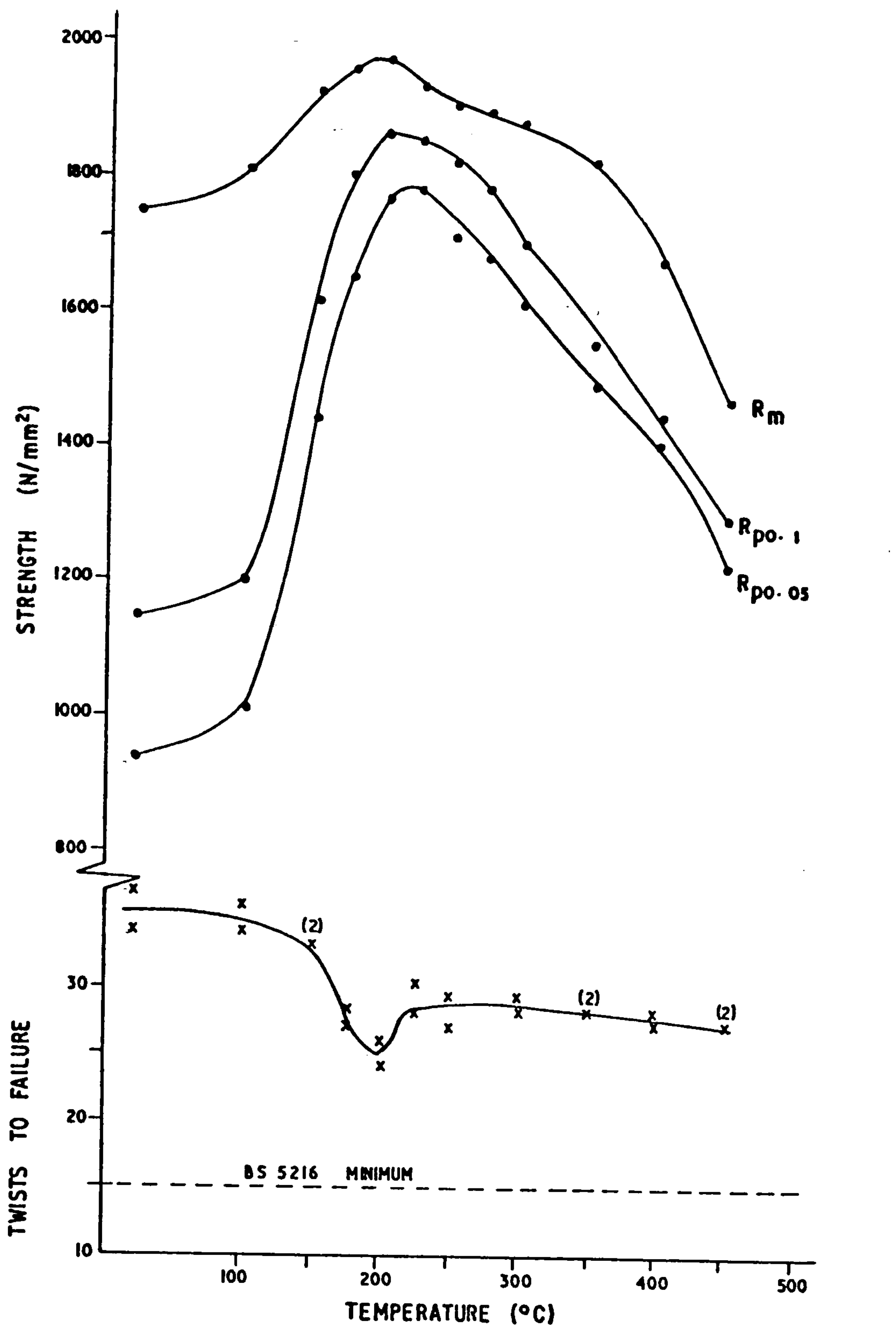

FIG. I EFFECT OF L.T.H.T. ON MECHANICAL PROPERTIES OF 2·65 mm WIRE TO BS 5216 HD 3.

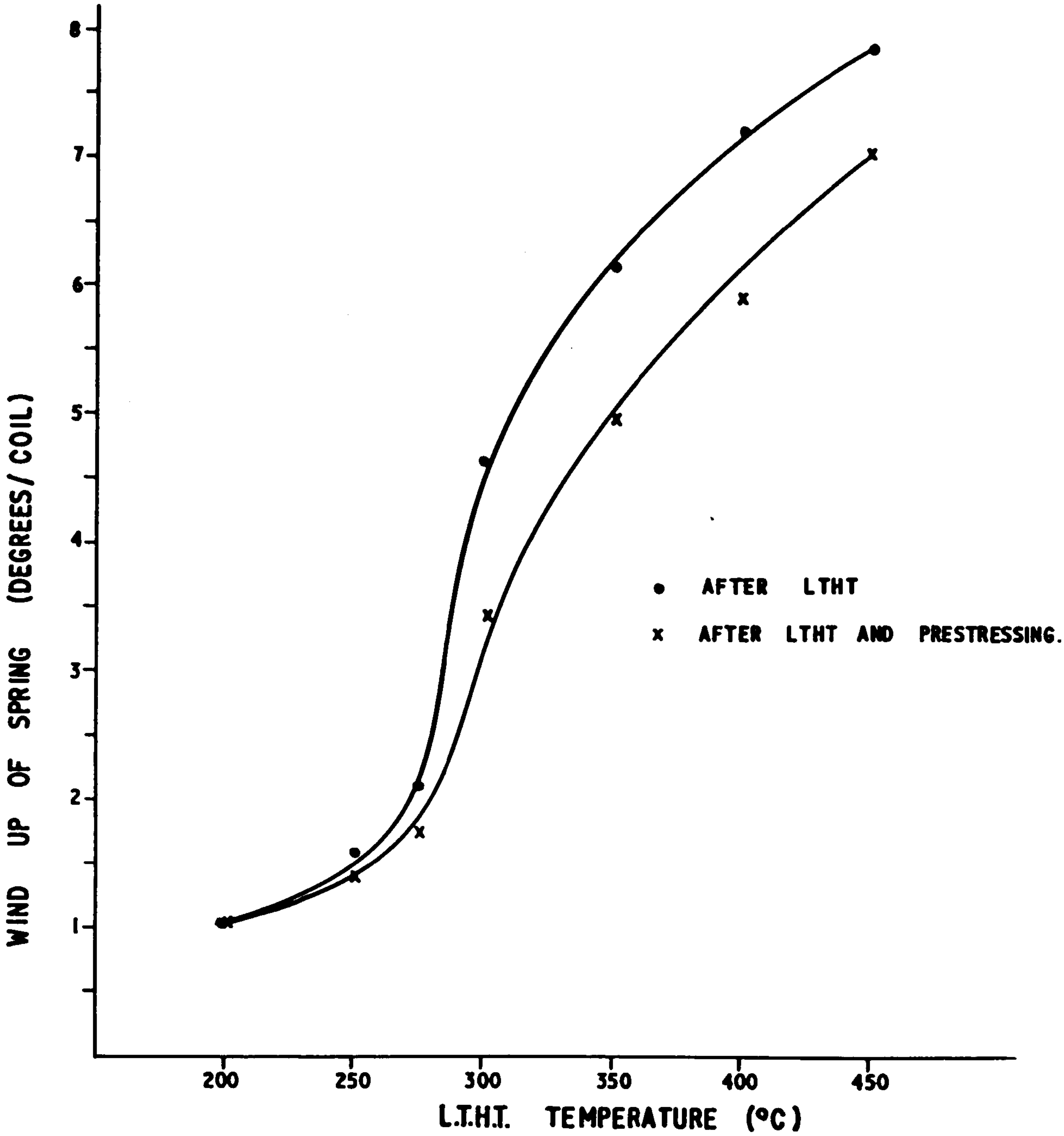

FIG. 2 EFFECT OF L.T.H.T ON WIND UP OF SPRINGS

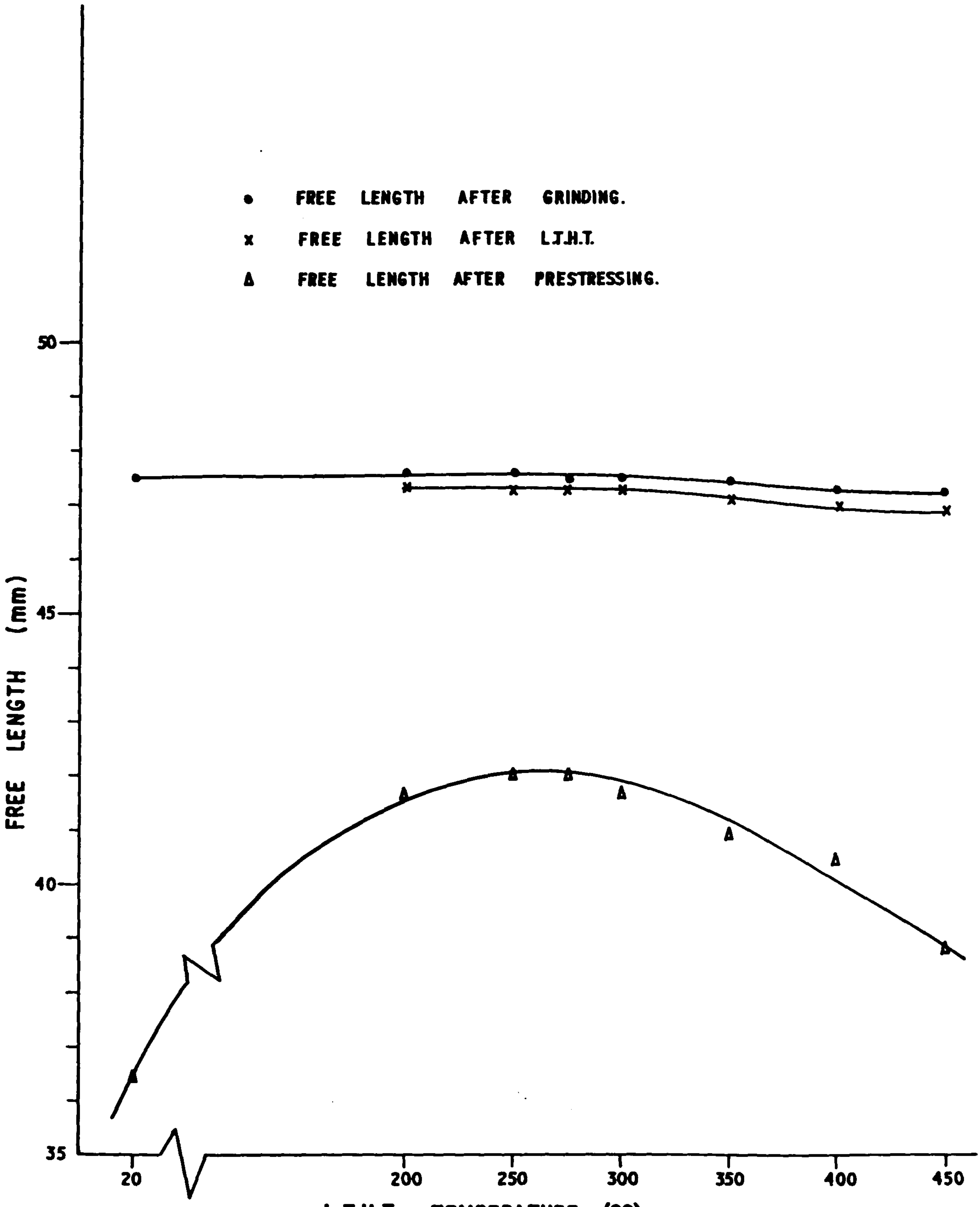

FIG. 3 EFFECT OF L.T.H.T. ON FREE LENGTH OF SPRINGS.

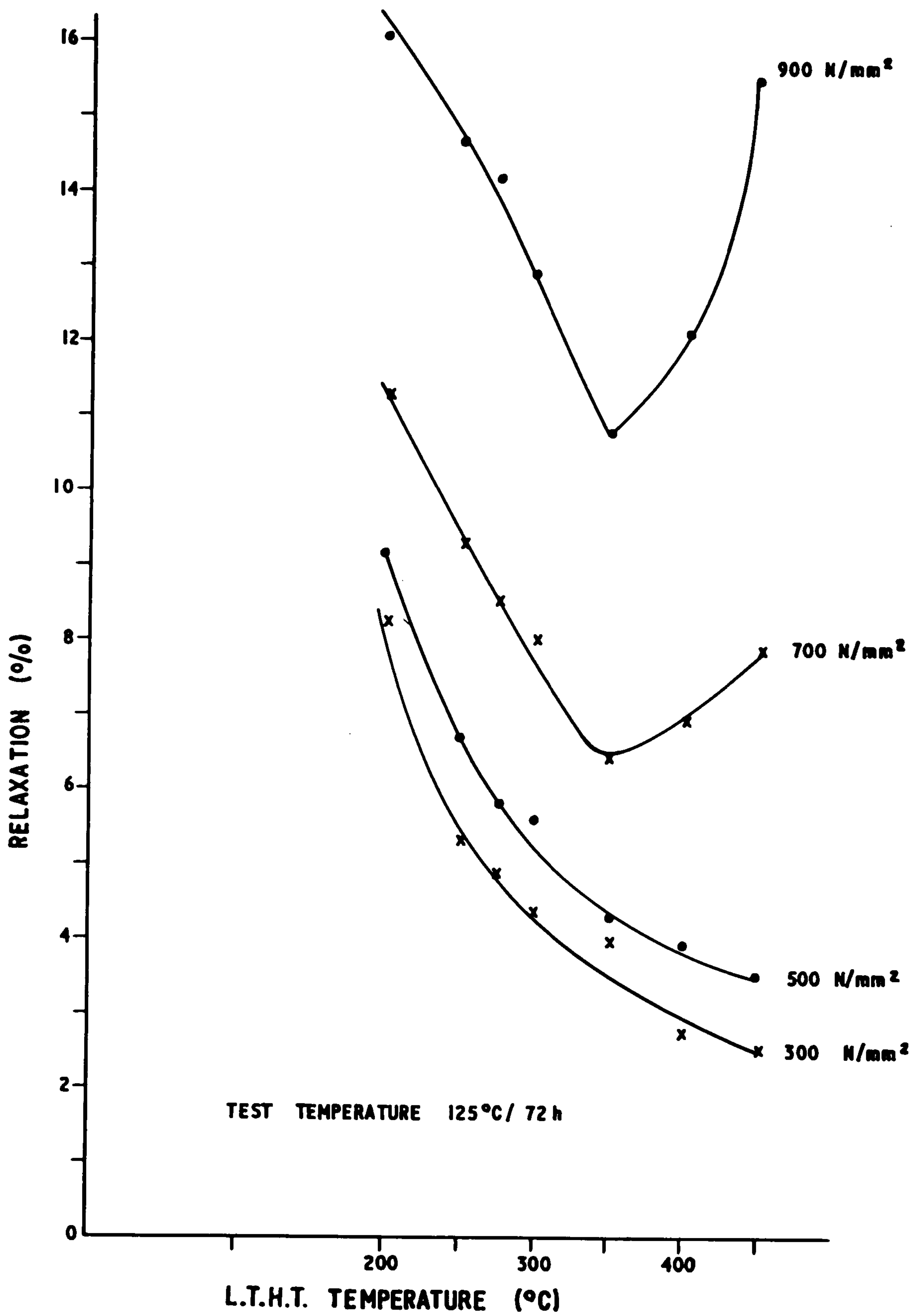

FIG. 4 EFFECT OF L.T.H.T. ON THE STRESS - RELAXATION OF UNPEENED SPRINGS AT VARIOUS STRESS LEVELS.

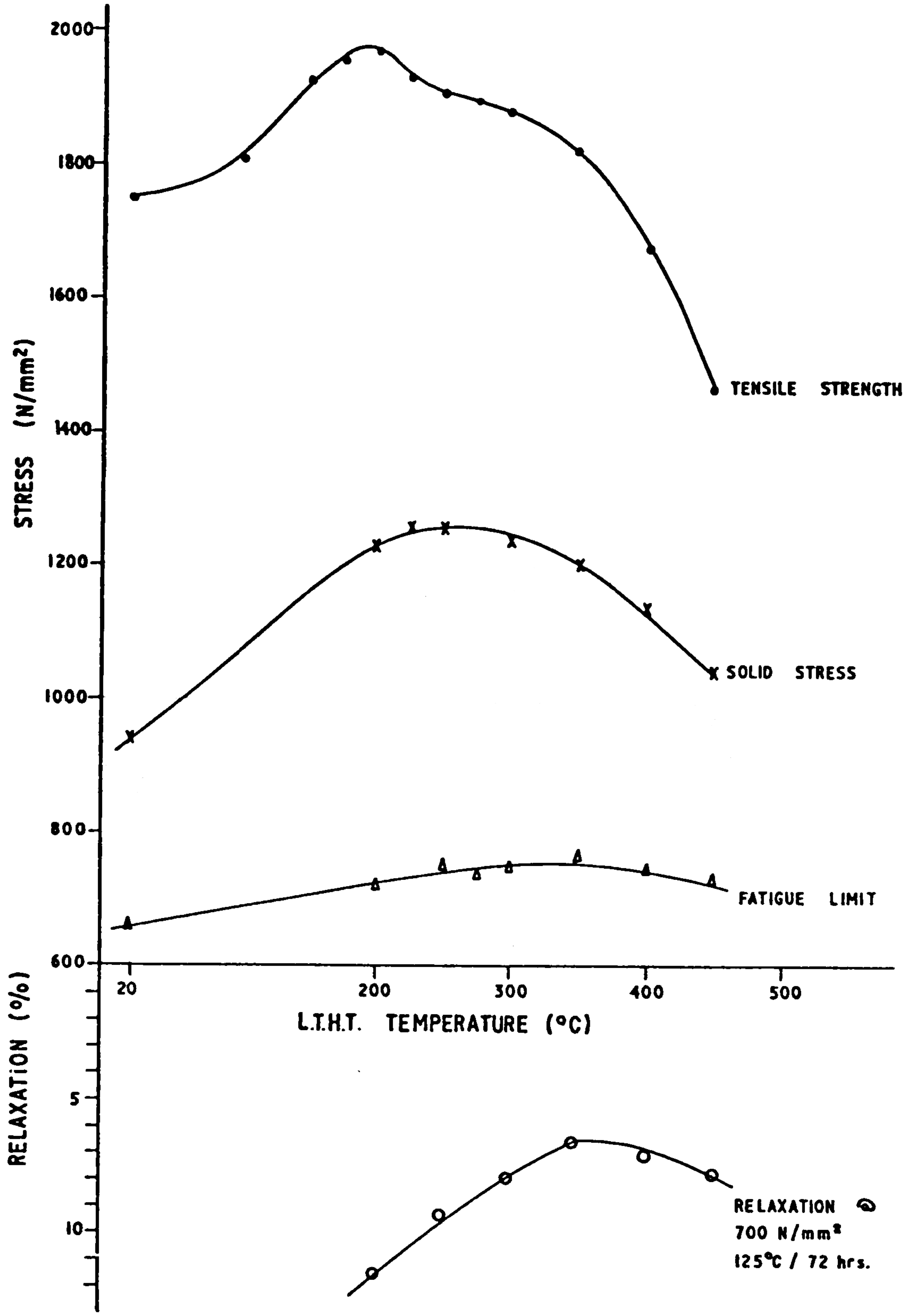

FIG. 5 EFFECT OF L.T.H.T. ON PARAMETERS OF UNPEENED SPRINGS.

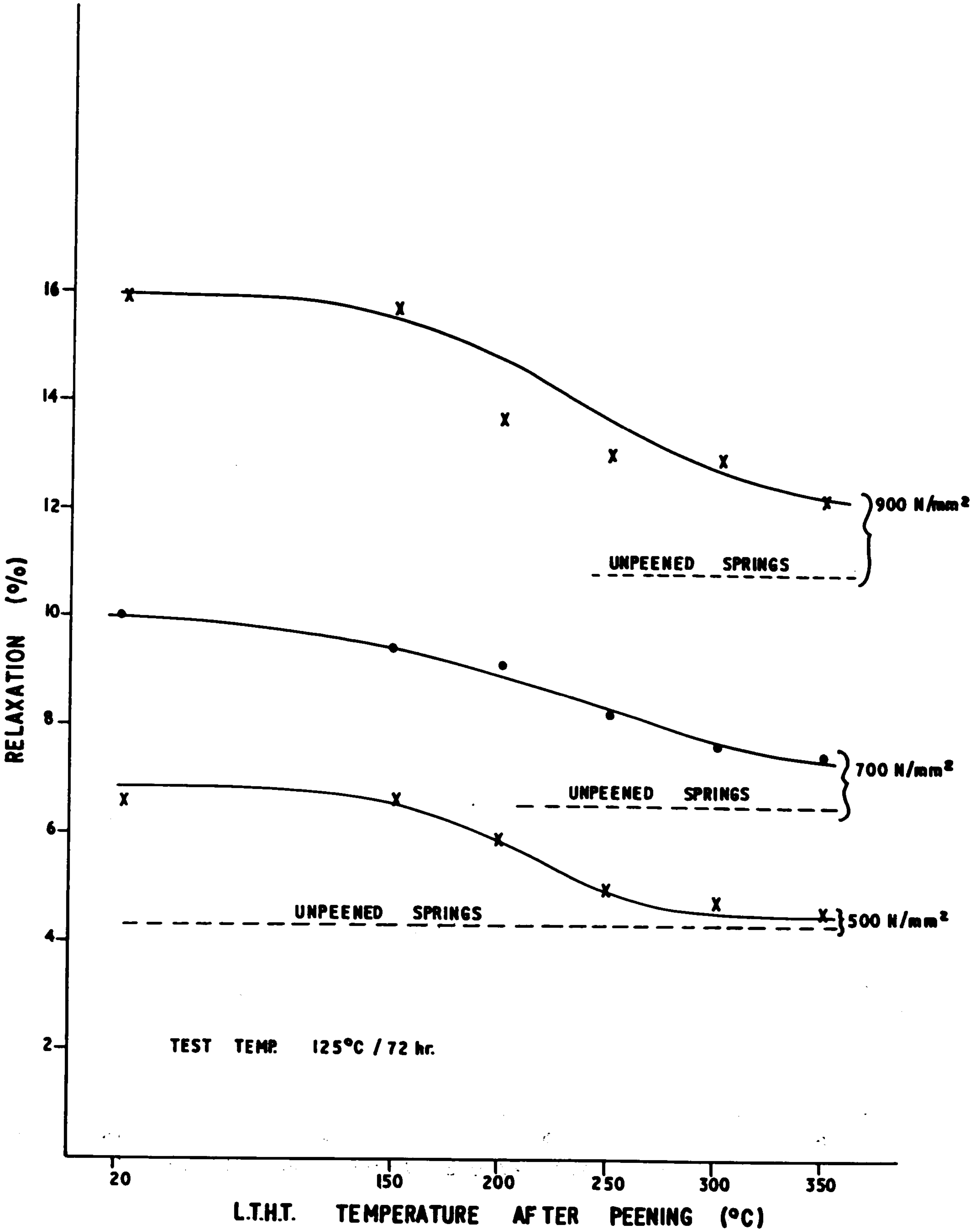

FIG. 6 EFFECT OF L.T.H.T. ON RELAXATION OF SHOT PEENED SPRINGS AT VARIOUS STRESS LEVELS.

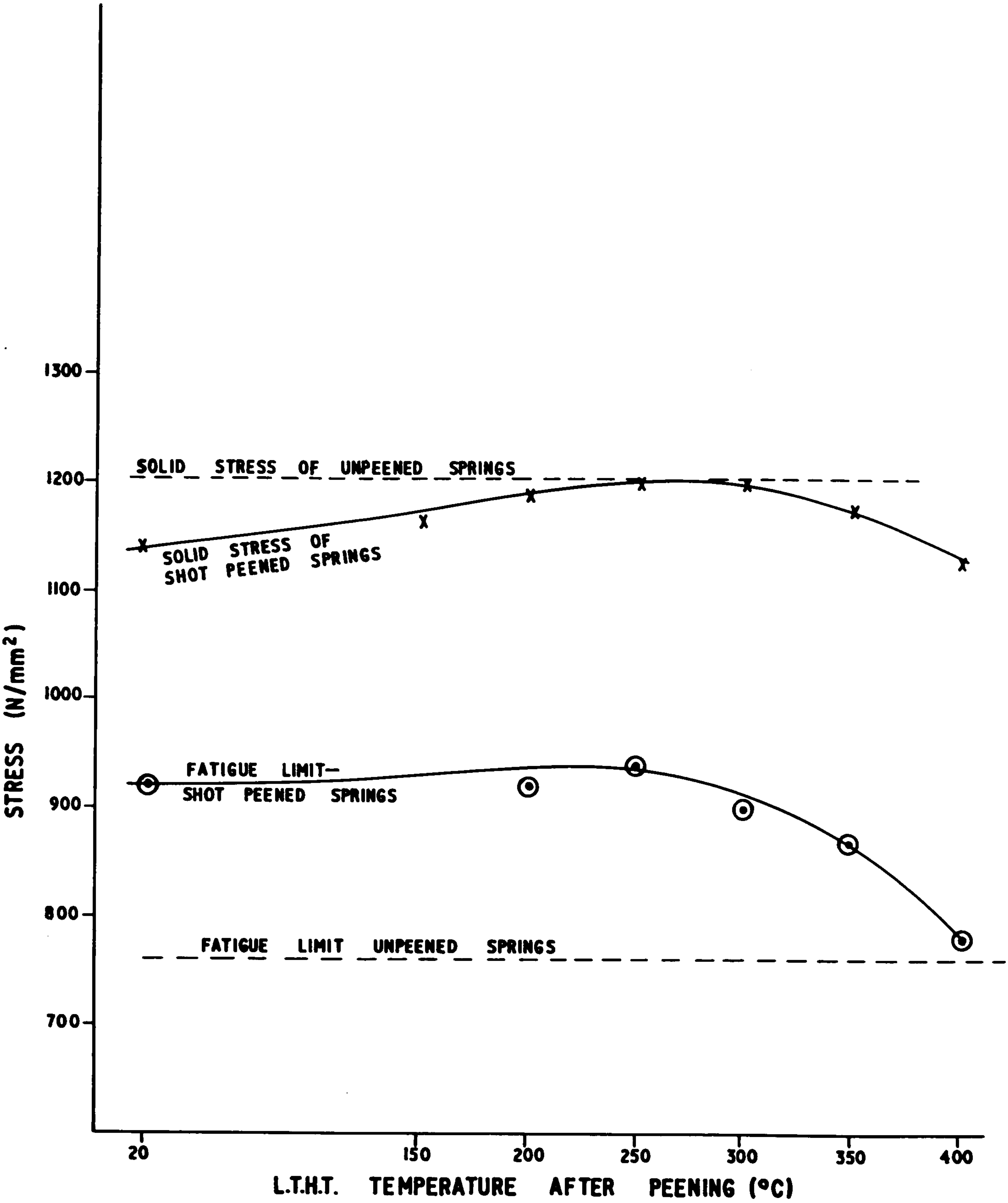

FIG. 7 EFFECT OF L.T.H.T. ON SOLID STRESS AND FATIGUE LIMIT OF SHOT PEENED SPRINGS.