THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

INITIAL TENSION IN CARBON AND STAINLESS STEEL SPRINGS COILED ON AUTOMATIC COILING MACHINES

by

M.S. Bayliss, B.Eng.

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SUMMARY AND CONCLUSIONS

The Association in Report 260(3), has previously looked at the maximum attainable initial tension in tension springs made from carbon steel wire coiled on a single point automatic coiling machine. The work described in the present report was undertaken to extend this knowledge to stainless steel wires, and also to investigate the effects of heat treatment temperature and the amount of initial tension on parameters such as wind up, elastic limit and reduction of the initial tension during LTHT. The results indicate that the LTHT reduces the initial tension by an amount dependent on the temperature. LTHT also recovers some of the elastic properties of the wire which were lost during drawing and spring forming, while at the same time reducing the initial tension.

The change in end loop position also appears to be dependent on the LTHT temperature, and also on the spring index and the initial tension. It was noticed that the stress formulae seem to be questionable, as the elastic limit appears to be dependent on index. This may of course be a function of the coiling process and not of the wire. In addition, it was found that the elastic limit occurs at the same deflection, regardless of the amount of initial tension in the spring for a given design. This suggests that at the moment when the applied load equals the initial tension, the surface stress in the material is zero.

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1. INTRODUCTION

Previous investigations(1,3) have looked at the maximum initial tension attainable and the effect the spring index and LTHT have on the initial tension.

This work was undertaken to extend the previous knowledge and to investigate the effects of the amount of initial tension in extension springs on the elastic limit of the material, wind up/down and relaxation of initial tension during LTHT. The project also investigated whether any of the produced effects were related to the wire size or to the material used.

Single and two point autocoiling machines were used to compare the maximum initial tension produced from each machine.

2. MATERIAL AND SPRING DESIGNS

Three materials were used in this work:-

1. A 0.7 mm patented carbon steel wire to BS 5216 M5 with a tensile strength of 2461 N/mm^2.
2. 0.7 mm and 1.63 mm stainless steel wires to BS 2056 En 58A with a tensile strength of 1945 N/mm^2 and 1908 N/mm^2 respectively.
3. A 0.7 mm high tensile stainless steel Sandvik 11R51SH with a tensile strength of 2780 N/mm^2.

The springs were coiled to four indices: 4, 6, 9 and 12, with four ranges of initial tension: 0, 1/3 max, 2/3 max, and maximum possible.

The actual designs were as follows:

Spring Index	4		6		9		12	
Wire diameter (mm)	0.7	1.63	0.7	1.63	0.7	1.63	0.7	1.63
Outside diameter (mm)	3.5	8.15	4.9	11.41	7.0	16.3	9.1	21.19
Active coils	30	30	20	20	15	15	10	10

3. PROCEDURE

Two types of coiling machines were used: a single point Torrington 115A equipped with a free running wire swift and a hardened silver steel coiling point for the 1.63 mm En58A wire, and a Wafios UFM8 two point machine equipped with a free running swift and carbide coiling points for the 0.7 mm carbon and stainless wires.

The BS 5216 M5 wire was coiled using standard tooling, whilst with the En 58A and Sandvik wires a size mandrel was used.

Springs were coiled to the maximum initial tension obtainable without causing damage to the wire, and then provided with English loops using a hand looping tool. Springs were produced to 66%, 33% and 0% of the measured maximum initial tension.

Load testing of the springs from the 1.63 mm wire was undertaken on a 'Coats Comaco' load tester, and those from the smaller 0.7 mm wire on a Probat SF 100EL load tester. The latter machine was connected to an X-Y recorder to produce a load deflection curve immediately.

The springs were divided into five batches, with three of each index and initial tension in each batch. The initial tension in each spring was measured graphically by plotting load/deflection curves. The relative positions of the end loops were measured on a Nikon profile projector. Low temperature heat treatment was then undertaken at a range of temperatures: 100, 150, 200, 250 and 300°C for the carbon steel wire, and 200, 300, 400 and 450°C for the stainless steel wires.

On completing the LTHT, the new position of the end loops was noted after the spring had been extended a small amount to eliminate intercoil friction. The springs, along with a non-heat treated batch, were again load tested to beyond the elastic limit, to allow the initial tension and maximum safe working stress to be found.

4. RESULTS AND DISCUSSION

The initial tension stress was calculated using the formula:

$$q = \frac{8PD}{\pi d^3}$$

where:

q is the shear stress due to load P
D is the mean coil diameter
d is the wire diameter

No stress correction factor was used for the initial tension stress, so that the results obtained could be compared to those in Report 123(1), in which a series of tests on springs were undertaken to find the maximum initial tension that the material would retain. Spring index and the tensile strength of the wire were found to be the two major variables. The published results gave, both graphically and theoretically, the maximum obtainable initial tension for light springs.

When calculating the maximum safe working stress, however, the stress correction factor was included, so that comparisons for the carbon steel wire could be made with data in SRAMA Report 260$^{(3)}$.

It can be seen from Fig. 1 that the initial tension stress curve for the BS 5216 M5 wire, plotted as the ratio:

$$\frac{\text{Initial Tension Stress}}{\text{Ultimate Tension Strength}} \times \frac{100}{1}\ \% \quad \text{against spring index,}$$

is considerably lower and of a different shape than that in (1). Here, the maximum initial tension obtained was in the index 8-9 range and of the order 11.5% of the tensile strength.

Fig. 2, however, shows the improvement obtained by using a size mandrel with a two point machine. Here, the En 58A was coiled with and without a size mandrel, the results showing that above an index of 5 a gain of some 2% over (1) has been achieved. Below index 5 it can be seen that the mandrel was so small that it was unable to support the wire, and the initial tension dropped to the lower range obtained without using a mandrel.

Fig. 3 for the Sandvik wire again shows the rapid dropping of initial tension below index 5. Although the rest of the curve is similar to that of Fig. 2 the actual initial tension force was some 40% higher due to the increase in tensile strength of the Sandvik wire.

Fig. 4 shows the results of the 1.63 mm stainless wire coiled on the single point machine. The results were very similar to those previously described, except that there is not the large drop in the results below index 5. There appears to be little difference between the two types of coiling machines, other than the two point machine's inability to coil to a high initial tension below a spring index of 5.

The percentage loss in initial tension during LTHT shown in Fig. 5 appears to be dependent only on the temperature, and the curves obtained are of a similar shape regardless of the wire diameter, index, or the as coiled initial tension. The effect of LTHT on the elastic limit of the wire is very noticeable, with the carbon steel wire showing a very steep rise in the limit at 250°C (Fig. 6). With the stainless steel wire the LTHT has had a much less definite effect, but in all cases (Figs. 7, 8, 9) the peak occurs in the 300° - 350°C range, which is considerably less than the more commonly used 400 - 450°C temperatures. A second noticeable feature of these curves is that the elastic limit is dependent on the index of the spring, which suggests that either the end loops of the springs were becoming plastic during testing and thus giving false elastic points, or that there are errors occurring with the stress formula applied to tension springs.

The change in end loop position of the springs has been proved to be dependent on the spring index, wire size and material. For the wind up of carbon steel and the wind down of stainless steel springs, the magnitude is proportional to the heat treatment temperature, with the index 4 spring changing approximately 50% less than index 12 (Figs. 10, 11, 12, 13). The results plotted for the changes in the end loop position are expressed as degrees/mm of wire in the spring. This means that the results are directly comparable regardless of spring design. The plotted results include the springs with zero initial tension, as these gave the largest movement. For initial tension approaching, the maximum obtained a figure of 50% less can be taken with other ranges scattered in between.

Figs. 11, 12 show the effect of the wire diameter for the En 58A wire on wind down. It can be seen that the o.7 mm En 58A were wound down approximately twice as much as the 1.63 mm wire for the higher indices.

Another factor noted from the load deflection curves (Figs. 14, 15) is that for dimensionally similar springs with differing initial tensions, the elastic limit always occurred at the same deflection and not the same load. This seems to suggest that the initial tension formed a reverse stress in the spring which became zero just as the barrel of the spring began to move. As can also be seen from Figs 14,15 this appears to hold true for springs in both as coiled and LTHT conditions.

5. RECOMMENDATION FOR FUTURE WORK

It is recommended that the validity of the stress equations should be investigated with respect to tension springs of various indices, with and without initial tension.

6. CONCLUSIONS

1. The maximum obtainable initial tension is slightly greater than that previously obtained.

2. The percentage loss in initial tension after LTHT was as follows:-

Carbon Steel BS 5216

Temperature °C	100	200	300
% loss in Initial Tension	7.5	27.5	57

Stainless Steel BS 2056

Temperature °C	Wire dia	200	300	400	450
% loss in Initial Tension	0.7 mm	6.5	13	27.5	47.5
	1.63 mm	10	18	35	42.5

Sandvik Stainless Steel

Temperature °C	200	300	400	450
% loss in Initial Tension	7.5	15	37	53

3. The maximum working stress can be increased by LTHT at the loss of some of the initial tension. The optimum temperatures were 250°C for carbon steel and 300°C for the stainless steels.

4. The amount of angular rotation of the end coils is dependent on the index and wire diameter such that if the wire diameter is doubled then the wind up is halved. Wind up is also dependent on the amount of initial tension and a high initial tension may reduce these changes by 50%.

5. The two point coiling machine, for indices of 5 or greater, can produce initial tension as high as the single point machines, providing a size mandrel is used. In general though it is so difficult to coil springs of index less than 5 on standard autocoilers that it is not in order to state that one type of machine is better than any other in this index range.

6. It appears from the results obtained that the elastic limit of a tension spring is not affected by the initial tension in the spring but by the stress produced by the deflection of the spring.

7. REFERENCES

1. BROWN, A.A.D. "Initial tension in springs made form light wire". C.S.F.R.O. Report No. 123, February 1961.

2. CHIRONIS, N.D. "Spring design and application". 1961.

3. SOUTHWARD, M.R. "An investigation into initial tension in extension springs". SRAMA Report No. 260, May 1976.

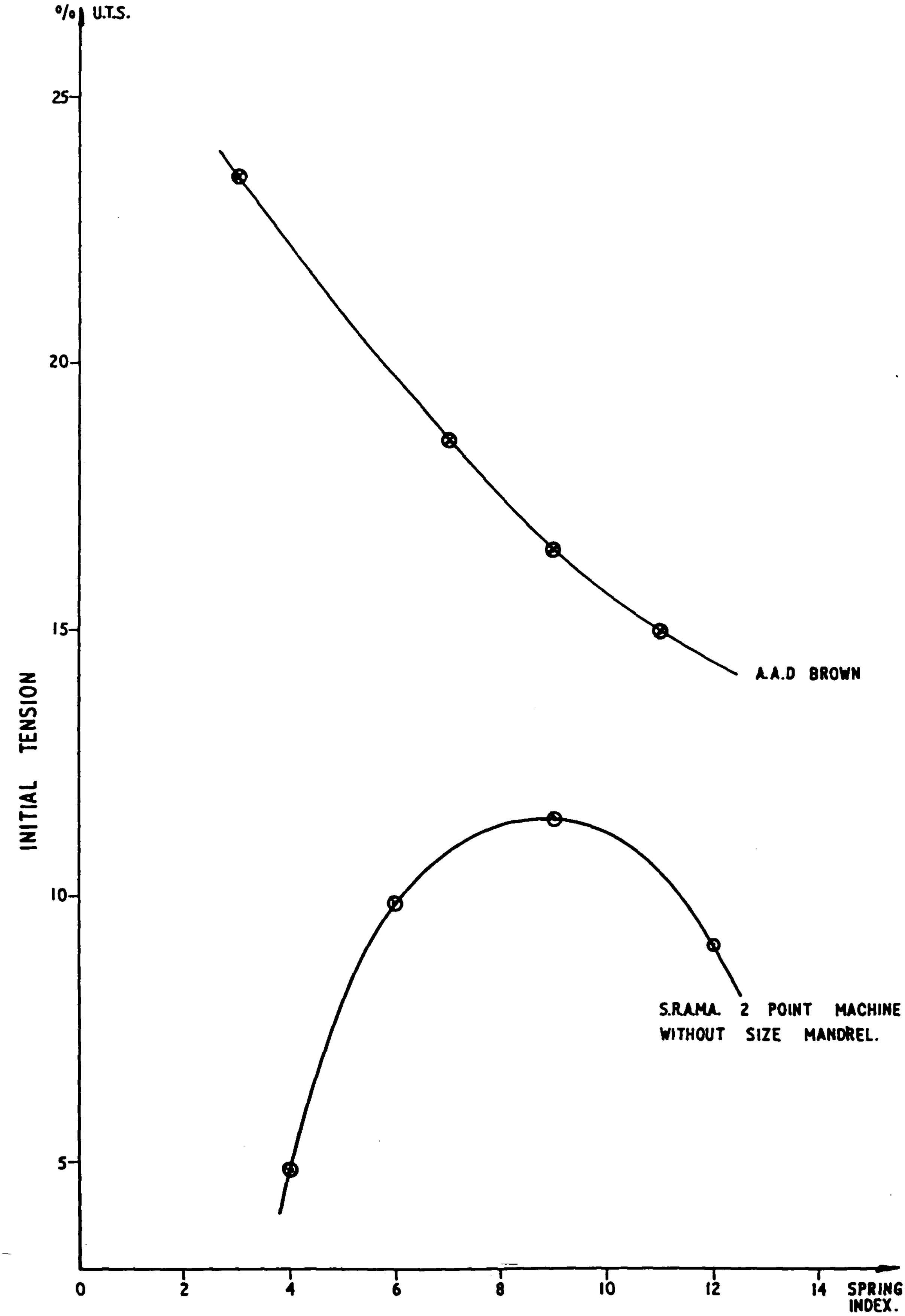

FIG. 1. INITIAL TENSION AS % OF U.T.S. v INDEX 0·7 mm. B.S. 5216 M5.

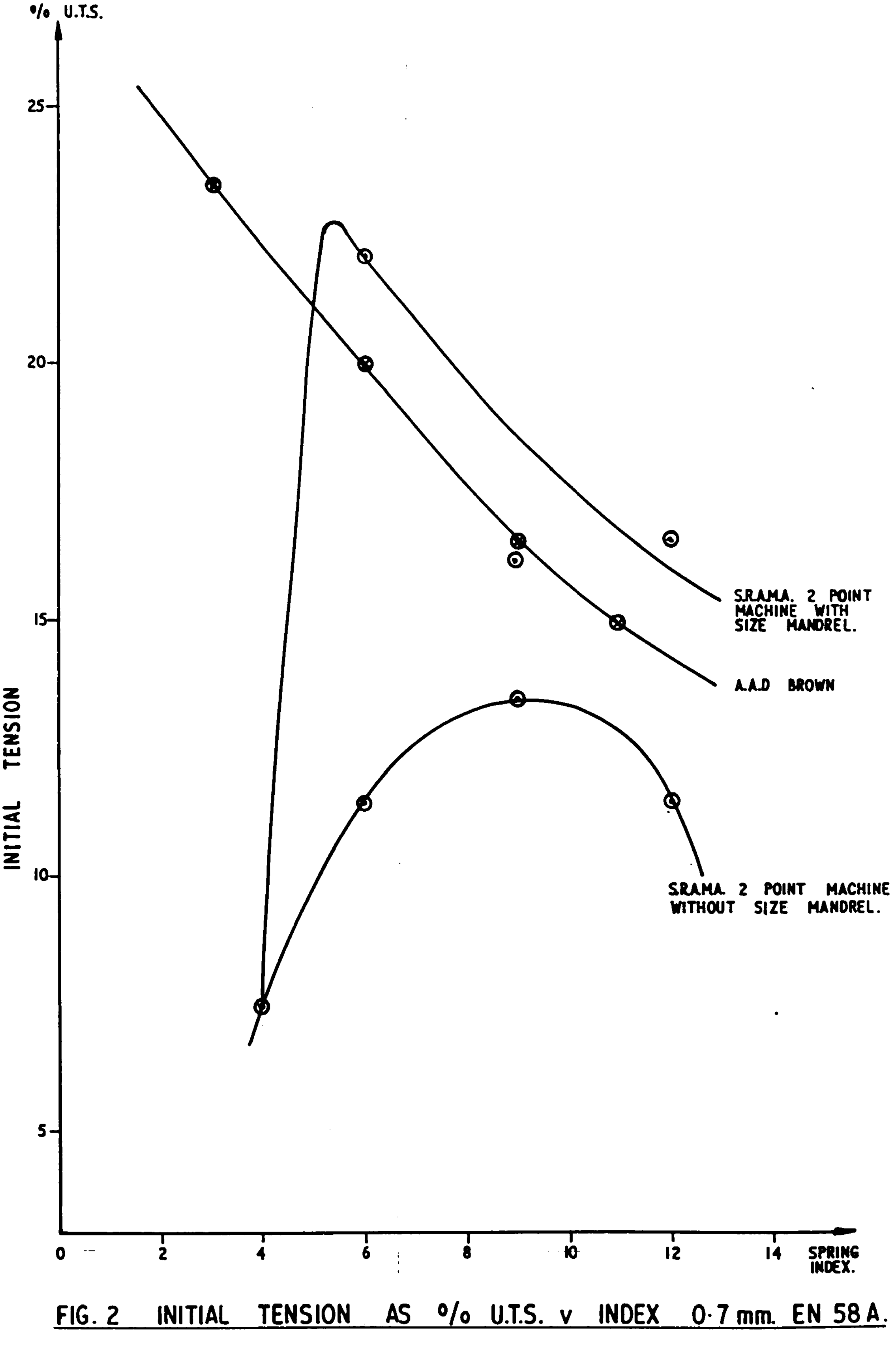

FIG. 2 INITIAL TENSION AS °/o U.T.S. v INDEX 0·7 mm. EN 58 A.

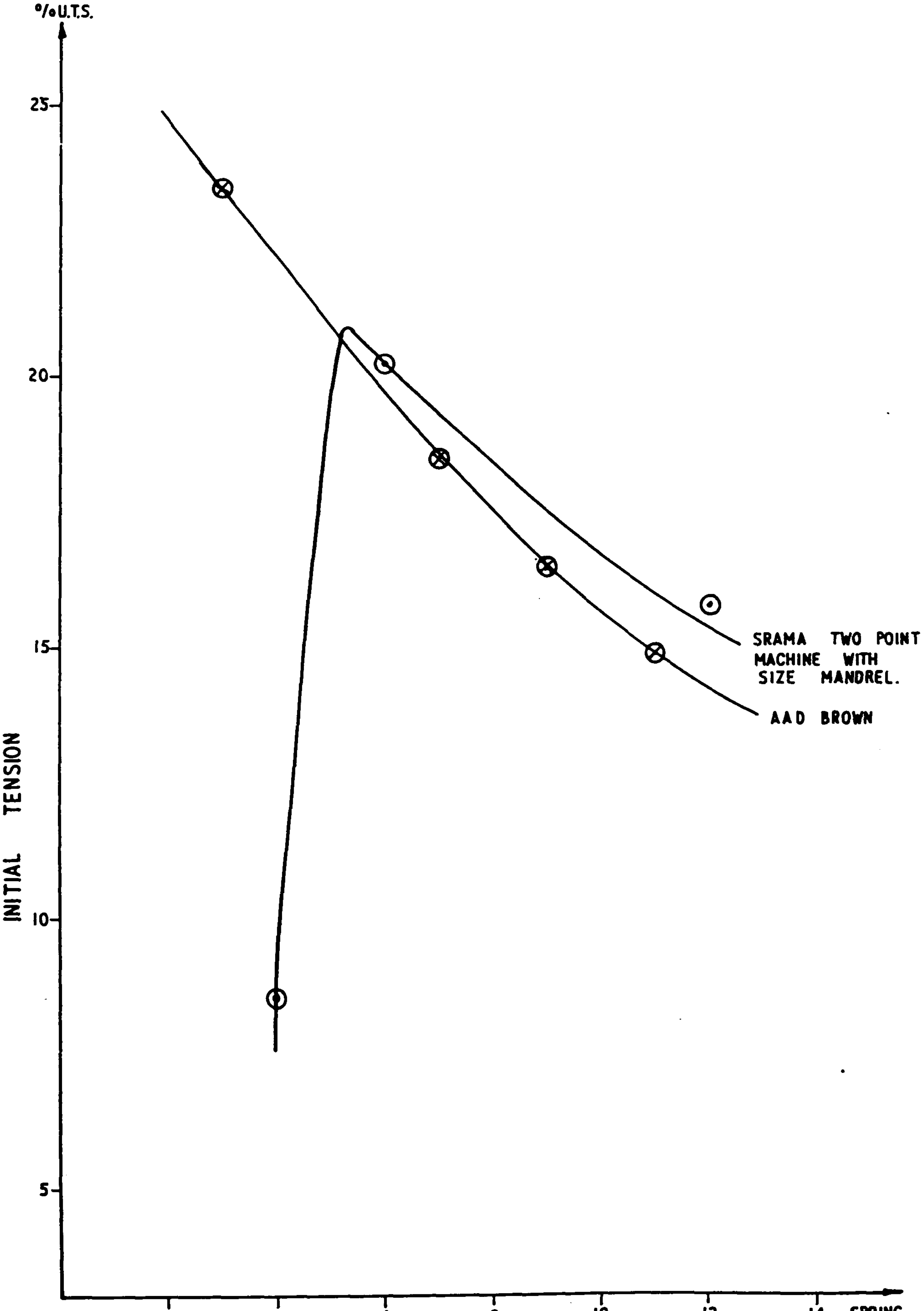

FIG. 3. INITIAL TENSION AS % OF U.T.S. v INDEX 0·7 mm SANDVIK 11 R 51 SH.

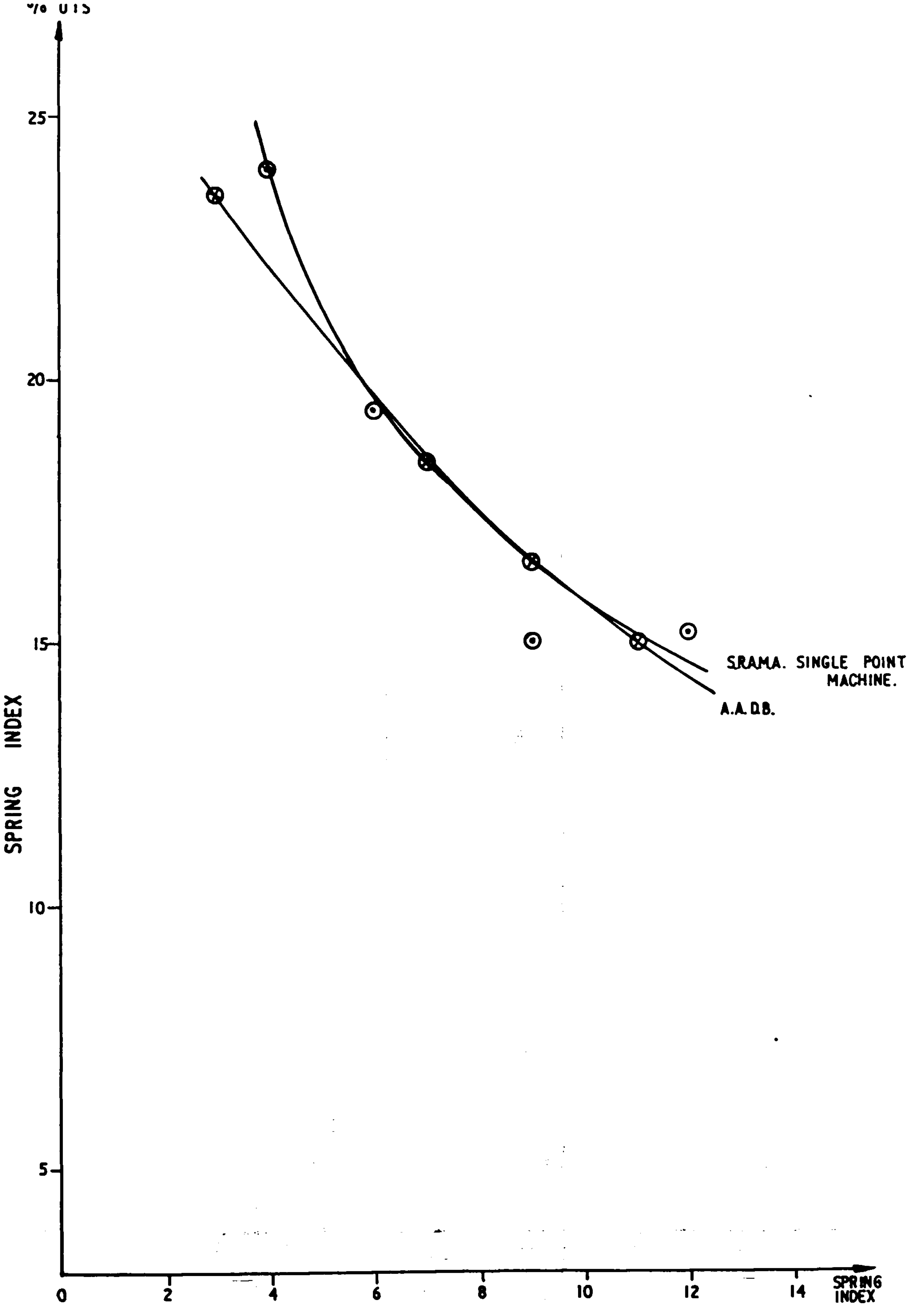

FIG. 4. INITIAL TENSION AS % U.T.S. v INDEX 1·63 mm.
EN 58 A.

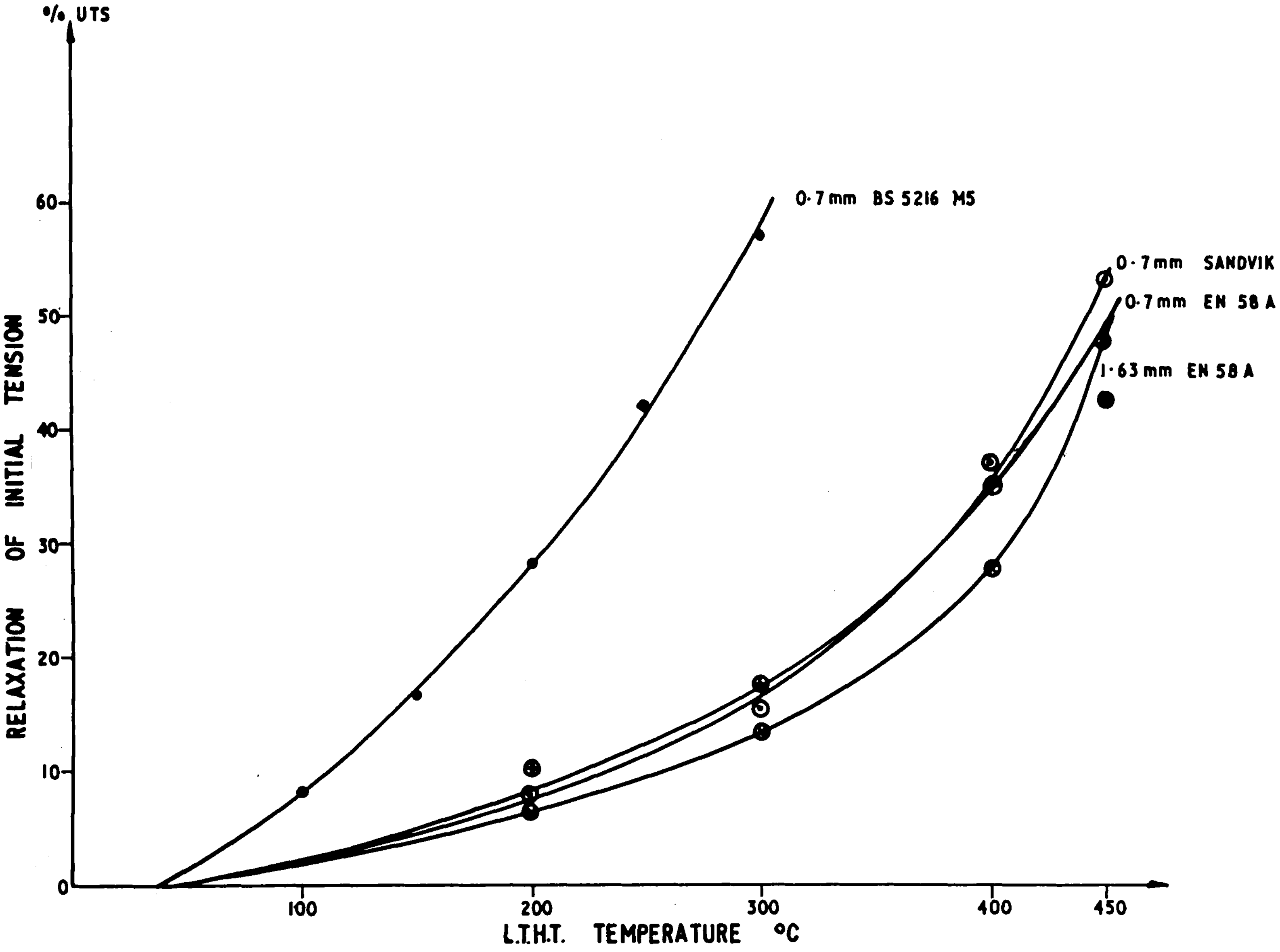

FIG. 5. % RELAXATION OF INITIAL TENSION v L.T.H.T. TEMPERATURE.

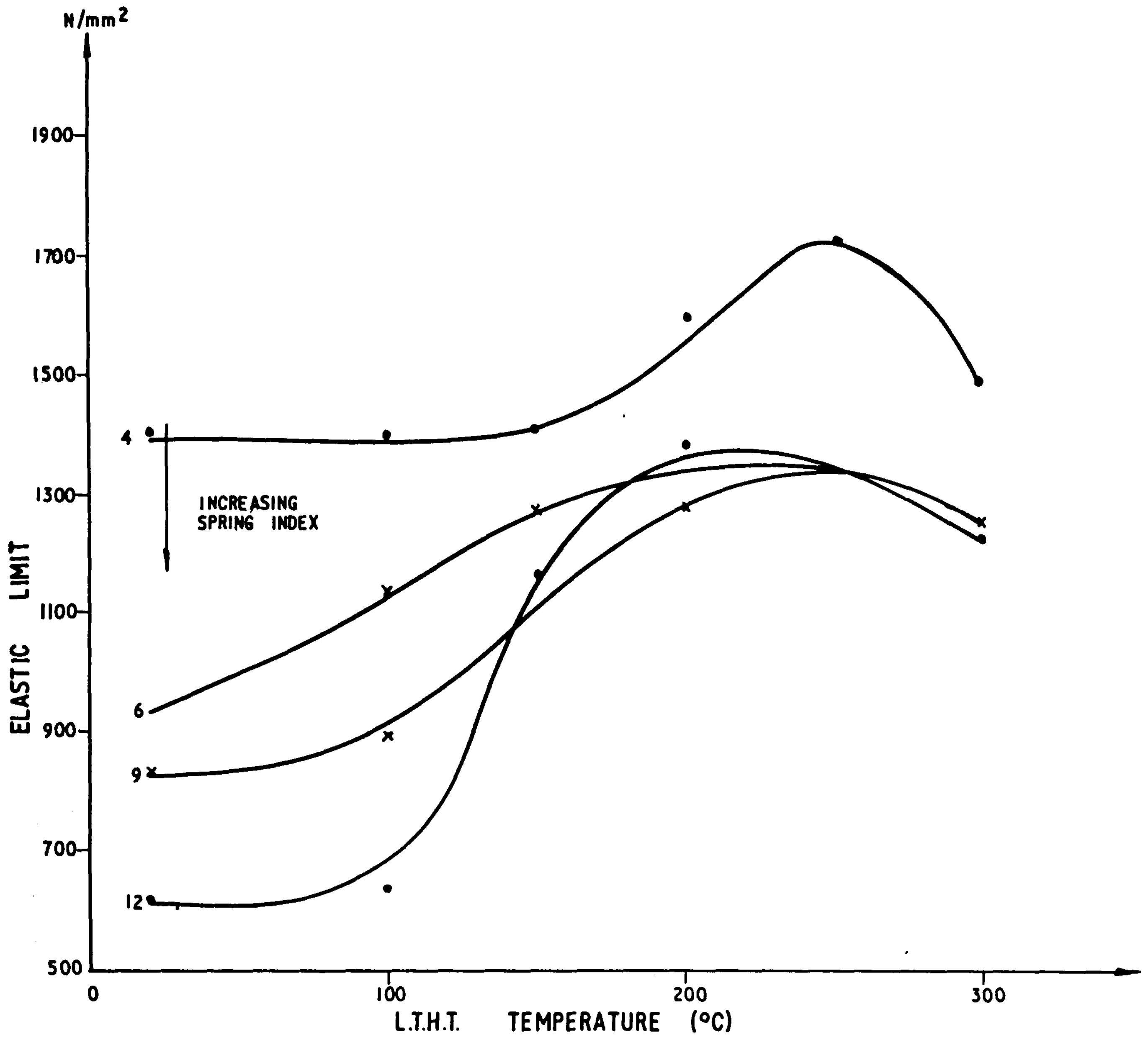

FIG. 6 ELASTIC LIMIT v LTHT TEMPERATURE 0·7mm BS 5216 M5.

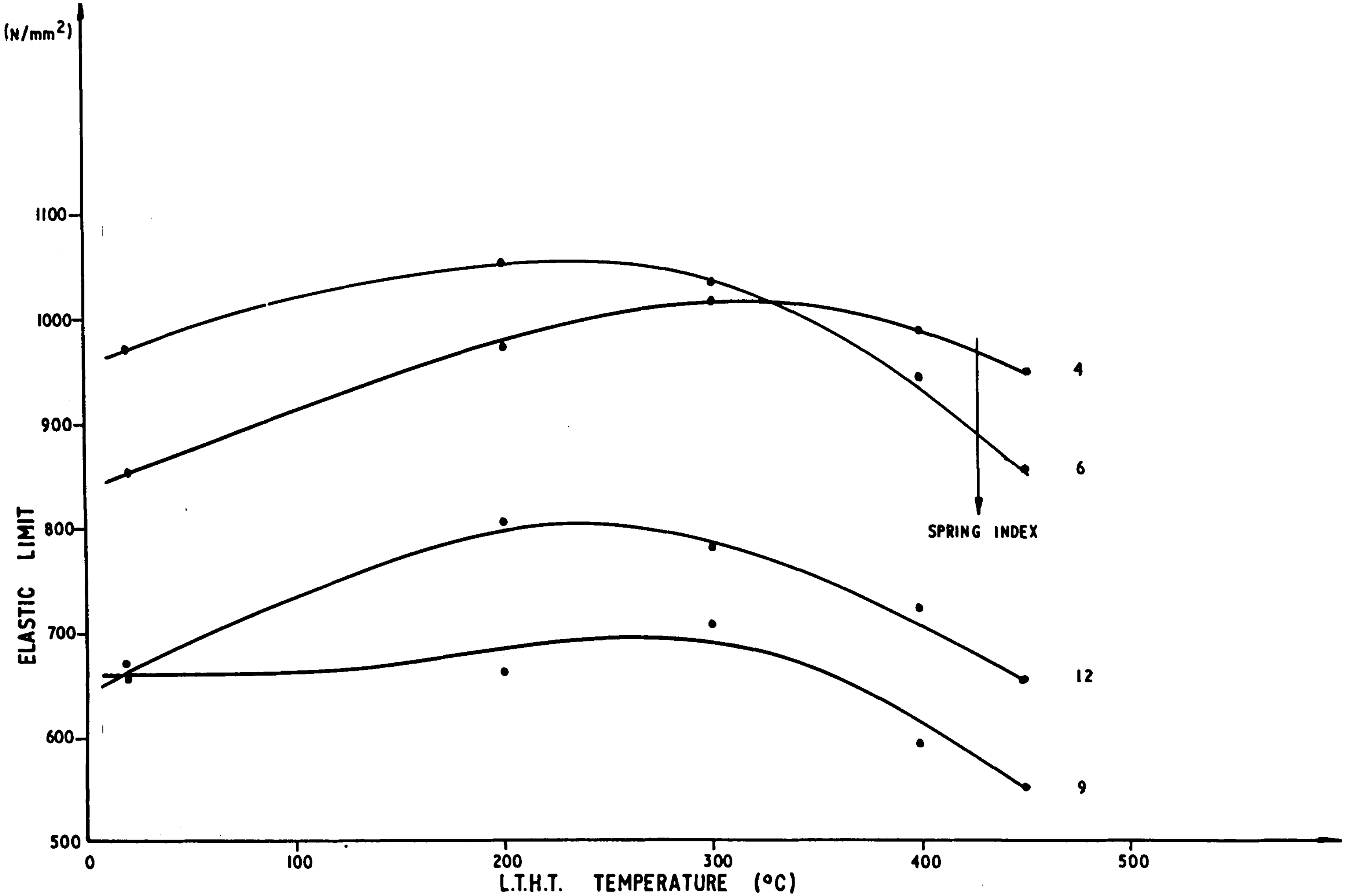

FIG. 7 ELASTIC LIMIT v L.T.H.T. TEMPERATURE 0·7 mm EN 58 A.

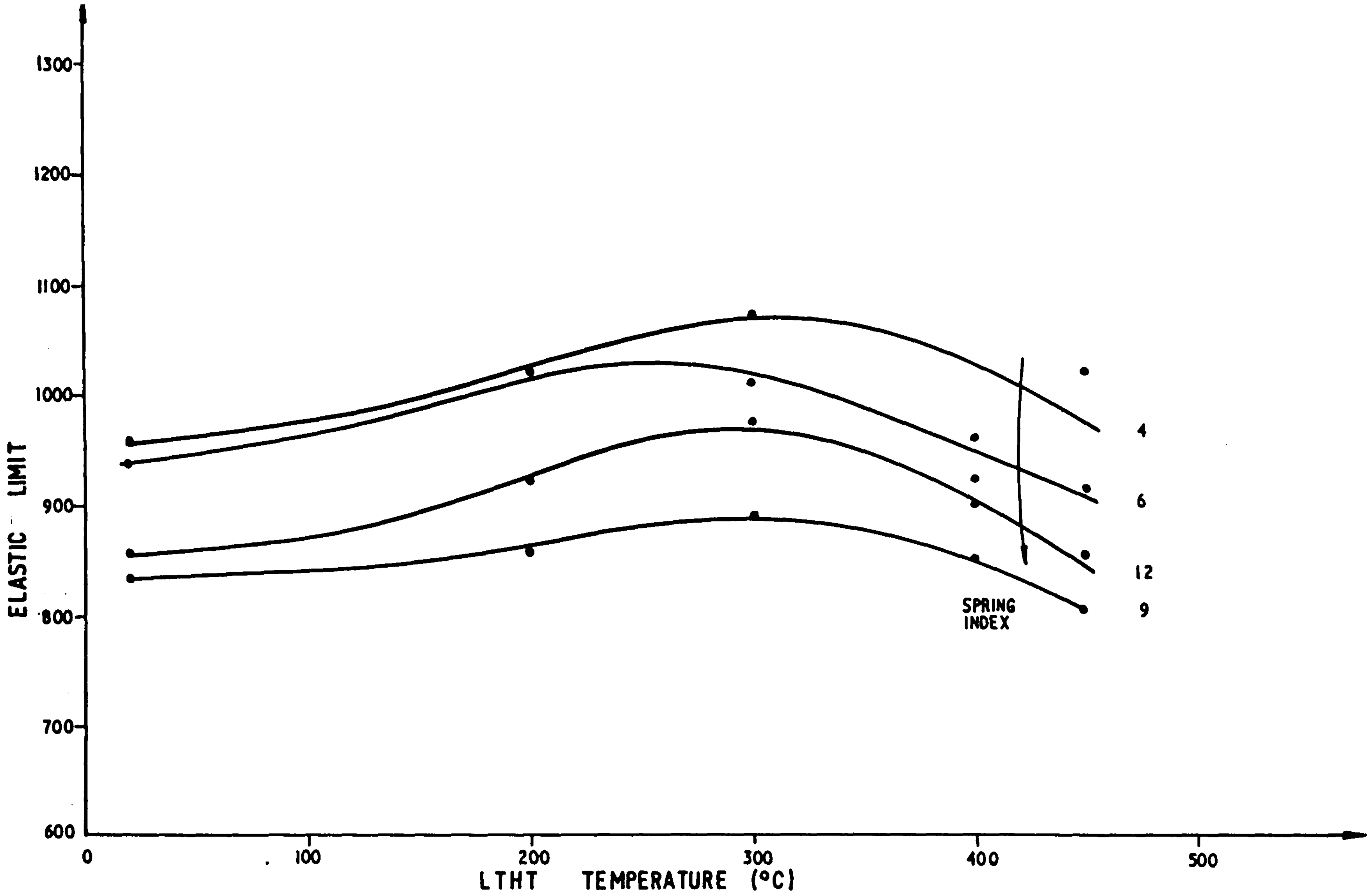

FIG. 8 ELASTIC LIMIT v L.T.H.T. TEMPERATURE 0·7mm SANDVIK 11R51SH.

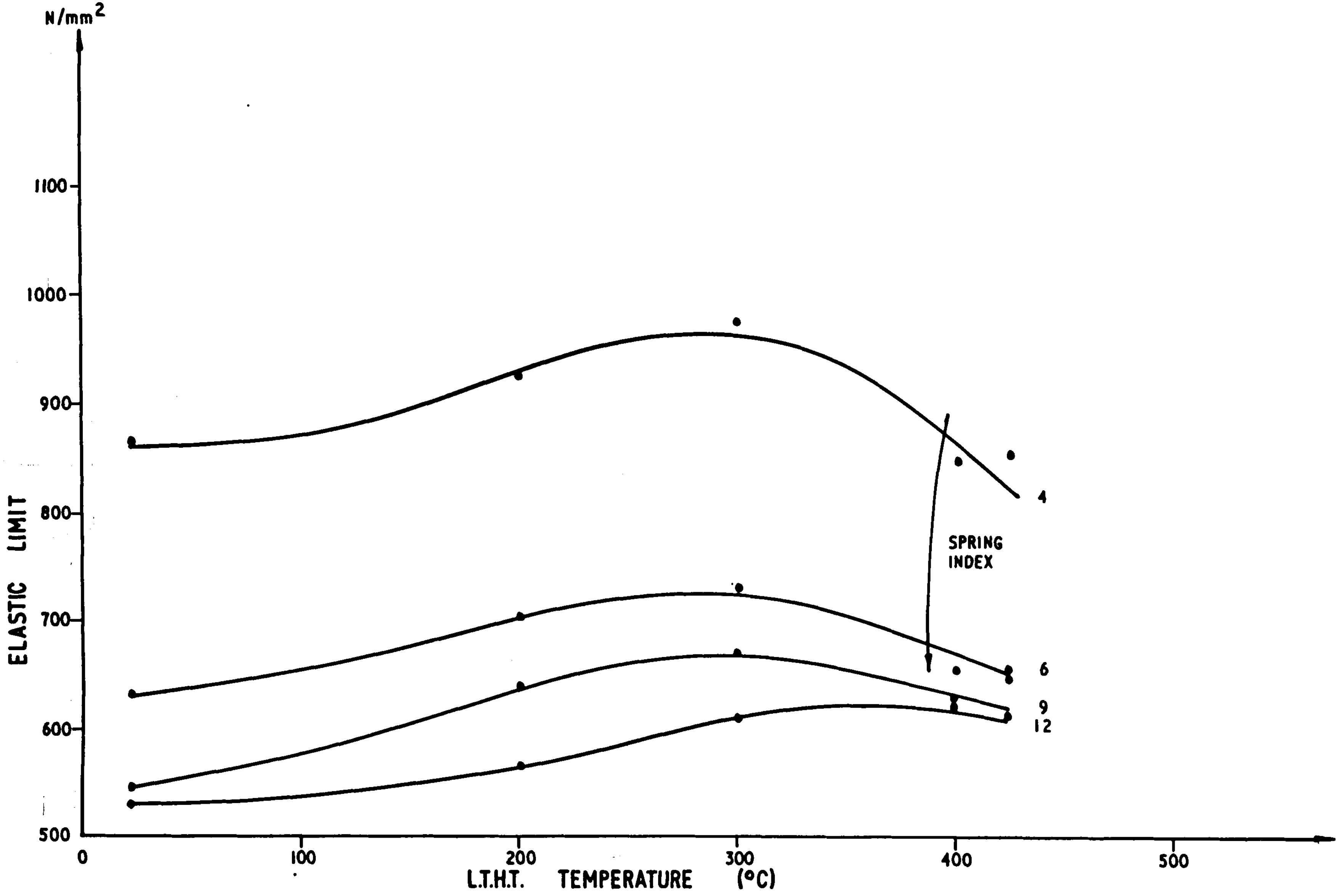

FIG. 9. ELASTIC LIMIT v L.T.H.T. TEMPERATURE 1·63mm EN58A.

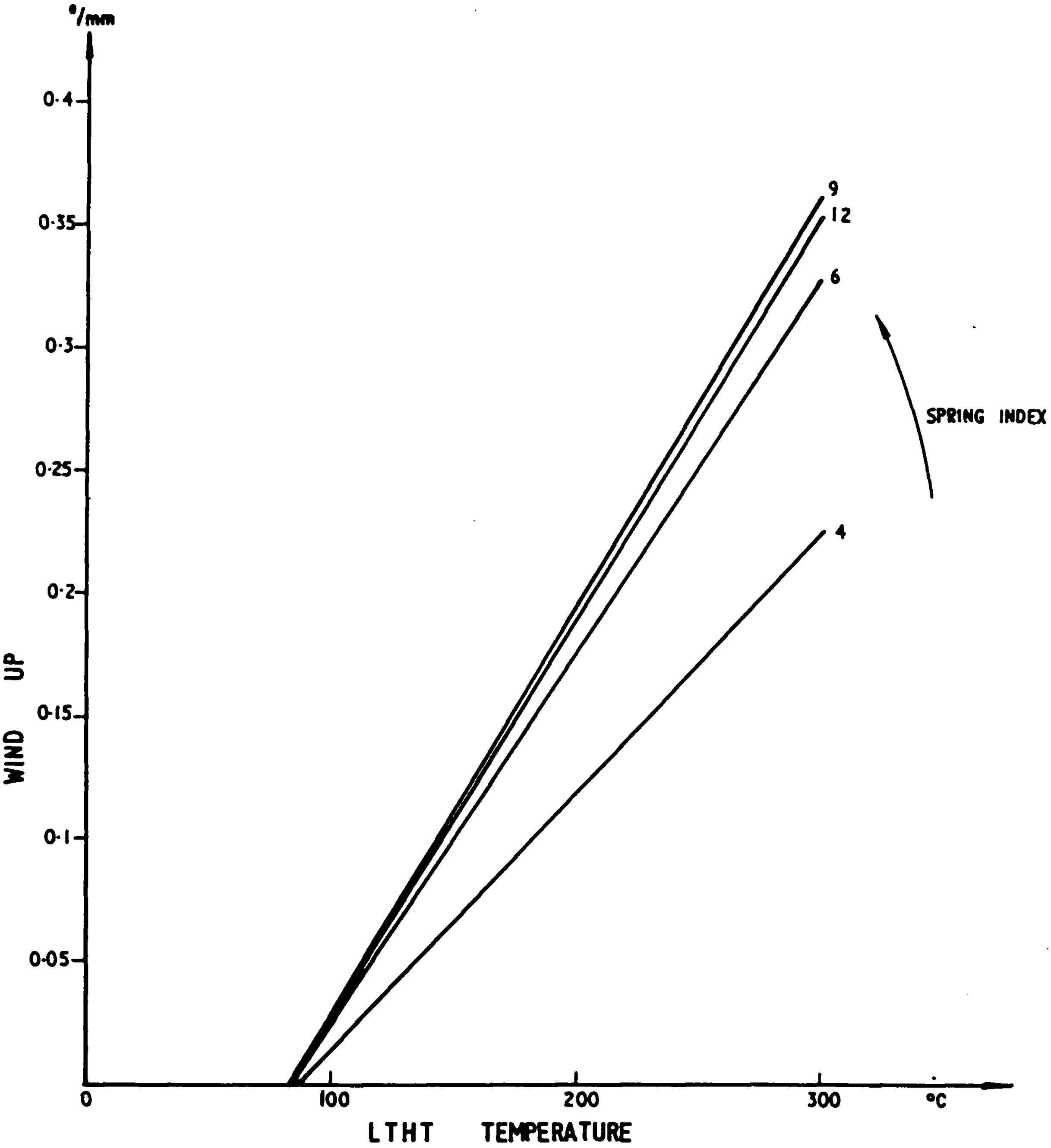

FIG. 10 WIND UP v LTHT TEMPERATURE 0·7mm BS5216 M5.

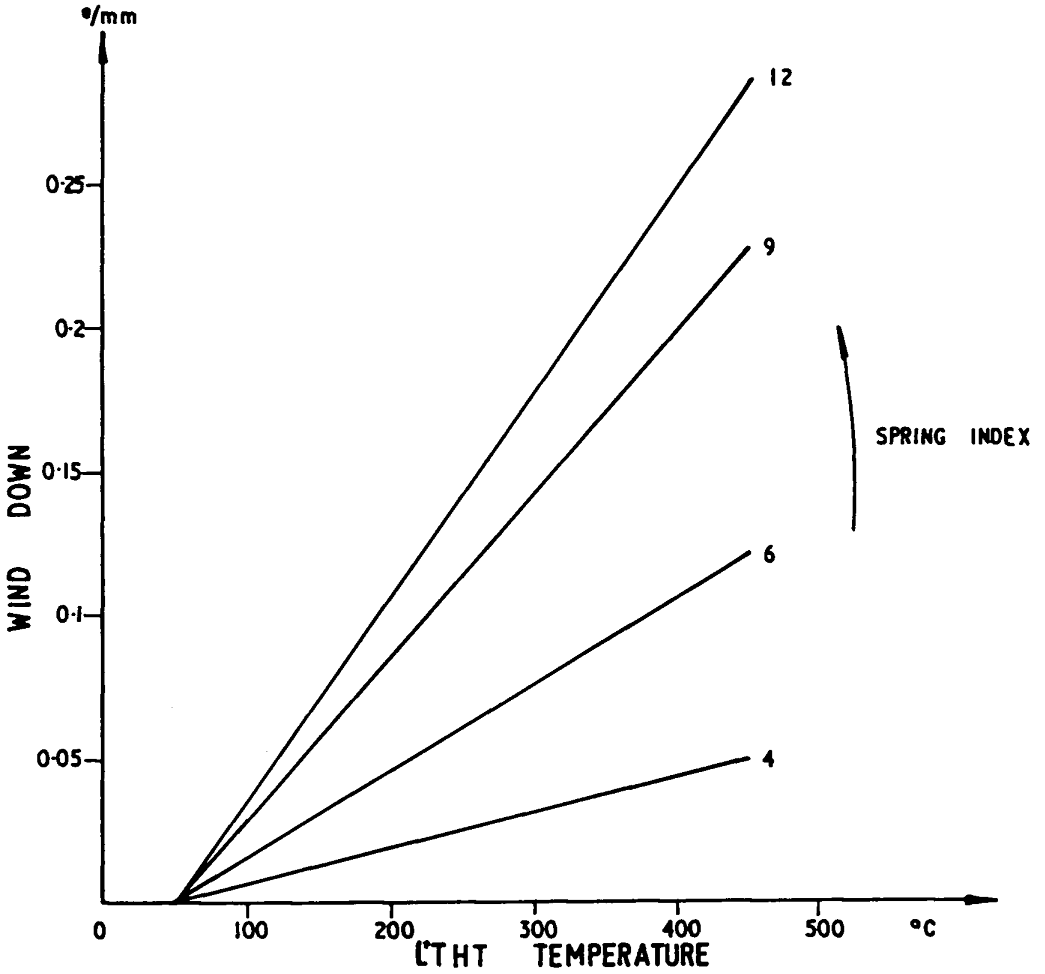

FIG. 11 WIND DOWN v L.T.H.T. TEMPERATURE 0·7mm EN 58A.

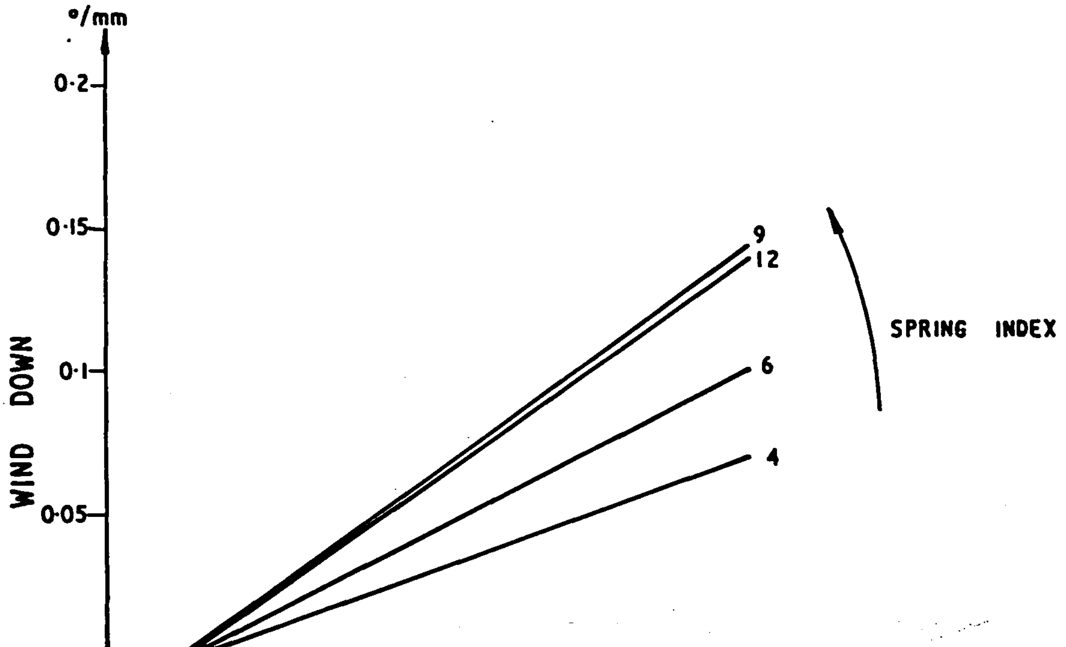

FIG. 12 WIND DOWN v LTHT TEMPERATURE 1·63mm EN 58A.

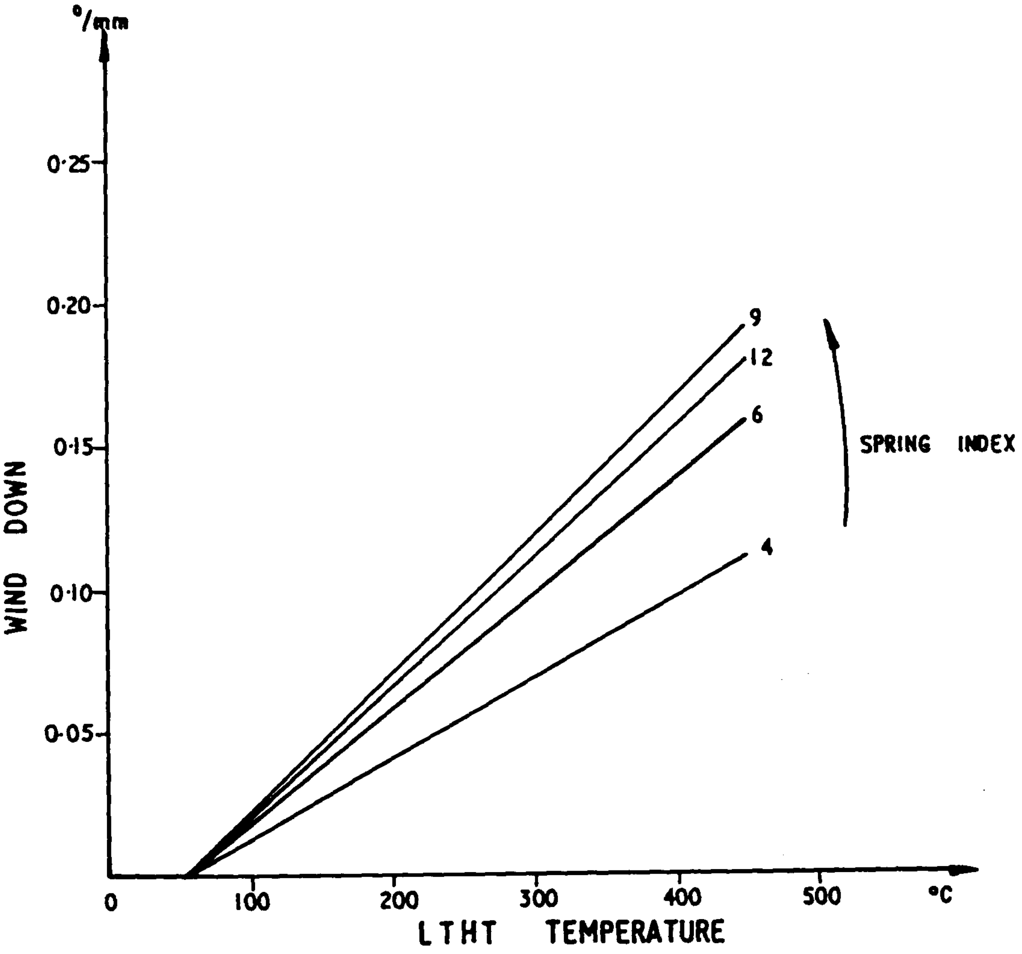

FIG. 13 WIND DOWN v L.T.H.T. TEMPERATURE 0·7 mm SANDVIK 11 R 51 SH.

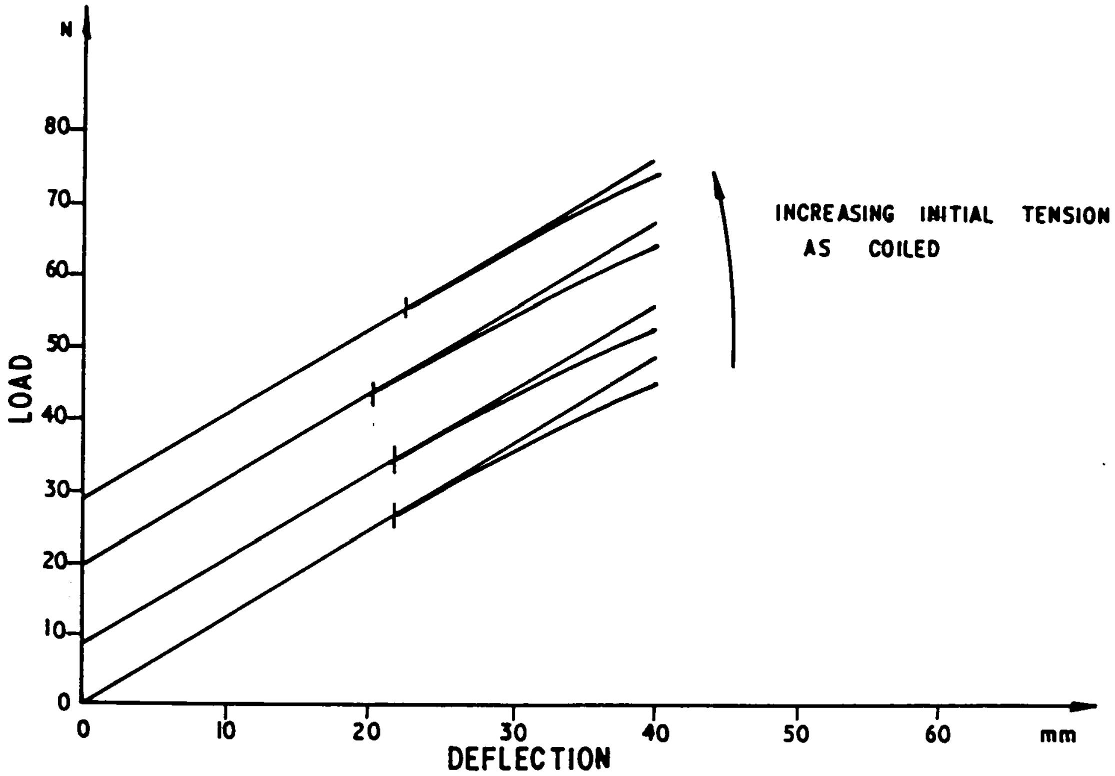

FIG. 14 LOAD v DEFLECTION CURVES 1·63 mm EN 58 A INDEX 9.

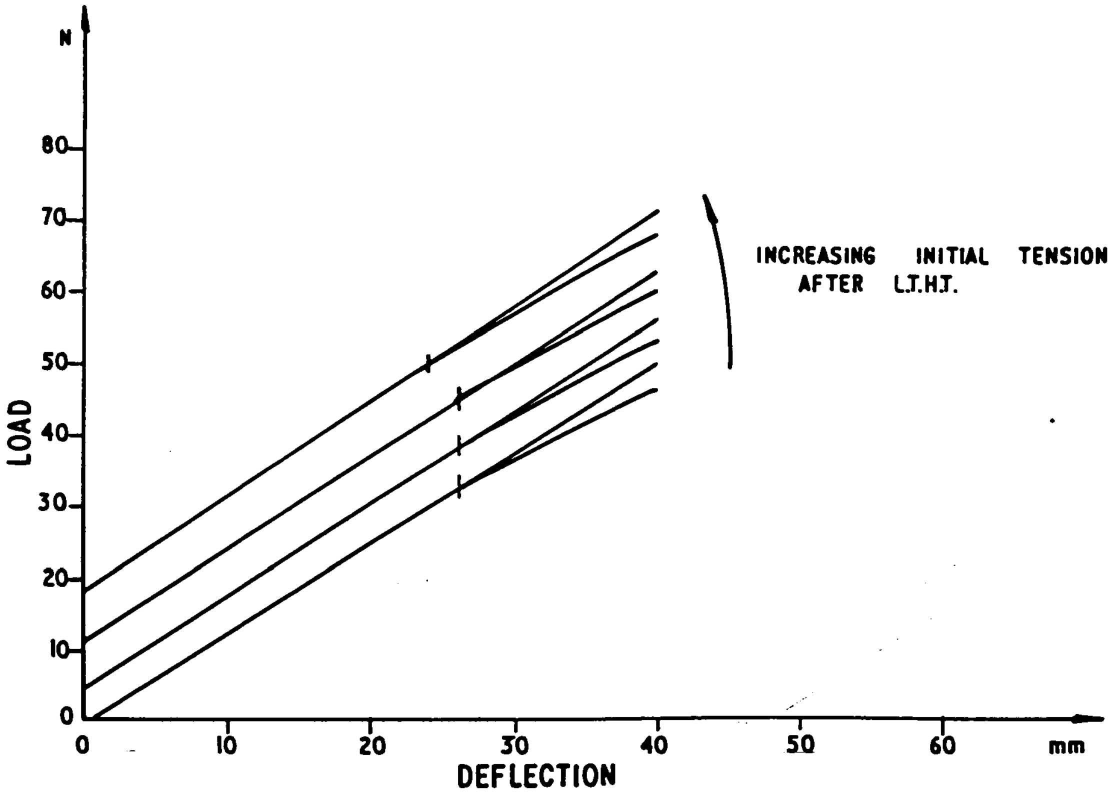

FIG. 15 LOAD v DEFLECTION CURVES 1·63 mm. EN 58 A INDEX 9.