THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

AN INVESTIGATION INTO INITIAL TENSION IN EXTENSION SPRINGS

by

M.R. Southward, B.Sc.

Report No. 260

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SUMMARY

In this programme of work, springs with a range of spring indices were coiled from cold drawn carbon steel wire on a single point automatic coiling machine set to obtain the maximum initial tension. The springs were subjected to a range of low temperature heat treatments; various parameters of the spring, namely initial tension, maximum working stress and angular position of the end loops, were determined as a function of the heat treatment temperature and the index of the spring.

Levels of initial tension between 15% and 20% of the tensile strength of the wire were obtained, more initial tension being developed in the low index springs. The loss in initial tension after heat treatment was found to be independent of spring index, varying only with the heat treatment temperatures. The maximum corrected working stress in the spring was increased by a stress relieving treatment; the optimum temperature was found to be about 250°C. The angular rotation of the end loops increased with heat treatment temperature and was found to be proportional to the length of wire in the barrel of the spring.

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CONTENTS

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1. INTRODUCTION

In a previous investigation[1] on the subject of "Initial Tension in Springs made from Light Wire" it was concluded that formulae established previously for determining the amount of initial tension that can be produced in tension springs had been excessively conservative; the report presented a formula which enabled the maximum value of the initial tension to be calculated as a function of the spring index.

For the present investigation, springs were coiled from cold drawn carbon steel wire on a single point coiling machine so adjusted as to produce the maximum initial tension in the spring. The springs were subjected to a range of low temperature heat treatments and the reduction in the amount of the initial tension and maximum working stress were determined as a function of the heat treatment temperature and the index of the spring.

Since the relative position of the end loops of tension springs can be important, the angular change in alignment of the end loops resulting from the heat treatment was also measured.

2. MATERIAL AND SPRING DESIGN

The material selected for the investigation was a patented cold drawn carbon steel wire, of 1.22 mm diameter, produced to BS1408C Range 3. The tensile strength, as determined from a sample of the wire, was found to be 2220 N/mm^2.

Four spring designs were used having indices of 5, 7, 9.5 and 12; the actual designs were as follows:-

Spring Index	5	7	9.5	12
Wire diameter (mm)	1.22	1.22	1.22	1.22
Outside Diameter (mm)	7.32	9.76	12.81	15.86
Active Coils	20	20	15	10
Free length (mm)	36.6	41.5	41.5	41.5

3. PROCEDURE

The springs were coiled on a Torrington 115A autocoiling machine with a silver steel single coiling point, the wire being fed from a free running swift. The coiling machine was adjusted until the amount of initial tension induced in the spring was the maximum that could be obtained without damaging the wire and which kept the spring within specification. A batch of springs of each design was coiled and English-type end loops were formed on the springs with a hand looping tool.

Three springs of each design were load tested on a Coats' "Comaco" load testing machine. Readings of load and deflection of each spring under test were recorded and plotted graphically. From the load-deflection curves, values of maximum working load and initial tension load were determined. For each spring design, three load positions were chosen which were greater than the initial tension load but lower than the maximum working load. By measuring the deflection at these loads, it was possible to determine graphically the initial tension in the spring. The springs were divided into five batches of three for each spring design and the initial tension load for each spring recorded. Furthermore, one end of the spring was held in a jig and the angular relationship of the end loops was determined and recorded. Each batch of springs was subjected to a different low temperature heat treatment of 100, 150, 200, 250 and 300°C for half an hour, after which the angular relationship of the end loops was measured and the amount of angular movement caused by the L.T.H.T. was determined.

Finally, each spring was load tested beyond its elastic limit and readings of load and deflection were recorded, thus enabling the initial tension load and maximum working load to be determined.

4. RESULTS AND DISCUSSION

The values of initial tension stress are calculated from the measured values of initial tension load by means of the formula:-

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

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

No correction factor was used in calculating the induced stress and the values given are those obtained without any heat treatment of the springs, which is consistent with the practice used in previous investigations (1), (2), and (4).

In Fig. 1, the values of the initial tension stress obtained in this investigation are compared with the published data of Chironis,[2] Roberts[3] and the Society of Automotive Engineers[4]. The three lines given by Chironis bear the following legend:

CH I Avoid this initial stress, if possible.

CH II Initial stress obtained by special set-up procedure.

CH III Initial stress to be used whenever possible.

The curve in Fig. 1 is produced from the empirical formula given by two sources [2], [6]:

$$\text{Initial tension stress} = \frac{700}{D/d} \text{ N/mm}^2$$

It will be noted that the values of initial stress obtained in this investigation are consistently higher than those previously published, this being particularly noticeable in the case of springs having higher indices.

In the paper by Brown[1], the value of the initial stress is not presented in absolute terms but as a function of the tensile strength of the wire. In order to compare the results of this investigation with those of Brown, the values of initial stress determined here have also been expressed as a percentage of the tensile strength; the results are compared in Fig. 2. Although the results obtained in this investigation are some 10% lower than those obtained previously, the two sets of data confirm that very much higher values of initial stress can be obtained without undue difficulty.

Of particular interest to the spring maker is the percentage loss of initial tension that occurs upon subjecting the springs to a low temperature heat treatment. From the results shown in Fig. 3, it can be seen that the percentage loss in initial tension is independent of the spring index and that 25% of the initial tension is removed with a L.T.H.T. at 200°C and 50% at 300°C.

The low temperature heat treatment, in addition to removing some of the initial tension stress, also has the effect of raising the elastic limit of the material and, hence, the maximum working stress.

The average of the three maximum working loads was used to obtain the maximum corrected working stress in the spring, using the equation:

$$q_{max} = \frac{8PDK}{\pi d^3}$$

where c is the spring index (equal to D/d), K is the Sopwith correction factor (equal to $\frac{c+0.2}{c+1}$) and the other symbols are as before.

The effect of the stress relieving treatment can be seen in Fig. 4, in which the change in maximum corrected working stress occurring with L.T.H.T. temperature is plotted for springs of each index. As was noticed in previous work,[(5)] the maximum working stress is raised considerably by the stress relieving treatment, the optimum temperature for all spring indices being about 250°C. From Fig. 4, it can be also noted that, in the as coiled and looped condition, the lower the spring index, the higher the maximum working stress. This variation is, however, reduced by the low temperature heat treatment which reduces the residual stresses induced during coiling, as well as improving the elastic properties of the material.

The change in the angular position of the end loops, expressed in degrees per coil, is shown in Fig. 5, from which it can be observed that, for any selected heat treatment temperature, the greatest rotation occurs at the largest values of spring index. The angular position change per coil was divided by the spring index, and the resulting data have been replotted in Fig. 6, in which a straight line can be drawn through the points with a correlation of 0.97. The ordinate can now be expressed as the angular rotation per unit length of wire used in the spring.

This relationship should be useful to springmakers since it enables the angular change in position of the end loop to be calculated from the length of wire used in the spring.

5. CONCLUSIONS

1. The maximum initial tension stress expressed as a percentage of the tensile strength of the wire can be assumed, for practical purposes, to be as follows:

Spring Index	3	5	10
$\frac{\text{Initial Tension Stress}}{\text{Tensile Strength}} \times 100$	22.5%	20%	15%

2. The percentage loss in initial tension after a low temperature heat treatment was as follows:-

Temperature	100°C	200°C	250°C	300°C
Loss in Initial Tension	5%	25%	37%	50%

3. The maximum corrected working stress in the spring was increased by low temperature heat treatment and, employing the optimum temperature of 250°C, was between 47% and 52% of the tensile strength of the wire.

4. The degree of angular rotation of the end loops, due to the heat treatment, can be calculated from the length of wire used in the barrel of the springs as follows:

Temperature	100°C	200°C	250°C	300°C
Rotation (degrees per mm length of wire)	0.01	0.12	0.18	0.24

7. REFERENCES

1. BROWN, A.A.D. "Initial Tension in Springs made from Light Wire". C.S.F.R.O. Report No. 123

2. CHIRONIS, N.P. "Spring Design and Application". 1961

3. ROBERTS, J.A. "Spring Design and Calculations". 1967

4. Society of Automotive Engineers Handbook: Supplement 9: Manual on Design and Application of Helical and Spiral Springs - Standard S.A.E. J795.

5. BIRD, G.C. "The Effect of End Loops Configuration on the Static and Dynamic Properties of Tension Springs". SRA Report No. 231.

6. BERRY, W.R. "Spring Design, A Practical Treatment" 1961.

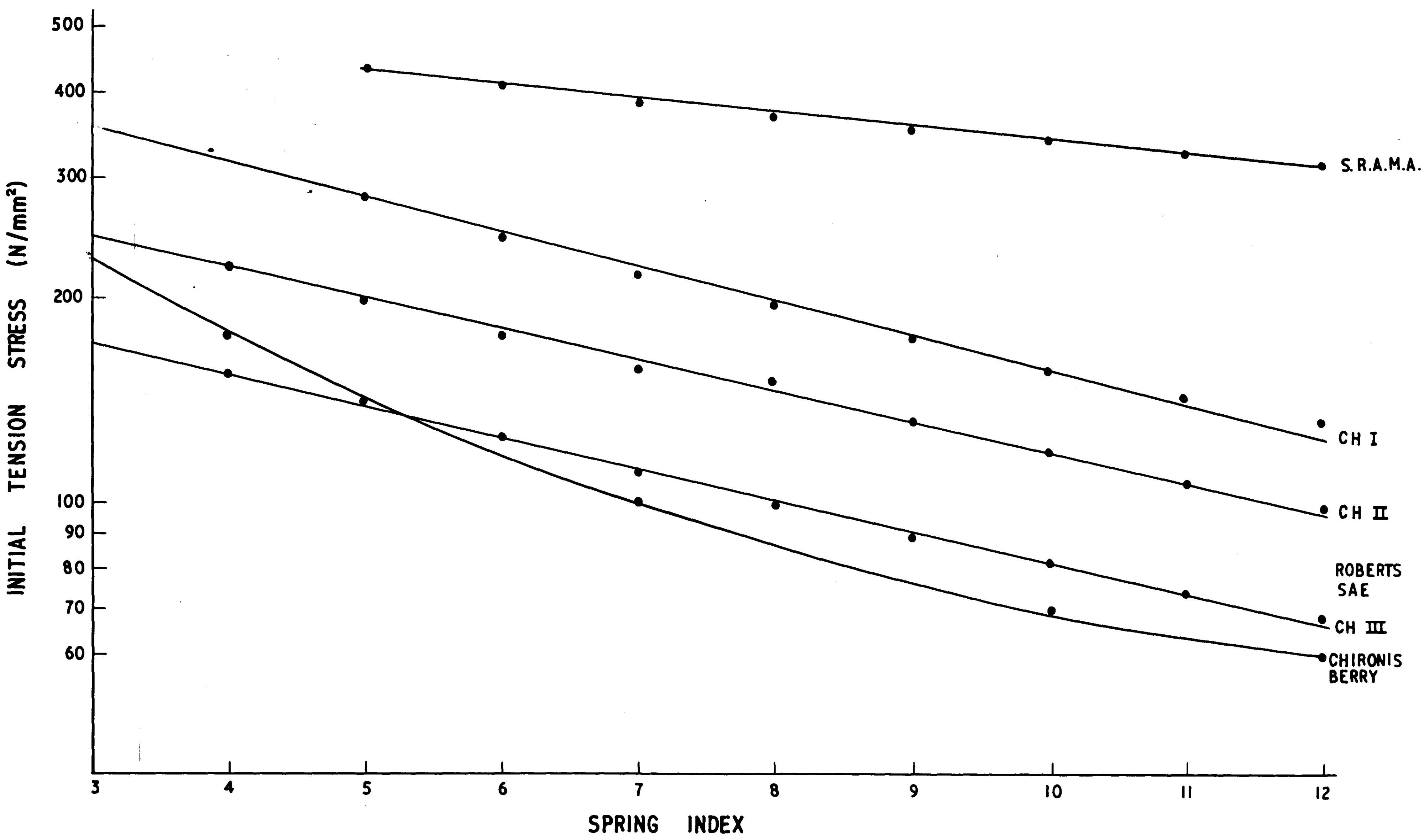

FIG. 1. EFFECT OF SPRING INDEX ON INITIAL TENSION STRESS.

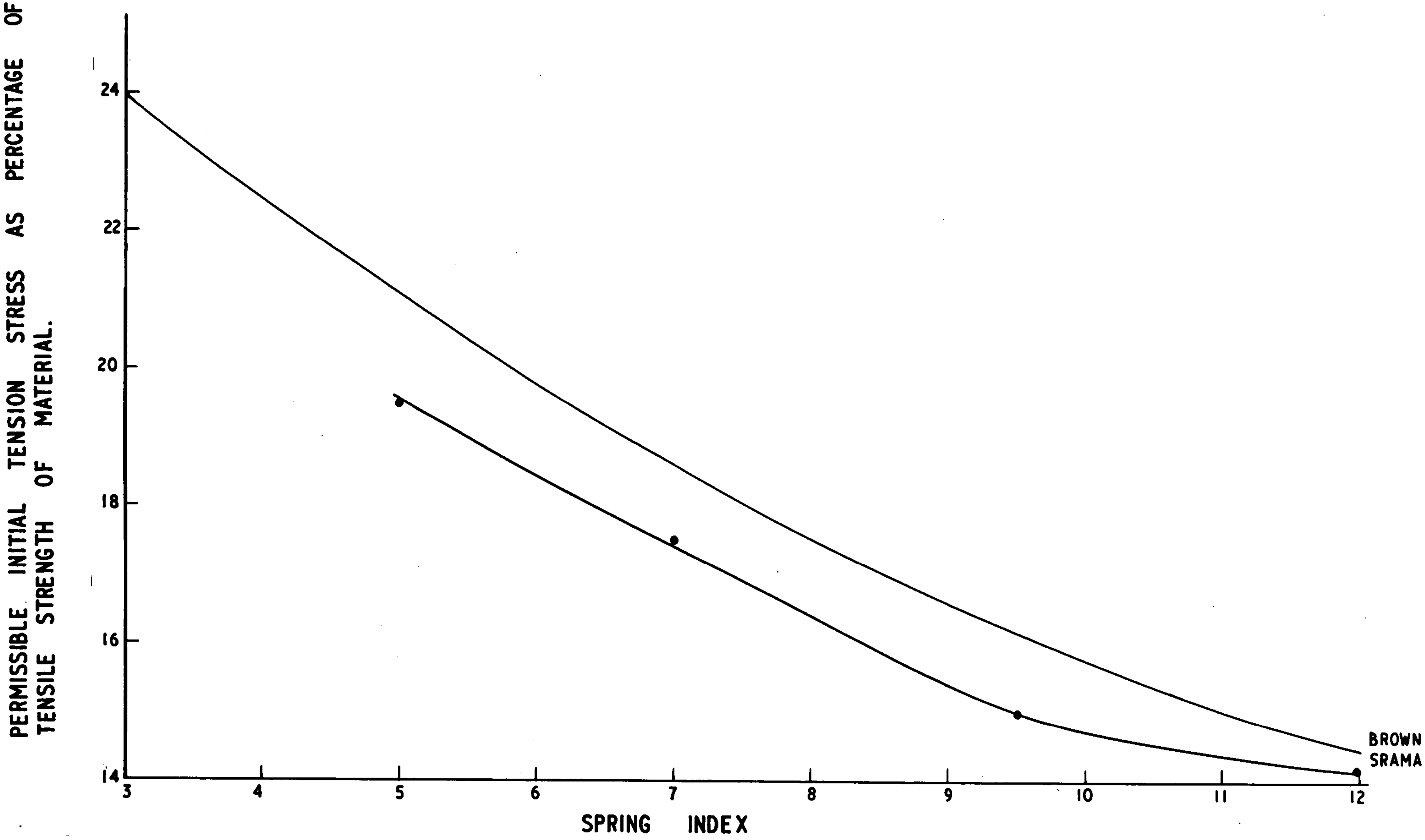

FIG. 2. EFFECT OF SPRING INDEX ON INITIAL TENSION AS A FUNCTION OF WIRE STRENGTH.

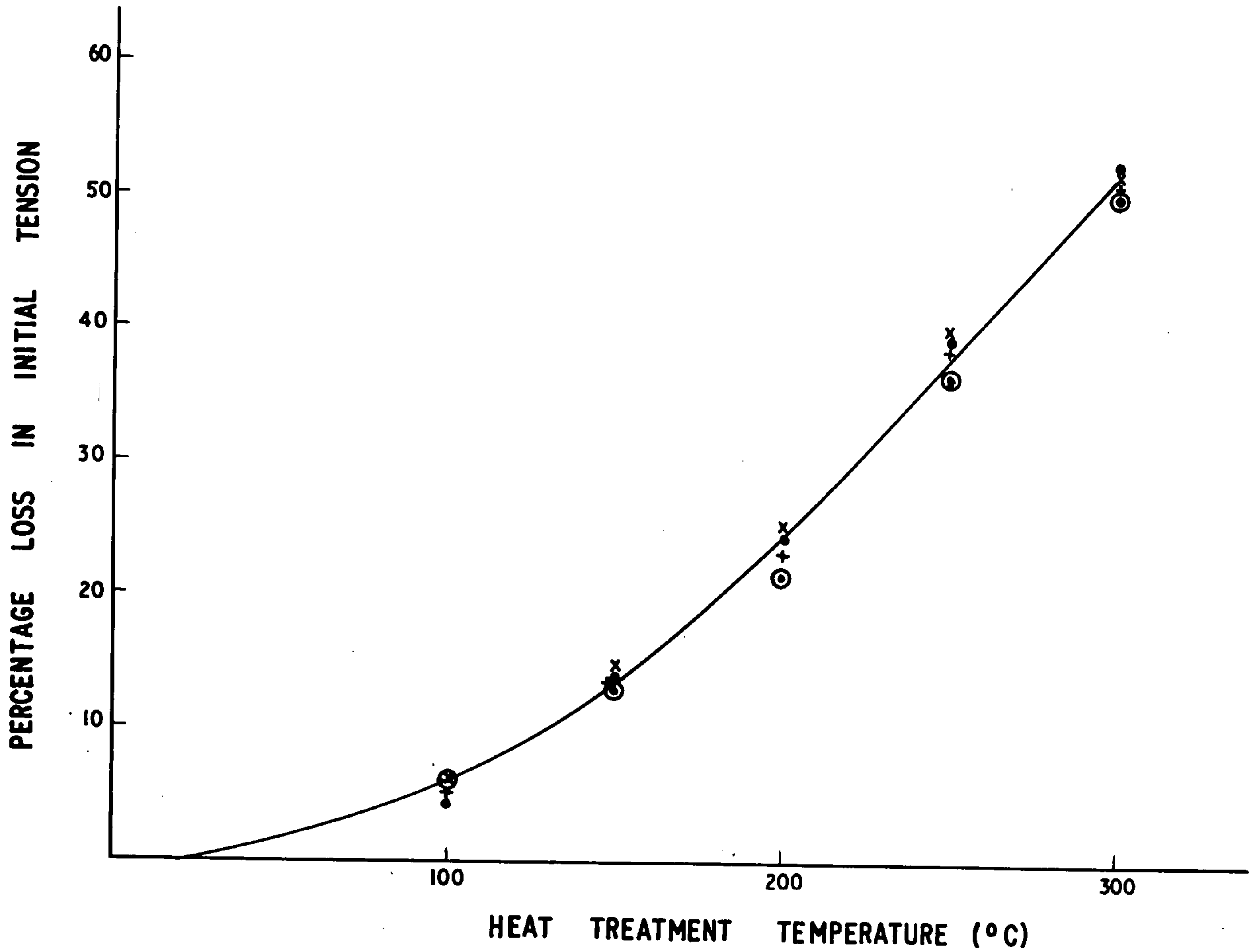

FIG. 3 EFFECT OF STRESS RELIEVING TEMPERATURE ON INITIAL TENSION.

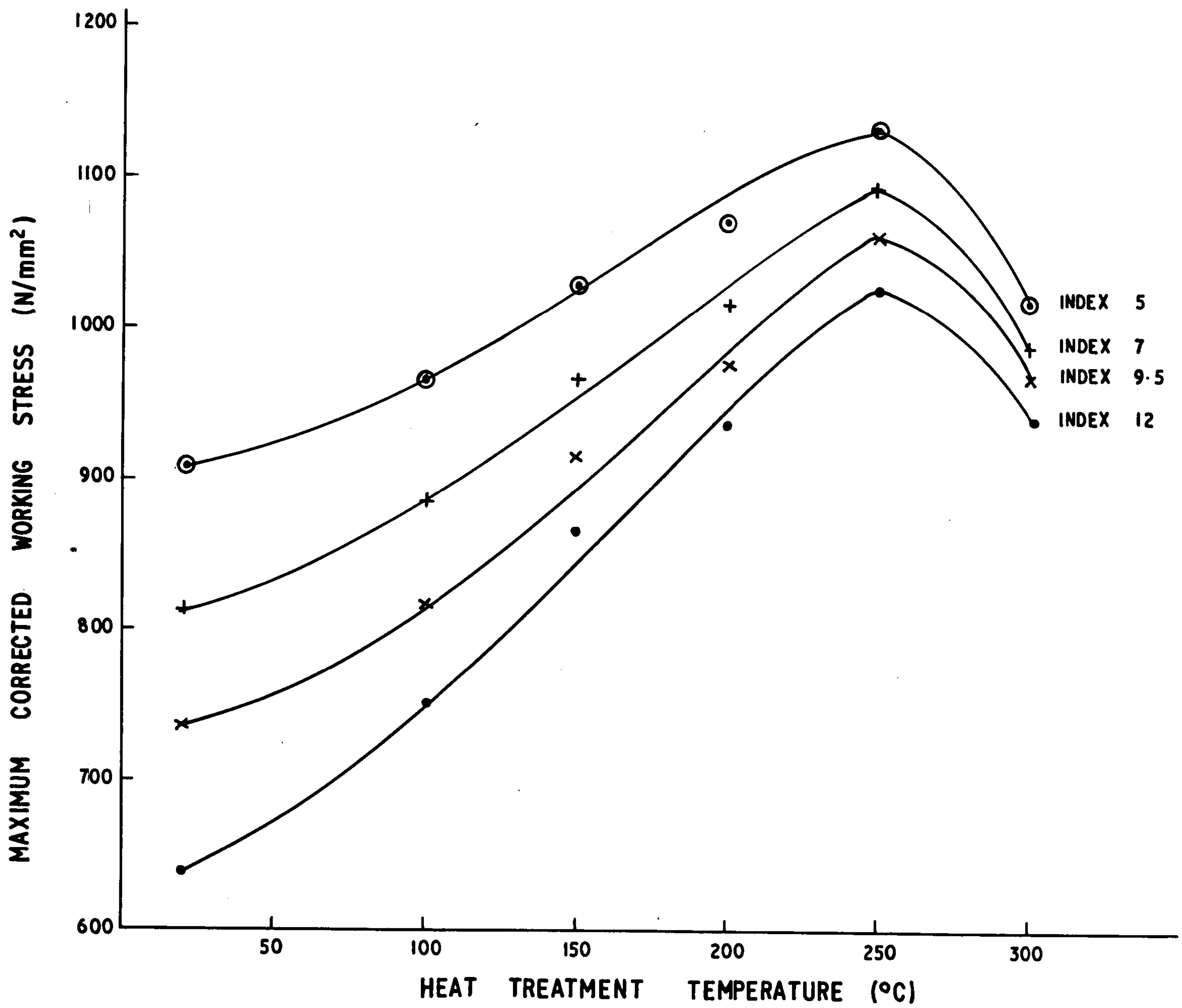

FIG. 4 EFFECT OF STRESS RELIEVING TEMPERATURE ON MAXIMUM WORKING STRESS.

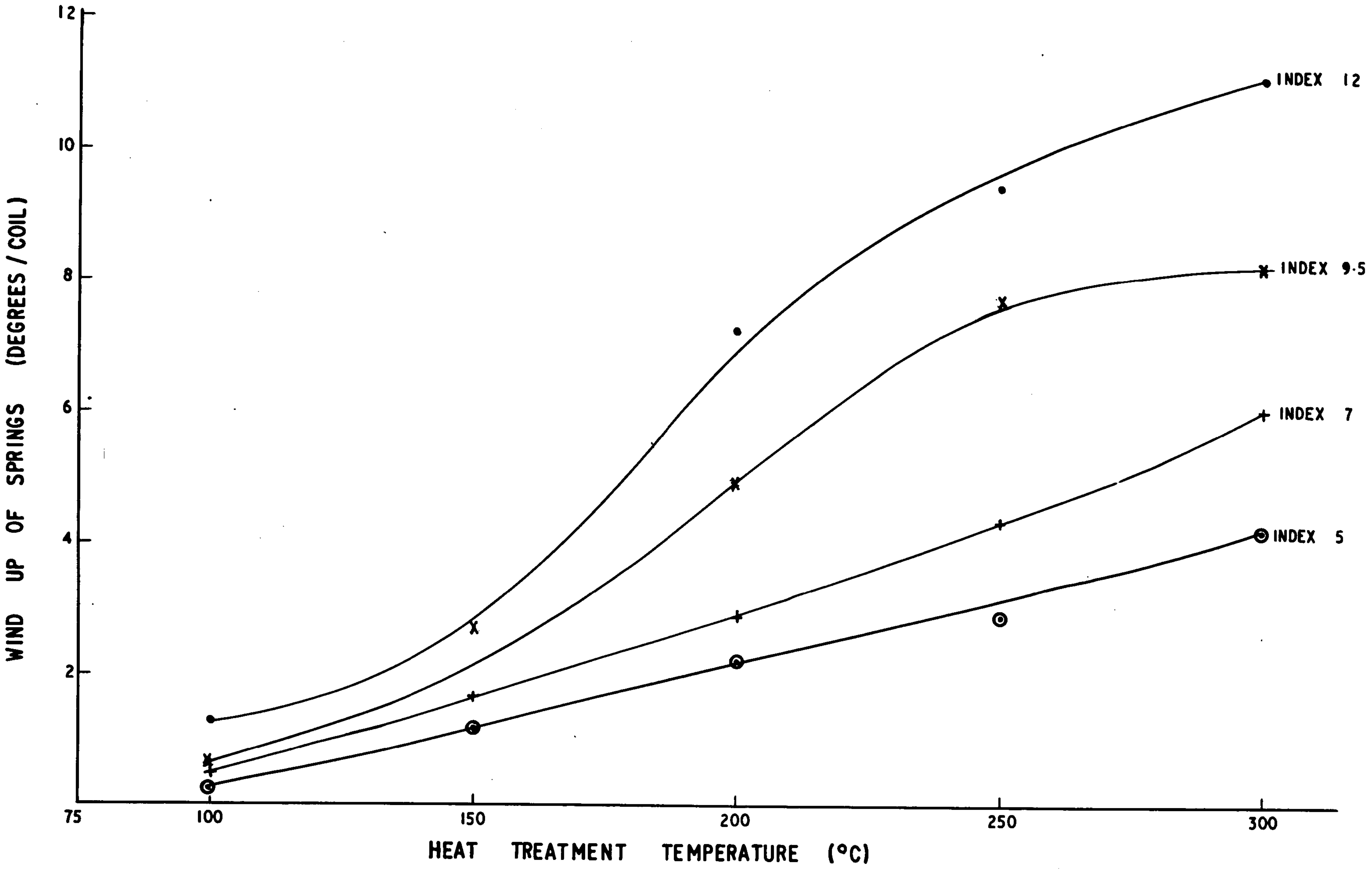

FIG. 5 EFFECT OF STRESS RELIEVING TEMPERATURE ON POSITION OF END LOOPS.

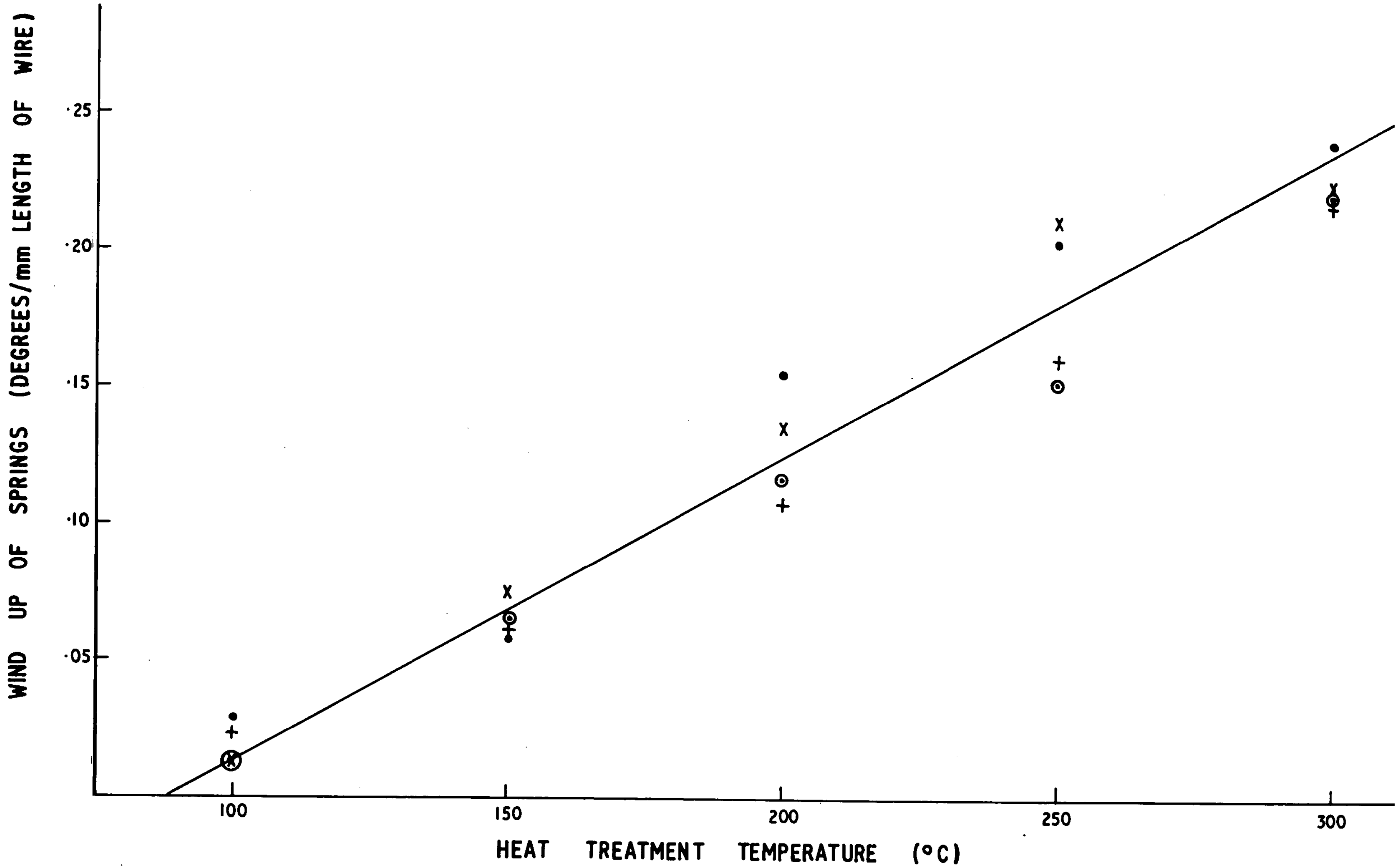

FIG. 6 WIND UP OF SPRINGS AS A FUNCTION OF LENGTH OF WIRE IN SPRING AND STRESS RELIEVING TEMPERATURE.