THE SPRING RESEARCH ASSOCIATION

AN INVESTIGATION INTO THE EFFECT OF SOLID STRESS ON THE PRESTRESSING OF COMPRESSION SPRINGS

by

G. C. Bird, B.Sc.

Report No. 208

(October 1972)

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SUMMARY

The object of the investigation was to determine the number of prestressing operations needed for practical purposes to stabilise springs made from two commonly used spring materials: BS 1408C Ranges 1 and 3, with varying solid stresses.

It was found that the number of prestressing operations needed to effectively stabilise a spring increased as the solid stress of the spring increased or as the torsional elastic limit of the wire decreased. Prestressing had little effect if the solid stress of the spring was below 50% of the Ultimate Tensile Strength. The maximum solid stress to which a spring could be coiled was found to be equivalent to approximately 80% of the U.T.S. of the wire.

To effectively stabilise a spring with a solid stress between 50% and 60% of the U.T.S. at least one prestressing operation was required. Between 60% and 70% two operations were needed, between 70% and 75% three were needed and above 75% at least five operations were required.

The work described was undertaken by The Spring Research Association under contract to BUD International, a division of the British United Shoe Machinery Company Ltd., who have now given their agreement to general release of this information. The SRA wish to thank BUD International for providing financial and other assistance for this work.

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1. INTRODUCTION

The prestressing or scragging operation is used on compression springs to obtain greater load carrying capacity by improving the stress distribution. The operation (Fig. 1) consists of coiling the spring to a length greater than the free length desired and compressing the spring to solid, beyond the elastic limit, causing a reduction in the free length of the spring. Repetition of the operation causes a reducing amount of further set in the spring until no further reduction in length is achieved by additional prestressing operations.

The purpose of this investigation is to determine the number of prestressing operations needed for practical purposes to stabilise springs made from two commonly used spring materials and with varying solid stresses.

2. SPRING DESIGN

The two materials chosen for the investigation were BS 1408C Range 1 and Range 3. Owing to the difficulty in obtaining Range 1 wire, wire of diameter 0.156 in had to be used instead of the 4 mm (0.158 in) diameter of the Range 3 wire. The four spring designs used each had the same number of coils (11.0) and had solid stresses of 600 N/mm^2, 800 N/mm^2, 1000 N/mm^2 and 1200 N/mm^2. The spring ends were closed but not ground and the springs received a low temperature heat treatment of $280^{o}C$ for $\frac{1}{2}$ hour after coiling. Details of the spring designs are shown in Table I.

3. PROCEDURE

The free length of each spring before prestressing was measured with the spring in a 'V' guide between two brass rollers, one of which was adjusted by a micrometer spindle until contact between the rollers and the spring ends caused a resistance meter to show full-scale deflection. At this point the micrometer reading was taken (see Research Report No. 188).

The springs were then closed to solid and released by a prestressing machine produced by B.U.D. International. This machine held the spring horizontally between two 'V' guides while the coils were compressed by two pneumatically operated arms. The arms were free to pivot about a vertical axis to allow the shape of the unground ends to be accommodated.

After a spring had been scragged once it was removed from the machine and its free length measured. This was repeated until the free length after two successive scrags was the same, and for each design ten springs were scragged and measured.

4. RESULTS

For each design the average free lengths of the springs are plotted in terms of solid stress against the number of scrags. The results from the four designs of spring for each material are plotted in Figs. 2 and 3 for Range 1 and Range 3 wire respectively.

In practice, however, it would not be necessary to stabilise a spring fully, but merely to eliminate the greatest part of the set which is likely to take place. For practical purposes therefore, a spring can be considered to be satisfactorily scragged when further scragging will not reduce the free length by more than 50% of the free length tolerance given in BS 1726. This figure can be related to stress and using Figures 2 and 3 a decision can be made as to when each spring has been sufficiently scragged. From these results a graph (Fig. 4) can be drawn, showing the number of scrags needed for a spring of any given solid stress.

Fig. 5 shows the theoretical stress to which a spring needs to be coiled to produce a desired solid stress after prestressing.

To enable the graphs in Figs. 4 and 5 to be used for other materials and wire diameters the solid stress can be expressed as a percentage of the Ultimate Tensile Strength (U.T.S.) of the wire, this being the most easily measurable quality of the material. In Fig. 6 the stresses after coiling and after prestressing are expressed as a percentage of the U.T.S. of the material and in Fig. 7 the number of prestressing operations needed is plotted against the solid stress as a percentage of U.T.S.

On each material two tensile and two torsion tests were performed, the data obtained being shown in Table II, and the torsional stress-strain curves for both materials in Fig. 7.

After the springs had been fully prestressed they were left and the free lengths measured at intervals from five minutes to one week. Recovery was only noticed on the two highest stressed designs from Range 1 wire and on the highest stressed design from Range 3 wire. It was found that where there was recovery it was of the order of 0.005 in in the free length in the first five or ten minutes and that further recovery was negligible.

5. DISCUSSION OF RESULTS

By reference to Figs. 2 and 3 it will be seen that the first prestressing operation accounts for about 85% of the total set and that the set after each subsequent prestressing decreases until further set is negligible.

It is noticeable that the number of scrags to fully stabilise the spring is greatly in excess of the number required to stabilise it for practical considerations, in some cases being ten times as great. For Range 1 wire the number of scrags considered sufficient changes from none with a solid stress of 670 N/mm^2 to seven with a solid stress of 1050 N/mm^2. For wire to Range 3 no scrags are needed with a solid stress below 850 N/mm^2 and only three scrags with a solid stress of 1340 N/mm^2.

If it is necessary to keep the number of prestressing operations below three then the solid stress in the spring should not be greater than 960 N/mm^2 (74.5% U.T.S) for Range 1 wire and 1280 N/mm^2 (71.5% U.T.S.) for Range 3 wire.

If, in order to obtain the desired solid stress, a spring needs to be coiled much longer than the final length, the danger occurs of the spring buckling during the first prestressing. The criterion of buckling is the slenderness ratio of free length/mean coil diameter of the spring, and a spring will not buckle however great the deflection if the ratio is less than 5.3 for a spring with both ends fixed, as is normally the case in load testing, or 2.65 with both ends pivoted. This means that for the spring design used, springs with a free length greater than 5 in would have a tendency to buckle during the first scrag, but as the springs were laterally guided in the B.U.D. machine used the possibility of buckling was eliminated.

There is a limit to the solid stress which a spring can be made to withstand as will be seen in Fig. 5. For Range 1 wire this occurs at a stress of 1050 N/mm^2 (81% U.T.S.), and for Range 3 wire at a stress of 1350 N/mm^2 (76% U.T.S.). This represents the maximum solid stress irrespective of buckling considerations or the number of scrags needed to stabilise the spring. Below a solid stress equal to the torsional elastic limit there should be no setting of the spring during scragging.

as the stresses in the spring are wholly within the elastic range. From the torsional stress-strain curves in Fig. 7 the values for this point are 530 N/mm^2 and 700 N/mm^2 for Range 1 and 3 wires respectively. When compared with curves in Fig. 5 it will be seen that they are tangential to the diagonal line, representing no set at these points.

When the curves of Figs. 4 and 5 are replotted expressing the solid stress as a percentage of the U.T.S., as in Figs. 6 and 7, the difference between the two ranges is greatly reduced so that single curves can be drawn through all the points. Two factors will be noted. One, that with a solid stress below 50% of the U.T.S. prestressing has no effect, secondly that the maximum solid stress that a spring can be designed to is approximately 80% of the U.T.S. of the wire.

6. CONCLUSIONS

(i) The number of prestressing operations needed to stabilise a spring increases as the solid stress of the spring increases.

(ii) The lower the torsional elastic limit of the wire, the greater is the number of prestressing operations required to stabilise a spring of a given solid stress.

(iii) There is a solid stress above which springs cannot be made to stand. This depends on the strength of the wire and is approximately equal to 80% of the Ultimate Tensile Strength.

(iv) Prestressing has little effect if the solid stress of the spring is less than 50% of the Ultimate Tensile Strength.

(v) Springs must be guided to prevent buckling when they are prestressed if the ratio free length/mean coil diameter is greater than 2.65 for pivoted end fittings and 5.3 for fixed end fittings.

(vi) The minimum numbers of prestressing operations required for compression springs made from material to BS 1408 are as follows:-

Solid Stress (% U.T.S.)	Minimum number of scrags required
below 50	0
50 - 62	1
63 - 69	2
70 - 73	3
74 - 78	5

7. ACKNOWLEDGEMENT

The work described was undertaken by The Spring Research Association under contract to BUD International, a division of the British United Shoe Machinery Company Ltd., who have now given their agreement to general release of this information. The SRA wish to thank BUD International for providing financial and other assistance for this work.

TABLE I

SPRING DESIGN

BS 1408C Range 1

	A	B	C	D
Wire diameter (d)	3.96 mm 0.156 in	3.96 mm 0.156 in	3.96 mm 0.156 in	3.96 mm 0.156 in
Mean coil diameter (D)	24.4 mm 0.960 in	24.4 mm 0.960 in	24.4 mm 0.960 in	24.4 mm 0.960 in
Spring index (c)	6.15	6.15	6.15	6.15
Total no. of coils (N)	11.00	11.00	11.00	11.00
No. of active coils (n)	9.00	9.00	9.00	9.00
Free length after prestressing	73.7 mm 2.90 in	82.3 mm 3.24 in	90.9 mm 3.58 in	99.6 mm 3.92 in
Solid stress after prestressing	(600 N/mm^2 87 000 lbf/in^2	800 N/mm^2 116 000 lbf/in^2	1000 N/mm^2 145 000 lbf/in^2	1200 N/mm^2 174 000 lbf/in^2
Tolerance on free length (to BS 1726)	±1.07 mm ±0.042 in	±1.19 mm ±0.047 in	±1.30 mm ±0.051 in	±1.40 mm ±0.055 in

BS 1408C Range 3

	E	F	G	H
Wire diameter (d)	4.0 mm 0.158 in	4.0 mm 0.158 in	4.0 mm 0.158 in	4.0 mm 0.158 in
Mean coil diameter (D)	24.0 mm 0.954 in	24.0 mm 0.954 in	24.0 mm 0.954 in	24.0 mm 0.954 in
Spring index (c)	6.00	6.00	6.00	6.00
Total no. of coils (N)	11.00	11.00	11.00	11.00
No. of active coils (n)	9.00	9.00	9.00	9.00
Free length after prestressing	73.2 mm 2.88 in	81.3 mm 3.20 in	89.7 mm 3.53 in	98.0 mm 3.86 in
Solid stress after prestressing	(600 N/mm^2 (87 000 lbf/in^2	800 N/mm^2 116 000 lbf/in^2	1000 N/mm^2 145 000 lbf/in^2	1200 N/mm^2 174 000 lbf/in^2
Tolerance on free length (to BS 1726)	±1.07 mm ±0.042 in	±1.17 mm ±0.046 in	±1.27 mm ±0.050 in	±1.37mm ±0.054 in

TABLE II MECHANICAL PROPERTIES OF WIRE

	RANGE 1	RANGE 3
Wire Diameter (mm)	3.96	4.0
Tensile Properties		
Ultimate Tensile Strength (N/mm^2)	1289	1792
0.1% Proof Stress (N/mm^2)	900	1574
0.2% Proof Stress (N/mm^2)	960	1637
0.5% Proof Stress (N/mm^2)	1036	1700
Elongation	9%	8%
Torsional Properties		
Max. Shear Strength (N/mm^2)	864	1362
0.1% Proof Stress (N/mm^2)	659	1028
0.2% Proof Stress (N/mm^2)	704	1095
0.5% Proof Stress (N/mm^2)	760	-
Twists to Failure	49	28

The figures given above are the mean of two determinations

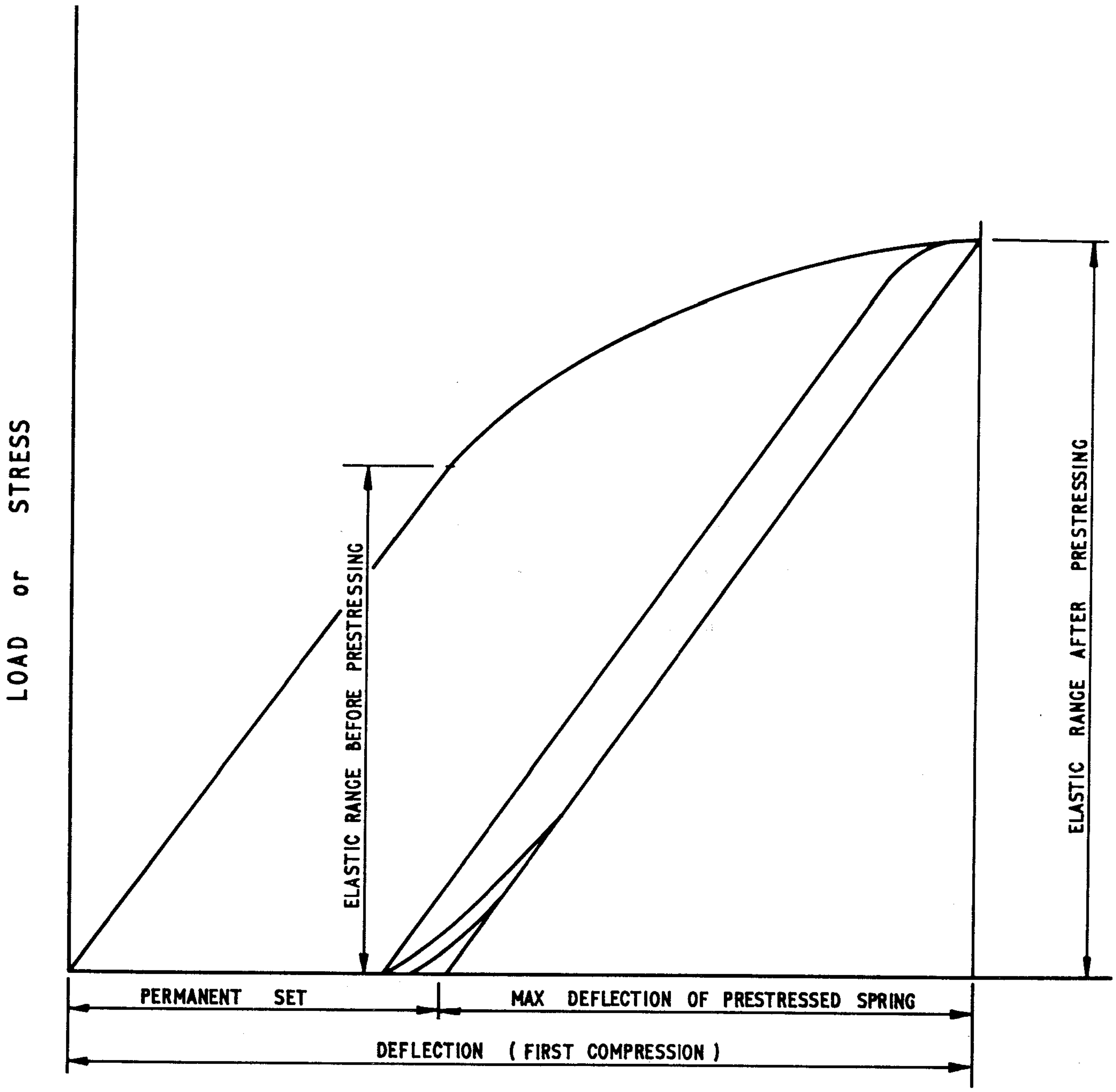

FIG. 1. PRESTRESSING OF A HELICAL SPRING

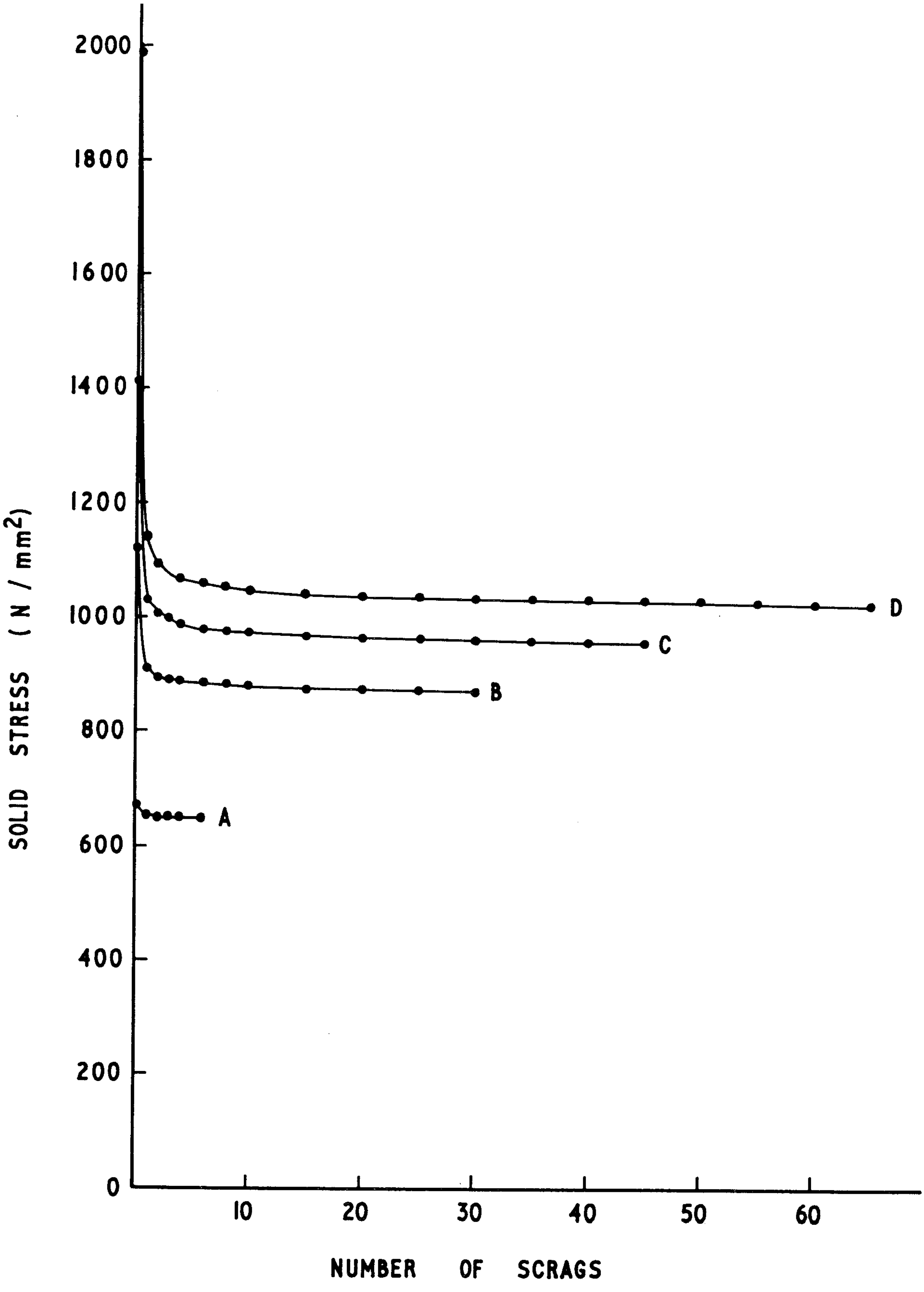

FIG. 2. REDUCTION IN SOLID STRESS OF RANGE I. SPRINGS DURING PRESTRESSING

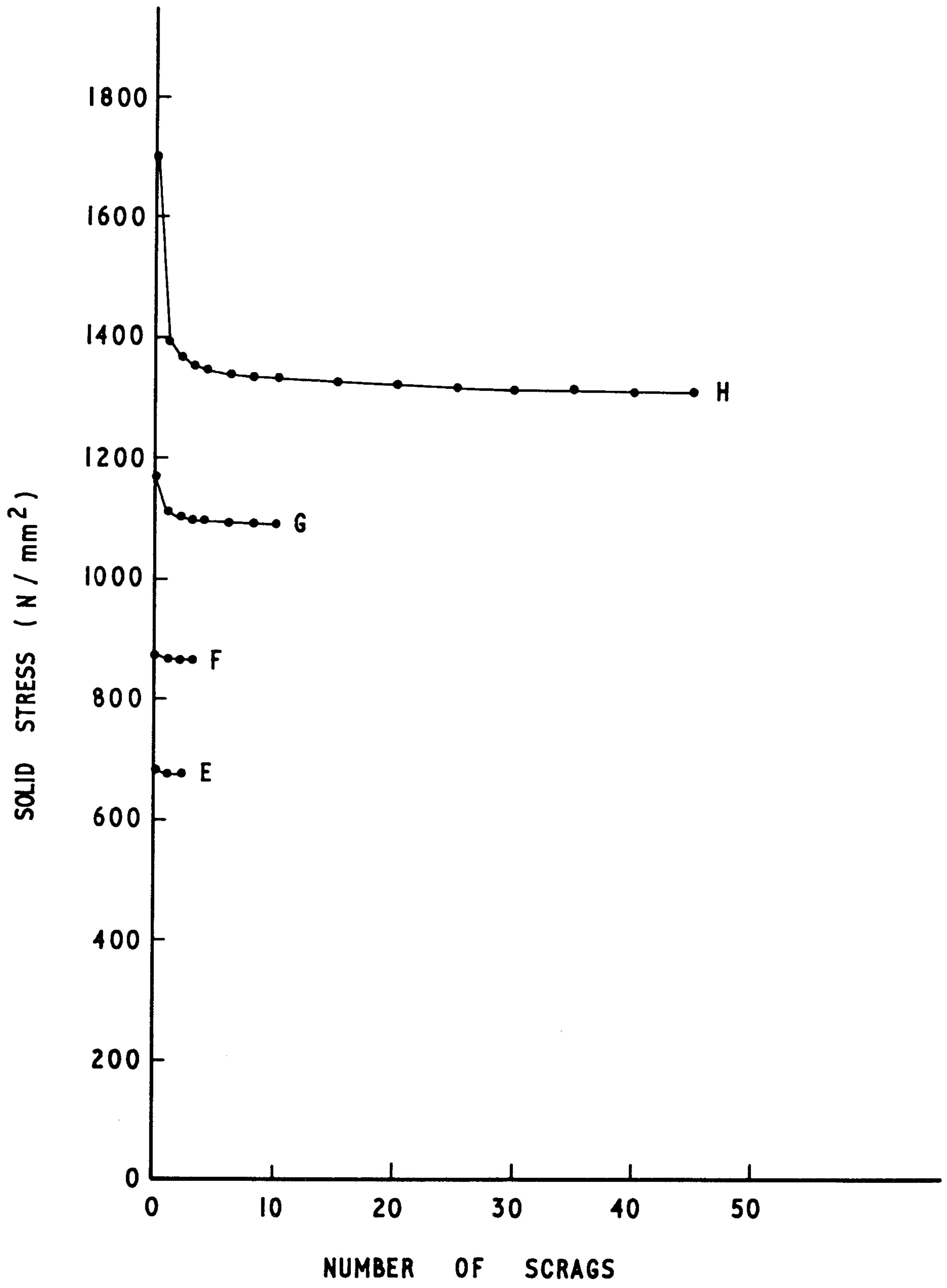

FIG. 3. REDUCTION IN SOLID STRESS OF RANGE 3 SPRINGS DURING PRESTRESSING

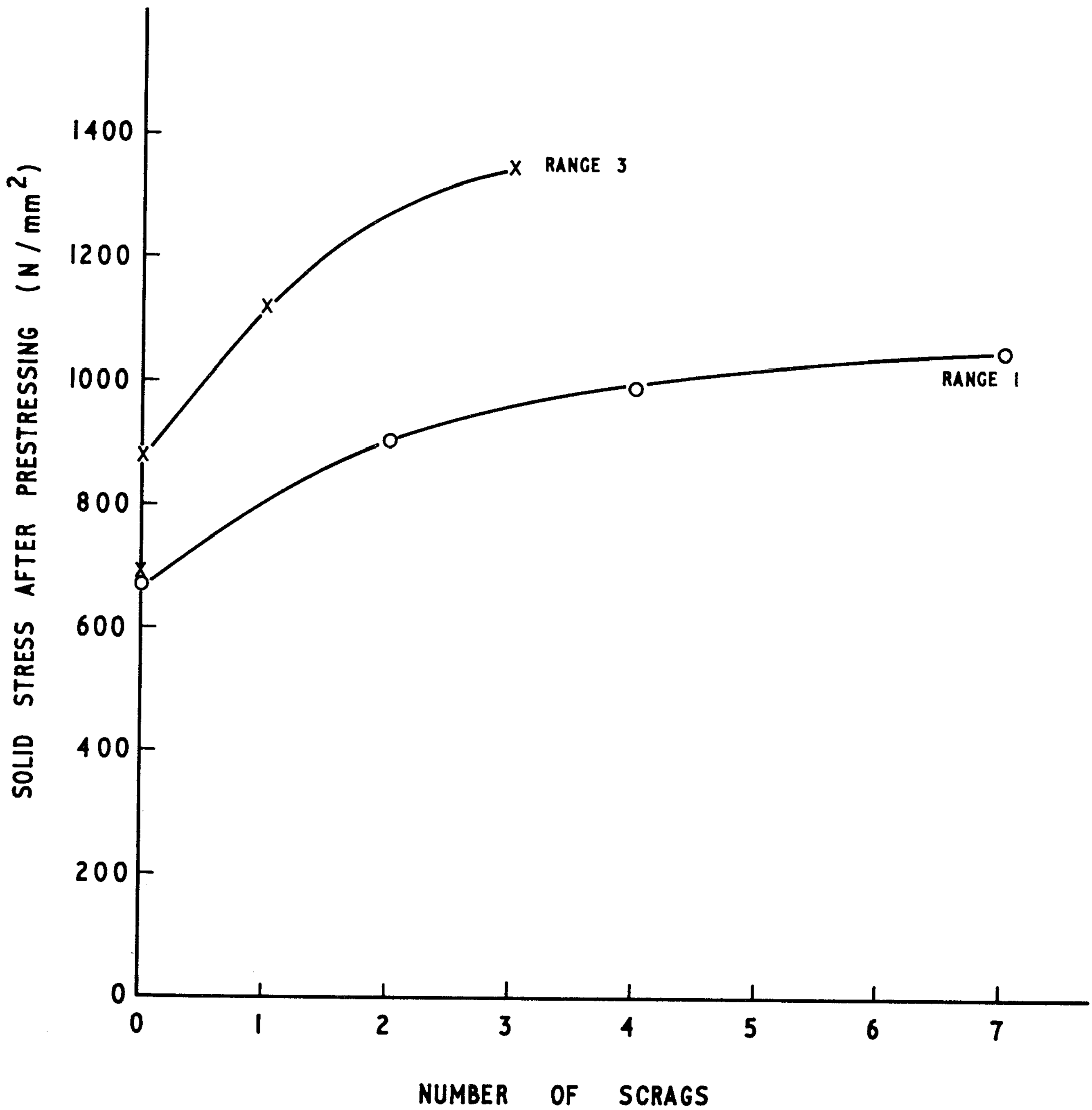

FIG. 4. NUMBER OF PRESTRESSING OPERATIONS NEEDED TO EFFECTIVELY STABILISE SPRINGS

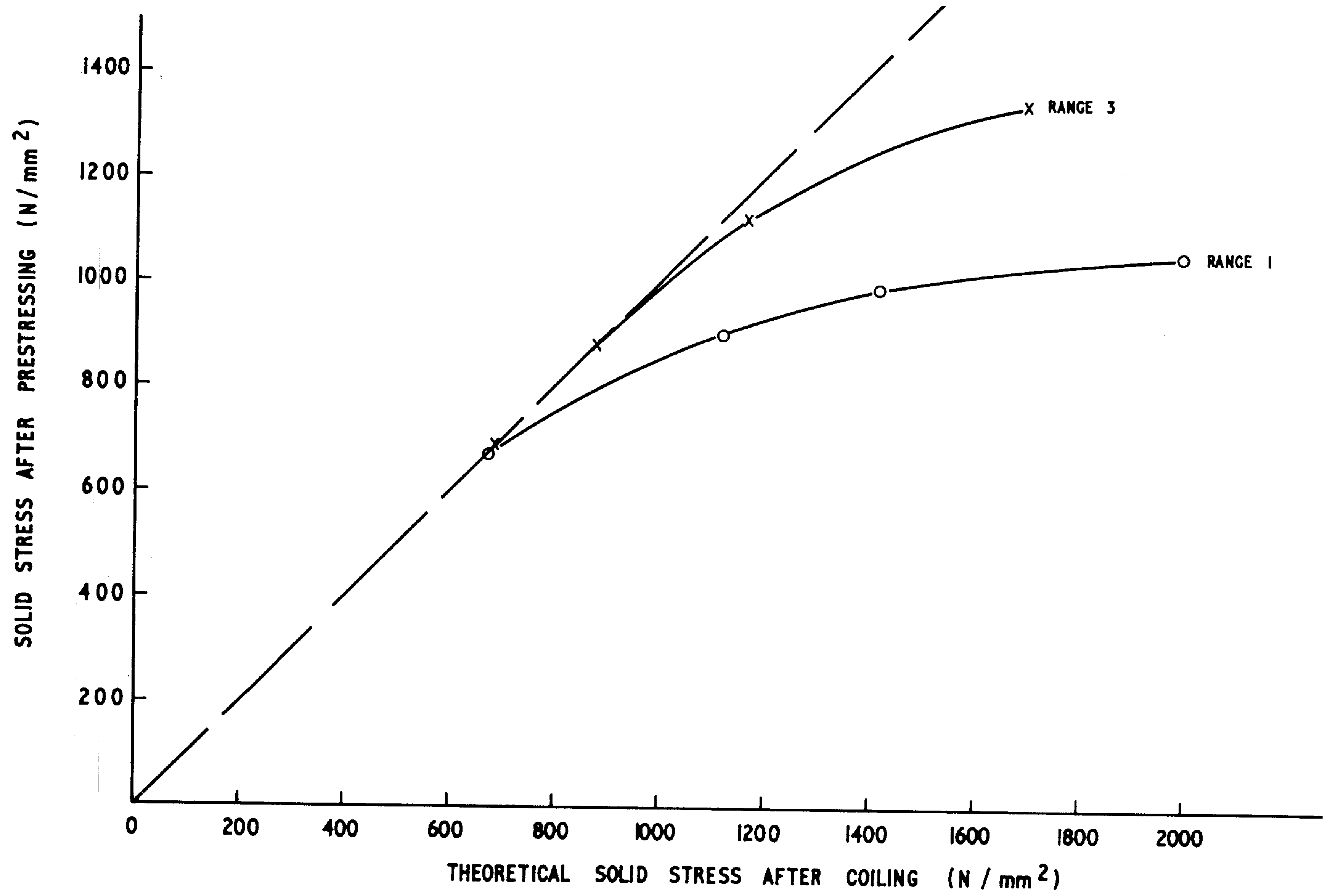

FIG. 5. STRESS REQUIRED ON COILING TO PRODUCE DESIRED SOLID STRESS AFTER PRESTRESSING

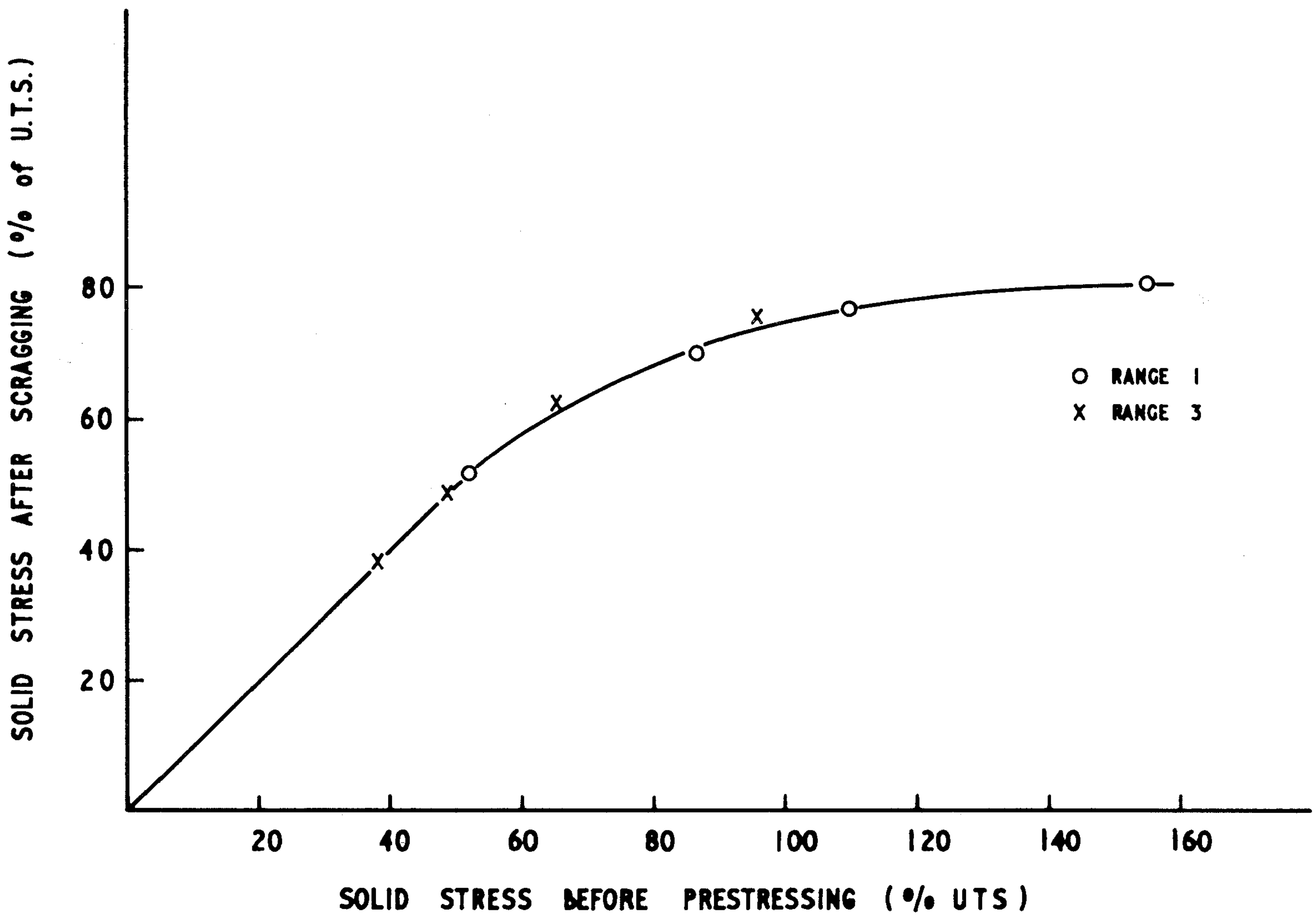

FIG. 6. STRESS BEFORE AND AFTER PRESTRESSING AS PERCENTAGE OF U.T.S.

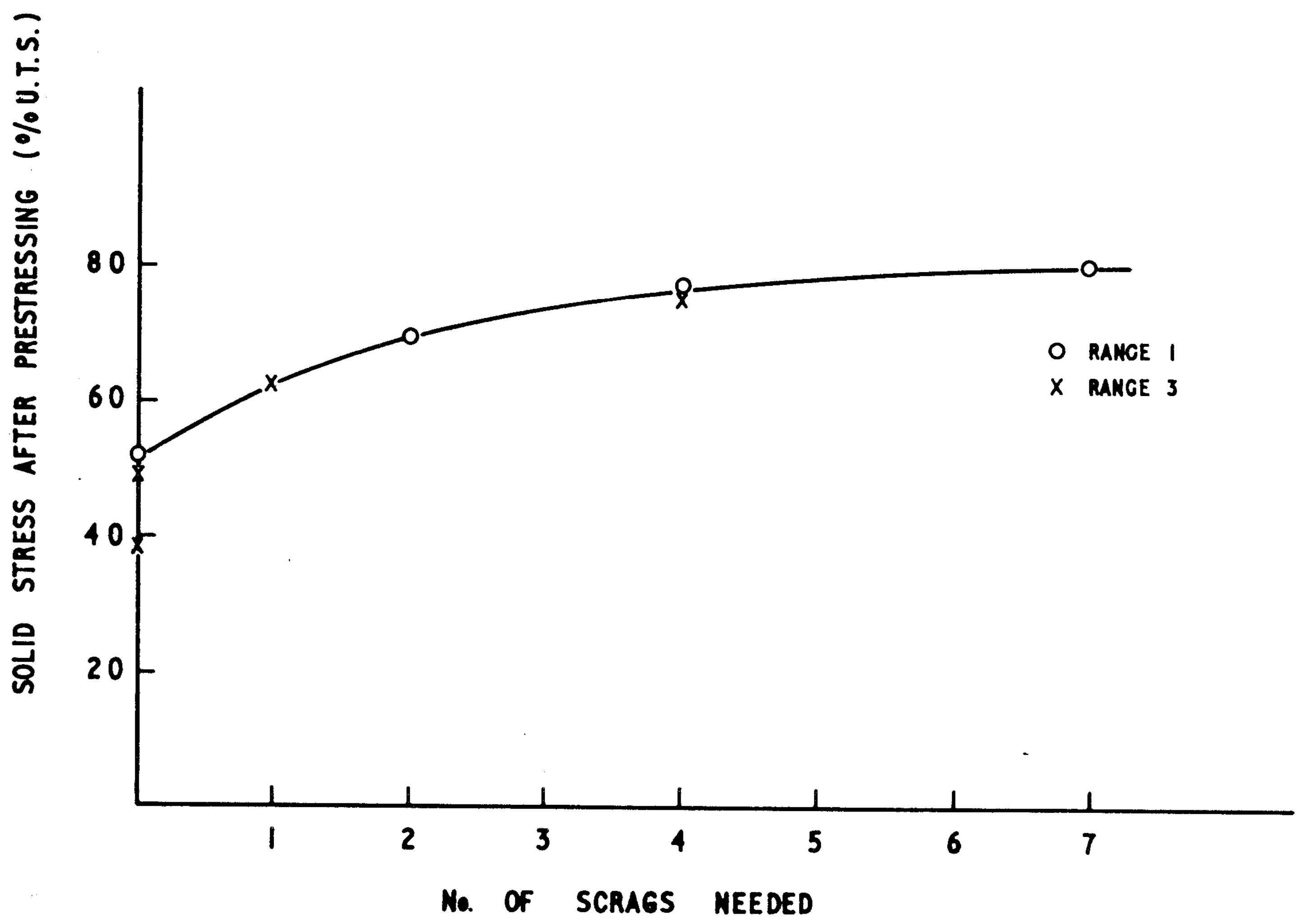

FIG. 7. NUMBER OF PRESTRESSING OPERATIONS REQUIRED FOR DESIRED SOLID STRESS AS PERCENTAGE OF U.T.S.

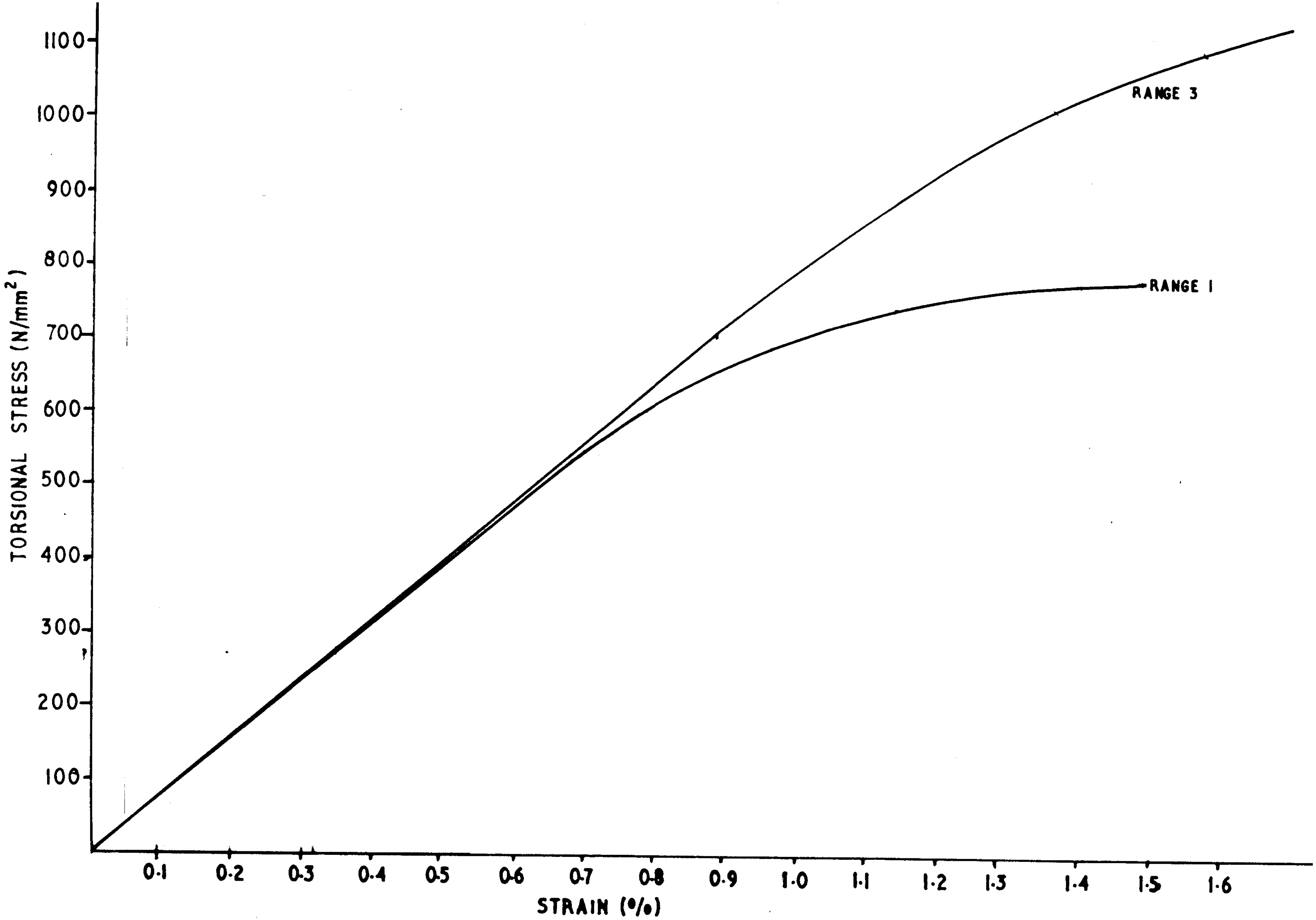

FIG. 8 TORSIONAL STRESS-STRAIN CURVES FOR RANGE 1 AND RANGE 3 WIRE