THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE EFFECT OF VARYING HARDNESS LEVELS ON THE FATIGUE AND RELAXATION PROPERTIES OF SPRINGS COILED FROM OIL HARDENED AND TEMPERED WIRE

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SUMMARY AND CONCLUSIONS

To determine what effect the tensile strength has on the properties of oil hardened and tempered wire, fatigue tests at a single level of initial stress have been carried out on springs coiled from wire manufactured to BS 2803, heat treated to tensile strengths both above and below the specified range. The springs were also tested for stress relaxation resistance at three stress levels at an operating temperature of 75°C.

This work indicated that an increase in tensile strength above the present BS 2803 range would be beneficial to the fatigue performance of the springs but would have an adverse effect on the relaxation resistance. A limited amount of work has also been done on the formability of wires hardened to the various strength levels.

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CONTENTS

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1. INTRODUCTION

There seems to be less agreement between the various national specifications on the tensile strength levels for pre-hardened and tempered carbon steel spring wire than might be expected. The purpose of this work has therefore been to examine the effect of tensile strength on the fatigue and relaxation properties of springs coiled from such wire. The present tensile strength ranges for a number of national spring wire specifications can be seen in Fig. 1.

As it proved im⁻ossible in practice to obtain wire of one size to the same specification spanning the range of tensile strengths shown in Fig. 1, special methods of heat treatment had to be developed in order to preserve the surface quality associated with continuously hardened and tempered wire but at the same time allowing flexibility in the process to produce material of different tensile strength levels.

A quantity of 3.7 mm diameter wire similar to BS 2803 Grade 2 but having a tensile strength above the specified range was obtained. The properties of this wire are given in Table I.

TABLE I CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF EXPERIMENTAL WIRE

	Size mm	C	Si	Mn	S	P	UTS N/mm^2	0.1% PS N/mm^2	Hardness HV
BS 2803	-	.55/ .75	.30 max	.60/ .90	.040 max	.040 max	1544/ 1698	-	
Exp.Wire	3.17	.67	.23	.85	.011	.007	1820	1618	570-580

A total of two hundred and six springs were coiled to the design given in Table II.

TABLE II SPRING DESIGN

Wire Dia mm	3.17
Mean Coil Dia mm	23.49
Active Coils	3.5
Total Coils	5.5
Spring Index	7.4

After coiling, the springs were given an appropriate heat treatment to produce hardnesses of 375, 440, 570 and 670 HV. They were then end ground and prestressed. The free length after prestressing decreased with decreasing hardness, ranging from 49 mm to 38 mm, which in turn gave solid stresses of 1570 N/mm^2 to 1030 N/mm^2.

2. EXPERIMENTAL PROCEDURE

2.1 Heat Treatment

Initial heat treatment trials using an electric muffle furnace and springs made from BS 2803 wire proved unsatisfactory, even though small blocks of carbon placed within the furnace were used to restrict scaling and decarburisation.

It was therefore necessary to develop a controlled atmosphere heat treatment method which would preserve the surface of the mill hardened and tempered wire and not produce decarburisation.

A small tube furnace was modified for use with an inert dry nitrogen atmosphere, this method allowed springs to be re-hardened without deterioration of the wire surface. These springs were then tempered in an air circulating furnace. This method was adopted for the heat treatment of all subsequent springs.

It was originally hoped that it would be possible to temper springs coiled from the high tensile wire to lower strength levels, leaving a relatively small number of springs to be re-hardened. Eight springs were therefore re-hardened and tempered to their initial hardness of 570-580 HV and eight springs produced from the pre-hardened and tempered wire (of similar hardness) were given a low temperature heat treatment at 350°C. These springs were then fatigue tested in pairs, each pair at the same stress, and the results analysed statistically to detect any significant difference in fatigue performance. It was found that the fatigue results for the re-heat treated springs were significantly better than the results obtained for springs given just an LTHT. The significance of these results will be discussed later. In view of these results it was necessary to re-harden all the springs required for the planned fatigue and relaxation testing using an inert nitrogen atmosphere, in order to allow valid comparisons to be made between the various hardness levels and the fatigue and relaxation properties.

Batches of springs were therefore re-hardened and tempered at temperatures of 245°C, 350°C, 440°C and 525°C, to give hardness values of 670, 570, 440 and 375 HV20 respectively.

2.2 Fatigue Testing

All the fatigue testing was carried out on unpeened springs. Springs for fatigue testing were individually load tested to determine the deflection necessary to produce the required stresses in the springs. Fatigue tests were then carried out using a multiple stage forced motion fatigue testing machine. Springs at each strength level were tested at 100 N/mm^2 initial stress to produce S/N curves. The same maximum stress levels were used in each case, to facilitate statistical comparison of results, should this prove necessary. Results are given in Table III and the S/N curves produced are shown in Figs. 2 and 3.

2.3 Relaxation Testing

Relaxation tests were limited by the number of springs available to a single temperature of 75°C. The normal SRAMA method of constant deflection relaxation testing using stainless steel bolts was employed at stress levels of 1000, 800 and 600 N/mm^2.

The springs heat treated to the lowest hardness level set down a considerable amount on prestressing and therefore could not be tested at 1000 N/mm^2 due to the solid stress limitations. The results of the relaxation tests are shown in Table IV and Fig 5.

2.4 Formability Tests

Reverse bend and torsional tests were performed on wires which had been hardened and tempered to the various strength levels and the results of these tests are shown in Table V.

3. DISCUSSION

3.1 Fatigue Results

It has already been mentioned that re-hardening and tempering springs coiled from pre-hardened and tempered wire resulted in an unexpected increase in fatigue life resistance.

The most probable reason for this apparently anomalous result is that the LTHT at 350°C had not completely removed the detrimental coiling stresses in the springs. These stresses would however be completely removed by the phase changes involved in re-hardening the springs.

The choice of 350°C was based on industrial practice and has been widely quoted in SRAMA literature as the recommended heat treatment after coiling. Such a treatment has also been employed in previous investigations[1]. From the results of the heat treatment experiments it will be seen that a treatment at 350°C would be very similar to the tempering conditions required to produce hardened and tempered wire springs to the strength level obtained from the pre-hardened and tempered wire used for this research. No systematic work has previously been undertaken by the Association on springs manufactured from BS 2803 to determine the effects of low temperature heat treatment after coiling on the resultant fatigue resistance, and it is suggested that such a topic could be a worthwhile subject for future research.

Since all the springs used in this investigation were heat treated after coiling to the various strength levels required it is considered that the experimental results obtained are consistent within themselves and therefore give an indication of the influence of the tensile strength on the fatigue and relaxation properties of carbon steel springs.

For the wire size under investigation (3.17 mm), the existing BS 2803 specification calls for a tensile strength of 1540-1695 N/mm^2, which equates to a hardness range of 470-512 HV. Reference to Fig. I, which shows the tensile strength ranges for other major national specifications, indicates that for 3.17 mm wire, an exceptionally wide range of strength levels from 1430 to 1870 N/mm^2 is embraced. In terms of hardness this would be approximately 440-570 HV. The results of fatigue tests at each hardness level are shown in Figs 2 and 3, and as would be expected fatigue life increased with increasing strength up to an optimum strength, above which the fatigue life of the springs diminished. It can be seen more clearly in Fig. 4 (which is drawn from figs 2 and 3) that a peak in fatigue performance exists. Springs heat treated to 570 HV clearly had the best fatigue performance of the springs tested. Unfortunately the limited quantity of wire available did not allow sufficient intermediate strength levels to be tested to allow a more precise determination of the peak.

Fig 4 does however indicate that it is unlikely that the present BS 2803 tensile range for 3.17 mm is the optimum for fatigue performance. To establish the precise optimum would require more work concentrating on the range 550-650 HV.

3.2 Relaxation Results

The effect of hardness on the relaxation resistance of carbon steel springs can be seen by an examination of Table IV and Fig 5. Minimum relaxation would appear to occur when springs are heat treated to a hardness range of about 470-520 HV, which corresponds to a tempering temperature of about 400°C. It is interesting to note that, according to Speich[(2)], during the third stage of tempering at about this temperature the transitional carbides produced at lower temperatures are dissolved and are replaced by the more stable spheroidal Fe_3C carbide. The presence of this stable carbide produced on tempering may be a possible explanation of the minimum relaxation behaviour observed. At higher tempering temperatures coalescence of the carbides occurs along with general softening which is reflected in a decrease in relaxation resistance.

3.3 General

The optimum hardness value for relaxation resistance seems to be lower than that for maximum fatigue resistance lying roughly within the present BS 2803 range. It would appear therefore that the present tensile range is around the optimum for relaxation resistance, but that for improved fatigue properties a higher tensile range would be required. In this case there may be an argument for having more than one tensile strength range for pre-hardened and tempered wire, and this would enable the user to select the appropriate tensile grade for a specific application.

The question naturally arises, could a higher tensile strength wire be satisfactorily formed into springs? Certainly the wire used in this project, which was 125 N/mm^2 (8 $tons/in^2$) above the present BS 2803 tensile range, was satisfactorily coiled, using an automatic machine. Unfortunately, the laboratory heat treatment facilities did not allow the rehardening of a sufficient length of wire for coiling or wrapping experiments, but reverse bend tests over a 10 mm radius and torsion tests were carried out, and the results obtained can be seen in Table V.

The hardest wires exhibited low results in reverse bend indicating that even if this hardness level had proved superior in fatigue it is possible that the benefits of this could not have been realised, due to the practical difficulties of forming wire at this hardness. Wire at 570HV, which is above the current standard tensile range, was capable of meeting the bend test requirements of BS 2803. However, the torsion test results, when equated to a gauge length of 100d, did not meet the BS 2803 requirements when heat treated to hardness levels of 570HV and above.

It appears that the fatigue performance of springs may well be improved by an increase in the tensile strength of the wire over the current British tensile range, specified in BS 2803. More detailed work over a narrower tensile range would be needed to locate the optimum tensile strength. Such a change would however be detrimental to the relaxation resistance of the springs.

4. CONCLUSIONS

1. Re-hardening and tempering springs coiled from pre-hardened and tempered wire to the original hardness increased the fatigue life of the springs above that of springs given a low temperature heat treatment at 350°C.

2. Some improvement in fatigue performance of springs coiled from pre-hardened and tempered wire may be obtained by the use of a tensile strength above the current BS 2803 range.

3. Such an increase in tensile strength could have an adverse effect on the relaxation resistance of the springs though in many cases this may be acceptable.

5. RECOMMENDATIONS FOR FURTHER WORK

The increase in fatigue life with re-hardening and tempering of springs in an inert atmosphere suggests that not all the detrimental stresses introduced during coiling are removed by a 350°C LTHT. Thus a study of the effects of LTHT temperature would appear necessary. An extension of the present work concentrating on a narrower range of tensile strengths around the optimum value for fatigue might prove of value. The work would also require extension to other wire sizes.

6. REFERENCES

1. BIRD G.C. "The Production of Spring Fatigue Data with Statistical Levels of Confidence. Part 3 of 7 parts. The Fatigue Properties of Springs Manufactured from Oil Hardened and Tempered Steel Wire to BS 2803 Grades I and II. SRAMA Report No. 225,

2. SPEICH G.R. "Tempering of Low Carbon Martensite". Trans. Metall. Soc. AIME, 1969, 245, Dec., p. 2553.

TABLE III FATIGUE TEST RESULTS, 100 N/mm^2 INITIAL STRESS

Hardness HV20	Max Stress N/mm^2	Life Cycles	Hardness HV20	Max Stress N/mm^2	Life Cycles
670	1100	27,000	440	1065	92,000
"	1050	27,000	"	1025	99,000
"	1050	54,000	"	995	195,000
"	1025	36,000	"	895	278,000
"	1000	63,000	"	875	189,000
"	975	36,000	"	830	73,000
"	950	36,000	"	825	333,000
"	925	27,000	"	790	496,000
"	900	45,000	"	705	418,000
"	875	34,000	"	700	10^7 UB
"	850	72,000	"	670	4,065,000
"	825	72,000	"	650	10^7 UB
"	800	99,000	"	615	966,000
"	775	67,000	"	600	10^7 UB
"	750	10^7 UB	"	550	10^7 UB
"	700	10^7 UB	375	850	63,000
"	650	10^7 UB	"	750	72,000
"	600	10^7 UB	"	700	540,000
"	550	10^7 UB	"	650	10^7 UB
570	1075	45,000	"	600	10^7 UB
"	1050	261,000	As Received	1100	45,000
"	1000	54,000	(118 tons)LTHT	1050	54,000
"	975	108,000	350°C	1045	48,000
"	950	515,000	"	1005	45,000
"	950	1,710,000	"	950	117,000
"	875	192,000	"	925	55,000
"	850	1,530,000	"	845	140,000
"	800	8,934,000	"	730	10^7 UB
"	775	$9x10^6$ UB	"	670	10^7 UB
"	750	7,563,000	"	610	10^7 UB
"	700	10^7 UB			
"	650	10^7 UB			
"	600	10^7 UB			
"	550	10^7 UB			
"	1065				

NOTE: UB = Unbroken

TABLE IV RELAXATION RESULTS, TEST TEMPERATURE 75°C, DURATION 96h

Hardness HV20	% Relaxation for an Initial Stress of:- 600 N/mm^2	800 N/mm^2	1000 N/mm^2
670	10.6 8.7	10.6 9.8 9.8	13.4 12.1 12.0
570	5.5 4.7 6.4	9.1 7.9 7.0	10.0 8.4 11.2
440	4.2 4.5	8.7 9.3 9.4	-
375	7.9 8.6 8.4	16.0 14.1 16.0	-
LTHT 350°C	4.2 3.2 4.3	5.6 5.6 5.3	8.2 7.7 7.2

TABLE V FORMABILITY TESTS

Hardness HV20	Reverse Bends to Failure	Twists to Failure	
		on 152 mm	Equivalent on 100d
670	2	2	4.2
570	5	4	8.4
440	9	9	18.8
375	9	-	-
As Recd. LTHT 350°C	9	10	20.9

(Results mean of 3 tests)

NOTE:

Torsional tests were performed using a wire length of 152 mm this is shorter than the standard length of 100d for this wire diameter which would be 317 mm.

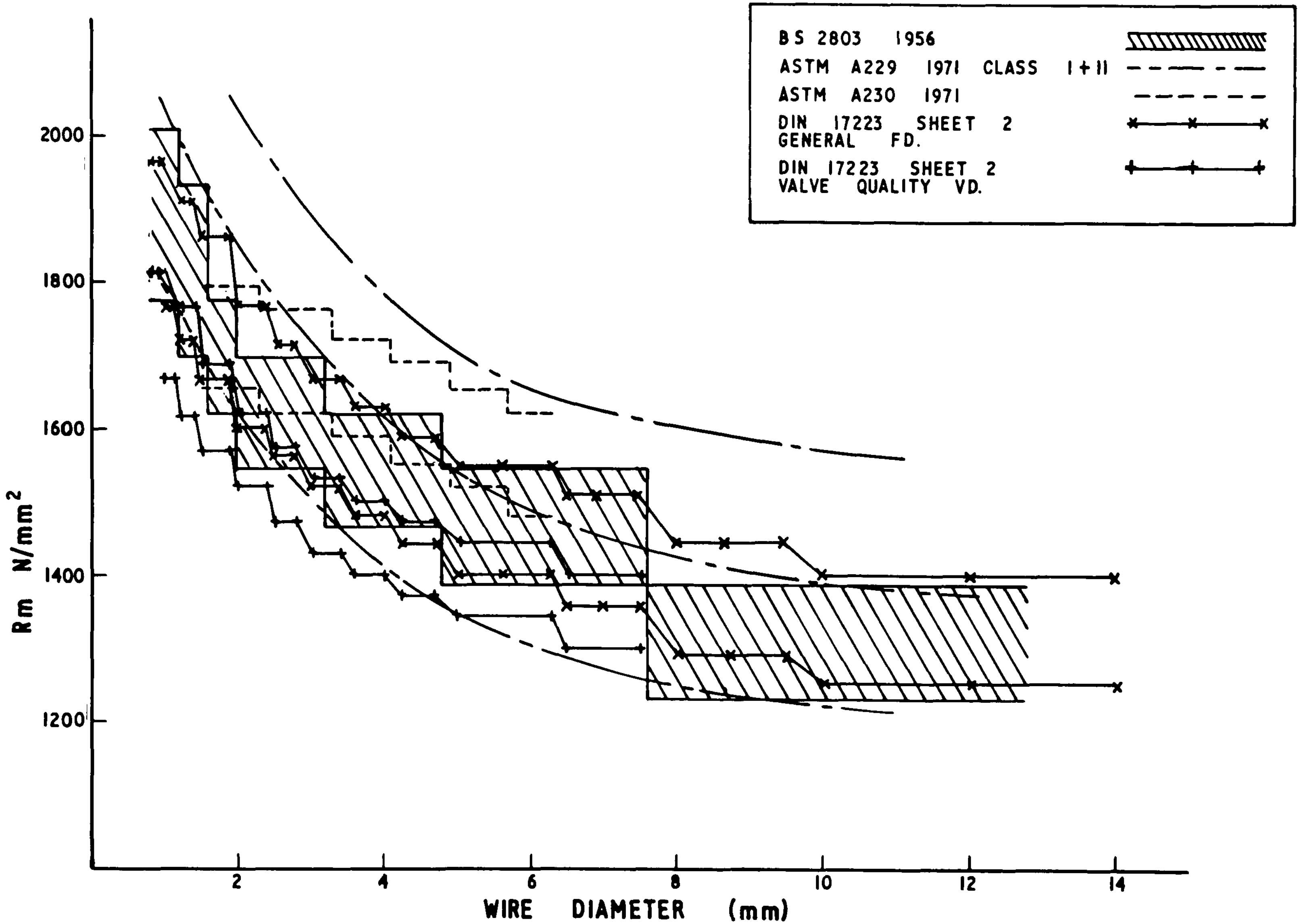

FIG. I. TENSILE STRENGTH RANGES FOR BS 2803 AND COMPARABLE FOREIGN SPECIFICATIONS.

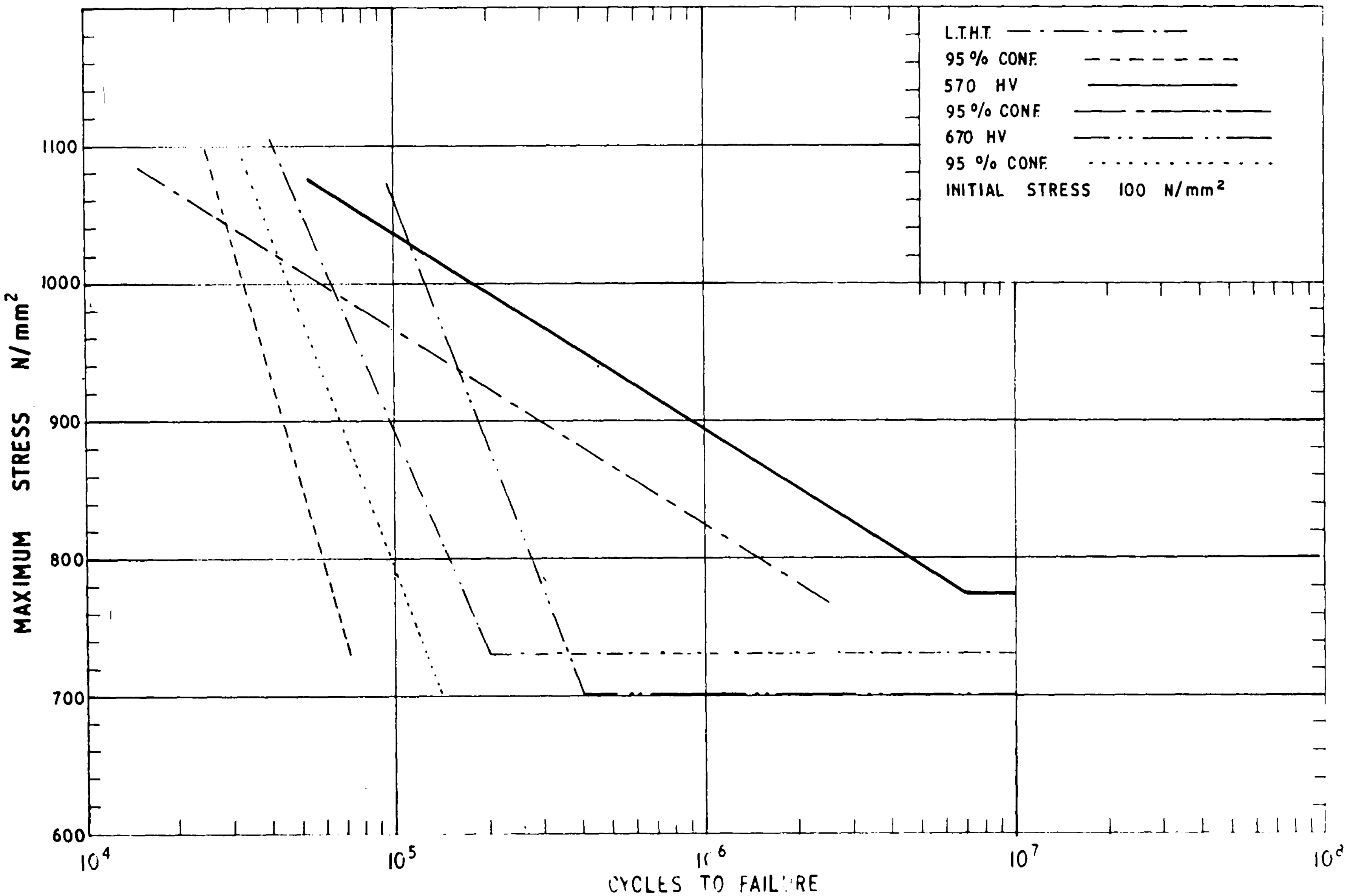

FIG. 2. S/N CURVES FOR SPRINGS AT DIFFERING HARDNESS LEVELS (1).

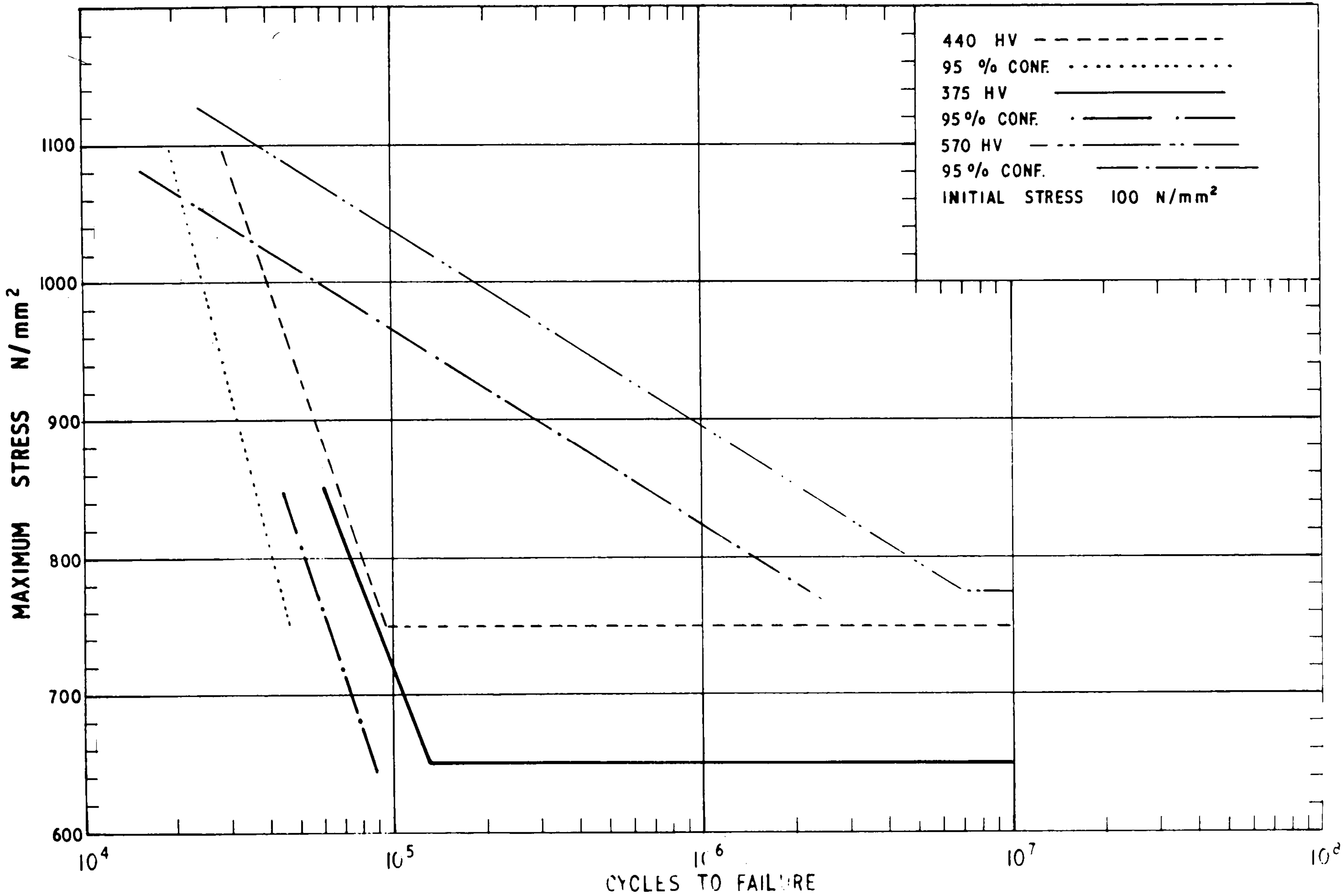

FIG. 3 S/N CURVES FOR SPRINGS AT DIFFERING HARDNESS LEVELS (2).

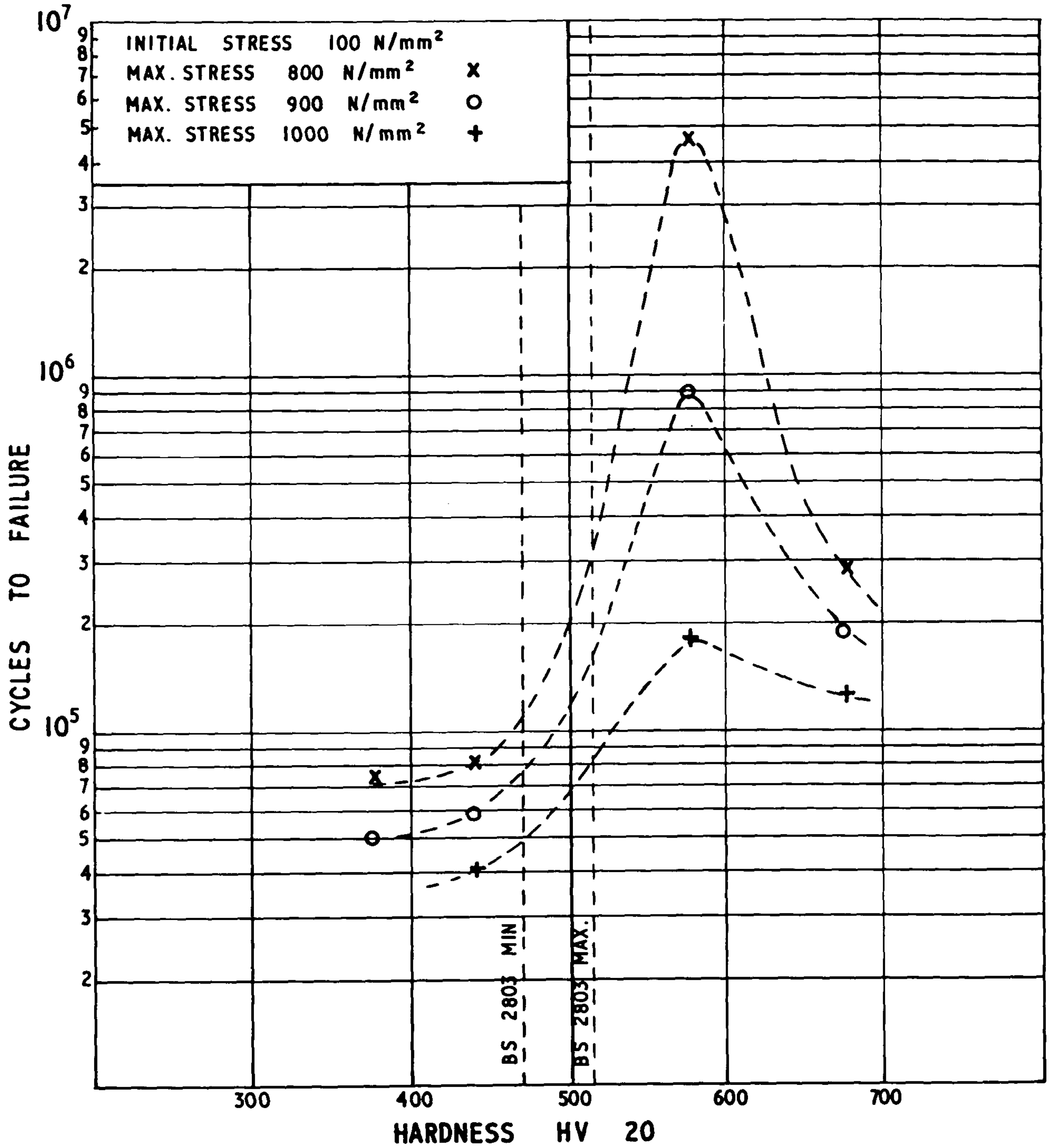

FIG. 4. TENTATIVE CURVES FOR HARDNESS v FATIGUE LIFE FOR SPRINGS FROM 3·17 mm (·125") BS. 2803 WIRE.

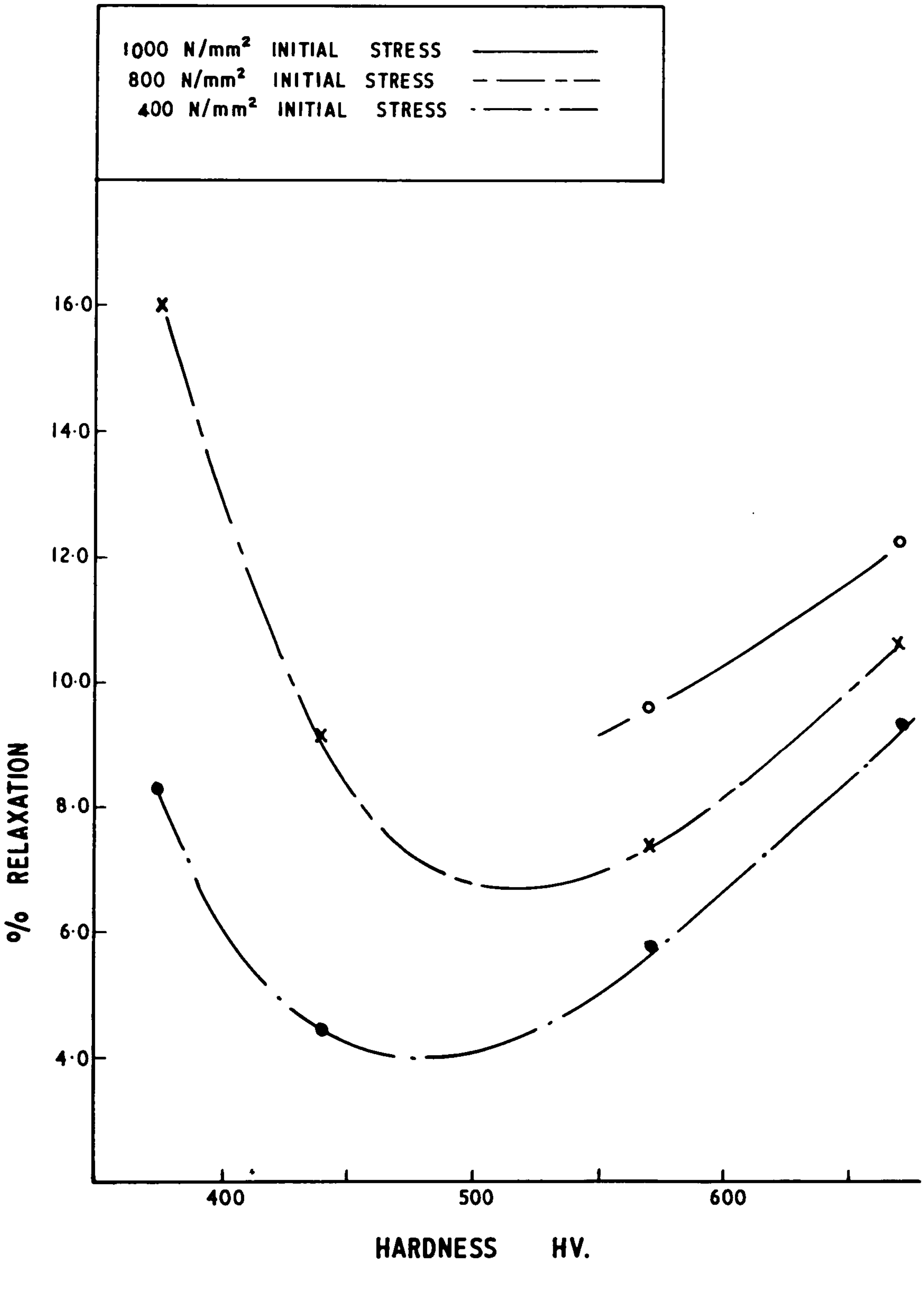

FIG. 5 EFFECT OF HARDNESS ON RELAXATION RESISTANCE AT 75° C FOR 96 HOURS.