THE SPRING RESEARCH ASSOCIATION

THE EFFECT OF STRAIN PEENING ON THE FATIGUE PROPERTIES OF HELICAL COMPRESSION SPRINGS MADE FROM PRE-HARDENED AND TEMPERED CARBON STEEL WIRE

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SUMMARY

An earlier study of the effect of strain peening on the fatigue properties of flat springs made from pre-hardened and tempered carbon steel strip yielded encouraging results. The present work, in which the investigation of the strain peening process is extended to helical compression springs made from pre-hardened and tempered carbon steel wire has shown that fatigue properties are markedly improved. The theoretical explanation is similar to that proposed for the flat springs but the residual stress distribution is more complex.

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1. INTRODUCTION

Recent work at SRA[1] has confirmed quantitatively that strain peening of flat springs made from pre-hardened and tempered carbon steel strip greatly improves the fatigue performance.

Previous work on strain peening concerned with springs which were stressed uniaxially in bending, was reviewed in the above mentioned report.

The aim of the present investigation was to determine whether the strain peening process can be applied successfully to helical compression springs.

Pre-hardened and tempered carbon steel wire was employed, the hardness, chemical composition and surface condition being similar to those of the strip used for the flat springs. The wire size was chosen as to be comparable with the strip thickness, that is 2.5 mm approximately. Strain peening was carried out at a stress corresponding to the torsional yield stress of the wire, as determined by static torsion testing. This stress level was selected for similar reasons to those used in choosing the stress for the work on flat springs.

It is a similar stress level to that used by Spaulding[2] for the strain peening of compression springs; in his paper however no details were given of the method employed, nor was fatigue testing carried out.

2. MATERIAL

2.1 Composition

A suitable quantity of Grade II, 2.6 mm diameter wire to BS 2803:1956 was obtained. The chemical composition is given in Table I, together with the nominal composition specified. The surface finish was satisfactory and a metallographic examination of a transverse section confirmed that the wire was free from either complete or partial decarburisation.

2.2 Spring Design and Manufacture

All springs were manufactured to the design given in Table II. The springs were coiled on an automatic coiling machine and, after end grinding, were stress relieved at 400°C for half an hour.

In choosing this design, consideration was given to the space which would remain between adjacent coils of a spring when it was compressed to the torsional yield stress of the material. This gap had to be wide enough to allow the passage of shot during the strain peening operation. The choice of a relatively high solid stress ensured that this gap would be adequate at the stress level selected.

2.3 Shot Peening

Thirty springs were shot peened in a 'Tumblast' WTBOA machine, using conventional CS 330 shot, to an Almen arc rise of 0.46-0.56 mm. These springs were subsequently stress relieved at 200°C for half an hour.

3. EXPERIMENTAL PROCEDURE

3.1 Static Tests on Wire

The tensile and torsional properties of the wire were determined in both the as-received and the low-temperature-heat-treated conditions. Tensile and torsional data, expressed as the mean of three sets of test results, are presented in Tables III and IV respectively. The twists-to-failure values are based on a gauge length of 100 times the wire diameter.

3.2 Strain Peening

Ten strain peening jigs, each capable of constraining a test spring at a pre-determined length, were constructed at SRA. Each jig consisted of two 5.1 cm diameter plates, 0.63 cm in thickness, with a 1.6 cm hole bored centrally through each. A test spring was clamped between the plates by means of three 0.46 cm threaded bolts passing through each plate at an angle of 120° to one another.

The compressed height of the spring was adjusted by means of a nut on the end of each bolt and the distance between the inside faces of the plates was measured using Vernier calipers. The end plates were bored to facilitate the passage of shot to the inside of the spring during strain peening. One of the strain peening jigs is shown in Fig. 1.

Each spring was individually load tested to determine the compressed length required to produce in the spring a corrected stress equivalent to the torsional elastic limit of the material, that is $800 N/mm^2$. Using the procedure described above, 20 springs were clamped to the appropriate compressed lengths and shot peened with conventional CS 330 shot to an Almen arc rise of

0.46-0.56 mm A2, all springs being subsequently stress relieved at 200°C for half an hour. The free lengths of the springs were measured before and after strain peening, and after low-temperature-heat-treatment. As the springs were not individually identifiable after strain peening, only average lengths are given in Table V. Average length data for the shot peened springs in the various conditions are also presented in this table.

3.3 Fatigue Testing

Fatigue testing was carried out on a multiple-stage, forced motion fatigue testing machine. All springs were tested from an initial torsional stress of $50N/mm^2$ to a series of maximum corrected torsional stresses, up to the solid stress. Fatigue data for the shot peened springs are presented in Fig. 2, and the results for the strain peened springs are shown in Fig. 3.

4. DISCUSSION

The fatigue performance of strain peened and prestressed springs made from pre-hardened and tempered carbon steel wire is clearly superior to that of shot peened and prestressed springs. A conservative assessment of the data indicates that strain peening raised the fatigue limit by 17% and that the fatigue limit was higher than the normal working stress. Moreover it should be noted that, since the strain peened springs had a lower solid stress, the increase in fatigue performance is even more pronounced[3].

Shot peening produces a system of biaxial residual compressive stresses on the surface of a spring; according to Almen and Black[6] the magnitude of the residual compressive stress is of the order of 50% of the yield stress in compression.

When an unpeened compression spring is prestressed, a residual shear stress, acting in the opposite direction to the applied torque, is induced in the surface layers of spring. This residual shear stress has both tensile and compressive components. The magnitude of the residual shear stress may be calculated from the spring design data, the torsional stress/strain curve of the spring material and the level of prestress[4]. When a shot peened compression spring is prestressed, the compressive component of the residual shear stress is increased and the tensile component is diminished[5]. This is due to a combination of the two residual stress systems mentioned previously. If prestressing is carried out in the same direction as subsequent loading in service, then the compressive component of the residual shear stress is always oriented in the direction of the tensile component of the applied stress. Hence the prestressing of a shot peened compression spring improves its fatigue performance.

A similar situation arises during the strain peening operation. In this case, however, the interaction of the stresses due to shot peening and the applied shear stress must be taken into account. This interaction has been considered previously for the simpler stress distribution which exists in uniaxial bending[6]. For compression springs, both the tensile and compressive components of the applied shear stress must be considered in relation to the stresses due to shot peening.

In the discussion referred to above, Almen states that when strain peening is carried out using a stress equal to 50% of the tensile yield stress, the resulting residual stress is equal to the compressive yield stress. Similarly, a residual stress equal to the tensile yield stress results from strain peening under an applied stress equal to half the compressive yield stress. In this investigation, strain peening was carried out under a shear stress equal to the torsional yield stress of the spring material. Since the tensile and compressive components of the applied shear stress have the same magnitude as the shear stress[7], and since the torsional yield stress is half the tensile and compressive yield stress, then, using Almen's argument, the sample would be expected to develop a residual tensile stress component and a residual compressive stress component, each having its respective yield stress magnitude. These magnitudes are, of course, the same. However, this situation would correspond to a residual shear stress having a magnitude twice that of the torsional elastic limit, which is impossible because of the elastic nature of residual stresses. Plastic deformation therefore takes place until the residual shear stress reaches the level of the torsional elastic limit. This explains the 'set-down' of the test springs during the strain peening operation.

The strain peening operation resulted in a residual shear stress having a magnitude equal to that of the torsional elastic limit. Prestressing a shot peened compression spring gives a residual shear stress of a lower magnitude than the torsional elastic limit. Hence, the strain peened compression springs exhibited the better fatigue resistance.

It is interesting to compare the results of this investigation with those of the previous work on the strain peening of flat springs. In both investigations the material used was of a similar composition, size and hardness. However, the springs were of two different types with differing modes of stress.

In each case, strain peening was carried out at a stress equal to the yield stress for the appropriate mode of stressing. For the flat springs, which were fatigue tested in unidirectional bending, the ratio of fatigue limit to tensile strength was 83% after strain peening. The compression springs, which were subjected to unidirectional torsional fatigue stresses, showed a ratio of fatigue limit to maximum shear stress of 77% after strain peening. Thus, for this material, strain peening produces similar fatigue performance in springs having different modes of stress.

5. CONCLUSIONS

1. Compared with shot peened and prestressed springs, the fatigue performance of compression springs made from pre-hardened and tempered carbon steel wire is markedly improved by strain peening and prestressing.

2. In springs made from pre-hardened and tempered carbon steel, strain peening raises the fatigue performance to a relatively similar level for different modes of stressing.

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TABLE I   CHEMICAL COMPOSITION

	%C	%Si	%Mn	%S	%P
Actual	0.67	0.21	0.82	0.012	0.011
Specified	0.55-0.75	0.3 Max	0.60-0.90	0.040 Max	0.040 Max

TABLE II   SPRING DESIGN

Wire diameter	mm	2.6
Mean coil diameter	mm	20.6
Total number of coils		5.5
Number of active coils		3.5
Free length after end grinding, shot peening and prestressing	mm	37.2
Free length after end grinding, strain peening and prestressing	mm	34.1
Solid stress of shot peened springs	N/mm^2	1150
Solid stress of strain peened springs	N/mm^2	1080

TABLE III TENSILE PROPERTIES

Condition	Tensile Strength	0.1% P.S.	0.2% P.S.	Elong.
	N/mm^2	N/mm^2	N/mm^2	%
As Drawn	1670	1520	1525	6.3
L.T.H.T. 400°C/½h.	1593	1526	1530	6.3

TABLE IV TORSIONAL PROPERTIES

Condition	Max. Shear Stress	0.1% P.S.	0.2% P.S.	Torsional Elastic Limit	Twists to Failure
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	
As Drawn	1403	940	972	785	20
L.T.H.T. 400°C/½h.	1303	943	979	800	24

TABLE V FREE LENGTH DATA FOR TEST SPRINGS

	Initial Length	Length After Peening	Loss in Length on Peening	Length After L.T.H.T.	Change in Length on L.T.H.T.	Length After Prestress	Set Down on Prestress	Overall Length Loss
	mm	mm	%	mm	%	mm	%	%
Strain Peened	40.2	34.1	15.2	34.6	+1.5	34.1	1.5	15.2
Shot Peened	40.3	40.2	0.2	40.2	0	37.2	7.5	7.7

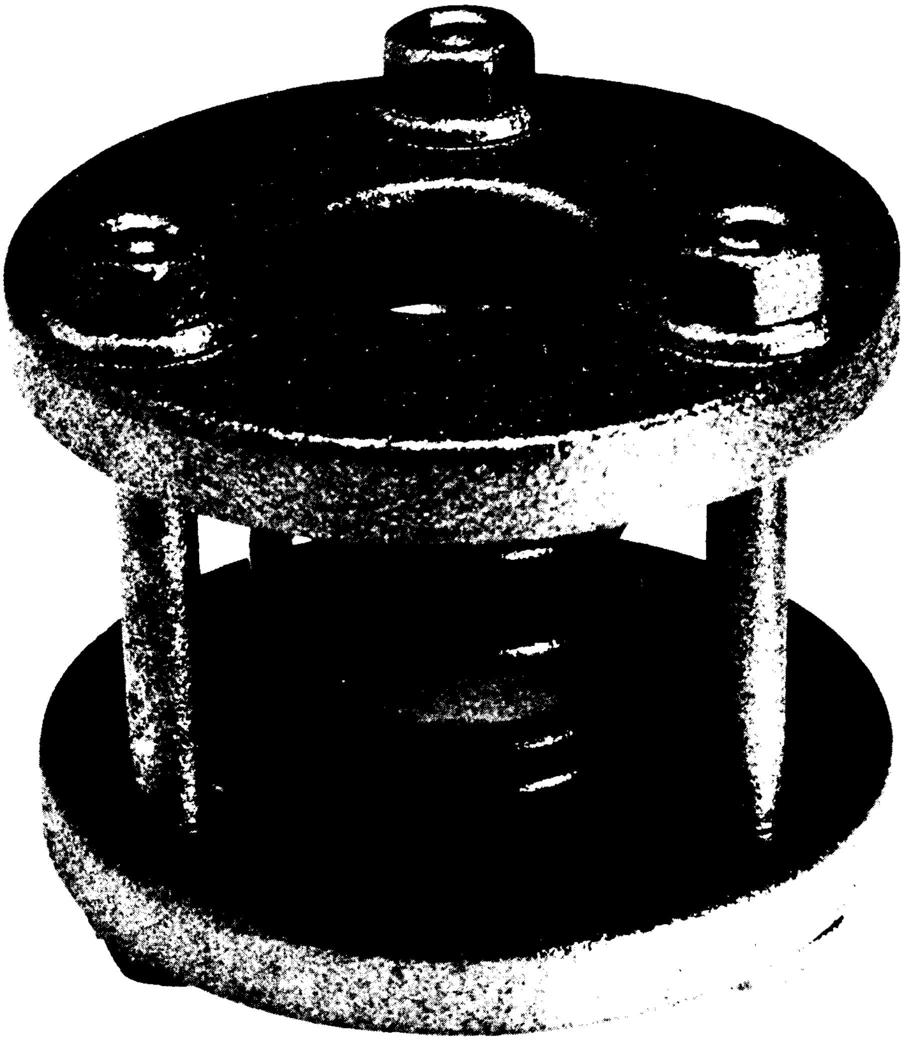

FIG. 1 STRAIN PEENING JIG

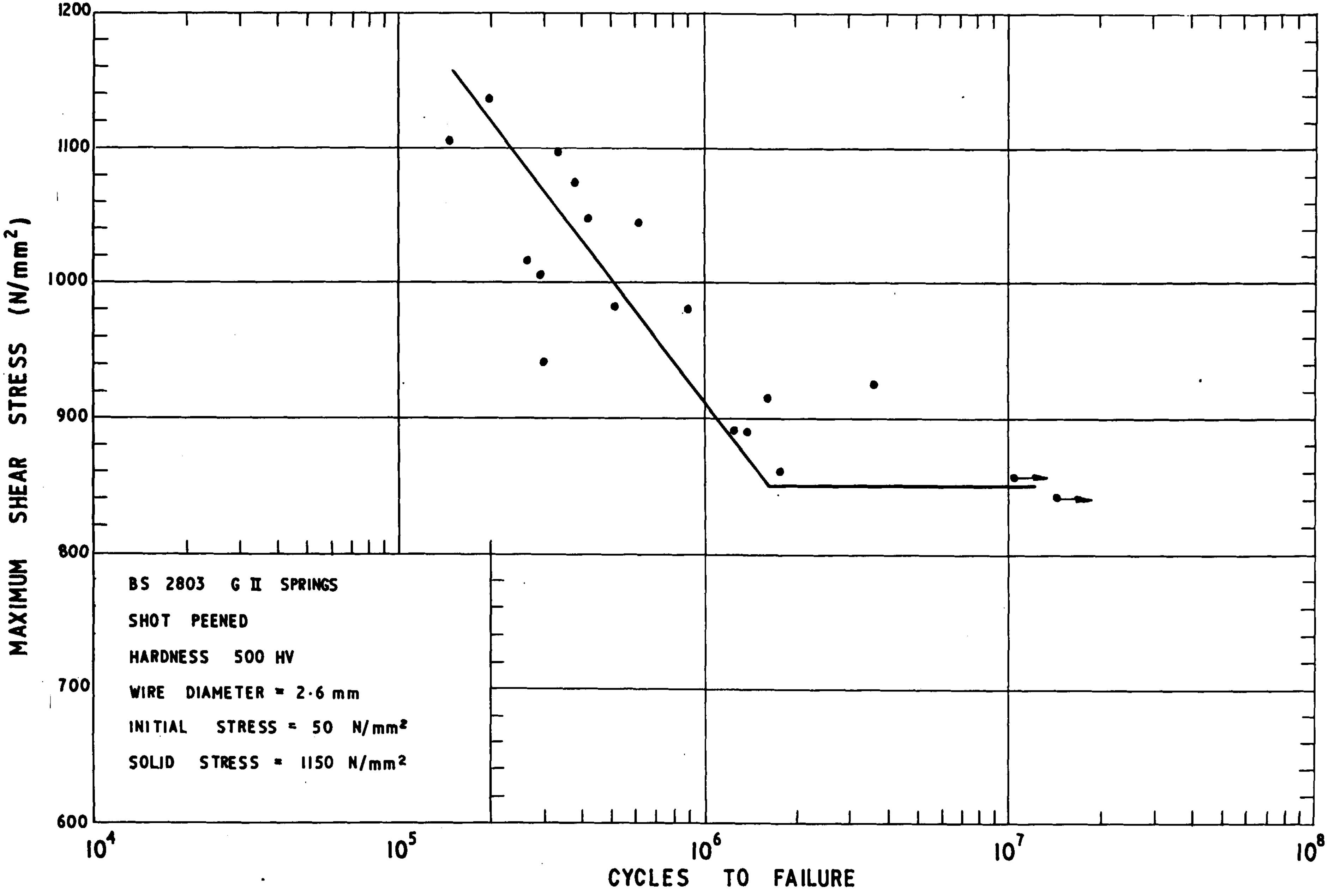

FIG. 2 S/N CURVE FOR SHOT PEENED SPRINGS.

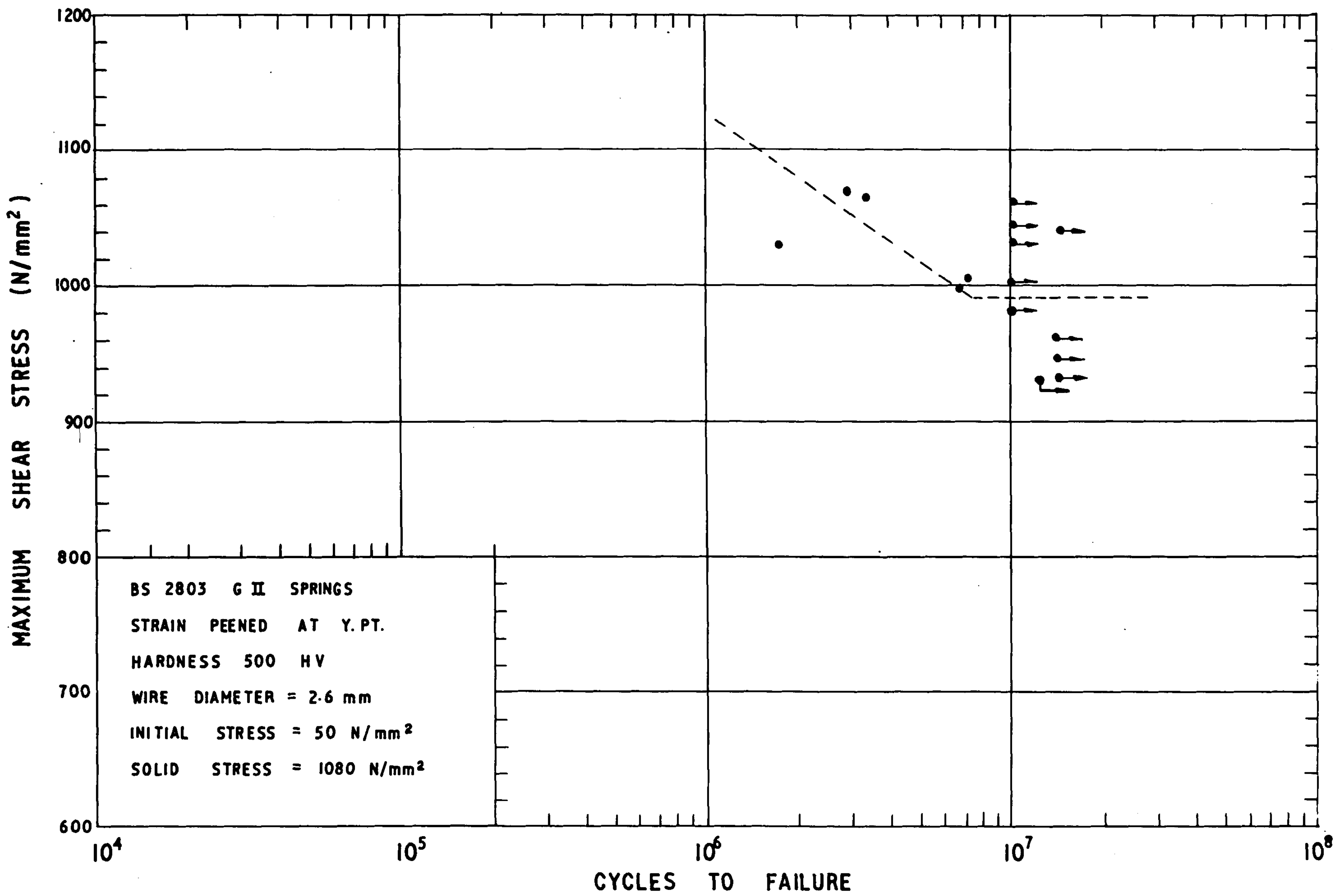

FIG. 3 FATIGUE DATA FOR STRAIN PEENED SPRINGS.