THE SPRING RESEARCH ASSOCIATION

THE EFFECTS OF HOT AND COLD PRESTRESSING ON THE FATIGUE AND RELAXATION PROPERTIES OF COMPRESSION SPRINGS MADE FROM Cr-V STEEL WIRE

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SUMMARY

An investigation carried out on shot peened compression springs made from 2.6 mm Cr-V steel wire, designated 735A50 in BS 970:Part 5:1972, has shown that, in the case of hot prestressing, an increase in the level of prestress improves the relaxation resistance.

At all levels of prestress, springs which had been prestressed at 200°C exhibited better relaxation resistance than cold prestressed springs. Over the range of solid stresses considered, prestressing at 200°C did not affect the fatigue performance. This work, together with previous studies of prestressing at various temperatures, indicates that prestressing of shot peened Cr-V steel valve springs at 200°C results in the optimum combination of fatigue and relaxation resistance.

June 1975

CONTENTS

Page No.

CONTENTS

Cont. ...

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1. INTRODUCTION

Previous work at SRA(1, 2) has demonstrated the value of hot prestressing in reducing the amount of relaxation occurring at elevated temperatures in valve springs made from low alloy steel wire. With both shot peened and unpeened springs, the amount of relaxation decreases as the prestressing temperature is increased. Indeed, with unpeened springs, it has been suggested(1) that, if the prestressing temperature is sufficiently high, then relaxation can be prevented completely. In practice, however, springs of this type are normally shot peened to improve their fatigue performance and, since it is known(2, 3) that the beneficial residual stresses induced by shot peening are progressively relieved at temperatures in excess of 200°C, the prestressing temperature is limited to this level. It seems likely, therefore, that the optimum combination of fatigue and relaxation resistance for shot peened engine valve springs made from low alloy steel will be produced by prestressing at 200°C. In this investigation, the effects of prestressing at 200°C on the fatigue and relaxation properties of shot peened Cr-V steel valve springs have been examined and the results compared with the fatigue and relaxation properties of cold pre-stressed springs.

In addition, the effect has been studied of the level of prestress on the relaxation and fatigue resistance of shot peened engine valve springs made from Cr-V steel, in both the hot and cold prestressed conditions. The springs used were all of the same design, except for variations in the as-coiled free lengths.

2. MATERIAL

2.1 Composition

Pre-hardened and tempered Cr-V steel wire having a diameter of 2.6 mm was used throughout this investigation. The wire was supplied to a normal commercial hardness of 500 to 550 HV and the actual chemical composition, together with the composition specified for Grade 735A50 in BS 970:Part 5:1972, is given in Table I.

2.2 Spring Design and Manufacture

The basic spring design is given in Table II. Three groups of springs, designated A, B and C, having different as-coiled free lengths, were produced for hot prestressing and springs having two different as-coiled lengths, Groups D and E, were used for cold prestressing. These lengths, which are shown in Table III, were calculated so as to produce solid stress values, after hot or cold prestressing, in the range 950 to 1250 N/mm^2.

All of the springs were end-ground after coiling and stress relieved at 400°C for half an hour. Each batch of springs was shot peened separately to an arc rise of 0.46 to 0.56 mm and 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 Cr-V steel 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 IV and V respectively. The twists-to-failure values were based on a gauge length of 100 x d. Examination of a transverse microsection of the wire showed that the structure consisted of uniformly tempered martensite with no evidence of decarburisation.

3.2 Prestressing

For both hot and cold prestressing, each spring in each group was individually identified, the free length being measured before and after prestressing. All of the springs were compressed six times to solid. The hot prestressing of Groups A, B and C was carried out in an air-circulating furnace at 200°C, using a parallel prestressing device operating on a scissors principle. All of the hot prestressed springs were oil-quenched to room temperature under restraint, in order to prevent immediate recovery from the prestressing operation. Each group contained at least 24 springs and the average percentage loss in length on pre-stressing was calculated, as was the "theoretical" solid stress before prestressing. The results are presented in Fig. 1, which relates the theoretical solid stress before prestressing to the percentage set-down for both hot and cold prestressed springs. Fig. 2 shows the relationship between the solid stresses before and after prestressing. The data from which these two graphs were plotted are summarised in Table III.

3.3 Relaxation Tests

Six springs from each group were subjected to a stress of 900 N/mm^2 at 150°C for 72 hours. These conditions were selected so as to be comparable with those used in previous relevant investigations(1, 2) and the percentage relaxation was calculated using the percentage loss in load method described in previous reports. The results are illustrated graphically in Fig. 3, which shows the percentage set-down occurring on prestressing against the percentage relaxation. In Fig. 4, a graph of solid stress after prestressing against percentage relaxation is presented.

3.4 Fatigue Tests

Springs from Groups A and D, which had the lowest solid stress levels were fatigue tested in the normal manner. Initial stresses of 100 N/mm^2 and 50 N/mm^2 were used, the latter being the minimum initial stress available on the fatigue machine. However, it was not possible to break any springs from either group, even at the lowest initial stress. Springs from groups C and E were fatigue tested using initial stresses of 100 and 200 N/mm^2 respectively. Fatigue data for these two groups are presented in Figs. 5 to 8, and also in Fig. 9, in the form of a modified Goodman diagram for an endurance of 10^6 cycles.

4. DISCUSSION

4.1 Solid Stress and Set-down

Fig. 1 shows that, with both hot and cold prestressed springs over the solid stress range considered, an approximately linear relationship exists between the theoretical solid stress and the percentage loss in length which occurs on prestressing. For a given theoretical as-coiled solid stress, hot prestressing at 200°C produces more permanent set than does cold prestressing. With hot prestressing at 200°C, it can be seen from Fig. 2 that, over the stress range considered, a linear relationship exists between the theoretical solid stress before prestressing and the solid stress after prestressing.

4.2 Relaxation

The relaxation data are presented in two alternative forms: in Fig. 3 the relationship is shown between the percentage set-down occurring on prestressing and the percentage relaxation in Fig. 4, the percentage relaxation is related to the solid stress after prestressing. With the hot prestressed springs, there was a marked improvement in relaxation resistance as the level of prestress was increased. With the cold prestressed springs, the relaxation resistance increased only slightly with an increasing level of prestress. At all levels of prestress within the range considered, the relaxation resistance of the springs was improved by prestressing at 200°C.

Relaxation occurs when residual stresses, which are elastic in nature, are relieved by conversion to plastic deformation. Under certain conditions of applied stress and temperature, the total effective residual stress in a spring may be progressively increased as a result of the continuous generation and interaction of atomic defects. The interaction of these defects is facilitated by pseudo-creep processes, which are so called because they resemble conventional creep mechanisms, except that they operate at lower temperatures. Thus, the spring exhibits permanent set (relaxation) when the residual stress reached the elastic limit of the material. It follows that, under constant test conditions (stress, temperature and time), relaxation decreases with increasing elastic limit. For fully prestressed compression springs, the effective torsional elastic limit of the material is the solid stress of the spring(4) and hence an increase in relaxation resistance is to be expected with increasing solid stress, (See Fig. 4).

The amount of residual stress present in the spring material before relaxation is also of importance: as this quantity increases, so the amount of additional residual stress that must be generated to produce relaxation decreases - assuming that the torsional elastic limit (solid stress) is the same. For a particular deformation process, the elastic stored energy, that is, the residual stress, is dependent on strain and temperature. Elastic stored energy increases with increasing strain and with decreasing temperature of deformation(5); relaxation is affected similarly by these variables. Although springs of Groups C and E had undergone a similar amount of strain, the Group C springs contained less stored energy after deformation than those of Group E because of the higher deformation temperature. Hence, it was to be expected that the hot prestressed group would exhibit less relaxation under the same test conditions. Fig. 4 shows that this is indeed the case, even though the Group E springs had the higher elastic limit. The influence of elastic limit on relaxation therefore seems to be less strong than the influence of the residual stress after prestressing. This finding becomes particularly evident if Groups A and E are considered. Group E springs exhibited greater relaxation than Group A springs, even though the solid stress of the former group was about 30% higher. However, Group A springs had undergone a smaller amount of strain at a higher temperature and hence contained far fewer residual stresses. It may be concluded, therefore, that the effect of the level of prestress on the relaxation resistance only manifests itself when the amount of residual stress present after prestressing is relatively low.

4.3 Fatigue

Relaxation resistance is not the only requirement for engine valve spring materials. Shot peening is normally carried out before cold prestressing in order to increase the fatigue resistance; on the other hand, recent work(2) has demonstrated that shot peening results in a decline in relaxation resistance. It has also been shown that, by hot prestressing, the relaxation resistance of shot peened springs can be raised to a level approaching that of unpeened springs. As yet, however, the effects of hot prestressing on the fatigue performance of shot peened springs has not been thoroughly investigated. In the present work the fatigue properties resulting from hot prestressing at 200°C after shot peening are compared with those of springs which had been cold prestressed after shot peening.

Fig. 13 is a Goodman diagram for an endurance of 10^6 cycles, which was constructed in order to compare the limited life fatigue performances of Groups C and E. The results obtained for the hot prestressed springs were marginally better, in spite of their lower solid stresses, but such small differences can not be regarded as significant. It may therefore be concluded that hot prestressing has no effect on the fatigue properties.

5. CONCLUSIONS

1. At all levels of prestress, prestressing of shot peened Cr-V steel valve springs at 200°C results in greater relaxation resistance than cold prestressing, without impairing the fatigue performance.

2. For shot peened Cr-V steel valve springs which are prestressed at 200°C an increase in the level of prestress significantly improves the relaxation resistance.

3. The results of the present investigation, considered in conjunction with data previously determined,(1, 2, 3) suggest that, for shot peened Cr-V steel valve springs, prestressing at 200°C results in the optimum combination of fatigue and relaxation properties.

6. REFERENCES

1. GRAY, S.D. "The Effect of Hot Prestressing on the Relaxation Properties of Helical Compression Springs manufactured from Cr-V Wire." SRA Report No. 215.

2. GRAY, S.D. "The Effect of Hot Prestressing on the Fatigue and Relaxation Properties of Helical Compression Springs manufactured from Low Alloy Steel Wire". SRA Report No. 234.

3. HAYNES, R. "The Effect of Shot Peening on the Fatigue Behaviour of Si-Mn Spring Steel". SRA Report No. 161.

4. BIRD, G.C. "An Investigation into the Effect of Solid Stress on the Prestressing of Compression Springs". SRA Report No. 208.

5. DIETER, G.E. "Mechanical Metallurgy". London, McGraw-Hill, 1961, p. 148.

TABLE I CHEMICAL COMPOSITION

	%C	%Si	%Mn	%Cr	%V	%S	%P
Actual	0.54	0.20	0.80	0.86	0.20	0.021	0.032
Specified	0.46 -0.54	0.10 -0.35	0.60 -0.90	0.80 -1.10	0.15 Min.	0.050 Max.	0.040 Max.

TABLE II SPRING DESIGN

Wire Diameter (mm)	2.6
Mean Coil Diameter (mm)	21.4
Total Number of Coils	5.5
Number of Actual Coils	3.5
Free Length after End Grinding and Prestressing (Hot or Cold)	32.2 -37.1
Solid Stress after End Grinding and Prestressing (Hot or Cold) N/mm^2	970-1240

TABLE III SOLID STRESSES BEFORE AND AFTER PRESTRESSING

	Group	Free Length before Prestressing	Solid Stress before Prestressing	Free Length after Prestressing	Solid Stress after Prestressing	Set-Down
		mm	N/mm^2	mm	N/mm^2	%
Hot Prestressed	A	36.6	1220	34.2	970	6.8
	B	40.7	1410	36.2	1070	11.0
	C	44.9	1640	36.9	1180	17.9
Cold Prestressed	D	33.3	1040	32.9	970	1.1
	E	42.3	1485	37.1	1240	12.3

TABLE IV TENSILE PROPERTIES

Condition	Tensile Strength	0.1% PS	0.2% PS	Elong.	R. of A.	Hardness
	N/mm^2	N/mm^2	N/mm^2	%	%	HV 30
As Received	1820	1655	1770	6.3	52.1	530-540
L.T.H.T.	1760	1677	1681	4.7	52.1	530-540

TABLE V TORSIONAL PROPERTIES

Condition	Max. Shear Strength	0.1% PS	0.2% PS	Twists-to-Failure
	N/mm^2	N/mm^2	N/mm^2	G.L. = 100d.
As Received	1510	1190	1270	4.9
L.T.H.T.	1450	1240	1275	5.5

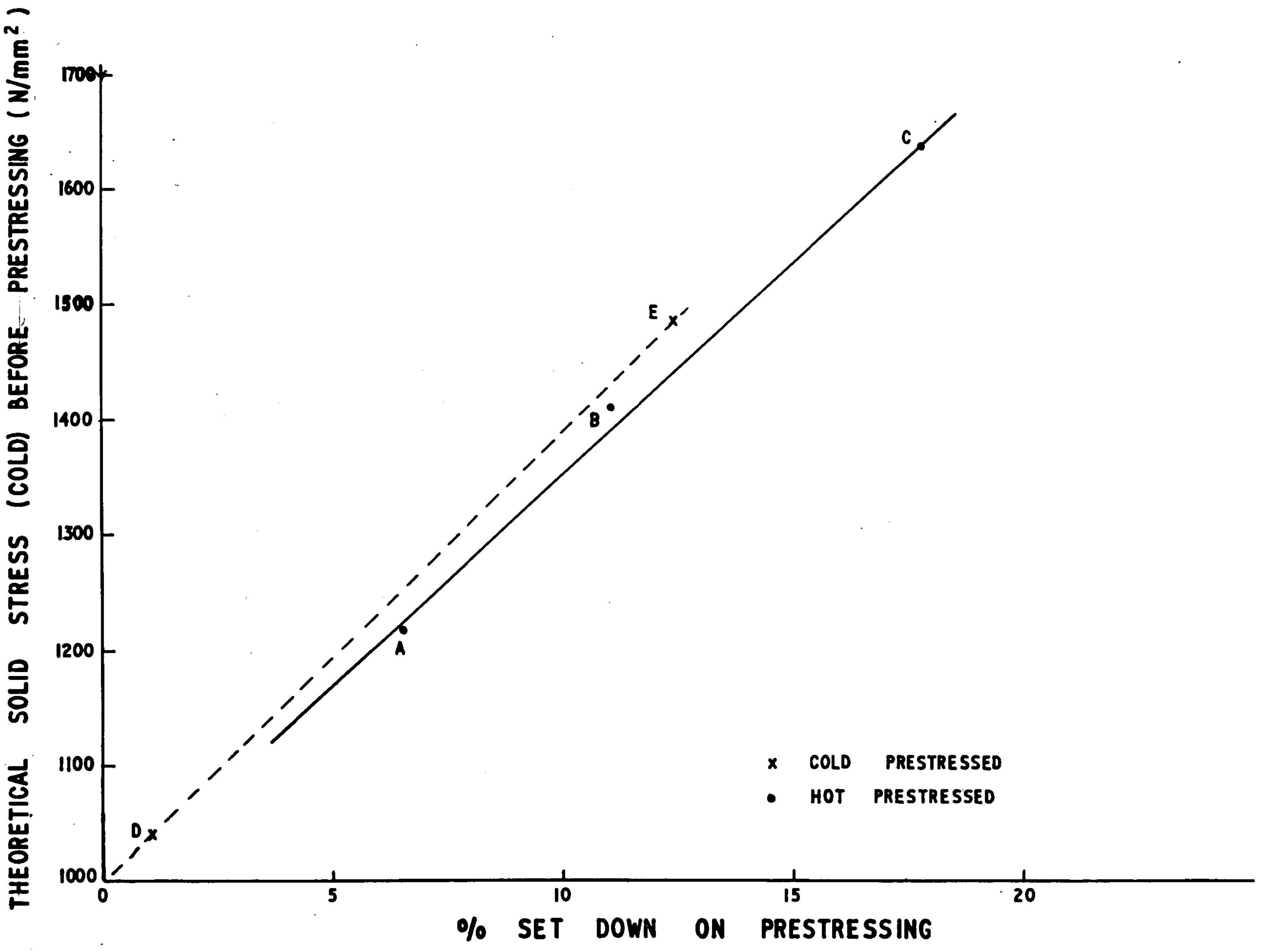

FIG. I. GRAPH OF THEORETICAL SOLID STRESS BEFORE PRESTRESSING AGAINST % SET-DOWN.

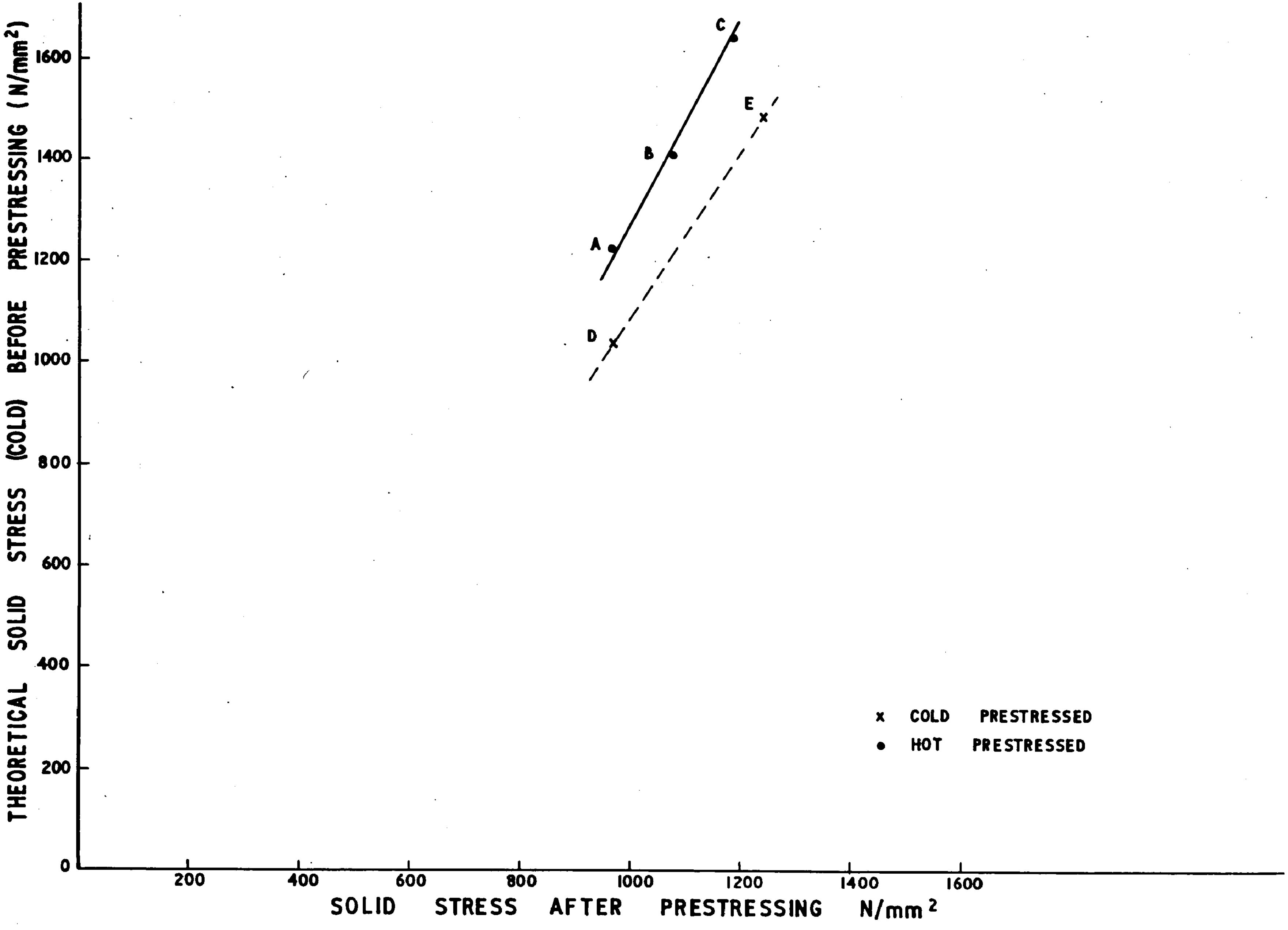

FIG. 2 GRAPH OF SOLID STRESS BEFORE AND AFTER PRESTRESSING.

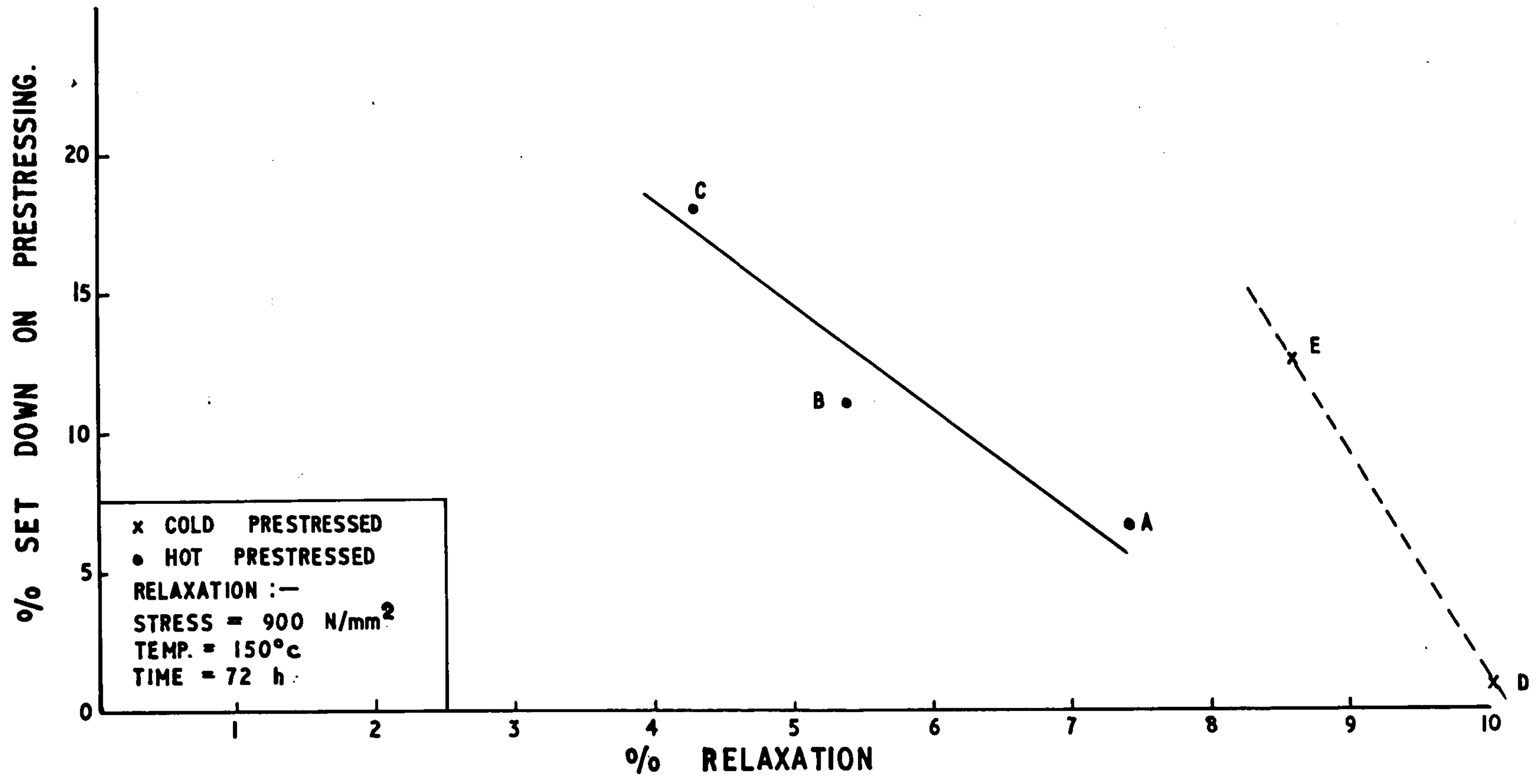

FIG. 3 GRAPH OF % SET – DOWN ON PRESTRESSING AGAINST % RELAXATION.

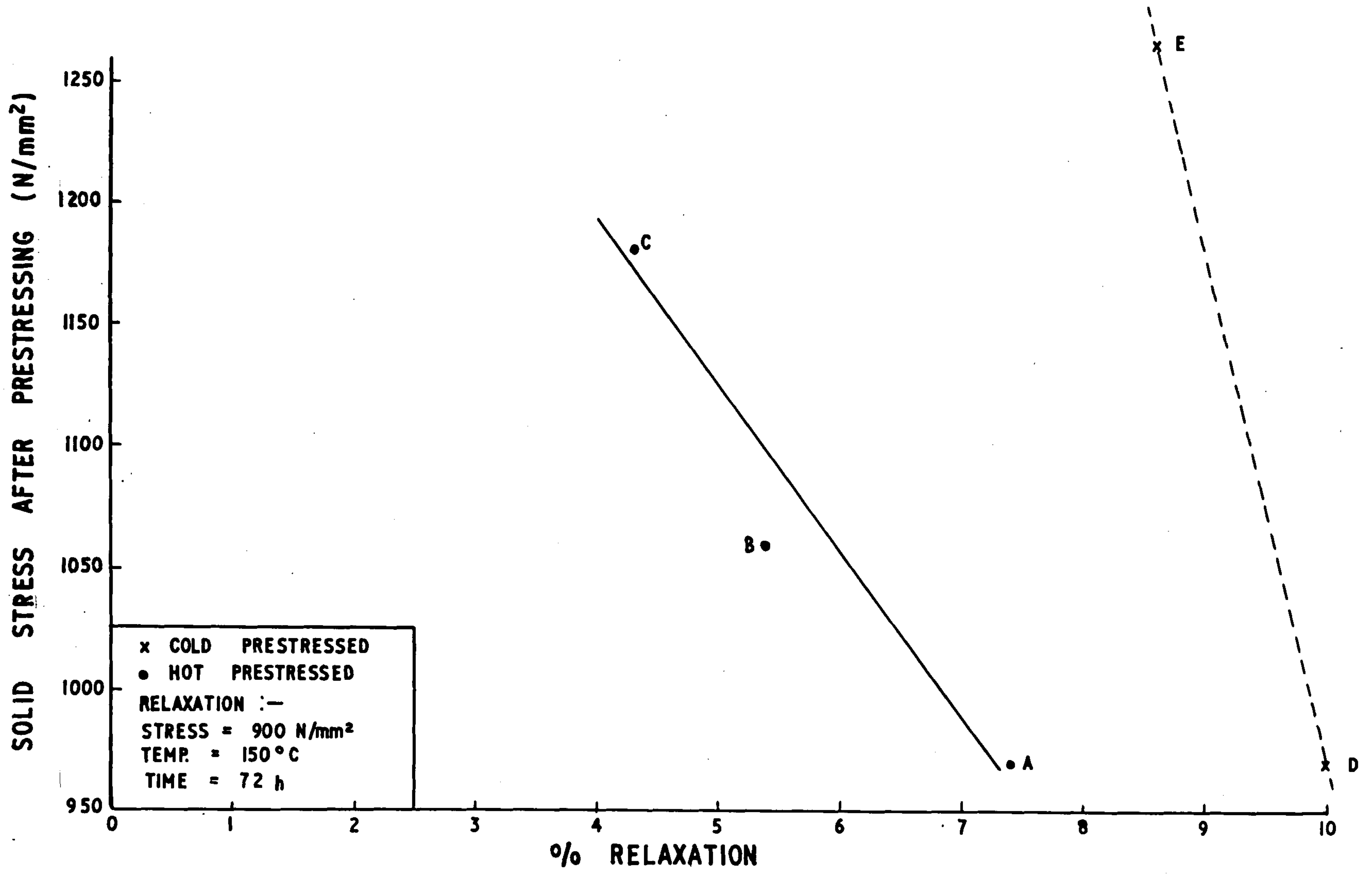

FIG. 4 GRAPH OF SOLID STRESS AFTER PRESTRESSING AGAINST % RELAXATION.

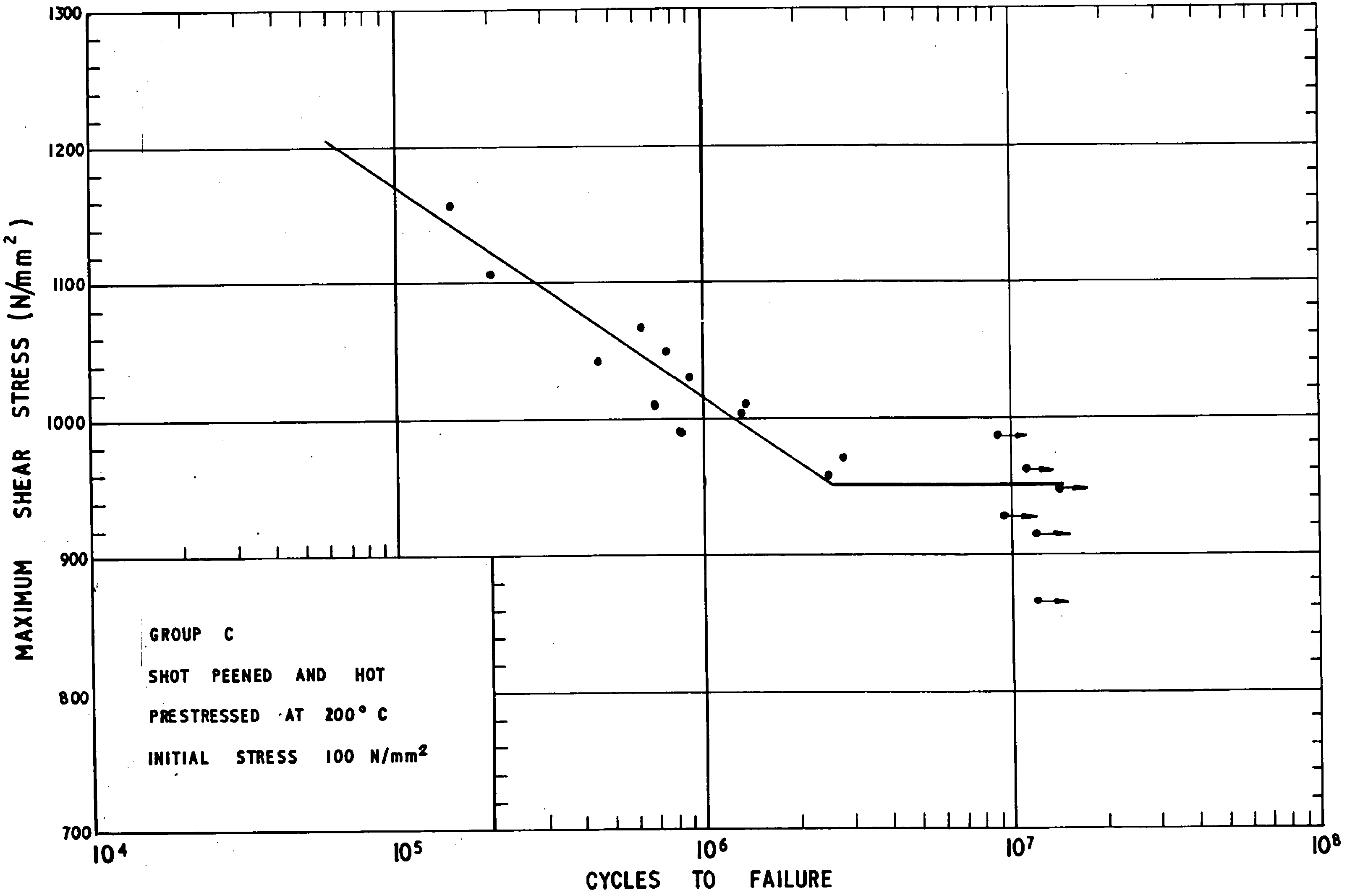

FIG. 5 S/N CURVE FOR GROUP C SPRINGS AT AN INITIAL STRESS OF 100 N/mm²

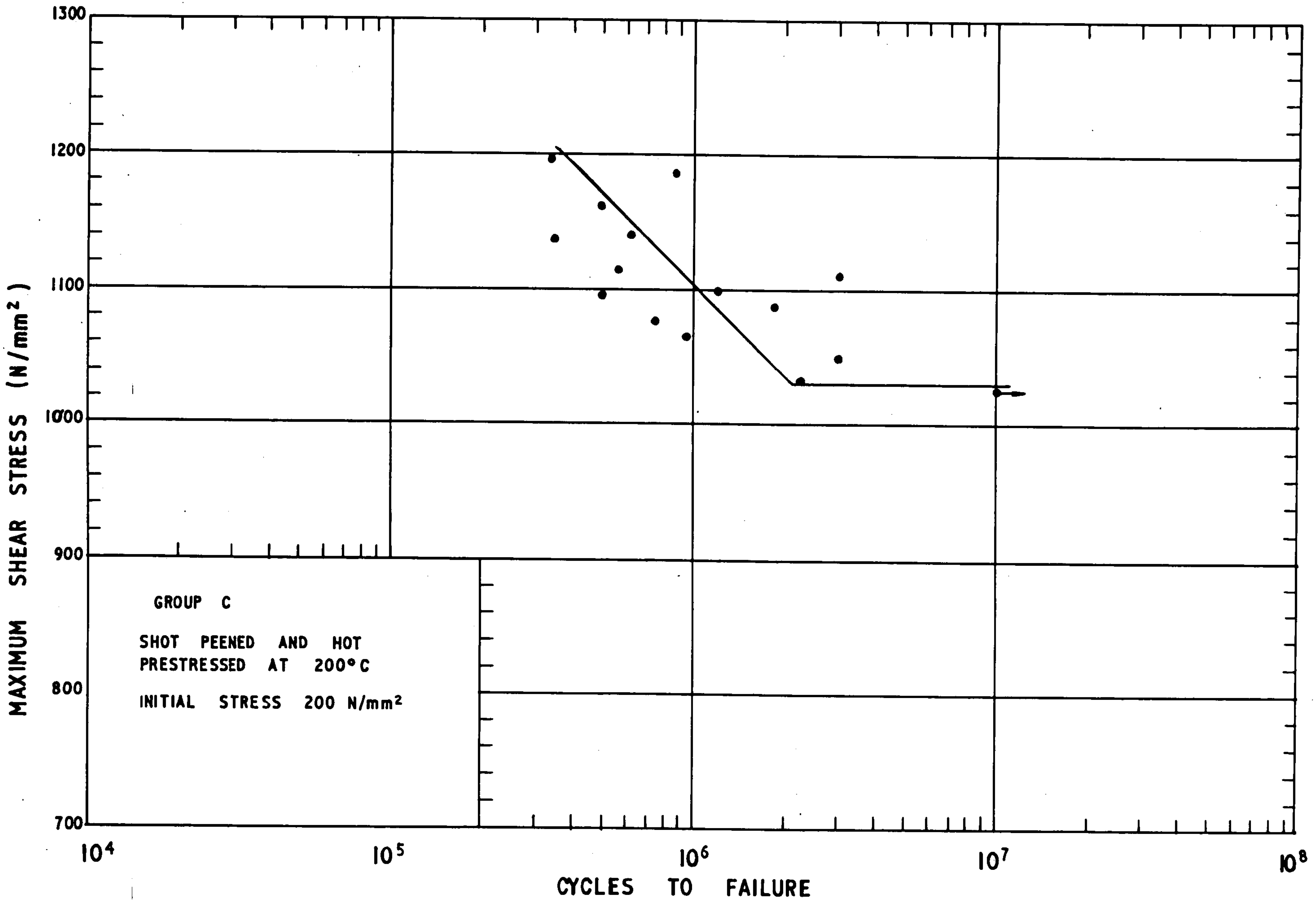

FIG 6 S/N CURVE FOR GROUP C SPRINGS AT AN INITIAL STRESS OF 200 N/mm²

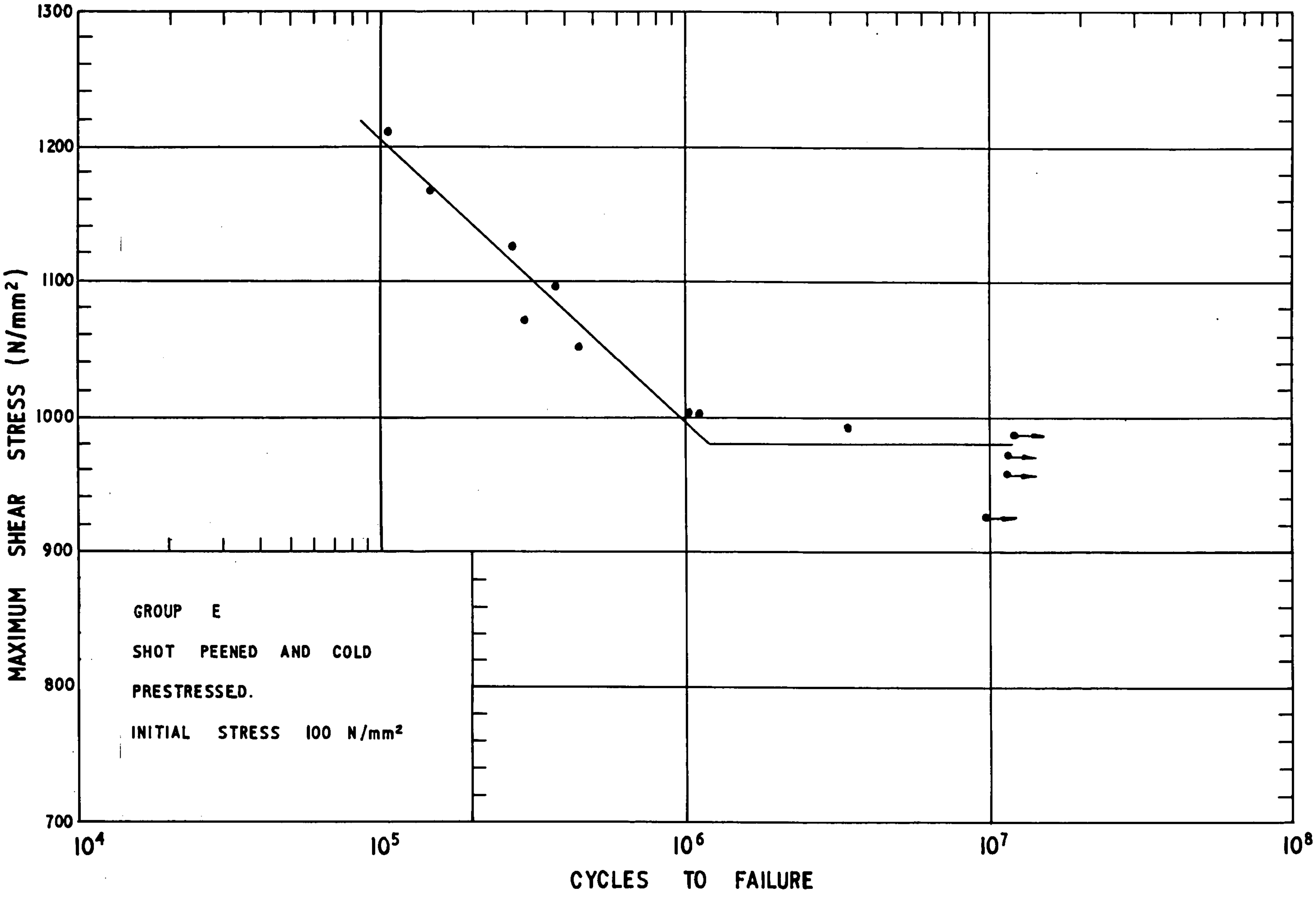

FIG. 7 S/N CURVE FOR GROUP E SPRINGS AT AN INITIAL STRESS OF 100 N/mm²

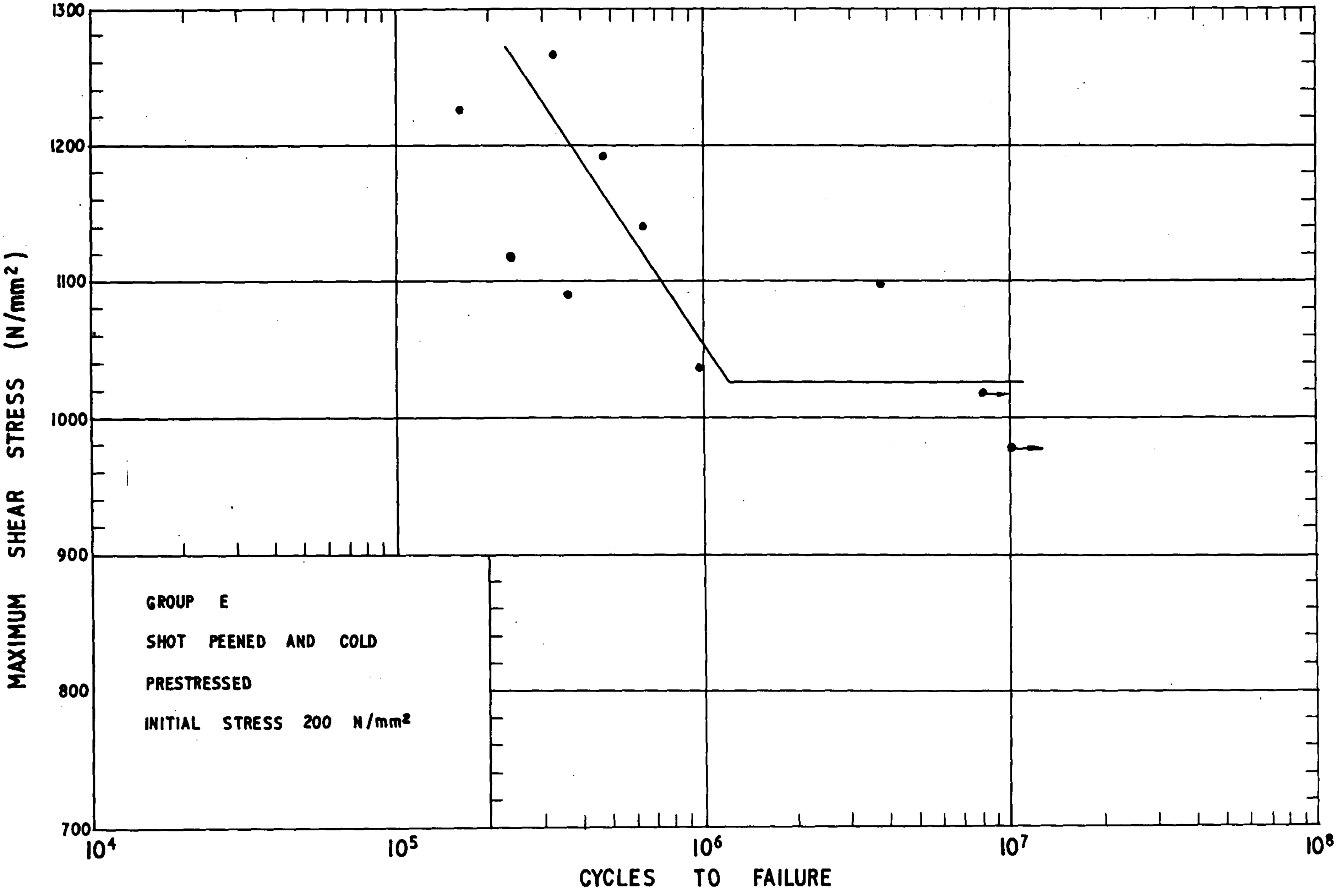

FIG. 8 S/N CURVE FOR GROUP E SPRINGS AT AN INITIAL STRESS OF 200 N/mm²

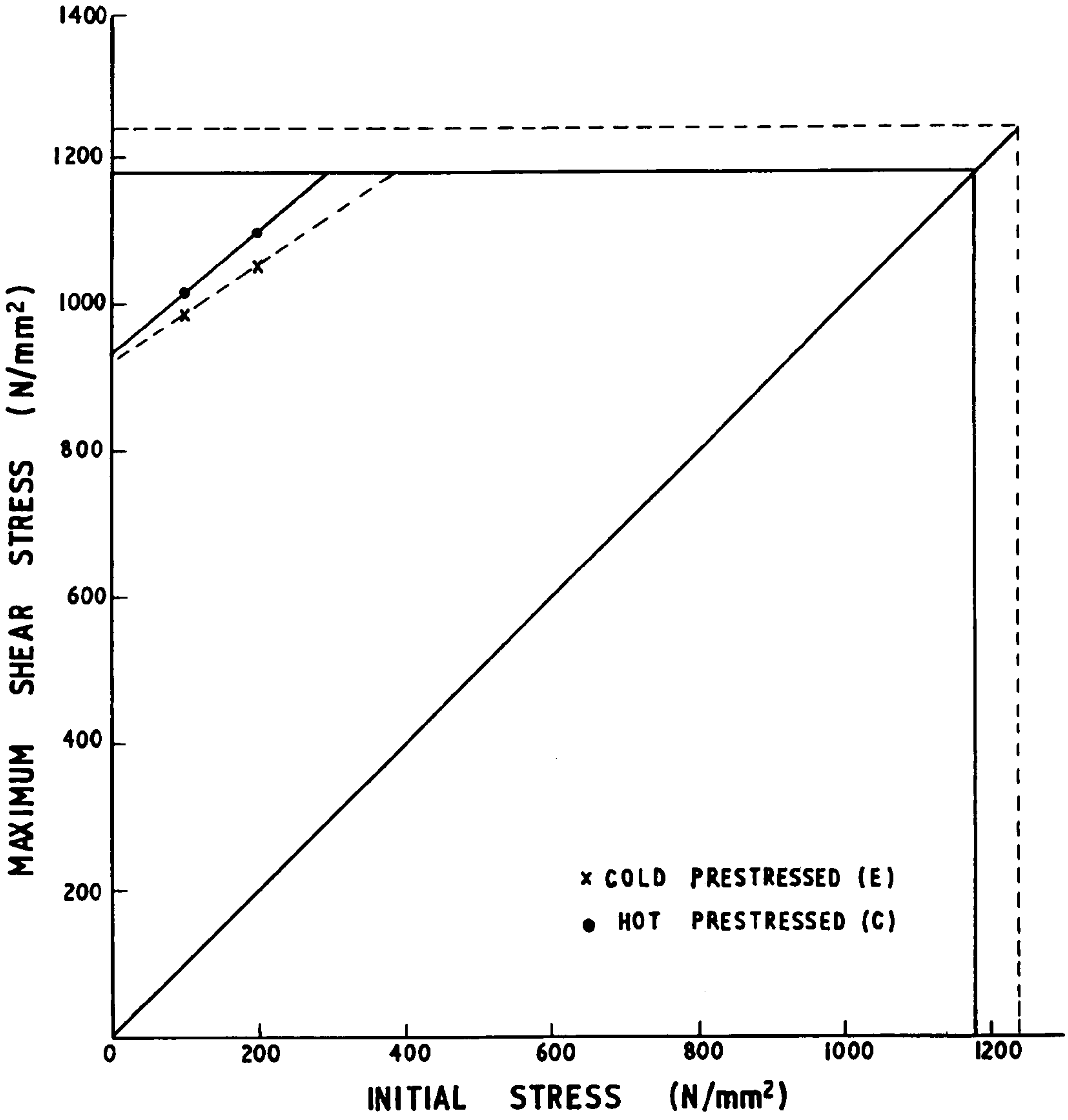

FIG. 9 MODIFIED GOODMAN DIAGRAM AT 10^6 CYCLES FOR GROUPS C AND E.