THE SPRING RESEARCH ASSOCIATION

AN INVESTIGATION INTO THE EFFECT OF SHOT SIZE IN SHOT-PEENING

by

G. C. Bird, B.Sc.

Report No. 217

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SUMMARY

Fatigue tests were carried out on helical compression springs of 1.22 mm (0.048 in), 2.34 mm (0.092 in) and 3.6 mm (0.144 in) wire diameters that had been shot-peened with S 110, S 330 and S 550 shot to establish the effect of shot size on fatigue performance. S/N curves were produced for an initial stress of 100 N/mm^2 and the results from the shot-peened springs compared with those from similar unpeened springs.

The loss in free length during prestressing the shot peened springs was measured and found to be greater than that for the unpeened springs. It was found that the larger the shot size used, the larger the amount of set.

The greatest improvement in fatigue life over the unpeened springs was found where the shot size was less than a quarter of the wire diameter. Where the shot size was greater than the wire diameter, a reduction in fatigue performance was recorded.

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1. INTRODUCTION

It is now well known that the process of shot-peening greatly improves the fatigue life of helical compression springs. Little is known, however, about the effect of the size of shot used on the fatigue performance or on the distortion produced in the springs.

The aim of this research project was to investigate these effects for one material using three sizes of shot and three different wire diameters. By comparing the fatigue properties with similar unpeened springs and from an examination of the springs after peening, the results were used to determine the most suitable shot size to produce the optimum fatigue performance without distortion.

2. SPRING DESIGN

The material used in all three wire sizes was to BS 1408C Range 2. In all designs, both the gaps between the coils and the inside diameter of the spring were kept larger than the biggest shot size so that the shot could pass freely through the springs. The solid stress of each spring design was adjusted to keep to approximately 70% of the minimum Ultimate Tensile Strength of the wire. Details of the spring designs used are given in Table I.

3. SHOT PEENING

The shot peening medium was cast steel shot in three sizes: S 110, S 330 and S 550. That is to say, the nominal size of the particles was 0.28 mm (0.011 in), 0.84 mm (0.033 in) and 1.40 mm (0.055 in) respectively.

Details of the ratios of shot size to wire diameters are given in Table II. It can be seen that in only one instance was the shot size greater than the wire diameter - with S 550 shot and the wire diameter 1.22 mm.

The springs were shot peened in a 'Wheelabrator' impeller type machine to 100% coverage, determined by visual inspection of the springs. The Almen arc rises obtained are given below

S 110 Shot	0.021 A2
S 330 Shot	0.023 A2
S 550 Shot	0.035 A2

4. EXPERIMENTAL PROCEDURE

4.1 General Procedure

The procedures used for each batch of peened springs were in the following order:

1. Low temperature heat treatment at 250°C for ½ hour after coiling

2. Measurement of free length and squareness and examination of general condition

3. Shot peen to 100% coverage

4. Remeasure free length and squareness and observe any change in shape

5. Low temperature heat treatment at 225°C for ½ hour

6. Prestress each spring ten times to solid

7. Remeasure free length and fatigue test to produce S/N curve for each batch.

In addition one batch of springs from each design was shot peened with S 330 shot and given the low temperature heat treatment immediately afterwards, as it had been suggested that this gave improved fatigue performance. This batch was not measured after shot peening, since the heat treatment had to be carried out without delay.

4.2 Free Length Measurement

The free lengths were measured by standing the springs on a horizontal surface and recording the maximum height of the spring. This was done before and after shot peening, and after all the springs had been fully prestressed.

4.3 Straightness Measurement

In addition to being generally examined for distortion, the springs were placed on a spindle on a Nikon profile projector, and the straightness of the spring determined by measuring the difference between the lowest and highest coil, with the end coils in a fixed position. This was carried out before and after shot peening.

4.4 Fatigue Testing

After the springs had been fully prestressed they were load tested to establish the machine strokes to give the required stress ranges. Fatigue testing was carried out on forced motion multiple spring testing machines with an initial stress of 100 N/mm^2. By varying the stress range applied to the springs, S/N curves were constructed for all the shot size and wires diameters.

5. RESULTS

The free length of the springs before and after shot-peening and after prestressing are shown in Table III.

Table IV shows the distortion in the springs as measured by the maximum out of squareness before and after peening.

The data obtained from fatigue testing are summarised in Table V showing the fatigue limits at 10^7 cycles and the percentage increase in the fatigue limit over the unpeened springs.

The S/N curves obtained are presented in Figs. 1-9. The results from the broken springs were analysed statistically to provide the 'best-fit' regression line. For comparison, the S/N curve for the unpeened springs is included on each figure, shown as a broken line. Fig. 10 shows the relationship between the fatigue performance and the shot size to wire diameter ratio.

6. DISCUSSION OF RESULTS

6.1 Free Length

The results in Table III show that with all sizes of shot, the effect of peening was to increase the length of springs made from 2.34 mm and 3.66 mm diameter wire and to decrease the length of those from 1.22 mm wire. In all cases, the change in length for a given size of spring was greater as the shot size increased. In general, the scatter in the free lengths after peening as indicated by the standard deviation was greater as the shot size increased and the wire diameter decreased. S 550 shot increased the standard deviation by between 60% and 130% depending on the wire diameter, S 330 shot only significantly affected the smallest wire size and S 110 shot did not appreciably affect the scatter for any wire diameter.

After prestressing, all the shot peened springs suffered a reduction in length and became shorter than the prestressed unpeened springs, those peened with the largest shot becoming the shortest. Thus the unpeened springs had the highest solid stress, those peened with S 110 shot the next highest and those peened with S 550 shot had the lowest solid stress.

The exception to this was when springs peened with S 330 shot were heat-treated immediately after shot peening. In this instance no measurements could be made after peening, but on prestressing they did not take as much set as the other springs peened with S 330 shot. For all wire sizes, in fact, the length after prestressing lay between the unpeened springs and those peened with S 110 shot.

6.2 Distortion

From the results presented in Table IV, it can be seen the distortion produced by peening, as measured by the straightness of the spring, was not as great as the change in free lengths. The largest increase was for springs of 1.22 mm wire peened with S 550 shot where distortion went up by 56% but S 110 shot on 3.66 mm wire had no noticeable effect. However, in all cases before and after peening, the straightness tolerance was within that specified by BS 1726 Class A.

6.3 Fatigue Testing

1.22 mm Springs

For springs of 1.22 mm dia wire the fatigue data obtained are presented in the form of S/N curves in Figs. 1-3 which show that the maximum fatigue lift was achieved with the smallest shot size (S 110). With the S 330 shot the fatigue limit was increased but under certain circumstances for finite life, the fatigue life was inferior to the unpeened springs. Those springs heat treated immediately after peening showed an improved fatigue limit though for finite life the scatter in the broken spring data was too great to draw any comparisons. For springs peened with S 550 shot the fatigue performance was poorer than that for unpeened springs under all conditions. This was the only case where the shot size was greater than the wire diameter.

2.34 mm Springs

For springs made from 2.34 mm diameter wire the S/N curves are shown in Figs. 4-6. The S 110 shot again gave the maximum lift in fatigue performance, a similar amount as for the smaller wire, approximately a 28% increase in fatigue limit over the unpeened springs. The springs peened with S 330 shot also showed the same improvement as previously, about 14%.

The springs peened with S 330 shot and heat treated immediately after peening appeared to have an inferior fatigue performance to those heat treated in the normal manner, though the large scatter in the endurances made it difficult to plot the S/N curves accurately. Penning with S 550 shot showed an improvement in fatigue performance for finite life though there was only a marginal improvement in the fatigue limit.

3.6 mm Springs

The S/N curves for springs from 3.66 mm diameter wire (Figs. 7-9) show that those peened with S 110 and S 330 shot had very similar fatigue performances, the lift in the fatigue limit again being about 28% over the unpeened springs. The fatigue limits of these springs were very close to the solid stress and only one of the S 330 shot peened springs was able to be broken. Again, the fatigue performance of the springs which had been heat treated immediately after peening was similar to that of the normal S 330 shot peened springs. The S 550 shot showed a greater improvement over the unpeened springs than for the other two wire sizes, though still well below the S 110 and S 330 peened springs.

The fatigue data presented on the S/N curves are summarised in Table V, giving the fatigue limits at 10^7 cycles for each combination of shot size and wire diameter. From this it can be seen that for S 110 where the shot is always less than 25% of the wire diameter the fatigue lift, expressed as a percentage above the unpeened fatigue limit is constant. For the S 330 shot, the fatigue lift was only as great as the S 110 when the shot size was less than 25% of the wire diameter. Where the S 550 shot used was larger than the wire diameter a decrease in fatigue performance was achieved and in all cases this shot size gave inferior fatigue performance to the S 110 and S 330. From Fig. 10 there appears to be an upper limit of about 28% to the improvement in fatigue properties from shot peening for this material and that as the shot size/wire diameter ratio becomes larger than one quarter the improvement becomes less marked. The heat treatment immediately after shot peening had no significant effect on the fatigue performance of the springs.

7. CONCLUSIONS

1. Distortion in springs, as measured both by scatter in free length and straightness of the springs, increased with increasing shot size and decreasing wire diameter, but still remained better than BS 1726 Class A.

2. No excessive distortion was achieved even with the biggest shot size/wire diameter ratio.

3. Shot peened springs sat down more than unpeened springs during prestressing and the larger the shot size, the greater the amount of set.

4. The improvement in fatigue performance is greatest where the shot size/wire diameter ratio is less than one quarter.

5. Peening with shot greater than the wire size is detrimental to the fatigue performance.

6. Heat treatment immediately after shot peening does not significantly improve fatigue performance but does appear to reduce the permanent set on prestressing.

TABLE I SPRING DESIGNS

WIRE DIAMETER	0.048 in 1.22 mm	0.092 in 2.34 mm	0.144 in 3.66 mm
MEAN COIL DIAMETER	0.384 in 9.75 mm	0.734 in 18.6 mm	1.152 in 29.3 mm
SPRING INDEX	8	8	8
TOTAL COILS	7.5	6.5	5.5
ACTIVE COILS	5.5	4.5	3.5
FREE LENGTH (AFTER PRESTRESSING)	1.07 in 27.2 mm	1.59 in 40.4 mm	1.84 in 46.7 mm
SOLID STRESS	180 000 lbf/in^2 1240 N/mm^2	160 000 lbf/in^2 1100 N/mm^2	140 000 lbf/in^2 960 N/mm^2

Ends Closed and Ground

TABLE II RATIO SHOT SIZE/WIRE DIAMETER

WIRE DIAMETER mm SHOT SIZE	1.22	2.34	3.66
S 110	0.23	0.12	0.08
S 330	0.69	0.36	0.23
S 550	1.15	0.60	0.38

TABLE III

EFFECT OF PEENING ON FREE LENGTH

WIRE DIAMETER \ SHOT SIZE	UNPEENED PRE-STRESSED	S 110			S 330			S 330 (LTHT after S/P)		S 550		
		BEFORE S/P	AFTER S/P	PRE-STRESSED	BEFORE S/P	AFTER S/P	PRE-STRESSED	BEFORE S/P	PRE-STRESSED	BEFORE S/P	AFTER S/P	PRE-STRESSED
1.22 mm (0.048 in)	26.7	27.6	27.2	25.1	27.6	26.9	24.7	27.6	26.0	27.6	26.7	24.5
2.34 mm (0.092 in)	40.9	41.2	41.7	39.3	41.2	42.2	39.1	41.2	40.4	41.2	42.3	38.4
3.66 mm (0.144 in)	47.1	47.5	47.9	45.6	47.5	48.4	45.3	47.5	46.4	47.6	48.8	44.1

Free lengths measured in millimetres. Measurement average for batch of springs.

TABLE IV

EFFECT OF PEENING ON STRAIGHTNESS

SHOT SIZE / WIRE DIAMETER	S 110		S 330		S 550		BS 1726 CLASS 'A' TOLERANCE
	BEFORE PEENING	AFTER PEENING	BEFORE PEENING	AFTER PEENING	BEFORE PEENING	AFTER PEENING	
1.22mm	0.0129	0.0134	0.0125	0.0183	0.0124	0.0194	0.021
2.34 mm	0.0229	0.0249	0.0211	0.0231	0.0239	0.0251	0.032
3.66 mm	0.0182	0.0182	0.0174	0.0179	0.0197	0.0149	0.037

Straightness measured in millimetres per millimetre. Measurements average for batch of springs.

TABLE V SUMMARY OF FATIGUE DATA

SHOT SIZE / WIRE DIAMETER	1.2 mm		2.34 mm		3.66 mm	
UNPEENED	760	-	760	-	690	-
S 110	970	28%	970	28%	890	28%
S 330	870	14%	870	14%	890	28%
S 550	650	-14%	770	1%	740	7%

Fatigue limit at 10^7 cycles in N/mm^2

Percentage increase in fatigue limit over unpeened springs

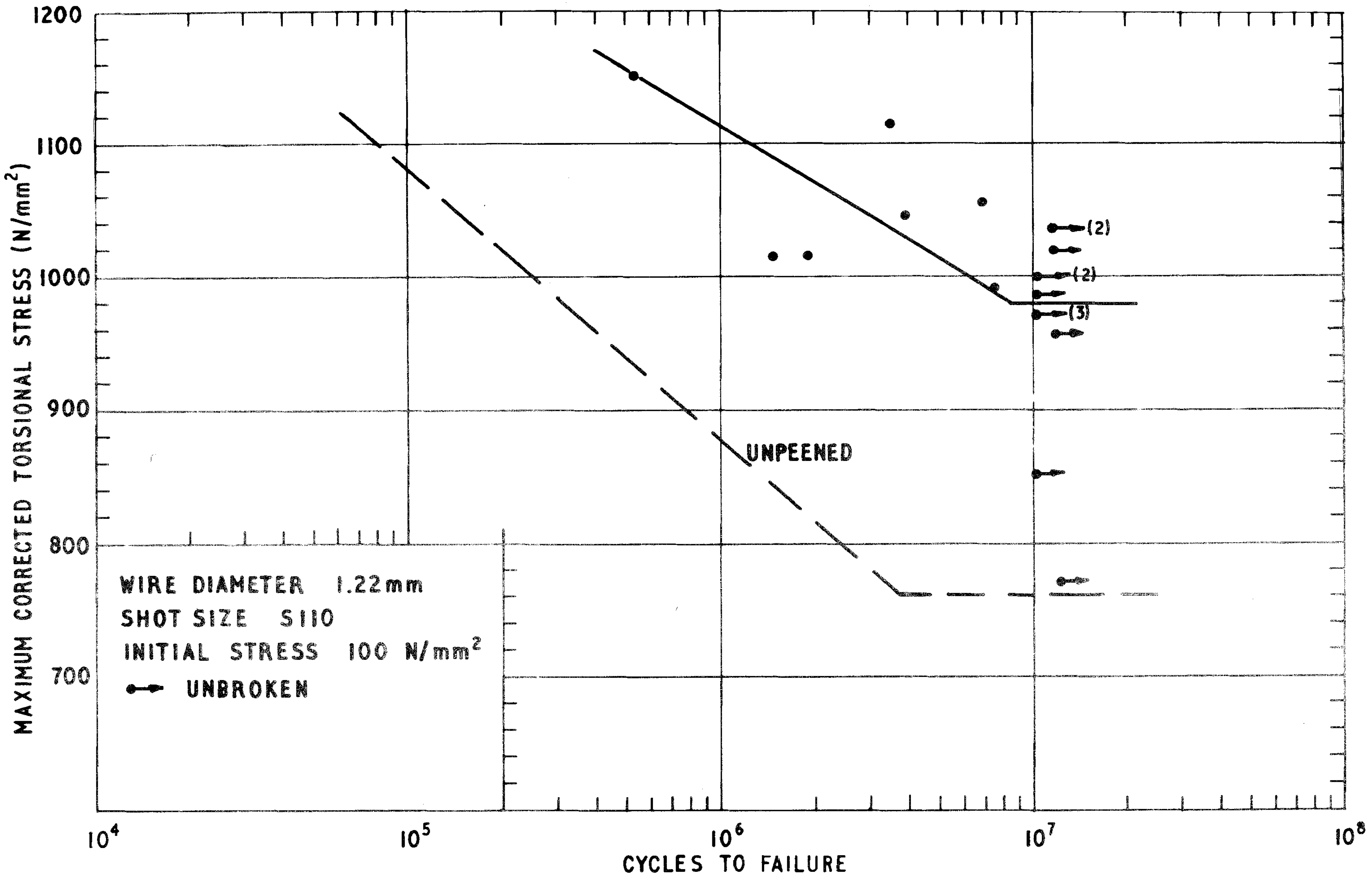

FIG. 1 S/N CURVE FOR SPRINGS FROM 1.22mm WIRE – S110 SHOT

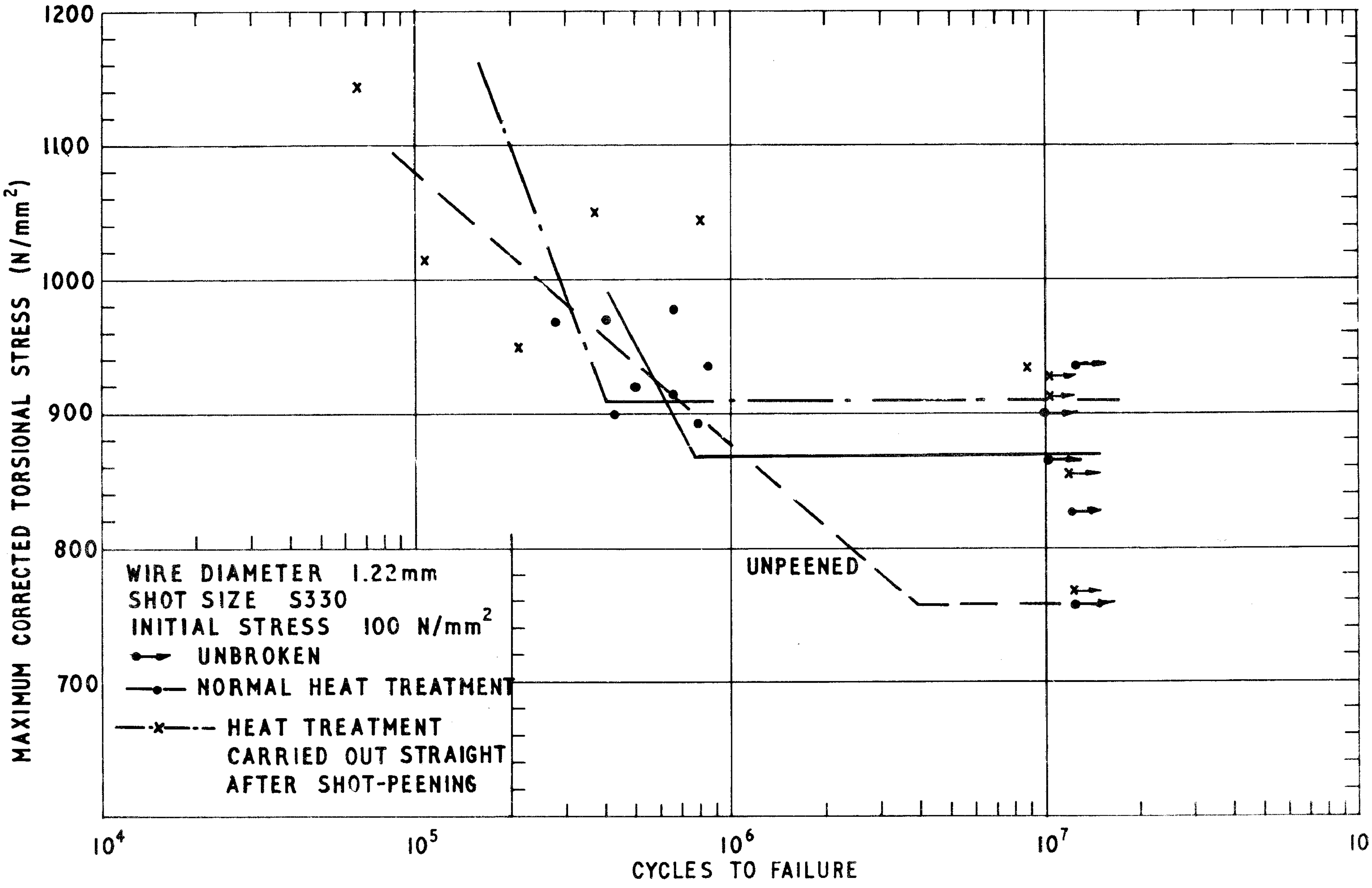

FIG. 2 S/N CURVE FOR SPRINGS FROM 1.22mm WIRE S330 SHOT

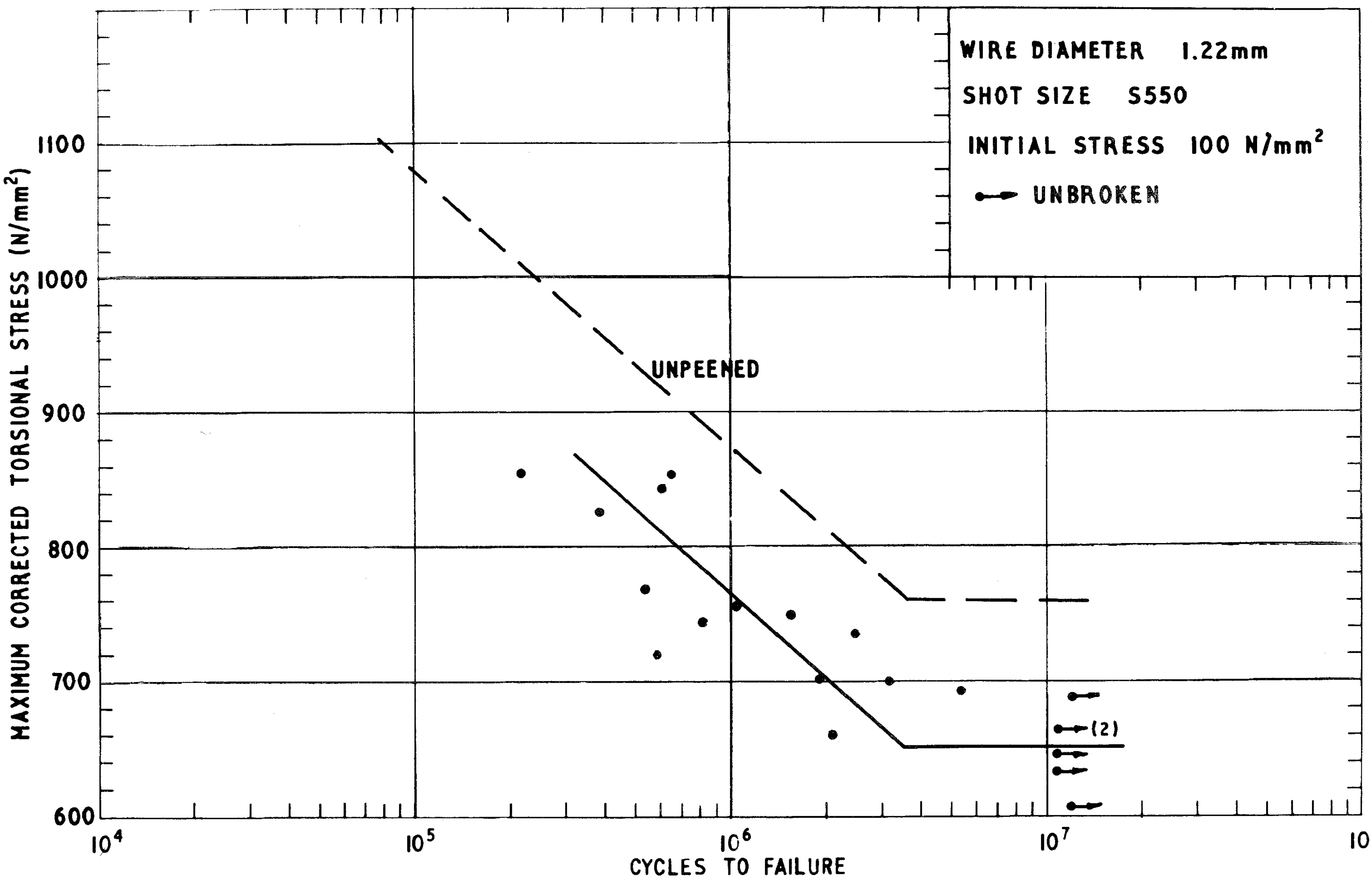

FIG. 3 S/N CURVE FOR SPRINGS FROM 1.22mm WIRE S550 SHOT

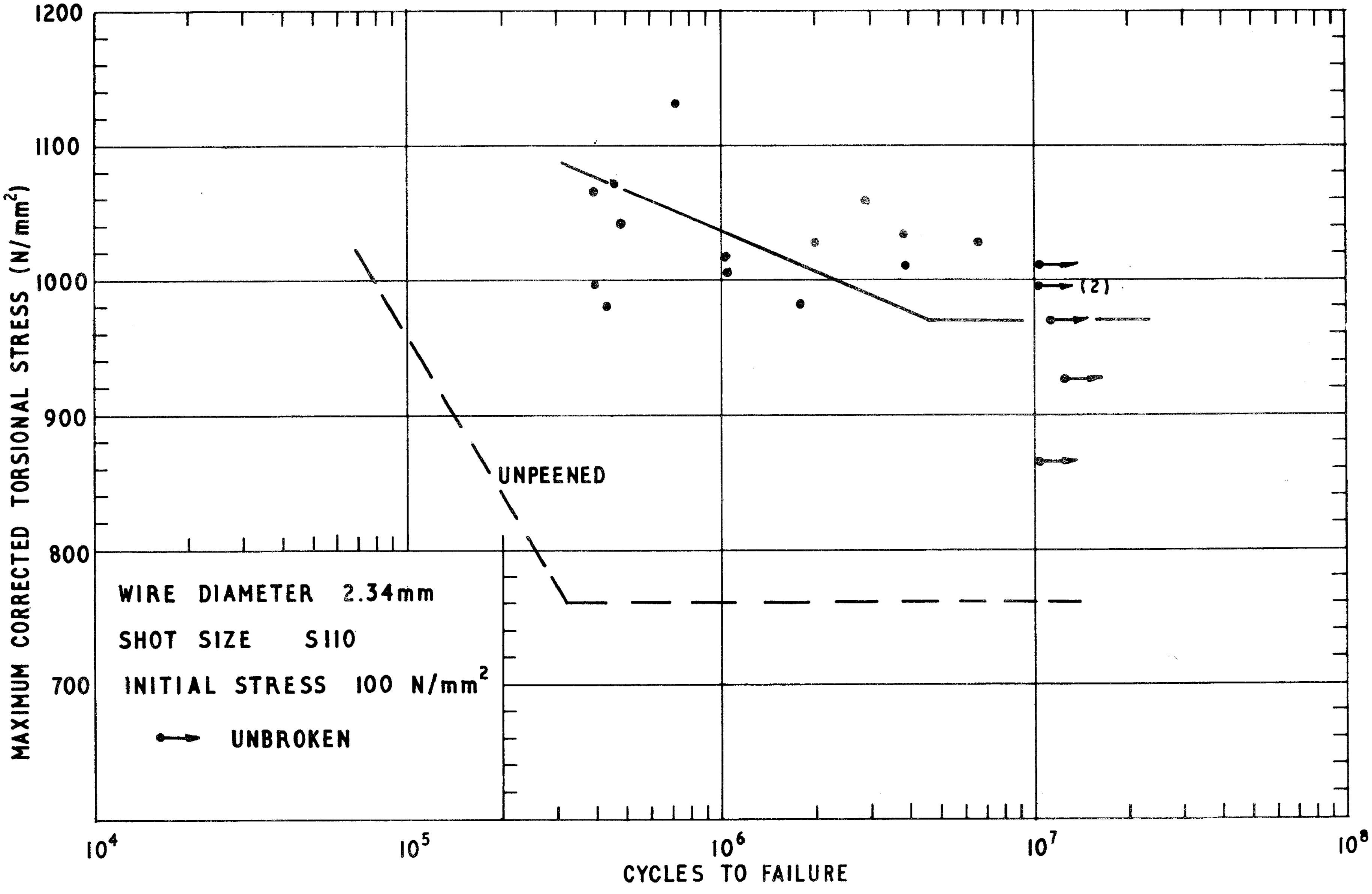

FIG.4 S/N CURVE FOR SPRINGS FROM 2.34mm WIRE S110 SHOT

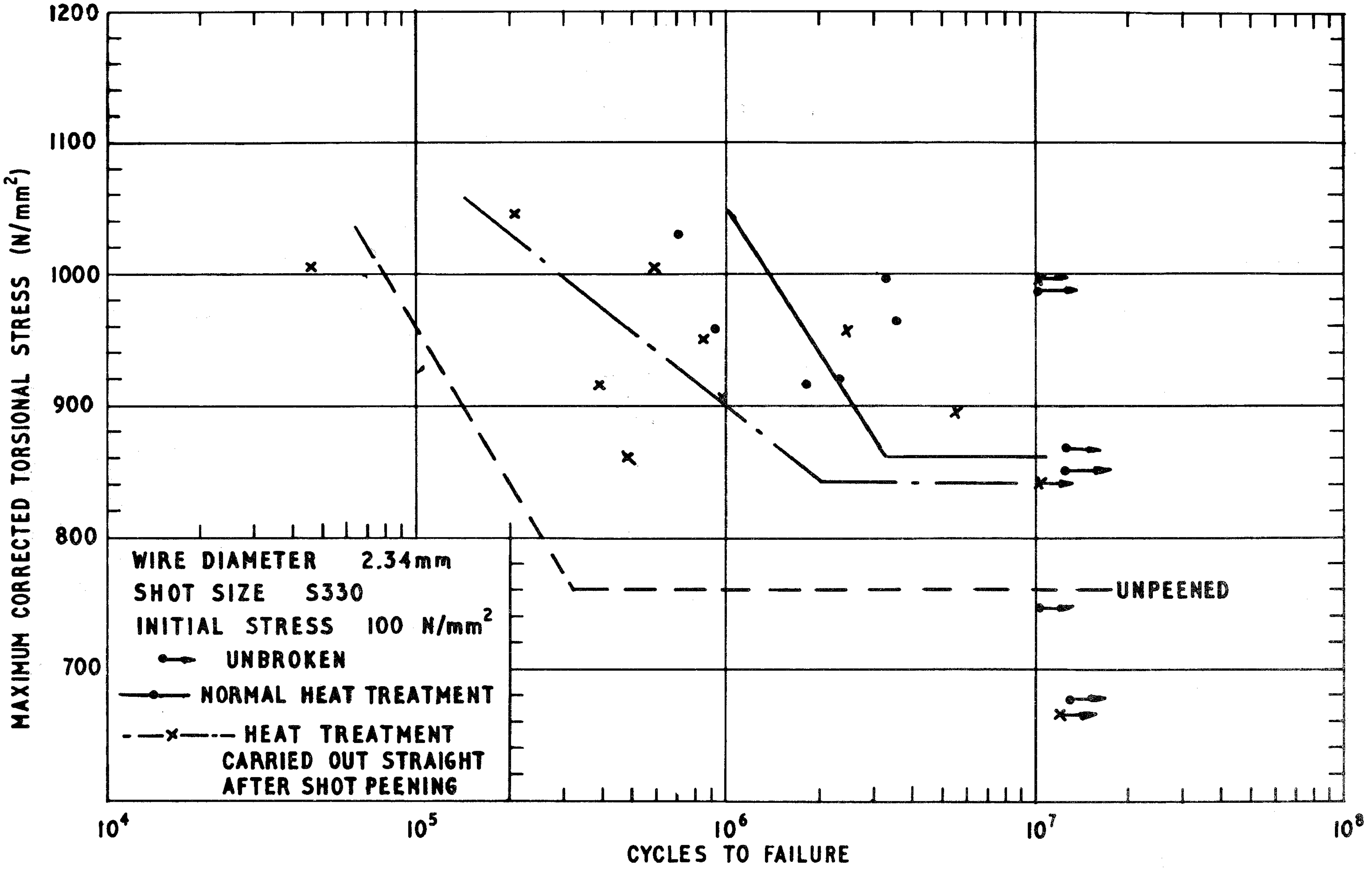

FIG. 5 S/N CURVE FOR SPRINGS FROM 2.34mm WIRE S330 SHOT

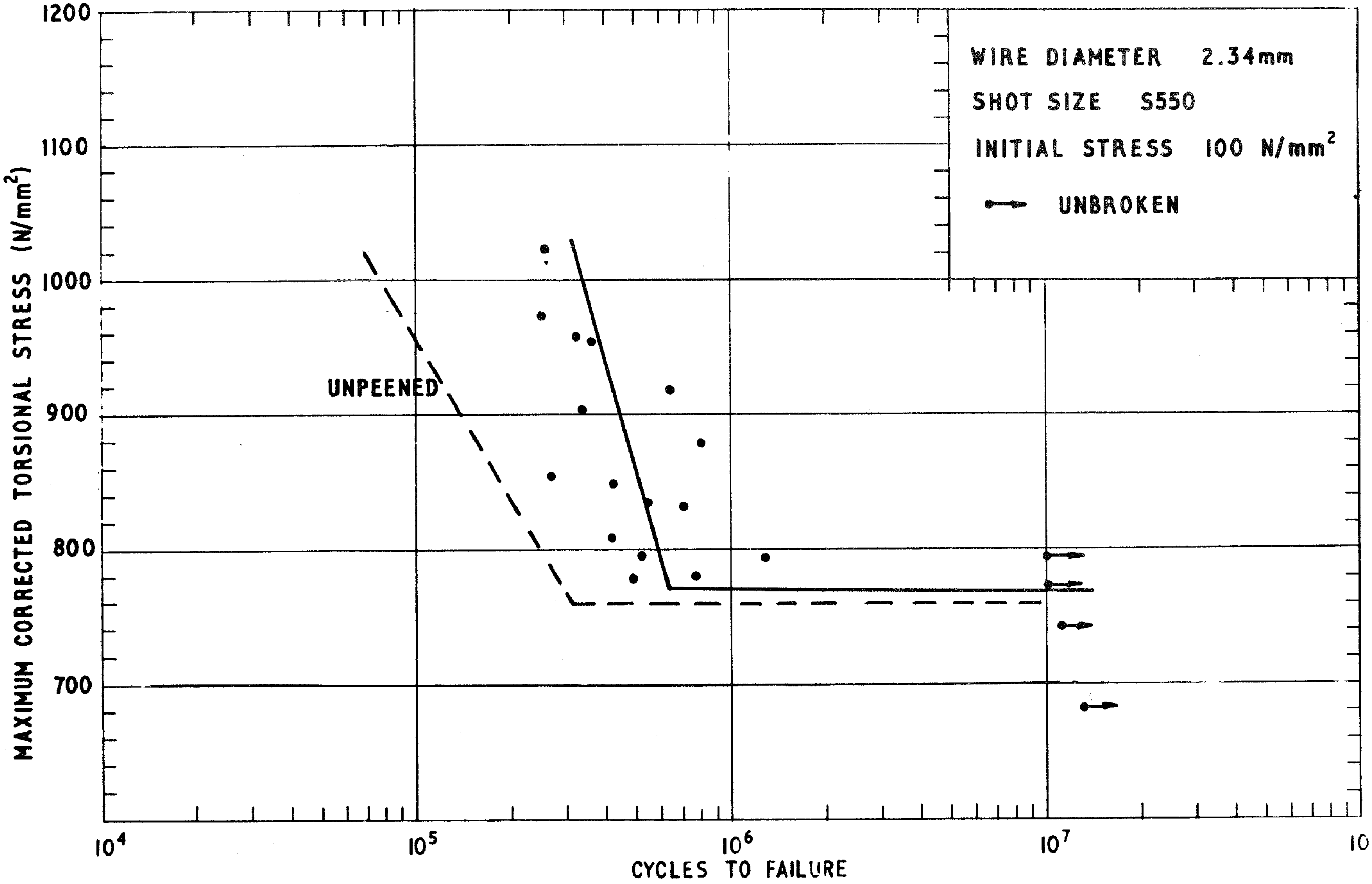

FIG.6 S/N CURVE FOR SPRINGS FROM 2.34mm WIRE S550 SHOT

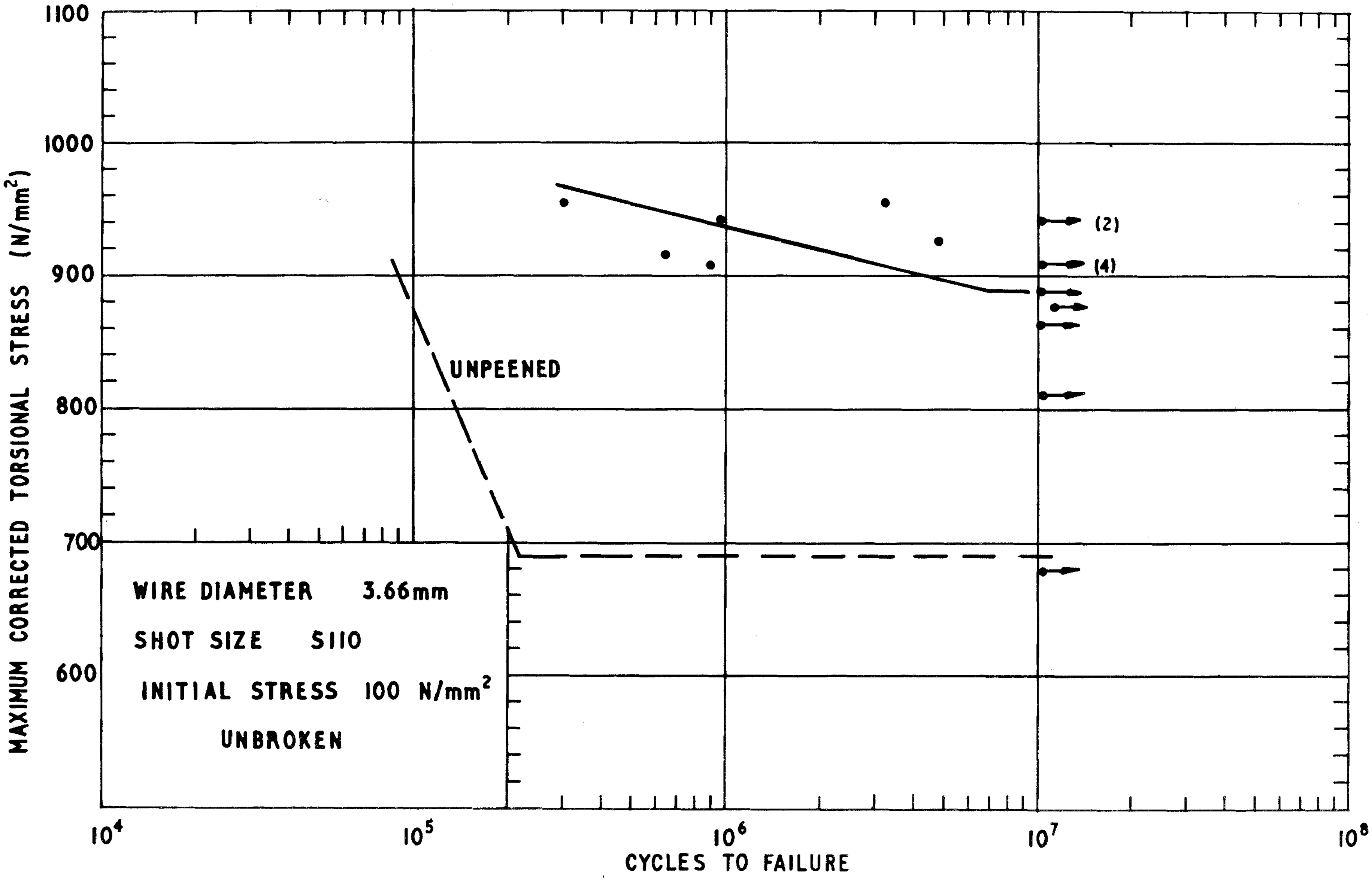

FIG. 7 S/N CURVE FOR SPRINGS FROM 3.66mm WIRE S110 SHOT

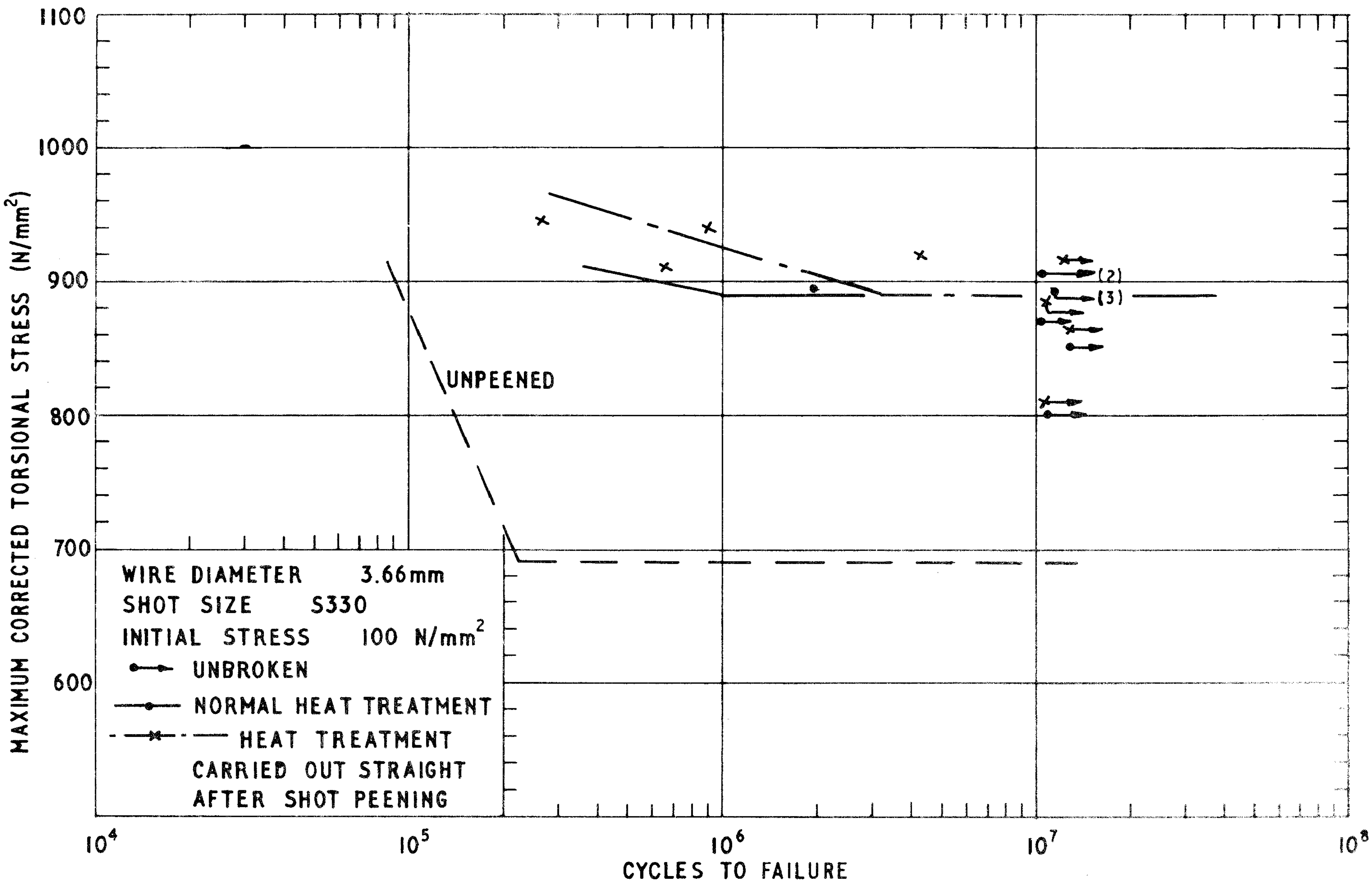

FIG. 8 S/N CURVE FOR SPRINGS FROM 3.66mm WIRE S330 SHOT

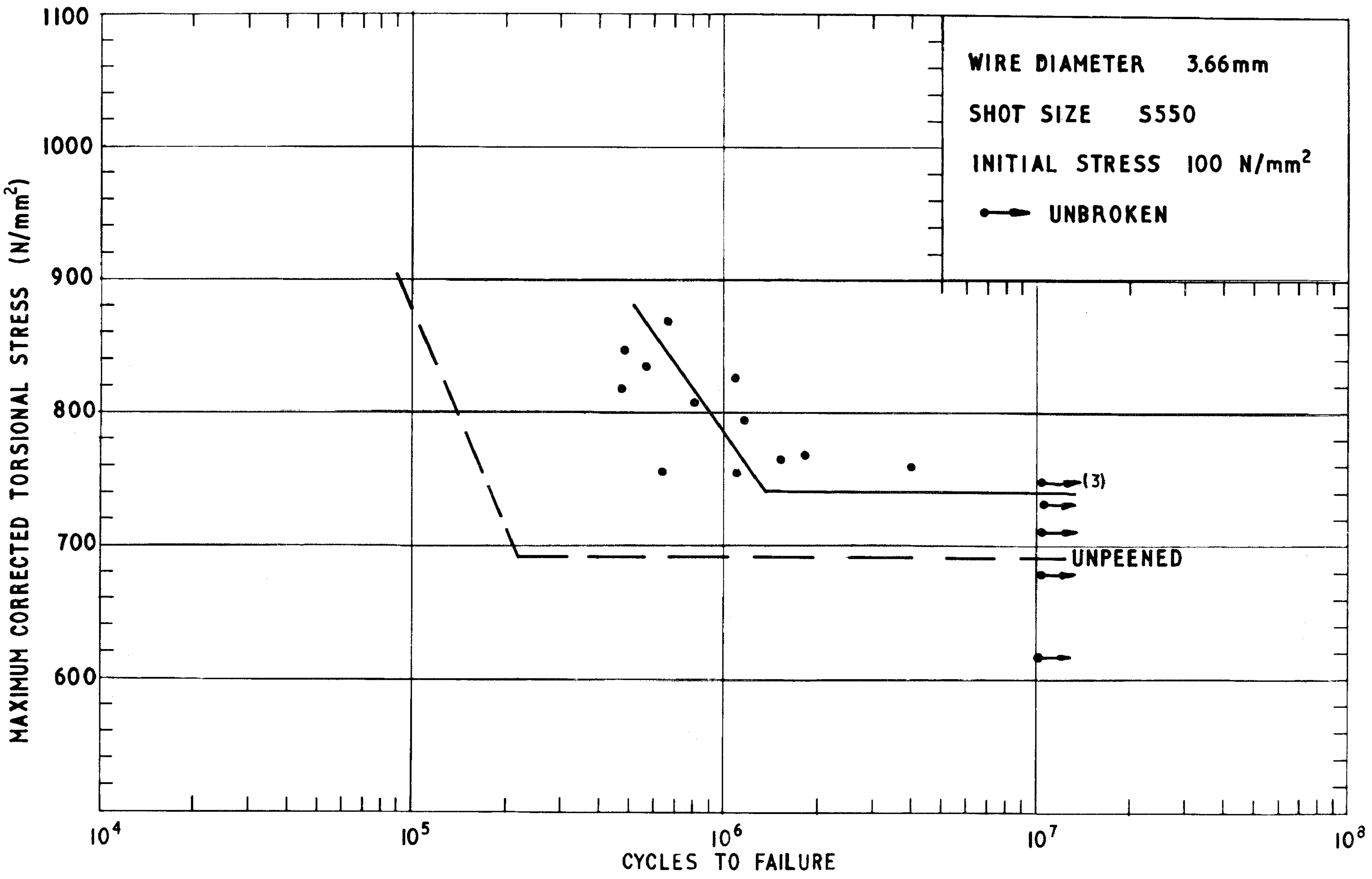

FIG. 9 S/N CURVE FOR SPRINGS FROM 3.66mm WIRE S550 SHOT

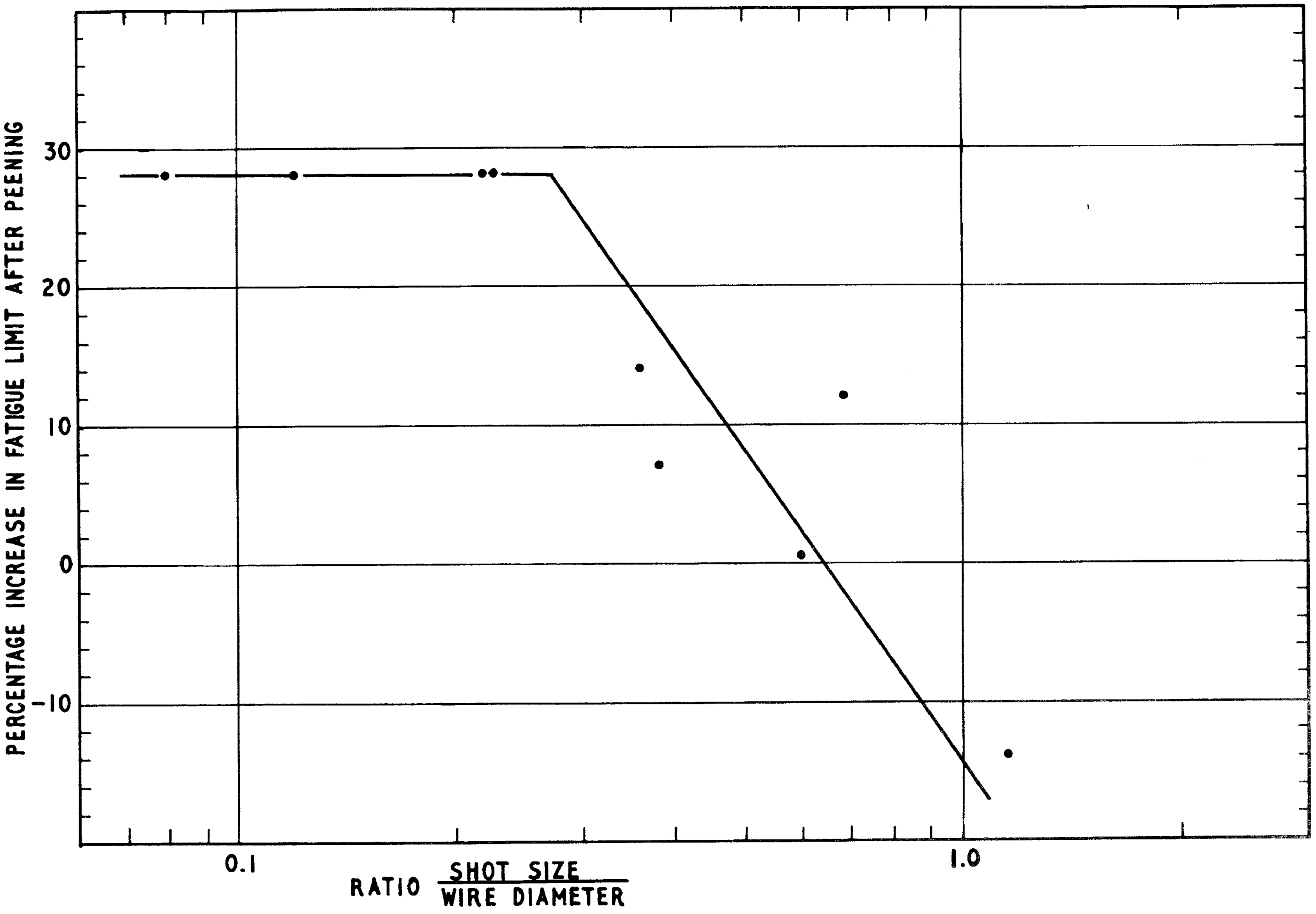

FIG. 10 GRAPH SHOWING EFFECT OF RELATIVE SHOT SIZE ON FATIGUE PERFORMANCE