THE SPRING RESEARCH ASSOCIATION

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

by

G. C. Bird, B.Sc

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1. INTRODUCTION

This part of the report deals with the fatigue data obtained from springs made from two grades of BS 2803, Grades I and II, which are suitable for use in fatigue applications.

The method used to produce the Goodman diagrams is described in Part 1 of the report and reference may be made to this.

2. MATERIAL

2.1 Material Properties

Hardened and tempered carbon steel wire is more expensive than patented and cold drawn wire but can be obtained in higher tensile strengths for wire diameters of 4mm and over. It is available in three surface conditions viz, BS 2803 Grade I, II and III, of which only the first two are suitable for fatigue applications. The material has slightly better stress relaxation properties than patented and cold drawn wire and can be used at temperatures up to 50°C higher for the same relaxation.

Because it requires no subsequent hardening and tempering after spring making it can be used without the fear of subsequent distortion or decarburisation.

2.2 Material specification

2.2.1 Tensile strength

The tensile strength for the wire diameter, 4mm, used is specified as 1470 - 1620 N/mm^2 (95- 105 tonf/in^2) for both Grades.

2.2.2 Decarburisation

Grade I - High Duty Wire (Ground):-
The prepared section shall show no decarburised zone.
Grade II - High Duty Wire:-
The prepared section shall show no totally decarburised zone. Partial decarburisation shall not extend farther below the surface than $1\frac{1}{2}$ per cent of the nominal diameter of the wire (0.06 mm for 4mm wire).

2.2.3 Chemical composition

The composition specified is given in Table 1.

3. SPRING DESIGN

The spring design specified was as detailed in Part 1 of the report. After coiling, all springs were given a low temperature heat treatment of 400°C for half an hour. Springs that had been shot peened were subsequently given a further heat treatment of 220°C for half an hour.

The parameters of the springs supplied by each of the four manufacturers are given in Table 3.

4. ANCILLIARY INVESTIGATION

4.1 Chemical analysis

A spring sample from each supplier was checked for each of its principle alloying elements to determine the chemical composition. The results obtained are given in Table 2.

4.2 Hardness determination

Because no wire samples were available from any supplier, an estimate of the tensile strength had to be determined from the hardness of a spring sample. The hardness levels and the approximate equivalent tensile strengths are given in Table 4. The hardness measurements given are the average of three readings.

4.3 Microstructure examination

Transverse and longitudinal microsections of springs from each supplier were prepared and examined for any internal defects and for variation in structure. All specimens examined had a typical tempered martensite structure and no decarburisation was found on springs from either Grade I or Grade II wire. The surface condition of the springs from each supplier was examined and all springs were found to have a good surface finish. Figs. 9 and 10 are photomicrographs of a transverse section of springs from Grade I, supplier 3 and Grade II, supplier 2 respectively, being representative of each grade.

5. FATIGUE TESTING

The fatigue testing to produce the Goodman diagrams was carried out as described in Part 1 of this report. Tables 4 and 5 give values of the fatigue limit for springs from each supplier and the stress relaxation, measured as a percentage loss in load for the fatigue limit at an initial stress of 300 N/mm^2, for Grade I and II material in the peened and unpeened conditions.

The Goodman diagrams for Grade I are shown in Figs. 1 and 2 for the unpeened springs and Figs. 3 and 4 for the shot peened springs. For Grade II springs the Goodman diagrams for the unpeened springs are shown in Figs. 5 and 6 and for the shot peened springs in Figs. 7 and 8. As explanined in Part 1 of the report the Goodman diagrams produced from the infinite life data show only the 95% Confidence level.

6. DISCUSSION OF RESULTS

6.1 BS 2803 Grade I

Table 2 shows that the chemical composition of the springs from all four suppliers lay within the specification.

No decarburisation was detected on any of the microstructures examined and all samples had the typical material structure, that of a sample from supplier 1 having a slightly coarser structure than the others.

The solid stress of the springs varied from supplier to supplier as Table 3 shows, with the springs from supplier 3 having the lowest. The recommended maximum solid stress for this material is 70% of the tensile strength, which for this particular wire size is approximately 1030 N/mm^2.

The tensile strengths (Table 4) estimated from the hardness measurements can only be approximate, but they indicate the wire of springs from suppliers 2, 3 and 4 lay at the lower end of the tensile specification.

Unpeened springs

The fatigue limits for the unpeened springs are shown in Table 4 from which it can be seen that springs from supplier 1 had the lowest fatigue strength at both initial stresses. The difference between the fatigue strengths of all suppliers was only 60 N/mm^2 and the differences are the same at both initial stress levels. Regarding the production of the finite life data, the majority of the springs which had broken by the 90% confidence level were from supplier 1. This is not what would be expected as the springs from this supplier had the highest solid stress and the wire had the highest tensile strength. The dynamic relaxation of the springs was calculated as the percentage loss in maximum load after the springs had completed 10^7 cycles when stressed between 300 N/mm^2 and the fatigue limit of the spring. For unpeened springs from all suppliers the relaxation measured was less than $1\frac{1}{2}$%.

The Goodman diagram for 10^5 cycles is shown in Fig. 1 and that for 10^6 and 10^7 cycles in Fig. 2.

Shot-peened springs

The shot-peened springs from supplier 2 had not been lanolin dipped before delivery and were found to be rusting, so before fatigue testing commenced they were shot-peened and heat-treated again in the Association's plant. The shot peened springs from suppliers 1 and 2 had very similar fatigue properties and formed all the springs that were broken for the 90% confidence level. Springs from these two batches also had the least dynamic relaxation.

Springs from supplier 3 and 4 appeared to have a very good fatigue performance and the dynamic relaxation in the springs was very high, of the order of 10%.

When the finite life data was obtained for the shot-peened springs, no springs were broken before 10^5 cycles at either initial stress level, even when tested to as high a stress level as possible. Therefore the Goodman diagram for 10^5 cycles (Fig. 3) for the shot-peened springs has been drawn with the 99% confidence level the same slope as that for 10^7 cycles (Fig. 4) through a point representing the maximum testing stress with 100 N/mm^2 initial stress.

6.2 BS 2803 Grade II

All the samples of springs from Grade II wire had a chemical composition within that specified. The tensile strengths estimated from the hardness values showed the wire from suppliers 2 and 3 to have approximately the minimum specified tensile strength, and that from supplier 4, had the highest tensile strength of the four batches.

When the microstructures of the spring samples were examined, all had the same type of ~~structure~~ and although permissible in the specification, no decarburisation was found.

Unpeened springs

As for the springs from Grade I quality, those from supplier 1 had the highest solid stress and those from supplier 3 and 4 the lowest. The fatigue performance of the springs was very similar to that of the springs from Grade I wire for infinite life but markedly poorer for shorter endurances, as can be seen from the Goodman diagrams in Figs. 5 and 6. This was principally because springs from supplier 3 formed all of those broken to produce the 90% confidence limit and also had the lowest fatigue limit. Because of the poor fatigue performance of the springs at 300 N/mm^2 initial stress, the shape of the Goodman diagram is different from Grade I wire.

One would expect the fatigue properties of Grade II wire not to be as good as that of Grade I wire which had been ground during some stage of manufacture to remove any decarburisation present. The similarity of the infinite life fatigue properties between the two grades is probably because of the lack of decarburisation in the Grade II wire.

Shot-peened springs

The fatigue performance of the shot peened Grade II springs was markedly lower than that of the Grade I springs. This may have been due to the fact that the springs from supplier 2, which were the poorest in Grade II wire (thus depressing the average fatigue performance) were above average in the Grade I wire. They had been shot peened again by S.R.A. which may have improved their fatigue performance.

For the same reason as for the Grade I springs, no fatigue data could be obtained for the shot peened springs at 10^5 cycles so the Goodman diagram for Grade II springs at 10^5 cycles (Fig. 7) was drawn in a similar manner to that for Grade I. The shot peened springs from supplier 3 had such a high relaxation that the fatigue limit could not be obtained at any initial stress. No particular reason for this very high figure, 13%, could be determined as the springs were prestressed during load testing and the hardness of the shot peened springs was approximately the same as that of the unpeened ones.

The dynamic relaxation of the unpeened Grade II springs was similar to that of the Grade I springs. The relaxation of the shot peened Grade II springs, with the exception of those from supplier 3, was less than that recorded for the Grade I springs.

Fig. 8 shows the Goodman diagram for 10^7 cycles for shot peened springs of Grade II material.

TABLE 1 SPECIFIED CHEMICAL COMPOSITION

ELEMENT	Percentage	
	MINIMUM	MAXIMUM
Carbon	0.55	0.75
Silicon	---	0.30
Manganese	0.60	0.90
Sulphur	---	0.040
Phosphorus	---	0.040

TABLE 2 ACTUAL CHEMICAL COMPOSITION

	CARBON %	SILICON %	MANGANESE %
GRADE I SUPPLIER 1	0.70	0.23	0.87
GRADE I SUPPLIER 2	0.67	0.22	0.74
GRADE I SUPPLIER 3	0.66	0.22	0.74
GRADE I SUPPLIER 4	0.68	0.22	0.74
GRADE II SUPPLIER 1	0.65	0.22	0.86
GRADE II SUPPLIER 2	0.66	0.25	0.74
GRADE II SUPPLIER 3	0.66	0.24	0.75
GRADE II SUPPLIER 4	0.68	0.23	0.74

TABLE 3 ACTUAL SPRING DIMENSIONS

BS 2803 GRADE I

	SUPPLIER			
	1	2	3	4
WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	29.6	30.0	30.0
SPRING INDEX	7.5	7.4	7.5	7.5
SPRING RATE (N/mm)	26.4	27.3	26.8	27.5
FREE LENGTH (mm)	50.0	50.0	47.5	49.0
SOLID STRESS (N/mm^2)	1110	1070	1025	1050

BS 2803 GRADE II

	SUPPLIER			
	1	2	3	4
WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	29.6	30.0	30.0
SPRING INDEX	7.5	7.4	7.5	7.5
SPRING RATE (N/mm)	28.0	27.0	26.5	26.1
FREE LENGTH (mm)	49.8	50.0	47.8	49.5
SOLID STRESS (N/mm^2)	1200	1100	1040	1040

TABLE 4 SPRING PROPERTIES - BS 2803 GRADE I

	SUPPLIER			
	1	2	3	4
HARDNESS (Hv 30)	473	451	451	451
EQUIVALENT TENSILE STRENGTH	1530	1460	1460	1460
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	680	700	720	740
FATIGUE LIMIT at 300 N/mm^2 Initial stress	800	820	840	860
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.2%	0.7%	1.6%	0.6%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	880	880	920	1040
FATIGUE LIMIT at 300 N/mm^2 Initial stress	980	980	1040	---
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	3.4%	6.8%	8.4%	9.4%

TABLE 5 SPRING PROPERTIES - BS 2803 GRADE II

	SUPPLIER			
	1	2	3	4
HARDNESS (Hv 30)	467	449	449	478
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1515	1455	1455	1550
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	700	720	680	720
FATIGUE LIMIT at 300 N/mm^2 Initial stress	820	820	800	840
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.5%	0.7%	1.6%	0.6%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	840	800	---	880
FATIGUE LIMIT at 300 N/mm^2 Initial stress	960	880	---	980
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	3.4%	1.0%	13.2%	3.4%

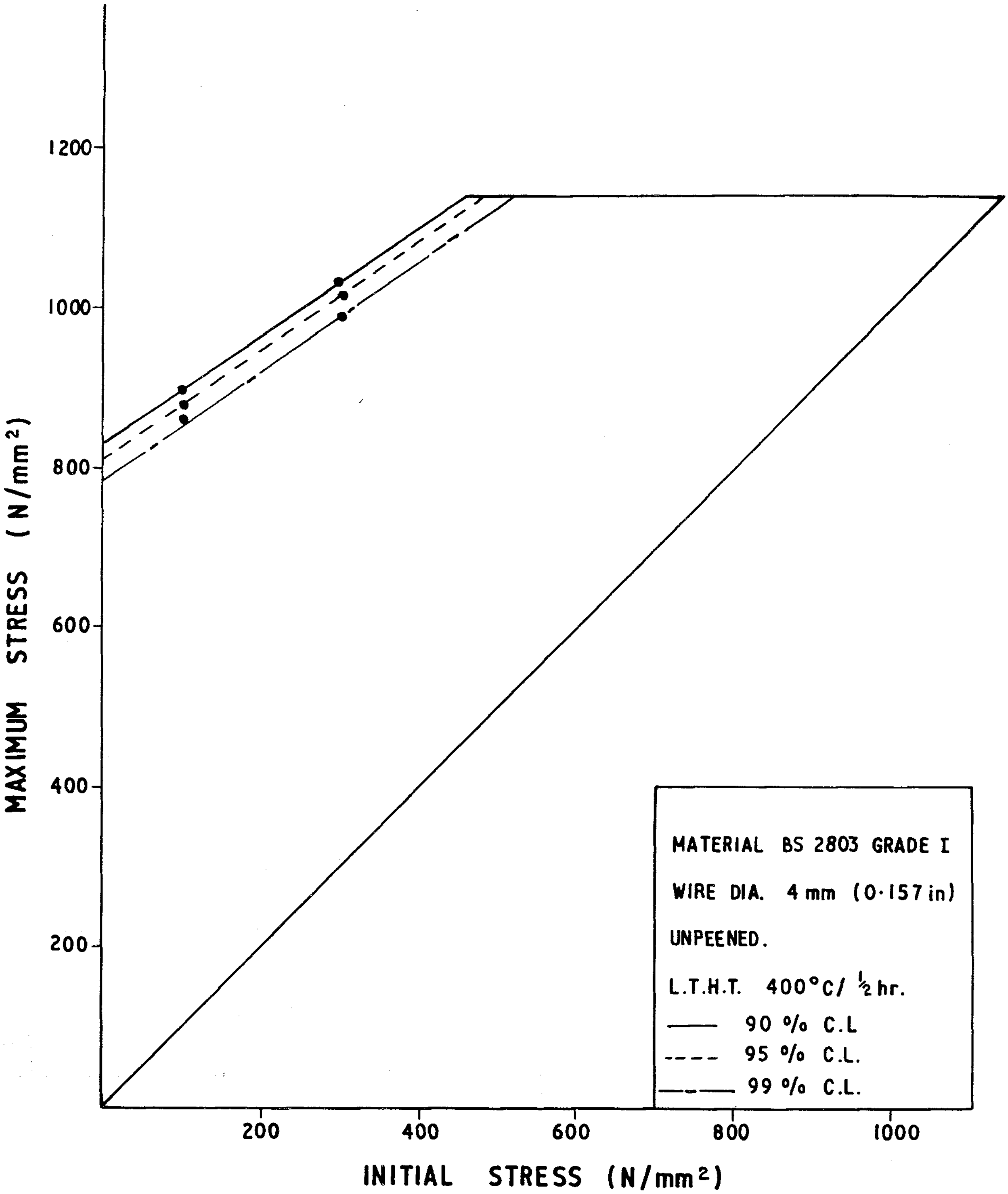

FIG. 1 GOODMAN DIAGRAM FOR BS 2803 GRADE I UNPEENED 10^5 CYCLES.

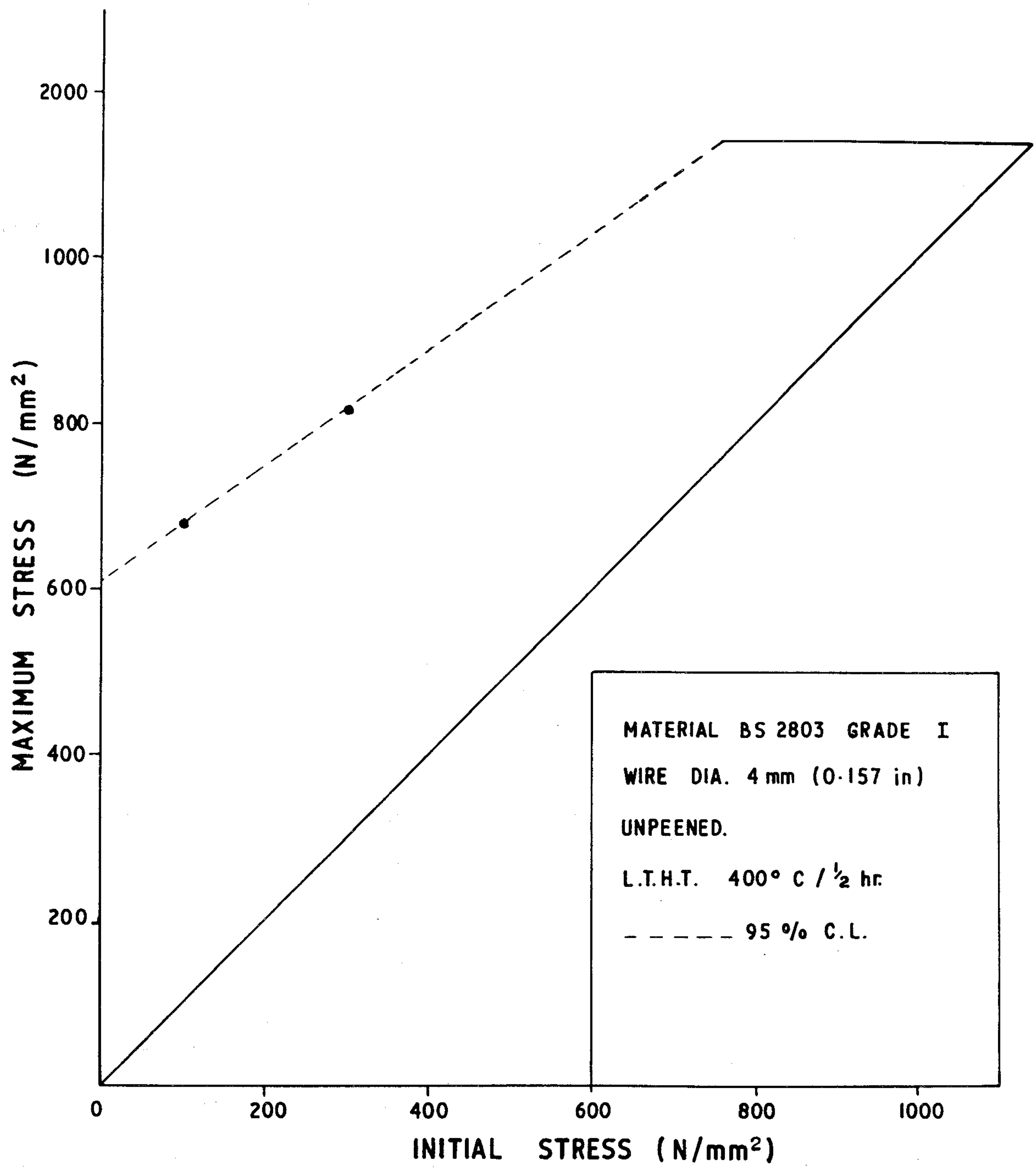

FIG. 2. GOODMAN DIAGRAM FOR BS 2803 GRADE I UNPEENED 10^6 AND 10^7 CYCLES.

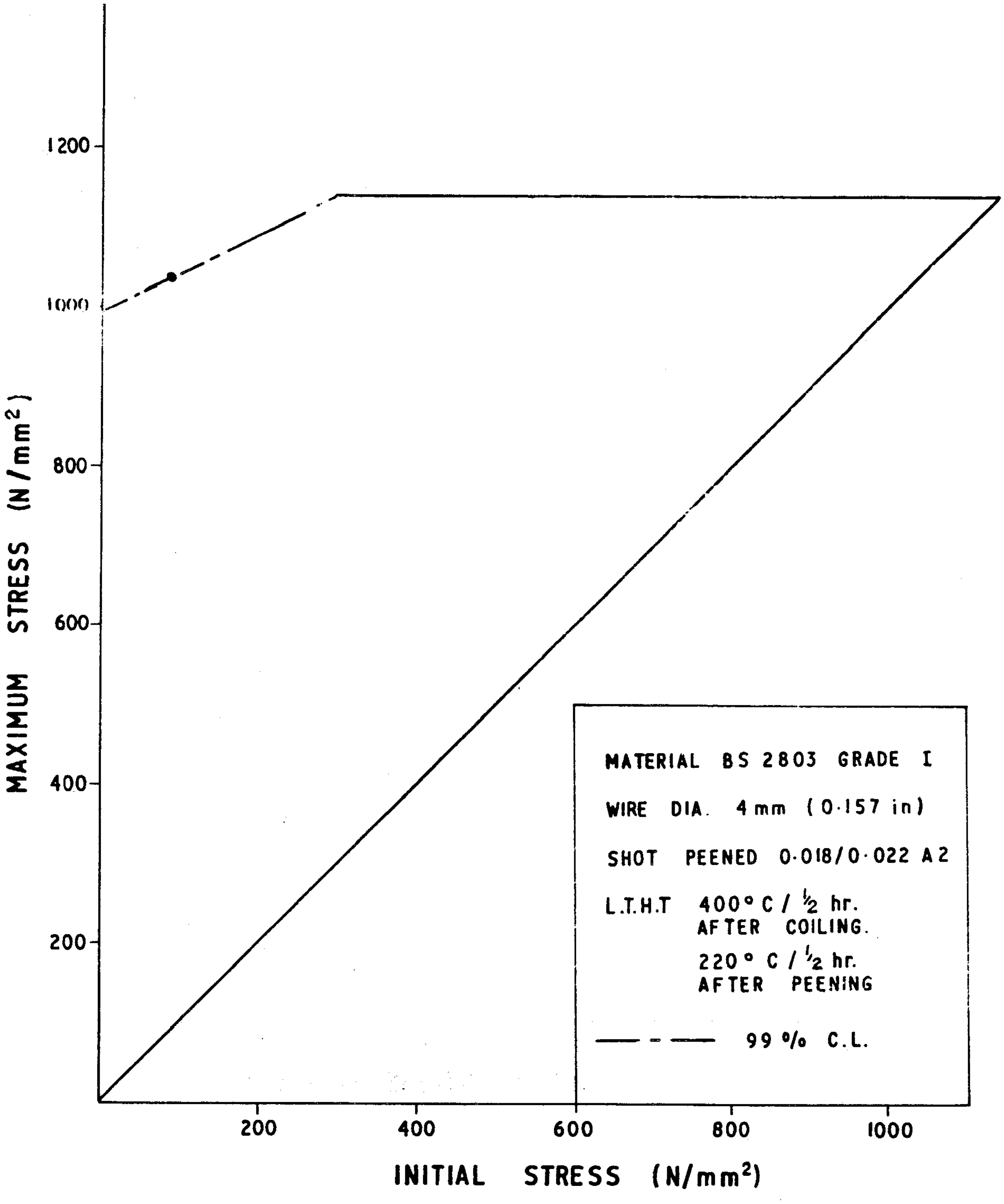

FIG. 3 GOODMAN DIAGRAM FOR BS 2803 GRADE I SHOT PEENED 10^5 CYCLES.

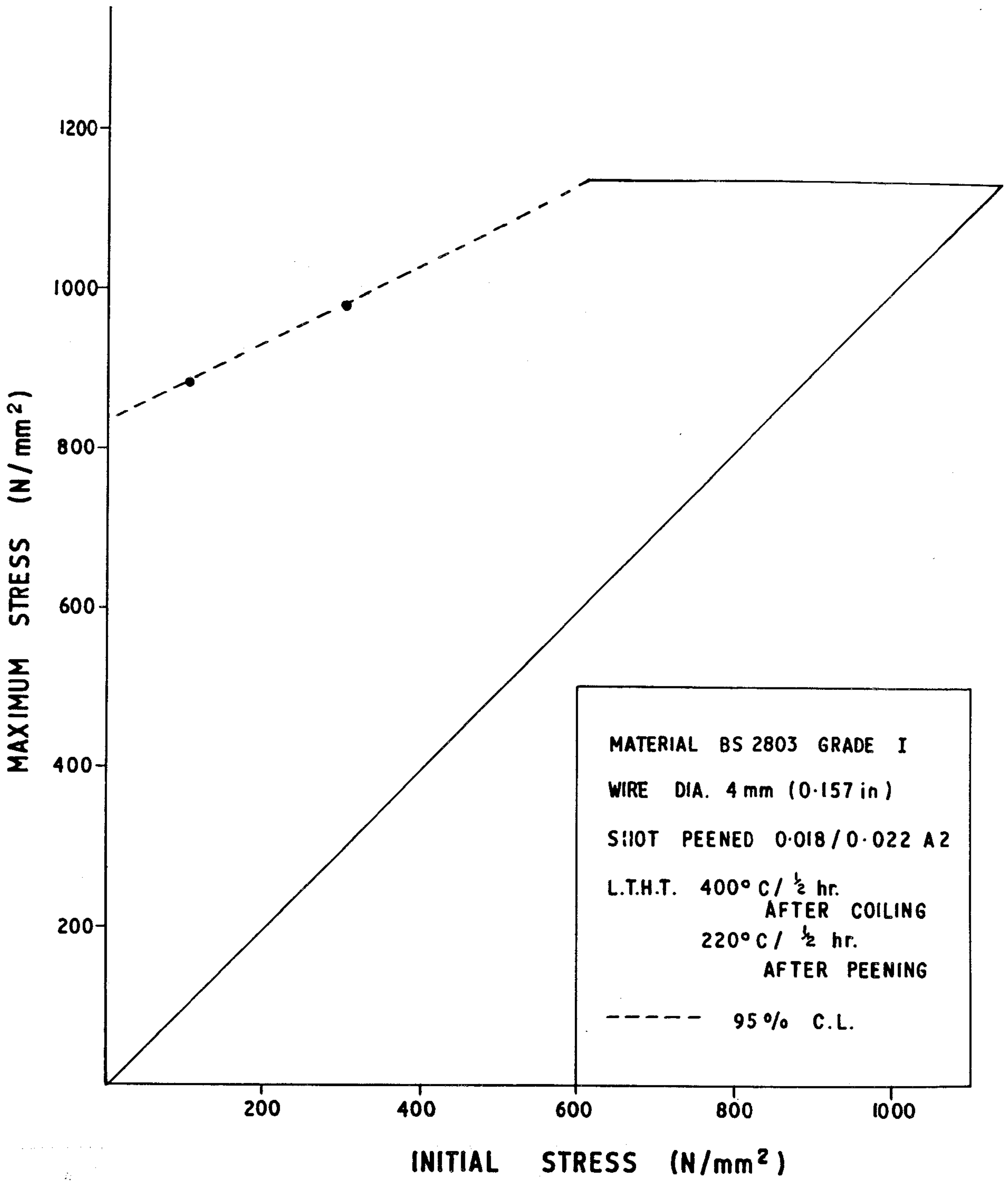

FIG. 4 GOODMAN DIAGRAM FOR BS 2803 GRADE I SHOT PEEN 10^6 AND 10^7 CYCLES

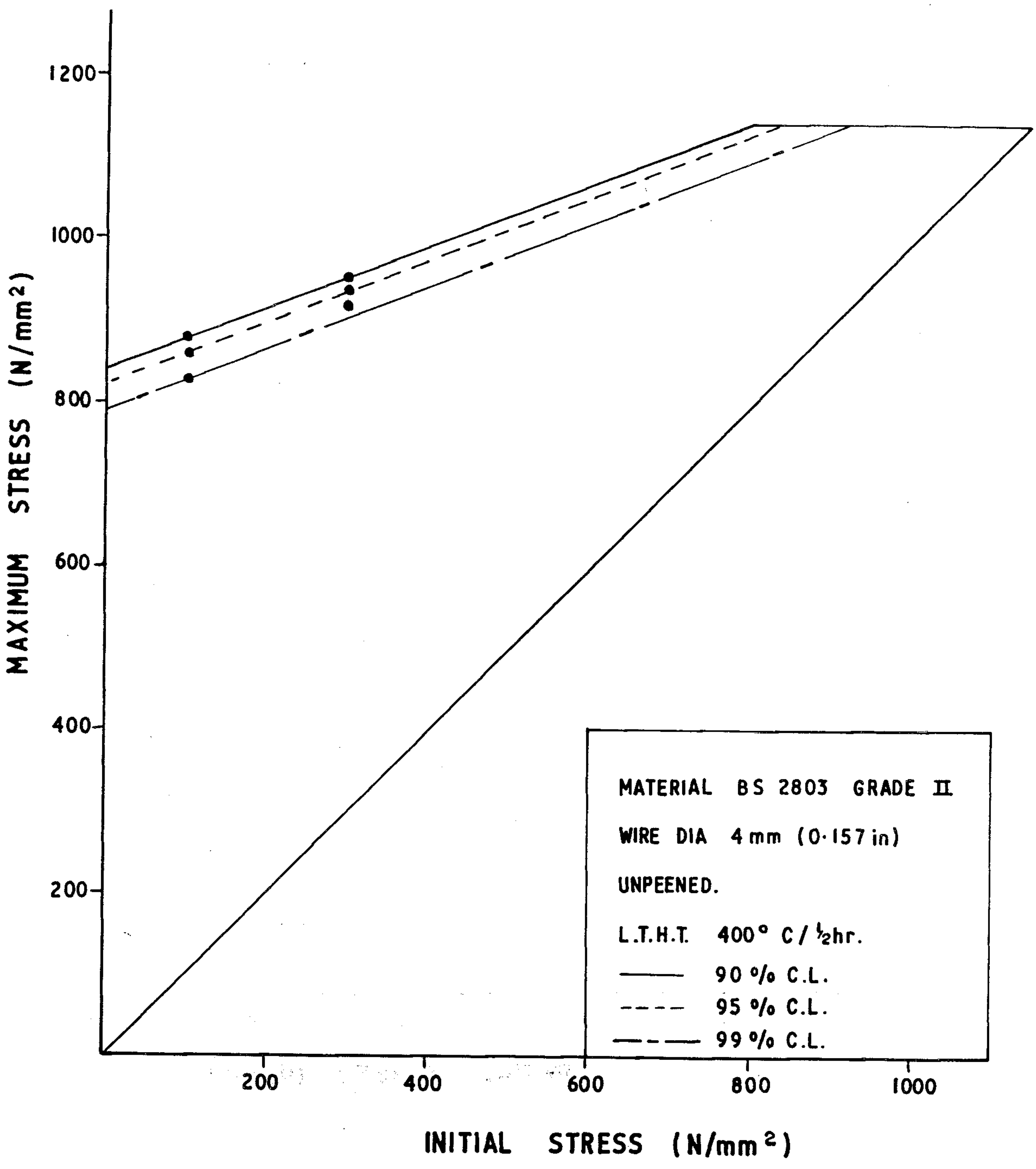

FIG. 5 GOODMAN DIAGRAM FOR BS 2803 GRADE II UNPEENED 10^5 CYCLES.

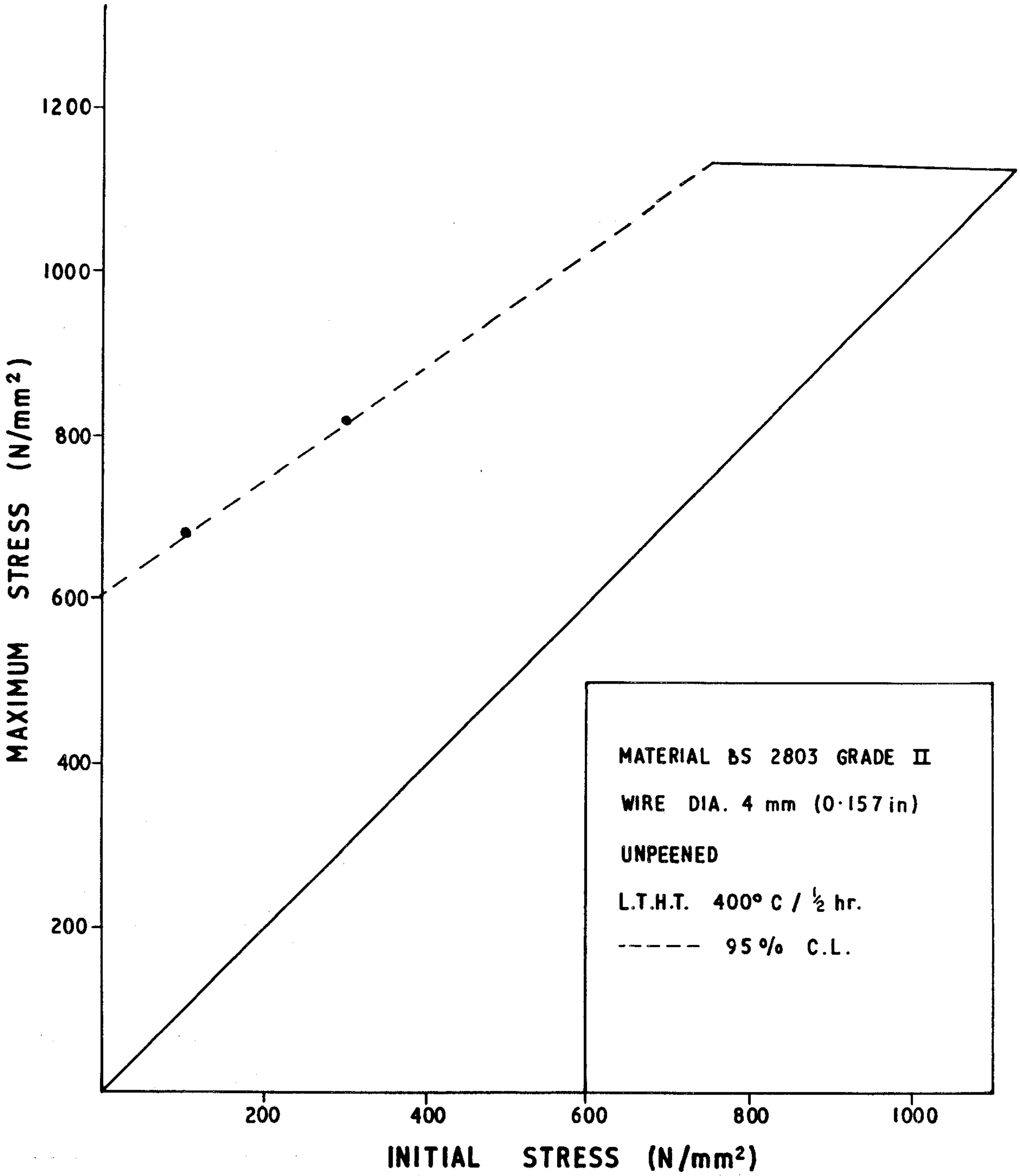

FIG. 6 GOODMAN DIAGRAM FOR BS 2803 GRADE II UNPEEN
10^6 AND 10^7 CYCLES.

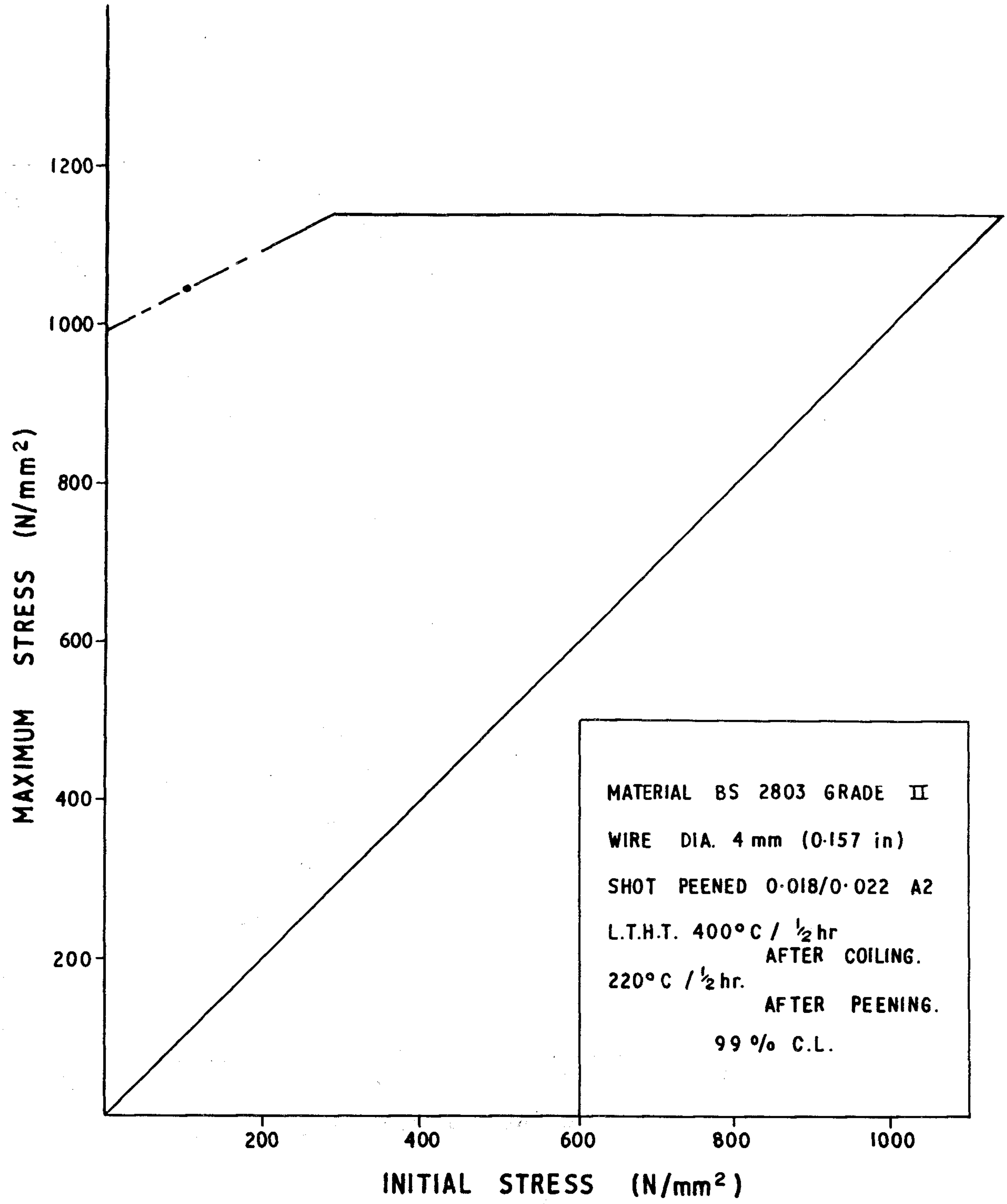

FIG. 7 GOODMAN DIAGRAM FOR BS 2803 GRADE II SHOT PEENED
10^5 CYCLES.

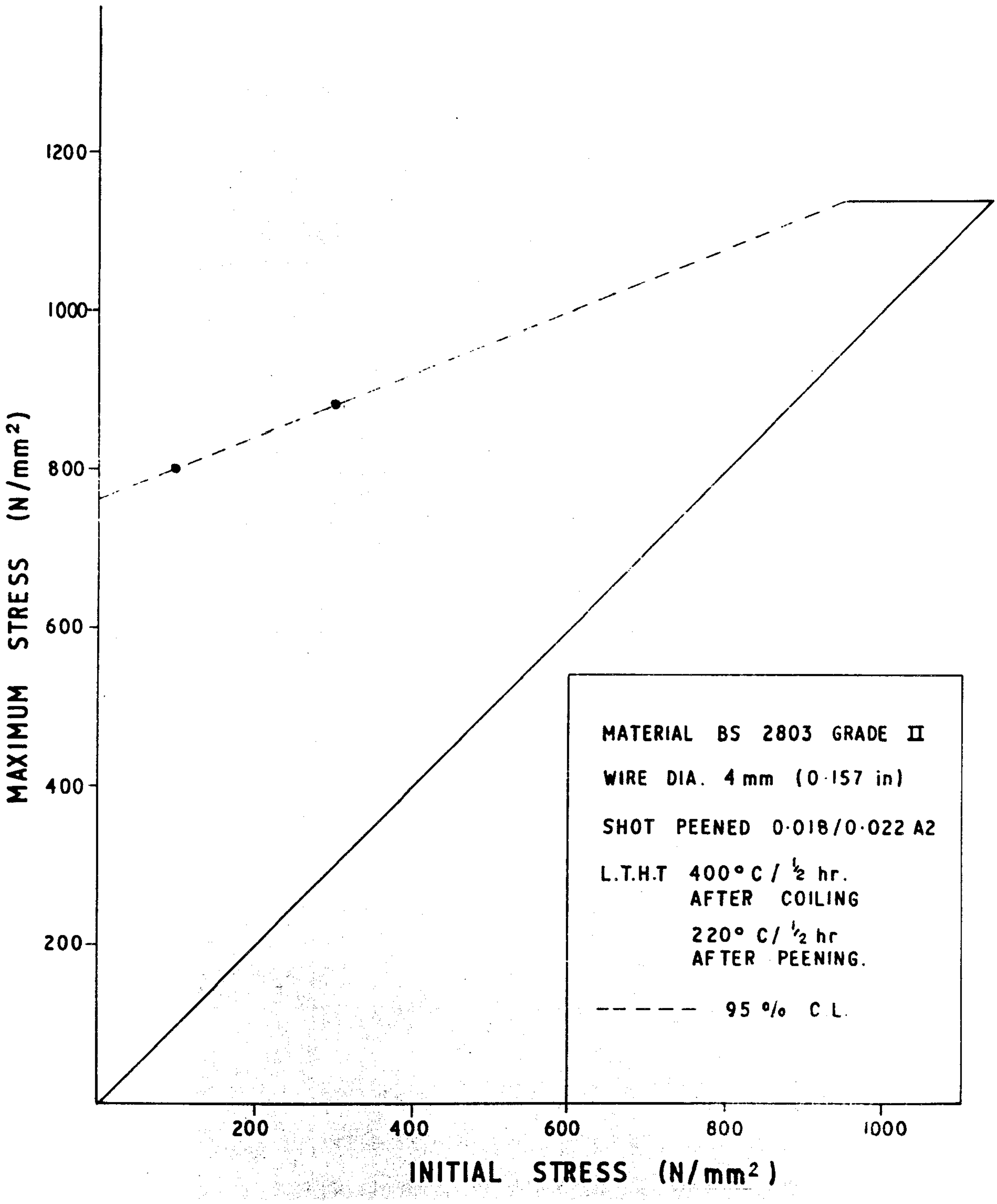

FIG. 8 GOODMAN DIAGRAM FOR BS 2803 GRADE II SHOT PEENED 10^6 AND 10^7 CYCLES.

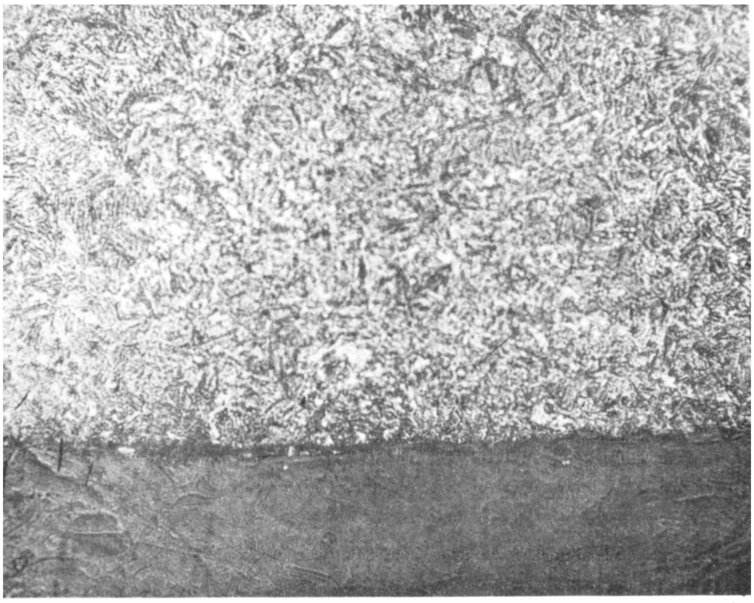

FIG. 9 (x400)

PHOTOMICROGRAPH OF SURFACE AND STRUCTURE OF BS 2803 GRADE I SPRING FROM SUPPLIER 3

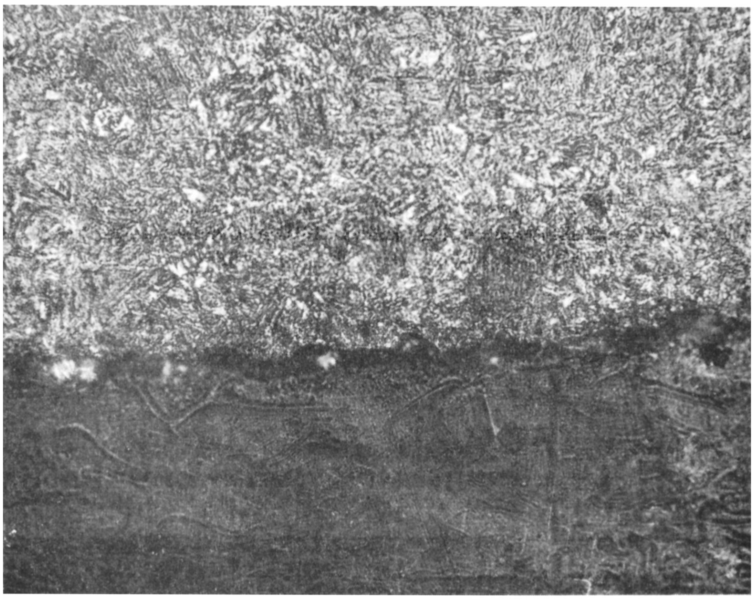

FIG. 10 (x400)

PHOTOMICROGRAPH OF SURFACE AND STRUCTURE OF BS 2803 GRADE II SPRING FROM SUPPLIER 2