THE SPRING RESEARCH ASSOCIATION

THE PRODUCTION OF SPRING FATIGUE DATA WITH STATISTICAL LEVELS OF CONFIDENCE

Part 2 of 7 parts

THE FATIGUE PROPERTIES OF SPRINGS MANUFACTURED FROM PATENTED COLD DRAWN STEEL SPRING WIRE TO BS 1408 C AND D

by

G. C. Bird, B.Sc.

Report No. 224

(February 1974)

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8. FIGURES

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1. INTRODUCTION

This part of the report deals with the fatigue data obtained from springs made from two grades of wire to BS 1408, Grade C high duty unground and Grade D high duty ground, and in three tensile ranges, Range 1, Range 2 and Range 3.

The method used to produce the Goodman diagrams is described in Part 1 of this report.

2. MATERIAL

2.1 Material Properties

Patented cold drawn spring steel wire to BS 1408 is the cheapest and most widely used spring steel material. It can be obtained in sizes between 0.25 mm (0.01 in) and 10.5 mm (0.413 in) and in three qualities:- BS 1408B - steel spring wire, BS 1408C - High duty unground steel spring wire, and BS 1408D - High duty ground steel spring wire. Only the last two qualities are recommended for fatigue applications and were used in the investigation. Each quality can be obtained in three ranges of tensile strength, viz: Ranges 1, 2 and 3, in increasing order of tensile strength.

Generally, BS 1408D is the cheapest and BS 1408D the most expensive, though there is little variation in cost for different tensile ranges of the same quality.

The main disadvantage of the material is the poor stress-relaxation property; therefore it is only recommended for use at temperatures up to 150°C. After coiling the material is normally given a low-temperature heat treatment to raise the torsional properties of the material and to remove the stresses induced in coiling.

2.2 Material specification

Specification for BS 1408 Grades C and D

2.2.1 Tensile strength

The tensile specification of the three ranges for the wire diameter, 4mm, used is shown below:-

Range 1 1240 - 1390 N/mm^2 (80 - 90 $tonf/in^2$)
Range 2 1390 - 1540 N/mm^2 (90 - 100 $tonf/in^2$)
Range 3 1540 - 1700 N/mm^2 (100 - 110 $tonf/in^2$)

A tolerance of +75 N/mm^2 (5 $tonf/in^2$) is allowed beyond the maximum tensile strength of the range specified, unless otherwise specified on the order.

2.2.2 Decarburisation

BS 1408C:-

The prepared section shall show no totally decarburised zone. Partial decarburisation as indicated by grain boundary ferrite shall not extend to a depth below the surface greater than 1½ per cent of the nominal diameter of the wire (0.06 mm for 4 mm wire).

BS 1408D:-

The prepared section shall be entirely free from decarburisation.

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 350°C for half-an-hour. Shot-peened springs were subsequently given a further heat treatment of 220°C for half-an-hour following the shot-peening process.

The parameters of the springs supplied by each of the four manufacturers are given in Table 1 for springs to BS 1408C and in Table 2 for springs to BS 1408D.

4. ANCILLIARY INVESTIGATION

4.1 Chemical Analysis

This material is essentially a plain carbon steel, cold drawn to produce the required tensile strength and has a wide permissible carbon composition, 0.55% to 0.85%. It was, therefore, not necessary to check the composition of samples from this material.

4.2 Hardness determination

Where wire samples had been sent by the manufacturers with the springs, the tensile strength of the samples, which were determined in the 'as received' condition, are given in Tables 3 - 8 according to the spring material. In addition, the hardness of a spring sample from each manufacturer was measured and the tensile strength estimated from this value. The hardness measurements quoted are the average of three readings. The tensile strength equivalents can only be regarded as approximate values because of the drawn structure of the material.

4.3 Microstructure examination

Transverse and longitudinal microsections of springs of each quality and from each supplier were prepared and examined for decarburisation and for variation in structure. The results are discussed in the appropriate section, 6.1 - 6.6. Generally, all the specimens examined had a typical cold drawn structure.

5. FATIGUE TESTING

The fatigue testing to produce the Goodman diagrams was carried out as described in Part 1 of this report. Tables 3 - 8 give values of the fatigue limit for each quality for springs from the four suppliers and the stress relaxation, measured as percentage loss in load for the fatigue limit at an initial stress of 300 N/mm^2.

The Goodman diagrams for all qualities in the peened and unpeened conditions are shown in Figs. 1 - 27. For each of the six qualities the Goodman diagrams are drawn for lives of 10^5, 10^6 and 10^7 cycles, though in some instances because of the shape of the S/N curve, the diagrams for 10^6 cycles and 10^7 cycles are the same and have been combined in a single diagram. As explained in Part 1 of this report, not all the Goodman diagrams have the full confidence levels. Those for infinite life show only the 95% confidence level and in some instances those for 10^5 cycles show only the 99% confidence level.

6. DISCUSSION OF RESULTS

6.1 BS 1408C Range 1

The principal characteristics of the four batches are summarised in Tables 1 and 3. Although only two wire samples were available for testing, from the hardness figures it would seem that all four batches lay within the tensile specification of 1240 - 1390 N/mm^2 (80 - 90 tonf/in^2). All the free heights of the springs were below the design height of 50 mm, which suggests that Range 1 wire may not be able to be coiled with a solid stress of 1140 N/mm^2, which is about 92% of the minimum tensile strength of the wire. The maximum free height and solid stress achieved was that of 48.4 mm and 1050 N/mm^2 from the springs of supplier 1, whose springs were, however, slightly distorted after prestressing.

Unpeened springs

From the fatigue data in Table 3 it can be seen that the fatigue limits for the springs of all four suppliers are very similar. The dynamic relaxation of the springs from three of the suppliers was about 0.6%, while those from supplier 3 exhibited a relaxation of about 2½%.

The Goodman diagram for 10^5 cycles is shown in Fig. 1. Full confidence levels were obtained at initial stresses of 100 N/mm^2 and 200 N/mm^2, but at an initial stress of 300 N/mm^2 only values of the 90% and 95% levels were obtained because the fatigue limit was very close to the solid stress of one batch of springs. The shape of the Goodman diagram is such that the confidence limits on the lines of maximum stress are almost parallel to the line of initial stress. The Goodman diagram for 10^6 and 10^7 cycles is of a similar shape, and is shown in Fig. 2.

Shot-peened springs

The fatigue performances of the shot-peened springs from different suppliers varied much more than for the unpeened springs. The shot-peened springs from supplier 2 represented the majority of the first 10% of springs broken for the finite life data, whereas for the unpeened springs very few of the springs from the same supplier had broken. The springs from supplier 4 which had the poorest finite life fatigue resistance when unpeened remained unbroken when tested wi~~th the~~ other batches. It is interesting to note that the springs from supplier 4 were obtained unpeened, and were shot-peened and heat treated by the Association.

The dynamic relaxation of the shot-peened springs was in all cases greater than for the unpeened springs. In fact, as Table 3 shows, the springs from supplier 3 had a relaxation of 8%, and they remained unbroken when tested with an initial stress of 300 N/mm^2.

Full confidence levels have been placed on Goodman diagrams for both 10^5 and 10^6 cycles (Figs. 3 and 4). In both cases, the three confidence levels are parallel to one another but the Goodman diagrams differ in shape. That for 10^5 cycles is similar in shape to that of the unpeened springs, whereas on the one for 10^6 cycles the confidence levels converge on the line of initial stress at about the tensile strength of the material. The Goodman diagram for 10^7 cycles is drawn in Fig. 5 and shows only the 95% confidence level.

For infinite life, the increase in maximum operating stress obtained by shot-peening was of the order of 20% at the lowest initial stress but as the initial stress increased the difference became less marked. The same is true for limited life so it could appear that with high initial stresses the benefits of shot-peening are not as great as for lower values.

6.2 BS 1408C Range 2

Because of the higher tensile strength of the Range 2 wire, generally the springs were able to be coiled to a higher solid stress than for Range 1 material. As for the Range 1 material, wire samples were only supplied with two of the batches, but the tensile strengths where applicable and the measured hardness figures converted to tensile strength show that for all four suppliers the wire was within the specified tensile range of 1390 - 1540 N/mm^2 (90 - 100 tonf/in^2).

Unpeened springs

The fatigue performances of springs from three of the suppliers were very similar (Table 4), but the springs from supplier 3 had a better fatigue performance and the dynamic relaxation was slightly greater.

The Goodman diagram for 10^5 cycles is shown in Fig. 6. For this material, complete confidence limits were obtained at three initial stress levels, and for this material the modified testing procedure (described in Part 1 of this report) was first used. Unfortunately, because the maximum testing stress was governed by the lowest solid stress of the four suppliers, the springs could not be stressed high enough to break before 10^5 cycles and the values for the diagram are obtained by the extrapolation of the S/N curves.

The springs from suppliers 2 and 4 accounted for almost all of those springs broken to produce the finite life data, and had the lowest fatigue limits for infinite life (Fig. 7). From Table 4 it can be seen that these were the two batches with the lowest solid stress.

Shot-peened springs

When the springs from supplier 2 were examined after fatigue testing to produce the finite life data it was found that they had not been lanolin dipped after shot-peening and had started to rust. Consequently, when fatigue tested, they all broke before springs from any of the other batches. The results for this supplier have been ignored and the data for finite life derived from the results of the other three suppliers. Before testing, to obtain the infinite life data, these springs were re-shot peened in the Association's plant.

The Goodman diagrams for 10^5, 10^6 and 10^7 cycles are shown in Figs. 8 - 10. Again the improvement in fatigue performance after shot-peening decreases as the initial stress is raised.

The fatigue limit for 10^7 ~~cycles~~ cycles for the shot-peened springs are shown in Table 4. The springs from supplier 4 have the best performance and those from supplier 3 have such a high relaxation that the fatigue limit cannot be determined with an initial stress of 300 N/mm^2. The fact that the springs from supplier 2, as mentioned above, were re-peened by S.R.A. may account for their improved fatigue performance over the Range 1 springs from the same supplier. For all four suppliers, the dynamic relaxation was higher than for the Range 1 shot-peened springs.

6.3 BS 1408C Range 3

As can be seen from Table 1, with the Range 3 wire all the springs could be coiled to the desired free lengths without distortion and there was little variation in the solid stresses of the four batches.

Table 5 shows the properties of the springs made from this quality. Where wire samples were available, the tensile tests conducted showed that the wire came within the specification for the range. There was however, a large variation in the hardness measurements, the value from springs of supplier 3 being the lowest.

Unpeened springs

The Goodman diagram for 10^5 cycles is shown in Fig. 11. Only two initial stresses were used for this material, 100 N/mm^2 and 300 N/mm^2, and when testing at the higher one, springs did not break before 10^5 cycles. The lower testing stress for each S/N curve was near the fatigue limit of some of the springs and there was a considerable amount of scatter in the results.

The Goodman diagram for 10^6 and 10^7 cycles is shown in Fig. 12. The springs from supplier 3 had the best infinite life performance although the relaxation was greater than for the other three batches. The springs from supplier 2 had the poorest infinite life performance, particularly at the higher initial stress, even though the wire from this supplier had the highest tensile strength. The structures of all four spring samples examined were very similar.

Shot-peened springs

With the shot-peened springs of this material, none were broken before 100 000 cycles. The slope of the S/N curve was such that a Goodman diagram with confidence limits could not be obtained for 10^5 cycles, and that the diagram for infinite life covered 10^6 and 10^7 cycles. The Goodman diagram for 10^5 cycles (Fig. 13) has therefore been drawn with the 99% confidence limit through the maximum testing stress at 100 N/mm^2 initial stress with the same slope as that for infinite life (Fig. 14)

As with the Range 2 springs, those from supplier 2 were discovered to have not been lanolin dipped and were beginning to rust. This was noted before the fatigue testing programme started and these springs, together with those of BS 1408D Range 2, were shot-peened again at S.R.A. to remove this rust. For both finite and infinite life, these springs had the best fatigue resistance of the four batches. Springs from the other batches were about equal, though those from supplier 3 again had a lower rate and solid stress as well as much greater dynamic relaxation.

6.4 BS 1408D Range 1

As for BS 1408C Range 1, only supplier 1 was able to make the springs with a free length approaching that of 50 mm and these were distorted after prestressing. In fact, as Table 2 shows, the solid stress of all four batches was approximately 1000 N/mm^2. For this particular quality the hardness figures of the springs were all very similar, and for the three wire specimens available, the measured tensile strengths all lay within the specification for Range 1 wire.

Unpeened springs

The Goodman diagrams for 10^5, 10^6 and 10^7 cycles are shown in Figs. 15 and 16. Because of the low solid stress of all the batches of springs, only two springs could be broken before 10^5 cycles and the confidence limits were obtained by extrapolation of the S/N curve. Springs from supplier 2 had the lowest fatigue resistance for both finite and infinite life. Metallographic examination of a specimen spring and wire from this supplier revealed partial decarburisation to a depth of 0.05 mm (0.002 in). This is the same as that found on springs of 1408C Range 1 from this supplier, although for 1408D the material is supposed to be free from decarburisation. Examination of springs from the other three batches of Range 1 wire, both C and D qualities revealed no patches of decarburisation.

The fatigue properties and dynamic relaxation of the three batches from suppliers 1, 3 and 4 were all very similar.

Shot-peened

The Goodman diagrams for 10^5, and 10^6 and 10^7 cycles are shown in Figs. 17 and 18. Again, no springs were broken before 100 000 cycles and the diagram for 10^5 cycles has been drawn in the same way as that for BS 1408C Range 3 shot-peened.

The fatigue performance of the springs from supplier 2 were noticeably poorer than the other three batches for all endurances, which is probably reflective of the decarburisation present in these springs. Because of the low solid stress of the springs from supplier 3 and 4, the fatigue limits could not be obtained with an initial stress of 300 N/mm^2.

6.5 BS 1408D Range 2

Here the hardness values measured for all four batches of springs (Table 7) were relatively close, and the tensile test on the one wire sample available indicated that the material of this wire was within the specification.

The solid stress of the springs from supplier 1 was 40 N/mm^2 higher than the design solid stress, but those of the other three batches were much lower.

Unpeened springs

The finite life results obtained from springs of this material were affected by the poor fatigue resistances of those from supplier 2, which formed virtually all of the first 10% of springs broken. This was particularly noticeable at the 100 N/mm^2 initial stress where the first springs stressed to 980 N/mm^2 broke at 40 000 cycles. From Table 2 it will be seen that the free length of these springs is much lower than that of the other three batches. A visual examination of a failed specimen from this supplier revealed that as well as a crack propagating from the fracture, two separate cracks were noted a complete turn either side of the fracture. It was subsequently found that the wire was cracked, causing the premature failures and the settling down of the spring. Because of this, therefore, the Goodman diagrams shown in Figs. 19 and 20 have been based on the results from supplier 1, 3 and 4 only.

Shot-peened springs

As previously mentioned in section 6.3 the springs from supplier 2 were shot-peened in the Associations plant to remove slight rust before fatigue testing.

With this material, difficulty was met when testing the springs with an initial stress of 300 N/mm^2 because of the smaller free length of springs from supplier 2. None of the springs could be stressed far above the fatigue limit, in fact only 12 springs were broken before 1 000 000 cycles. Consequently only the 99% confidence limit can be estimated for 10^5 cycles (Fig. 21), drawn in the same way as that for BS 1408C Range 3 shot-peened, but a complete Goodman diagram is shown for 10^6 cycles (Fig. 22).

From Table 7 it can be seen that springs from supplier 1 had the worst fatigue performance, in fact they were the only ones which could be broken at 300 N/mm^2 initial stress. There was, however, a large amount of dynamic relaxation in the springs from the other three batches which may account for their apparantly better fatigue performance. The Goodman diagram for 10^7 cycles is shown in Fig. 23.

6.6 BS 1408D Range 3

Here the two wire samples on which the tensile tests were performed indicated that the wire came within the specification (Table 8). As would be expected for Range 3 wire all four suppliers were able to make the springs to the desired free length and solid stress.

Unpeened springs

The Goodman diagram for 10^5 cycles is shown in Fig. 24. As would be expected, springs made from this material had the best fatigue resistance of all the BS 1408 unpeened springs. In fact, during the testing to produce the finite life data, none were broken before 10^5 cycles although the maximum testing stress was 1060 N/mm^2. Therefore, the confidence limits for 10^5 cycles had to be obtained by extrapolation of the S/N curve. In fact, 4 out of the 6 points thus obtained had a value greater than the solid stress of the spring. This explanins the shape of the Goodman diagram where only the 99% confidence level lies entirely below the solid stress of the spring design.

The infinite life fatigue limits are very close for all four batches and are the highest for all the BS 1408 quality springs. The Goodman diagram for 10^6 and 10^7 cycles is shown in Fig. 25.

Shot-peened springs

Because of the uncertainty about the material of the shot-peened springs from supplier 4, springs from suppliers 1, 2 and 3 only were used to produce the results for this material.

The Goodman diagrams for 10^5, and 10^6 and 10^7 cycles are shown in Figs. 26 and 27 and it will be seen that the one for 10^7 cycles is very similar to that for 1408C Range 3. The springs broken to obtain the diagram for 10^5 cycles were almost all from supplier 2, whose springs also had the greatest dynamic relaxation of the three batches.

TABLE 1 SPRING DIMENSIONS - BS 1408C

BS 1408C Range 1

	SUPPLIER			
	1	2	3	4
WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	29.6	30.4	30.0	30.0
SPRING INDEX	7.4	7.6	7.5	7.5
SPRING RATE (N/mm)	27.3	27.3	26.6	27.8
FREE LENGTH (mm)	48.4	47.2	47.6	47.0
SOLID STRESS (N/mm^2)	1050	1050	970	980

BS 1408C Range 2

WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	30.0	30.0	30.0
SPRING INDEX	7.5	7.5	7.5	7.5
SPRING RATE (N/mm)	27.3	27.2	26.4	28.2
FREE LENGTH (mm)	50.2	47.3	50.5	46.9
SOLID STRESS (N/mm^2)	1140	1000	1120	1000

BS 1408C Range 3

WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER	30.0	30.0	30.0	30.0
SPRING INDEX	7.5	7.5	7.5	7.5
SPRING RATE (N/mm)	27.0	27.3	26.8	27.5
FREE LENGTH (mm)	50.0	50.1	50.2	50.8
SOLID STRESS (N/mm^2)	1130	1150	1120	1110

TABLE 2 SPRING DIMENSIONS - BS 1408D

BS 1408D Range 1

	SUPPLIER			
	1	2	3	4
WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	30.4	30.0	30.0
SPRING INDEX	7.5	7.6	7.5	7.5
SPRING RATE (N/mm)	25.0	26.8	25.9	27.8
FREE LENGTH (mm)	49.4	47.4	48.1	46.3
SOLID STRESS (N/mm^2)	1010	1010	970	960

BS 1408D Range 2

WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	30.4	30.0	30.0
SPRING INDEX	7.5	7.5	7.5	7.5
SPRING RATE (N/mm)	27.5	27.1	24.3	28.0
FREE LENGTH (mm)	50.9	47.4	49.4	49.1
SOLID STRESS (N/mm^2)	1180	1025	1000	1075

BS 1408D Range 3

WIRE DIAMETER (mm)	4.0	4.0	4.0	4.0
MEAN COIL DIAMETER (mm)	30.0	30.0	30.0	30.0
SPRING INDEX	7.5	7.5	7.5	7.5
SPRING RATE (N/mm)	27.1	26.8	28.2	27.0
FREE LENGTH (mm)	51.2	50.6	49.1	51.0
SOLID STRESS (N/mm^2)	1150	1090	1160	1140

TABLE 3 SPRING PROPERTIES - BS 1408C Range 1

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	1360	1390	---
HARDNESS (Hv 30)	432	423	432	412
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1390	1360	1390	1335
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	660	660	700	680
FATIGUE LIMIT at 300 N/mm^2 Initial stress	840	800	860	800
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.5%	0.8%	2.3%	0.8%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	840	760	800	860
FATIGUE LIMIT at 300 N/mm^2 Initial stress	960	880	---	980
DYNAMIC RELAXATION:- 10^7 cycles 300 N/mm^2 Initial stress	1.2%	1.2%	8.1%	5.3%

TABLE 4 SPRING PROPERTIES - BS 1408C Range 2

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	1420	---	1465
HARDNESS (Hv 30)	438	435	435	426
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1405	1405	1405	1375
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	720	680	780	680
FATIGUE LIMIT at 300 N/mm^2 Initial stress	840	820	940	800
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.2%	1.0%	2.4%	1.0%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	860	860	920	920
FATIGUE LIMIT at 300 N/mm^2 Initial stress	940	980	---	1080
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	3.9%	5.7%	8.7%	8.9%

TABLE 5 SPRING PROPERTIES - BS 1408C Range 3

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	1730	---	1632
HARDNESS (Hv 30)	441	483	423	453
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1420	1520	1360	1450
<u>UNPEENED</u>				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	660	640	760	700
FATIGUE LIMIT at 300 N/mm^2 Initial stress	820	800	900	860
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.4%	0.6%	1.5%	0.7%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	840	880	800	860
FATIGUE LIMIT at 300 N/mm^2 Initial stress	960	980	---	960
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	1.4%	2.3%	10.6%	1.8%

TABLE 6 SPRING PROPERTIES - BS 1408D Range 1

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	1369	1425	1360
HARDNESS (Hv 30)	420	418	412	418
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1350	1345	1320	1345
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	680	660	700	680
FATIGUE LIMIT at 300 N/mm^2 Initial stress	860	780	820	820
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	1.4%	0.6%	1.3%	1.2%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	840	780	840	880
FATIGUE LIMIT at 300 N/mm^2 Initial stress	960	900	---	---
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	3.9%	3.0%	---	---

TABLE 7 SPRING PROPERTIES - BS 1408D Range 2

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	---	---	1535
HARDNESS (Hv 30)	453	429	447	441
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1450	1380	1435	1420
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	700	660	680	800
FATIGUE LIMIT at 300 N/mm^2 Initial stress	840	800	840	900
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.4%	0.3%	2.7%	1.5%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	860	860	840	960
FATIGUE LIMIT at 300 N/mm^2 Initial stress	940	---	1040	---
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	1.0%	10.1%	7.6%	7.2%

TABLE 8 SPRING PROPERTIES - BS 1408D Range 3

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	1720	---	1760
HARDNESS (Hv 30)	480	470	463	441
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1515	1500	1480	1420
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	720	740	760	780
FATIGUE LIMIT at 300 N/mm^2 Initial stress	840	840	880	880
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	900	800	840	---
FATIGUE LIMIT at 300 N/mm^2 Initial stress	1000	960	1020	---
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	2.8%	3.5%	2.7%	---

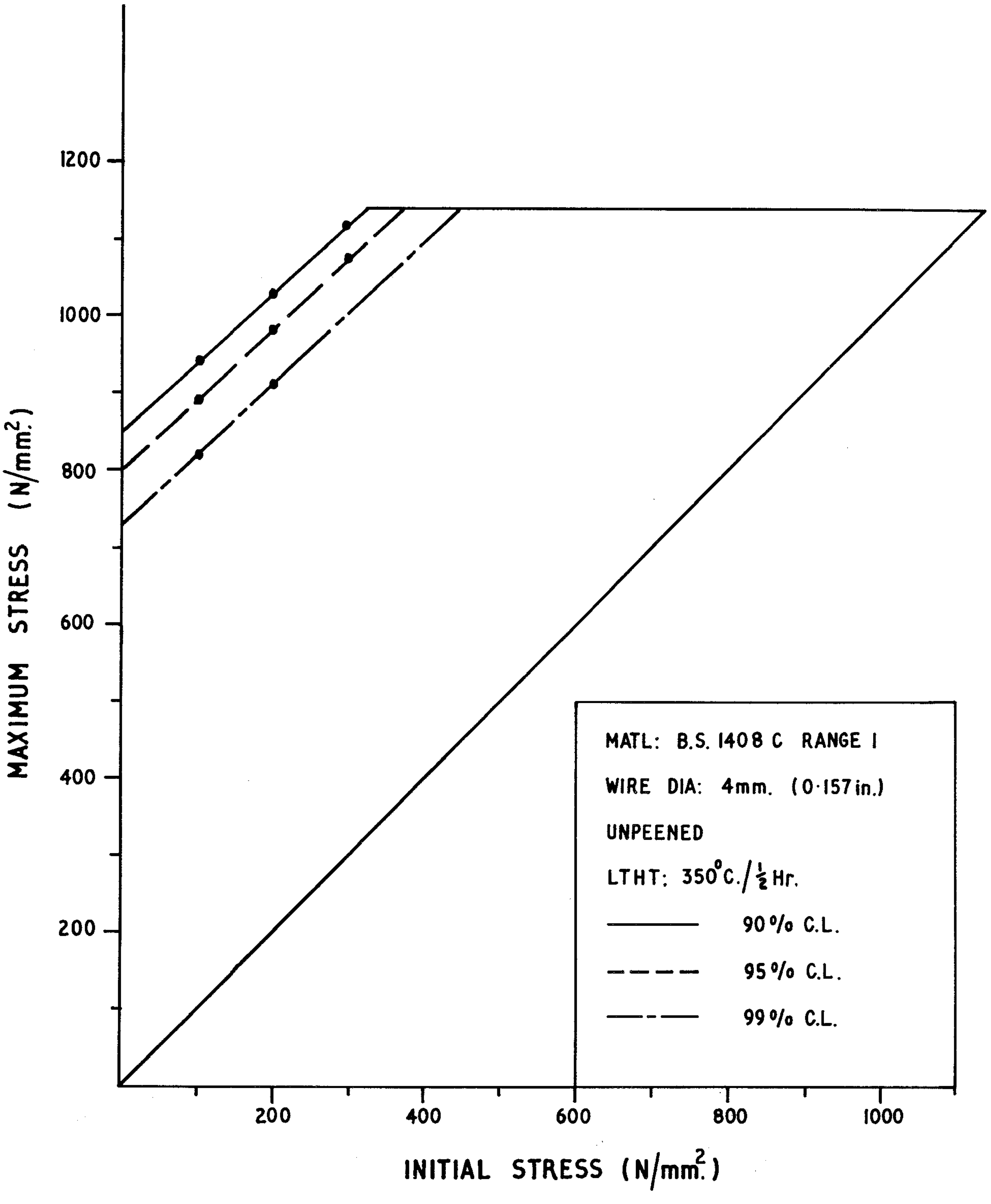

FIG. 1. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 1

UNPEENED —— 10^5 CYCLES

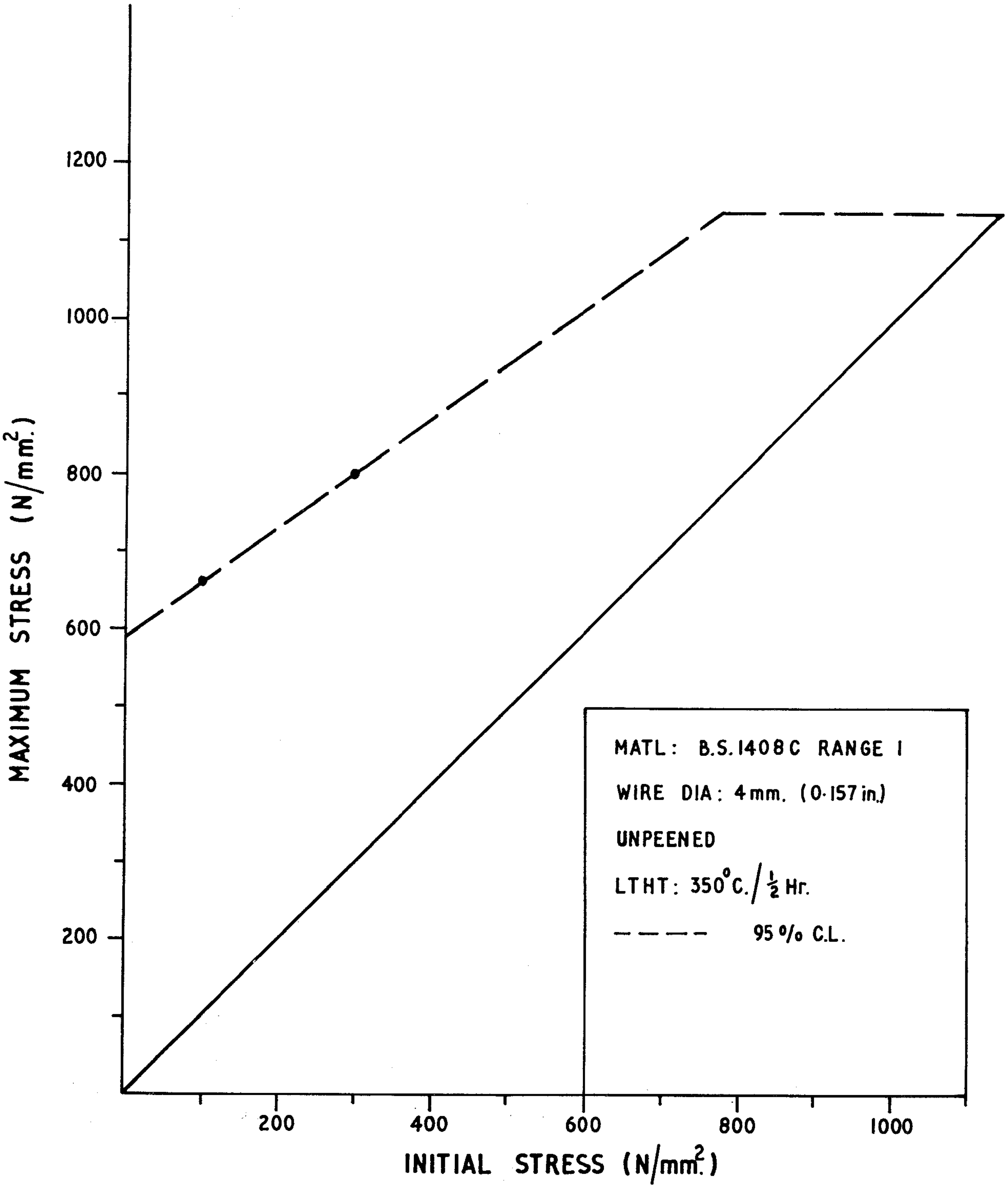

FIG. 2. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE I

UNPEENED 10^6 & 10^7 CYCLES

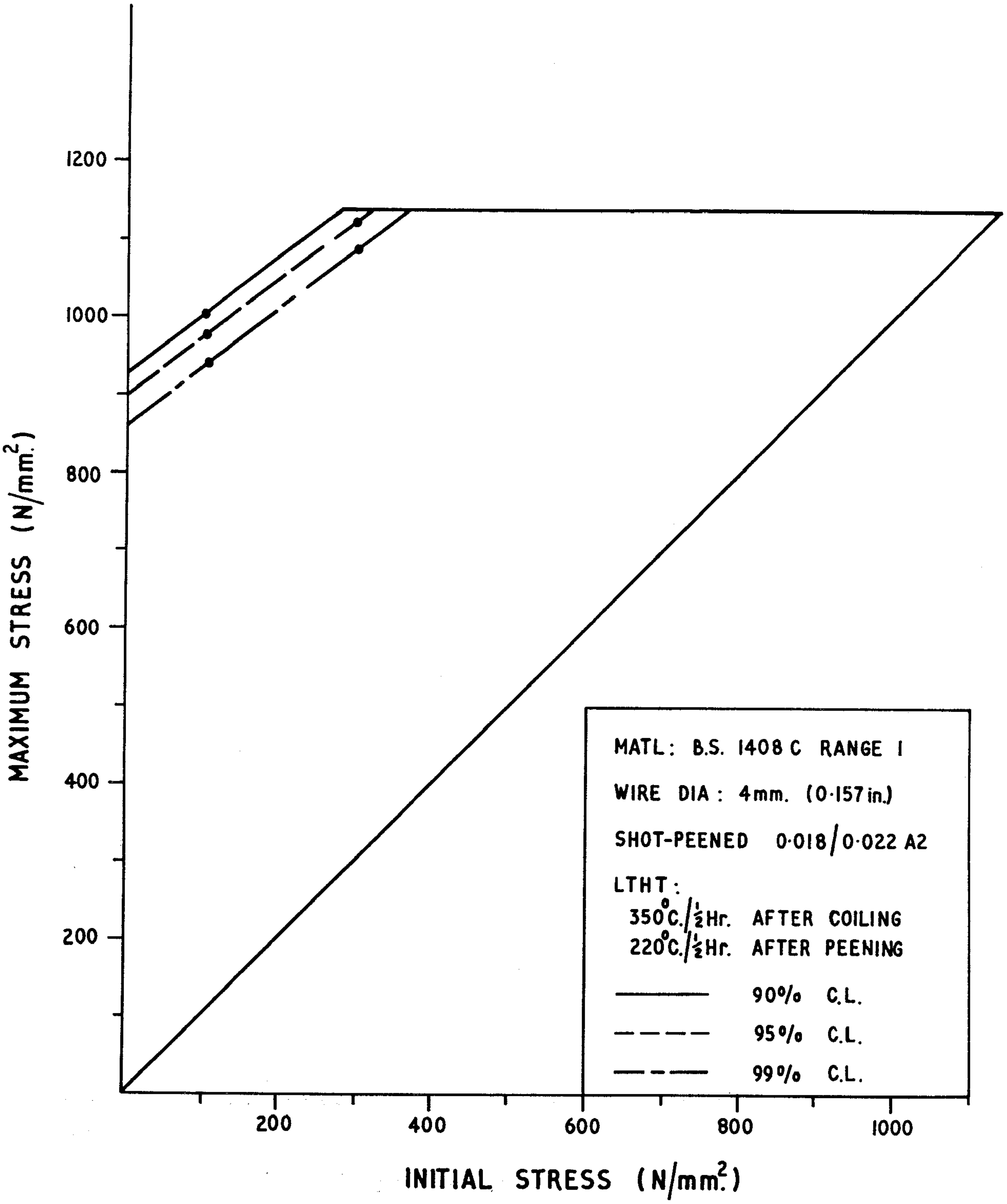

FIG. 3. GOODMAN DIAGRAM FOR B.S. 1408C RANGE I

SHOT-PEENED 10^5 CYCLES

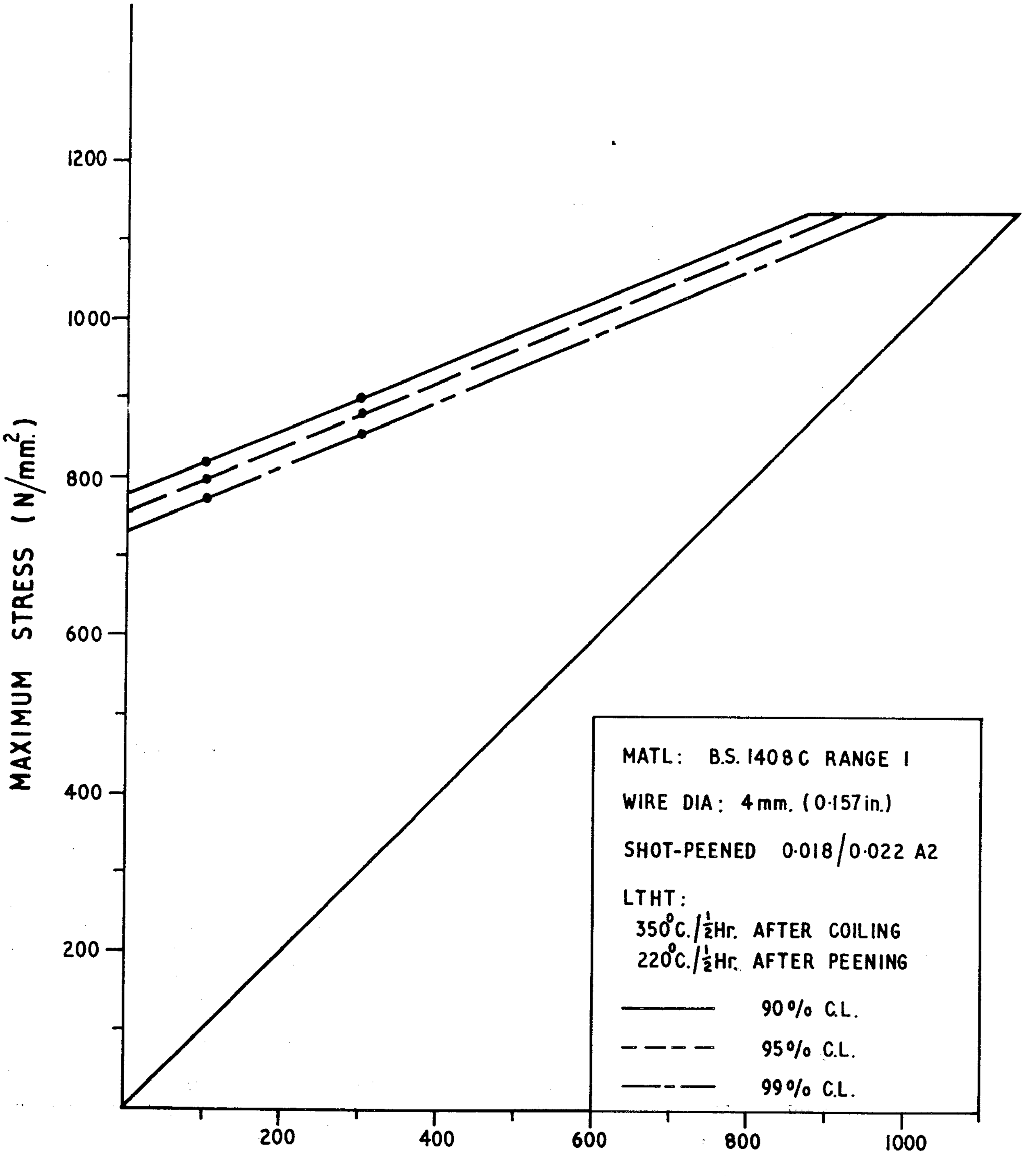

FIG. 4. GOODMAN DIAGRAM FOR B.S. 1408C RANGE I

SHOT-PEENED 10^6 CYCLES

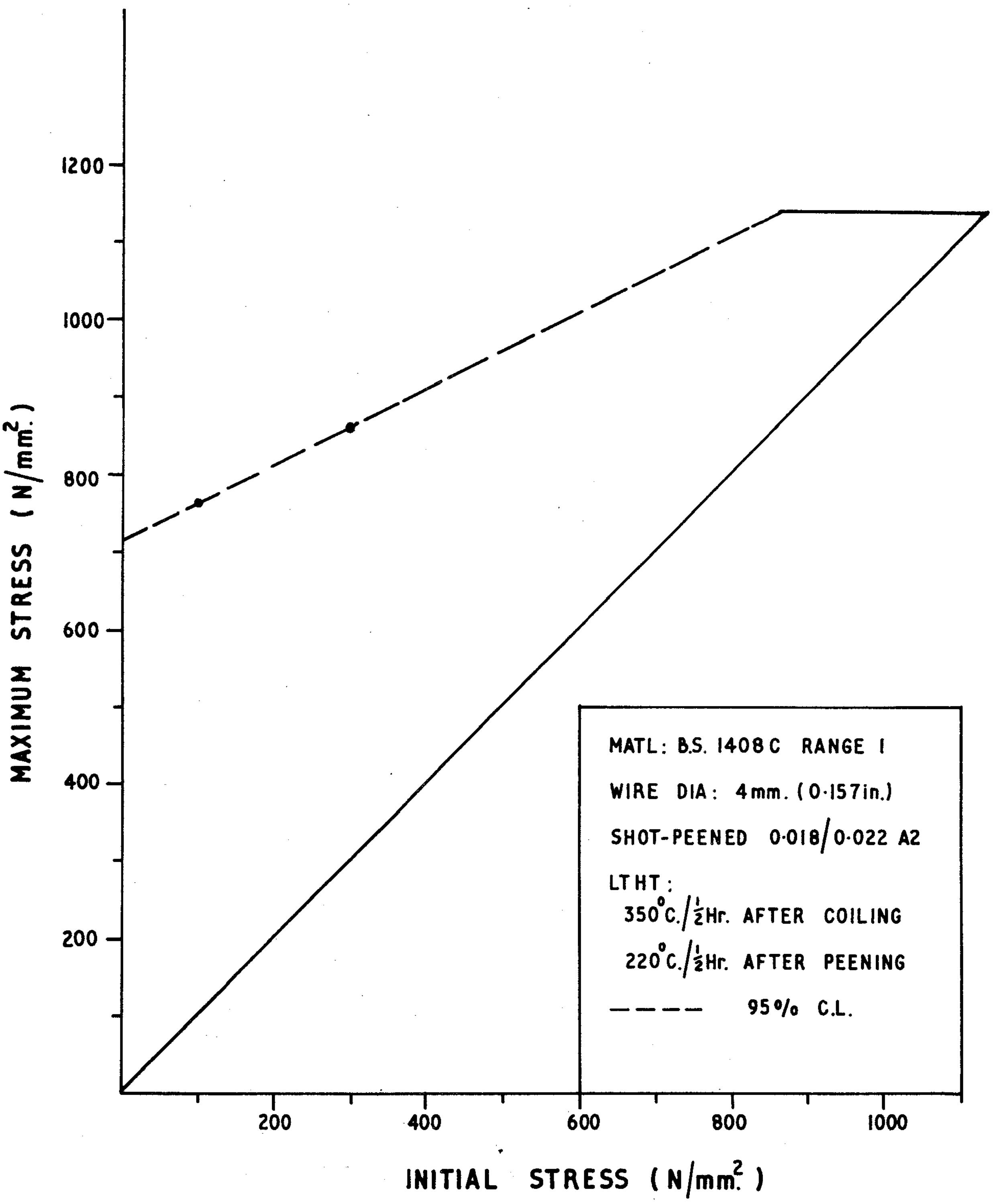

FIG. 5. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE I

SHOT-PEENED 10^7 CYCLES

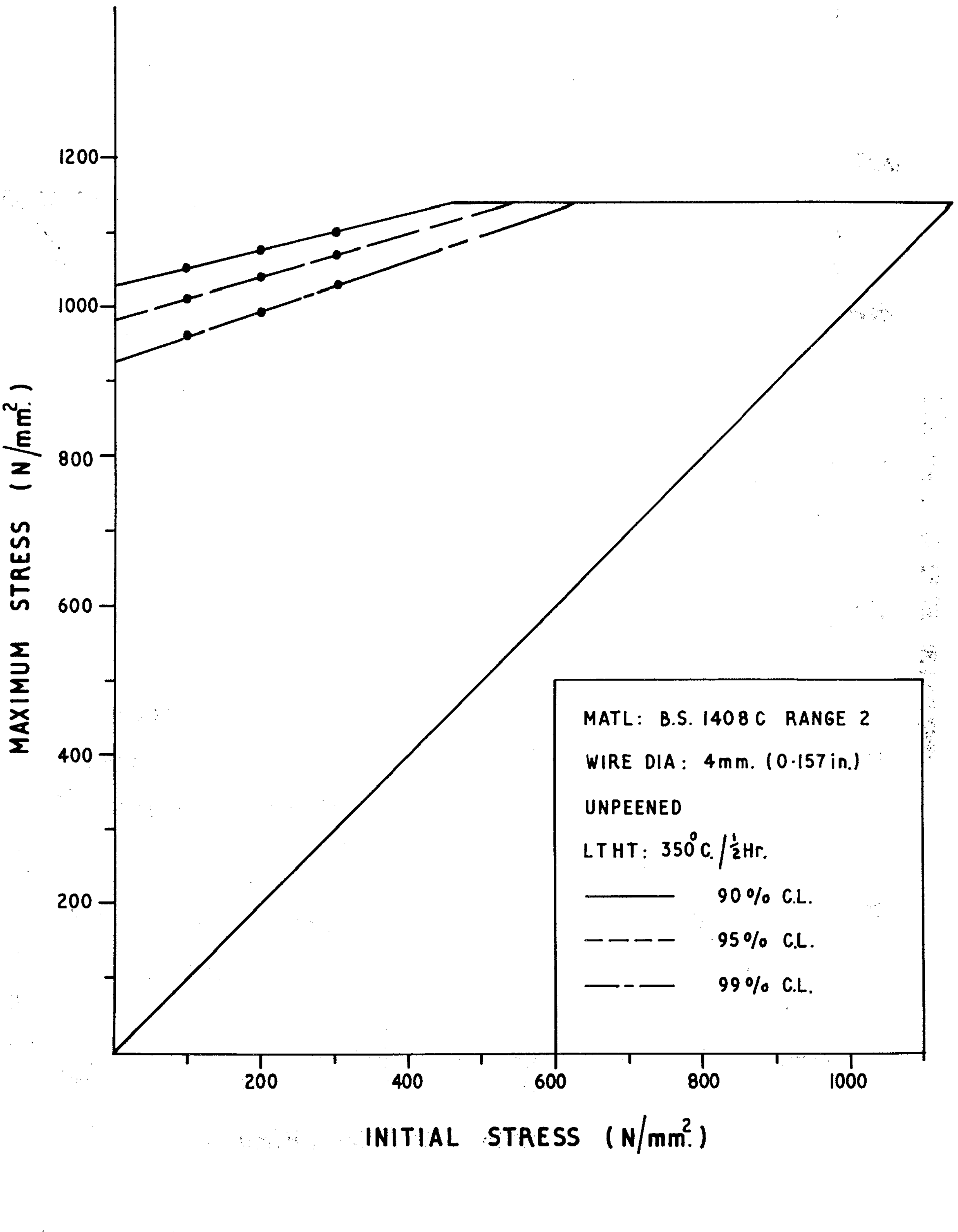

FIG. 6. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 2

UNPEENED 10^5 CYCLES

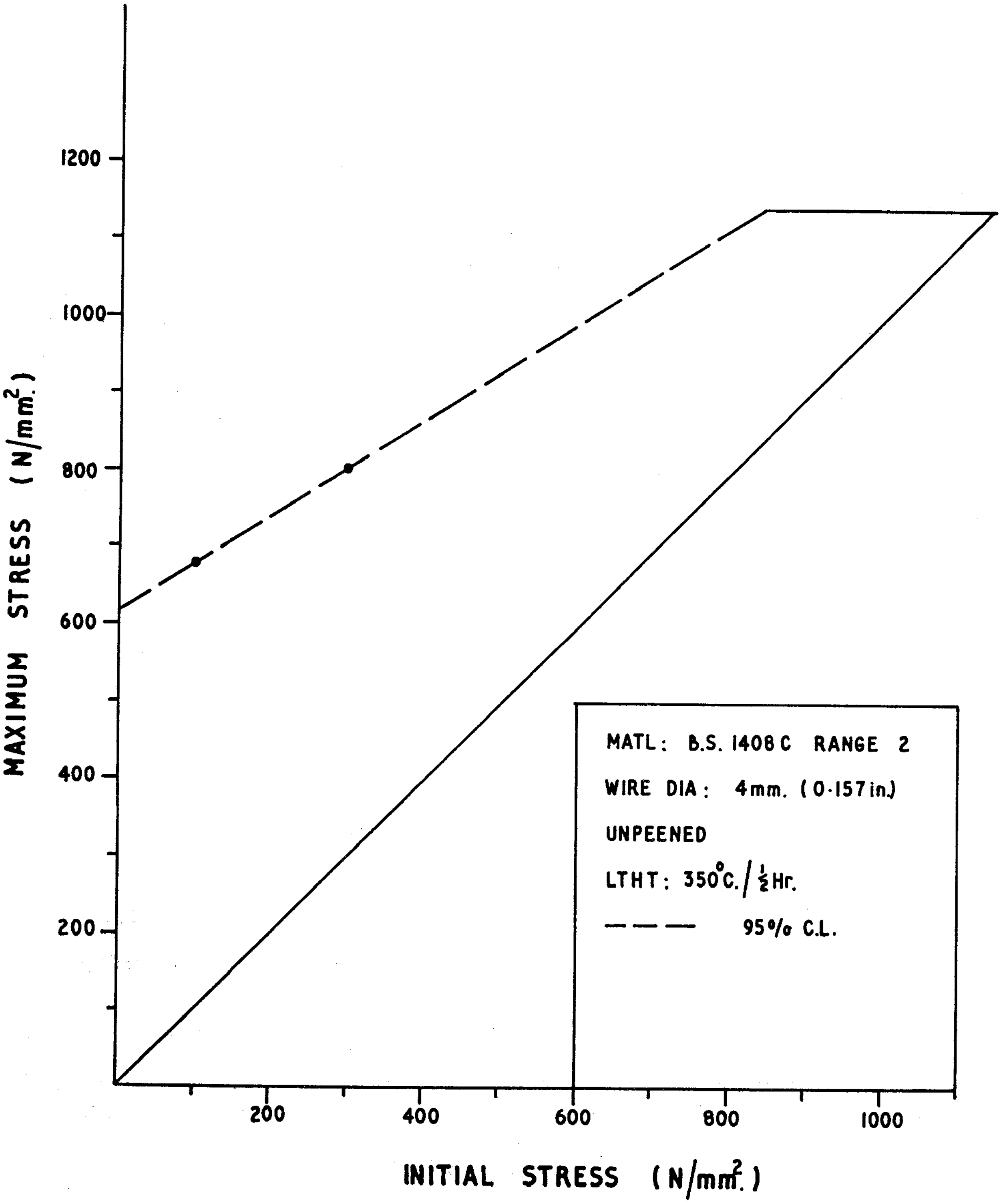

FIG. 7. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 2

UNPEENED ——— 10^6 & 10^7 CYCLES

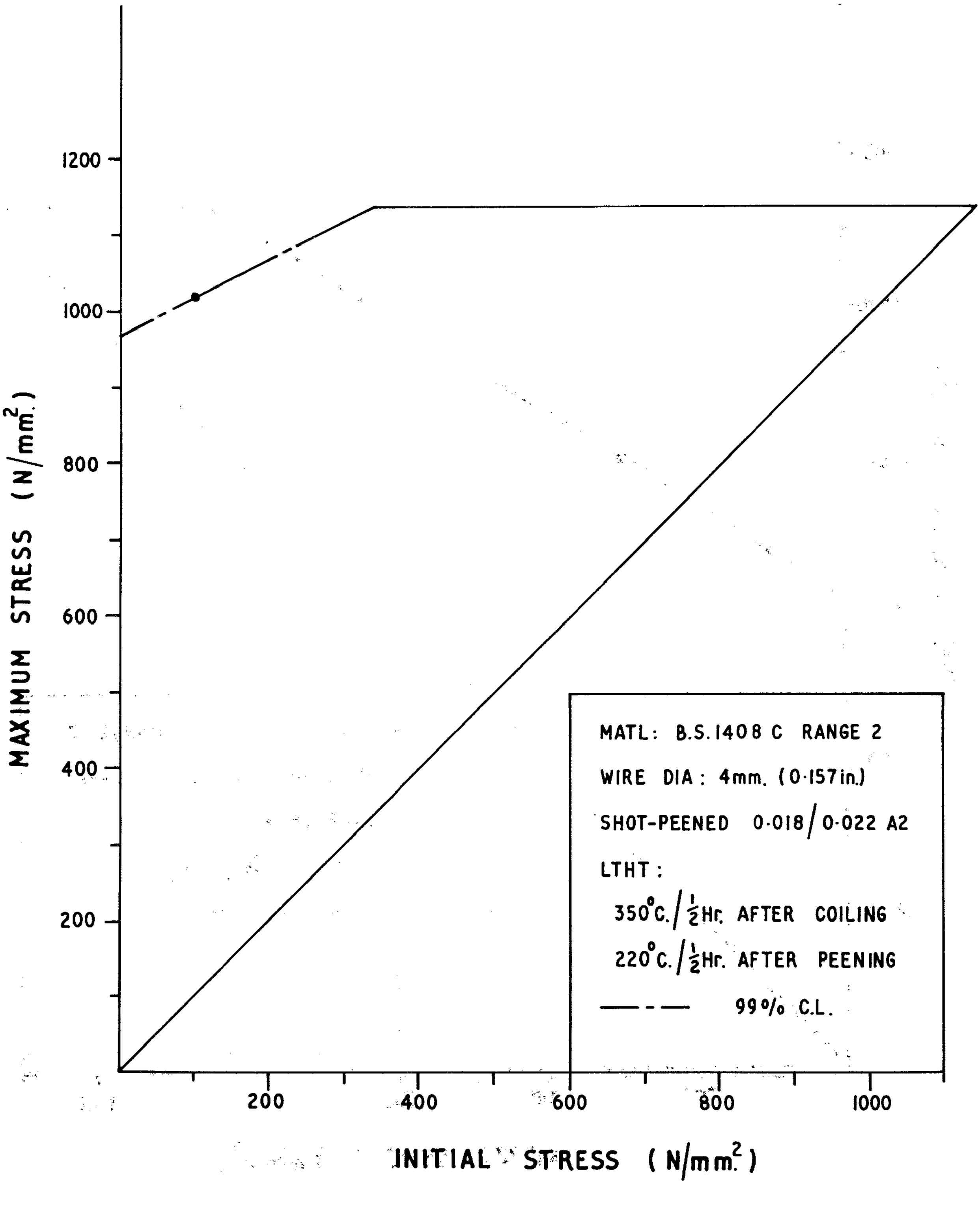

FIG. 8. GOODMAN DIAGRAM FOR B.S. 1408C RANGE 2

SHOT-PEENED 10^5 CYCLES

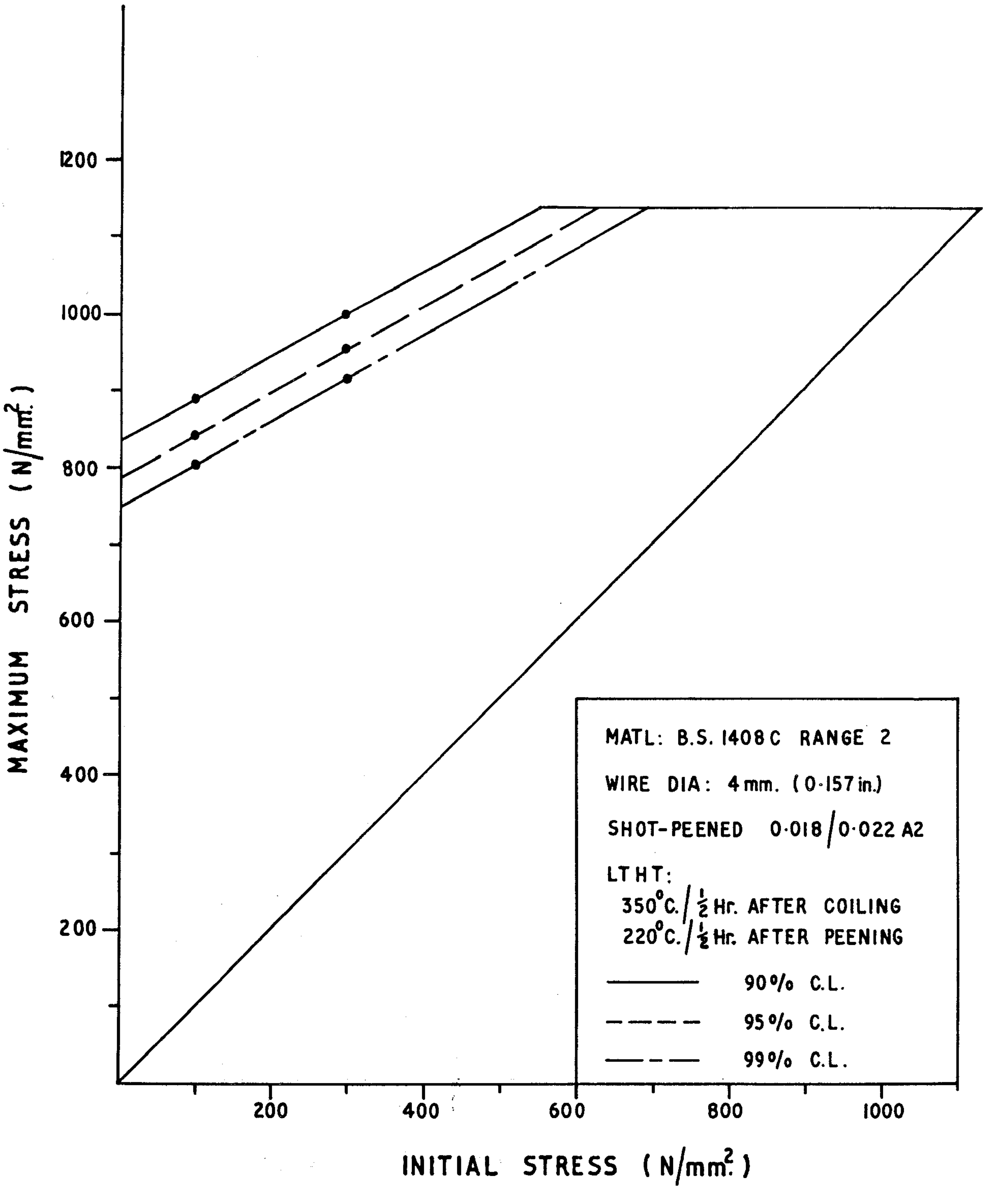

FIG. 9. GOODMAN DIAGRAM FOR B.S. 1408C RANGE 2

SHOT-PEENED 10^6 CYCLES

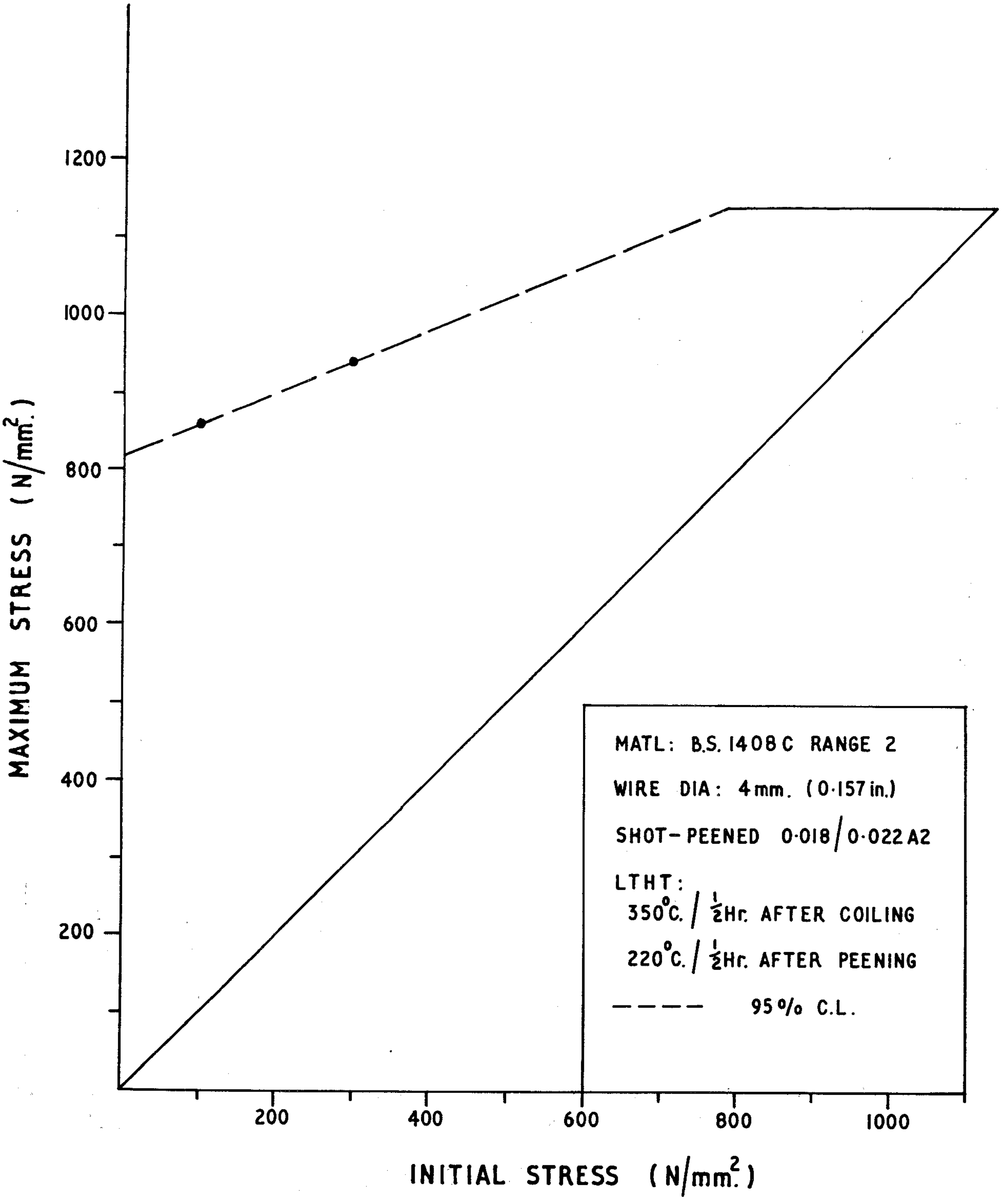

FIG. 10. GOODMAN DIAGRAM FOR B.S. 1408C RANGE 2

SHOT-PEENED 10^7 CYCLES

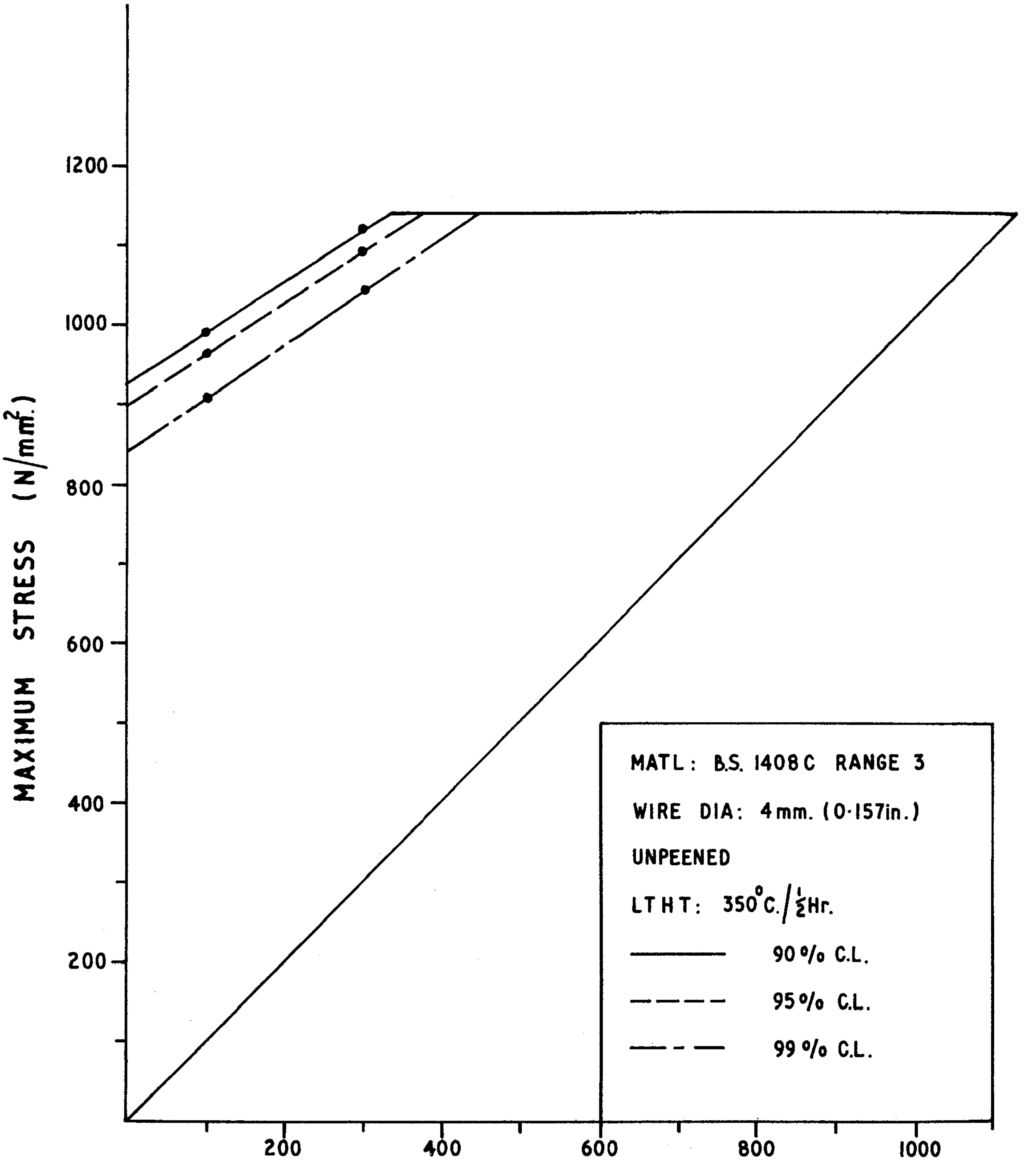

FIG. 11. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 3

UNPEENED 10^5 CYCLES

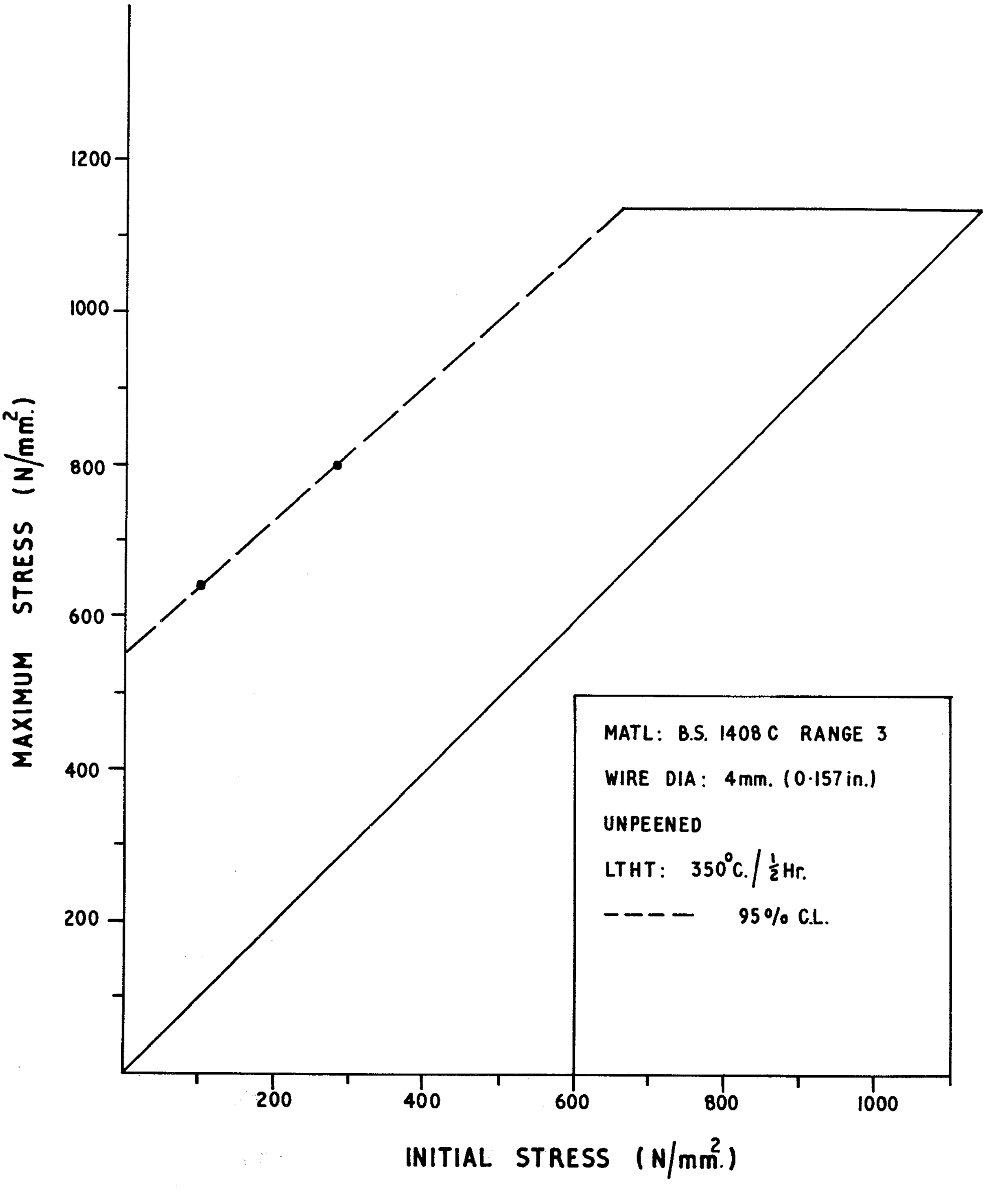

FIG. 12. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 3

UNPEENED 10^6 & 10^7 CYCLES

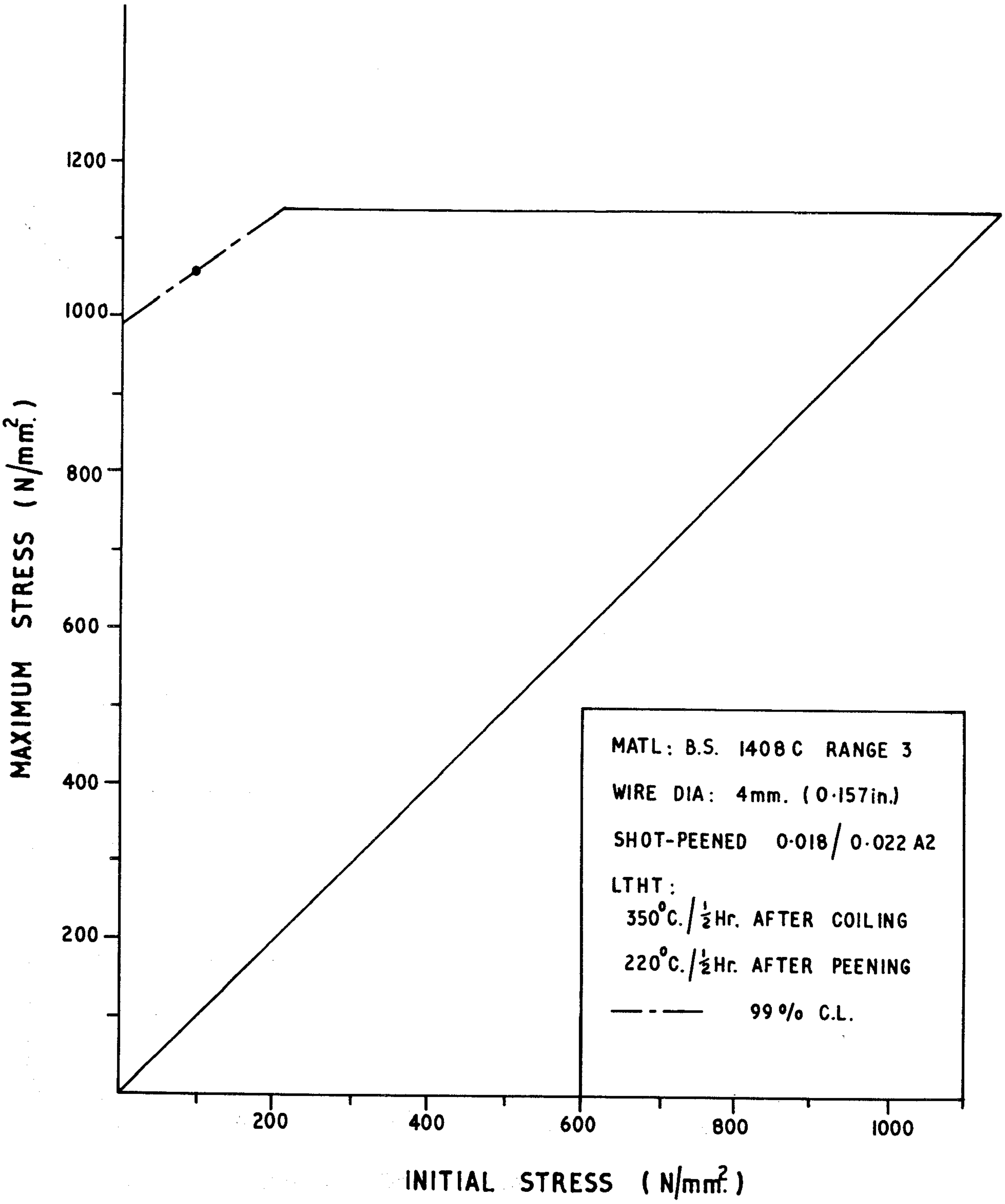

FIG. 13. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 3

SHOT-PEENED 10^5 CYCLES

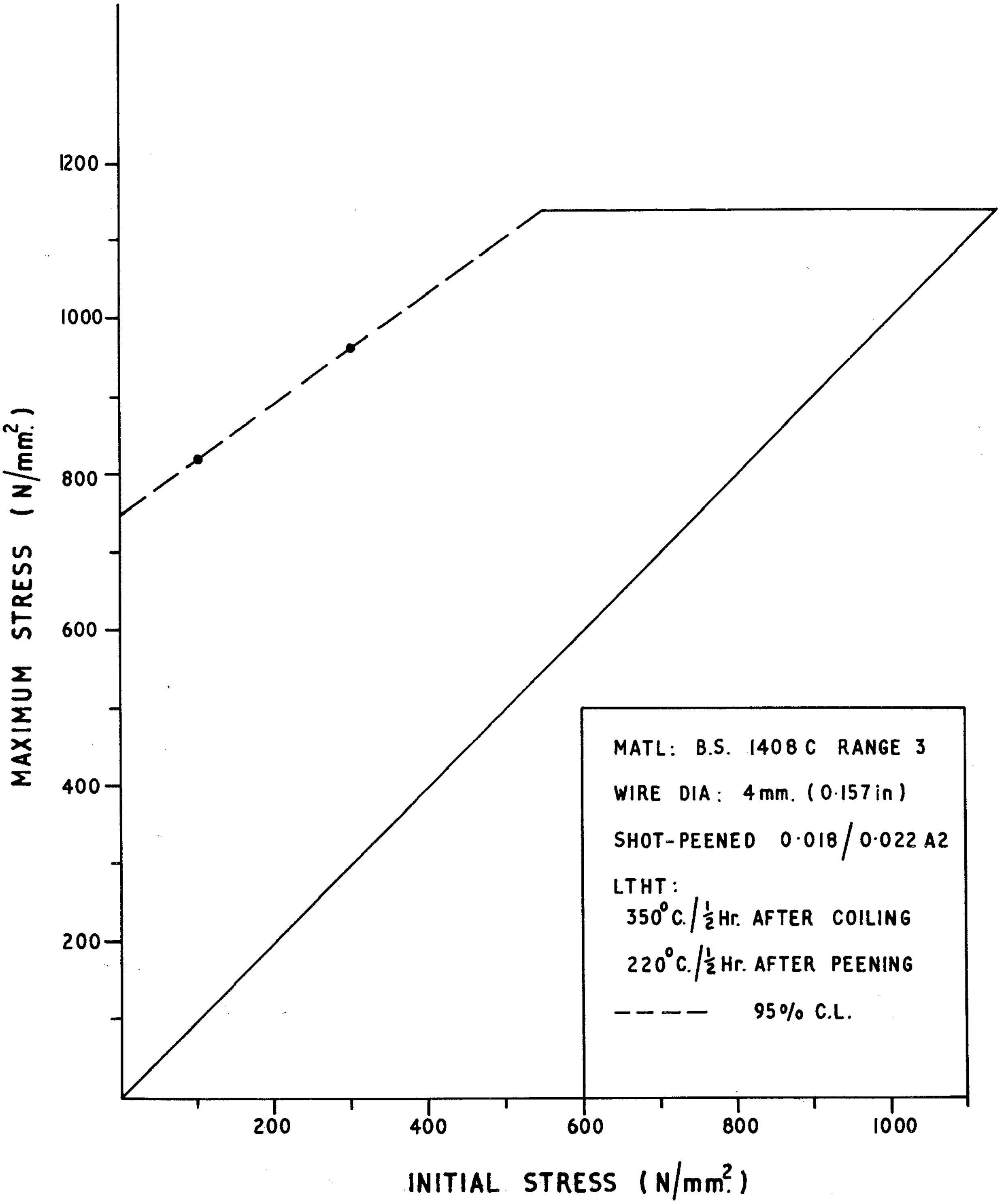

FIG. 14. GOODMAN DIAGRAM FOR B.S. 1408 C RANGE 3

SHOT-PEENED 10^6 & 10^7 CYCLES

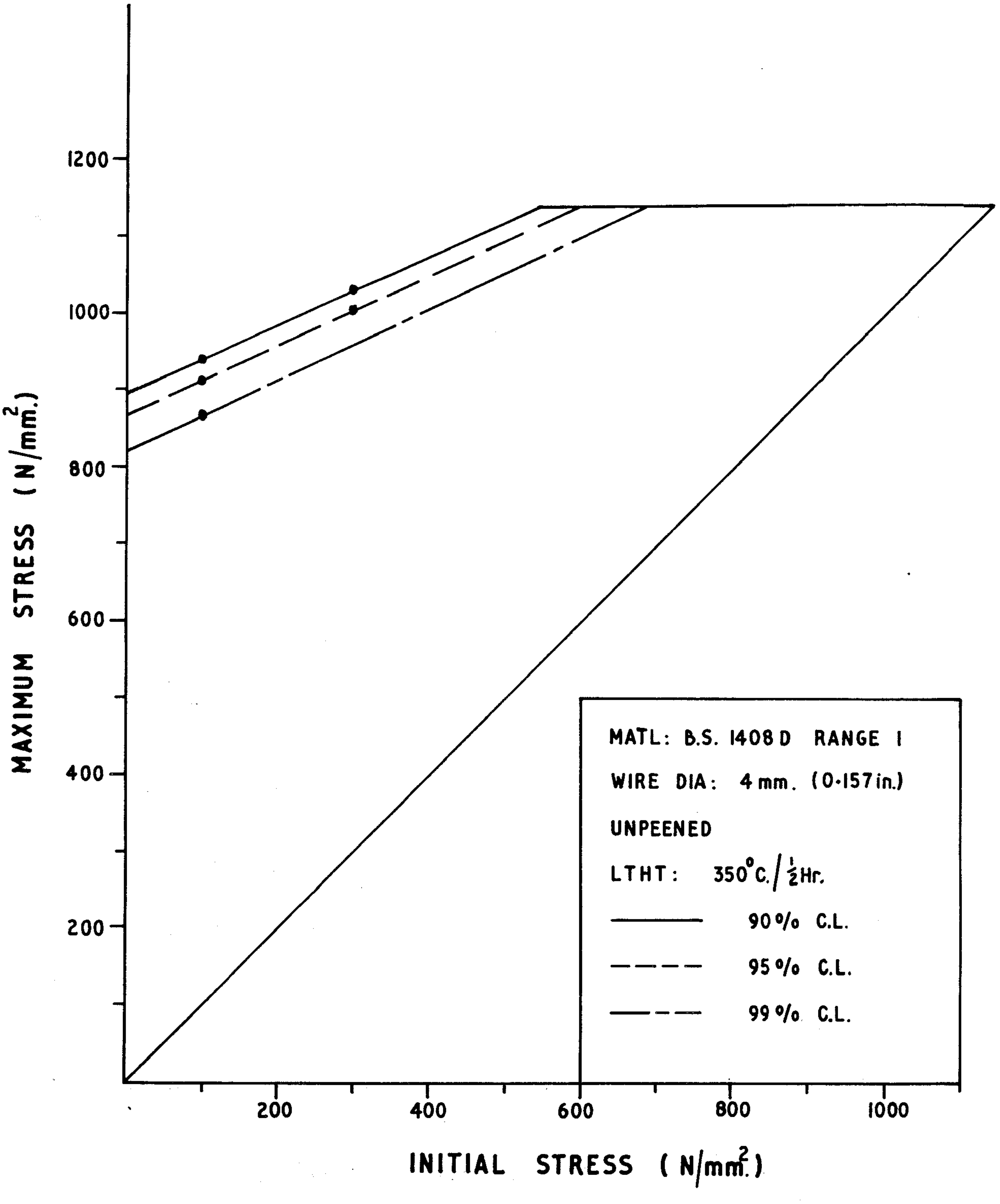

FIG. 15. GOODMAN DIAGRAM FOR B.S. 1408 D RANGE I

UNPEENED 10^5 CYCLES

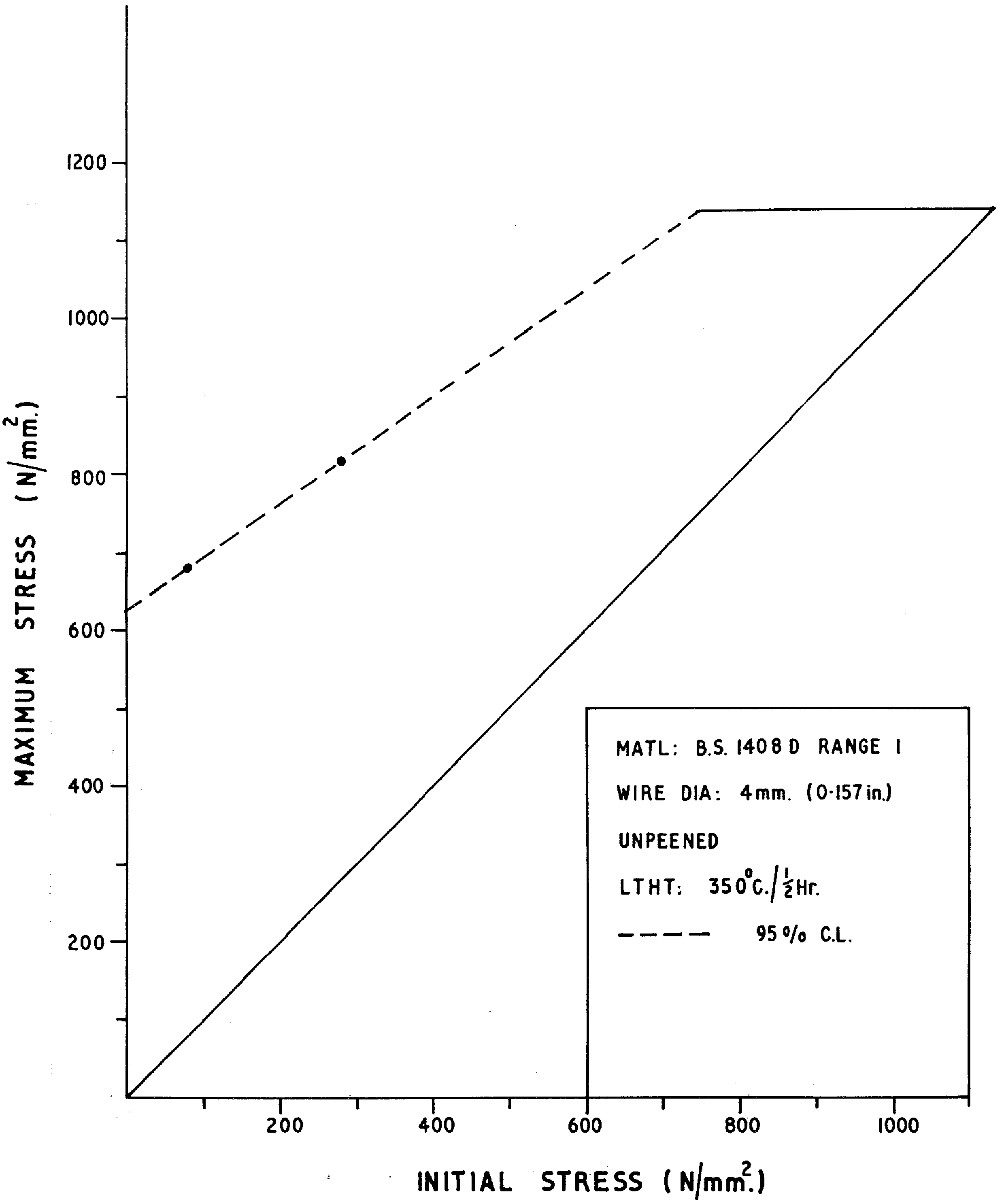

FIG. 16. GOODMAN DIAGRAM FOR B.S. 1408 D RANGE I

UNPEENED 10^6 & 10^7 CYCLES

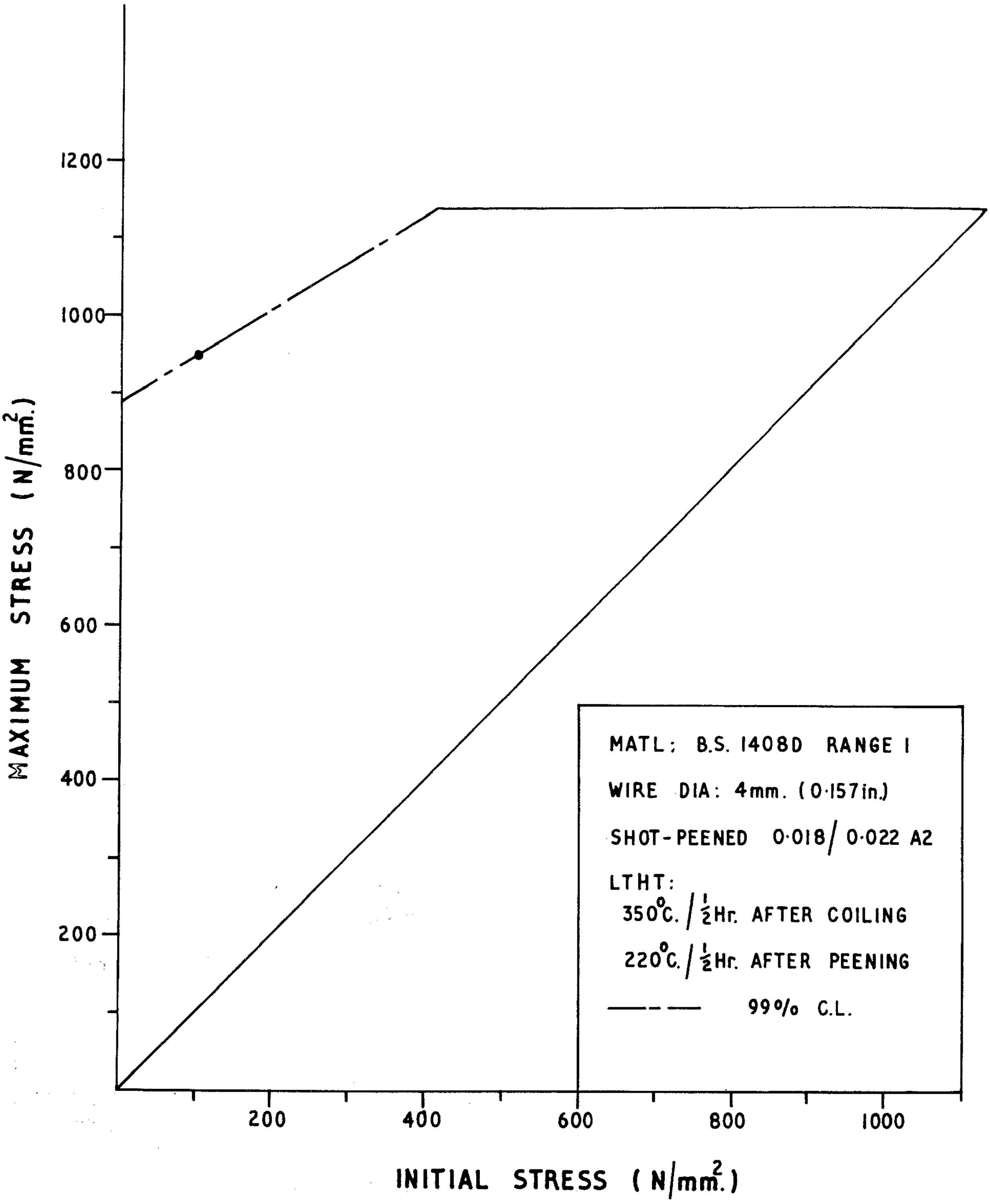

FIG. 17. GOODMAN DIAGRAM FOR B.S. 1408D RANGE I

SHOT-PEENED 10^5 CYCLES

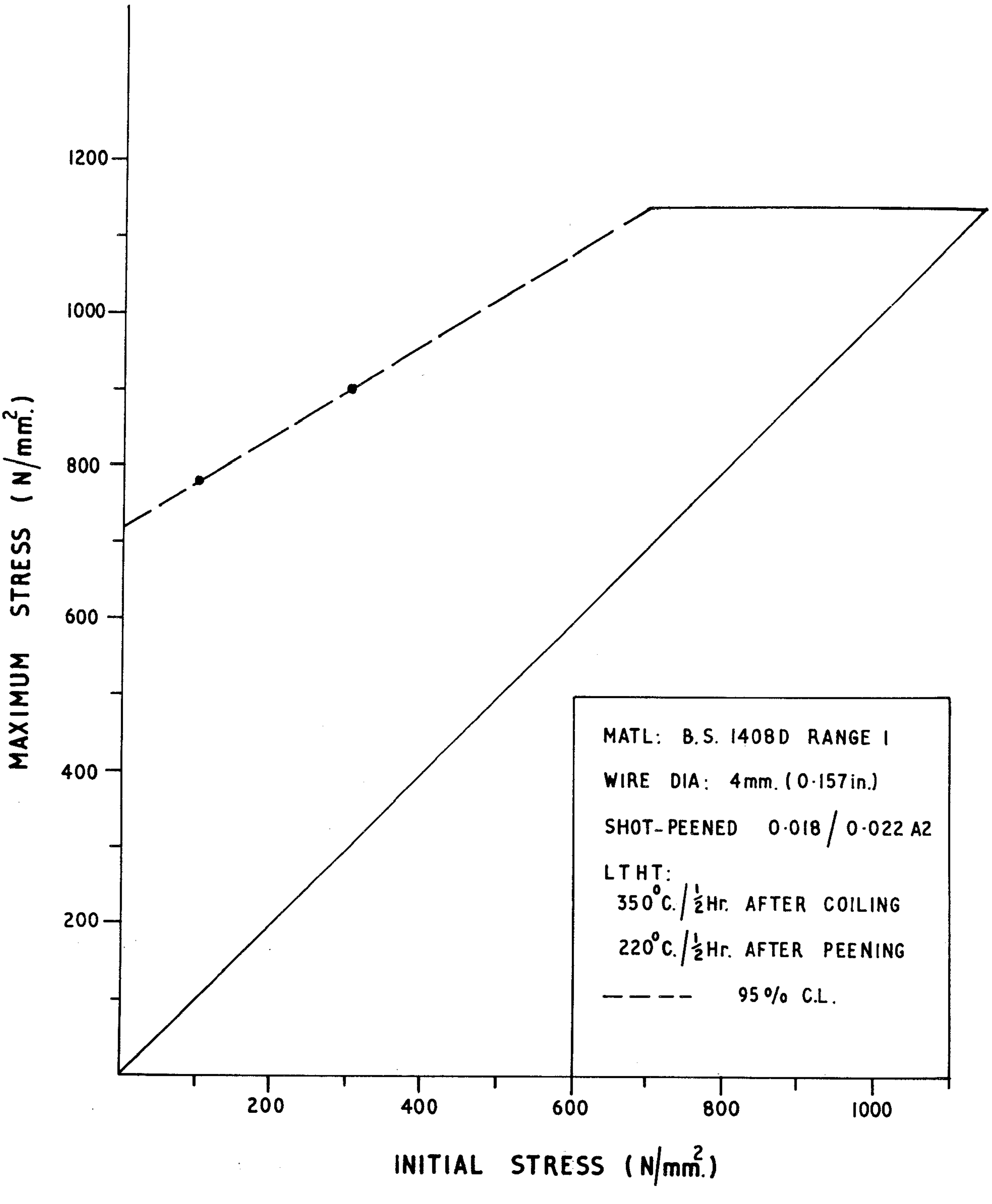

FIG. 18. GOODMAN DIAGRAM FOR B.S. 1408D RANGE I

SHOT-PEENED 10^6 & 10^7 CYCLES

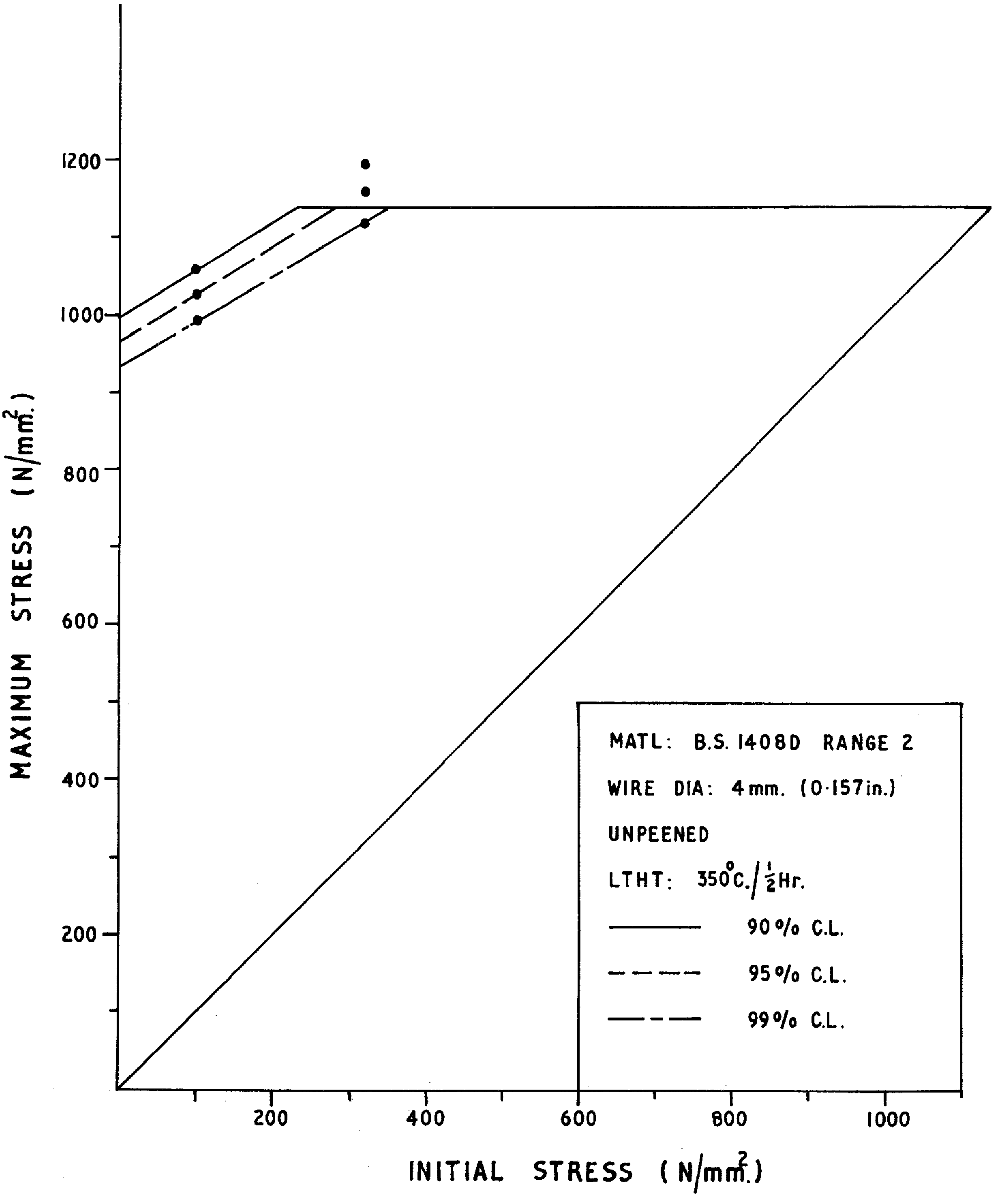

FIG. 19. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 2

UNPEENED 10^5 CYCLES

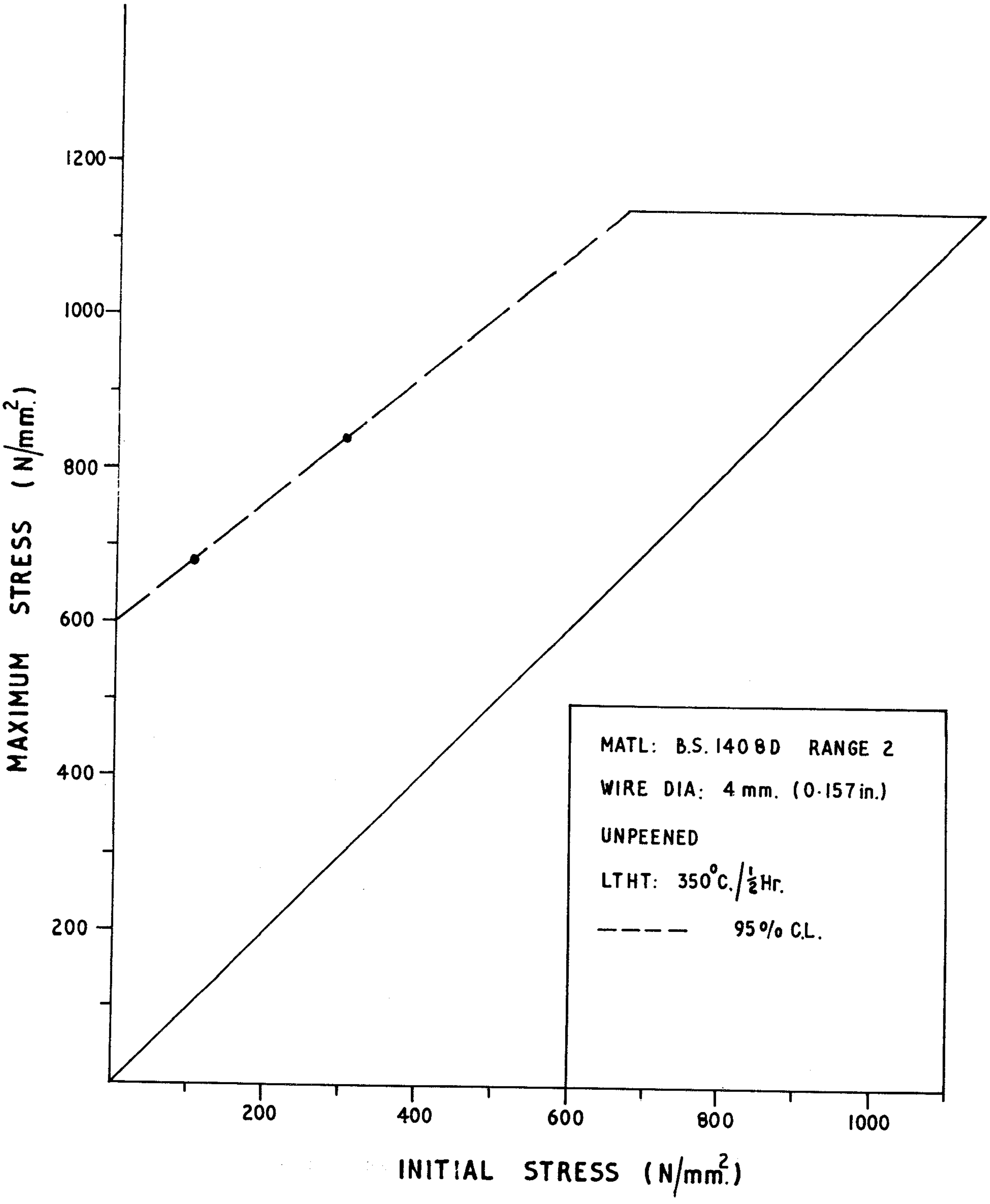

FIG. 20. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 2

UNPEENED 10^6 & 10^7 CYCLES

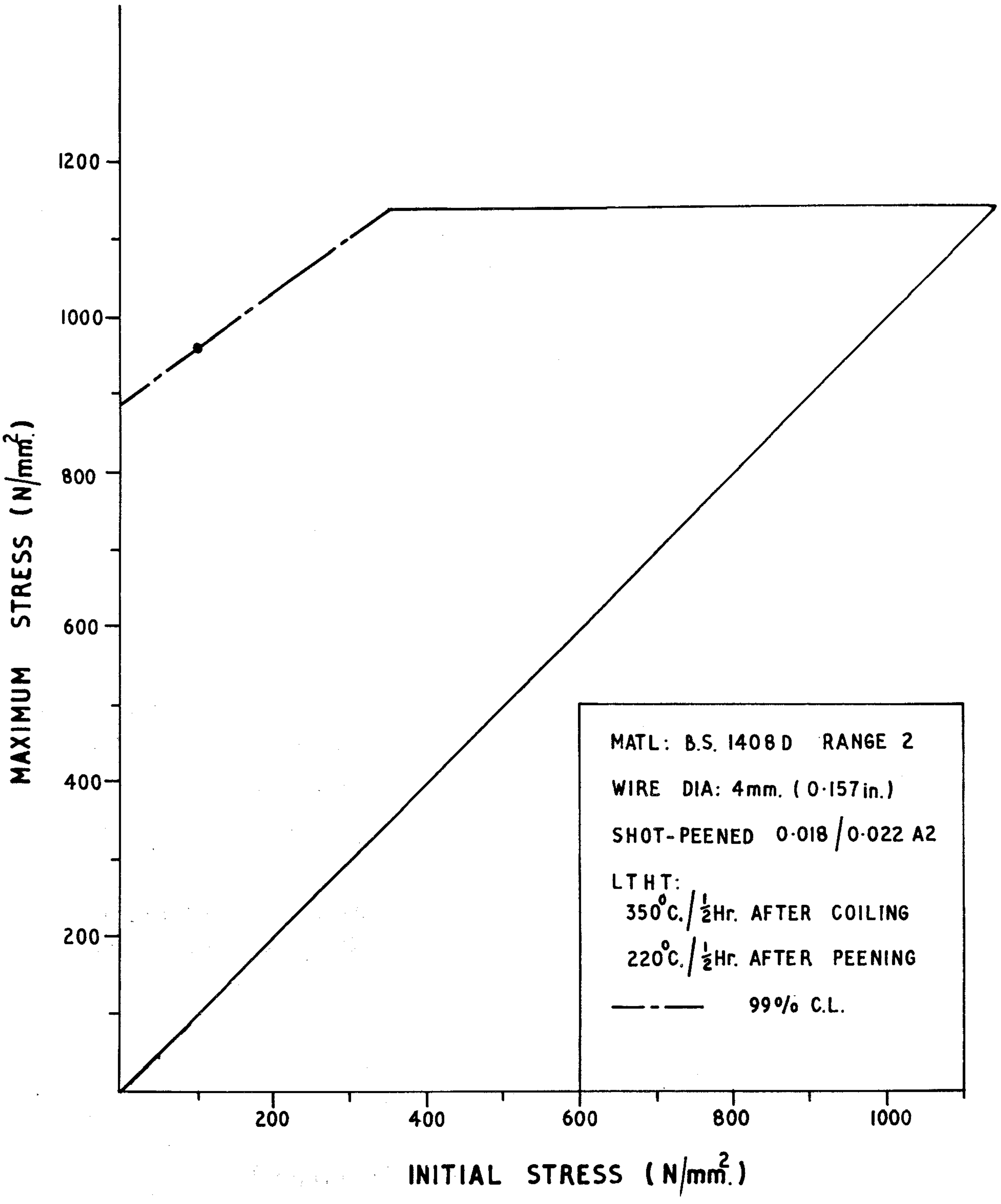

FIG. 21. GOODMAN DIAGRAM FOR B.S. 1408 D RANGE 2

SHOT-PEENED 10^5 CYCLES

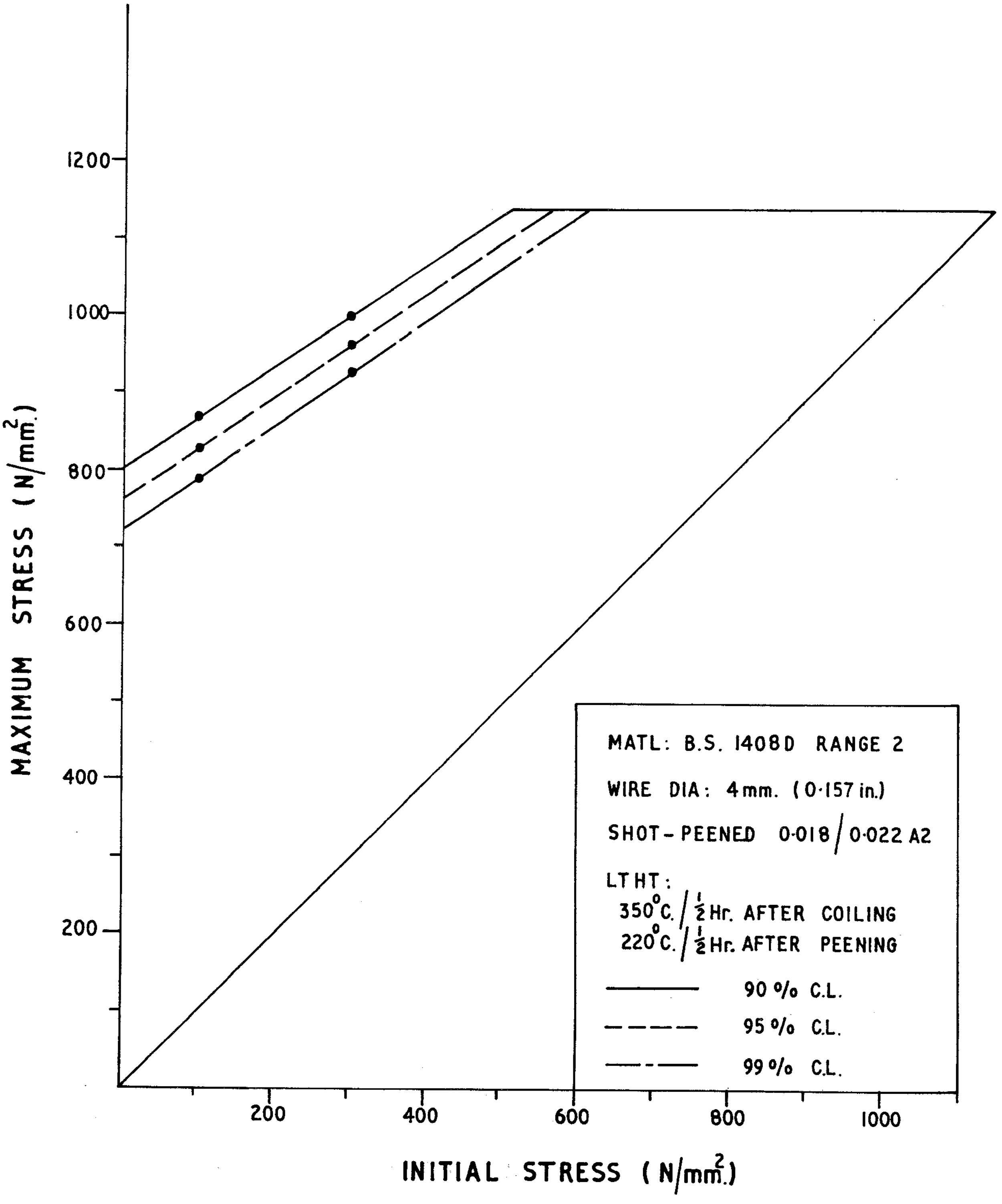

FIG. 22. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 2

SHOT-PEENED 10^6 CYCLES

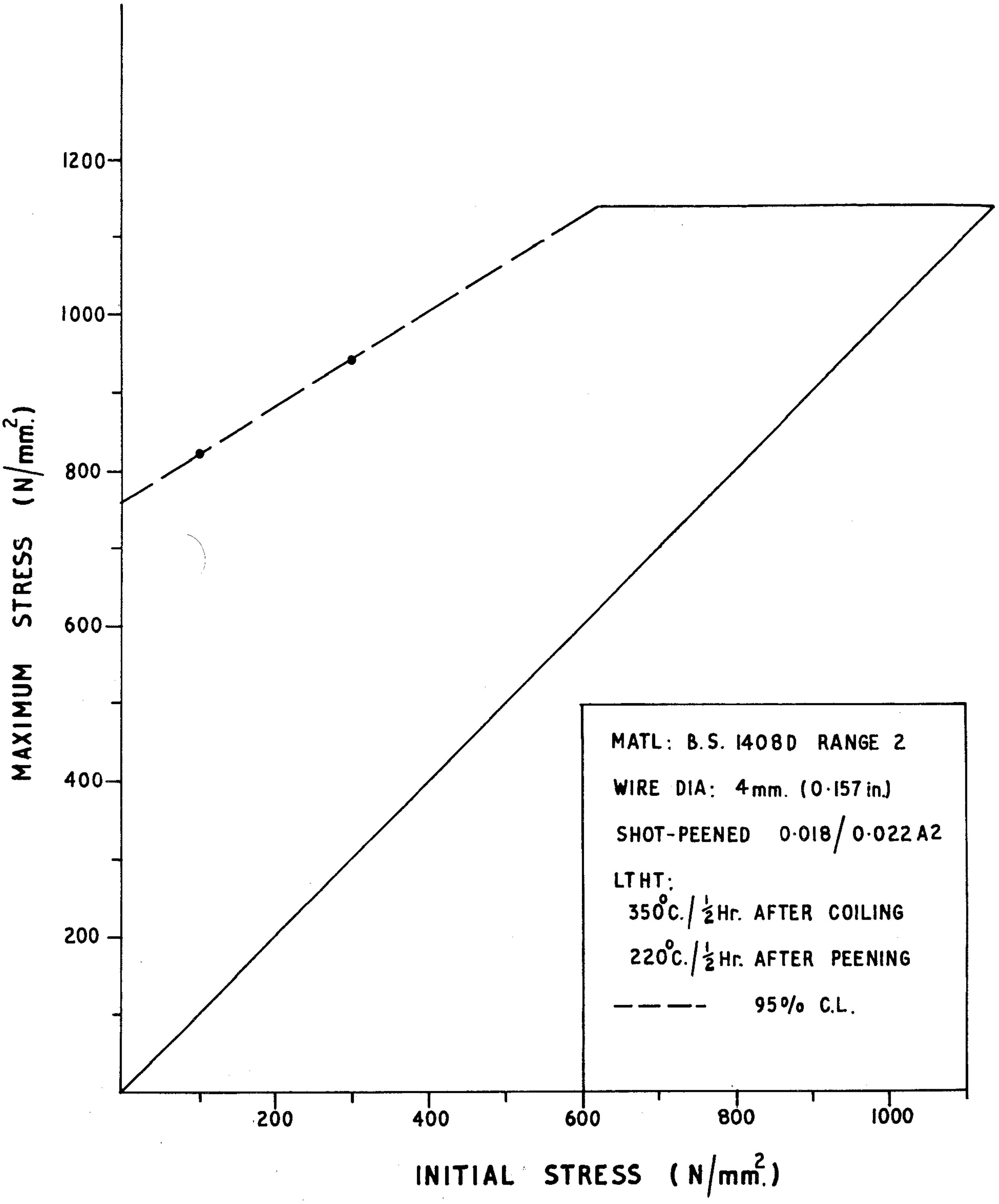

FIG. 23. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 2

SHOT-PEENED 10^7 CYCLES

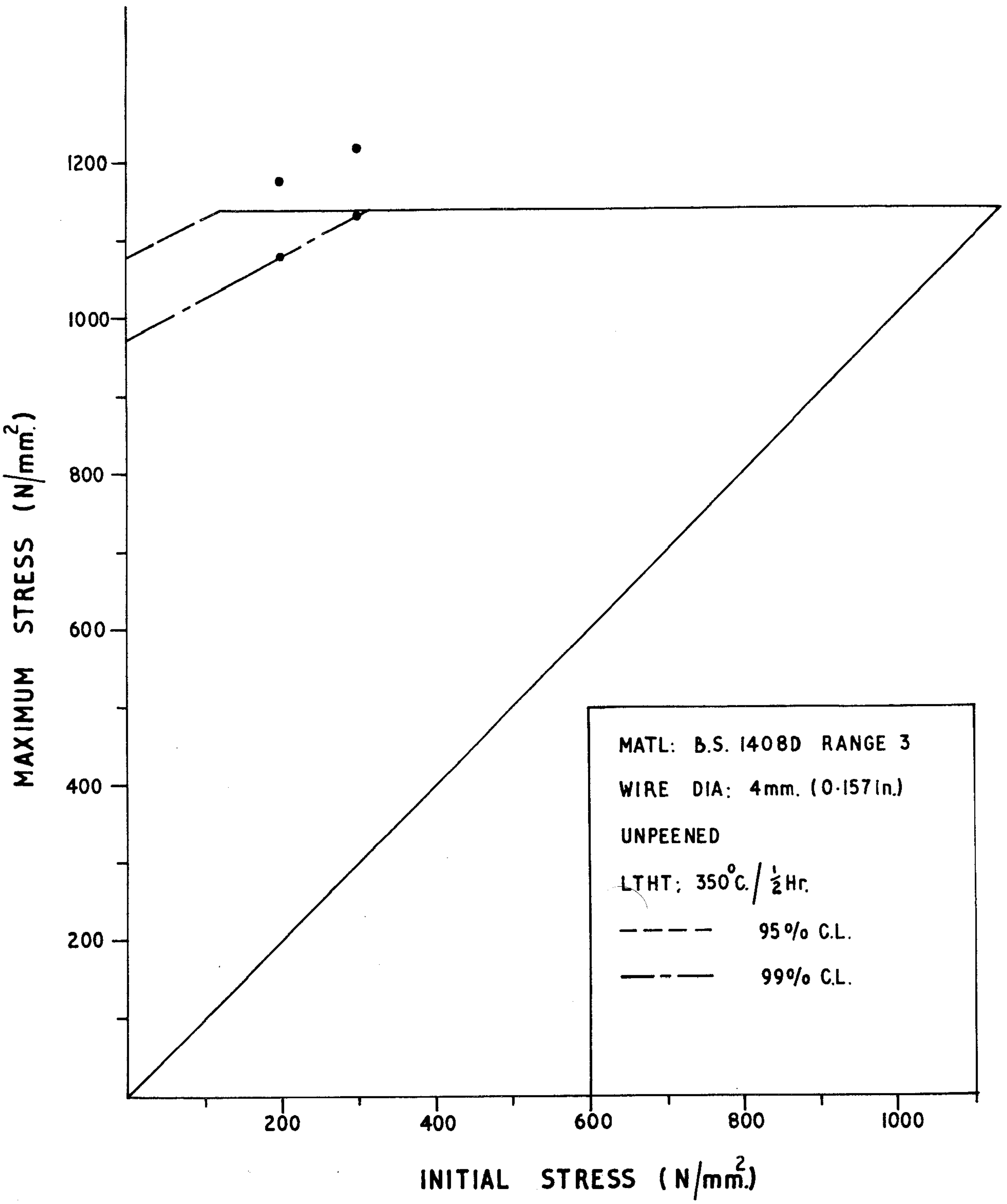

FIG. 24. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 3

UNPEENED 10^5 CYCLES

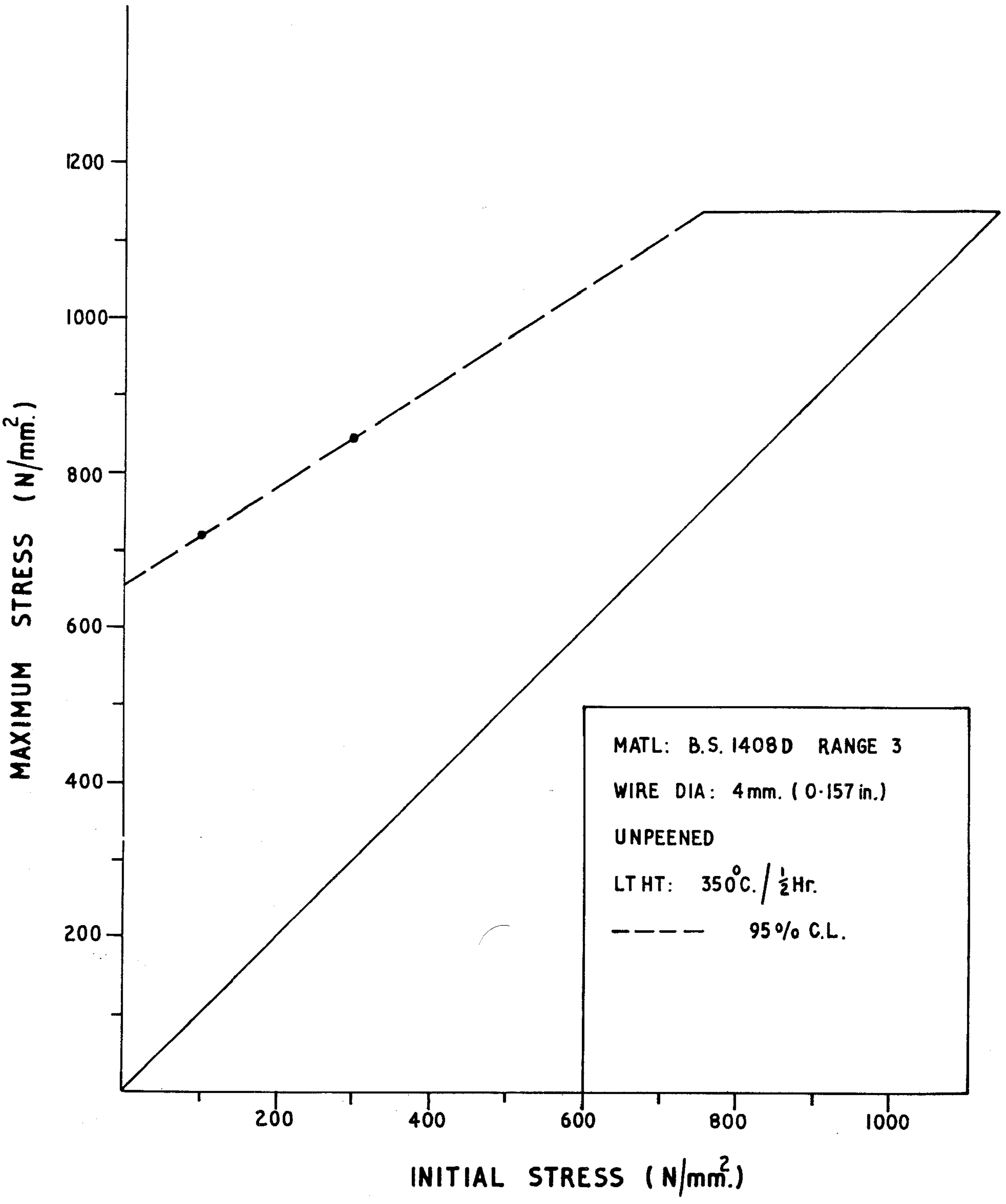

FIG. 25. GOODMAN DIAGRAM FOR B.S. 1408 D RANGE 3

UNPEENED 10^6 & 10^7 CYCLES

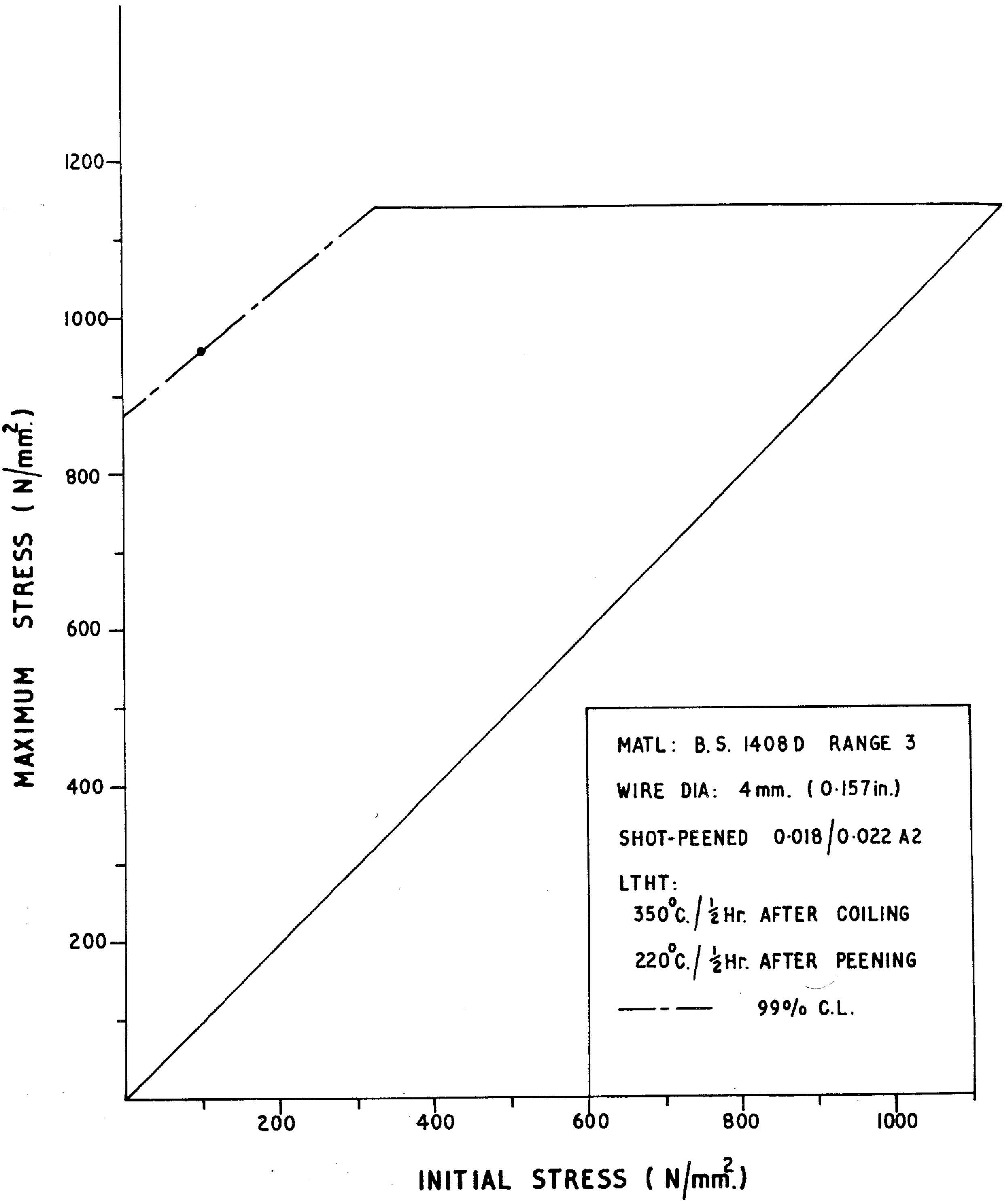

FIG. 26. GOODMAN DIAGRAM FOR B.S. 1408D RANGE 3

SHOT-PEENED 10^5 CYCLES

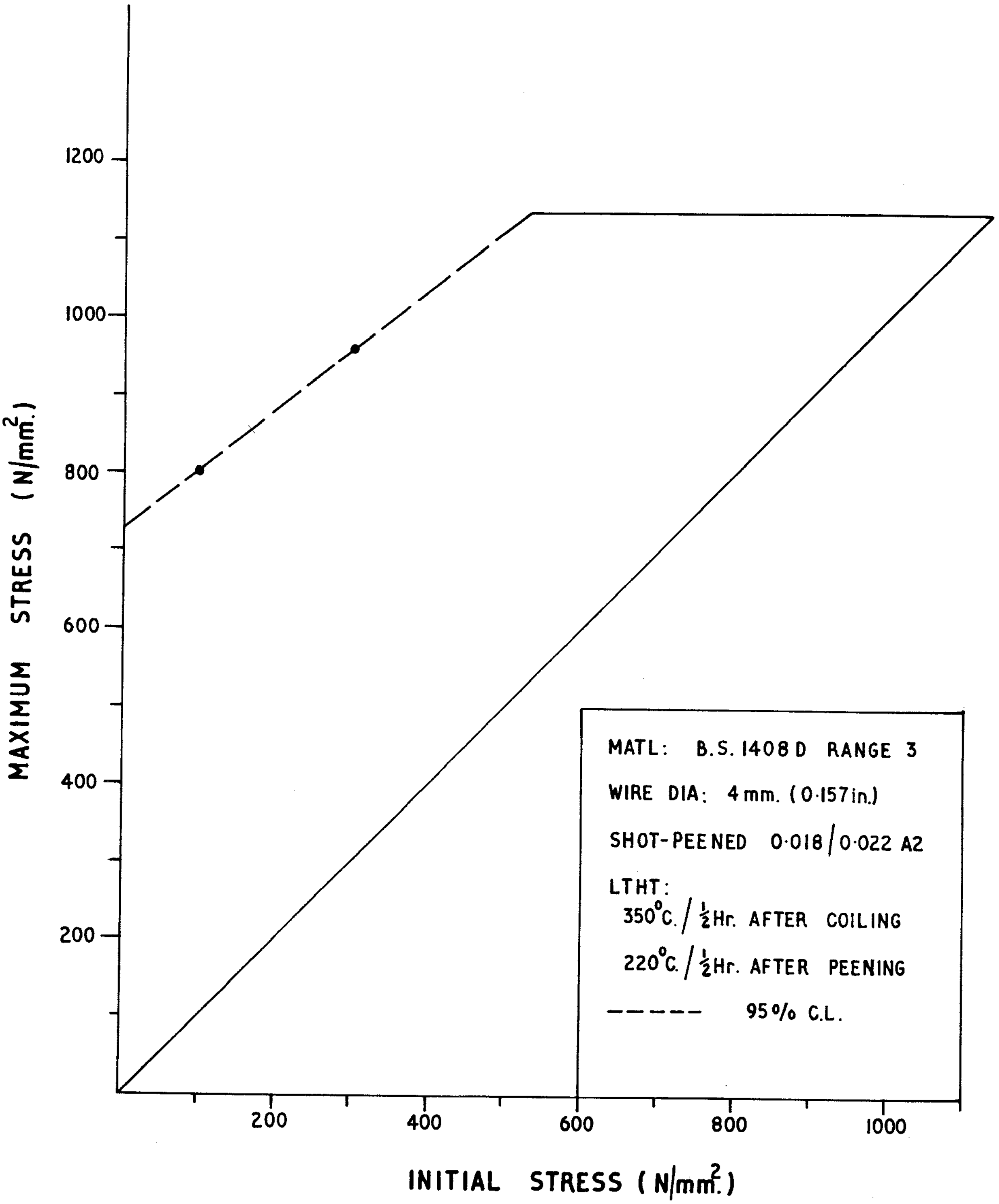

FIG. 27. GOODMAN DIAGRAM FOR B.S. 1408 D RANGE 3

SHOT-PEENED 10^6 & 10^7 CYCLES