THE SPRING RESEARCH ASSOCIATION

THE PRODUCTION OF SPRING FATIGUE DATA WITH STATISTICAL LEVELS OF CONFIDENCE

Part 4 of 7 parts

THE FATIGUE PROPERTIES OF SPRINGS MANUFACTURED FROM CHROME-VANADIUM WIRE TO En 47 GRADE 1 TO BS 1429

by

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1. INTRODUCTION

This part of the report deals with the fatigue and other data obtained from springs made from ground wire to En 47.

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

2. MATERIAL

2.1 Material Properties

The material used, En 47, is one of a group of steels classed under BS 1429 which relates to annealed steel wire for the manufacture of springs which are to be heat treated after fabrication. En 47 is an alloy steel containing chromium and vanadium which gives it superior stress-relaxation properties to BS 2803 wire. For this reason it is used extensively for engine valve springs, where the wire is usually about 4mm diameter. The steel is provided in two grades: Grade 1 - ground and Grade 2 unground. In view of its freedom from decarburisation and surface defects, ground wire (Grade 1) is recommended for applications where it is essential to have the highest possible resistance to fatigue failure.

A material to the same chemical composition as En 47 can be supplied in the pre-hardened and tempered condition, and one supplier used this. The advantages of the annealed wire are that the springs are easier to coil and can be hardened and tempered to give any required tensile strength, but the disadvantages are that the hardening and tempering process is not condusive to large scale production of springs and that the process can cause distortion to the spring or decarburisation of the wire.

2.2 Material specification

No tensile strength is specified for this material since the tempering temperature can be adjusted to produce any tensile strength below that achieved on hardening.

For Grade 1 material used in the research programme there should be no decarburisation evident in the specimens examined.

The chemical composition specified is given in Table 1.

3. SPRING DESIGN

The spring design specified was as laid down in Part 1 of the report. The springs were to be coiled from annealed material and hardened and tempered to 500/550 Hv. Shot-peened springs were given a subsequent 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 manufacturer was chemically analysed to determine the composition of its three main alloying elements, Carbon, Chromium and Vanadium. The results obtained are given in Table 2.

4.2 Hardness determination

To check that the springs had been hardened and tempered correctly, a sample spring from each manufacturer was mounted and the hardness measured. The hardness figures shown in Table 4 are the average of three determinations.

Only in one case was a wire sample received with the springs, from suppler 3. The tensile strength of the wire was measured and is given Table 4.

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 hardened and tempered structure.

5. FATIGUE TESTING

The fatigue testing to produce the Goodman diagrams was carried out as described in Part 1 of the report. The values of the fatigue limit of the peened and unpeened springs for each supplier, together with the dynamic relaxation at the fatigue limit, are shown in Table 4.

The Goodman diagrams for the unpeened springs are shown in Figs. 1 and 2, and for the shot-peened springs in Figs. 3 and 4.

6. DISCUSSION OF RESULTS

6.1 Ancilliary investigation

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, all having a very similar structure.

As it is impossible to detect whether the springs were coiled from hardened and tempered wire or from annealed wire and subsequently hardened and tempered, it has been determined from the suppliers that all except supplier 2 used annealed material. Thus, the hardness of the sample from supplier 2 is the condition in which the material was supplied. After coiling, these springs were merely given a low temperature heat treatment of 400°C for half-an-hour.

The surface condition of sample springs from the four suppliers were examined and found to be similar to one another though not as good as that of the springs made from BS 2803. A photomicrograph of a typical structure and surface, that of a spring from supplier 1, is shown in Fig. 5.

The solid stress of the batches of springs varied considerably from supplier to supplier. The springs from supplier 1 had a very high solid stress but were slightly distorted, and those from suppliers 3 and 4 had the lowest solid stress of the four batches.

6.2 Unpeened springs

The fatigue limits for the unpeened springs are given in Table 4 from which it can be seen that there is a very large difference in the fatigue performance of springs from different suppliers, although the variation in dynamic relaxation can be regarded as insignificant. The springs which have the best fatigue properties are those from supplier 3 which had the lowest solid stress but the highest hardness reading. The springs from suppliers 1 and 2 had very similar fatigue performances. Those from supplier 4 had the poorest fatigue performance, and hence it was possible to determine the fatigue limit with an initial stress of 500 N/mm^2 in addition to 100 N/mm^2 and 300 N/mm^2 for the other materials. Springs from this manufacturer also had the poorest finite life fatigue performance, the majority breaking before any of those from the other three suppliers. Thus the Goodman diagrams for finite and infinite life, Figs. 1 and 2, are based on the data from springs of supplier 4.

The results of the ancilliary investigations carried out gave no apparant reason why the unpeened springs from supplier 4 would have such as poor fatigue performance. Any defect in the material should have been discovered and would have also affected the shot-peened springs which were from the same batch.

6.3 Shot-peened springs

The shot-peened springs showed almost as wide a variation in fatigue properties as the unpeened springs although the order of the suppliers was totally different. The springs from supplier 3 had the best fatigue performance although the dynamic relaxation was so high, about 8%, that no springs could be broken with an intial stress of 300 N/mm^2, even at 10^7 cycles. All the springs broken to produce the finite life data were from supplier 2. However, even with 100 N/mm^2 initial stress, no springs 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. 3) has therefore been drawn through the maximum testing stress at 100 N/mm^2 with the same slope as the diagram for infinite life (Fig. 4). The springs from supplier 2 had the poorest fatigue properties for both limited and unlimited life. The springs from supplier 4, which were the poorest in the unpeened condition, in the shot-peened condition had a very good fatigue performance for both finite and infinite life. The dynamic relaxation of all the springs, except those from supplier 3, were very similar, though in all cases slightly greater than for the unpeened springs.

The general conclusion from these results is that the surface condition of the wire plays an important part in determining the fatigue properties as this is the only variable between the shot-peened and unpeened springs.

TABLE 1 SPECIFIED CHEMICAL COMPOSITION

	Percentage	
	Minimum	Maximum
Carbon	0.45	0.55
Manganese	0.50	0.80
Chromium	0.80	1.20
Vanadium	0.15	---
Silicon	---	0.50
Sulphur	---	0.05
Phosphorus	---	0.05

TABLE 2 ACTUAL CHEMICAL COMPOSITION

	CARBON %	CHROMIUM %	VANADIUM %
SUPPLIER 1	0.52	1.10	0.25
SUPPLIER 2	0.53	1.02	0.20
SUPPLIER 3	0.50	1.02	0.20
SUPPLIER 4	0.50	1.06	0.19

TABLE 3 ACTUAL SPRING DESIGNS

	SUPPLIER			
	1	2	3	4
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)	27.7	27.8	26.8	26.1
FREE LENGTH (mm)	51.7	50.4	48.4	50.3
SOLID STRESS (N/mm^2)	1310	1160	1080	1080

TABLE 4 SPRING PROPERTIES

	SUPPLIER			
	1	2	3	4
MEASURED TENSILE STRENGTH (N/mm^2)	---	---	1552	---
HARDNESS (Hv 30)	527	487	530	523
EQUIVALENT TENSILE STRENGTH (N/mm^2)	1630	1530	1630	1620
UNPEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	660	640	780	520
FATIGUE LIMIT at 300 N/mm^2 Initial stress	840	800	960	700
FATIGUE LIMIT at 500 N/mm^2 Initial stress	---	---	---	900
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	0.0%	0.3%	0.6%	0.6%
SHOT-PEENED				
FATIGUE LIMIT at 100 N/mm^2 Initial stress	880	780	960	880
FATIGUE LIMIT at 300 N/mm^2 Initial stress	980	880	---	---
DYNAMIC RELAXATION:- 10^7 cycles, 300 N/mm^2 Initial stress	-1.4%	0.9%	7.7%	1.2%

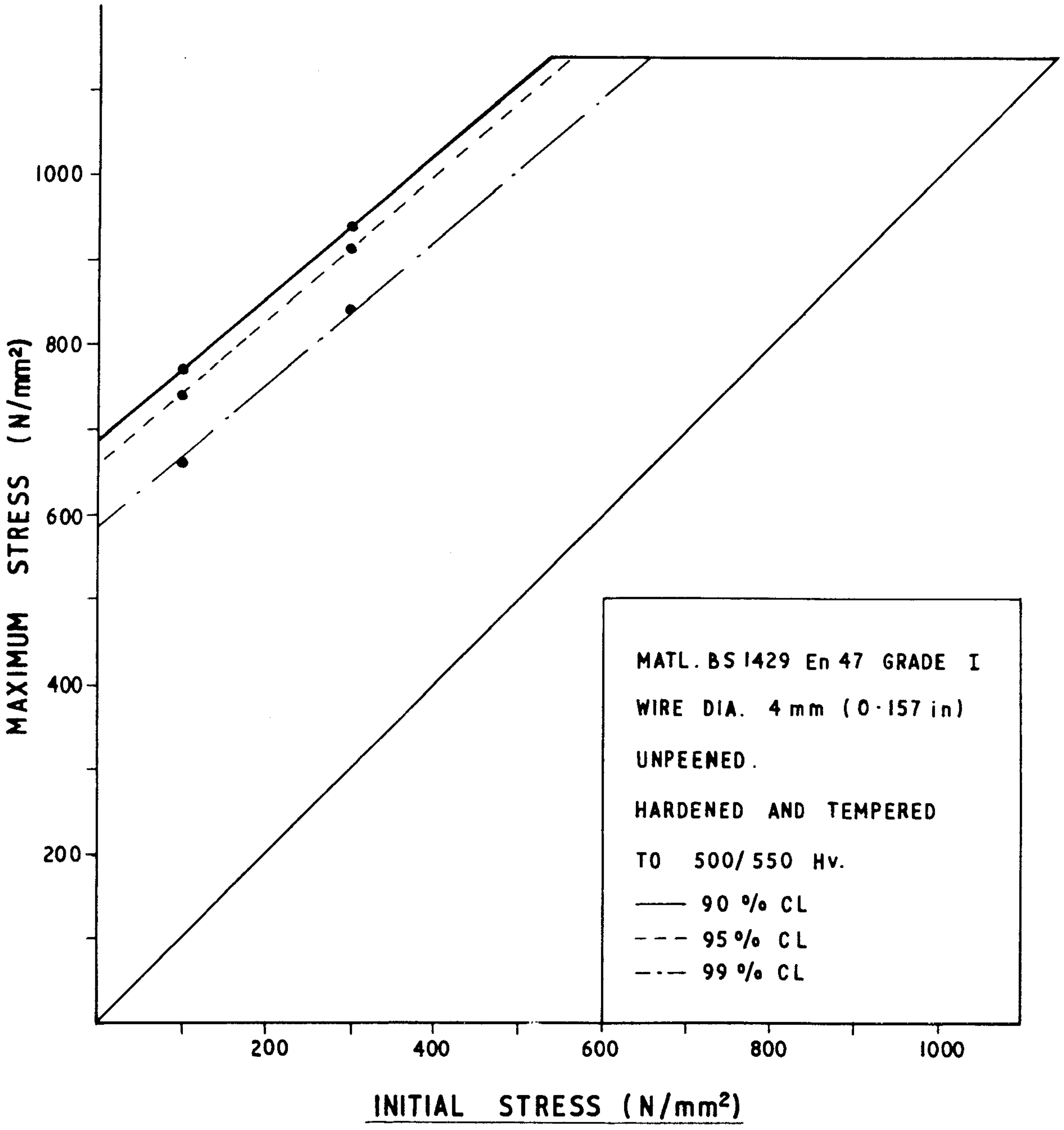

FIG. 1 GOODMAN DIAGRAM FOR En 47 UNPEENED 10^5 CYCLES

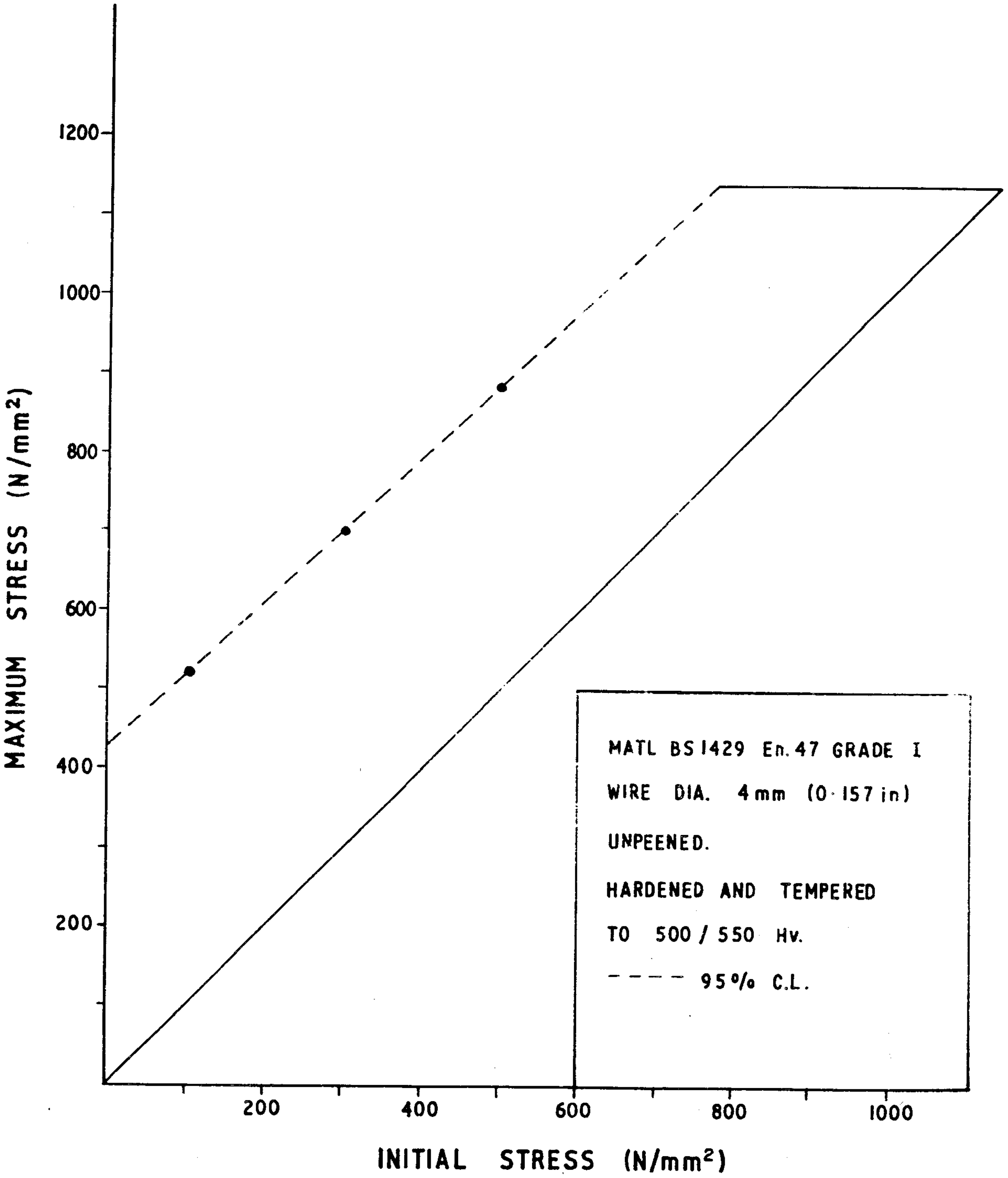

FIG. 2 GOODMAN DIAGRAM FOR En 47 UNPEENED 10^6 & 10^7 CYCLES

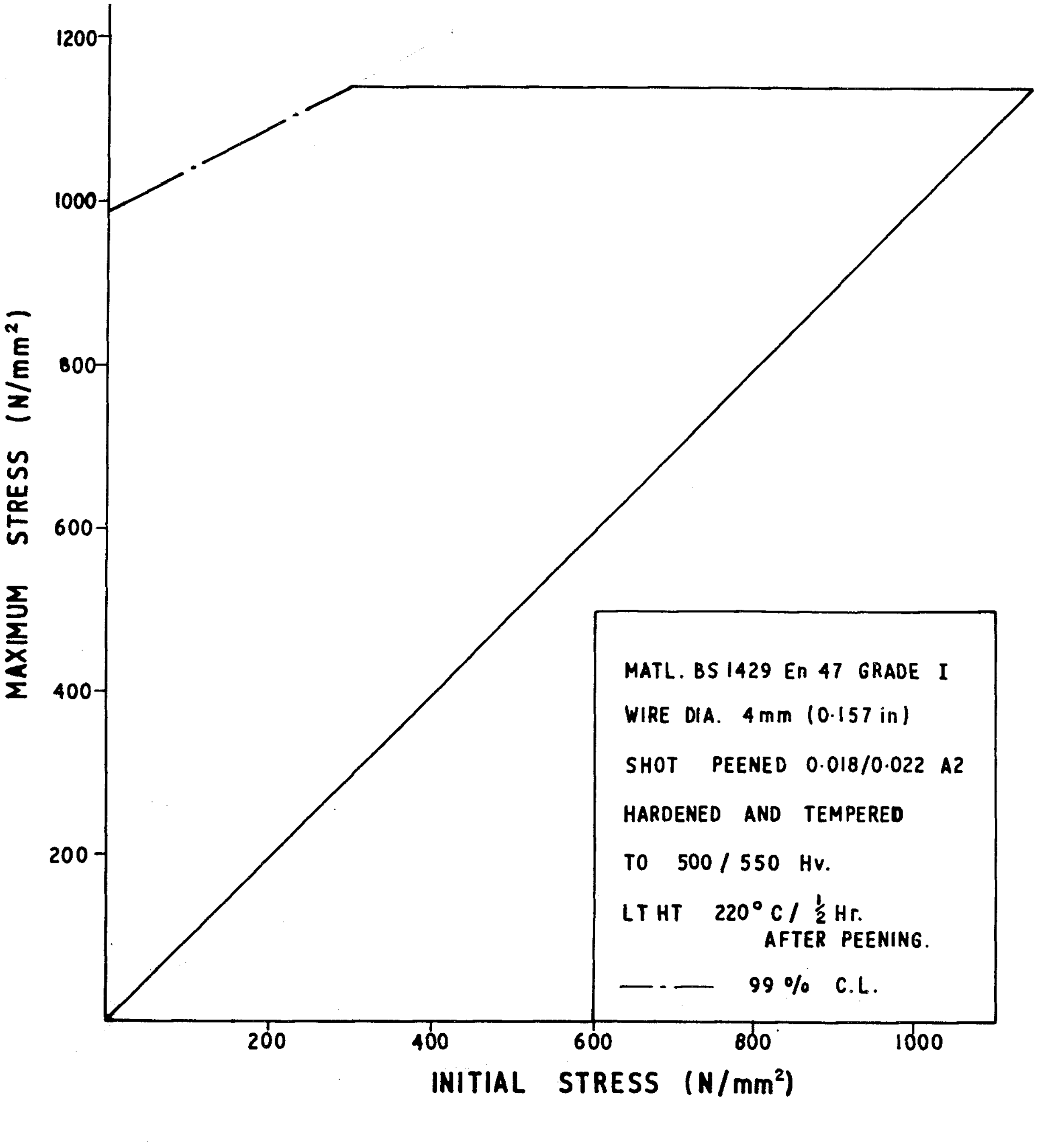

FIG.3 GOODMAN DIAGRAM FOR En47 SHOT PEENED 10^5 CYCLES

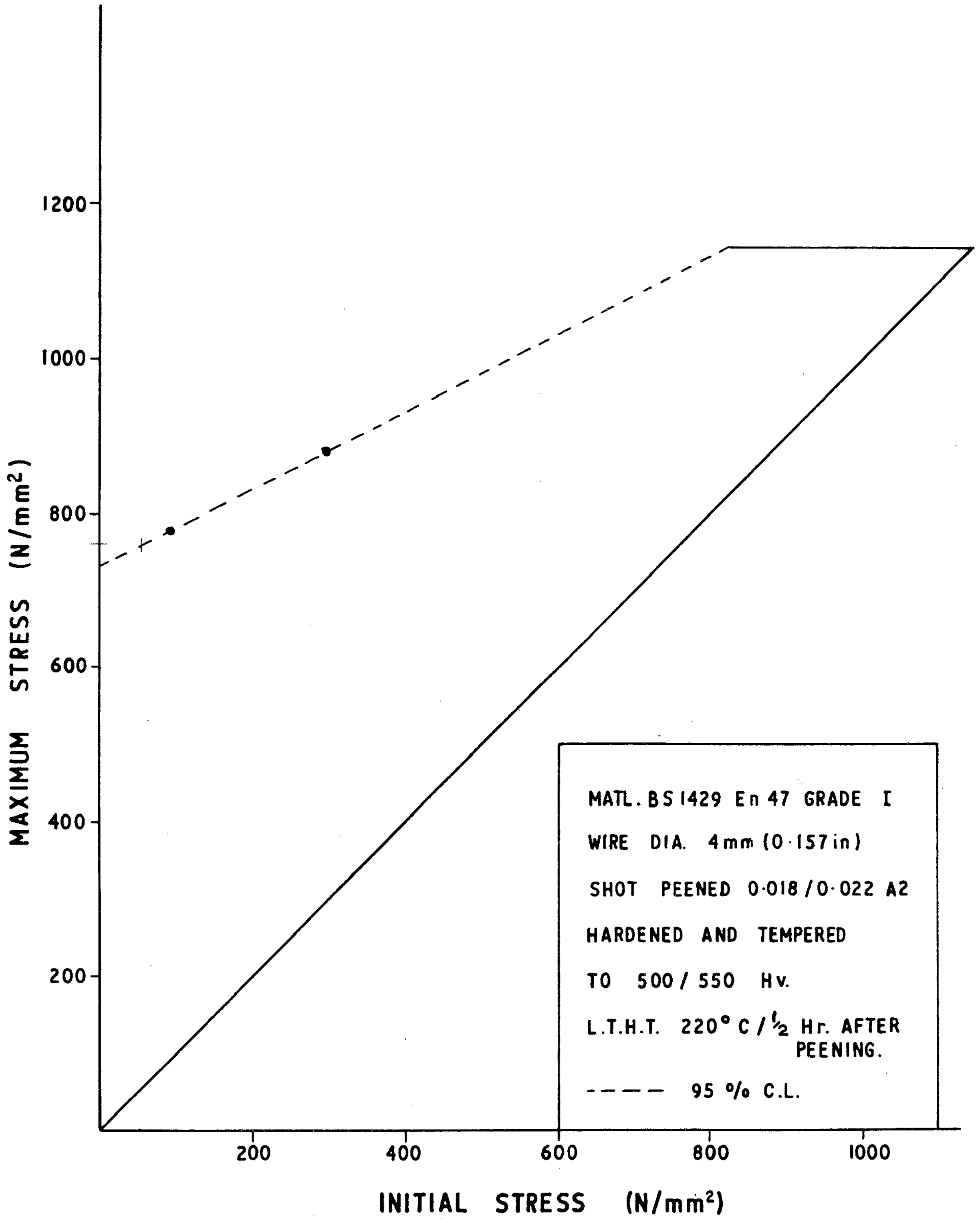

FIG. 4 GOODMAN DIAGRAM FOR En 47 SHOT PEENED 10^6 & 10^7 CYCLES

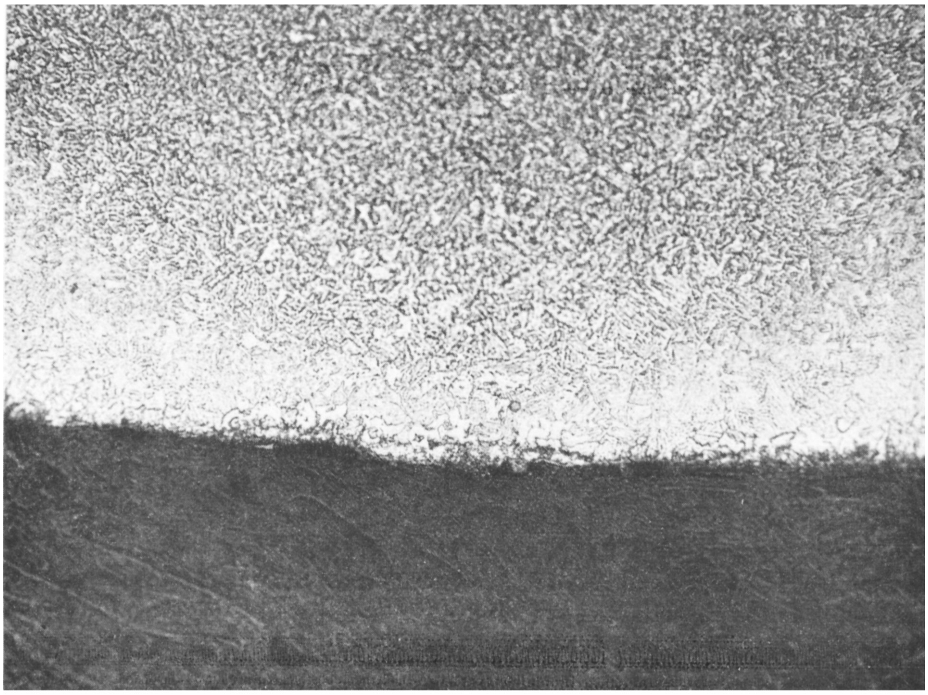

FIG. 5

PHOTOMICROGRAPH OF SURFACE AND STRUCTURE OF En47 SPRING FROM SUPPLIER 1 (x400)