THE SPRING RESEARCH & MANUFACTURERS' ASSOCIATION

THE EFFECT OF DECARBURIZATION ON THE FATIGUE PROPERTIES OF HARDENED AND TEMPERED CARBON STEEL SPRINGS

Report No. 329

by

A.R. Hood B.Sc., M. Met.

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SUMMARY

The effect of three different decarburization treatments on the fatigue properties of springs coiled from 2.8 mm carbon steel have been evaluated.

The presence of partial decarburization to a maximum depth of 0.025 mm (0.9% of wire diameter), as produced by the heating of springs for one hour at 900°C in moist air reduced the fatigue ratio of the springs from 0.52 to 0.46.

The presence of complete decarburization to a maximum depth 0.01 mm (0.4% of wire diameter) plus partial decarburization to a maximum depth of 0.085 mm (3% of wire diameter), as produced by heating springs for one hour at 950°C in moist air further reduced the fatigue ratio to 0.40.

However, complete decarburization to a depth of 0.02 mm (0.7% of wire diameter) plus partial decarburization to a maximum depth of 0.06 mm (2.1% of wire diameter), as produced by heating springs for one hour at 850°C in oxide scale only reduced the fatigue ratio to 0.45.

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1. INTRODUCTION

British Standard wire specifications such as BS 1429[1], BS 2803[2] and BS 5216[3] contain sections regulating the depth and type of decarburization allowable in the material. However, the relevance of the specified decarburization levels to the properties of coil springs produced from the wire has not been ascertained.

It is commonly thought that decarburization has a more deleterious effect on dynamic properties than on static properties. Therefore, the work covered by this report has been undertaken to investigate the effect of different levels and types of decarburization on the fatigue properties of hardened and tempered light springs.

2. MATERIAL AND SPRING DESIGN

Springs were coiled to the design shown in Table I using 2.8 mm diameter wire to BS 5216[3] specification. After coiling the springs were stress relieved for 30 minutes at 275°C and then end ground.

2.1 Undecarburized Wire

The chemical composition of the wire conformed to both BS 5216 and BS 2803 specification (Table II).

The tensile properties of the wire both in the hard drawn condition and after heat treatment to produce properties similar to those obtainable from BS 2803 Grade I[2] wire are contained in Table III; both sets of R_m values conform to the relevant specifications.

As well as tensile tests, wire in both conditions was subjected to the relevant torsion, wrapping and decarburization tests. The as drawn HD3 wire passed all the tests easily. After heat treatment (see section 4), it was found that specimen wires conformed to the BS 2803 torsion and decarburization tests but would not perform a wrapping test once the minimum specified R_m value of 1544 N/mm^2 was reached. However, as the springs were already coiled it was considered that the fatigue results were unlikely to be greatly affected. The full torsional properties of the heat treated wire are given in Table IV.

The tensile and torsional properties of the undecarburized wire correlate well with previous results[4] for BS 2803 wire springs which had been low temperature heat treated at 400°C.

2.2 Decarburized Wire

Specimens of wire were decarburized and then hardened and tempered with each group of springs (sections 3 and 4). The tensile and torsional properties corresponding to each decarburization treatment are included in Table III and IV respectively.

The drop in tensile and torsional properties for one hour at 900°C in moist air and the one hour at 850°C in scale specimens is very similar, while the one hour at 950°C in moist air specimens show a further decline in both properties. By far the most remarkable of the mechanical property variations is that in the twists to failure (Table IV). While the reduction in the area results from the tensile tests show considerable scatter and no definite trend, the drop in twists to failure from more than twenty for the decarburized 850°C in scale specimens to four for both the moist air sets of specimens is indisputable.

3. DECARBURIZATION

3.1 Definitions

For BS 2803 grade II high duty wire[2] the decarburization specification states that "The section shall show no totally decarburized zone. Partial decarburization shall not extend farther below the surface than a depth equal to 1½% of the nominal diameter of the wire".

Such decarburization specifications are based on the use of metallographic examination to gain a qualitative impression of the depth of decarburization as "the thickness of the layer in which the structure differs significantly from that of the core".[5] BS 2803 specifies the examination of suitably prepared[2] sections at a magnification of 200 diameters (x200). It was found, however, that such a low magnification failed to reveal certain aspects of the decarburization. Therefore, in this report representative photomicrographs of polished sections etched in 2% Nital have been reproduced not only at x200 but also, where necessary, at x600 magnification. The term "totally decarburized" as used in the specification refers to the presence of a surface layer of "blocky" ferrite. In this report this will be referred to as "complete decarburization" in accordance with more modern standards[5]. The term "partial decarburization" has been assessed as the presence of visible grain boundary oxidation, i.e. constituents outlining the austenite grain boundaries. Two such constituents can be readily identified in most specimens e.g. in Figs. 1 (b) and 2 (b) dark threads can be distinguished within light etching bands. The presence of these two constituents has been reported and discussed elsewhere[6]. For the purpose of this report they will be referred to as oxide filaments and partial decarburization respectively.

Where estimates of the maximum depth of decarburization have been made, these refer to the deepest penetration of the visible decarburization at isolated points[5].

3.2 Experimental Procedure and Results

Initial tests on the production of controlled amounts of decarburization were carried out on wire samples in a variety of environments. Several different types of decarburization were produced, ranging in intensity from thin threads of "oxide" to large amounts of "blocky" ferrite. However, none of the procedures tried would produce partial decarburization to a depth greater than 1% of the wire diameter without also producing some complete decarburization.

Following the prelimary tests the two most promising decarburization methods which were feasible using the equipment available were:-

(a) heating of springs at high temperatures in moist air,
(b) heating of springs packed in crushed millscale

The amount of decarburization produced was in both cases, dependent upon both time and temperature. In order to reduce the number of variables involved a time of one hour was chosen and the temperature varied to alter the depth and type of decarburization (Table V).

3.2.1 Decarburization in moist air

Moisture was introduced into the furnace atmosphere by placing small pieces of graphite which had been well soaked in teepol solution close to the springs during heating.

Figs. 1 and 2 illustrate representative microstructures of the springs decarburized at 900°C for one hour. The decarburization present in this set of springs was found to be evenly distributed round the circumference of the wire and to be all of similar type. The air cooled structure (Fig. 1) showed partial decarburization to a maximum depth of 0.085 mm i.e. 3% of wire diameter, with oxide filaments penetrating to a maximum depth of 0.025 mm (0.9% of wire diameter). After hardening and tempering, however, (Fig. 2) the penetration of the partial decarburization was reduced to the same depth (0.025 mm) as that of oxide filaments.

Springs heated for one hour at 950°C displayed the microstructure illustrated in Figs. 3 and 4. In the air cooled samples a complete rim of ferrite was present, displaying a variety of morphologies:

"Blocky", grain boundary and Widmanstatten ferrite structures are all visible in Fig. 3, to a maximum depth of 0.27 mm i.e. 9.6% of wire diameter. Again oxide filaments are visible within the outer ferrite layer.

After hardening and tempering the various ferrite morphologies in the air cooled structure gave an uneven distribution of partial decarburization (Fig. 4a) to a maximum depth of 0.085 mm (3% of wire diameter) with some small patches of complete decarburization (Fig. 4b), with a maximum depth of 0.01 mm (0.4% of wire diameter).

In both cases the oxide filament showed a maximum penetration depth of 0.025 mm (0.9% of wire diameter).

3.2.2 Decarburization in scale

Although the heating of springs and wire in contact with iron oxide scale rapidly produced decarburization, it was difficult to obtain evenly distributed decarburization of similar character on a reproducible basis.

Industrial millscale was dried, ground and sieved and then separated into three fractions: fine (100 mesh), medium (36 mesh) and coarse (16 mesh). An "ideal packing" mixture was prepared using 20% fine, 40% medium and 40% coarse fractions.

Sets of four springs were well degreased and then buried in the scale mixture in a small stainless steel box, the box being mechanically vibrated to settle the scale mixture round the springs and obtain as intimate a wire/scale contact as possible. Moisture was again introduced into the furnace atmosphere using damp graphite.

The springs were heated at 850°C for one hour and then removed from the scale as rapidly as possible in order to ensure that the cooling rate of the scale decarburized springs was as close as possible to that of the air decarburized springs. (It had been found that, if the springs were allowed to cool in the box, carbon diffusion occurred and the intense surface decarburization was lost).

Due to the difficulty of ensuring uniform wire/scale contact, the decarburization produced in the springs was somewhat patchy (Figs. 5 and 6). In the air cooled condition large amounts of excess grain boundary ferrite were present round most of the circumference of the wire (Fig. 5a) with a maximum depth of 0.32 mm (11% of wire diameter). The areas of blocky ferrite also present (Fig. 5b) had a maximum depth of 0.06 mm (2.1% of wire diameter). "Oxide filaments" were visible in both types of ferrite to a maximum depth of 0.025 mm (0.9% of wire diameter).

The hardened and tempered springs contained variable amounts of partial decarburization (Fig. 6) with a maximum depth of 0.06 mm (2.1% of wire diameter), plus some small patches of complete decarburization (Fig. 6c). No oxide filaments were discernible in the samples examined.

3.2.3 Control springs

In order to obtain material approximately equal to BS 1429 grade 1[1] and BS 2803 grade 1[2], i.e. with zero decarburization, it was found necessary to coat the BS 5216 springs thoroughly with Berkatekt before austenitising for the minimum possible time (see section 4.2).

4. HEAT TREATMENT

4.1 Decarburized Springs

After the appropriate decarburization treatment the springs were air cooled and then shot peened for 1 min. to remove the layer of scale acquired during decarburization. The springs were then well coated with Berkatekt to prevent further scaling, and reaustenitised for 5 mins. at 850°C before oil quenching. (It was found that austenitising times longer than 5 mins allowed carbon diffusion and much of the visible decarburization was lost).

Finally, a tempering treatment of 45 mins. at 400°C was given.

4.2 Control Springs

In an attempt to eliminate surface condition as a variable these springs were also shot peened for 1 min. before coating with Berkatekt. As the HD3 wire had a slightly coarser pearlite structure than the decarburized air cooled material, these springs were austenitised for 10 mins. at 850°C before oil quenching and tempering as in 4.1.

A typical microstructure of a control spring is shown in Fig. 7 while Fig. 8 illustrates the usual microstructure of BS 2803 Grade I wire.

5. FATIGUE TESTING

After tempering all springs were stabilised by cold scragging 20 times.

The heavy scaling which occurred during the decarburization in moist air treatment caused a considerable loss in wire diameter, and a resultant change in spring dimensions (Table VI).

A minimum of eight springs were measured from each group and the mean of the measured parameters used to calculate the appropriate loads for fatigue testing by substitution in:-

$$P = \frac{\tau \pi d^3}{8DK} \qquad \text{.......... (i)}$$ [7]

Where P = load

τ = required stress

d = wire diameter

D = mean coil diameter

$$k = \frac{c+0.2}{c-1}, \qquad c = \frac{D}{d}$$

From each of the four groups of springs $\frac{\pi d^3}{8DK}$ was taken as a constant (A) based on the mean dimensions of the springs. Values of A are included in Table VI.

Because of the variation in the tensile strength of the material after decarburization it was decided to compare the fatigue ratios i.e. $\frac{\text{fatigue limit}}{\text{tensile strength}}$ of each group of springs.

Normally fatigue ratios refer to the fatigue limit at zero initial stress. As fatigue testing of springs, having zero initial stress is impracticable, it is necessary to generate fatigue data at two or more initial stress levels and from the data produced extrapolate to conditions of zero initial stress. Since the number of test springs, having the required surface condition was limited, testing was confined to one initial stress level of 200 N/mm^2. The four groups of springs were tested using an eight station forced motion fatigue testing machine. The initial choice of maximum test stress levels for the control group of springs was based on the results of the previous work at SRAMA(4,8).

The results of the tests on the control springs are expressed as an S/N curve in Fig. 9. From this data the fatigue limit for this group of springs was estimated at 825 N/mm^2. Using this value as a guide and allowing for the reduced tensile strength of the decarburized material, low stress fatigue tests were carried out and the fatigue limit for each decarburization group of springs determined (Table VII). The results for the 900°C in moist air and the 850°C in scale groups showed little scatter and well defined fatigue limits were obtained. For the 950°C in moist air group a much greater scatter of results was found at stress levels just above the fatigue limit quoted.

6. DISCUSSION OF RESULTS

6.1 Decarburization

For the springs decarburized in moist air, although the partial decarburization was reduced during hardening and tempering of the decarburized springs, presumably by carbon diffusion, the oxide filaments remained unaltered. Also, the depth of oxide penetration was the same at both decarburizing temperatures, suggesting that the inward diffusion of the oxygen may be controlled by grain boundary energies.

Although dark etching threads were visible in the air cooled 850^{o}C in scale specimens (Fig. 5) it is possible that these were not truly oxide filaments as the decarburization in this case was produced by contact of the carbon containing structure with a solid oxide as opposed to gaseous oxygen being free to penetrate the material.

The appearance of the partial decarburization after hardening and tempering differs in the three groups of springs. In the 900^{o}C in moist air samples (Fig. 2) the dark threads (designated "oxide") lie within narrow light etching filaments (probably "relief constituent"[6]). This has the effect of introducing narrow, sharply incised filaments of softer material into the prior austenite grain boundaries of the wire surface.

For the 950^{o}C in moist air springs (Fig. 4) the threads of 'oxide' are less easily discernible but the narrow filaments of partial decarburization penetrate much more deeply into the wire surface, frequently following the prior austenite grain boundary completely round a grain. The small areas of complete decarburization were invariably associated with a deep penetration of partial decarburization.

In contrast the 850^{o}C in scale specimens (Fig. 6) show relatively thick filaments of partial decarburization with less strict adherence to the prior austenite grain boundaries so that small islands of decarburization products can be discerned within the martensitic matrix. The areas of complete decarburization were much larger than for the 950°C in moist air springs and usually not associated with an increased amount of grain boundary oxidation. In general the decarburization was much less well distributed round the circumference of the wire than in the air decarburized springs.

Industrially, decarburization by contact with scale is most likely to occur during heating and rolling of ingot or bar stock. If material containing this type of decarburization is drawn to fine wire, the bulk of the surface decarburization would be expected to be removed, leaving a structure containing small "islands" of decarburization products. Fig. 10 shows a sample of BS 2803 Grade III wire containing just this type of decarburization.

The type of decarburization found in the moist air sample is more likely to be produced during careless heat treatment of wire after drawing or of springs after coiling. During the preliminary work carried out to establish a suitable decarburization method it was found that heating wire at relatively low temperatures (even below 850°C)in a moist atmosphere produced thin dark threads of "oxide". However, these threads could not be distinguished at x200 magnification. Therefore, if such oxidation products were included in specifications the metallographic examination techniques would require a magnification of at least x400. Before recommending such a change further work would be required to check the fatigue properties of springs containing only this type of defect.

6.2 Mechanical Properties

The decrease in the tensile and torsional properties of the decarburized wires must be mainly attributable to the presence of the decarburization products. The only other variable present is that of grain size, and while the deleterious effect of increased grain size on the strength of pearlite structures is well known, it is generally thought[9,10] that grain size has very little influence on the mechanical properties of quenched and tempered martensite.

It remains, therefore, to consider why the 900°C in moist air and 850°C in scale samples show such similar mechanical properties (apart from the twists to failure) (Tables III and IV), when the depths and types of decarburization differ greatly (Table V).

There are two main aspects of the decarburization products which seem especially relevant:-

(i) the decarburized material will be softer i.e. less strong than the martensite core material of the wire,

(ii) the penetration of the various decarburization products into the material acts as a stress raiser and nucleation point for cracking.

The presence of low carbon, low strength structures e.g. ferrite, in the material (aspect (i)) would be expected to reduce the tensile and torsional properties. However, if this were the only effect present, the properties of the 950°C in moist air and 850°C in scale specimens should have been similar as both showed similar amounts of complete and partial decarburization.

For aspect (ii), not only will an increased depth of penetration affect the cracking resistance of the material but the dimensions of the penetrating constituent will also be critical. Fracture mechanics predicts:-

$$\sigma_t = 2\sigma_a \left(\frac{L}{R}\right)^{\frac{1}{2}} \qquad \text{.......... (ii)}$$

Where σ_t = stress at crack tip
$_a$ = applied stress
L = crack length
R = crack tip radius

Comparison of Figs. 2, 4 and 6 clearly shows that while the 850°C in scale sample contains more visible decarburization the morphology of the decarburization products gives thicker filaments of the soft material compared to the moist air samples. Thus it seems reasonable to suppose than an inter-

-action of the two effects i.e. crack length and crack tip radius could cause the material strength variations found here.

This reasoning is also consistent with the twists to failure results where the two moist air decarburized samples, containing the more severe crack assisting structures, show a vastly inferior resistance.

6.3 Fatigue Properties

The arguments put forward in section 6.2 can also be applied to the fatigue results where the drop in fatigue ratio (from 0.52 to 0.46) after decarburizing at 900^{o}C in moist air to give a maximum depth of decarburization of 0.025 mm is almost identical to that for the 850^{o}C in scale treatment (f.r. 0.45, maximum depth of decarburization 0.06), while the 950^{o}C moist air springs show a further decrease in fatigue ratio to 0.40 with an increase of decarburization penetration to 0.085 mm. In the case of fatigue the effect of variable austenite grain size should also be considered. Previous work(10) has shown that an increase in the prior austenite grain size increases the fatigue crack initiation rate of martensitic structures and that cracks form preferentially on the previous austenite grain boundaries. However, the partial decarburization found here also follows the austenite grain boundaries. Therefore, it seems reasonable to presume that the effects of the large amounts of decarburization present here will have swamped any grain size contribution.

It has been reported elsewhere(6) that the morphology of the decarburization (or oxidation) present has as important an effect on fatigue as does the extent of the decarburization. Watkinson(6) reported that oxide penetration and thin filaments of partial decarburization such as found in the moist air decarburized springs are more deleterious to fatigue resistance than patches of complete decarburization. The results of the work covered by this report certainly seem to confirm Watkinson's(6) results for the torsional fatigue of spring steels.

It seems likely that the presence of small areas of complete decarburization, which is banned in the BS 2803 specification, is actually less deleterious than oxygen penetration from exposure to moist air during heat treatment of either wire or springs. It must not be thought, however, that areas of complete decarburization do not aversely affect the fatigue properties of the springs - they most certainly do, but it should also be realised that less obvious types of decarburization can have an equally bad or even worse effect.

7. CONCLUSIONS

1. Springs coiled from 2.8 mm diameter BS 5216 HD3 wire, after heat treatment to produce BS 2803 Grade I mechanical properties, have a fatigue limit of 825 N/mm^2 at an initial stress of 200 N/mm^2 and showed a fatigue ratio of 0.52.

2. Surface decarburization of BS 2803 springs for one hour at 900°C in moist air produced thin filaments of partial decarburization to a maximum depth of 0.025 mm (0.9% of wire diameter). The fatigue limit for this group of springs was decreased to 675 N/mm^2 and the fatigue ratio reduced to 0.46.

3. Surface decarburization of BS 2803 springs for one hour at 950°C in moist air produced a few small areas of complete decarburization to a maximum depth of 0.01 mm (0.4% of wire diameter) plus thin filaments of partial decarburization to a maximum depth of 0.085 mm (3% of wire diameter). The fatigue limit of these springs was 500 N/mm^2 and the fatigue ratio 0.04.

4. Surface decarburization of BS 2803 springs for one hour at 850°C in crushed millscale produced a few fairly large areas of complete decarburization to a maximum depth of 0.02 mm (0.7% of wire diameter) plus fairly thick filaments and 'islands' of partial decarburization to a maximum depth of 0.06 mm (2.1% of wire diameter). The fatigue limit of this group of springs was 650 N/mm^2 and the fatigue ratio 0.45.

8. RECOMMENDATIONS FOR FURTHER WORK

It is recommended that fatigue tests should be carried out on BS 2803 springs containing surface grain boundary filaments of oxide without any further decarburization.

9. REFERENCES

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TABLE I SPRING DESIGN

Spring Parameter	Magnitude
Wire Diameter (mm)	2.8
Mean Coil Diameter (mm)	22.4
Total Coils	5.5
Working Coils	3.5
Rate (N/mm)	15.5
Free Length (ends closed and ground) (mm)	39.3
Solid Length (mm)	15.4
Solid Stress (N/mm^2)	1120

TABLE II CHEMICAL COMPOSITION

Element	%C	%Si	%Mn	%P	%S
Actual	0.67	0.16	0.71	0.022	0.020
BS 1429[1] En42B Specification	0.60-0.70	0.35 max	0.55-0.80	0.05 max	0.05 max
BS 2803[2] Specification	0.55-0.75	0.30 max	0.60-0.90	0.04 max	0.04 max
BS 5216[3] Specification	0.55-0.85	0.35 max	0.30-1.00	0.03 max	0.03 max

TABLE III TENSILE PROPERTIES

Material Properties	R_m (N/mm^2)	Proof Stresses (N/mm^2)		Reduction in area (%)
		$R_{p0.1}$	$R_{p0.2}$	
As received (BS 5216)[3]	1740 1720 1755	1445 1300 1340	1600 1490 1530	
Zero Decarburisation hardened and tempered	1575 1580	1410 1400	1440 1430	40 40
Decarburized one hour at 900°C in moist air	1480 1470	1365 1340	1390 1370	31 39
Decarburized one hour at 950°C in moist air	1260 1260	1165 1150	1190 1175	44 30
Decarburized one hour at 850°C in scale	1455 1450	1300 1305	1335 1330	44 40

TABLE IV TORSIONAL PROPERTIES

Decarburisation Treatment	L of P (N/mm^2)	Proof Stresses (N/mm^2)		Twist to failure
		0.1%	0.2%	
None	765 765	950 960	1000 1010	22 22
1 hour at 900°C in moist air	640 670	860 900	920 945	4 4
1 hour at 950°C in moist air	460 470	690 660	755 715	4 4
1 hour at 850°C in scale	570 550	825 820	880 875	22 23

TABLE V DEPTHS AND TYPES OF DECARBURIZATION

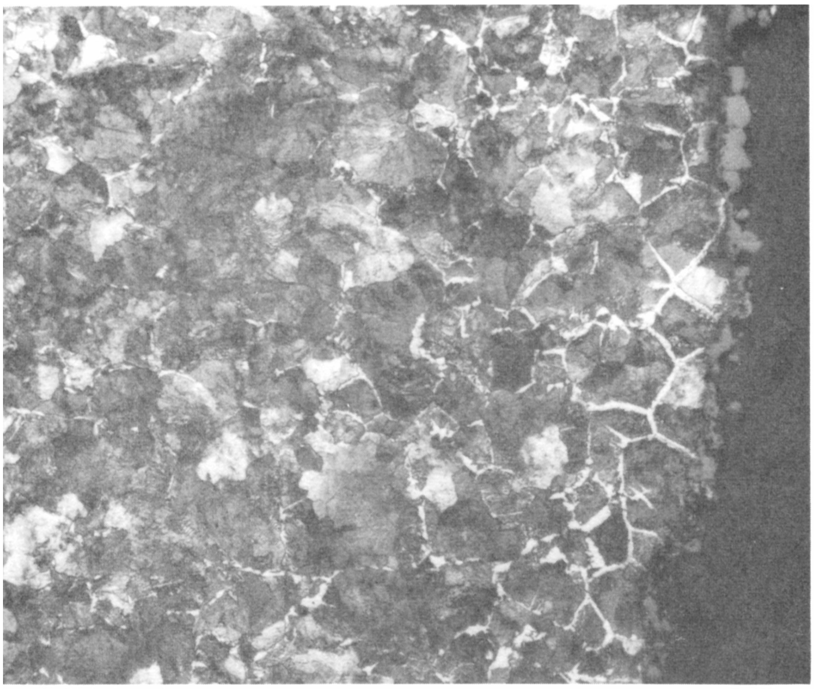
Decarburization Treatment	Type and maximum depth of decarburization in hardened and tempered condition
1 hour at 900°C in moist air	Partial to 0.025mm (0.9% wire diameter)
1 hour at 950°C in moist air	Complete to 0.01mm (0.4% wire diameter) Partial to 0.085mm (3% wire diameter)
1 hour at 850°C in scale	Complete to 0.02mm (0.7% wire diameter) Partial to 0.06mm (2.1% wire diameter)

TABLE VI SPRING DIMENSIONS AND LOAD DETERMINATION CONSTANTS

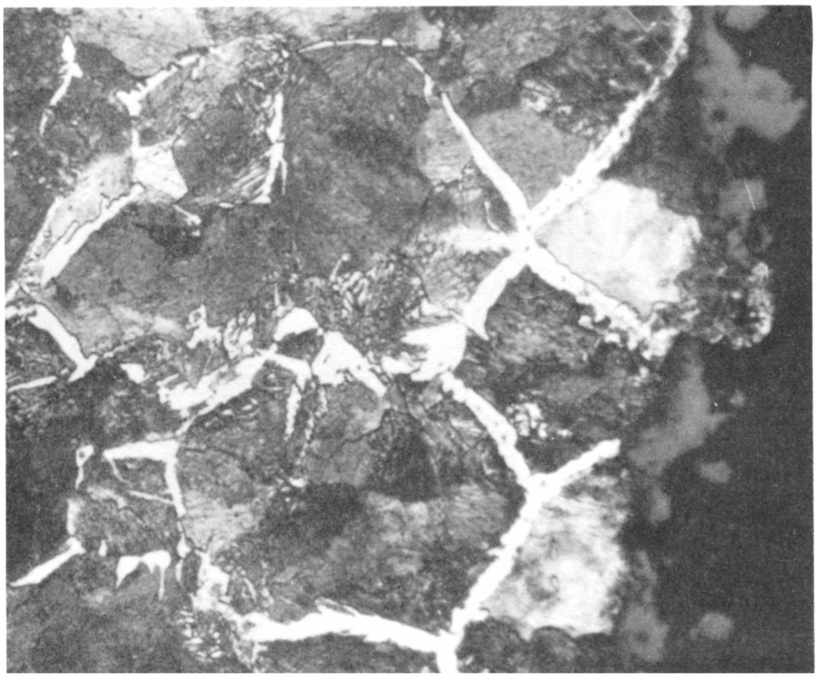
Decarburization Treatment	Outside Diameter of spring (mm)	Wire Diameter (mm)	Constant (A)
None	24.71	2.80	0.335
1 hour at 900°C in moist air	24.65	2.69	0.299
1 hour at 950°C in moist air	24.60	2.64	0.270
1 hour at 850°C in scale	24.80	2.79	0.330

TABLE VII FATIGUE RESULTS

Decarburization Treatment	R_m (N/mm^2)	Fatigue Limit at 200 N/mm^2 (N/mm^2)	Fatigue Ratio $\frac{F.L.}{R_m}$
Nil	1580	825	0.52
1 hour at 900°C in moist air	1475	675	0.46
1 hour at 950°C in moist air	1260	500	0.40
1 hour at 850°C in scale	1455	650	0.45

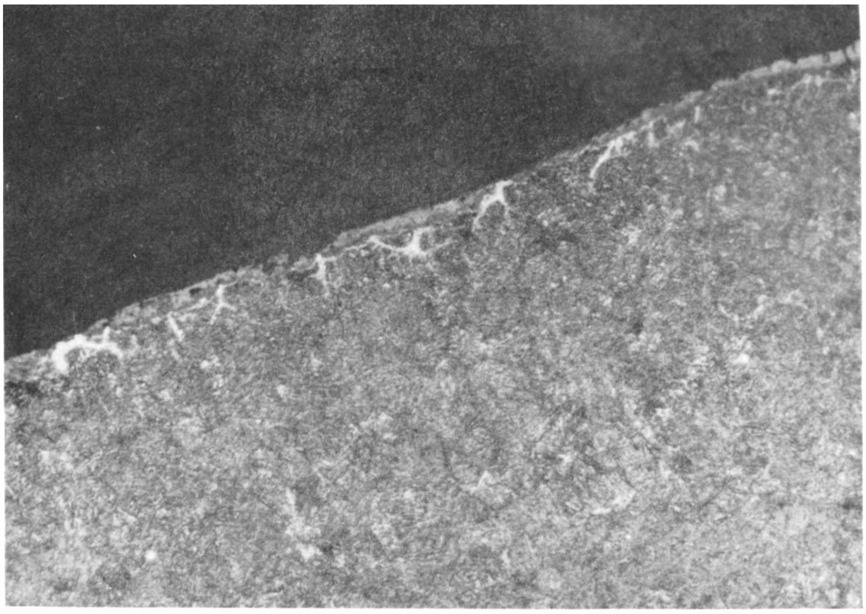


(a) (x 200)

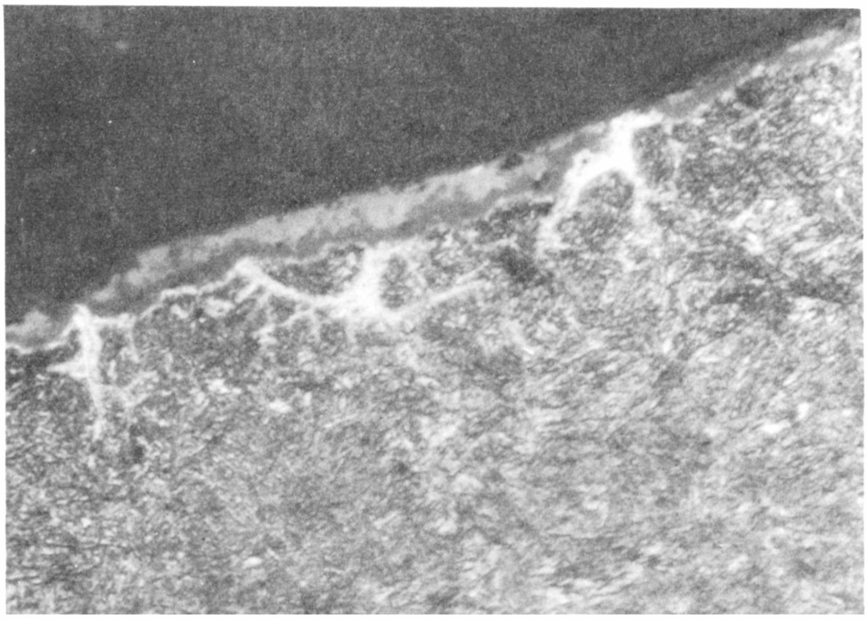


(b) (x 600)

FIG. 1 AIR COOLED MICROSTRUCTURES OF SPRING DECARBURISED FOR 1 HOUR AT 900°C IN MOIST AIR

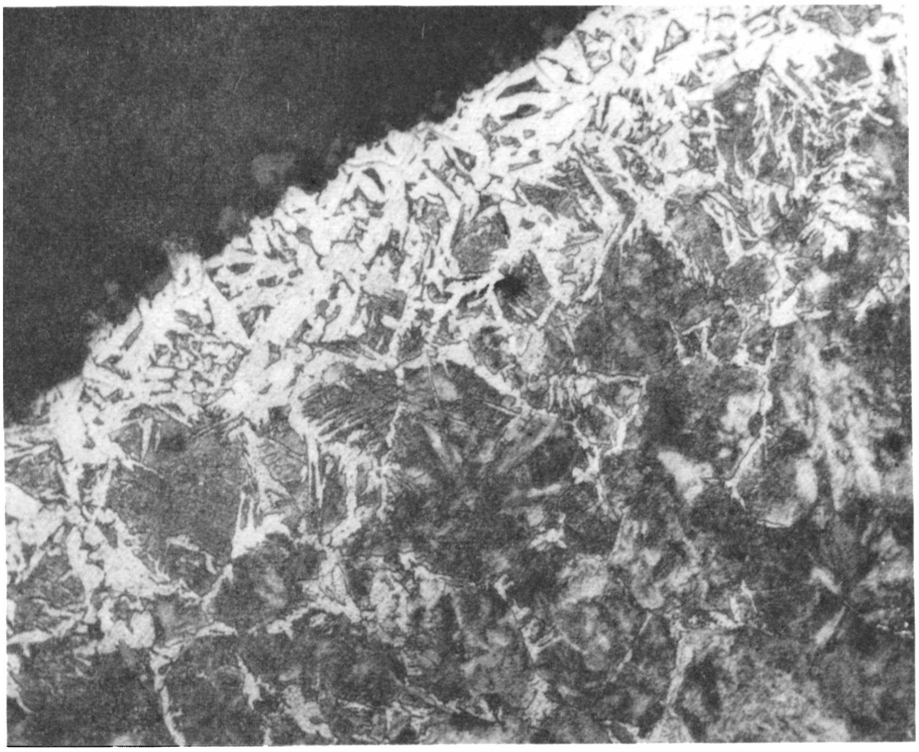


(a) (x 200)



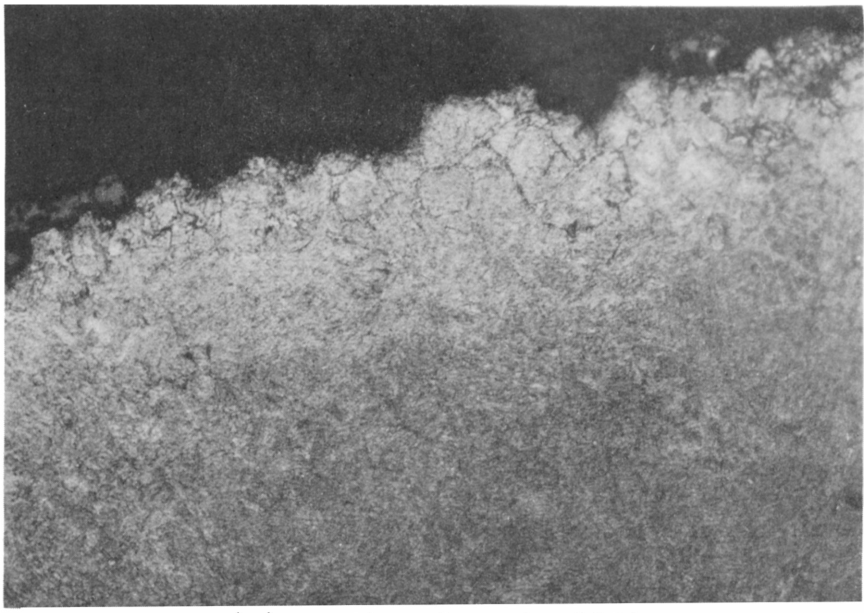
(b) (x 600)

FIG. 2 HARDENED AND TEMPERED MICROSTRUCTURES OF SPRING DECARBURISED FOR 1 HOUR AT 900°C IN MOIST AIR

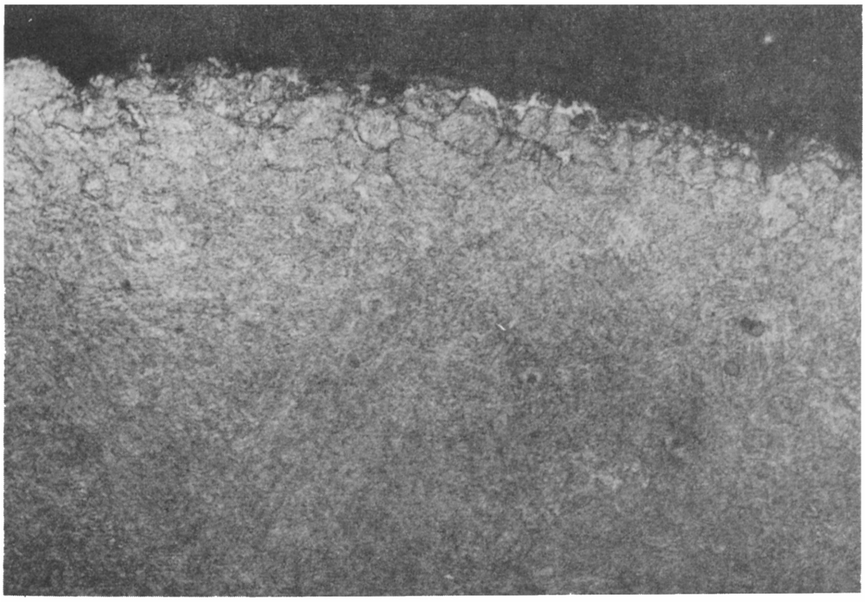


(x 200)

FIG. 3 AIR COOLED MICROSTRUCTURE OF SPRING DECARBURISED FOR 1 HOUR AT 950°C IN MOIST AIR

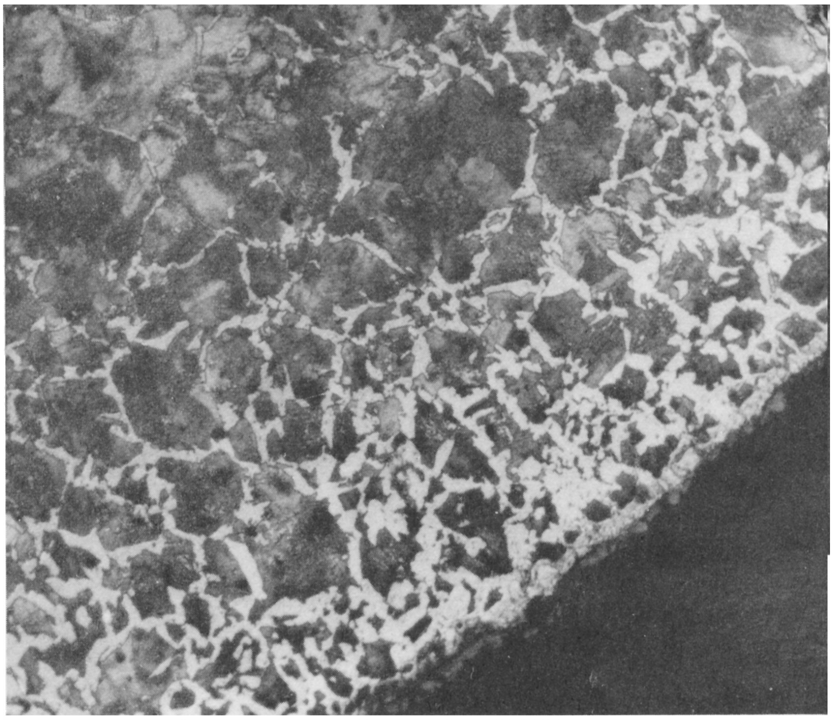


(a) View 1 (x 200)

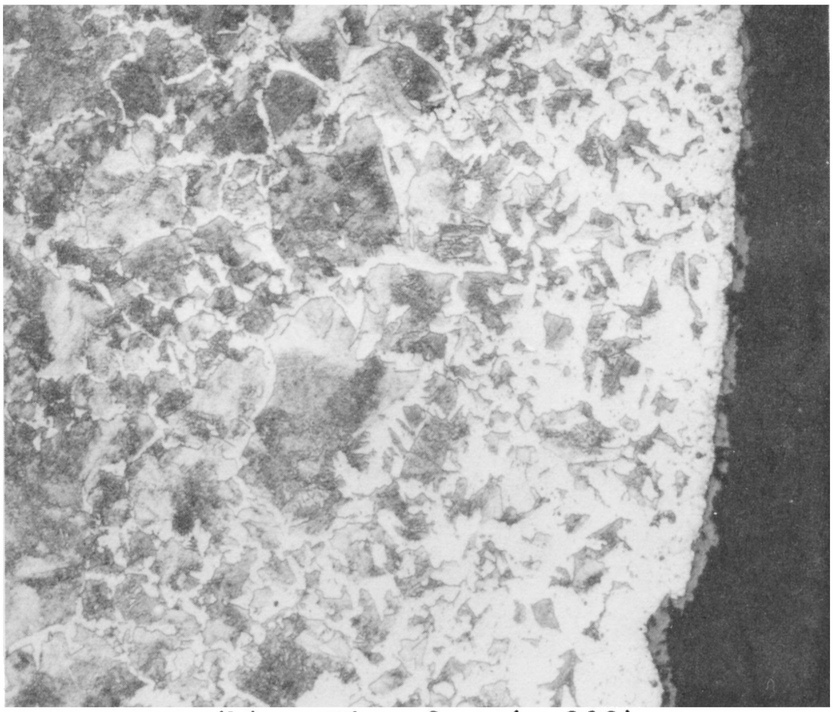


(b) View 2 (x 200)

FIG. 4 HARDENED AND TEMPERED MICROSTRUCTURES OF SPRING DECARBURISED FOR 1 HOUR AT 950°C IN MOIST AIR



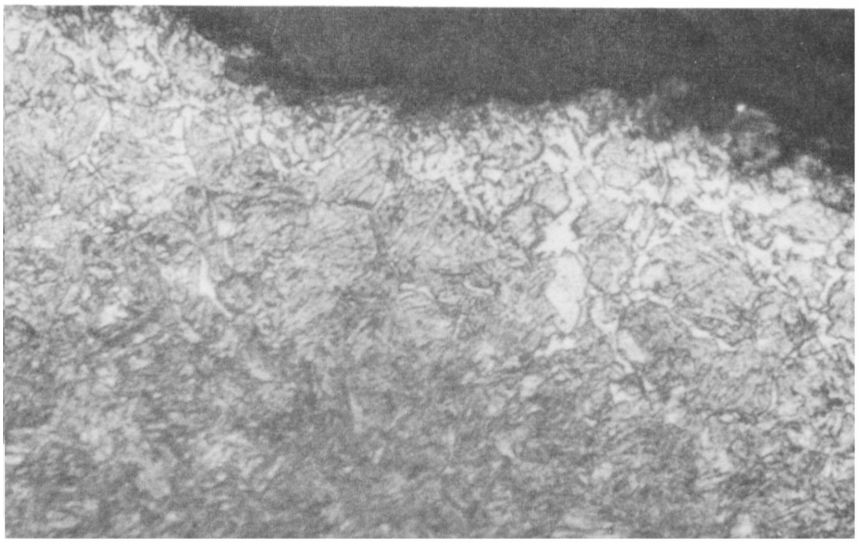
(a) View 1 (x 200)



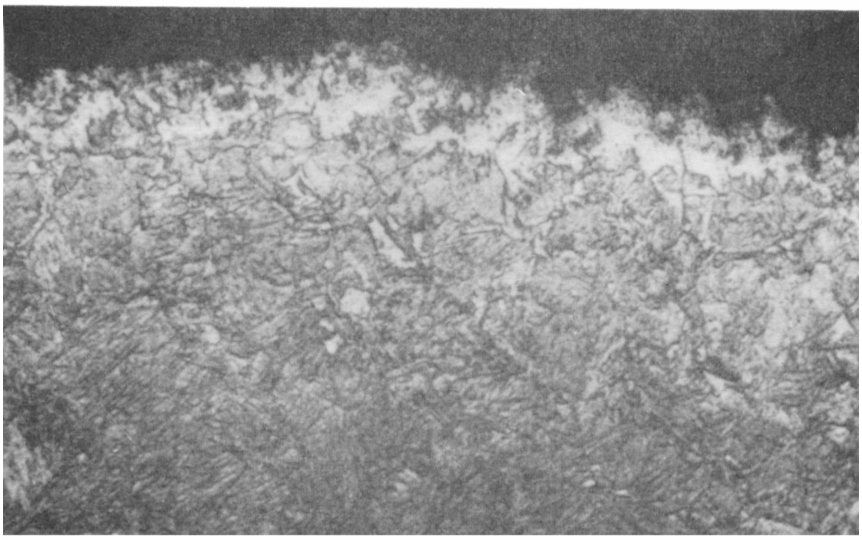
(b) View 2 (x 200)

FIG. 5 AIR COOLED MICROSTRUCTURES OF SPRING DECARBURISED FOR 1 HOUR at 850^{o}C IN SCALE

(a) View 1 (x 200)



(b) View 1 (x 600)



(c) View 2 (x 600)

FIG. 6 HARDENED AND TEMPERED MICROSTRUCTURES OF SPRING DECARBURISED FOR 1 HOUR AT 850°C IN SCALE

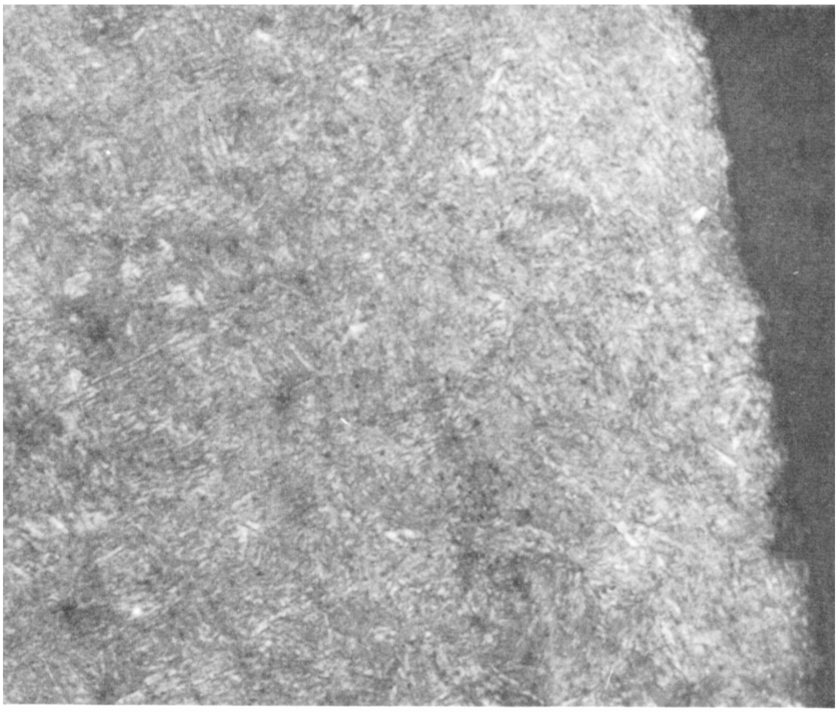


FIG. 7 (x 600)

MICROSTRUCTURE OF CONTROL SPRING

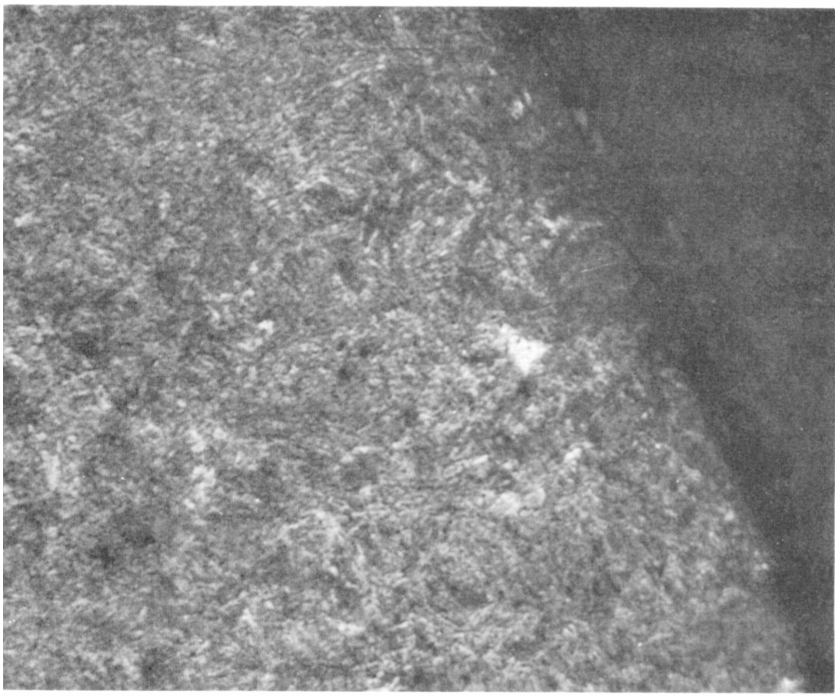


FIG. 8 (x 600)

MICROSTRUCTURE OF BS 2803 GRADE I WIRE

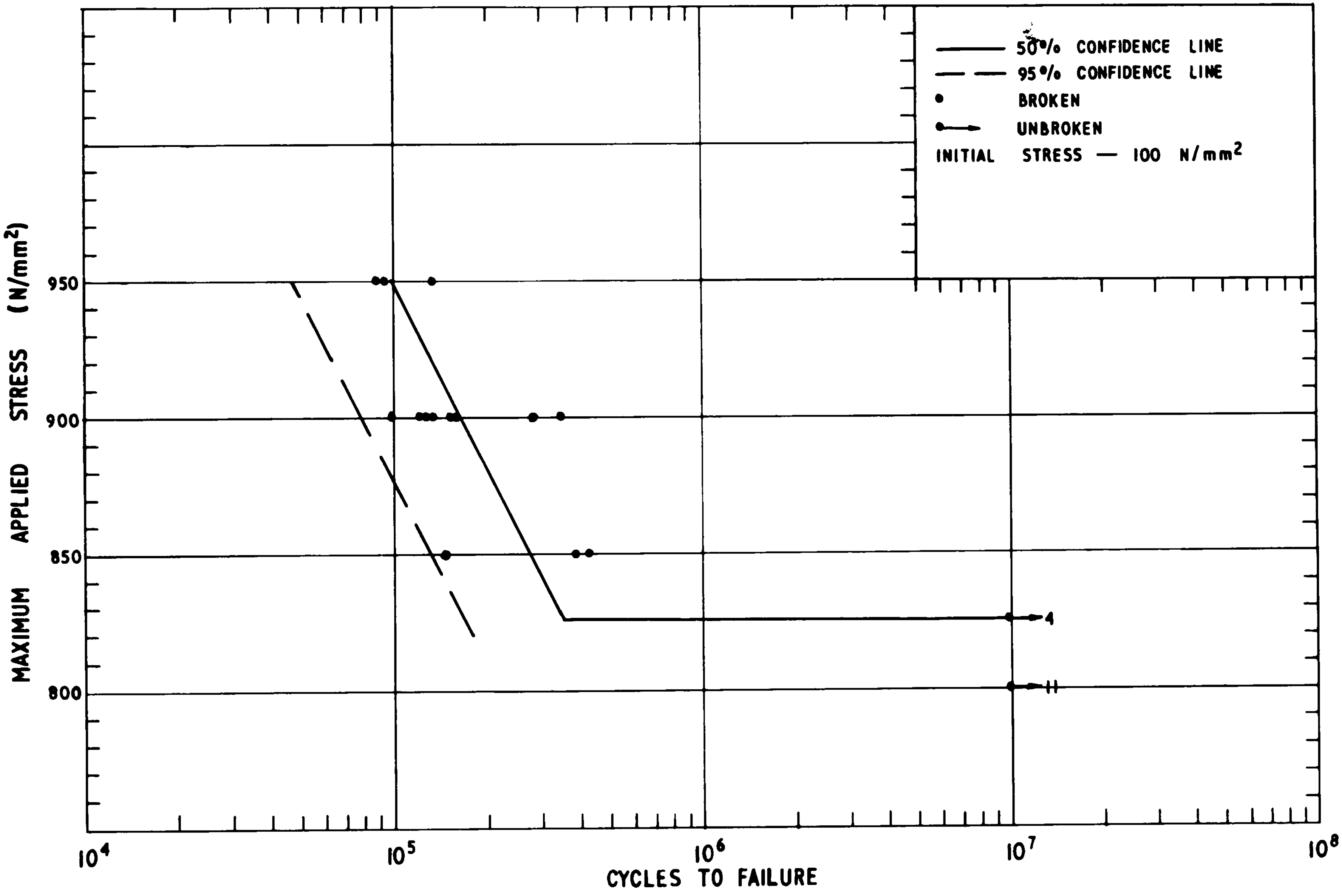


FIG. 9 S/N CURVE FOR SPRINGS WITH ZERO DECARBURISATION.

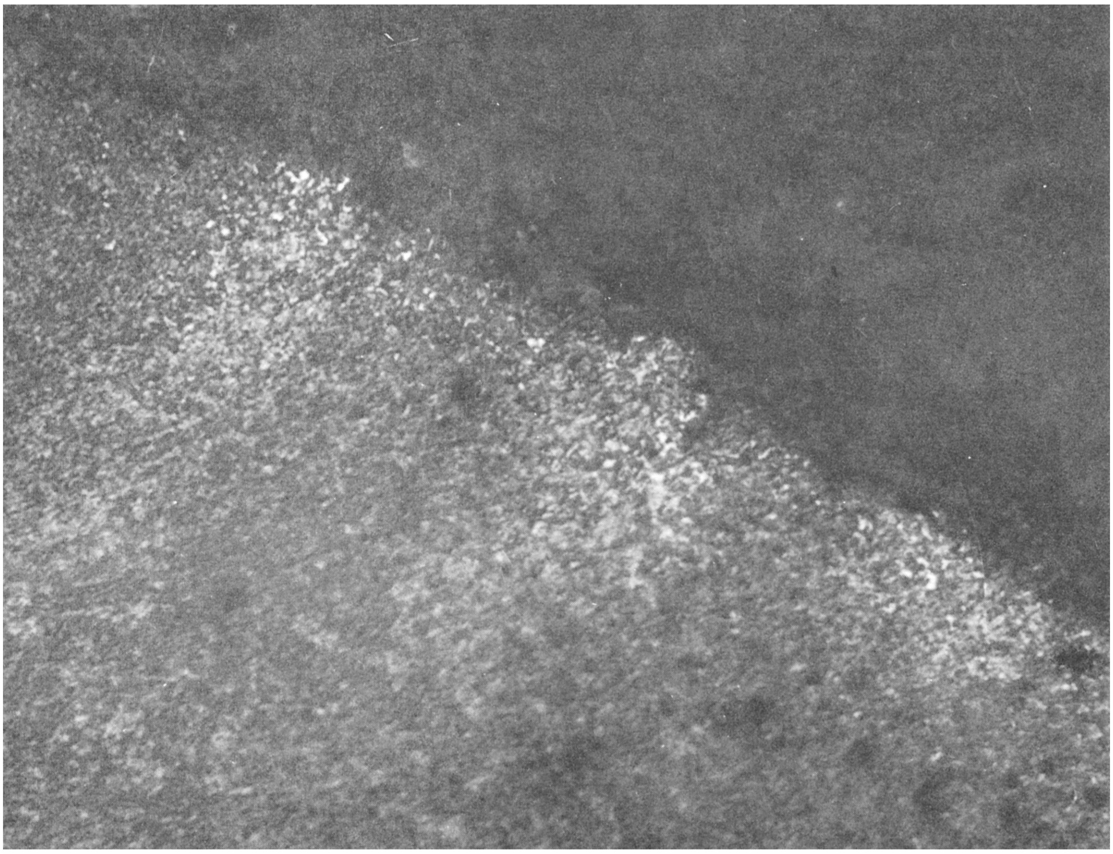


FIG. 10 MICROSTRUCTURE OF BS 2803 GRADE III WIRE (x 600)