THE COIL SPRING FEDERATION RESEARCH ORGANISATION

The Mechanical and Fatigue Properties of Helical Compression Springs made from Patented Hard Drawn and Oil Tempered Wires

Report No. 114

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Summary

Fatigue tests have been carried out on one oil tempered and two patented hard drawn qualities of spring wire in general use and S-N curves and modified Goodman diagrams constructed for each material.

Oil tempered wire to B.S.2803 Grade 1 was comparable in fatigue properties to EN.49D Range 2 wire to B.S.1408 of the same diameter; both were superior to the other hard drawn wire which was of larger diameter and had a less smooth surface finish. Further work is recommended.

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THE MECHANICAL AND FATIGUE PROPERTIES OF HELICAL COMPRESSION SPRINGS MADE FROM PATENTED HARD DRAWN AND OIL TEMPERED WIRES

by J.W. Mee, A.Met., A.I.M.

1. INTRODUCTION

The majority of published information on the fatigue properties of metals refers either to push-pull stress or reversed bending stress. There is comparatively little data published on torsional properties, particularly for British spring materials.

To obtain torsional fatigue data a study has commenced of a wide range of materials available in the United Kingdom for the manufacture of cold formed springs. This report presents results of tests carried out on springs manufactured from oil tempered spring wire to B.S.2803 and from two patented hard drawn spring wires, one of which was to specification EN.49D Range 2.

2. MATERIALS

Two types of patented hard drawn wire and one oil tempered wire were supplied to cast analyses as shown in Table I.

Table I Chemical compositions of three spring wires

Specification	Wire Dia. (ins)	Cast analysis					
		C %	Mn %	Si %	S %	P %	Cu %
B.S.1408 EN.49D Range 2	0.104	0.74	0.48	0.16	0.015	0.024	
B.S.2803 Oil tempered Grade 1	0.104	0.64	0.75	0.23	0.013	0.023	
Patented hard drawn	0.144	0.82	0.64	0.24	0.027	0.010	0.02

3. MECHANICAL PROPERTIES

The limit of proportionality and ultimate strength in tension and torsion were obtained for the "as received" condition and after low temperature heat treatment at 350°C for 30 minutes. Additionally, the low temperature heat-treated wires were prestressed in torsion to determine to what level the apparent torsional limit of proportionality could be elevated.

The results are given in the following table.

Table II Mechanical properties of three spring wires

Specification and condition	Tensile Tests			Torsion Tests			
	B.S.S. Range t.s.i.	U.T.S. t.s.i.	L.of P. t.s.i.	Ultimate strength t.s.i.	Turns to failure	L. of P. (t.s.i)	
							after pre-stressing
EN.49D, as received	100-110	105	50	89	29	29	62
EN.49D, L.T.H.T. 350°C	-	104	77	86	24	52	63
Oil tempered, as received	100-110	103	88	89	24	63	68
Oil tempered, L.T.H.T. 350°C	-	103	87	87	23	58	68
Hard drawn, as received	-	99	40	70	30	20	42
Hard drawn, L.T.H.T. 350°C	-	97	62	73	32	44	53

The experimental values given above are the mean of three determinations.

The limit of proportionality for "as received" EN.49D material appeared to be rather low but check measurements confirmed the values. It was noticed that the effect of low temperature heat treatment on the oil tempered wire was to lower the limit of proportionality in torsion. This was an unexpected result and might indicate that the original heat treatment of the wire was incorrect.

It is interesting to note that the L. of P. of EN.49D wire in the "as received" condition is less than half the value for oil tempered wire. The effect of prestressing, however, is most marked in the former case and the L. of P. is elevated to a value comparable with (but still less than) the value for prestressed oil tempered wire. The effect of a low temperature heat treatment was to narrow the difference still further by an additional elevation of the L. of P. of the EN.49D material.

4. SPRING MANUFACTURE

The springs were all manufactured on an automatic coiling machine to the following designs.

Table III Design of Experimental Springs

Dimension	EN.49D	Oil tempered	Patented hard drawn
Wire dia. (ins)	0.104	0.104	0.144
Mean coil dia. (ins)	0.945	0.945	1.156
Free length (ins)	1.65	1.65	1.75
No. of active coils	3.5	3.5	3.3
Total number of coils	5.5	5.5	5.3
Rate (lbs/in)	56	56	120

After coiling, the springs were given a low temperature heat-treatment at 350°C for 30 minutes followed by rough end grinding, pre-stressing and finish grinding.

5. LOAD TESTING

Each spring, before fatigue testing was load tested after first being compressed solid and a load deflection curve obtained. The curves were not linear owing to the effect of the end coils, which continued to close on increased compression. These characteristic curves were required in order that accurate computation of the stresses applied by the fatigue testing machine could be made.

6. FATIGUE TESTING

Fatigue tests were carried out on the springs using variable speed spring testing machines, one of which is shown with its covers removed in Figure 1. Each machine was capable of testing four pairs of springs simultaneously. They were mounted about a central camshaft carrying four cams each individually adjustable in stroke from zero to one inch. Each spring mounting (which was individually adjustable) carried a circuit breaker, which stopped the machine when a spring fractured or when the minimum load on any spring fell below a predetermined value, due to commencement of failure.

Each series of springs was tested at 3 different levels of initial stress. The stress range was varied to produce, at the lowest initial stress, a full fatigue curve and, at the higher initial stress levels. stresses which would give fatigue failure at 10^6 and 10^7 cycles.

The results of the fatigue testing are presented as modified Goodman diagrams for each material in Figs. 2 - 4 and the fatigue curves for the lowest initial stress level are given in Fig. 5. The patented hard drawn wire springs were tested initially at an initial stress of 2 tons/sq.in.; it was found, however, that the EN.49D and pretempered springs required an initial stress of 5 tons/sq.in. to prevent the cut-out switches from operating, for this reason different initial stress levels are given for the fatigue curves in Fig. 5.

Examination of the fatigue fractures showed that for the EN.49D and oil tempered materials failure generally originated on the inside of the coil. In the case of the patented hard drawn material however, the origin of failure was more random around the circumference of the wire, this may be related to the rougher surface condition which is referred to below.

The stresses on the springs were applied by circular profile cams and were calculated from formulae based on static loading. The speed of the machines throughout these tests was never more than 1200 r.p.m.

The ratio of fatigue limit (zero initial stress) to ultimate tensile strength of the "as-received" material was calculated; the values are given below:

Fatigue limit/U.T.S. ratio for three spring wires

Material	Fatigue limit tons/sq.in.	U.T.S. tons/sq.in.	Fatigue/U.T.S. ratio
EN.49D	49	105	0.47
Oil tempered	48	103	0.47
Patented hard drawn	38	99	0.38

7. METALLOGRAPHIC EXAMINATION

The general metallurgical structures of longitudinal sections of the three wires in the "as received" condition are shown in figs. 6 - 8. There is a marked difference between the structures of the two hard drawn wires. It would appear that the EN.49D wire had received more cold work and this is borne out by the low tensile strength of the other hard drawn wire; some of the difference could have been due to the difference in diameter of the two wires. The oil tempered wire had a tempered martensitic structure indicative of a satisfactory heat treatment; some slight banding of the structure was apparent.

Transverse sections of the wires, mounted in a manner suitable for supporting the edges, were polished and examined microscopically.

The results for surface finish are shown in Figs. 9 - 11. The surface conditions for EN.49D and oil tempered wires were undulating to about the same degree. The finish for the patented hard drawn wire showed more angular irregularities which would contribute to the lower fatigue properties of this material.

Decarburisation measurements were also made. The EN.49D and pretempered material had patchy decarburisation, the total affected depth varying from 0 to 0.002". The patented hard drawn material was decarburised to a total affected depth ranging from 0.002" to 0.005".

8. CONCLUSIONS AND RECOMMENDATIONS

The patented hard drawn wire used in this investigation was similar to EN.49C in tensile strength, metallurgical structure and decarburisation.

The fatigue properties of springs made from hard drawn EN.49D range 2 wire and oil tempered spring wire are comparable. As is usual with compression springs some scatter was apparent in the results and the lowest fatigue curve was drawn for each case.

The patented hard drawn wire had fatigue properties inferior to those of the other two materials and this could be mainly attributed to the lower tensile strength and rougher surface condition of this material. It is recommended that fatigue tests be carried out on springs made from EN.49C, D (range 3), STA.1 and STA.3 wire having the same diameter. The effect of shot-peening on the fatigue properties of the materials already investigated and those recommended for future work should also be examined.

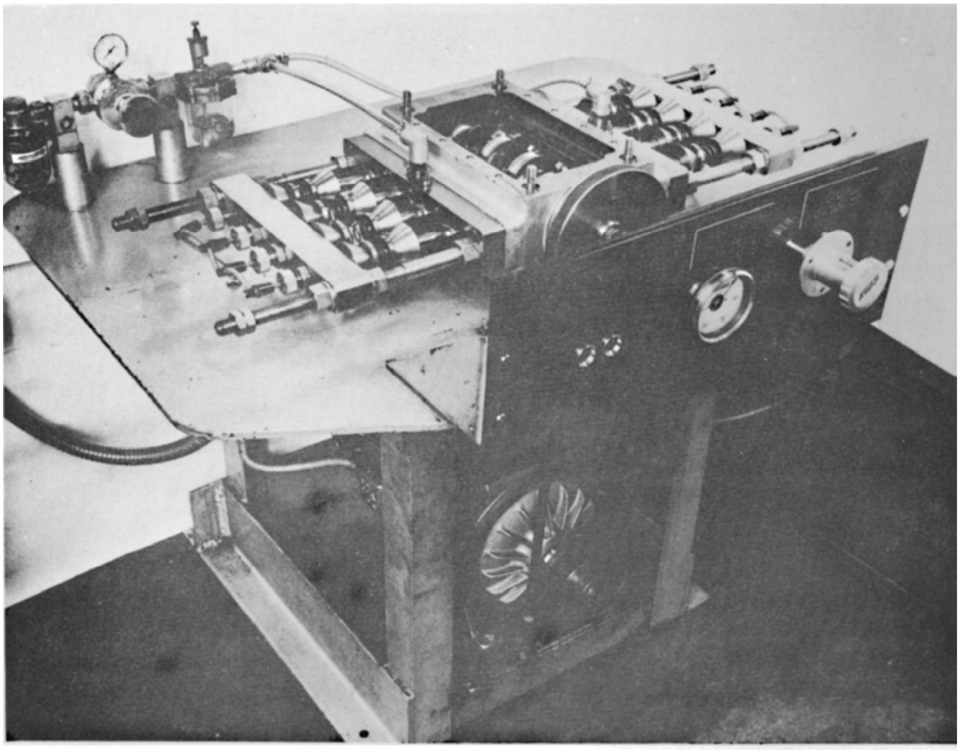


Fig.1 High speed fatigue testing machine with covers removed to show working parts

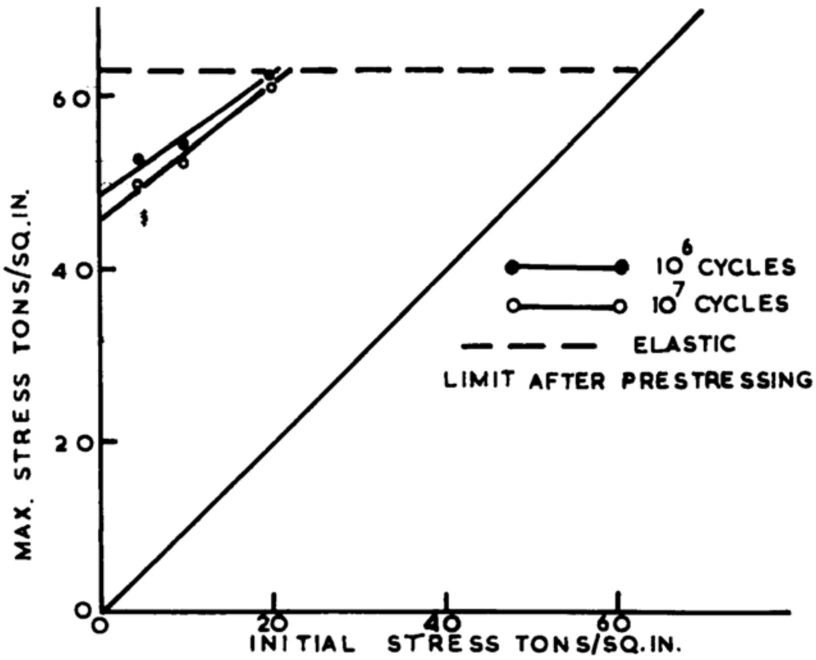


FIG 2 MODIFIED GOODMAN DIAGRAM FOR HARD DRAWN EN49D WIRE SPRINGS

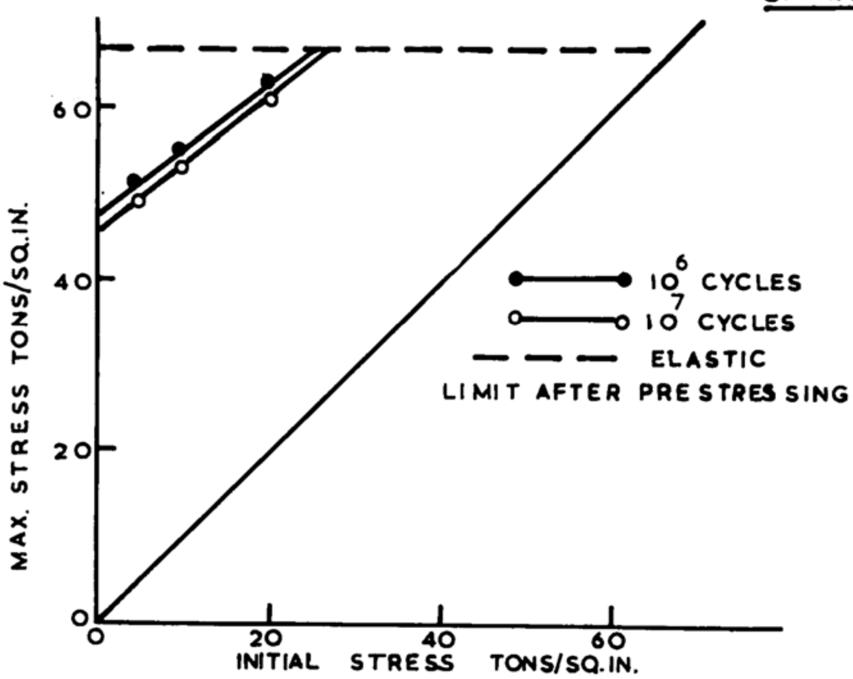


FIG3 MODIFIED GOODMAN DIAGRAM FOR OIL TEMPERED WIRE SPRINGS

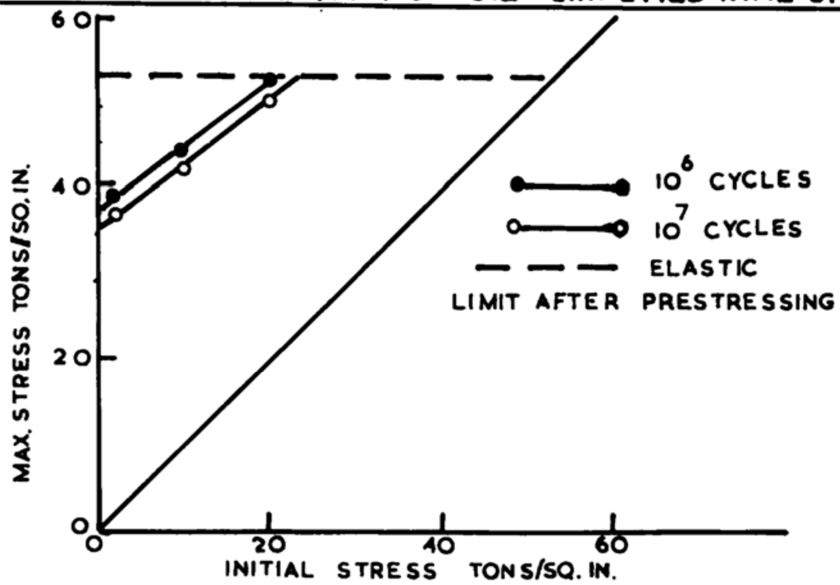


FIG4 MODIFIED GOODMAN DIAGRAM FOR PATENTED HARD DRAWN WIRE SPRINGS

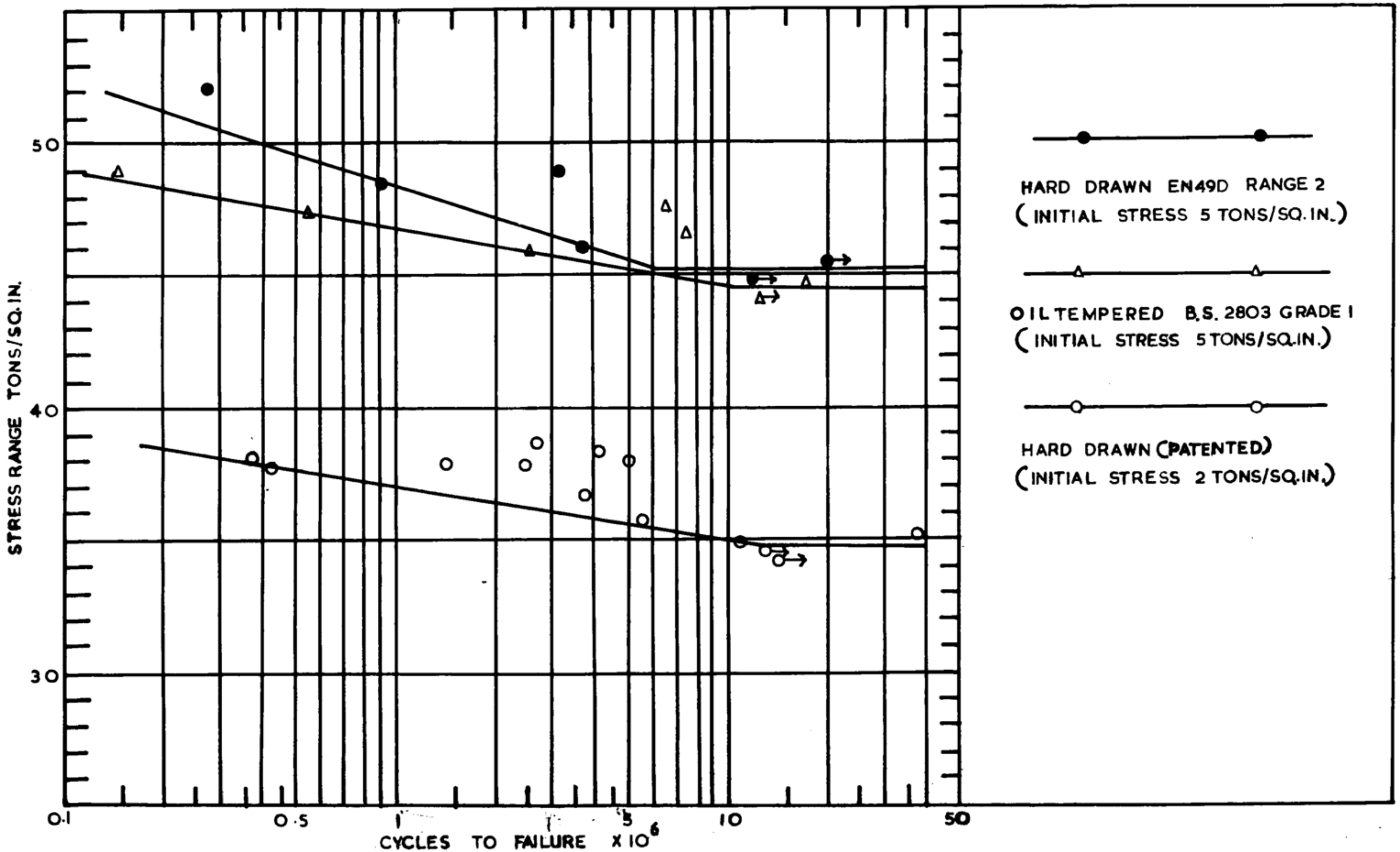
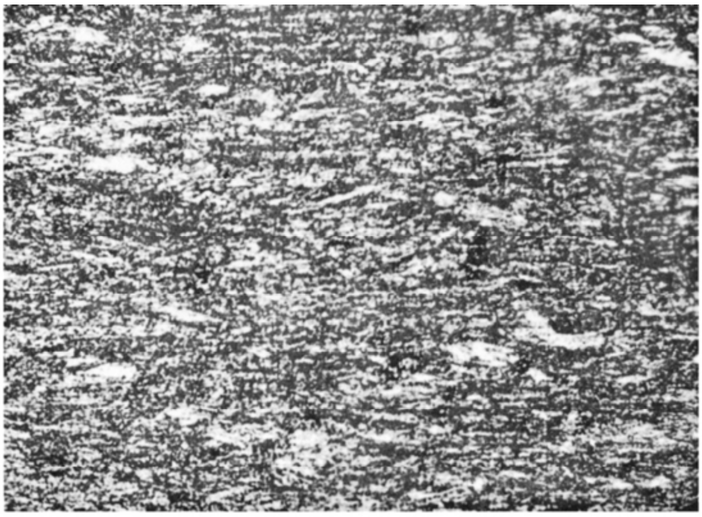
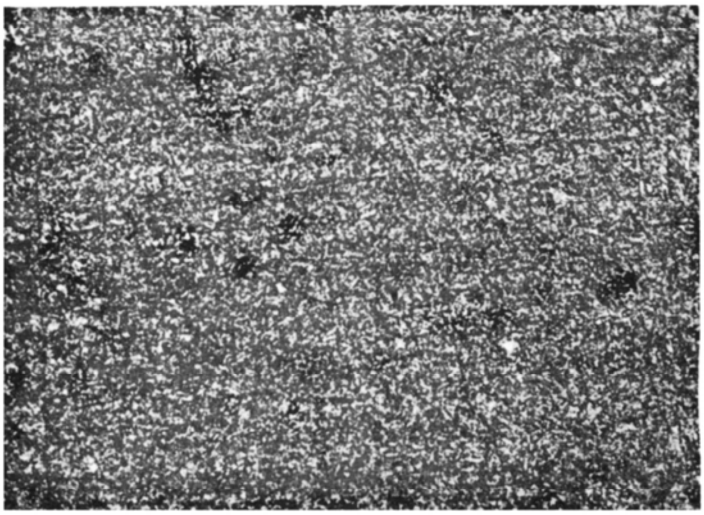


FIG. 5. FATIGUE CURVES FOR SPRINGS COILED FROM HARD DRAWN AND OIL TEMPERED WIRES



x 400

Fig.6 Metallographic structure of longitudinal section of hard drawn EN.49D range 2 wire



x 400

Fig.7 Metallographic structure of longitudinal section of oil tempered wire to B.S. 2803

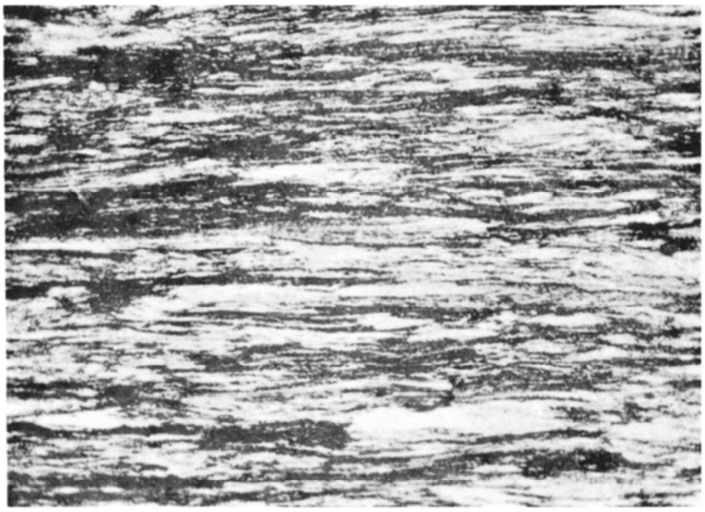


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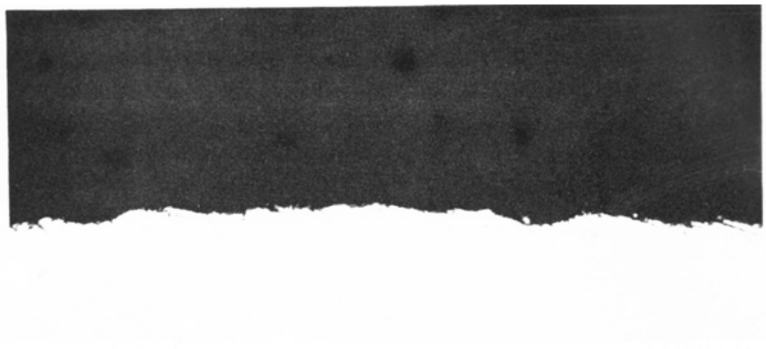
Fig.8 Metallographic structure of longitudinal section of patented hard drawn wire



x 400

Fig.9 Transverse section, unetched, of surface of hard drawn EN.49D range 2 wire

x 400

Fig.10 Transverse section, unetched, of surface of oil tempered wire to B.S. 2803

x 400

Fig.11 Transverse section, unetched, of surface of patented hard drawn wire