THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

A COMPARISON OF MUSIC WIRES PRODUCED BY BRITISH AND CONTINENTAL WIRE MILLS

by

K. Brummitt, B.Sc.

Report No. 301

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SUMMARY AND CONCLUSIONS

Traditionally continental and particularly Swedish music wires have been regarded as superior to the British product. With the establishment of the BS 5216 specification it was felt that the position should be examined. A total of 24 coils of wire in three sizes from six wire mills were examined. Measurements were made of the tensile and torsional properties of the material. Springs coiled from the wires were subjected to long term ambient temperature relaxation tests and the wires assessed for coilability.

From this work it was concluded that:

In most respects British wires are at least equal to their continental rivals. The British M5 wires examined, tended to have relatively low tensile strengths and this seems to account for the differences noted in this work. In general there would seem to be no advantage in using continental wire unless a high tensile strength is required.

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1. INTRODUCTION

The British spring maker faces a choice when buying wire, between buying a home produced wire or a Continental wire which costs approximately one third more. Occasionally there is no option because either a special quality of wire required is not available from a UK source or because a customer specification calls for a wire from a particular source (e.g. Swedish wire). In Britain, continental wires have a high reputation for quality which is one reason for their use by the British spring maker, but other considerations also lead the user to favour them. These are mainly commercial factors such as delivery times (particularly when stocks of foreign wire are held in the UK). If sufficient weight of wire is involved, it may on occasion be cheaper to buy Continental wire!

It is the purpose of this report to make a technical comparison between the wires to provide guidance to the springmaker in selecting the appropriate material for a given application.

2. MATERIAL

British music wire to BS 5216 is available in two tensile grades, namely M4 and M5. Wire from British sources was therefore purchased to BS 5216. The continental wires were purchased simply as music wire and were supplied against individual wire manufacturers 'house' specifications which in many cases met various foreign national wire standards. Three wire sizes 1.5, 0.71 and 0.30 mm were chosen but in some cases 0.315 mm and 0.70 mm wires were used due to problems of availability. The chemical compositions of the various wires is shown in Table I. Two wires are missing from the sets. The German (E) wire could not be obtained in 1.5 mm dia in the time available, as the small quantity required was insufficient to warrant production of a size not otherwise on order. The British (D) wire is not included as a 0.71 mm M5 wire because the wire supplied proved to be outside the specified tensile range and the quoted time for the delivery of a replacement coil would have considerably delayed completion of the work.

TABLE I CHEMICAL COMPOSITION OF THE VARIOUS WIRES

Wire	Origin	Size mm	Composition %				
			C	Si	Mn	S	P
BS 5216M	British Specif-cation	-	0.70/ 1.00	0.35 max	0.25/ 0.75	0.030 max	0.030 max
A4	Sweden	0.315	0.85	0.21	0.55	0.010	0.011
A5	Sweden	0.315	0.88	0.18	0.53	0.008	0.007
A4	Sweden	0.710	0.86	0.18	0.55	0.012	0.008
A5	Sweden	0.710	0.85	0.18	0.56	0.010	0.015
A4	Sweden	1.5	0.87	0.19	0.52	0.011	0.016
B4	Britain	0.30	0.82	0.19	0.64	0.013	0.013
B5	Britain	0.30	0.82	0.19	0.64	0.013	0.013
B4	Britain	0.70	0.82	0.12	0.64	0.013	0.013
B5	Britain	0.70	0.82	0.12	0.64	0.013	0.013
B4	Britain	1.5	0.82	0.20	0.66	0.014	0.004
B5	Britain	1.5	0.80	0.22	0.60	0.19	0.014
C	Sweden	0.30	0.90	0.21	0.54	0.011	0.017
C	Sweden	0.70	0.86	0.20	0.39	0.026	0.005
C	Sweden	1.5	0.89	0.22	0.58	0.027	0.14
D4	Britain	0.30	0.73	0.21	0.68	0.019	0.030
D5	Britain	0.30	0.81	0.24	0.66	0.027	0.014
D4	Britain	0.71	0.75	0.19	0.64	0.018	0.011
D4	Britain	1.5	0.75	0.19	0.64	0.018	0.011
D5	Britain	1.5	0.75	0.19	0.64	0.018	0.011
E	Germany	0.30	0.95	0.37	0.36	0.014	0.015
E	Germany	0.71	0.88	0.29	0.48	0.015	0.011
F	Belgium	0.30	1.02	0.27	0.50	0.013	0.015
F	Belgium	0.71	0.97	0.26	0.48	0.027	0.014
F	Belgium	1.5	0.92	0.28	0.45	0.021	0.017

It is perhaps worth noting that three other coils of British M5 wire proved to be outside (below) the specified tensile range. Two of these coils were replaced by the manufacturer, the third was diverted to other work within the Association.

For coilability measurement springs were coiled from each wire to one of the designs in Table II.

TABLE II SPRING DESIGNS FOR COILABILITY

Wire dia mm	Mean coil dia mm	No. of coils	Free length mm
0.3	4.2	13	15
0.71	9.3	9	20
1.5	18.5	10	40

A selection of wires were also coiled to a design as in Table III for relaxation tests. These springs were given low temperature heat treatment at 200°C for 30 minutes prior to end grinding and stressing, the springs used for coilability assessment had closed ends but these were left unground and heat treatment was given to the springs before assessment.

3. EXPERIMENTAL PROCEDURES

3.1 Metallographic Examination

Longitudinal and transverse sections were taken from each wire, mounted, polished and examined at maginifications up to 400X after etching in 4% nital. All the wires showed a hard drawn pearlite structure. None of the wires showed any surface defect although slight amounts of partial decarburisation were observed on the surface of three of the 1.5 mm dia wires, none exceeded the limits set by BS 5216 M (Table IV).

3.2 Mechanical Testing

Wires were tensile tested in the as received condition and also after a LTHT at 250°C. The torsional properties of the 0.71 and 1.5 mm wires were also measured in the as received condition.

3.3 Relaxation Tests

Relaxation tests were limited to springs produced from 0.71 mm and 1.5 mm wires since the small size of the 0.3 mm wire made it impossible to design a highly stressed compression spring which could readily be tested using the Association's existing equipment. In the 0.71 mm wire, springs were produced and tested from A4 and A5 wire (Sweden), B4 and B5 (Britain), E and F (Belgium). For the 1.5 mm, wire comprising A4 (Sweden), C (Sweden), D4 and D5 (Britain) and F (Belgium), were used.

The springs were load tested to establish the length at which a desired stress would be imposed, then compressed to this length using a nut and bolt assembly. The springs were held at the compressed length for 1000 hours then re-load tested at the original compressed length to determine the loss in load and hence the relaxation.

3.4 Coilability Trials

Coilability trials were made on all the wire samples. The 0.3 mm and 0.71 mm diameter wires were coiled on the Association's Wafios automatic spring coiling machine. The 1.5 mm wires were coiled using the Association's Torrington coiling machine. For each wire size once the machine was set up to produce the springs all the wires of that size were coiled with only minor initial adjustments to achieve the correct free length etc. with a new coil of wire. No adjustments were made for drift while the trials were in progress on a particular coil.

After each coil of wire was placed on the machine 200 springs were coiled to allow the machine to settle at the settings. 1000 springs were then produced. The last 10 in each 100 springs produced were collected and measured in the "as coiled" condition for dimensional consistency. It was found that the free length of the springs was the most easily measured variable and therefore the most sensitive. This was then measured for each of the springs sampled.

4. RESULTS

4.1 Chemical Composition

The British and Swedish music wires all had compositions within the range specified by BS 5216 M. Wires from German and Belgian sources generally had high levels of carbon and silicon but only in two cases did this exceed the BS ranges. These were the German (E) wire of 0.3 mm dia and the Belgian (F) wire in the same size. These compositions would agree with DIN 17223 which only specifies limits of S, P and Cu. The full chemical compositions of the wires are given in Table I.

4.2 Mechanical Testing

Results are presented in Table V for tensile tests undertaken on wire in the "as received" condition and after LTHT (250°C, 30 min), Table VI gives the results of the torsion tests. The results given for the wires B5 in 1.5 and 0.71 mm dia and D5 in 0.71 and 0.315 mm dia are for the wires used in the tests, in each of these cases the wire originally supplied was below the tensile range specified by BS 5216 M5. In three cases subsequent coils were satisfactory, in the fourth case (D5 0.71 mm dia wire) the delivery time quoted for a replacement coil was unacceptably long, therefore no replacement was obtained.

4.3 Wrapping Test

The 1.5 mm and 0.7 mm wires were close coiled around their own diameter, none of the wires showed any sign of failure after eight complete coils had been laid on, this would satisfy BS 5216 M.

4.4 Relaxation Tests

The results of the relaxation tests are given in Table VII and Figs 1-5.

4.5 Coilability Trials

The results of these trials are shown in Tables VIII, IX and X. The most significant figure is the short term standard deviation since the overall standard deviation would have been reduced if during coiling the machine had been corrected either manually or automatically for long term drift as would normally be done.

5. DISCUSSION

5.1 Chemical Composition

Even though the continental wires were not produced to BS 5216, with three exceptions, all the compositions of the wires examined could be considered to meet the compositional requirements of BS 5216 M. Of those wires which were slightly outside the BS 5216 specification the carbon content of the Belgian F 0.30 mm wire and the silicon content of the German E 0.30 mm wire could be accounted for by the normal heterogeneity between product analysis and the cast analysis.

It is clear from Table I that of the 24 different wires examined continental produced music wires have a somewhat higher carbon content than the British music wires and it is felt that this feature enables the higher tensile strengths to be more easily obtained. In view of the difficulties experienced during this investigation in obtaining British produced BS 5216 M5 wire to the required tensile strength level there would appear to be grounds for UK manufacturers to increase their carbon levels accordingly.

5.2 Mechanical Properties

Out of six coils of British M5 wire ordered, four proved to be below the specified tensile range on delivery. This must cast some doubts on the ability of the British wire industry to meet the higher tensile requirements of the new BS 5216 M5 standard. Of the foreign suppliers one of the Swedish suppliers (A) produces music wire in five tensile strength grades. The two grades most commonly used in this country were obtained. In the 0.3 (.315) mm and 0.71 mm sizes the high tensile wire had a tensile strength within the BS 5216 M5 range and the lower tensile wire had a tensile strength within the M4 range. Only the lower tensile wire was obtained in the 1.5 mm dia, the tensile strength of this wire was within the tensile range specified by BS 5216 M5. The second Swedish supplier (C) produces music wire to a single grade. In the 0.3 mm and 1.5 mm sizes the tensile strengths of this wire fitted the M4 tensile range. The 0.71 mm wire from this supplier had a tensile strength below that of the M4 range. This coil carried a label stating the wire was to BS 1408 M1, the tensile strength of the wire did meet the requirements of this older specification.

The German music wire was available in one tensile strength, the wires obtained met the M4 tensile range for the 0.3 mm wire and the M5 range for the 0.71 mm wire.

The Belgian music wire was available in two strength levels, normal and high strength, additionally the smallest size 0.3 mm is available as an extra high strength wire. Only the high strength grade was obtained for this work. The 0.3 mm wire had a tensile strength which corresponded to the M4 range the 0.7 mm wire had a tensile strength within the M5 range, the 1.5 mm wire was at the top of the M5 range. It would be possible to obtain 0.3 mm wire with a tensile within the M5 range by ordering the extra high strength wire. It would seem that if the springmaker wants a high tensile strength continental wire mills are more likely to provide a reliable product.

All the foreign wires met the specification to which they were produced, the majority also met one or other of the two British music wire standards. Even higher tensile music wires are available from Swedish sources but the usage of these wires is very limited.

5.3 Long Term Relaxation

As mentioned elsewhere in the report, the relaxation work was confined to the two larger wire sizes. This is simply because with decreasing wire size the length of a highly stressed spring resistant to buckling decreases, with the equipment available it would not have been possible to measure relaxation on a spring coiled from 0.3 mm wire. For the same reason, tests on 0.71 mm wire were confined to stresses up to 1200 N/mm^2. At these stresses springs coiled from 0.71 mm wire did not show any significant relaxation.

Overall there does not appear to be a basis for choosing any particular wire for relaxation resistance. The higher tensile wires had a better performance, therefore the performance of the D5 wire is perhaps not a good indication of the performance of a British wire to BS 5216 M5 which typically fits at the bottom of, or below the specified range. For normal working stresses therefore, there is little to choose between the wires. If ambient temperature relaxation at very high stress levels is of prime importance then one of the special very high tensile wires available from Sweden might provide a superior performance.

5.4 Coilability

The best measure of coilability is the short term standard deviation since the overall standard deviation is affected by long term drift which would normally be corrected either automatically or by routine inspection and adjustment. If we assume that the spring manufacturer wishes to meet the free length tolerances set down for light springs in BS 1726 then the value for the short term standard deviation should be below one third of the calculated tolerance i.e. > 99.7% of the springs lie within the tolerance band. This criterion was met by the Belgian (F) wire in the 1.5 mm dia size, by the Belgian (F) and one Swedish (C) wire in the 0.71 mm size and by one Swedish (C) wire in the 0.3 mm size.

This result is not as bad as it appears because the springs were deliberately designed with a high index to make coiling difficult (increase the free length variation). Widening the limits to 95% satisfactory springs (i.e. 5 in 100 rejects) gives the following wires as satisfactory, 1.5 mm B5, C, D4 and F, that is four out of seven coils tested satisfactory. 0.71 mm A4, A5, C and F four out of eight coils tested satisfactory and 0.3 mm A4, A5, B4, C and D4, four out of nine coils satisfactory. Overall there does not seem to be any advantage in buying foreign wire for better coilability.

5.5 Other Points

The surfaces of the 1.5 mm wires were stripped of lubricant by boiling in 10% sodium hydroxide followed by ultrasonic cleaning in trichlorethylene. Examination of the surfaces with a 20 diameter magnification showed that the Swedish wires had a polished surface while the other wires had a good drawn surface. There is no advantage in spring performance from the use of polished wire but if appearance is of importance then this would be an advantage.

The continental wires in general and the Swedish wires in particular were better presented than their British counterparts. The wrapping was better, the coils well labelled and the starting end marked, this together with the polished wire surface helps give an impression of quality to the product.

Stocks of various Swedish music wires are held in this country and the wire is generally available at very short delivery times, this may make these wires attractive even if the cost is greater. This does not appear to be true of the other continental wires which had to be obtained direct from the continental mills.

Overall little evidence has been found to suggest that wires produced by British mills are inferior to their continental rivals except in tensile strength. For many years continental music wires have been produced with higher tensile strengths than the British wires. The new BS 5216 M standard makes provision for higher tensile British music wires but this has not yet been reflected in the wires available. It may well be that as the new standard becomes more fully assimilated by the industry that British wires will reliably meet the requirements of the BS 5216 M5 specification which would make them the equal of the foreign wires. At present however, if a high tensile wire is required, continental wire mills appear to be a more reliable source.

6. CONCLUSIONS

In most respects British wires are at least equal to their continental rivals. British M5 wires however, tend to have relatively low tensile strengths and this seems to account for the differences noted in this work. In general there would seem to be no advantage in using continental wire unless a high tensile strength is required.

7. REFERENCE

Reynolds L.F. "The Influence of Surface Roughness of As Drawn Wire on the Fatigue Performance of Helical Compression Springs." SRAMA Report No. 298.

TABLE III SPRING DESIGNS FOR RELAXATION WORK

Wire dia	Mean coil dia	No. active coils	Free length
0.71	4.29	7.5	14
1.5	13.0	3.5	32

TABLE IV WIRE DEFECTS FOUND DURING METALLOGRAPHIC EXAMINATION

Wire	Dia (mm)	Defect
C	1.5	0.006 mm partial decarburisation
D4	1.5	" " "
F	1.5	Visible trace of decarburisation

TABLE V TENSILE PROPERTIES OF THE WIRES

Wire	Size mm	As Received			LTHT 250°C 30 min		
		R_m N/mm²	R_po.1 N/mm²	R_p0.2 N/mm²	R_m N/mm²	R_p0.1 N/mm²	R_p0.2 N/mm²
A4	0.315	2785	-	-	-	-	-
A5	0.315	2970	-	-	-	-	-
A4	0.71	2480	1955	2170	2445	2285	2345
A5	0.71	2670	2090	2300	2515	2380	2405
A4	1.5	2335	1665	1925	2355	2100	2210
B4	0.30	2725	-				
B5	0.30	3030					
B4	0.71	2370	1685	1914	2110	1850	1965
B5	0.71	2550	2005	2225	2510	2365	-
B4	1.5	2120	1695	1875	2120	1840	1980
B5	1.5	2255	1700	1910	2135	1900	2030
C	0.30	2870					
C	0.70	2270	1845	2065	2285	2150	2225
C	1.5	2080	1435	1600	2175	1930	2030
D4	0.30	2840	-				
D5	0.30	3040	-				
D4	0.71	2505	1915	2160	2455	2345	2345
D4	1.5	2060	1820	1940	2060	1915	2020
D5	1.5	2370	2150	2240	2310	2145	2225
E	0.30	2830	-				
E	0.71	2640	2400	2420	2625	2540	-
F	0.30	2880	-				
F	0.71	2620	1905	2255	2595	2485	2545
F	1.5	2370	1760	2040	2420	2285	2340

TABLE VI TORSIONAL PROPERTIES OF THE WIRES

Wire	Size mm	0.1% Proof Stress N/mm^2	0.2% Proof Stress N/mm^2
A4	0.71	675	900
A5	0.71	695	935
A4	1.5	795	920
B4	0.71	790	970
B5	0.71	740	970
B4	1.5	780	895
B5	1.5	1035	1120
C	0.70	750	1010
C	1.5	835	975
D4	0.71	835	1090
D4	1.5	990	1125
D5	1.5	1050	1215
E	0.71	930	1225
F	0.71	575	775
F	1.5	735	915

TABLE VII RELAXATION TEST RESULTS 0.71 mm dia WIRES

Wire	No. of Samples	Test Stress N/mm^2	Mean Relaxation %
A4	3	600	1.5
A4	3	800	-1.8
A4	5	1000	-1.9
A4	5	1200	0.8
A5	3	600	1.8
A5	3	800	-1.7
A5	5	1000	-1.3
A5	5	1200	0.4
B4	3	600	1.35
B4	3	800	1.70
B4	5	1000	1.90
B4	5	1200	0.75
B5	3	600	2.5
B5	3	800	1.3
B5	5	1000	-2.2
B5	5	1200	-0.6
F	3	600	-0.4
F	3	800	-2.4
F	5	1000	-2.3
F	5	1200	-1.1

Note: A negative relaxation represents a recovery of previous set.

TABLE VIII COILABILITY RESULTS 1.5 mm WIRES

	90-100	190-200	290-300	390-400	490-500	590-600	690-700	790-800	890-900	990-1000	Overall	Short Term Standard Deviation
A4	39.86/ .526	40.96/ .464	39.77/ .420	40.57/ .581	40.84/ .697	39.30/ .355	39.53/ .770	40.54/ .423	40.39/ .403	40.00/ .437	40.17/ .734	0.524
B4	39.42/ .509	39.25/ .630	39.38/ .368	39.31/ .403	39.26/ .545	39.27/ .445	39.44/ .473	39.44/ .619	39.15/ .408	39.22/ .629	39.31/ .497	0.512
B5	40.20/ .148	40.27/ .397	41.00/ .316	42.04/ .232	42.03/ .388	39.15/ .488	38.45/ .487	38.31/ .461	37.93/ .423	38.65/ .370	39.81/ .150	0.385
C	39.20/ .208	36.75/ .344	36.47/ .460	36.17/ .202	35.93/ .360	36.73/ .497	37.02/ .212	36.57/ .340	36.34/ .272	36.44/ .458	36.76/ .929	0.352
D4	39.93/ .324	39.74/ .357	39.88/ .420	39.60/ .497	39.43/ .334	39.38/ .224	39.79/ .429	39.91/ .458	39.88/ .834	39.87/ .390	39.74/ .473	0.454
D5	40.40/ .572	30.20/ .177	40.81/ .563	40.97/ .173	40.18/ .619	42.24/ .525	41.65/ .724	41.97/ .793	41.79/ .764	41.09/ .602	41.13/ .909	0.588
F	39.49/ .284	39.48/ .280	39.04/ .241	39.52/ .328	38.99/ .197	39.00/ .384	39.67/ .297	39.61/ .248	39.73/ .233	39.43/ .307	39.39/ .381	0.284

Mean Free Length mm/ Standard Deviation

TABLE IX COILABILITY RESULTS 0.71 mm WIRES

	90-100	190-200	290-300	390-400	490-500	590-600	690-700	790-800	890-900	990-1000	Overall	Short Term Standard Deviation
A4	20.37/ .185	20.53/ .596	20.31/ .066	20.04/ .075	20.22/ .194	20.33/ .102	20.25/ .070	20.19/ .144	20.18/ .111	20.17/ .059	20.26/ .247	0.221
A5	20.08/ .284	19.73/ .431	19.98/ .171	19.97/ .171	19.93/ .174	20.23/ .081	19.93/ .162	19.99/ .288	20.16/ .151	20.84/ .246	20.01/ .261	0.236
B4	20.31/ .261	21.04/ .299	20.43/ .201	19.95/ .258	20.36/ .723	19.76/ .278	20.04/ .325	20.10/ .493	20.55/ .178	20.32/ .329	20.28/ .489	0.368
B5	19.71/ .376	20.04/ .194	19.95/ .203	19.68/ .292	19.89/ .238	19.98/ .168	19.91/ .410	19.68/ .321	19.56/ .407	20.06/ .332	19.84/ .334	0.306
C	19.92/ .100	19.90/ .316	19.87/ .114	19.96/ .145	19.90/ .154	19.92/ .164	19.81/ .186	19.94/ .094	19.89/ .121	20.03/ .207	19.91/ .173	0.172
D4	19.96/ .177	19.98/ .476	20.00/ .763	20.72/ .162	20.48/ .128	19.70/ .159	19.88/ .228	20.10/ .116	19.73/ .264	19.87 .140	20.04/ .439	0.326
E	20.22/ .343	20.19/ .208	20.06/ .330	19.95/ .377	19.92/ .401	20.04/ .307	19.92/ .327	20.04/ .306	20.07/ .349	19.95/ .244	20.03/ .324	0.324
F	20.75/ .100	20.76/ .195	20.72/ .158	20.71/ .098	20.85/ .118	20.53/ .136	20.51/ .118	20.58/ .157	20.54/ .155	20.48/ .074	20.64/ .177	0.135

Mean Free Length mm/ Standard Deviation

TABLE X COILABILITY RESULTS 0.3 mm WIRE

	90-100	190-200	290-300	390-400	490-500	590-600	690-700	790-800	890-900	990-1000	Overall	Short Term Standard Deviation
A4	15.76/ .333	14.83/ .228	14.74/ .085	14.91/ .192	14.54/ .140	14.69/ .172	14.77/ .131	14.67/ .202	14.98/ .169	14.95/ .144	14.88/ .370	0.191
A5	13.95/ .235	14.26/ .269	13.75/ .284	14.01/ .229	13.75/ .221	13.22/ .294	13.01/ .292	13.40/ .114	13.41/ .186	13.58/ .131	13.63/ .430	0.233
B4	14.77/ .522	14.39/ .104	14.32/ .133	14.37/ .074	14.29/ .051	14.18/ .109	14.15/ .070	14.27/ .110	14.18/ .115	14.22/ .128	14.31/ .251	0.191
B5	14.58/ .088	14.38/ .118	14.63/ .713	13.72/ .127	13.44/ .132	13.58/ .209	13.35/ .080	13.25/ .077	13.32/ .098	13.24/ .100	13.75/ .587	0.252
C	14.82/ .238	14.54/ .141	14.58/ .201	14.43/ .099	14.44/ .048	14.10/ .098	14.13/ .095	14.32/ .178	13.78/ .106	14.33/ .053	14.35/ .307	0.139
D4	15.61/ .209	15.74/ .226	14.24/ .123	14.99/ .233	15.14/ .207	15.05/ .382	14.44/ .148	14.33/ .163	14.46/ .1609	14.53/ .094	14.85/ .547	0.209
D5	14.99/ .426	14.83/ .194	14.84/ .318	14.74/ .336	15.46/ .171	15.53/ .236	14.75/ .104	15.39/ .626	15.09/ .249	14.48/ .498	15.01/ .474	0.351
E	14.99/ .254	15.05/ .330	14.35/ .412	14.99/ .347	13.64/ .202	14.15/ .208	15.65/ 366	13.39/ .349	13.46/ .431	12.68/ .215	14.24/ .944	0.322
F	14.65/ .278	14.90/ .505	15.24/ .376	15.46/ .427	14.96/ .464	15.11/ .332	14.86/ .319	15.32/ .944	14.85/ .491	13.84/ .349	14.92/ .631	0.483

Mean Free Length mm/ Standard Deviation

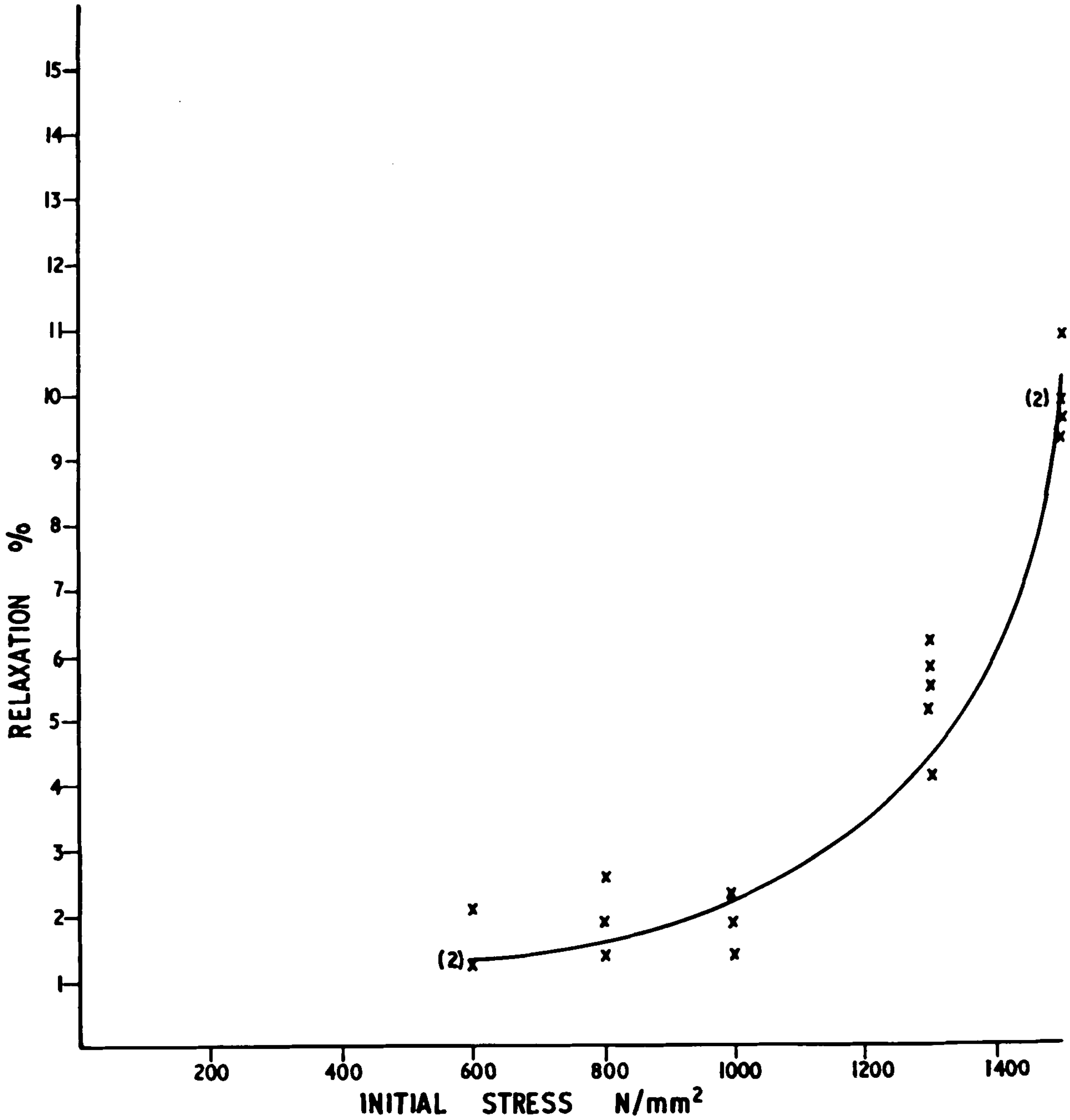

FIG. I RELAXATION AFTER 1000 HOURS AT ROOM TEMPERATURE 1·5 mm. A4 WIRE.

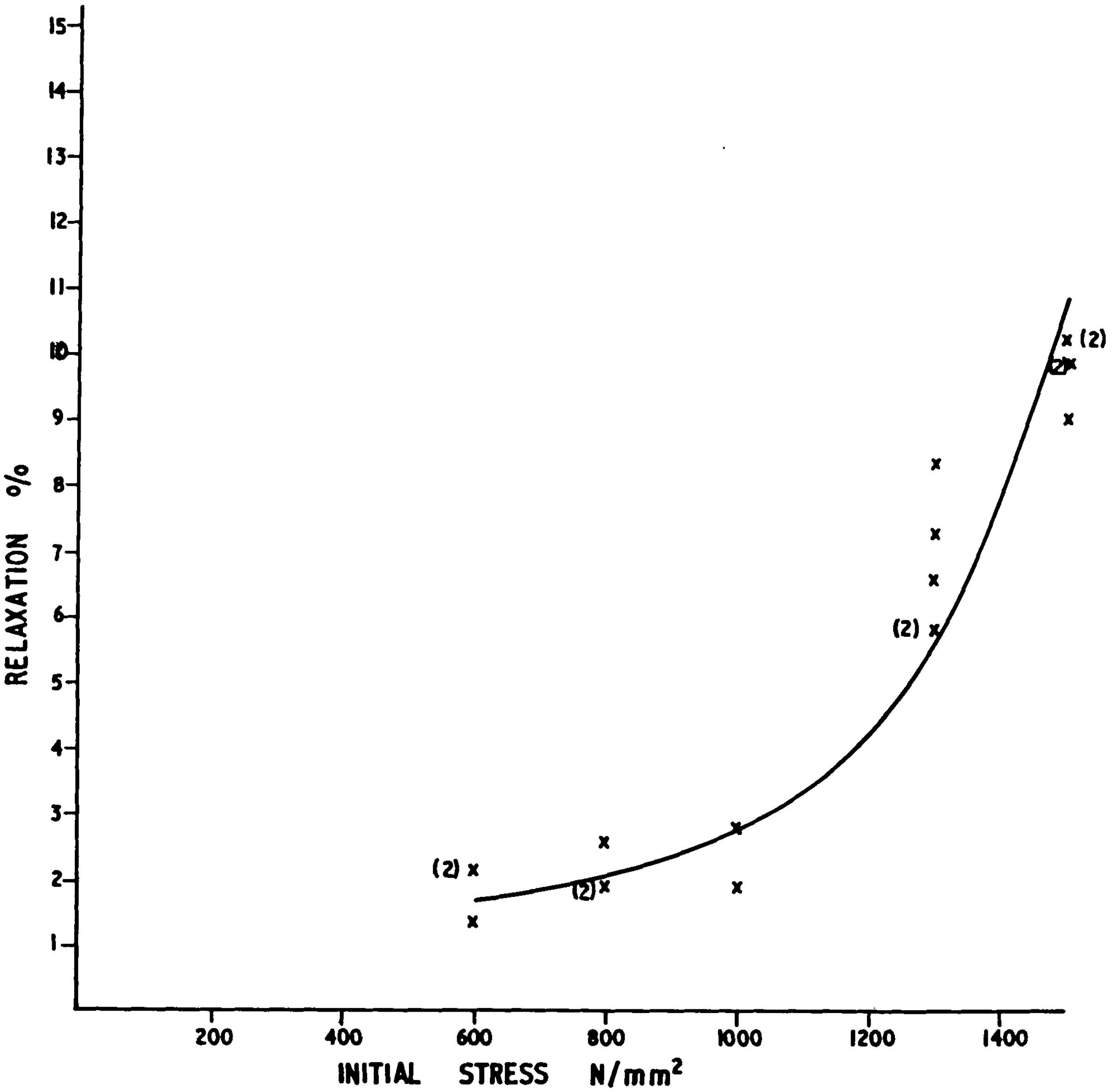

FIG. 2 RELAXATION AFTER 1000 HOURS AT ROOM TEMPERATURE 1·5 mm C WIRE.

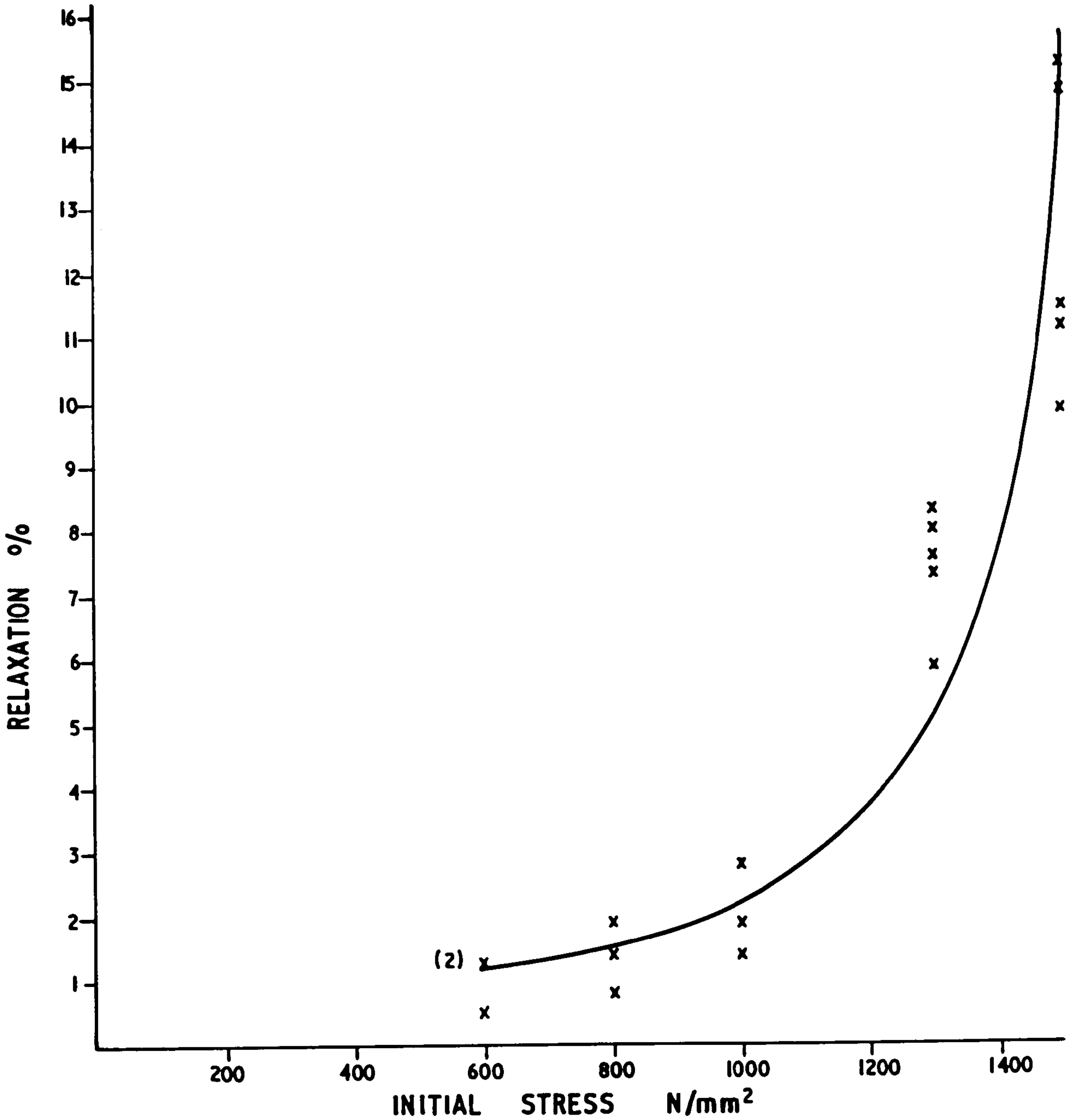

FIG. 3 RELAXATION AFTER 1000 HOURS AT ROOM TEMPERATURE 1·5 mm D4 WIRE.

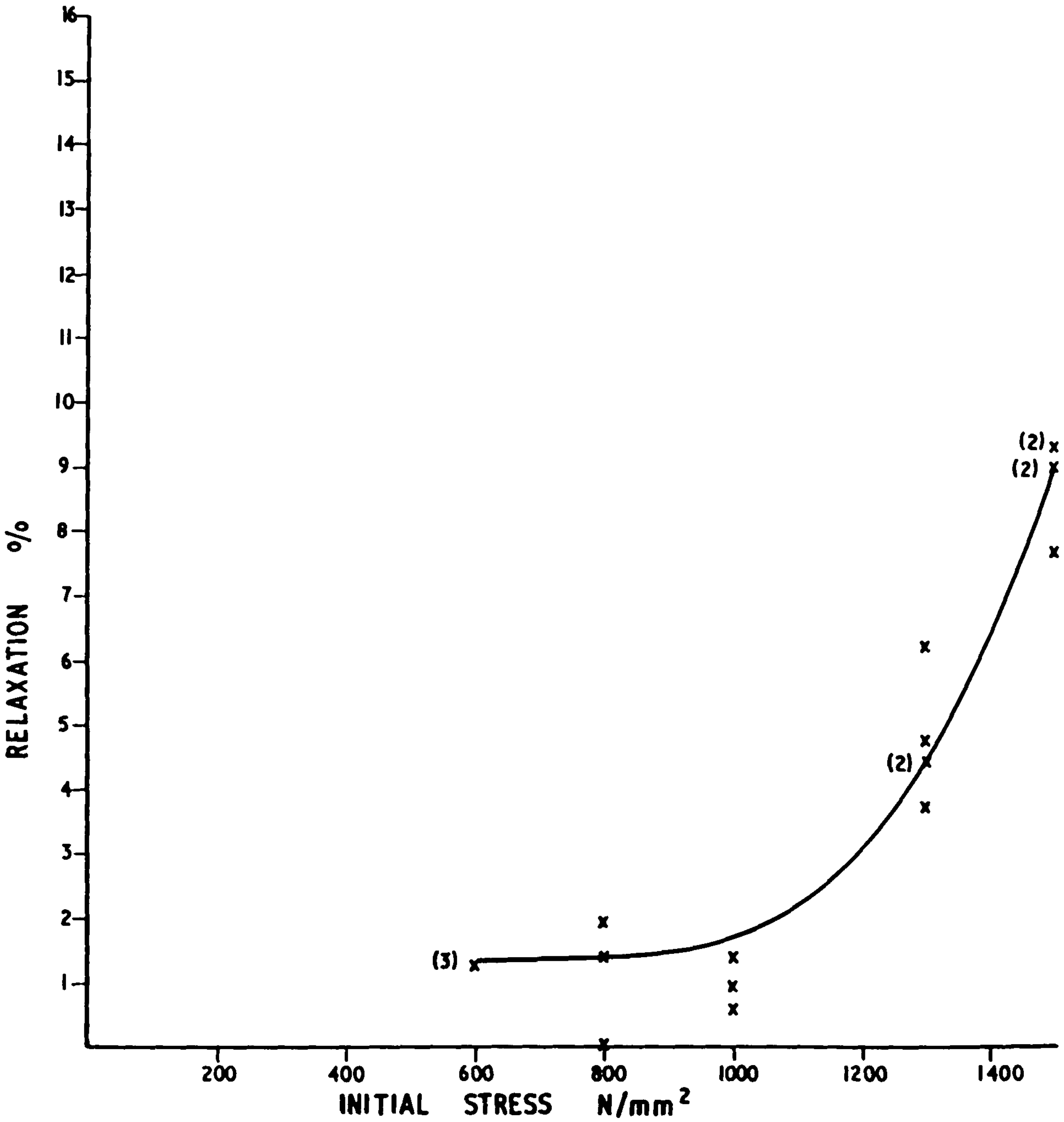

FIG. 4 RELAXATION AFTER 1000 HOURS AT ROOM TEMPERATURE 1·5 mm. D5 WIRE.

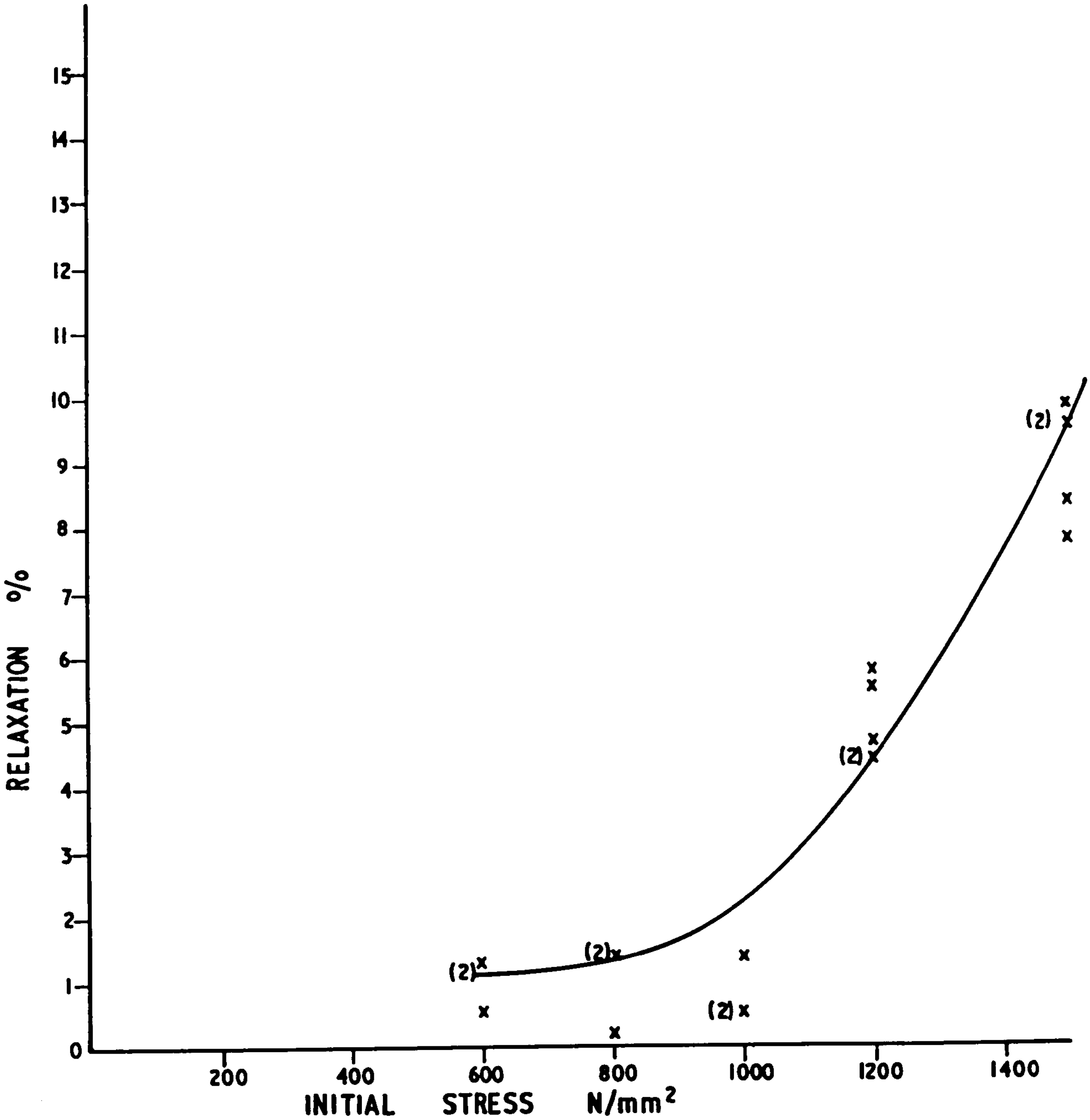

FIG. 5 RELAXATION AFTER 1000 HOURS AT ROOM TEMPERATURE 1·5 mm F WIRE.