EXPERIENCES OF SEASON CRACKING DURING THE GREAT WAR.

OWEN W. ELLIS, M.Sc., Assoc.M.Inst.C.E.

During the Great War no less than about 2,500,000 brass rods of varying sizes and shape and made to meet varying specifications were inspected by members of the examination staff associated with the Metallurgical Laboratory of the Royal Laboratory Department of the Ordnance Factories, Woolwich. Of these rods about one per cent. were tested mechanically in the test house of the same laboratory.

The various specification test figures were in practice associated with certain letters, A, B, C, and G, so that throughout the United Kingdom such terms as "Rod Metal A" and "Rod Metal G," etc., had, at the Armistice, a quite definite significance, both to manufacturers and to users of rod. By "Rod Metal A" was understood rod so manufactured as to give the following test figures:—

Yield point	20 tons square inch
Maximum stress . . .	30 ,, ,, ,,
Elongation per cent. . . .	20 ($L = 4\sqrt{a}$)

The test figures associated with the other classes of rod metal were as follows:—

Class of Metal.	Yield Point, Tons Sq. In.	Maximum Stress, Tons Sq. In.	Elongation, Per Cent.
B . .	12	20	30
C . .	6	12	10
G . .	8	20	12
Manganese bronze .	18	32/36	20

The approximate number of rods of the above five classes utilised in the Ordnance Factories for various purposes between 1914 and 1918 were as follows:—

Class of Metal.	Number of Rods.
A	870,000
B.	230,000
C.	240,000
G.	1,120,000
Manganese bronze	40,000
Total	2,500,000

Here it may at once be stated that no instance of failure due to season-cracking of rod of circular cross-section to the B and C specifications or of manganese bronze rod were noted during the whole war period. This paper is therefore concerned only with material designed to meet one or other of the following specifications:—

Class of Metals.	A.	G.
Yield point	20	8
Maximum stress	30	20
Elongation per cent.	20	12

A considerable amount of C metal square section rod failed owing to the defect now under discussion.

Brass rod to the A specification of 38 different diameters was employed at various times during the war in the manufacture of Service articles. These rods varied in diameter from 0·156 inch to 2·15 inches. No case of failure due to season-cracking, however, was recorded in rods less than 0·5 inch in diameter. A complete statement of the approximate number of failures in rods above and including those of 0·5 inch diameter will, therefore, suffice to give some idea on the incidence of season-cracking in these rods:—

TABLE I.

Diameter of Rod. (Inch).	Total Number of Rods Examined.	Total Number which Failed by Season-Cracking.	Percentage Failure.
2·15	19,040	320	1·68
2·0	1,450	nil	—
1·875	5,700	500	8·77
1·8	990	nil	—
1·75	300	nil	—
1·55	1,420	50	3·52 (1)
1·45	20,790	120	0·58
1·41	39,140	760	1·94
1·375	38,310	1,800	4·70
1·3125	50	nil	—
1·3	80	nil	—
1·25	490	nil	—
1·125	400	100	25·00 (1)
1·0625	11,260	640	5·68
1	21,300	1,460	6·85 (1)
0·875	1,960	20	1·02 (1)
0·86	84,370	4,570	5·43
0·8	8,717	nil	—
0·75	610	140	22·95 (1)
0·7	9,200	910	9·89
0·675	4,130	70	1·69 (1)
0·625	30,990	2,250	7·26
0·5625	1,580	nil	—
0·5	60,920	130	0·21 (1)

Here it may be well to note that the rods were in all cases forwarded from the manufacturer's works in consignments containing from about 10 to as many as about 10,000 rods and that season-cracking was generally confined to the rods of individual consignments. Rarely, if ever, was the phenomenon noted in single rods of any given consignment. It may, therefore, be assumed that in most cases the individual rods of each complete consignment were the subject of almost identical treatment.

Of rods to the "G" specification thirty-seven sizes were used during the war. The diameter of these rods varied from 0·072 inch to 2·4 inches, but as no instance of failure due to season-cracking was noted in any rod of less than 1·0625 inch diameter, only those rods will be considered in this connection which were of this and of greater diameter.

TABLE II.

Diameter of Rod (Inch).	Total Number of Rods Examined.	Total Number which Failed by Season-cracking.	Percentage Failure.
2·4	60	nil	—
2·2	230	nil	—
1·8	39,200	740	1·89
1·55	1.510	nil	—
1·41	10,210	nil	—
1·375	136,630	5,570	4·08
1·343	123,940	nil	—
1·3125	110	nil	—
1·25	1.930	nil	—
1·125	2,820	nil	—
1·0625	140,470	6,460	4·59

Before discussing the information contained in the above tables it should be noted that for certain sizes of A metal rod but one set of failures was recorded. For example, in the case of supplies of rod of 1·55 inch diameter only 50 rods out of a total of 1420 rods failed. These 50 rods represented a complete consignment of rods which had emanated from one source and were each and all, therefore, likely to have been subjected to somewhat similar mechanical treatment.

In Table I note has been made of such isolated cases—the figure 1 having been placed in brackets in association with the details tabulated of these rods. The high percentage failure value for 1·875 inch A metal rods is also worthy of note here as being to some extent explicable on account of the uniformity of origin for this diameter of rod.

Now, apart from the last mentioned abnormal instance of high percentage failure and the isolated cases already noted and marked in Table I, both the A and the G metal rods of low diameter have proved, as might have been expected, more liable to failure on account of season-cracking than similar rods of high diameter. The objection may be raised that no record of failure in rods of certain intermediate and smaller sizes is given. Here again, however, uniformity of origin and of treatment may account for freedom from this defect. It is obvious that where success had once been obtained in manufacture there would be no desire on the part of manufacturers to change their practice.

The phenomenon of what may be termed "wholesale" season-cracking of rods was first observed during the war period in 1914. It had previously been noted on many occasions, but failures having then had but little effect on output, were returned to manufacturers for *their* consideration. The defect was now noted in rods of high diameter which it was admitted had been subjected to somewhat drastic treatment in manufacture. The phenomenon, however, did not prove a really serious handicap to output until about the end of 1915, when quite appreciable quantities of 1·375 inch and 1·0625 inch rod showed the defect soon after receipt at the works. As a consequence large consignments of rod were rejected.

It may be of interest to note how the defect was discovered. From the beginning of the war, in pursuance of old practice, every rod of every consignment was examined for flaws. In a number of instances rods were discovered possessed of superficial cracks of the type usually associated with this trouble. These cracked rods were separated from the consignment and returned to the makers. No long while elapsed, however, before complaints from the shops of cracked rods reached those in control of the work of inspection. These complaints were a cause of considerable surprise, since it was felt by the examiners that their work was thus being called in question. However, re-examination of consignments of rods from which had already been removed all cracked bars for return to the makers revealed the presence of other defective material. Further, it was discovered that in practically every instance the defective material in any given consignment increased in amount from day to day. For example, of a lot of 227 rods it was found on first examination that no less than 202 were ruptured; these were removed for return to the makers. The following day it was discovered that of the remaining 25 rods 9 had failed by season-cracking. Ultimately the entire consignment became useless for service. Of another lot of 948 rods 54 were found to be cracked on first examination. The entire consignment became the subject of condemnation on account of season-cracking within quite a short period of the first inspection.

Meanwhile experiments were being made with a view to preventing the trouble. An attempt was made quite early to determine whether the tensile test would supply information as to the state of the rod. With this end in view a correlation of internal stress and tensile strength was aimed at. The experiments made were somewhat crude in character, but may here be worthy of note. The experimental method adopted consisted in the milling of narrow slots, symmetrical to given diameters, through longitudinal axes of the rods. The presence of internal stresses in the outer layers of rods so treated is at once revealed by the widening of the slot as milling proceeds. If slots are thus milled to the same depth in various rods then the difference between the width of the slot at the top and that of the slot at the bottom, which should coincide with the width of the milling cutter, will constitute a measure of the internal stress in individual rods. The following table contains results which were obtained on 1·0625 inch rod so treated in which the slots were milled to a depth of 2 inches:—

Yield Point. Tons Per Sq. In.	Breaking Stress. Tons Per Sq. In.	Elongation. Per Cent.	Increase in Width of Slot in Inches.
27·0	34·5	22·0	0·0606
26·0	32·5	27·5	0·0541
26·0	31·0	28·0	0·0481
24·5	30·0	24·0	0·0478
24·0	29·5	31·0	0·0475
24·0	29·0	30·0	0·0436
23·5	27·5	34·5	0·0386
24·0	28·5	28·5	0·0375
25·0	29·5	24·0	0·0362
24·0	29·0	30·0	0·0361

These figures, which represent trials made on rods taken indiscriminately from a consignment of quite similarly treated rods, some of which were in process of season cracking, show very clearly that a relation between the relative internal stress in worked rods and the yield point and maximum stress values does exist.

These experiments, however, proved valueless. It was discovered that large quanties of rod which had been in store for appreciably long periods and had shown no sign of this defect were possessed of mechanical properties equal to, if not better than, those quoted in the above table. This line of investigation was, therefore, abandoned and attention directed to low-temperature annealing.

Preliminary low-temperature annealing experiments also were made in 1915. At this time it was required that rod to the A specification, which, as has already been stated, calls for a yield point of 20 tons per square inch, be used for certain services. The problem thus presented was so to anneal the rods as to leave them possessed of yield points of 20 tons per square inch. Happily for the experimenters a change in specification precluded the necessity for continued work in this field. Such work as was conducted, however, proved futile to effect removal of deleterious internal stress without reducing the yield point of the treated material below the specification limit of 20 tons per square inch. The above problem is one which, therefore, has yet to be solved.

Serious trouble in respect of output was occasioned by "season-cracking" in the fall of 1916 and the subject of the low-temperature annealing of brass rod to the G specification was faced. The drop in the yield point of annealed rods was at this time of less serious import—the problem, in fact, was to determine the least temperature that could be employed successfully in works' practice to eliminate internal stress.

Preliminary trials were made at 400° C. with the following results:—

Series.	Condition of Rod.	Yield Point. Tons Sq. In.	Maximum Stress. Tons Sq. In.	Elongation. Per Cent. on 2 Ins.
1.	As received	23·0	30·0	30·0
	,,	22·0	28·2	32·0
	,,	23·0	28·5	34·0
	Average	22·7	28·9	32·0
	After annealing at 400° C. for 2 hrs.	9·0	23·0	61·0
	,,	9·0	23·5	58·0
	,,	9·0	23·0	55·5
	,,	10·0	24·5	55·0
	Average	9·3	23·5	57·4
2.	As received	16·5	28·0	33·5
	,,	18·5	28·5	41·0
	,,	17·5	28·0	48·0
	Average	17·5	28·2	40·8
	After annealing at 400° C. for 2 hrs.	11·5	25·5	49·0
	,,	12·0	27·0	43·0
	Average	11·8	26·3	46·0

The special interest of these test results lies not so much in the fact that the mercuric chloride test proved the treated samples to be devoid of deleterious internal stress, but in the fact that the annealing affected the mechanical properties of the rod possessed of the higher tenacity and lower ductility so much more than those of the other rods. While in the former case the yield point, as a result of annealing, was reduced by 59·0 per cent., in the latter case a reduction of but 32·6 per cent. transpired. The reduction in maximum stress values also show quite marked differences in magnitude, being 18·7 per cent. and 6·7 per cent. respectively, while the difference in percentage increase of percentage elongation is yet more marked than are the above differences, being 79·4 in the former and 12·7 in the latter case.

In order to test this somewhat remarkable discovery the effect of annealing further samples from the same rods was determined. In this instance, however, annealing was carried out at a temperature of 600° C. for 35 minutes.

The mechanical test figures recorded for the annealed samples were as follows :—

Series.	Condition of Rod.	Yield Point. Tons Sq. In.	Maximum Stress. Tons Sq. In.	Elongation. Per Cent. on 2 Ins.
1.	Annealed at 600° C.			
	for 35 mins.	8·0	24·0	54·5
	,,	8·5	25·0	59·0
	Average	8·3	24·5	56·8
2.	Annealed at 600° C.			
	for 35 mins.	12·5	26·5	37·5
	,,	10·0	24·0	51·0
	Average	11·3	25·3	43·8

To elaborate is quite unnecessary. The fact that the annealing in this second case has resulted in almost identical changes in mechanical properties is obvious.

Concurrently with these trials at 600° C. were being conducted low temperature annealing tests on samples taken from rods which formed part of a consignment, certain rods of which had already ruptured in store. The first series of experiments was made on samples taken from a series of six rods chosen at random, one of which was possessed of the following mechanical properties :—

Yield point	24·5 tons sq. inch.
Maximum stress . . .	31·0 ,, ,, ,,
Elongation	31·0 per cent. on 2 inches.

Samples of this particular rod cracked within half an hour of their immersion in a N/100 solution of mercuric chloride. The samples from the other five rods were annealed at the temperature quoted in the following tables :—

Temperature of Annealing ° C.	Yield Point. Tons Sq. In.	Maximum Stress. Tons Sq. In.	Elongation. Per Cent. on 2 Ins.
100	25	32	27
200	19	26	35
300	19	30	35
400 (circa)	10	26	52
600 ,,	6	21	69

The times of annealing varied from 2 to 2½ hours. In the case of the sample annealed at 100° C. rupture occurred within one hour of its introduction into the test solution, while the sample annealed at 200° C. cracked after about 3½ hours immersion.

No signs of rupture occurred in the other samples, even after prolonged immersion in the mercuric chloride.

The second series of trials were made on samples taken from one rod. Twelve samples, marked 1 to 12, were taken and treated as follows :—

1 and 2	Left in condition as received.
3 and 4	Annealed for 2 hours at 100° C.
5 and 6	,, ,, 200° ,,
7 and 8	,, ,, 300° ,,
9 and 10	,, ,, 400° ,,
11 and 12	,, ,, 600° ,,

The samples marked with the odd numbers were employed in the manufacture of test specimens $\frac{1}{4}$ square inch in area, while the remainder were treated in N/100 mercuric chloride solution.

The results of the tensile tests made on the odd numbers were as follows :—

Number.	Yield Point. Tons Sq. In.	Maximum Stress. Tons Sq. In.	Elongation. Per Cent on 2 Ins.
1	23·0	27·5	28·5
3	23·0	28·0	28·5
5	20·0	27·5	32·0
7	18·0	27·5	35·0
9	11·0	25·5	48·0
11	7·0	21·5	48·5

In every case, with the exception of No. 11 test, the test was satisfactory. In the last instance, however, the test sample broke outside the gauge length. This fact does not, it is considered, detract from the general value of the results recorded.

The results of the immersion tests are given below :—

Number.	Time in Solution.	Remarks.
2.	$\frac{1}{2}$ hour	Ill-defined cracks.
	1 ,,	Cracks strongly defined.
	$1\frac{1}{2}$ hours	Further strongly defined cracks.
	2 ,,	Cracks much developed.
4.	$\frac{1}{2}$ hour	Ill-defined cracks.
	1 ,,	Cracks strongly defined.
	$1\frac{1}{2}$ hours	Further strongly defined cracks.
	2 ,,	Cracks much developed.
6.	$\frac{1}{2}$ hour	No cracks revealed.
	1 ,,	,,
	$1\frac{1}{2}$ hours	,,
	2 ,,	,,
	6 ,,	,,
8.	6 ,,	,,
10.	6 ,,	,,
12.	6 ,,	,,

The conclusion arrived at from consideration of the above results was that a 2 hours annealing at from 200° C. to 300° C. would be quite sufficient to remove all deleterious stress from such rod as was then being received into store. Since, however, the mechanical properties of the material were not affected in such a way as to render them outside the G specification by annealing at 400° C., and since annealing at 350° C. for about $\frac{1}{2}$ an hour was found much the same in effect as the longer annealing at the lower temperature, this annealing temperature was employed in works practice and with success. As a result of this treatment many hundreds of rods, which otherwise would have failed by season-cracking, were passed into service. The success which attended the Ordnance Factories practice of low-temperature annealing was made known to certain of the manufacturers whose material had been the subject of investigation and it may here be worthy of note that the author has the pleasure of knowing that at least two of the firms notified of the successful issue of the above experiments in practice employed and are employing, where necessary, low-temperature annealing with equally good results.

In conclusion, the author desires to record his indebtedness to those members of his staff who assisted him in the work of inspection of rod metal during the war and, in particular, to Mr. W. Good, who had immediate control of the metal examiners, and to Mr. E. Cross, who was in charge of the test house. His thanks are also due to the Chief Superintendent of Ordnance Factories for his permission to publish this paper.