THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

ON THE OPTIMISATION OF THE AUSTEMPERING PROCESS FOR CS70 SPRING STEEL

Report No. 410

by

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SUMMARY

This report illustrates the range of mechanical properties that may be obtained when austempering CS70 carbon steel strip. The aim of the work was to define the austempering process conditions under which the elastic limit of CS70 spring steel is optimised.

Optimisation of the spring properties was found to be achieved by employing a comparatively low austenitizing temperature during austempering. It should be noted however that specifying a hardness or tensile strength from the austempering process is a very poor method of ensuring optimised spring properties, since neither of the parameters correlated with a high elastic limit.

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1. INTRODUCTION

Many flat springs are formed from annealed 0.7% carbon steel, and are subsequently heat treated to generate spring properties. This heat treatment may be accomplished by hardening and tempering to produce tempered martensite, or austempering to produce lower bainite, since it is possible to obtain hardnesses in the normal 'spring hard' range of 400-600 Vickers by either process (see the TTT diagram, Fig 1). Austempering is often the preferred process because it is claimed to involve less handling, and to yield less distortion, greater ductility, and better resistance to hydrogen embrittlement, than is the case for hardened and tempered structures.

The mechanical properties of austemred wire and strip have been compared with their hardened and tempered counterparts in a previous SRAMA report [1]. However, the heat treatment conditions under which the mechanical properties are optimised in the austempering process are not clearly defined, and this is the purpose of this investigation. For spring applications it is desirable to maximise the elastic limit of the material, hence

increasing the working range of the spring, while at the same time maintaining sufficient ductility to prevent catastrophic failure.

2. MATERIALS USED

The investigation was carried out using 0.7mm thick CS70 steel strip in the annealed condition, to BS5770 part 2 1981. The structure and hardness of the material was checked on receipt by SRAMA, and found to consist of partially spheroidised carbides in a matrix of ferrite with a hardness of 170 Hv5. The tensile strength of this raw material was checked at 500 N/mm^2, and the chemical analysis is shown in Table I. Also shown in Table I is the chemical analysis of the strip material tested in a previous programme of work[1], because the previous results serve to reinforce the conclusions of this work and so have been included throughout this report. The 25mm wide strip was stamped out and deburred form dumbell shaped tensile test pieces, approximately 200mm long.

3. HEAT TREATMENT

All austempering was carried out on a normal commercial basis, using either the in-house facilities of members, or the subcontract services of companies who supply a service to the UK spring industry. For each batch of dumbells that were heat treated, SRAMA requested that the shaker hearth austenitizing temperature be recorded, together with the salt bath temperature and throughput time.

As a result, six satisfactory batches of austempered test pieces were received, and these were arbitrarily assigned identification letters A-F. Details of the heat treatments given are shown in Table II. One batch of test pieces, G, had an unacceptably low hardness result, and testing of this batch was discontinued after checking the microstructure produced. Results of batches H and I, which originate from work recorded in SRAMA Report no. 364, are included for comparison purposes.

4. METALLOGRAPHY

Longitudinal and transverse sections from each batch of heat treated test pieces were taken, mounted and polished for metallographic examination. The hardness was measured in VPN using a load of 5 Kg. The sections were then etched in 4% nital to reveal the microstructure. Details of the results of the metallographic examination are summarised in Table II, and fully described below.

It can be seen that all the austempering heat treatment conditions employed produced bainite, and invariably lower rather than upper bainite. However, for batches B, E and I, positive identification of a lighter etching phase within the bainite matrix was made, and this second phase is believed to be untempered martensite. Reference to the TTT diagram shown as Fig 1. will reveal how it is possible to generate martensite

within the bainite, if the time allowed in the salt bath is insufficient for complete transformation to bainite.

The carbides observed in microstructures of batches C and D originate from the spheroidised carbides of the original raw material structure, which did not fully dissolve in the austenite during passage through the shaker hearth furnace. However, sufficient carbon did dissolve in the austenite to enable transformation to lower bainite.

The microstructure of batch E was conspicuously coarser than that produced in any other batch, and this is likely to be due to the high austenitizing temperature employed, which will have resulted in austenite grain coarsening prior to the bainite transformation.

The microstructure of batch G was a mixture of ferrite, pearlite and bainite, which probably arose due to insufficiently rapid quenching into the salt bath resulting in partial transformation to ferrite and pearlite prior to the bainite transformation.

It should be noted that lower bainite in CS70 is metallographically indistinguishable from tempered martensite unless some proportion of untempered martensite is present as shown in Fig 2. The presence of fine carbides, as shown in Fig 3, does not help in determining these two microstructures.

Hence, when a microstructure is described as bainite in this report it is assumed to be bainite rather than tempered martensite because an austempering heat treatment had been specified.

5. MECHANICAL TESTING

Five samples from each batch of heat treated test pieces were tested on SRAMA's Amsler tensile testing machine to the conditions stipulated in the NATLAS quality manual, to determine the elastic limit, the 0.1% and 0.2% proof stresses and tensile strength. A clip on extensometer connected to an x-y plotter, was used in the determination of the mechanical properties. Elongation and reduction of area were calculated from measurements made with a micrometer on each test piece. The mean, range and standard deviation of these test results are presented in Table III.

6. DISCUSSION OF RESULTS

To observe the effect of heat treatment conditions on the mechanical properties, Table IV has been drawn up, in order of decreasing elastic limit produced. From this table it can be seen that no clear correlation exists between hardness and elastic limit, and the range of elastic properties achievable is very wide. For these reasons, it appears that hardness, which is the usual method used for specifying the properties required from the austempering process, is not a satisfactory means of specifying.

However, specifying tensile strength will not give any more reliable a guide to the elastic properties than specifying hardness. Although neither is it a practical proposition to specify the elastic limit on a routine basis, elastic limit is the only reliable measure of optimised mechanical properties from the austempering process and, for a critical application, there must be a case for specifying this parameter.

It should also be noted that no clear correlation of hardness and tensile strength exists for austempered CS70, whereas for hardened & tempered products there is good correlation between hardness and tensile strength.

Nonetheless, Table IV does give a clear indication about how the elastic properties of austempered CS70 may be maximised. High elastic limit is associated with low austenitizing temperature, as illustrated by the austempering of batches C and D. Accurate control of austenitizing temperature at 800/810 C, which is substantially lower than that generally used by commercial heat treaters, appears to be the key to achieving consistently good spring properties.

7. CONCLUSION

Optimum spring properties are realised from the austempering process when an austenitizing temperature of 800-810 is employed. While it is not necessary to take all carbides in the raw material into solution at this temperature, it is necessary to leave components in the salt bath long enough to enable full transformation to bainite.

8. REFERENCE

1. O'Malley, M. "The Mechanical Properties of Bainite and Martensite Wire and Strip", SRAMA Report No 364, February 1984.

TABLE I CHEMICAL ANALYSIS OF CS70 STRIPS

Type	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
Dumbells	.66	.27	.63	.016	.004	.02	.005	.03	.02
Strips	.63	.25	.55	.009	.027	-	-	-	-

TABLE II HEAT TREATMENT CONDITIONS & MICROSTRUCTURES PRODUCED

Batch	Austenitizing Temp/oC	Salt Bath Temp/oC	Salt Bath Time/mins	Hardness Hv5	Structure
A	850	340	22	490	B
B	860	330	12	555	B & M
C	810	285	20	600	Carbides in B
D	800	335	15	505	Carbides in B
E	900	290	25	635	Coarse B & M
F	900	330	25	545	B
G	860	360	12	390	P & F & B
H	850	335	20	505	B
I	850	290	20	590	B & M

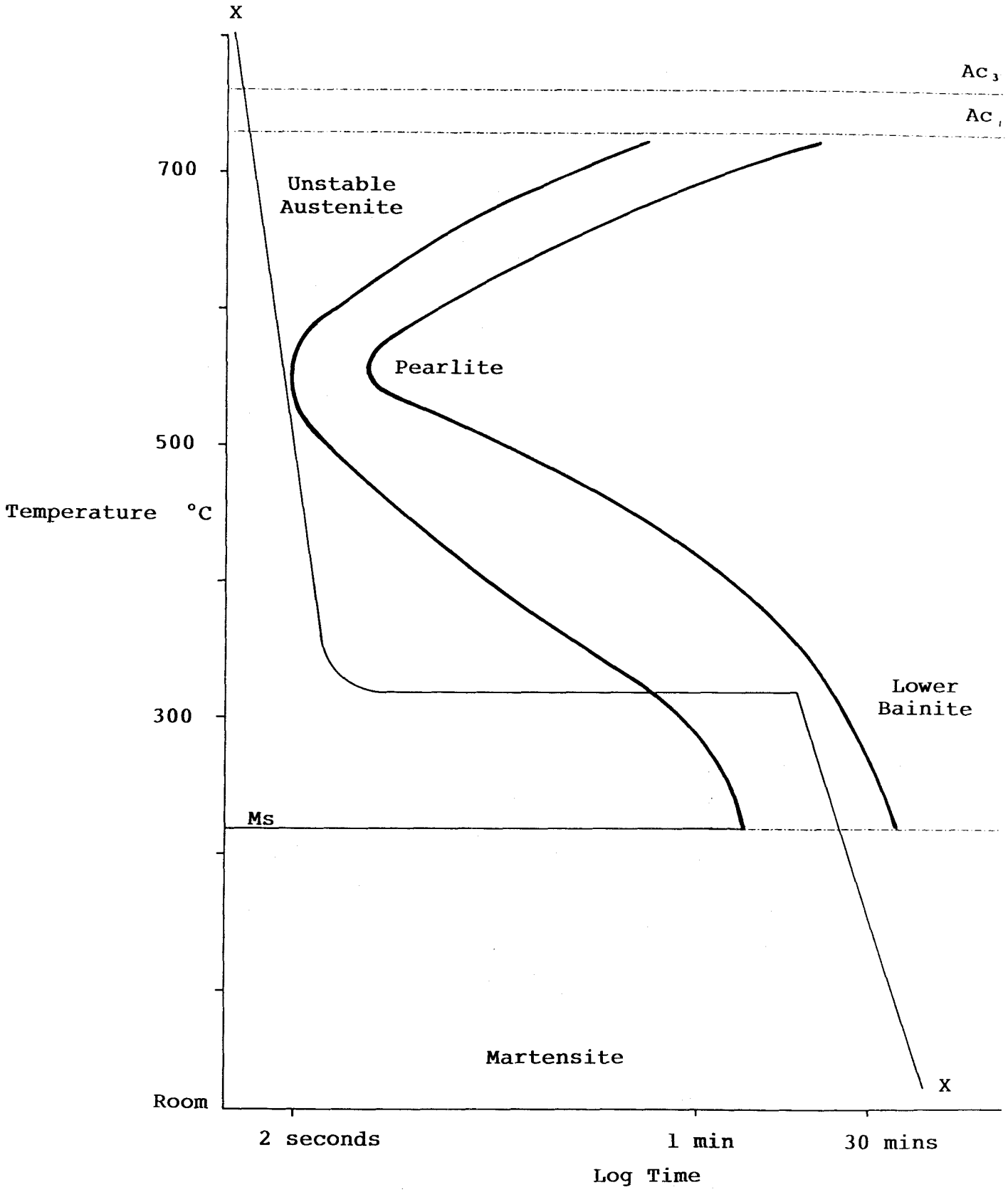
Where B = Lower bainite
M = Martensite
P = Pearlite
F = Ferrite

TABLE III MECHANICAL PROPERTY RESULTS

Batch	Elastic limit N/mm^2	0.1% proof stress N/mm^2	0.2% proof stress N/mm^2	Tensile strength N/mm^2	Elongation %	Red'n of area %
A Mean	1138	1351	1395	1560	9.6	40
Range	130	33	26	22	3.0	11
Standard Deviation	62	15	13	8	1.1	4
B Mean	1183	1454	1516	1687	9.0	38
Range	146	68	48	53	2.0	11
Standard Deviation	59	26	19	20	1.0	4
C Mean	1334	1752	1820	1999	8.6	31
Range	240	26	19	44	3.0	9
Standard Deviation	94	9	8	19	1.1	3
D Mean	1240	1465	1504	1634	10.2	39
Range	136	48	38	38	4.0	6
Standard Deviation	60	21	15	15	1.6	2
E Mean	992	1442	1545	1778	9.2	33
Range	205	31	29	25	8.0	8
Standard Deviation	80	12	12	11	3.3	4
F Mean	1123	1424	1484	1606	7.6	37
Range	160	119	120	32	7.0	6
Standard Deviation	61	44	44	12	3.6	2
H Mean	935	1365	1405	1555	—	39
Standard Deviation	92	18	21	35		4
I Mean	1160	1505	1585	1815	—	37
Standard Deviation	48	19	21	21		4

TABLE IV SUMMARY OF MECHANICAL PROPERTIES PRODUCED

Batch	Elastic limit N/mm^2	Hardness Hv5	Tensile strength N/mm^2	Reduction of area/%	Heat Treatment		
					Aust Temp ^oC	Salt Temp ^oC	Time in Salt/mins
C	1334	600	1999	31	810	285	20
D	1240	505	1634	39	800	335	15
B	1183	555	1687	38	860	330	12
I	1160	590	1815	37	850	290	20
A	1138	490	1560	40	850	340	22
F	1123	545	1606	37	900	330	25
E	992	635	1778	33	900	290	25
H	936	505	1555	39	850	335	20



Line X-X represents a possible thermal history of a CS70 spring component during an austempering treatment that resulted in incomplete transformation to bainite and a microstructure similar to that shown in fig 2.

Fig 1: TTT Diagram for CS70

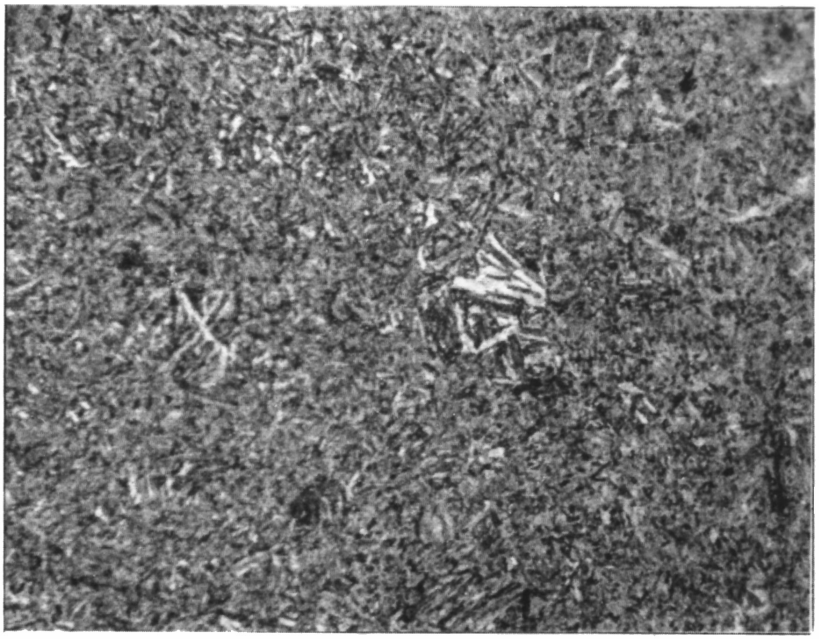


Fig 2 x540

Structure obtained for Batch I, consisting of a small proportion of untempered martensite within a matrix of lower bainite

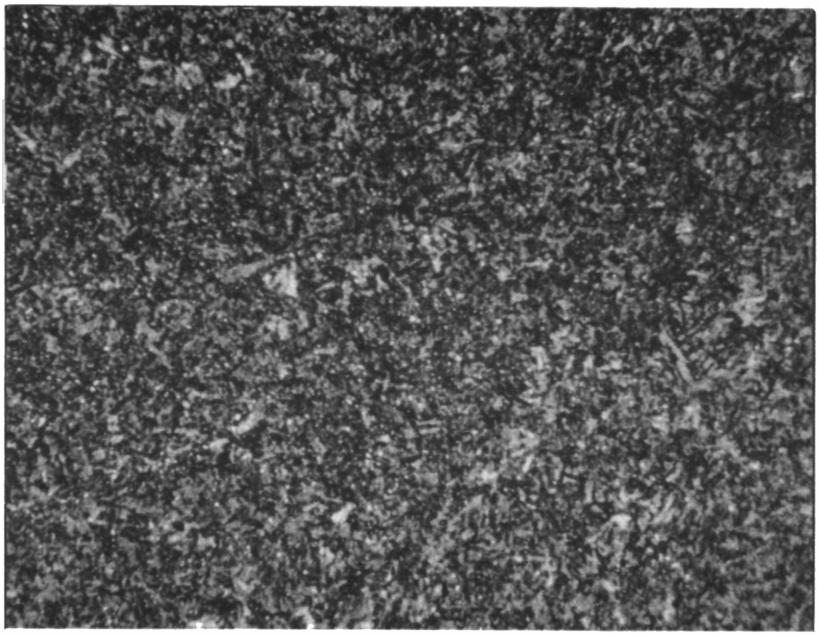


Fig 3 x690

Structure obtained for Batch D, consisting of fine carbides within a matrix of lower bainite.