AN INVESTIGATION INTO THE HEAT-TREATMENT OF SILICO-MANGANESE SPRING STEELS

B. R. NIJHAWAN, PH.D. (SHEFFIELD), B.SC. (MET.)

(*Assistant Director, National Metallurgical Laboratory, Council of Scientific and Industrial Research, Jamshedpur*)

A GENERAL impression prevails in the metallurgical field that low carbon silico-manganese spring steels are abnormally sensitive to heat-treatment and are difficult to harden completely. There is a considerable difference of opinion as to the correct treatment of low carbon silico-manganese steel. Colbeck and Hanson[1] have established that temperatures required for complete hardening of these steels are very much higher than the corresponding hardening temperatures for plain carbon steels with the same carbon contents. In one steel containing carbon 0·39%, silicon 1·98%, sulphur 0·027%, phosphorus 0·041% and manganese 0·885%, they put forward a temperature of 1110°C. for complete hardening. In another case with carbon 0 50%, silicon 1·5%, sulphur 0·039%, phosphorus 0·039% and manganese 0·865%—a temperature of 900°C. was claimed to secure complete hardening. Andrew[2] pointed out the theoretical aspects of the problem inasmuch as the high silicon contents of the steels gradually lifted up the A_1 critical points and lowered the A_3 critical points until in a 2% silicon iron, the A_3 point was completely absent. These have also been the observations of Baker[3] and of Hadfield and Osmond[4].

With, of course, increasing amounts of carbon in the silicon steels, the percentage of silicon required to cause the disappearance of A_3 point or in brief to close the $\alpha + \gamma$ loop would be higher. In practice with low carbon silicon steels, A_1 point gets uplifted so that higher heat-treating temperatures would be needed to form homogeneous Austenite which would on quenching yield the requisite hardened martensitic structures.

Andrew and Richardson[5] have shown that silico-manganese spring steels require a higher temperature in comparison to chrome-vanadium or plain carbon spring steels for hardening and further that the former are the most susceptible to decarburisation during heat-treatment and to mass effect. Burns[6] also observed that silico-manganese steels require a high hardening temperature to develop their best mechanical properties. Charpy & Cornu[7,8] and Vigoroux[9] also observed the elimination of A_1 and A_3 critical points in silicon steels. Guillet[10] has recommended a hardening temperature of 850°C. for steels containing 0·35 — 0·45% carbon, 2% silicon and about 1% manganese.

EXPERIMENTAL PROCEDURE—

The object of the present investigation undertaken by the author was to further explore the hardening characteristics of various compositions of Indian silico-manganese spring steels. The steels were rolled into flat bars of different sections and cambered into a spring leaf as used in railway locomotives, carriages and wagons. These flat bars were then subjected to different heat-treatments. Individual heat-treated spring leaf was then subjected to a "Scragging" test. This consisted of putting the cambered, heat-treated spring leaf bar under a powerful steam hammer. At dead centre of the standard length of the bars camber AB (Fig. 1) was measured. The hammer was then made to press the cambered

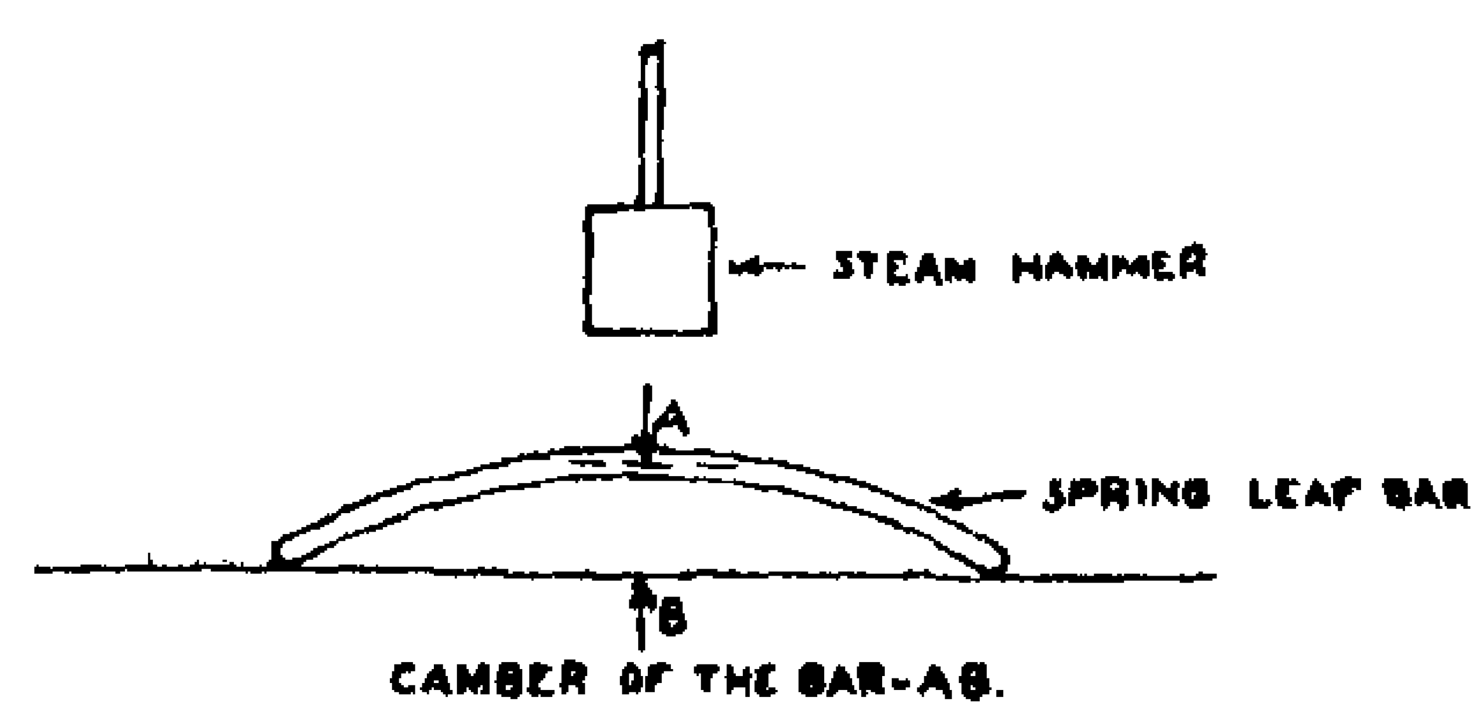

FIG 1.

spring bar totally flat. It was then released. The camber AB was again measured. If the permanent set after the first blow exceeded 5/16", the bar was considered to have failed in the test. Again the hammer pressed the spring bar flat six times in succession. The camber AB (Fig. 1) was again finally measured. The bar should not show any more permanent set beyond what it had obtained after the first hammer blow if it were to pass the "Scragging" test.

TABLE

Results of Tests on Silico-

Batch and Sample No.	Type Carbon (C) and Silicon (Si)	Section All bars were of the same fixed length (Width × thickness)	Chemical Analysis			Heat Treatment				Scragging Tests		
			C %	Mn %	Si %	Quenched in	Quenched from (temperature)	Soaked for	Tempered at (temperature)	Initial reading	After first blow	Set after first blow
Batch A 2	Medium C ,, Si	4½″ × 7/16″	0·55	1·00	1·88	Oil	950° C.	30 Min.	350° C.	3·5/16″	2·15/16″	3/8″
,, ,, 6	do	do	do	do	do	Water	do	do	do	do	3·3/16″	1/8″
,, ,, 10	do	do	do	do	do	do	900° C.	do	do	do	3·3/4″	1/16″
,, ,, 9	do	do	do	do	do	do	850° C.	do	do	3·13/16″	3·11/16″	1/8″
,, ,, 3	do	4″ × 6/16″	0·54	0·96	1·95	Oil	950° C.	do	do	3·7/8″	3·5/16″	9/16″
,, ,, 7	do	do	do	do	do	Water	do	do	do	3·9/16″	3·7/16	1/8″
,, ,, 8	do	do	do	do	do	do	920° C.	do	do	4·1/8″	4″	1/8″
Batch B 12	Low C High Si	3·1/8″ × ½″	0·47	0·91	1·83	Oil	900° C.	do	do	3″	2·13/16″	3/16″
,, ,, 11	do	do	0·46	do	1·80	Water	850° C.	do	do	3·1/16″	2·15/16″	1/8″
,, ,, 13	do	do	do	do	do	Oil	do	do	325° C.	3·1/4	3·0″	1/4″
,, ,, 20	do	4″ × ½″	0·50	0·98	2·10	Oil	do	do	350° C.	2·13/16	2·3/4″	1/16″
,, ,, 21	do	do	do	do	do	Water	do	do	do	2·15/16″	2·15/16″	Nil
Batch C 1	Low C Low Si	4″ × 7/16″	0·51	0·93	1·76	Oil	950° C.	30 Min.	350° C.	3·5/8″	2·7/8″	3/4″
,, ,, 5	do	do	do	do	do	do	975° C.	do	do	3·11/16″	3·1/8″	9/16″
,, ,, 4	do	do	do	do	do	Water	950° C.	do	do	3·9/16″	3·3/8″	3/16″
Batch D 16	High C Low Si	4″ × ½″	0·64	0·90	1·89	do	850° C.	do	do	2·15/16″	2·29/32″	1/32″
,, ,, 17	do	do	do	do	do	do	900° C.	do	do	do	2·15/16″	Nil
,, ,, 18	do	do	do	do	do	Oil	do	do	do	3″	2·13/16″	3/16″
,, ,, 19	do	do	do	do	do	do	850° C.	do	do	2·13/16	2·5/8″	3/16″

I
Manganese Spring Steel Flats

(Reading) AB (Fig. 1)			Hardness Test			Microscopic Examination (Microstructures)
After sixth blow	Set after sixth blow	Perfor mance in scrag-ging test	Surface Section: B.H.N. Centre	Surface Section: B.H.N. Ends	V.P.H.N On Cross Section	
2·15/16"	Nil	Failed	461	477, 477	564, 570, 550	Tempered Martensite with little feathery ferrite at grain boundaries. Grain size fine to medium. Troostite at boundaries
3·3/16"	Nil	OK. Stood	524	534, 555	635, 618	Uniform tempered martensite with complete absence of free (fethery) ferrite indicating proper quenching
3·1/4"	Nil	do	601	578	644, 626	do
3·11/16"	Nil	do	555	534	640, 618	do
3·5/16"	Nil	Failed	444	444, 429	564, 564	Tempered martensite with free ferrite at grain boundaries. Martensite more tempered than other samples
3·7/16"	Nil	OK. Stood	555	555, 551	593, 618	Uniform tempered martensite witn complete absence of free ferrite indicating proper quenching
4"	Nil	do	606	578, 601	635, 626	do
2·13/16"	Nil	do	495	514, 415	543, 511	Tempered martensite with ferrite at grain boundaries
2·15/16"	Nil	do	534	534, 477	601, 593, 582	Uniform fine grained tempered mortensite with complete absence of free ferrite at grain boundaries
3"	Nil	Just Passed if tempered at 350t°.Cit would have failed	477	444, 444	571, 593, 505	Tempered martensite with some free ferrite at grain boundaries
2·3/4"	Nil	OK. Stood	503	495, 471	580, 586	Fine grained tempered martensite with no free ferrite at grain boundaries
2·15/16"	Nil	do	555	555, 538	601, 630	Tempered martensite completely free from any free ferrite seperation
2·13/16"	1/16"	Failed	372	363, 365	459, 449	Fine grained tempered martensite with feathery free ferrite at grain boundaries indicating separation during oil quenching
3·1/16"	do	do	444	415, 426	536, 511	Tempered mortensite structure with lots of grain boundary ferrite in feathery from indicating separation during oil quenching
3·3/8"	Nil	OK. Stood	514	522, 514	609, 618, 6J1	Tempered martensite structure with extremely small amount of feathery ferrite at grain boundaries indicating drastic quench
2·29/32"	Nil	do	526	530, 564	606, 593	Tempered martensite structure with no free ferrite
2·15/16"	Nil	do	564	530, 538	571, 571	do
2·13/16"	Nil	do	514	461, 440	550, 557	Fine grained tempered martensite with very small amounts of feathery free ferrite at the grain boundaries
2·5/8"	Nil	do	514	520, 550	557, 571	do

Different sections of each bar were then subjected to a thorough microscopic examination and its micro-structure studied. As would be observed from the details of microscopic examination in Table I those bars which had passed the "Scragging" test exhibited tempered martensitic structures with practically no or a little feathery free Ferrite which had separated during quenching for hardening. Failed bars showed feathery Ferrite formation at the grain-boundaries.

Brinell and Vickers Pyramid Hardness measurements were taken at the ends and centres of the bars on the surface as well as on the cross sections of the bars.

Some typical results obtained during the above tests are recorded in Table I.

From the results of the above experiments it would be observed that fast quenching rates applicable in water-quenching even from 850° invariably gave satisfactory "Scragging" test results whilst oil quenching failed to give satisfactory response in the "Scragging" test in some cases from temperatures as high as 975°C. Water-quenching cannot, however, be recommended for commercial practice owing to the dangers it involves of distortion, warpage, cracking, etc., in particular for high carbon compositions. For low carbon compositions upto 0·40% carbon water-quenching may be safely employed. The above tests were conducted under ideal laboratory conditions of oil bath, regulated heating, one bar singly heat-treated at a time, etc. In commercial practice, the spring bars have to be heat-treated in batches and not singly. Thus although oil-quench from 850°C. have yielded in some cases satisfactory results in the "Scragging" test, in commercial practice higher hardenning temperatures of 900°C. or above would be most essential for satisfactory hardening and "Scragging" test performance.

Before, however, finalizing the commercial heat-treating procedure, it would be best to conduct individual laboratory experiments in the first place and to formulate the commercial procedure in the light of the foregoing results obtained. It may also be pointed out here that in comparison with plain-carbon spring steels silico-manganese spring steels require much greater care and attention, *e.g.* renewal and stirring of oil or water bath, uniformity of heat-treating temperatures and soaking, quick and proper manipulation of the transfer of the steel to the quenching media, etc. Silico-manganese steels are highly sensitive to these heat-treatment abnormalities.

Another factor for which separate research will be necessary, is the effect of "Austenitic grain Size" on the hardenability of silico-manganese spring steel bearing in mind that fine-Austenitic grained Steels are of shallow hardening types and coarse-Austenitic grained of deep hardening types. With an optimum Austenitic grain size much lower oil or water hardening temperatures may be quite feasible eliminating thereby risks of over-heating, decarburization, distortion, warpage, macro- and micro-cracking, etc., accompanying high-temperature heat treatments.

1. Colbeck and Hanson, *J. I. S. I.*, 1924, **109**, No. I, **377**. 2. Andrew, *Ibid.*, Discussion on the above paper, p. 395. 3. Baker, *Ibid.*, 1903, No II, p. 312. 4. Hadfield and Osmond, *Ibid.*, 1890, No. I, p. 62. 5. Andrew and Richardson, *Ibid.*, 1935, **131**, No. I, 129. 6. Burns, *Ibid.*, 1932, **125**, No. I, 303. 7. Charpy and Cornu, *Comptes Rendus*, 1913, **25**, 1240. 8. *Ibid.*, 1913, **117**, 319; *Revue de Metallurgie*, June 1915, **12**, 493. 9. Vigoroux, *Comptes Rendus*, 1913, **116**, 1374. 10. Guillet, *J. I. S. I.*, 1906, No. II; *Precisde Metallographie; Les industries Metallurgiques, a'l'avant guerre.*

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Professor A. D. Gardner, Regius Professor of Medicine at Oxford, in announcing this stated that during research into chemical substaces a new sideline has been found and Sir Robert Robinson, Waynflete Professor of Chemistry at Oxford, had wished to explore this, and for this purpose had applied to the British Empire Cancer Campaign for funds.