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Investigation of Structure, Chemical and Phase Composition of Silicon Spring Steel Scale

M. V. Temlyantsev[1], K. S. Konoz[1], O. V. Kuznetsova[1], V. B. Deev[2], and E. Ya. Zhivago[1]

[1]Siberian state industrial University, Novokuznetsk, Russia
[2]National research technological University «MISIS», Moscow, Russia

Abstract

The article presents the results of investigation of structure, chemical and phase composition of scale formed on siliceous spring steels during high-temperature heating prior to rolling. It is established that in 40S2 steel, the hematite layer bordering furnace atmosphere has a minimum thickness of about 40–60 μm, the magnetite layer has thickness of 250 ± 280 μm, the largest thickness of 800 ± 900 μm has wustite layer with secondary ferriferous oxide released during cooling, bordering the steel surface. The scale layer adjacent to the steel surface is characterized by a much greater macrostructural, chemical, and phase inhomogeneity. In addition to wustite–ferriferous oxide mixture, iron silicates with an increased silicon content are present. Approaching the steel surface, the number of zones enriched with silicon increases. When 60S2ChA steel is heated to 1180–1200°C, zones enriched with silicon are observed in the scale at a distance of 200 ± 250 μm from the metal surface, and when heated to temperatures of 1310 ± 1315°C at a much larger distance, reaching 700–800 μm.

Keywords: scale, steel heating, siliceous springs steel, scale microstructure

Corresponding Author:
M. V. Temlyantsev
uchebn_otdel@sibsiu.ru

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1. Introduction

40S2, 50S2, 55S2, 60S2, 60C2ChA, 70S3A siliceous springs steel and their analogues are widely used in production of springs, shock absorbers of various purposes and rod spring clips (elastic elements of rail fasteners, connecting rails with sleepers) [1–3]. Such metal products are produced from hot-rolled steel using special technologies, including shot blasting, winding and heat treatment. At the same time, the quality of finished springs, as well as their performance properties, depends to a large extent on quality of surface of original rolled metal [1–4].

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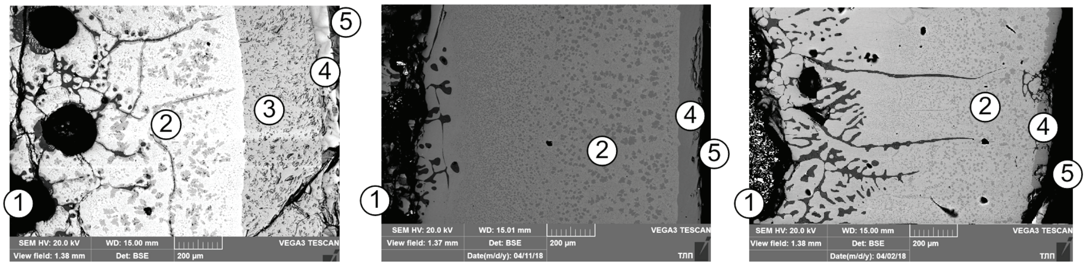
When designing technologies for production of rolled metal for springs of various purposes, special attention is paid to the problem of scale formation during heating in continuous furnaces and scale removal during rolling [4–6]. Scale is one of the most common reasons for deterioration of rolled metal surface quality and it can lead to origin of scabs, rippling, pockmarks, which, as stress concentrators, reduce springs endurance, shortening their service life. Efficiency of descaling highly depends on its properties, chemical and phase composition, and, which is the most important, on structure of steel-scale interface [7, 8]. In connection with this, obtaining new information on chemical, phase composition, and features of structure of scale in siliceous spring steels is relevant and has great practical value [9–12].

2. Research

In the present work, the structure, chemical and phase composition of scale in 40S2 (chemical composition, %: 0.377 C, 1.604 Si, 0.65 Mn, 0.204 Cr) and 60S2ChA (chemical composition, %: 0.576 C, 1.439 Si, 0, 66 Mn, 0.736 Cr, 0.024 Ni, 0.031 Cu, 0.004 S, 0.008 P) steels is investigated on TESCAN VEGA 3 electron scanning microscope with OXFORD AZtec energy dispersive attachment for micro-X-ray analysis (National University of Science and Technology MISIS) [12]. For 40S2 steel, scale slabs of 1–1.5 mm thick were selected from steel samples heated to 1175°C, and holding time was 25 minutes. For 60S2ChA steel two types of scale samples were investigated. The first one is scale taken from the surface of continuously cast billets (CCB) after heating to 1160–1200°C in continuous furnace and the second one is scale after steel samples heating to 1310–1315°C (thermal reflowing) in a laboratory electric furnace in air. After heating, the samples with scale were cooled in air under conditions of natural convection.

3. Analysis of Results

Figure 1 shows a general view of scale microstructure. For 40S2 steel, the hematite layer bordering atmosphere of furnace has a minimum thickness of about 40–60 μm, the ferriferous oxide layer has thickness of 250 ± 280 μm, the largest thickness of 800 ± 900 μm has a wustite layer with secondary magnetite, bordering steel surface. Chemical and phase composition of hematite and ferriferous oxide layers is relatively uniform over the thickness and perimeter for the scale of all investigated steel grades (Figure 2(a)). In Table 1 their compositions are shown at various points for the scale layers of 40S2 steel.

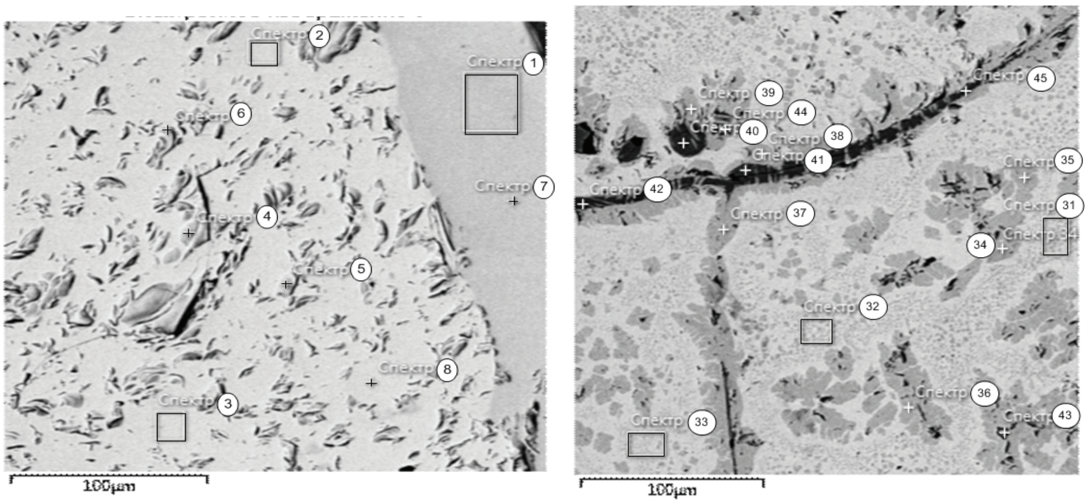


(a) (b) (c)

Figure 1: Microstructure of the scale of 40S2 (a) and 60S2ChA steels ((b) = CCB, (c) = sample); 1 = steel surface; 2 = FeO + FeO + Fe_3O_4; 3 = Fe_3O_4; 4 = Fe_2O_3; 5 = furnace atmosphere.

Table 1: Chemical composition (% by weight) of hematite and ferriferous oxide layers of 40S2 steel scale.

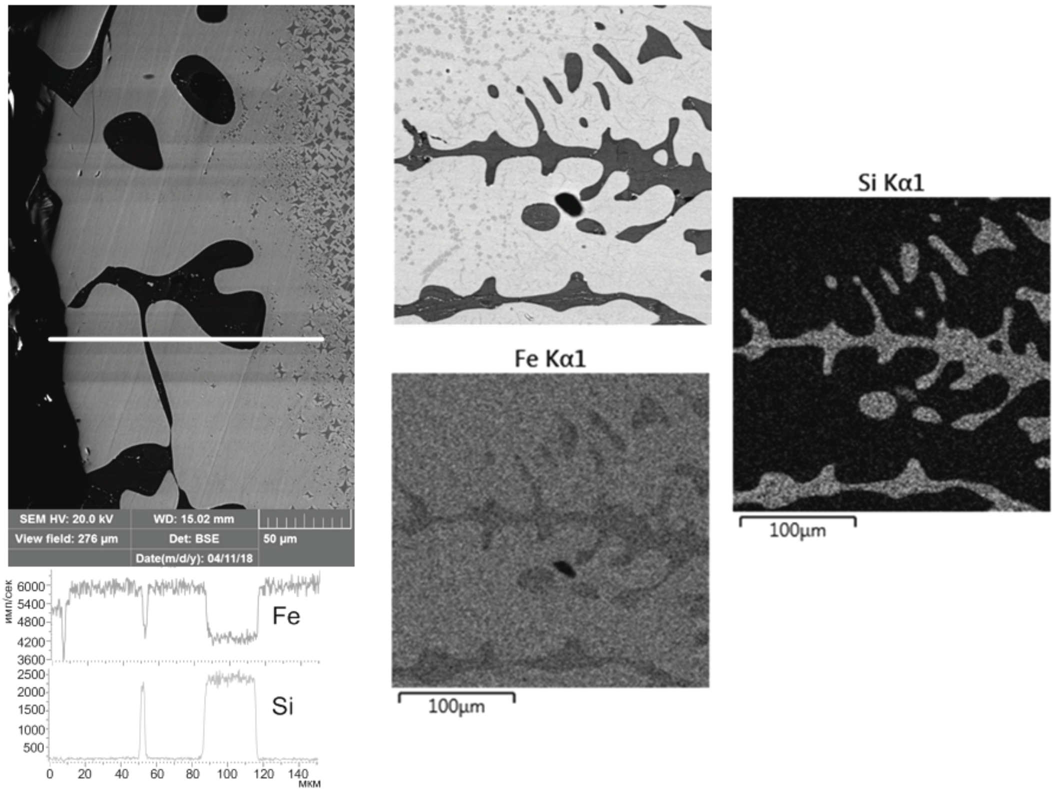
Distribution No.	O	Si	P	S	Mn	Fe	Total
1 hematite	33.52	0.09	0	0	0.08	66.31	100
7 hematite	34.11	0.06	0.03	0	0.1	65.7	100
2 ferriferous oxide	31,37	0	0.02	0.03	0.44	68.14	100
3 ferriferous oxide	31.17	0.06	0	0.02	0.52	68.23	100
4 ferriferous oxide	31.52	0	0	0.03	0.42	68.02	100
5 ferriferous oxide	31.21	0.02	0	0.01	0.45	68.3	100
6 ferriferous oxide	31.86	0.02	0	0.01	0.37	67.74	100
8 ferriferous oxide	30.19	0.12	0.03	0.03	0.48	69.16	100



(a) (b)

Figure 2: Microstructures of hematite and ferriferous oxide (a), wustite layers with secondary ferriferous oxide (b) scales in 40S2 steel.

The scale layer adjacent to steel surface (Table 2, Figures 2(b) and 3) is characterized by much greater macrostructural, chemical, and phase inhomogeneity. In addition



(a) (b)

Figure 3: Microstructure and chemical heterogeneity of scale zones of 60S2ChA steel CCB (a) and of sample (b) adjacent to the steel surface.

to wustite-ferriferous oxide mixture, iron silicates are also present, characterized by increased (up to 13% by weight) silicon content. At the same time, an increase in heating temperature to scale melting promotes origin of macrostructural, chemical, and phase inhomogeneity over the thickness of wustite layer with secondary ferriferous oxide released during cooling.

As we approach the steel surface, the number of zones enriched with silicon increases. When 60S2ChA steel grade is heated to 1180–1200°C, zones enriched with silicon are observed in the scale at a distance of 200 ± 250 μm from metal surface, and when heated to temperatures of 1310 ± 1315°C at a much larger distance, reaching 700–800 μm. The presence of such a developed zone of structural and phase heterogeneity worsens scale removal [7, 8] during rolling of the CCB.

Table 2: Chemical composition (wt %) of the wustite layer with the secondary scale ferriferous oxide emission during 40S2 steel cooling.

Distribution No.	O	Si	P	S	Mn	Fe	Cu	Mo	Total
31 wustite + ferriferous oxide	27.58	0.4	0	0.03	0.55	71.44	–	–	100
32 wustite + ferriferous oxide	27.97	0.06	0.02	0.05	0.42	71.49	–	–	100
33 wustite + ferriferous oxide	27.37	0.04	0.01	0.03	0.43	72.12	–	–	100
34 wustite + ferriferous oxide	31.02	0.02	0	0.05	0.42	68.5	–	–	100
35 wustite + ferriferous oxide	31.77	0.44	0.02	0	0.35	67.43	–	–	100
36 wustite + ferriferous oxide	31.44	0.01	0.01	0.02	0.4	68.12	–	–	100
37 wustite + ferriferous oxide	31.24	0.3	0.02	0	0.31	68.12	–	–	100
38 wustite + ferriferous oxide	31.1	0.33	0	0.04	0.35	68.17	–	–	100
39 wustite + ferriferous oxide	31.67	0.22	0	0	0.36	67.75	–	–	100
40 iron silicates	36.74	13.58	0.08	0.03	1.61	47.96	–	–	100
41 iron silicates	36.26	13.48	0.14	0	1.65	48.47	–	–	100
42 iron silicates	36.04	13.34	0.14	0	1.35	49.14	–	–	100
45 iron silicates	31.87	7.39	0.01	0.02	1.09	59.62	–	–	100
43 iron silicates	26.72	2.12	0	0.05	0.3	70.24	0.22	0.35	100
44 iron silicates	31.77	1.61	0.04	0.04	0.45	66.09	–	–	100

4. Conclusions

Using electronic scanning microscopy, the scale structure is investigated. It is established that for 40S2 steel ferriferous oxide layer bordering furnace atmosphere has a minimum thickness of about 40–60 μm, ferriferous oxide layer has thickness of 250 ± 280 μm, the largest thickness of 800 ± 900 μm has a wustite layer with secondary ferriferous oxide released during cooling, bordering the steel surface. Chemical and phase compositions of hematite and magnetite layers are relatively uniform over the thickness and perimeter. The scale layer adjacent to the steel surface is characterized by a much greater macrostructural, chemical, and phase inhomogeneity. In addition to wustite–ferriferous oxide mixture, iron silicates with increased silicon content are present. As we approach the steel surface, the number of zones enriched with silicon increases. When 60S2ChA steel is heated to 1180–1200°C, zones enriched with silicon are observed in the scale at a distance of 200 ± 250 μm from the metal surface, and when heated to temperatures of 1310 ± 1315°C at a much larger distance, reaching 700–800 μm.

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