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The Structure of the Silumin Coat on Alloy Cast Steels

T. Szymczak*
Department of Materials Engineering and Production Systems, Technical University of Łódź
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland
*Corresponding author. E-mail address: tomasz.szymczak@p.lodz.pl

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Abstract

The work presents the analysis results of the structure of the coat obtained by dipping in silumin AlSi5 of two grades of alloy cast steel: GX6CrNiTi18-10 (LH18N9T) and GX39Cr13 (LH14). The temperature of the silumin bath was 750±5°C, and the hold-up time of the cast steel element τ = 180 s. The absolute thickness of the coat obtained in the given conditions was g = 104 μm on cast steel GX6CrNiTi18-10 and g = 132 μm on GX39Cr13. The obtained coat consisted of three layers of different phase structure. The first layer from the base "$g_{1'}$" was constructed of the phase AlFe including Si and alloy additives of the tested cast steel grades: Cr and Ni (GX6CrNiTi18-10) and Cr (GX39Cr13). The second layer "$g_{1''}$" of intermetallic phases AlFe which also contains Si and Cr crystallizes on it. The last, external layer "g_2" of the coat consists of the silumin containing the intermetallic phases AlFeSi which additionally can contain alloy additives of the cast steel. It was shown that there were no carbides on the coat of the tested cast steels which are the component of their microstructure, as it took place in the case of the coat on the high speed steels.

Keywords: Innovative Casting Technologies, Dip Coating, Alloy Cast Steel, Silumin

1. Introduction

The works [1, 2] present the structure of the silumin coat on alloy steel: acid resistant steel X6CrNiTi18-10 (1H18N9T) and high speed steels HS18-0-1 (SW18) and HS6-5-2 (SW7M). The silumin AlSi5 coats were applied by dipping of the tested alloy steel grades. Irrespective of the alloy steel grade the coat consisted of three layers with different phase structure. The diagram of the silumin coat of "g" thickness with the marked layers is presented in Fig. 1.

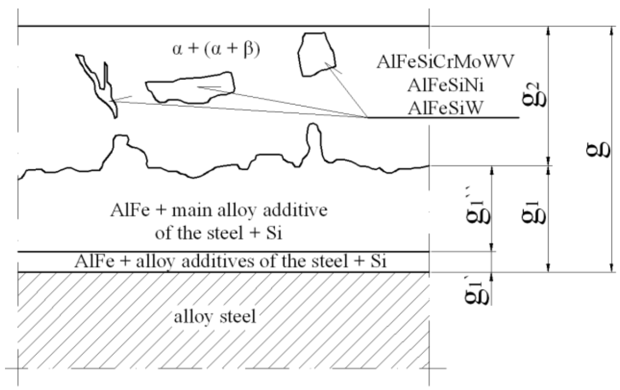


Fig. 1. A general diagram of the silumin coat structure on the alloy steels

The first beginning from the ground layer of the thickness “$g_{1'}$” consists of the phase AlFe containing the alloy additives of the steel. The second layer “$g_{1''}$” crystallizes on it and consists of the phase AlFe also containing the main additive of the steel, i.e. Cr (X6CrNiTi18-10) and W (HS18-0-1) as well as Mo and W on HS6-5-2. The layers “$g_{1'}$” and „$g_{1''}$” together comprise the so called diffusion transitional layer “g_1”. Over the whole thickness of the layer “g_1” there appear composition phases of the sub-eutectic silumin: α and eutectic system α+β as well as elongation of the inter-metallic phases. On steels X6CrNiTi18-10 and HS18-0-1 these phases are the following: AlFeSiNi and AlFeSiW, however on the high speed steels there appear carbides which are typical for these steels. These carbides are of the following types: $M_{23}C_6$, MC, M_2C and M_6C [3, 4]. The approximate temperature of their intensive merge in austenite is 900÷1000°C ($M_{23}C_6$), more than 1000°C (M_6C) and more than 1100°C (MC). Different thicknesses of the coat were obtained on the tested steel grades. For silumin the temperature t = 750°C and the time of dipping of the steel specimen in the bath τ = 180 s it was about 50 μm on steel X6CrNiTi18-10 and on the high speed steels it was g ≈ 200 μm (HS18-0-1) and g ≈ 150 μm (HS6-5-2), correspondingly.

The aim of the present work is to present the structure of the coat from silumin AlSi5 on alloy cast steel.

2. Methodology of the research

Two grades of alloy cast steel were chosen for the analysis: acid-resistant cast steel GX6CrNiTi18-10 and stainless cast steel GX39Cr13. The chemical composition and the microstructure of the tested cast steel grades are presented in Table 1 and Figure 2 (a, b), correspondingly.

The microstructure of cast steel GX6CrNiTi18-10 consists of dendrites of austenite and carbides concentrated mainly on the borders of the dendritic cells; however, the microstructure of cast steel GX39Cr13 ferritic with the carbides. Both cast steel grades have carbides of the same type $(Fe, Cr)_{23}C_6$ but different concentration of iron and chromium [3, 5]. Regarding a much higher concentration of Fe in cast steel GX39Cr13 the carbides which appear in it are characterized by higher concentration and lower Cr concentration in comparison to the carbides in cast steel GX6CrNiTi18-10.

The bars with the diameter d = 10mm and thickness l = 70mm were made from the tested high speed steel. The silumin AlSi5 coat was made on them by dipping. The silimunum bath had a temperature of t = 750±5°C, the time of dipping the steel specimen in it was τ = 180 s. Before dipping in the bath the cast steel bars were mechanically cleaned, chemically degreased and preheated to the temperature of 50°C.

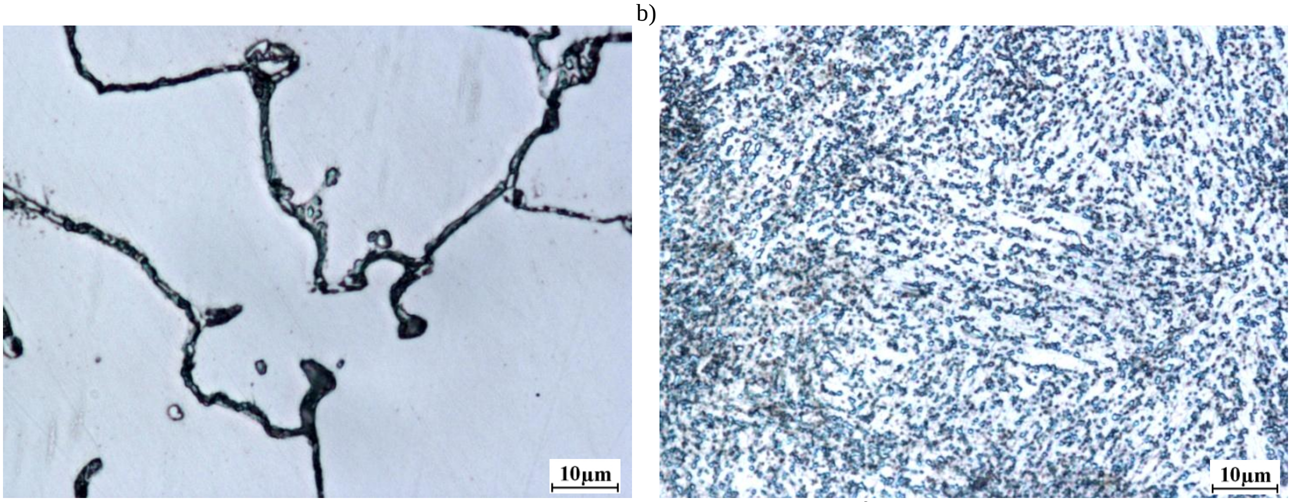
The metallographic analysis of the alloy cast steel and the coats was carried out using the Nikon MA200 Eclipse optical microscope equipped with a Digital camera.

The point microanalysis of concentration and the maps of the elements distribution were shown using the detector EDS by Pioneer and VANTAGE software by NORAN.

Table 1.
The chemical composition of the tested alloy cast steel grades

Cast steel grade	Chemical composition, %					
	C	Cr	Ni	Mn	Mo	Ti
GX6CrNiTi18-10	0.08	20.28	8.90	0.96	0.17	0.23
GX39Cr13	0.35	13.32	0.14	0.70	-	-

a) b)



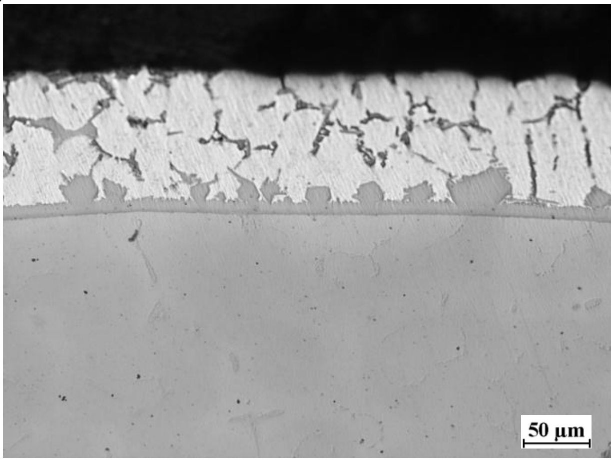
Microstructure: austenite, carbides, non-metallic inclusions   Microstructure: ferrite, carbides, non-metallic inclusions

Fig. 2 (a, b). Microstructure of the tested alloy cast steel grades: a – GX6CrNiTi18-10 and b – GX39Cr13

3. Research results

The representative coats of silumin AlSi5 on the tested alloy cast steels are shown in Figure 3 (a, b).

a)



b)

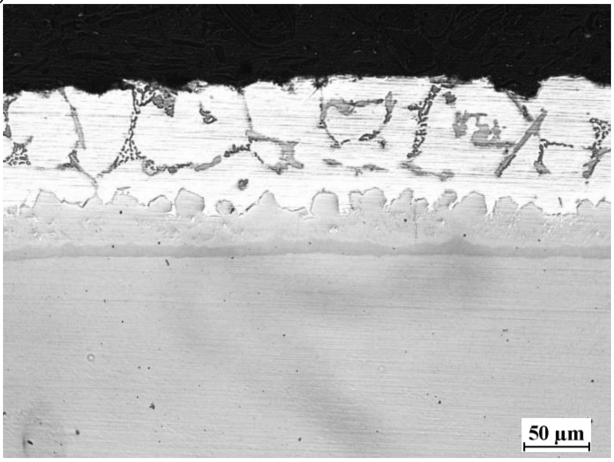


Fig. 3 (a, b). Representative coats made of silumin AlSi5 on cast steel, correspondingly: a – GX 6CrNiTi18-10 and b – GX39Cr13

It follows from the presented data that there is a three-layer silumin coat on the tested grades of the alloy cast steel. The thicknesses: of coat “g”, the transition layer “g_1” and the thin layer crystallizing directly on steel “$g_{1'}$” are presented in Table 2.

Table 2.
The total thickness of the coat and its compounding layers on the tested grades of cast steel

Cast steel grade	Thickness, µm		
	“g”	“g_1”	“$g_{1'}$”
GX6CrNiTi18-10	104.0	12.1	2.6
GX39Cr13	132.0	31.0	8.3

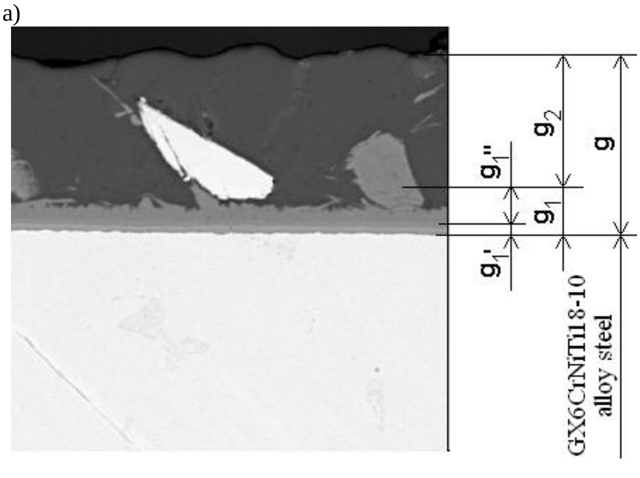
It follows from the presented data that a larger thickness of the coat “g” appears on cast steel GX39Cr13 in comparison to cast steel GX6CrNiTi18-10, however the thickness of the compounding layers of the coat “g_1” and “$g_{1'}$” are three times larger than on cast steel GX39Cr13. In comparison to the coat made on steel X6CrNiTi18-10 with the austenitic microstructure with carbides (g ≈ 50 µm) on the identical cast steel, the coat was twice as thick and it was g = 104 µm. Different thicknesses were also obtained on the steels and cast steels with the ferritic microstructure with carbides. On the high speed steels the complete thickness of the coat was within the range of g = 150÷200 µm, and on cast steel GX39Cr13 the coat of a smaller thickness g = 132 µm was obtained.

In order to determine the structure of the coat layers on alloy cast steels the maps of distribution of their composing elements and silumin AlSi5 were made and the concentration of the elements in the selected points of the coat was also determined.

Figure 4a shows the coat on cast steel GX6CrNiTi18-10 obtained in silumin AlSi5 with the marked component layers. The maps of the distribution: Al, Si, Cr, Fe Ni and Ti in this area are presented in Figure 4b.

Layer “g_1” has a high concentration of Al, Fe and Si and an increased concentration of Cr and Ni. These results confirm the appearance of the AlFe phase in this layer which has small amounts of: Si, Cr and Ni. In layer “g_2”, a high concentration of Al and smaller areas with a high concentration of Si appear, which confirms the appearance of the compound phases of silumin in it.

a)



b)

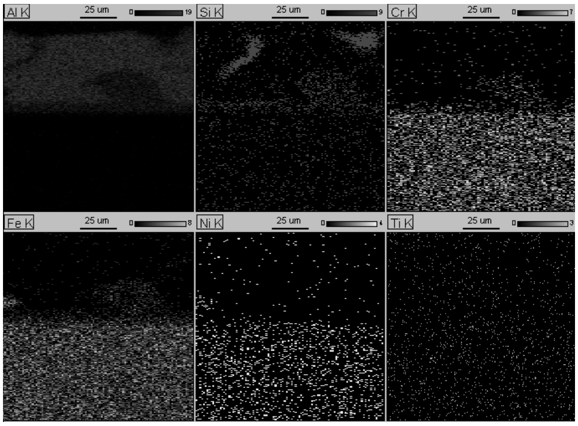
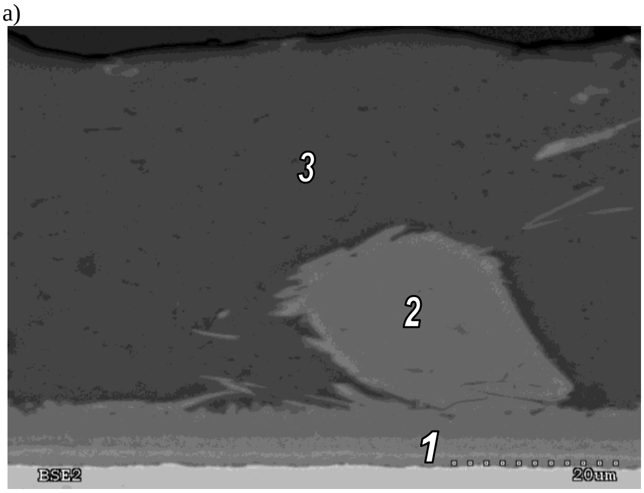


Fig. 4 (a, b). The coat of silumin AlSi5 on cast steel GX6CrNiTi18-10 and distribution maps of the elements: Al, Si, Cr, Fe Ni and Ti (b)

Figure 5 (a, b) presents points 1÷4 of the elements concentration measuring in the coat on cast steel GX6CrNiTi18-10; however, the concentration of the elements in these points is shown in Figure 6 (a÷d).

It follows from the presented data that the high concentration of Al = 55.4% and Fe = 27.0% as well as the increased concentration of Si = 5.94%; Cr = 8.2% and Ni = 3.3% in the layer “g_1” (point 1). Here there is the AlFe phase including Si, Cr and Ni. The measuring point 2 was placed in the layer “g_1”. There appears a high concentration of aluminum (61.7%) and iron (22.1%) and an increased concentration of silicon (7.7%) and chromium (8.2%) and some quantity of nickel (0.3%). Thus, this is the AlFeSiCr phase. In the layer “g_2” in the measuring point 3 there is a high concentration of Al = 98.7% and some Si = 0.8% and Fe = 0.5%, which confirms the appearance of the phase α which is the component of the silumin AlSi5 used to make the coat. Again, in layer “g_2” in free precipitation with the lamellar morphology the measuring point 4 was placed. There appears a high concentration of Al = 69.3% and an increased concentration of Ni = 13.11%; Si = 9.5% i Fe = 8.1%. It can be supposed that it is the AlFeSiNi phase.

a)



b)

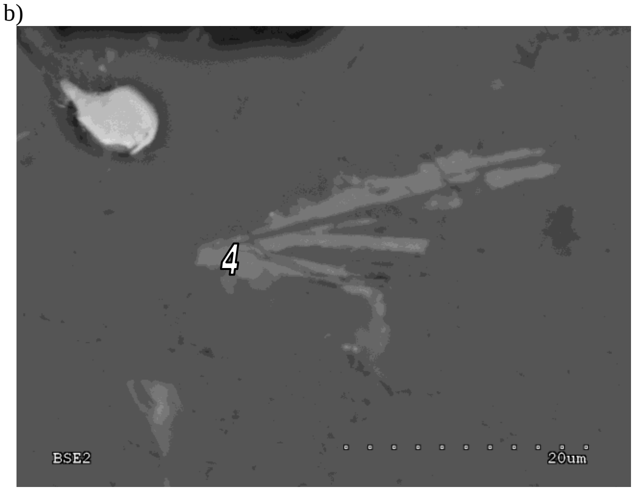


Fig. 5 (a, b). The coat of silumin AlSi5 on cast steel GX6CrNiTi18-10 with points 1÷4 to measure the concentration of the elements

a)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.3325	1.667	69.27	55.43	+/- 0.29
Si-K	0.0238	2.497	7.13	5.94	+/- 0.17
Cr-K	0.0794	1.047	5.39	8.31	+/- 0.21
Fe-K	0.2447	1.105	16.33	27.04	+/- 0.43
Ni-K	0.0291	1.127	1.89	3.28	+/- 0.18
Total			100.00	100.00	

b)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.4104	1.503	73.27	61.68	+/- 0.31
Si-K	0.0305	2.533	8.83	7.73	+/- 0.20
Cr-K	0.0766	1.074	5.07	8.23	+/- 0.14
Fe-K	0.1962	1.124	12.66	22.06	+/- 0.40
Ni-K	0.0027	1.132	0.17	0.31	+/- 0.13
Total			100.00	100.00	

c)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.9782	1.009	99.01	98.73	+/- 0.41
Si-K	0.0025	3.116	0.75	0.77	+/- 0.09
Fe-K	0.0043	1.155	0.24	0.50	+/- 0.10
Total			100.00	100.00	

d)

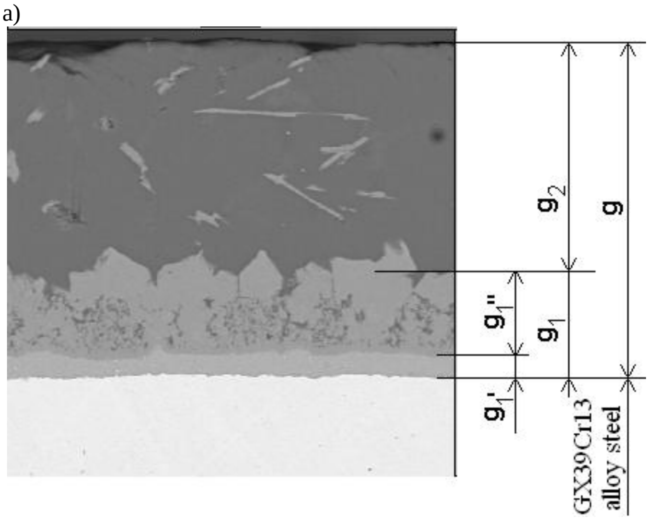
Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.4815	1.439	78.40	69.29	+/- 0.34
Si-K	0.0356	2.683	10.37	9.54	+/- 0.22
Fe-K	0.0743	1.085	4.41	8.06	+/- 0.30
Ni-K	0.1175	1.116	6.82	13.11	+/- 0.45
Total			100.00	100.00	

Fig. 6 (a÷d). The analysis results of the elements concentration in points: a – 1, b – 2, c – 3 and d – 4, correspondingly

Figure 7a presents the coat on cast steel GX6CrNiTi18-10 obtained in silumin AlSi5 and its compounding layers. The maps of distribution of: Al, Si, Cr and Re in this area are shown in Figure 7b.

a)



b)

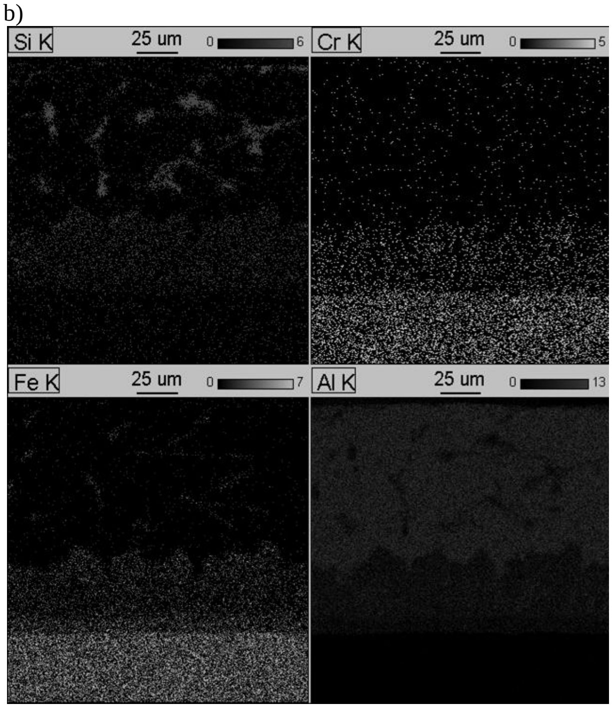


Fig. 7 (a, b). The coat made of silumin AlSi5 on cast steel GX39Cr13 and the map of distribution of elements: Al, Si, Fe and Cr (b)

It follows from the presented data that there is a high concentration of Al and Fe and the increased concentration of Cr and Si in layer “g_1”. In layer “g_2” there appears a high concentration of Al and in some areas there is a high concentration of Si and a small concentration of Fe.

Points 1÷4 of measuring of the elements concentration in the silumin coat on cast steel GX39Cr13 and the results of the analysis are presented in Figures 8 and 9 (a, b), correspondingly.

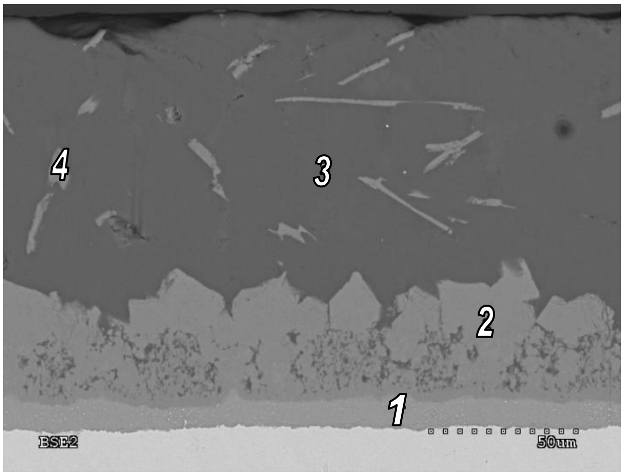


Fig. 8. The coat of silumin AlSi5 on cast steel GX39Cr13 with points 1÷4 to measure the elements concentration

a)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Si-K	0.0041	2.503	1.29	1.02	+/- 0.07
Cr-K	0.0519	0.997	3.53	5.18	+/- 0.19
Fe-K	0.3811	1.090	26.41	41.54	+/- 0.51
Al-K	0.2896	1.805	68.76	52.26	+/- 0.29
Total			100.00	100.00	

b)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Si-K	0.0292	2.527	8.47	7.39	+/- 0.20
Cr-K	0.0620	1.066	4.09	6.61	+/- 0.13
Fe-K	0.2188	1.120	14.12	24.51	+/- 0.44
Al-K	0.4062	1.514	73.33	61.49	+/- 0.32
Total			100.00	100.00	

c)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Si-K	0.0026	3.096	0.77	0.80	+/- 0.09
Cr-K	0.0005	1.172	0.03	0.05	+/- 0.07
Fe-K	0.0050	1.154	0.28	0.58	+/- 0.11
Al-K	0.9748	1.011	98.92	98.57	+/- 0.41
Total			100.00	100.00	

d)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Si-K	0.0645	2.414	17.44	15.56	+/- 0.24
Fe-K	0.2366	1.118	14.90	26.44	+/- 0.44
Al-K	0.3960	1.465	67.65	57.99	+/- 0.31
Total			100.00	100.00	

Fig. 9 (a÷d). The results of the analysis of the concentration of the elements in points: a – 1, b – 2, c – 3 and d – 4, correspondingly

The measuring points were located similar to those of the coat on cast steel GX6CrNiTi18-10. The obtained results of the measuring of the concentration of elements were also similar; however, in the coat on cast steel GX39Cr13 nickel does not appear contrary to the coat on cast steel GX6CrNiTi18-10.

4. Summary

A similar structure of the silumin coat on both tested cast steel grades allowed formulating a general structure of the coat on cast steel. A similar phase structure of the coat on cast steel presented in the introduction can also be mentioned.

Generalizing the presented data, it can be stated that the coat on alloy cast steel consists of three layers. The first two layers beginning from the steel ground "$g_{1'}$" and "$g_{1''}$" contain both compounding elements of cast steel and silumin. They make up the so called diffusion transitional layer "g_1" which joins cast steel with the external part of coat "g_2". Layer "g_1" consists of the basic phase of AlFe containing Si and compounding alloy additives of cast steel: Cr and Ni (GX6CrNiTi18-10) and Cr (GX39Cr13). In the next layer "$g_{1''}$" the AlFe phase appears containing Si and the main alloy additive of the cast steel. In both cases it was chromium. Layer "g_2" mainly consists of the compounding phases of silumin AlSi5, that is the initial phase α and the eclectic system $\alpha + \beta$. Also the free lamellar elongations of the inter-metallic phases appear: AlNiFeSi (GX6CrNiTi18-10) or $Al_9Fe_3Si_2$ (GX39Cr13).

5. Conclusions

It follows from the data presented in this work that:

- The dipped silumin coat on alloy cast steel consists of three layers of different phase composition.
- The first layer of the cast steel ground consists mainly of the AlFe phase including Si and compounding additives of the alloy cast steel, the second one consists of AlFe including Si and the main alloy additive of the cast steel, the third one, however, consists of the phases of silumin AlSi5 and the lamellar precipitations of the AlNiFeSi (GX6CrNiTi18-10) or $Al_9Fe_3Si_2$ (GX39Cr13) phase.
- Regarding the appearance of the diffusive transitional layer in the tested coats they can be used for layer casting of the *alloy cast steel – aluminum alloy* type.

Acknowledgements

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