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Alfinated coating structure on HS6-5-2 (SW7M) high speed steel

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Abstract

The paper presents the results of immersion alfinated coating structure in AlSi5 silumin on HS6-5-2 (SW7M) high speed steel. Alfinating bath temperature was 750 ± 5 ° C, time of sample immersion was τ = 180s. Thickness of obtained coating under specified conditions was g = 150µm. Manufactured coating consists of three layers of different construction phase. The first layer from the substrate „$g_{1'}$" constructed with a AlFe phase consist of alloy additives constituents of HS6-5-2 (SW7M) steel: W, Mo, V, Cr and Si. On it crystallizes the second layer „$g_{1''}$" of AlFeWMoCr intermetallic phases also containing Si and small amount of V. Last, the outer layer „g_2" of the coating is composed with silumin including AlFeWMoCrVSi intermetallic phases. Within all layers of the coating occurs carbides. Penetration of carbides to individual coating layers is mainly due to steel surface partial melting and crystallizing layers „$g_{1'}$" and „$g_{1''}$" by alfinating liquid and shifting into her of carbides as well as partial carbides rejection by crystallization front of intermetallic phases occurs in coating.

Keywords: Innovative cast technologies, Alfinating, High speed steel, Silumin, Carbides

1. Introduction

Theoretical basis of alfinating process is precisely decribed in work [1].

The paper [2] shows a diagram of alfinated coating construction, deposited on alloy steels, elaborated on a base of coating extracted from AlSi5 silumin researches and deposited on steels: acid resistant X6CrNiTi18-10 (1H18N9T) and high speed HS18-0-1 (SW18) steels. From the presented data results that coating obtained on alloy steels consists of three layers of different construction phase. A scheme of alfinated coating with the thickness of „g" with marked constituent layers is presented in Figure 1.

The first layer from the substrate „$g_{1'}$" is constructed with a AlFe phase consist of steel constituents additives. On it crystallizes the second layer „$g_{1''}$" composed with AlFe phase consist of main alloy additive of steel Cr and W in X6CrNiTi18-10 and HS18-0-1 steels respectively. Layers „$g_{1'}$" and „$g_{1''}$" create, so called, diffusion transient layer „g_1". Within the whole thickness of „g_1" layer, except from mentioned above elements, occurs also silicon. In the outer layer with the thickness of „g_2" occurs component phases of hypo-eutectic silumin: α, α+β eutectic and precipitations of intermetallic phases: AlFeNi and AlFeW on X6CrNiTi18-10 and HS18-0-1steels respectively. On examinated types of alloy steels obtained different thickness of coating. For the silumin temperature t = 750°C and sample immersion time - τ = 180s - in bath on X6CrNiTi18-10 steel was about 50µm. On HS18-0-1 steel coating thickness was four times higher g ≈ 200µm.

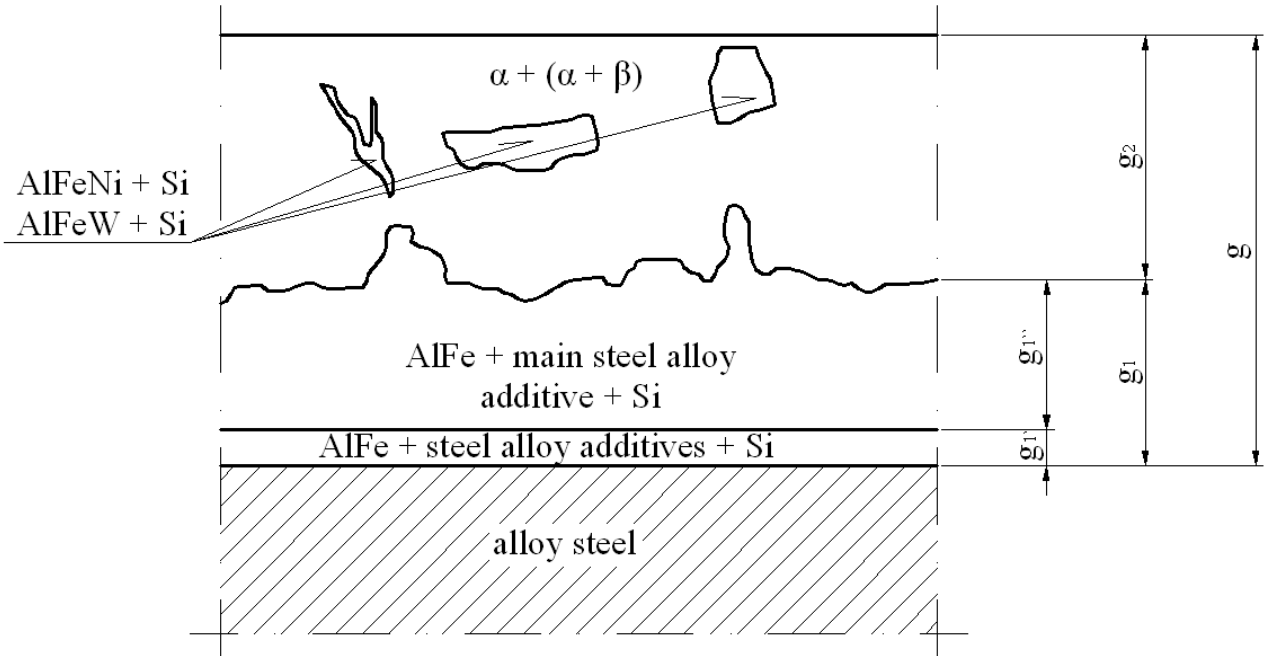


Fig. 1. General diagram of the alfinate coating on alloy steel

The aim of this work is present the structure of alfinating coating deposited on high speed steel - HS6-5-2 (SW7M) – including the occurance of carbides.

2. Research methodology

High speed HS6-5-2 steel was predicted for researches. Its chemical composition and microstructure is shown in table 1 and Figure 2 respectively.

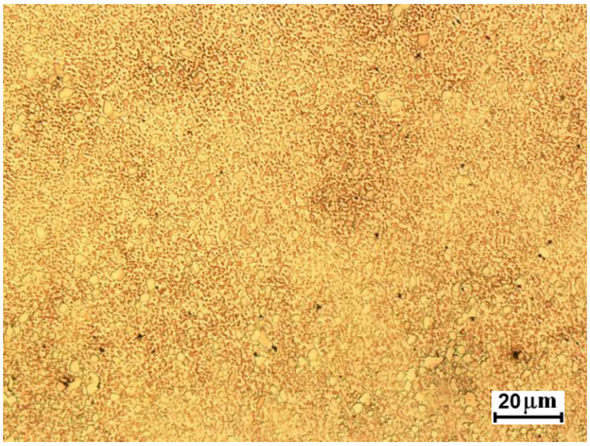
Table 1.
High Speed steel - HS6-5-2 (SW7M) – chemical composition

Average content, %										
C	Si	Ni	Cr	Mn	Ti	Fe	W	Mo	V	Cu
0,91	0,27	0,15	4,11	0,36	0,008	79,7	6,75	5,40	1,76	0,11

Investigated steel – HS6-5-2 in annealed state posses ferritic microstructure with carbides: $M_{23}C_6$, MC, M_2C and M_6C.

From the examined material performed samples (roller shape) with diameter of d = 10mm and length l = 70mm. Next, prepared on them immersion coatings in AlSi5 silumin. Silumin bath temperature was t = 750±5°C, sample immersion time τ = 180s. Before placing in a bath, the samples were mechanical clean off, chemical degrease and undergo of preheating up to 50°C temperature.

Metallographic researches of investigated steel types, coatings and compound castings carried out on optical microscope Nikon MA200 Eclipse equipped with digital camera.



Microstructure: ferrite, carbides

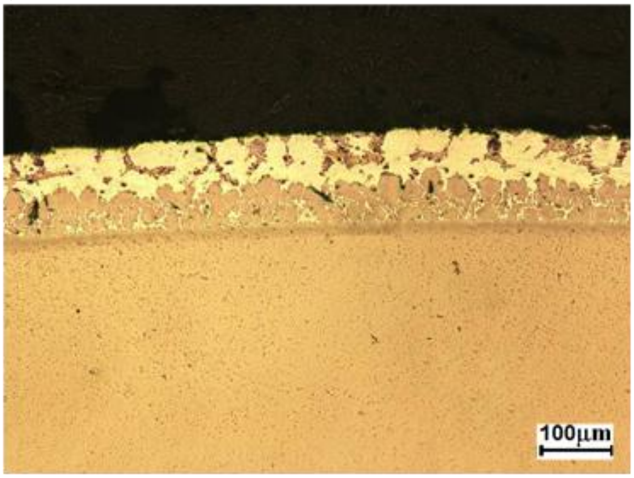
Fig. 2. Microstructure of high Speer steel - HS6-5-2

Point microanalysis of concentration and elements distribution maps executed with use of EDS Pioneer detector and VENTAGE software of NORAN Co.

3. Results

An example of silumin AlSi5 coating on HS6-5-2 steel is illustrated in Figure 3(a÷b).

a)



b)

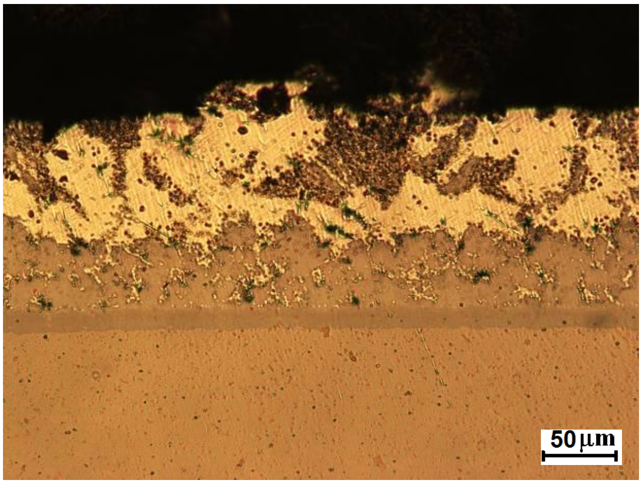


Fig. 3 (a, b). Coating alfinated in AlSi5 silumin on high speed steel HS6-5-2

From the data result three-layer construction of alfinated coating deposited on investigated type of steel. Thicknesses of: coating „g”, interlayer „g_1”and thin layer crystallized directly on steel „$g_{1'}$” are presented in table 2.

Table 2.
Thickness of coating on HS6-5-2 steel and its compound layers

Thickness, µm		
„$g_{1'}$”	„g_1”	„g”
7,0	72,5	150,0

From the presented above measurements results different, however, near value of coating thickness g = 150µm deposited on HS6-5-2 steel compared with presented in work [2] coating on HS18-0-1 steel g = 200µm. Both presented steels has ferritic with carbides microstructure. Thickness of coating for X6CrNiTi18-10 steel with austenitic plus carbides microstructure was g = 50µm [2]. So obtained 3÷4 times greater thickness of coating on investigated ferritic with carbides steels in comparison with steel with austenitic plus carbides microstructure.

To define layers structure of this coating manufactured on HS6-5-2 steel execute maps of element distribution of silumin and determined its concentration in selected points of coating.

Figure 4 illustrates coating on HS6-5-2 steel obtained in silumin AlSi5 with marked its component layers. Distribution maps: Al, Si, Cr, Fe and Ni within this area is pictured in Figure 4b.

In „g_1” layer is present high concentration of Al, Fe, and Si and increased of Cr and Mo. Received results certify about presence of AlFe phase in interlayer and containing small amount of: Si, Cr and Mo. Within this layer area occurs also carbides (Fig. 4a).

In general, in high speed steel occurs carbides: : M_3C, $M_{23}C_6$, MC, M_2C i M_6C [3], however in annealed state in equilibrium state with ferrite are only mentioned below carbides: $M_{23}C_6$, MC, M_2C and M_6C. In alloy steels with high contents of carbides creative elements, for example in high speed steels carbides are present as composite form. Composition of such carbides depends on kind and content of carbides creative elements and carbon in steel. In investigated steel (HS6-5-2) carbides of MC, M_2C i M_6C type assume respectively shape of: $(Fe_{0,06}W_{0,1}Mo_{0,15}V_{0,65}Cr_{0,07})C_{0,89}$; $(Fe_{0,27}W_{0,44}Mo_{0,55}V_{0,43}\ Cr_{0,29})C$ and $(Fe_{2,52}W_{0,76}Mo_{0,79}V_{0,26}Cr_{0,29})C$ [3]. Chemical composition of presented carbides is shown in table 3.

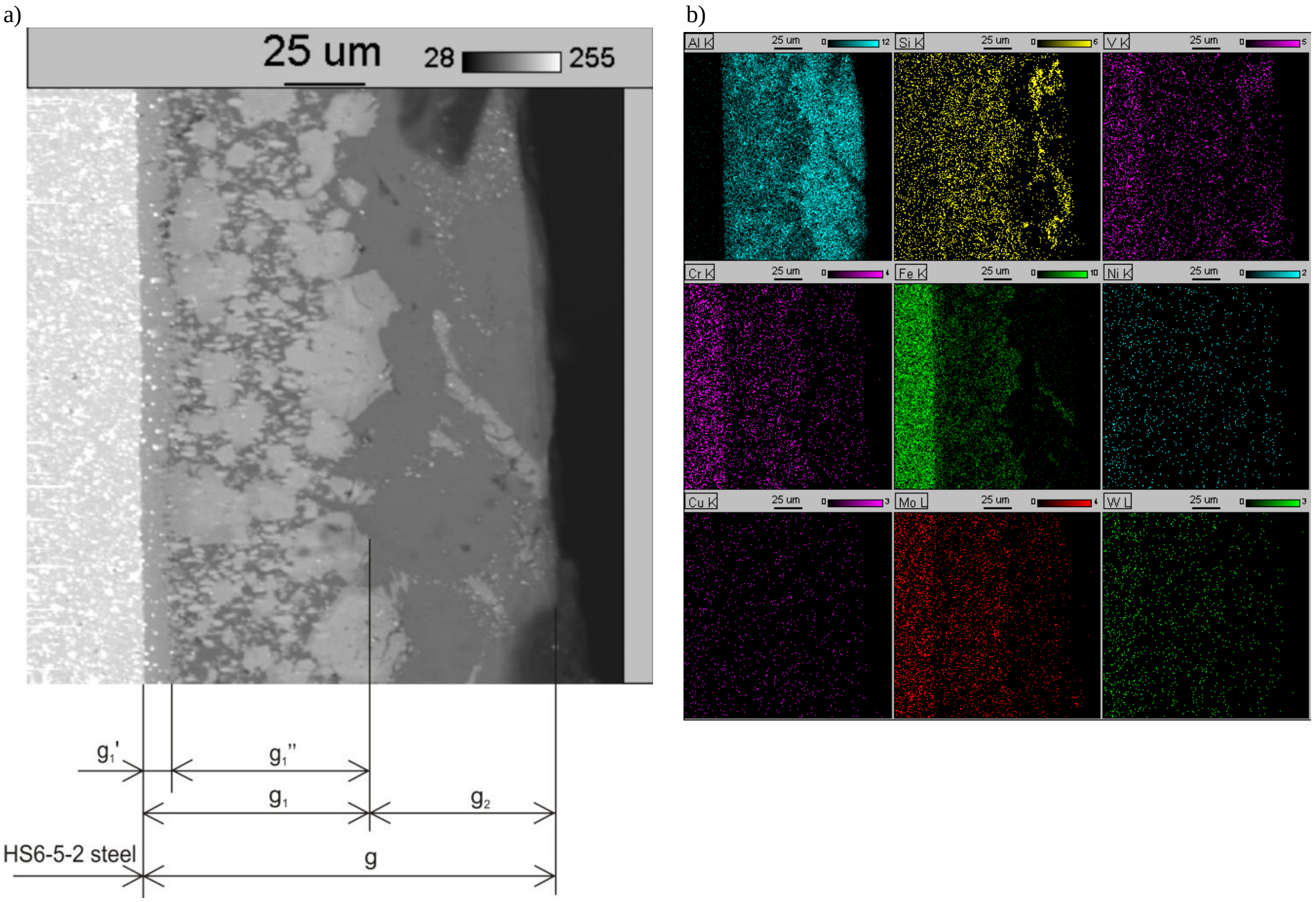


Fig. 4 (a, b). Coating obtained from AlSi5 on HS6-5-2 (a) and its element distribution maps: Al, Si, V, Cr, Fe, Ni, Cu, Mo and W (b)

Table 3.
Chemical composition of carbides: MC, M_2C and M_6C in HS6-5-2 steel [3]

Carbide type	Structural formula	Chemical composition, %					
		C	Fe	W	Mo	V	Cr
MC	$(Fe_{0,06}W_{0,1}Mo_{0,15}V_{0,66}Cr_{0,07})C_{0,89}$	13,65	4,03	23,6	14,1	43,57	4,63
M_2C	$(Fe_{0,27}W_{0,44}Mo_{0,55}V_{0,43}Cr_{0,29})C$	6,1	7,95	41,8	27,8	11,7	7,8
M_6C	$(Fe_{2,52}W_{0,76}Mo_{0,79}V_{0,26}Cr_{0,29})C$	3,01	35,3	35,3	19,0	3,3	3,8

$(Fe, W, Mo, V, Cr)_{23}C_6$ carbides, occurs in HS6-5-2 are characterized by high content of Fe and Cr and increased of W and Mo [4]. Percent fraction of presented carbides in microstructure of investigated high speed steel in annealed steel is: M_6C (16%), $M_{23}C_6$ (9%) and MC (3%) [4]. Other area microstructure complete alloy ferrite. Such ferrite in high speed steels in annealed state contain: 1,0÷1,5%W; less than 1,0%Mo; 0,1÷0,4%V and 2,0÷3,5%Cr [4]. An approximate temperature on intensive dissolving of presented carbides in austenite is: 900÷1000°C ($M_{23}C_6$), over 1000°C (M_6C) and over 1100°C (MC). Penetration process of carbides to the „g_1" layer probably proceed in described below way. Surface layer of steel sample during alfinating process undergo of intensive dissolving by aluminum which is present in silumin bath. It is supposed that carbides possess relatively high melting point, much more higher than temperature of alfinating bath, do not undergo of dissolve. They are transfered into silumin direction in result of liquid convection movements nearby surface of alfinating element. The movement of carbide transfer is stopped by crystallization of coating interlayer. In whole „g_2" outer layer (topcoat) occurs Al and Si and additionally Fe as bright lamellar precipitations. From described data results that „g_2" layer is construct mainly with hypo-eutectic silumin phases as well as lamellar precipitations of AlFeSi phase. In this layer occurs also areas with high concentration of Al and Si and increased in specified points of Cr, V, Mo and W. It can be carbides in matrix of silumin phases. Presence of carbides in „g_2" outer layer can be caused by partial dissolving of crystallize „g_1" layer containing carbides and transfer of cluster of AlFeSiCrMo phase to the alfinating liquid. Within „g_2" outer layer creates an areas with increased concentration of Al, Fe, Si, Cr and Mo containing carbides too. It follows there secondary crystallization of intermetallic phases containing atoms of Al, Fe, Si, Cr and Mo. Crystallization front of this phases probably transfer part of carbides to the silumin. Silumin crystallization process in the area of top coat, proceeded after removing sample from the bath, causes storage of carbides dispersed in small distance from lamellar precipitations of intermetallic phases.

Presented maps do not enable to differentiate and define of „$g_{1'}$" and „$g_{1''}$" structure included in „g_1"layer. Different structure of this layers pointed out an analysis of element concentration in points. Lay-out of 1÷5 points in coating on HS6-5-2 steel is shown in Figure 5, whereas the elements concentration in this points in Figure 6 (a÷e).

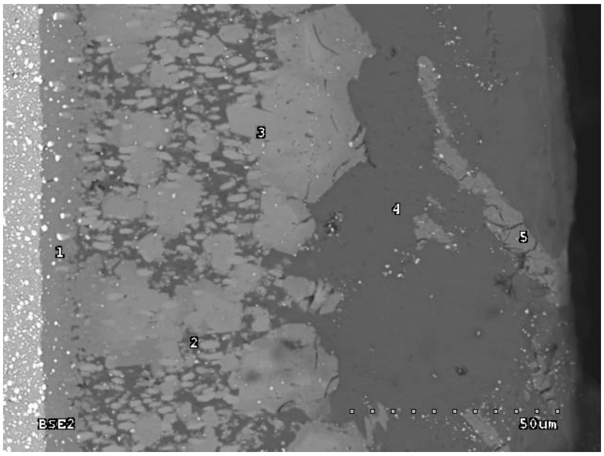


Fig. 5. AlSi5 silumin coating on HS6-5-2 steel with located points 1÷5 of elements concentration measurements

a)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.3752	1.429	69.15	53.63	+/- 0.45
Si-K	0.0275	1.907	6.50	5.25	+/- 0.16
Fe-K	0.3180	1.093	21.64	34.74	+/- 0.63
Ni-K	0.0018	1.108	0.12	0.20	+/- 0.22
Mn-K	0.0025	1.114	0.17	0.28	+/- 0.16
W -M	0.0133	2.046	0.52	2.73	+/- 0.39
Mo-L	0.0037	1.583	0.21	0.58	+/- 0.16
Cr-K	0.0177	1.031	1.22	1.83	+/- 0.22
V -K	0.0033	1.083	0.25	0.36	+/- 0.09
Cu-K	0.0035	1.161	0.22	0.41	+/- 0.31
Total			100.00	100.00	

b)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.4173	1.279	72.68	53.35	+/- 0.43
Si-K	0.0341	1.773	7.91	6.04	+/- 0.20
Fe-K	0.1847	1.066	12.95	19.68	+/- 0.52
Ni-K	0.0021	1.053	0.14	0.22	+/- 0.22
Mn-K	0.0029	1.093	0.21	0.31	+/- 0.15
W -M	0.0650	1.906	2.48	12.40	+/- 0.48
Mo-L	0.0379	1.633	2.37	6.18	+/- 0.24
Cr-K	0.0137	1.055	1.02	1.45	+/- 0.12
V -K	0.0021	1.101	0.17	0.23	+/- 0.09
Cu-K	0.0011	1.118	0.07	0.13	+/- 0.31
Total			100.00	100.00	

c)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.3854	1.342	70.40	51.71	+/- 0.43
Si-K	0.0286	1.799	6.73	5.15	+/- 0.18
Fe-K	0.2389	1.072	16.83	25.59	+/- 0.58
Mn-K	0.0021	1.096	0.15	0.23	+/- 0.17
W -M	0.0494	1.937	1.91	9.56	+/- 0.45
Mo-L	0.0290	1.604	1.78	4.66	+/- 0.23
Cr-K	0.0265	1.044	1.96	2.77	+/- 0.14
V -K	0.0025	1.091	0.20	0.27	+/- 0.10
Cu-K	0.0005	1.129	0.03	0.06	+/- 0.31
Total			100.00	100.00	

d)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.9874	1.001	98.88	98.84	+/- 0.74
Si-K	0.0050	2.340	1.12	1.16	+/- 0.18
Total			100.00	100.00	

e)

Quantitative Analysis

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.3393	1.415	62.10	48.02	+/- 0.43
Si-K	0.0604	1.817	13.63	10.97	+/- 0.22
Fe-K	0.3020	1.095	20.66	33.08	+/- 0.60
Ni-K	0.0041	1.107	0.27	0.45	+/- 0.22
W -M	0.0146	1.952	0.54	2.86	+/- 0.88
Mo-L	0.0071	1.589	0.41	1.13	+/- 0.16
Cr-K	0.0035	1.038	0.25	0.37	+/- 0.11
V -K	0.0287	1.090	2.14	3.12	+/- 0.12
Total			100.00	100.00	

Fig. 6 (a÷e). Results of element concentration measurement in coating on HS6-5-2 steel, accomplished respectively in points: 1 – a, 2 – b, 3 – c, 4 – d, 5 – e

From the presented data results high concentration of Al = 53,6% and Fe = 34,7% and increased of Si = 5,2% in „$g_{1'}$" layer (point 1). The most important alloy additives of HS6-5-2 steel in this layer occurs in the following quantity: W = 2,7%; Cr = 1,8%; Mo = 0,6% i V = 0,4%. Within the „$g_{1''}$" layer located two measurement points 2 and 3. In point 2 occurs high concentration of Al (53,4%), Fe (22,6%) and W (12,4%) and increased of Si (6,4%), Mo (6,2%) and Cr (1,4%) as well as small amount of V (0,2%). Composition in point 3 is following: Al = 51,7%; Fe = 25,6%; W = 9,6%; Si = 5,2%; Mo = 4,7%; Cr = 2,8% and V =

0,3%. Relatively high concentration of W and Mo (point 2 and 3) simultaneously by low of Cr and V could be caused by electron beam of EDS analyzer of M_6C carbide. An outer „g_2" layer is compound with hypo-eutectic silumin phases (point 4) with unbounded precipitations of intermetallic phases. The phase with marked point no.5 contain: 48,0%Al; 33,1%Fe; 11,0%Si; 3,1%V; 2,9%W; 1,1%Mo and Cr = 0,4%. Relatively high concentration of V in this point indicate on occurrence, round the analyzing area, of MC carbide. In different coating layers occurs also small amount (up to 0,45%) of Mn, Cu and Ni. From the displayed data results that „g_1'" layer is construct with AlFe phase containing small amount, however significant, quantity alloy additives of HS6-5-2 (W, Cr, Mo and V) and Si. The second layer „g_1''", from the substrate side is AlFeWMoCrSi phase. Because of close contents of W(6,75%), Mo(5,40%) and Cr(4,11%) in examined HS6-5-2 steel, those chemical elements can be assume as main alloy additives. In the outer „g_2" layer occurs hypo-eutectic silumin phases and unbounded precipitations of compound AlFeSiVW-MoCr intermetallic phases. Moreover in all compound layers of describing coating occurs carbides. Therefore, structure of alfinated coating on HS6-5-2 (Fig. 1) steel can be supplemented by occurring carbides. So reconstruct structure of alfinated coating in AlSi5 silumin on HS6-5-2 steel is shown in Figure 7.

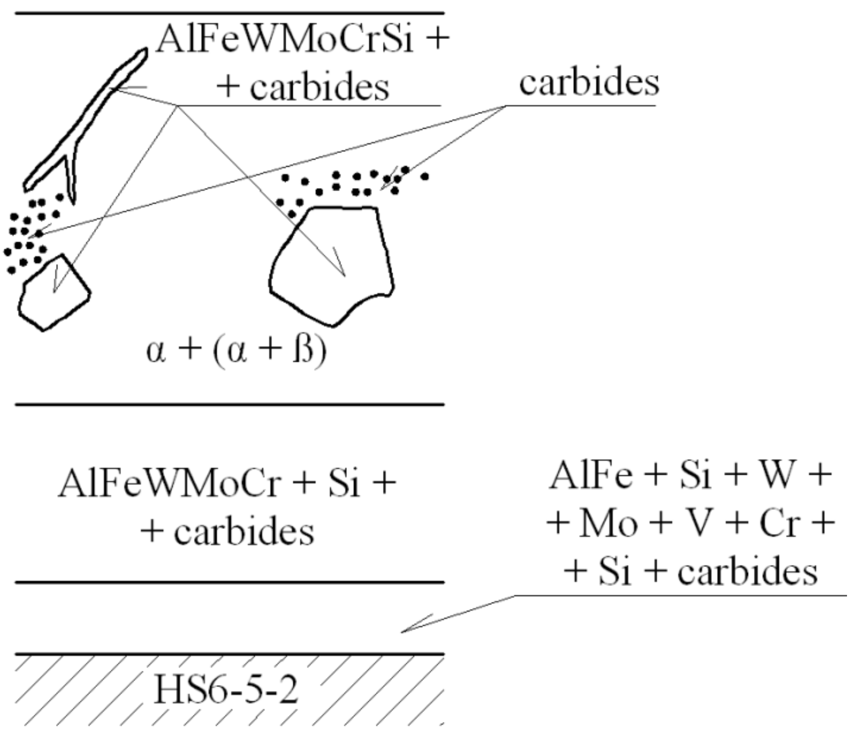


Fig. 7. Structure of alfinated coating in AlSi5 silumin on investigated steel - HS6-5-2

Scheme of hypothetical mechanism of coating creation on HS6-5-2 steel is illustrated in Figure 8(a÷f). Preliminary warming up a sample up to t_{wp} = 50°C is placed in silumin bath with temperature t_k = 750°C (Fig. 8a). During immersion time (τ_1) of the sample occurs the local temperature decrease of the bath near them and crystallization over the surface of the sample a small amount of silumin layer. During further sample heating, this layer undergo of rapidly molten. At the same time there is heat of sample in the direction of the axis and temperature compensation in the entire cross-section. The next step is to increase the temperature of the sample up to contact temperature ,,t_s''. It is the temperature on surface of an ideal contact of two substance in which there is equality of temperature and heat flux. Starting from temperature „t_s" follows simultaneous heating of sample surface layer and rounded silumin (Fig. 8b). The increase of temperature in this area is caused by a temperature gradient ($t_s < t_k$) and convective movement of liquid metal which transfers heat from further area of silumin.

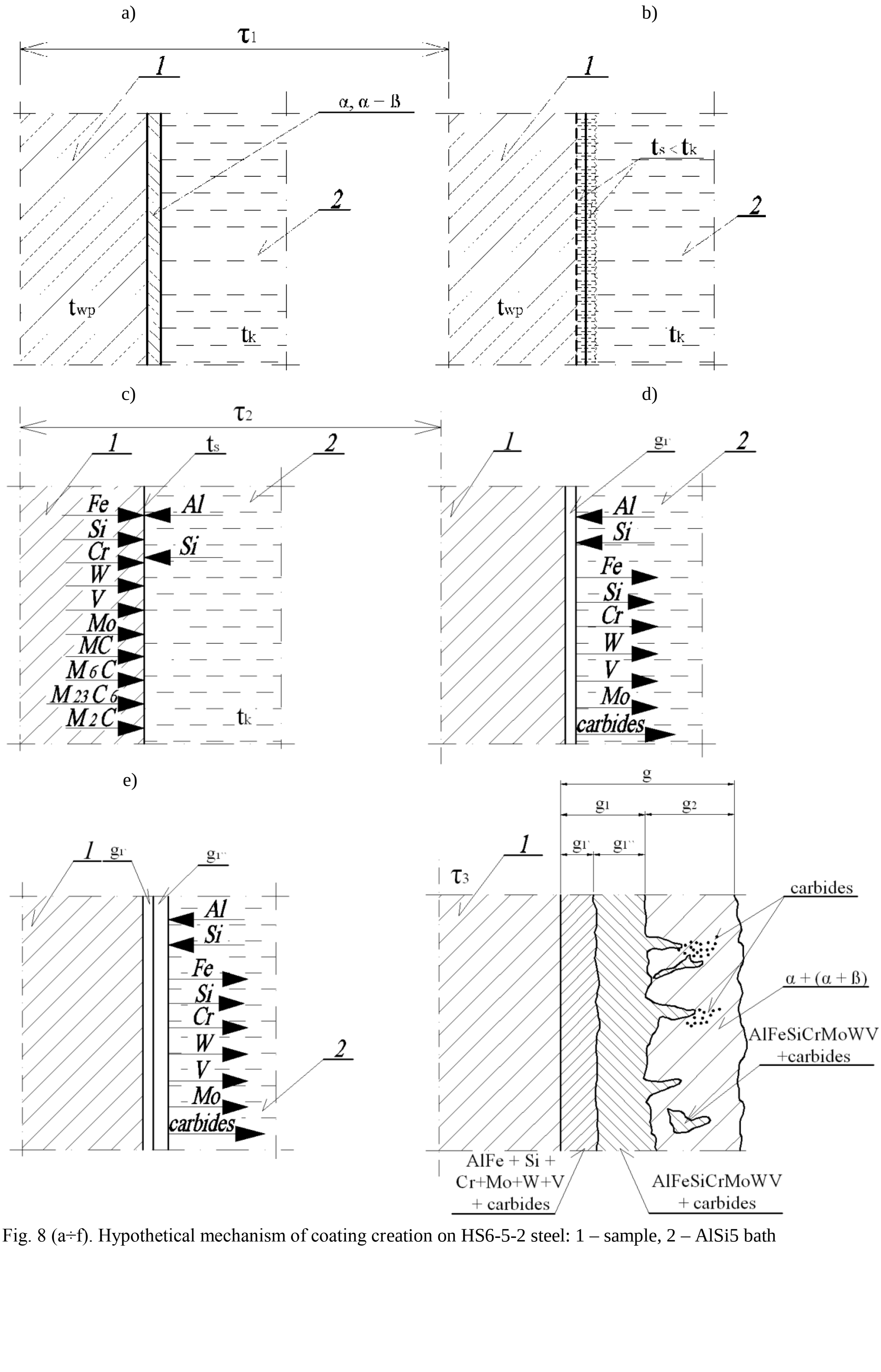


Fig. 8 (a÷f). Hypothetical mechanism of coating creation on HS6-5-2 steel: 1 – sample, 2 – AlSi5 bath

Probably during the warming-up of the sample up to the contact temperature dissolution process of surface layer proceed caused by silumin whose intensity increases with increasing bath temperature. When sample achieve a contact temperature begins second stage proceed during τ_2 time (Fig. 8c). Sample surface is wetted by liquid silumin and viscosity process proceed. The intensity of sample surface dissolution by silumin is very intensive and Si and Al from atom reaction diffusion is following from bath to the sample and Fe, Si, W, V, Cr i Mo from sample to the bath. As a result of sample dissolving by alfinating bath proceed the transfer of carbides from steel to surface. Also occurs at the sample surface a liquid with high concentration of Al and Fe and also containing significant amount of Si from silumin bath as well as small amount of Cr, W, Mo, V from dissolved alloy ferrite present in HS6-5-2 steel. As a result of liquid over-cooling in terms of liquidus curve proceed crystallization process over sample surface „$g_{1'}$" construct with AlFe phase containing Si, Cr, W, V and Mo (Fig. 8d). Crystallization front of this layer push Cr, W, V, Mo atoms and partly carbides into liquid. A number of carbides remain also in „$g_{1'}$" layer. Crystallizing „$g_{1'}$" layer is partly dissolving by liquid silumin with the result that near its surface establish convenient conditions to peritectic reaction proceed by which „$g_{1''}$" layer crystallize construct with AlFeSiVWMoCr phase (Fig. 8e). This phase posses higher concentration of Al and Si and decreased Fe in compare with phase present in „$g_{1'}$" layer. There also occurs carbides. As a result of previously described phenomena: dissolving „$g_{1''}$" layer by liquid silumin and transfer (pushing) phases concerning in it proceed secondary crystallization of lamellar precipitations of AlFeSiVWMoCr phase within the „g_2"layer. Those precipitations can contain carbides. The complete crystallization of the „g_2" outer layer follows during τ_3 time after removing of the sample from the bath (Fig. 8f). Crystallize than a silumin of alfinating bath. In described silumin apart from lamellar AlFeSiVWMoCr phase precipitations there are areas with dispersed carbides, push into silumin by crystallization front of lamellar phases.

Presented alfinating technology of high speed steel enable to obtain in coating carbides, what creates new opportunities to obtain selected properties, especially coating wear-resistant coating.

4. Conclusions

Due to the presented results following conclusions:

- Alfinated coating deposited on HS6-5-2 steel is construct with 3 layers with different phase structure,
- First layer, from the steel substrate is mainly build with AlFe phase containing Cr, W, Mo, V and Si. Second layer is construct with AlFeSiWMoCrV phase including Si and the third layer with AlSi5 silumin phases as well as lamellar AlFeSiWMoCrV phase precipitations containing Si,
- Carbides are contained within all coating layers present in HS6-5-2 steel,
- Carbides occurance in individual coating layers is mainly caused by dissolving by alfinated liquid of sample surface and crystallizing on its„$g_{1'}$" i „$g_{1''}$" layers and carbides elevated from those areas into alfinating liquid.

Acknowledgements

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