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The Silumin Coat Structure on Alloy Ductile Iron

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Abstract

The work presents the research results of the silumin coat structure applied on the carbidic alloy ductile iron with the metal matrix: pearlitic, bainitic and martensitic. The coats were made in the AlSi5 silumin bath at the temperature $t_k = 750\pm5°C$. The holding time of cast iron element in the bath was $\tau = 180s$. Irrespective of the kind of tested ductile iron the obtained coat consisted of three layers with a different phase composition. The first layer from the cast iron ground “$g_{1'}$” is built from Fe_4CSi carbide which contains selected alloy additives of the cast iron. On it the second layer “$g_{1''}$” crystallizes. It consists of the AlFeSi inter-metallic phase which can appear in its pure form or contain a small quantity of the alloy additives of the cast iron. The last external part of the layer “g_2” mainly consists of the hypo-eutectic phases of silumin. The AlFeSi inter-metallic phases in the form of free precipitations with a lamellar or faceted morphology can also appear there. These phases also can contain a small quantity of the alloy additives of the cast iron. More than that, in all the layers of the coat there are graphite precipitations. The phenomenon of graphite movement to the coat is caused by intensive dissolving of the cast iron element surface by the aluminum of the silumin bath.

Keywords: Innovative casting technologies, Dip-coats, Alloy ductile iron, Silumin

1. Introduction

The works [1÷3] present the structure of the silumin dip-coat on steels and alloy steels. The following steel grades were used for the research: X6CrNiTi18-10 acid-resisting steel (1H18N9T), HS18-0-1 (SW18) rapid steel and HS6-5-2 (SW7M) and GX6CrNiTi18-10 (LH18N9T) cast steels and GX39Cr13 (LH14). On the tested alloy steel grades a silumin dip-coat was applied consisting of three layers with a different phase structure. The scheme of the silumin coat with the thickness “g” and the marked composing layers is presented in Figure 1.

The first layer from the ground with the thickness “$g_{1'}$” consists of the AlFe phase containing the component additives of the steel or cast steel. On it, the layer “$g_{1''}$” crystallizes, it consists of the AlFe phase containing the main alloy additive of the steel or cast steel, that is Cr (X6CrNiTi18-10, GX6CrNiTi18-10, GX39Cr13) and W (HS18-0-1) and Mo and W on HS6-5-2. The layers “$g_{1'}$” and “$g_{1''}$” form the so called integrated diffusion transitive layer “g_1”. On the whole thickness of the layer “g_1”, apart from the previously mentioned element, silicon appears. In the external layer with the thickness “g_2” there are phases of hypo-eutectic silumin: α (Al) and eutectic α+β (Al+Si) as well as free precipitations of the inter-metallic phases marked as AlFeSiX. This marking informs that apart from Al, Fe and Si the phases may also contain a free configuration of the remaining composing elements of the iron alloy and silumin used for making the coat. In all the layers of the rapid steels there are also carbides, typical for these steels. These carbides are as follows: $M_{23}C_6$, MC, M_2C and M_6C [4, 5]. On the tested steel grades and alloy cast steels the obtained coats were of a different thickness.

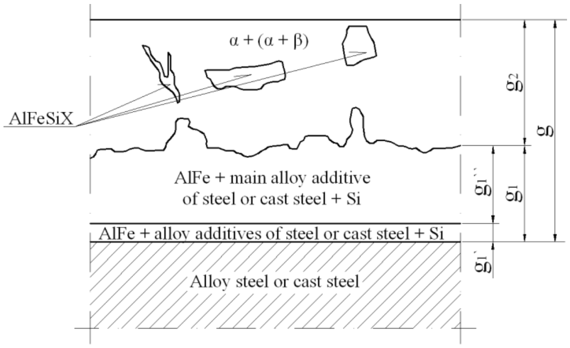


Fig. 1. General scheme of the silumin coat structure on the steels and alloy cast steels

For the temperature of silumin, t = 750°C, and the time of dipping of the element from the alloy iron in the bath, τ = 180s, a relatively small thickness of the coat was obtained on the alloys with the austenitic microstructure g = 50÷100μm, however, on the alloys with the ferritic microstructure the thickness of the coat was bigger, g = 130÷200μm.

Regarding a much smaller quantity of the alloy additives in the cast iron in comparison to the presented grades of the steel and cast steel and the appearance of graphite precipitations in the cast iron it should be supposed that the coat obtained on the cast steel will be of a different structure than that on the presented steel and cast steel.

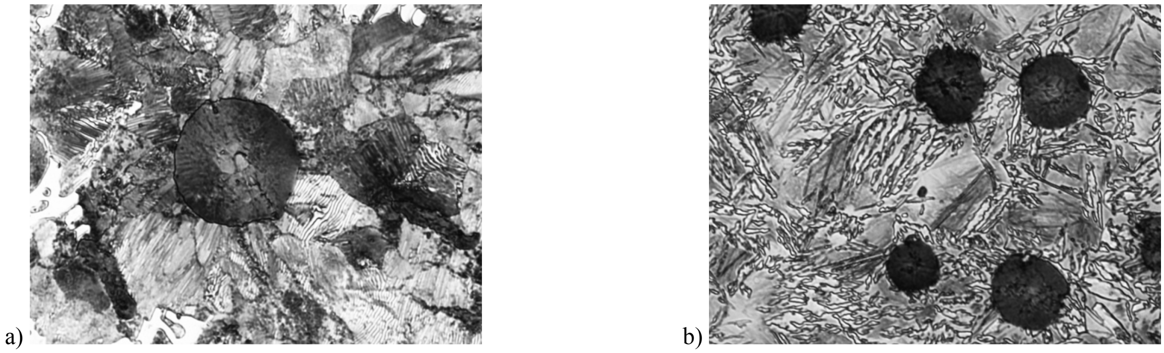
The aim of the current work is to present the structure of the AlSi5 silumin coat on the cast irons.

2. Methodology of the research

For the research three kinds of the carbidic alloy ductile iron with different metal base were chosen: pearlitic, bainitic and martensitic. Their chemical composition and microstructure is presented in Table 1 and in the Figure 2 (a÷c).

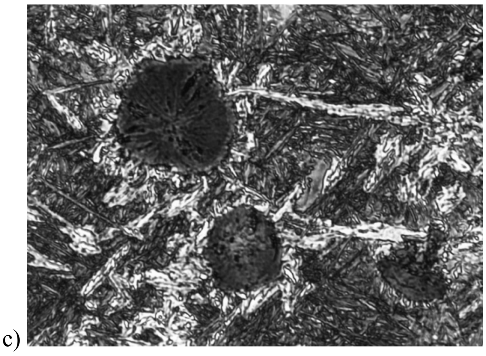
Table 1.
Chemical composition of the tested kinds of the carbidic alloy ductile iron

Kind of the metal matrix	Average content, %									
	C	Si	Mn	P	S	Cr	Mo	Ni	Mg	Cu
Pearlitic	3.81	2.33	0.53	0.05	0.02	1.16	0.02	0.01	0.05	1.33
Bainitic	3.76	2.25	0.21	0.03	0.02	0.17	1.02	1.06	0.05	-
Martensitic	3.70	2.52	0.24	0.04	0.02	0.42	1.36	1.81	0.05	0.01



Microstructure: nodular graphite, pearlite, carbides, non-metallic inclusions

Microstructure: nodular graphite, upper and lower bainite, carbides, non-metallic inclusions



Microstructure: nodular graphite, martensite, carbides, non-metallic inclusions

Fig. 2 (a÷c). Microstructure of the tested kinds of carbidic alloy ductile iron with a different metal matrix: a – pearlitic, b – bainitic i c – martensitic

The rods with the diameter d=10mm and length l = 70mm were made from the tested kinds of ductile iron and then a coat was made by dipping them into the AlSi5 silumin bath. The silumin contained 4.69%Si; 0.46%Fe and Cu, Mg, Cr and Ni in the quantity of 0.10% of each mentioned element. The silumin bath had the temperature, $t_k = 750 \pm 5°C$, and the time of dipping of the cast steel specimen was $\tau = 180s$. Before dipping in the bath the steel rods were mechanically cleared, chemically degreased and pre-heated to the temperature of 50°C.

The micrographic tests of the cast steel and the coats were carried out on the MA200 Eclipse optic microscope by Nikon equipped with a digital camera.

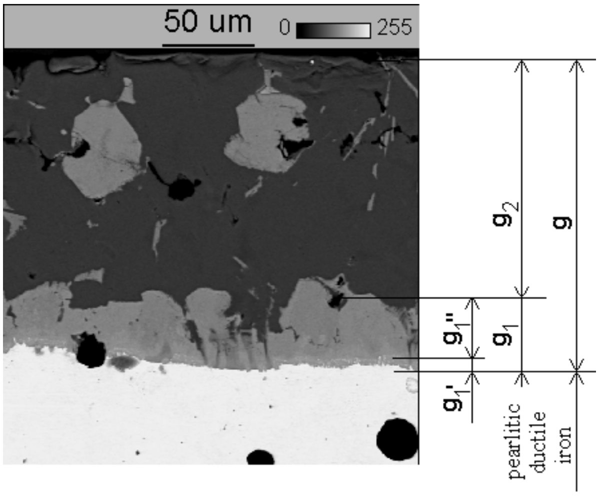
The point microanalysis of the concentration and the element distribution maps were made using the EDS detector by Pioneer and the VENTAGE software by NORAN.

3. The results of the research

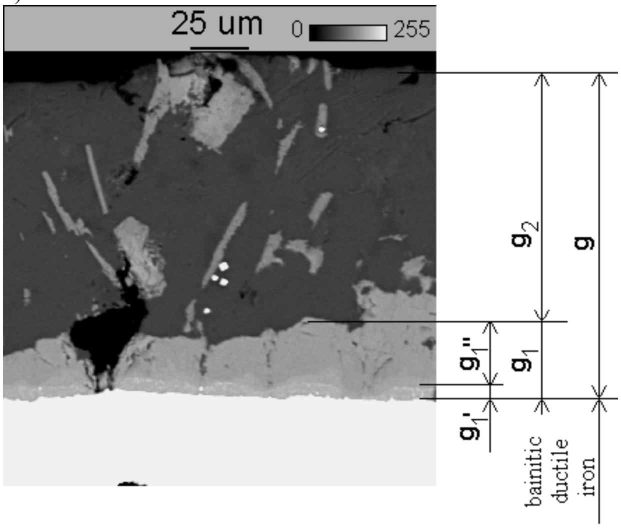
The representative coats from AlSi5 silumin on the tested kinds of ductile iron with the marked composing layers are presented in Figure 3 (a÷c).

It follows from the presented data that there is a three-layer silumin coat irrespective of the kind of ductile cast iron. A similar layer structure of the coat was obtained on the cast steels and steels. Thus, in the coat on the ductile iron there is a transition layer “g_1” and external layer “g_2”, however, in the transition layer there are two layers with the thickness “$g_{1'}$” and “$g_{1''}$” correspondingly. Different values of the total thickness of the coat “g” on the tested kinds of ductile iron were obtained, which is shown in Figure 4. This Figure also presents the thickness of the transition layer “g_1” in the tested coats. It follows from the presented data that the thickest coat was obtained on the pearlitic cast iron ($g \approx 170\mu m$); thinner on the bainitic ($g \approx 135\mu m$), and the thinnest on martensitic ($g \approx 120\mu m$). The differences in the thickness of the transitional layer “g_1” were definitely smaller. For all tested kinds of cast iron the thickness is within the range $g_1 = 22 \div 25\mu m$. The layer “$g_{1'}$” in the thinnest layer of the coat and on all kinds of tested cast irons it is within the range 3÷5µm.

a)



b)



c)

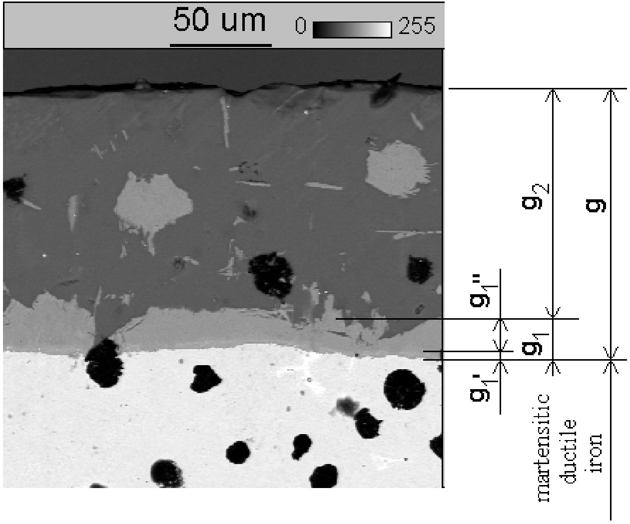


Fig. 3 (a÷c). Representative coats made in AlSi5 silumin on ductile iron correspondingy: a – pearlitic, b – bainitic and c – martensitic

An important component differentiating the coat made on the cast iron from the coat on the steel and cast steel is the appearance of graphite precipitations in all the composing layers. It is caused by strong dissolving of the cast iron element by the silumin bath. The graphite as a phase with high thermal resistance is not subjected to dissolving by the silumin bath. However, the external layer of the metal matrix of the cast iron is subjected to dissolving, that is why precipitations of the graphite intervene into certain layers of the coat.

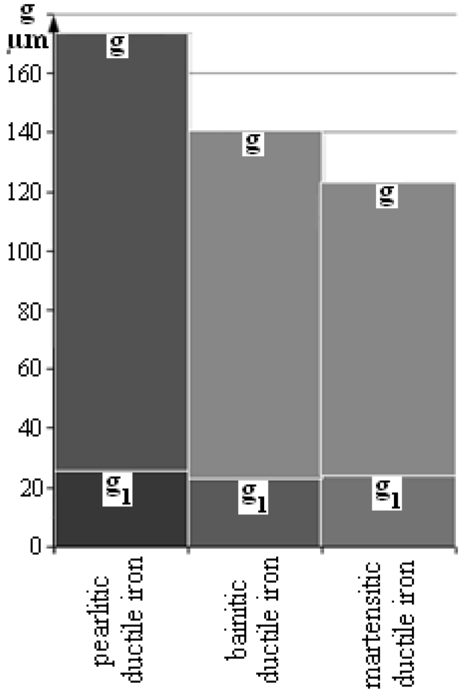


Fig. 4. Total thickness of the coat "g" and its transitional layers "g_1" on the tested kinds of cast irons

In order to determine the structure of particular layers of the coat on the tested alloy cast irons the distribution maps of the composing elements of the cast iron and silumin were made for the tested coats. Figure 5 presents a sample distribution map: Al, Si, Cr, Fe, Cu and C in the coat on the pearlitic cast iron (zone from Fig. 3a).

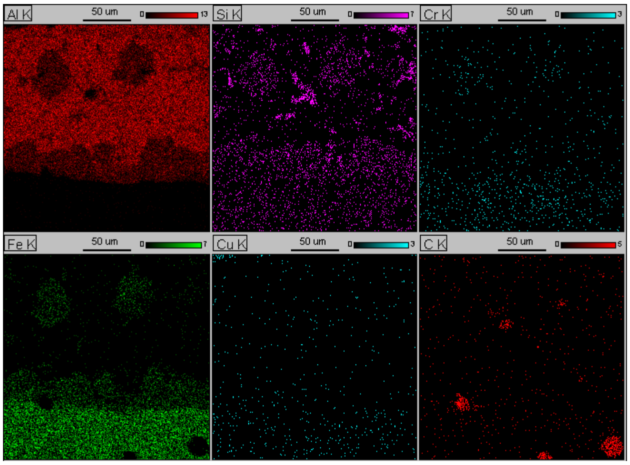


Fig. 5. Distribution map: Al, Si, Cr, Fe, Cu and C in the coat on pearlitic ductile iron (zone from Fig. 3a)

It follows from the presented data that there is a high concentration of aluminum and iron in the transition layer "g_1". There is also an increased concentration of silicon. Practically in the whole domain of the "g_2" layer there is a high or increased concentration of Al, however, silicon and iron appear in high concentrations only in certain places. These places are probably the domains with appearance of eutectic precipitations of the β phase (Si) and AlFeSi inter-metallic phases (high concentration of Al, Fe and Si). The pearlitic cast iron alloy additives, i.e. Cr and Cu penetrate the coat to an insignificant degree. The domains with a high concentration of carbon in the tested coat correspond to the graphite precipitations. Similar results were obtained for the coats on bainitic and martensitic cast iron. In order to determine the structure of the coat on the tested kinds of cast iron in more details and especially the "g_1" layer the quantitative analysis of elements was carried out in the typical points of the coat. The exemplifying results of this analysis are presented for the coat on the pearlitic ductile iron. The scanning picture of this coat with the marked measuring points is shown in Figure 6, however the quantitative analysis of the elements in particular measuring points are presented in Figure 7 (a÷e).

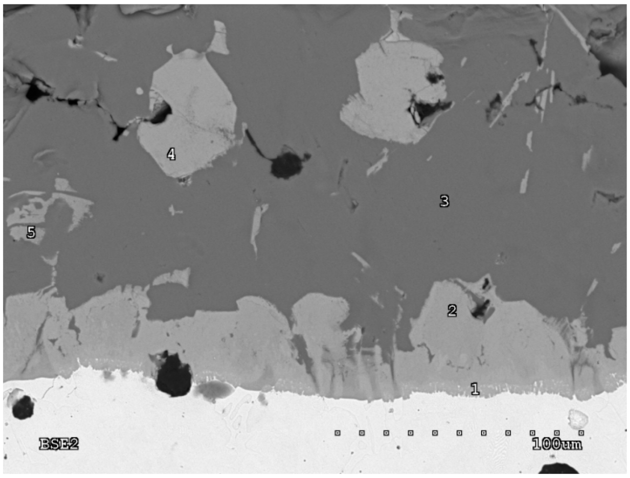


Fig. 6. The scanning picture of the AlSi5 silumin coat on pearlitic ductile iron with the marked points 1÷5 measuring the element concentration

a)

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Quantitative Analysis

Element  k-ratio    ZAF   Atom %  Element  Wt % Err.
         (calc.)                    Wt %   (1-Sigma)
  Al-K   0.0022   2.828    1.26     0.63   +/- 0.11
  Si-K   0.0139   2.030    5.42     2.81   +/- 0.10
  Cr-K   0.0111   0.798    0.92     0.89   +/- 0.07
  Fe-K   0.9305   1.006   90.60    93.56   +/- 0.69
  Cu-K   0.0183   1.152    1.80     2.11   +/- 0.22
  Total                  100.00   100.00
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b)

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Quantitative Analysis

Element  k-ratio    ZAF   Atom %  Element  Wt % Err.
         (calc.)                    Wt %   (1-Sigma)
  Al-K   0.3872   1.568   72.93    60.72   +/- 0.31
  Si-K   0.0282   2.595    8.45     7.33   +/- 0.20
  Cr-K   0.0151   1.051    0.99     1.59   +/- 0.15
  Mn-K   0.0144   1.133    0.96     1.63   +/- 0.13
  Fe-K   0.2591   1.109   16.67    28.73   +/- 0.46
  Total                  100.00   100.00
```

c)

```
Quantitative Analysis

Element  k-ratio    ZAF    Atom %  Element  Wt % Err.
         (calc.)                     Wt %   (1-Sigma)
  Al-K    0.9691   1.017    99.00   98.51    +/- 0.41
  Si-K    0.0018   3.182     0.55    0.57    +/- 0.09
  Fe-K    0.0080   1.154     0.45    0.93    +/- 0.11
  Total                    100.00  100.00
```

d)

```
Quantitative Analysis

Element  k-ratio    ZAF    Atom %  Element  Wt % Err.
         (calc.)                     Wt %   (1-Sigma)
  Al-K    0.3715   1.588    71.24   58.99    +/- 0.31
  Si-K    0.0323   2.566     9.62    8.29    +/- 0.21
  Cr-K    0.0075   1.045     0.49    0.78    +/- 0.15
  Mn-K    0.0134   1.132     0.90    1.51    +/- 0.13
  Fe-K    0.2750   1.106    17.75   30.42    +/- 0.48
  Total                    100.00  100.00
```

e)

```
Quantitative Analysis

Element  k-ratio    ZAF    Atom %  Element  Wt % Err.
         (calc.)                     Wt %   (1-Sigma)
  Si-K    0.0306   2.778     8.89    8.49    +/- 0.23
  Fe-K    0.1358   1.133     8.11   15.39    +/- 0.41
  Al-K    0.5973   1.274    83.00   76.12    +/- 0.36
  Total                    100.00  100.00
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Fig. 7 (a÷e). The elements concentration in particular measuring points: a – 1, b – 2, c – 3, d – 4 i e – 5 of the tested layer

Point 1 was placed in the “$g_{1'}$” layer; point 2 in the “$g_{1''}$” layer, and points 3÷5 in the zone of the external “g_2” layer. Point 3 is situated on the dark zone which is the background of this layer; points 4 and 5 are in grey free precipitations of the inter-metallic phases. In the “$g_{1'}$” layer (point 1 – Fig. 7a) there is a phase with a high content of Fe (93.6%); some Si (2.8%) and low Al (0.63%). In the “$g_{1'}$” layer of the coat on the bainitic and martensitic cast iron a similar concentration of these elements was obtained. In the works [6÷8] in was mentioned that in the non-alloy ductile iron the “$g_{1'}$” layer consists of Fe_4CSi carbide. In the coat on the alloy cast iron this layer presents a more complex structure because apart from the mentioned elements there are also alloy additives of the tested kinds of cast iron. On the pearlitic cast iron they are: Cu = 2.11% and Cr = 0.89% (point 1 – Fig. 7a), however, on the bainitic Ni and on the martensitic cast iron: Ni, Mo and Cr. The concentration of each mentioned element in the “$g_{1'}$” layer on the bainitic and martensitic cast iron is within the range of 0.9÷1.8%. The “$g_{1''}$” layer in the coat on the pearlitic cast iron (point 2 – Fig. 7b) consists of the AlFeSi phase having the following concentration of the elements: Al (60.72%); Fe (28.73%) and Si (7.33%). There are also alloy additives of the pearlitic cast iron Mn (1.63%) and Cr (1.59%). In the “$g_{1''}$” layer on the remaining tested kinds of cast iron the pure AlFeSi phase was obtained with a very similar concentration of Al, Fe and Si as it was in the coat on the pearlitic cast iron. In point 3 (Fig. 7c) of the coat on the pearlitic cast iron there is a high concentration of Al (98.51%) and low of Si and Fe. It should be then supposed that this is the silumin α phase appearing in the “g_2” layer. Free lamellar and faceted precipitations which appear in this layer are built from the pure AlFeSi phase (point 5 – Fig. 7e) or contain small quantities of the alloy additives of the cast iron, e.g. Cr and Mn (point 4 – Fig. 7d). Thus, this layer is mainly built from hypo-eutectic silumin and free precipitations of the inter-metallic phases. On the remaining tested ductile iron it has a similar structure as in the coat on the pearlitic cast iron. The following alloy additives can appear in the free precipitations of the phases: Mo, Ni, Cr and Mn (in the coat on martensitic cast iron).

4. Conclusions

The presented data allow generalizing the structure of the coat on alloy ductile iron. A generalized diagram of this structure is shown in Figure 8.

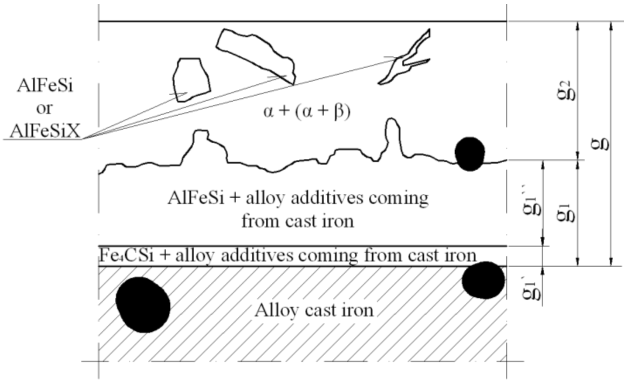

Fig. 8. The generalized diagram of the silumin coat structure on alloy ductile iron

The “$g_{1'}$” layer consists of Fe_4CSi carbide which contains small quantities of the selected alloy additives of the cast iron. The next “$g_{1''}$” layer consists of the inter-metallic AlFeSi phase, which can appear in a pure state, i.e. without the alloy additives of the cast iron or contain a small quantity of them. Regarding the relatively low content of the alloy additives in the tested kinds of the ductile Irons in the transition layer of the “g_1” coat there are much smaller quantities of them in comparison with the coat on the steels and cast steels. The external “g_2” layer of the tested coat mainly consisted of AlSi5 composing phases, i.e. the initial α phase and the eutectic α + β one. There are free lamellar precipitations of the AlSi5 inter-metallic phases or rarely AlFeSiX. The precipitations of graphite appear in all the layers of the coat obtained on the ductile iron.

Acknowledgements

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