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# Effect of silicon concentration in bath on the structure and thickness of grey cast iron coating after alphinising

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## ABSTRACT

**Purpose:** This paper presents the results of studies on the effect of silicon content in alphinising bath on the thickness of diffusion layer „g1" and of coating „g" produced by immersion on the grey cast iron, grade EN-GJL-250. The temperature of alphinising bath was 750±5°C, and the time of holding the cast iron insert was $\tau = 180s$.

**Design/methodology/approach:** It has been proved that in the bath of commercially pure aluminium and of AlSi1,5 alloy, the diffusion layer and coating produced on grey cast iron are of the highest thickness, comprised in a range of g1 = 40÷50µm and g = 220÷230µm., respectively. The diffusion layer produced in these baths is characterised by a compact, columnar structure of the $Al_3Fe$ phase.

**Findings:** An increase in silicon concentration in the alphinising bath to about 11% changes the structure of diffusion layer into the faceted one and makes other phases appear as well. Right on the surface of the cast iron insert, the $Fe_4CSi$ carbide is present, followed by the $Al_{12}Fe_3Si_2$ phase, on which the $Al_9Fe_3Si_2$ phase is superimposed. Raising further silicon concentration in bath to a level well above 11% Si, i.e. to about 17% Si, does not change the phase constitution of the diffusion layer. What it causes is only a fragmentation (breaking of continuity) of the layer, thus making it useless in the process of producing a layered casting. An increase in silicon concentration in the alphinising bath in a range of 7÷17% Si reduces the thickness of diffusion layer in a range of g1 = 38÷22µm and that of coating in a range of g = 155÷92 µm. It is supposed that the decrease in thickness of the diffusion layer and of coating with the increasing concentration of silicon in alphinising bath is due to a reduced rate of the reactive diffusion.

**Originality/value:** This is an immediate effect of the enlarged number of silicon atoms and of the presence of the precipitates of primary silicon crystals adhering to the surface of cast iron insert. The reason of occurrence of a monophase structure in the diffusion layer produced in aluminium bath or in bath of AlSi1,5 is the lack of silicon atoms or low concentration of this element in the region of the surface layer dissolved on cast iron insert.

**Keywords: Casting; Aluminium; Silumins; Grey cast iron; Alphinising; Layered castings; X-ray microanalysis**

MATERIALS MANUFACTURING AND PROCESSING

## 1. Introduction

It is to be expected that production of layered castings composed of a ferrous alloy and silumin, obtained by the technique of alphinised coatings, will be gradually spreading to cover with its range elements used in construction of vehicles, machines and installations. At present, some publications have already appeared on the application of this process in automotive industry for elements of the suspension system and pistons with ring washers, and also for compressor bodies operating in different media [1÷6]. In [5÷11] the technological factors have

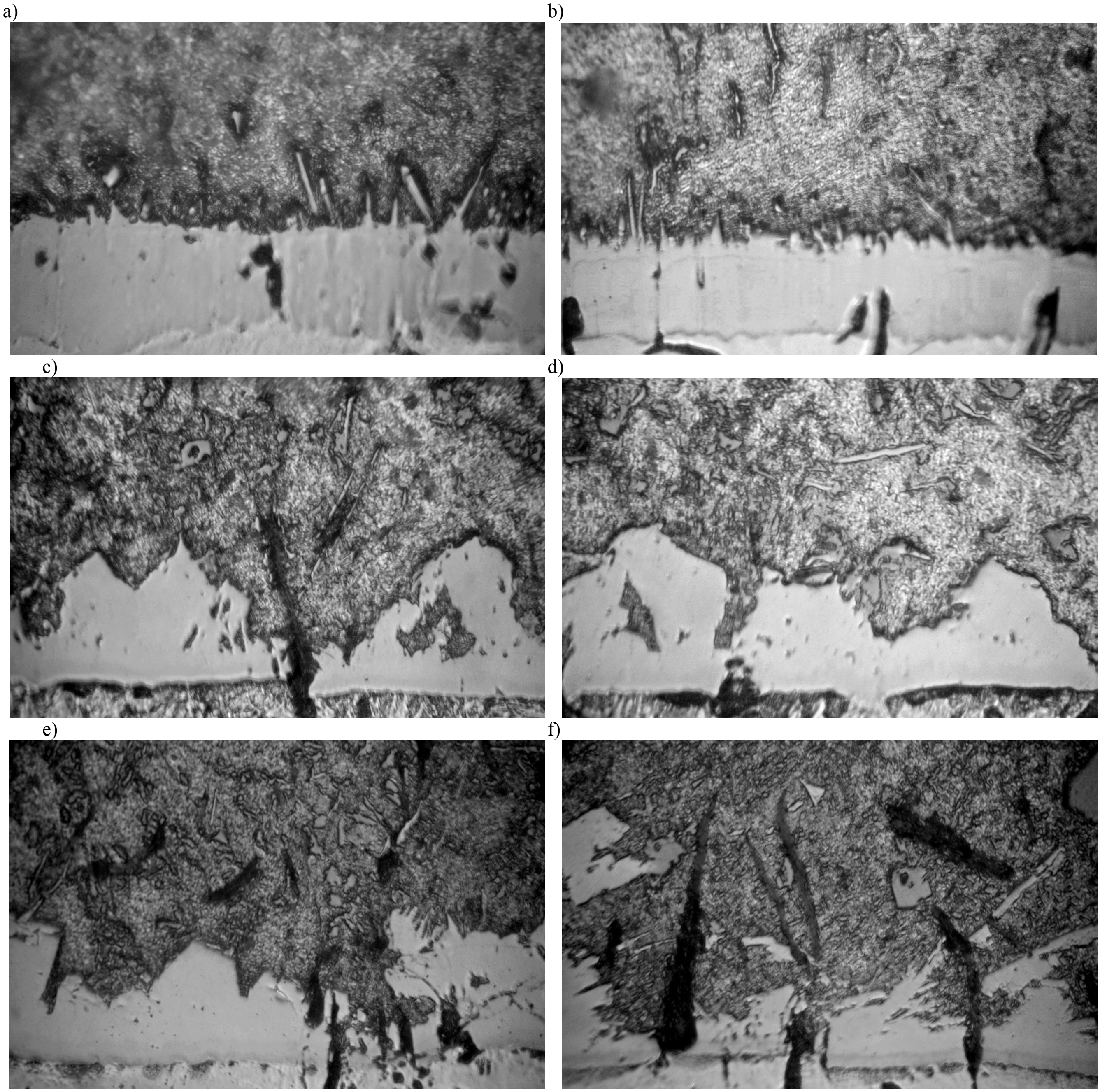



Fig. 1 (a÷f). Si content in alloy for alphinising vs thickness of the alphinised layer „$g_1$” in coating produced on grey cast iron: a – 0%Si, b – 1,5Si, c – 7%Si, d – 11%Si, e – 12%Si, f – 17%Si

been discussed which affect the structure and thickness of the alphinised layer, the mechanism of its crystallisation, and formation of a layered casting. It has been proved that thickness of the alphinised layer, and hence the quality of bond obtained between the insert and silumin, depend largely on the following factors: type of ferrous alloy (steel, cast iron), roughness height „Rz”(„Ra”), its area, temperature of the alphinisng bath, and time during which the insert is held in bath. In this study, additionally to the above mentioned factors, the effect of the silicon content in alphinising bath on the thickness of diffusion layer and of coating formed on grey cast iron was investigated. The investigations were carried out on grey cast iron, grade EN-GJL-250, using the bath of a temperature $t_k$ = 750±5°C and the time of holding $\tau$ = 180s. The chemical composition of the alloys selected for alphinising is shown in Table 1. The remaining methods of investigation were analogical to those described in [5÷11].

Table 1.
The chemical composition of Al-Si alloys

| No | Alloy | Chemical composition, % | |
|---|---|---|---|
| | | Si | Fe |
| 1 | Al 99,85 | 0,11 | 0,04 |
| 2 | AlSi1,5 | 1,46 | 0,13 |
| 3 | AlSi7 | 7,23 | 0,18 |
| 4 | AlSi11 | 11,16 | 0,14 |
| 5 | AlSi12 | 12,67 | 0,15 |
| 6 | AlSi17 | 16,59 | 0,14 |

## 2. The results of investigation

From the data presented in [5÷11] it follows that coating produced by the alphinising process is composed of two main layers. The first layer is a diffusion layer crystallising directly on the insert; in this study its thickness has been designated as „$g_1$". The second layer is crystallising on the first layer; its thickness jointly with the layer „$g_1$" has been designated as „g". Figure 1 (a÷f) shows the effect of Si on the thickness of layer „$g_1$". From the plotted relationship it follows that an increase in the content of silicon changes the structure and thickness of the layer. The layers produced by immersion in commercially pure aluminium and in an alloy containing about 1,5%Si (Fig. 1 a and b) are characterised by a compact, columnar structure. Further increase in silicon content changes the columnar structure into a faceted one (Fig. 1 c÷f) and causes some discontinuities in the layer when silicon content reaches the level of about 12 and 17% Si. The thickness of layer „$g_1$" and of coating „g" changing in function of the silicon content is shown in Figure 2.

From the plotted curve it follows that the thickest layer and coating are obtained in the case of aluminium and its alloy containing 1,5% Si. Further increase in Si content up to about 11% reduces thickness of both the layer and the coating but in a rather moderate way. A considerable reduction in the thickness of the alphinised layer is caused by the silicon content in alloy ranging from 11 to 17%.

The deposition of coating in the bath of aluminium and AlSi1,5 alloy causes formation on the cast iron surface of an $Al_3Fe$ phase, followed by the phase α or by a mixture of phases α and β(Si) in the case of AlSi1,5 alloy. This is further confirmed by the, shown in Figure 3 (a, b), example of a linear distribution of Al, Si and Fe concentration on the cross-section of coating produced in aluminium. From the data obtained it follows that it is very important to explain the mechanism by which the increasing silicon concentration makes the coating thickness decrease during the process of alphinising.

In [9] the mechanism of crystallisation of the diffusion layers and of the coating was described, wherefrom it follows that when the coating of AlSi11 silumin is formed on cast iron, the layers that are successively crystallising are those shown in Figure 4. The first layer from the side of the substrate is $Fe_4CSi$ carbide, in which the equilibrium concentrations are 4,55% C and 10,66% Si [12]. On this carbide crystallises the next layer of $Al_{12}Fe_3Si_2$ phase with equilibrium concentration of 32,25% Fe; 5,44% Si and 62,30% Al [13]. On the $Al_{12}Fe_3Si_2$ phase crystallises the $Al_9Fe_3Si_2$ phase which in the state of equilibrium contains 27,17% Fe; 13,77% Si and 59,05% Al [13].

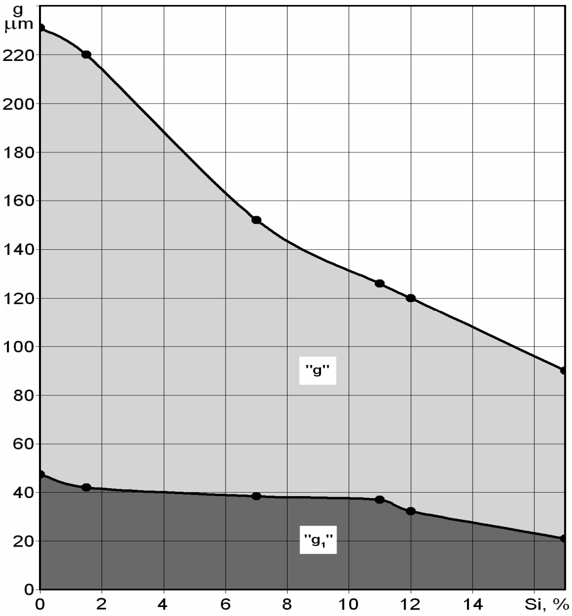
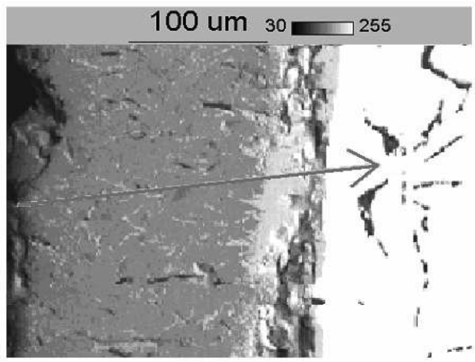



Fig. 2. Thickness of layer „$g_1$" and of coating „g" changing in function of silicon content

a)




b)

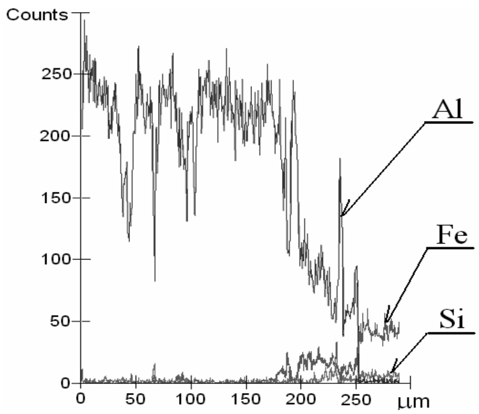



Fig. 3 (a, b). Linear distribution of elements in coating formed in aluminium bath on grey cast iron: a – measuring line, b – linear distribution of Al, Fe i Si

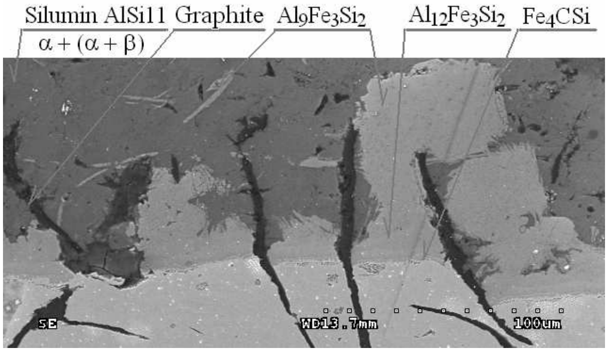



Fig. 4. The structure of alphinised layer produced on grey cast iron after alfinizing in AlSi11 bath at $t_k$ = 750°C, τ = 180s

From the investigations described previously it follows that in the case of commercially pure aluminium and AlSi1,5 alloy, directly on the substrate crystallises $Al_3Fe$ phase; on this phase crystallises aluminium or aluminium with silicon precipitated in solid state from the solution of phase α, due to its solubility varying from 1,65% at the temperature of eutectic crystallisation (577°C) to almost 0% at ambient temperature (AlSi1,5). Absence of silicon atoms in alphinising bath or their low concentration does not impede the process of reactive diffusion, thus causing the crystallisation of a relatively coarse and continuous layer of $Al_3Fe$ (Fig. 1 a and b). Increasing silicon content in the alphinising bath raises the concentration of silicon atoms near the, dissolved by Al, surface of insert; this effect is additionally enhanced by the presence of silicon atoms from the dissolved cast iron layer. This reduces the rate of reactive diffusion, reducing - as a consequence - the thickness of the diffusion layer „$g_1$" (Fig. 1 c÷f). In nearly-eutectic silumin, few precipitates of the hypereutectic silicon crystals may appear; on the other hand, they are quite numerous in hypereutectic silumin. Their presence and adherence to the surface of insert considerably hinder the dissolution process, similar as it happens in the case of Al, Fe and Si atoms diffusion. Consequently, in this group of silumins, the thickness of the diffusion layer and of the coating decreases. The diffusion layer undergoes also the process of fragmentation.

## 3. Conclusions

From the data presented in this study the following conclusions are drawn:

- the diffusion layer „$g_1$" in coatings produced in the bath of aluminium and AlSi1,5 alloy is composed of the $Al_3Fe$ phase,
- the thickness of the diffusion layer „$g_1$" and of the coating „g" decreases with increasing concentration of silicon in the alphinising bath,
- the silicon concentration in the alphinising bath should not exceed 11,5%, and it should be adjusted to the required type of microstructure and mechanical properties of silumin making the layered casting.

## Acknowledgements

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