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Model of the Alphinising Coating Crystallisation on Iron Alloys

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Abstract

The study presents a hypothetical model of crystallisation of the alphinising coating produced on iron alloys by immersion in the bath of silumin. Basing on a wide-range of experiments and investigations, the effect of the type of inserted material (“armco” iron, C45 steel, grey cast iron and nodular graphite cast iron) and of the technological regime of the alphinising process (chemical composition of silumin bath, its temperature, the time of holding an insert in the bath, and the insert surface roughness height “Rz”) on the coating structure was determined. The type of the coating structure was established by metallographic examinations carried out by optical microscopy, electron transmission microsopy and scanning electron microscopy, using additionally an X-ray microanalyser and X-ray diffraction patterns. The results of these investigations were described in [1÷7]. Basing on the obtained results, a probable model of the crystallisation of an alphinising coating on iron alloys, produced by immersion in the alphinising bath, was developed. It has been stated that, most probably, the alphinising process begins when the insert reaches its contact temperature “t_s”.. Since that moment, due to the wetting process and convection movement of bath around the insert surface, an intense process of the dissolution starts. A reactive diffusion of the atoms of Fe and Si from the insert to the bath and of the atoms of Al and Si from the bath to the insert takes place. An intermetallic Al_3Fe phase is crystallising on the steel, while on the cast iron, a silicon carbide Fe_4CSi is growing, probably due to carbon diffusion from graphite. Then, on the steel, as an effect of the peritectic reaction, are successively crystallising the phases of $Al_{12}Fe_3Si_2$ and $Al_9Fe_3Si_2$. The Al_3Fe phase probably crystallises on the cast iron to be transformed later, due to peritectic reaction, into an $Al_{12}Fe_3Si_2$ phase on which the $Al_9Fe_3Si_2$ phase will be growing. When the insert is taken out from the bath, on the $Al_9Fe_3Si_2$ phase are crystallising the phase constituents present in the silumin bath. It has been proved that the process of crystallisation of the alphinising coating and its thickness are also affected by the roughness height “Rz”. There is a critical value of “Rz”, different for the steel and cast iron, up to which the thickness of the coating is growing, and which - when exceeded - makes the coating thickness decrease.

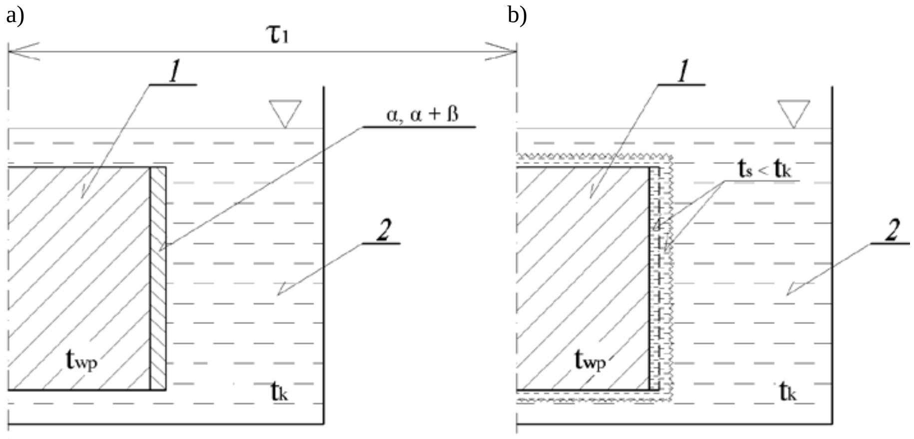
Keywords: Innovative casting technologies, Iron alloys, Silumins, Alphinising, Layered castings, X-ray microanalysis

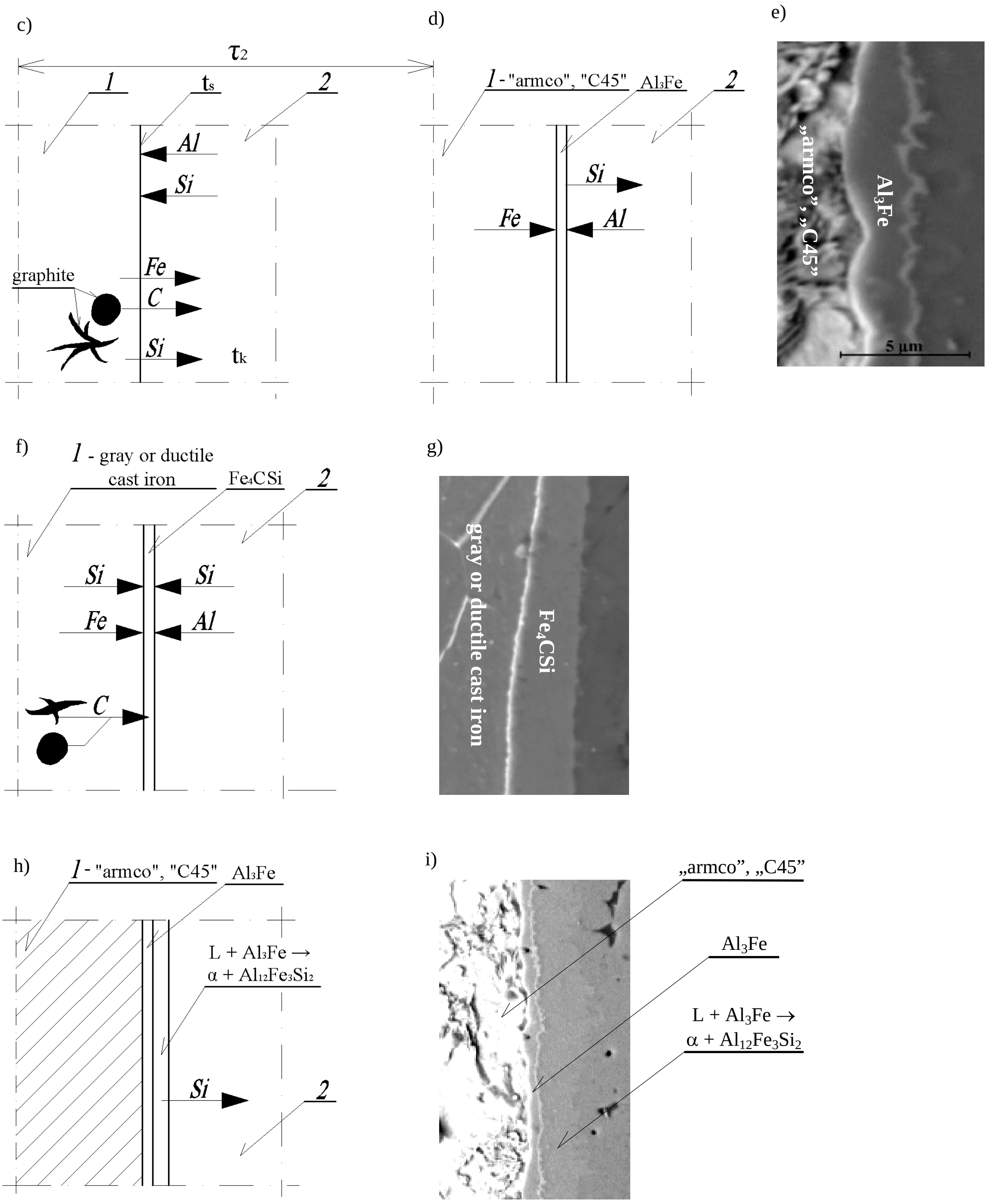
1. Introduction

Alphinising coatings are used as a means of bonding the layered castings made from aluminium alloys with iron alloys (steel, cast iron). Bonds of this type are used in production of silumin pistons for I.C. engines with sub-ring inserts made from austenitic “Niresist” cast iron. The data currently available in reference literature indicate that it is possible to produce also other layered castings, e.g. for elements of the suspension system in cars and for compressor bodies operating in various media [8÷10]. Though bonds in the layered castings have long since been obtained by the process of alphinising coating, until now no theoretical backgrounds of the crystallisation process of this coating and of the bond formation with silumin have been developed. At the Chair of Materials Engineering and Production Systems of the Technical University of Lodz, since several years, advanced research works have been carried out on this subject. The results are presented in [1÷7]. In these studies it has been proved that the alphinising coating is composed of four layers which, in turn, are composed of different phases. It has been, moreover, observed that the structure of the first layer contacting directly the insert surface depends on the type of material from which this insert has been made. As proved by the investigations, the thickness of the individual layers as well as that of the whole alphinising coating depends on the following factors: the type of material used for an insert (steel, cast iron), the chemical composition of the alphinising bath and its temperature, the time of immersing the insert in the bath, and the roughness height “Rz” on the insert surface. This study describes the probable process of crystallisation of an alphinising coating. The description was based on the results of the extensive investigations carried out until now.

2. Model of the alphinising coating crystallisation

Basing on the data given in [1÷7], a probable mechanism of the crystallisation of an alphinising coating on iron alloys has been proposed. A schematic representation of the hypothetical process of crystallisation of an alphinising coating on iron alloys is shown in Figure 1 (a÷o). The insert preheated to a temperature “t_{wp}” is immersed in silumin bath of temperature “t_k” (a). At this moment, during the time τ_1, a local drop occurs in the temperature of the silumin surrounding the insert, combined with its crystallisation on the insert surface. At the same time, the insert is heated in the direction from the surface towards its axis. From a simulation analysis of the insert heating process it follows that for the specimens of a diameter d = 10mm and length l = 50mm, used in the investigations, the time required for the temperature to reach an equal level on the entire specimen cross-section amounts to about 2,5s. After this time, the specimen temperature is raising to a level higher than the point of solidus, and after the lapse of about 3s to a level higher than the liquidus point of the silumin alphinising bath. In the surface layer of the specimen, at a depth of from several hundreth up to several tenth of millimetre, the point of both solidus and liquidus is reached during several tenth of a second. Therefore it is to be supposed that the time needed by the silumin to crystallise on an insert and redissolve on it next does not go beyond the interval of 0,1÷0,2s. After this time, the insert is heated to its contact temperature “t_s” which, for example, for “armco” iron is t_s = 566°C, and for the grey cast iron t_s = 572,3°C, with temperature on the insert axis reaching 561,6°C and 567,8°C, respectively. The contact temperature is the temperature equal for the insert surface and for the, surrounding

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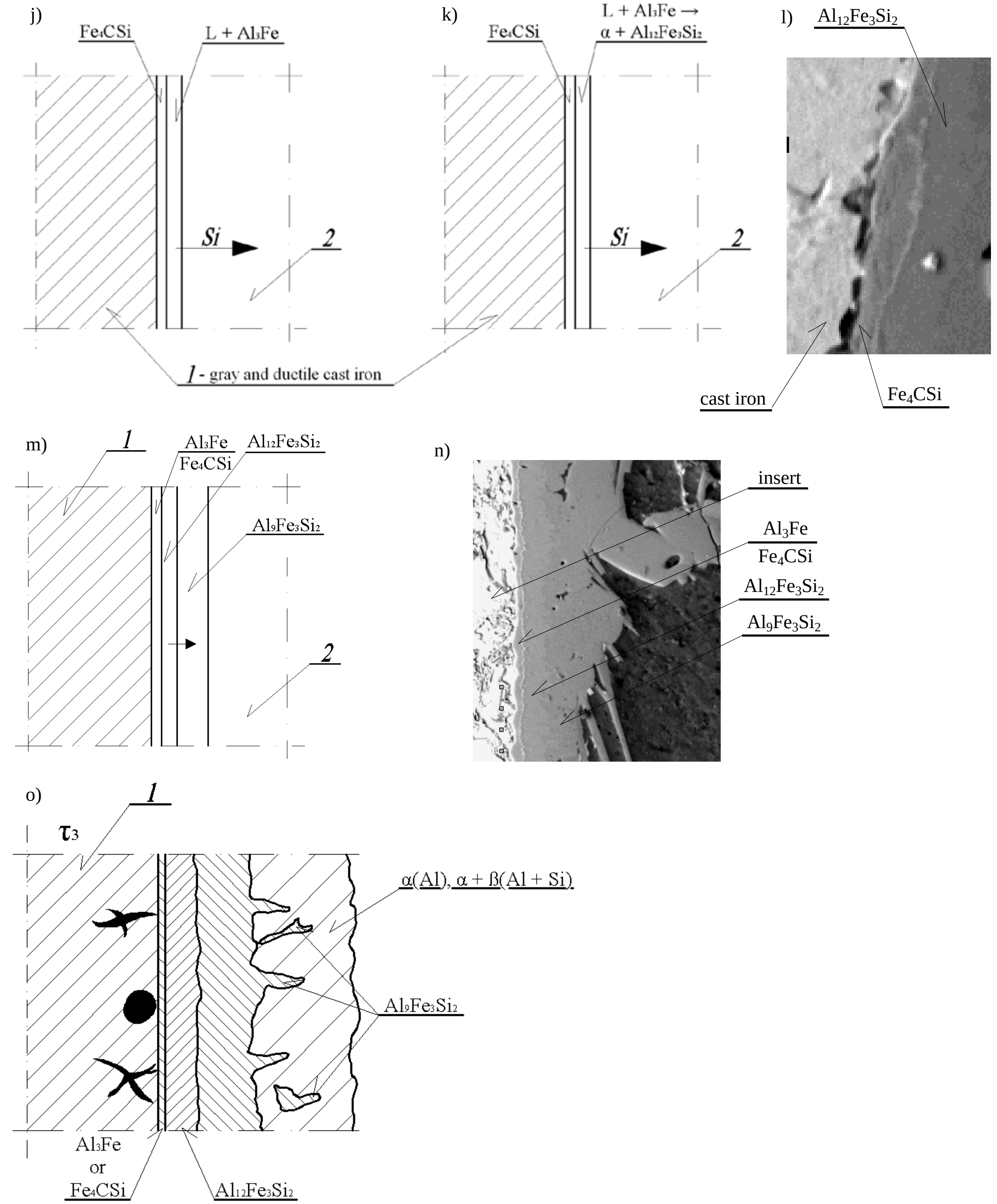

Fig. 1(a÷o). Schematic representation of a hypothetical process of crystallisation of an alphinising coating on iron alloys: 1 – insert, 2 – silumin bath this insert, silumin in the alphinising bath. Starting with the temperature “t_s”, a simultaneous heating of the external layer of the insert and of the alphinising silumin bath surrounding this insert takes place. Then the temperature of the liquid silumin surrounding the insert increases as a result of heat transfer from the remote regions of the silumin bath and as an effect of the temperature gradient and of the convection movement of molten metal. Probably, during preheating of the insert to a temperature “t_s” its surface layer is being dissolved by aluminium at a rate increasing with the increase of temperature (b). As soon as the insert surface reaches its contact temperature “t_s”, the second stage proceeding within the time τ_2 (c) begins. The surface of the insert is wetted by molten silumin and the viscosity-controlled process takes place. The rate at which the surface is being dissolved by aluminium is very high. Then, a reactive diffusion of the atoms of iron and silicon from the insert to the bath and of the atoms of aluminium and silicon from the bath to the insert surface, combined with their adsorption, starts (c). The concentration of atoms near the insert surface is increasing, the increase of Fe and Al atoms concentration being very pronounced, that of Si atoms less. Therefore “armco” iron and C45 steel, both having low concentration of silicon, make a good substrate for the crystallisation of an intermetallic Al_3Fe phase (d, e), while on the grey and nodular graphite cast irons a Fe_4CSi carbide is crystallising with small amounts of Al dissolved in it (f, g). Hence it follows that in the cast iron there is a partial diffusion of carbon from graphite to the dissolved layer of Fe and of Si from the cast iron and the alphinising bath. The presence of the atoms of Fe, C and Si makes the Fe_4CSi carbide crystallise. Its crystallisation front is “pushing” the atoms of aluminium deep into the alphinising bath. Further sequence of the intermetallic phases crystallisation on “armco” iron, on C45 steel and on the grey and nodular graphite cast irons remains basically the same. In steels, the crystallisation front of the Al_3Fe phase is “pushing” Si atoms inside the bath, which results in partial peritectic reation: $L + Al_3Fe \rightarrow \alpha + Al_{12}Fe_3Si_2$ (h, i). In cast irons, it is probably the metastable Al_3Fe phase which is the first one to form (j); the next to form due to peritectic reaction is the $Al_{12}Fe_3Si_2$ phase (k, l). Its crystallisation front “pushes” the Si atoms into the interior of the alphinising bath, and at the same time the concentration of Fe and Al in the bath is decreasing. This makes the next partial peritectic reaction occur. This is the reaction: $L + Al_{12}Fe_3Si_2 \rightarrow \alpha + Al_9Fe_3Si_2$, due to which the $Al_9Fe_3Si_2$ phase, characterised by lower concentration of Fe and Al and increased content of Si in respect of the $Al_{12}Fe_3Si_2$ phase, is crystallising (m, n) Any prolongation of the time during which the insert is immersed in the alphinising bath increases the thickness of the crystallising phases. Time τ_3 (o) is the time during which the insert is being taken out from the bath. During this time, the crystallisation of the silumin present in the alphinising bath takes place on the $Al_9Fe_3Si_2$ phase.

From the data presented here it follows that the kinetics of crystallisation of the alphinising coating is of a very complex character. The crystallisation process takes place in a time very short, which proves that the processes of dissolution, taking place on the insert surface, and of the reactive diffusion are very intense. They are, to a great extent, dependent on the quality of the insert surface, i.e. on the roughness height. Figure 2 shows the effect of the roughness height “Rz” in “armco” iron, C45 steel and grey and nodular graphite irons on the thickness of the alphinising coating.

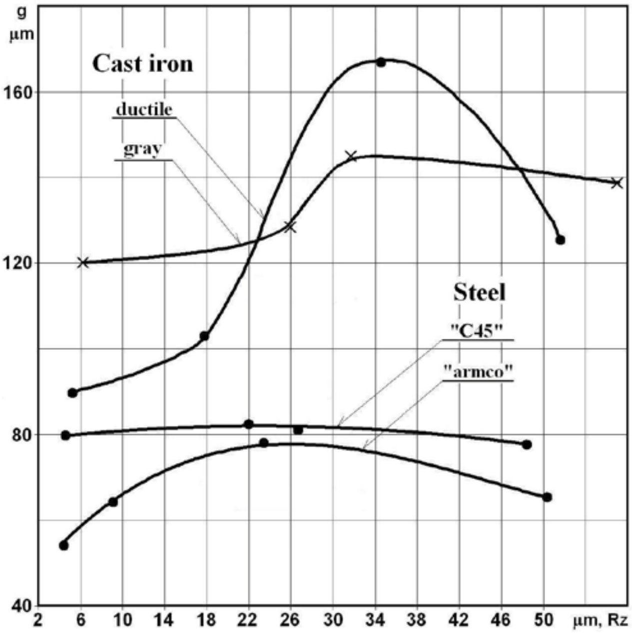

Fig. 2. Effect of roughness height “Rz” on the surface of iron alloys on the thickness of alphinising coating

From the above diagram it follows that, irrespective of the type of iron alloy, an increase in the surface roughness “Rz” initially makes the thickness of the alphinising layer increase, too, up to a certain critical value which, when reached, makes thickness of the coating decrease. This critical value assumes the following values: for steel it is comprised in the range of Rz = 22÷27µm, whereas for cast iron it amounts to Rz = 31÷35µm. Small height of the roughness “Rz” on the surface of an insert, e.g. after grinding, gives a relatively small insert/alphinising bath interface surface. This makes the specimen get heated within its entire volume up to a temperature “t_s” in a relatively long time. An increase in the value of “Rz”, e.g. after finish turning, to a critical level increases the area of the insert/alphinising bath interface surface. An immediate consequence is rapid heating of the roughness peaks and next of the whole roughness volume up to a temperature “t_s”. As a consequence of this state, the rate of the specimen heating increases in direction towards its axis. With the critical value of “Rz” exceeded, the roughness peak area becomes larger which, in turn, reduces the heating rate, and due to this also the heating rate on the entire specimen cross-section. The time of the specimen preheating to a temperature “t_s” becomes longer again. At the next stage, due to wetting of the specimen by molten silumin and the viscosity-related phenomena, a reactive diffusion of the atoms of Al and Si from the bath to the specimen takes places, along with the Fe and Si atoms getting adsorbed by the bath from the specimen. The surface roughness is dissolving. When the value of “Rz” is small after grinding, the difference in Al, Fe and Si concentrations between the area of the roughness peak and the recess is small, too. As a consequence, both the concentration undercooling as well as the undercooling caused by a negative curvature of the liquid/solid interface assume low values; this, in turn, reduces the rate of growth of the intermetallic phases, first, and of the silumin next. The coating of a small thickness is formed. The increase of “Rz” to a critical value, due to the roughness getting rapidly heated, increases the rate of reactive diffusion. Probably, the roughness gets quickly dissolved. When the roughness is high, the difference in Al, Fe and Si concentrations between the recess of a large radius and the area in which the peak of the roughness was, is quite considerable. So, this area is affected by strong concentration undercooling, probably stronger than the undercooling due to a negative curvature of the recess. This, in turn, is the cause of very rapid dissolution of roughness in the region of the recesses. As a consequence, undercooling in the region of the recesses is stronger than it is in the region of the dissolved roughness peaks - the fact which favours quick crystallisation of a relatively thick layer of the intermetallic phases and of silumin. Exceeding the critical value of “Rz” reduces the intensity of preheating both the roughness and the specimen to a temperature of the silumin bath. Hence, the time of the processes discussed previously is shorter. The concentration undercooling as well as that resulting from a negative curvature of the liquid/solid interface are supposed to be reduced, too. The consequence is decreasing thickness of the coating.

3. Conclusions

The described model of the process of crystallisation of the alphinising coating on iron alloys produced by the technique of immersion seems to be highly probable. It has been developed as a result of wide- range investigations carried out on the alphinising coatings, including metallographic examinations by optical microscopy, and by TEM and SEM, X-ray microanalysis and X-ray diffraction, and as such can make a basis for the development of some models of the crystallisation of immersion coatings produced by alloys other than silumins.

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