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Effect of the Surface Layer of Iron Casting on the Growth of Protective Coating During Hot-Dip Galvanizing

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Abstract

The paper presents the results of investigations of the growth of protective coating on the surface of ductile iron casting during the hot-dip galvanizing treatment. Ductile iron of the EN-GJS-600-3 grade was melted and two moulds made by different technologies were poured to obtain castings with different surface roughness parameters. After the determination of surface roughness, the hot-dip galvanizing treatment was carried out. Based on the results of investigations, the effect of casting surface roughness on the kinetics of the zinc coating growth was evaluated. It was found that surface roughness exerts an important effect on the thickness of produced zinc coating.

Keywords: Hot-dip galvanizing, Ductile iron, Surface roughness

1. Introduction

Zinc coatings applied on the structural elements made from iron alloys are one of the most common and at the same time most effective means of long-term protection against atmospheric corrosion. The method of corrosion protection most widespread and most commonly used in practice is hot-dip galvanizing [1 ÷ 5]. Compared to other methods of the coating generation, protective coatings produced by hot-dip galvanizing offer the following advantages: the whole production cycle is not time-consuming, the coating has an alloy layer which enhances its adhesion to the substrate, it is possible to obtain coatings of increased thickness which significantly extends the duration of active protection, and – last but not least – coatings have a very aesthetic appearance [6 ÷ 8]. Analysis of the literature [9 ÷ 11] shows that coatings produced by immersion are composed of two layers:

- alloy layer - which includes sub-layers of intermetallic Fe-Zn phases:
  - Γ_1 phase - Fe_3Zn_{10} crystallizing in a bcc system, containing 72% - 79% Zn;
  - δ phase - $FeZn_{10}$ crystallizing in a hexagonal configuration, containing 88.5% - 93.0% Zn;
  - ζ phase - $FeZn_{13}$, with monoclinic lattice, containing 94 - 95% Zn;

  and
- an outer layer (η) which is a solid solution of iron in zinc.

During hot-dip galvanizing of items made from the Fe-C alloys with high silicon content, the alloy layer is composed of maximum two sub-layers, i.e. the intermetallic δ phase and ζ phase. The quality of protective coating depends on a number of factors such as the chemical composition of the substrate material, its microstructure and surface condition. The surface condition is the parameter most important in the process of obtaining high-quality protective coatings and again it depends on a number of different factors such as the technological process by which the galvanized object has been made (casting, rolling), and a method adopted for its storage and transport (impurities, oxides). Before the galvanizing process, proper casting surface pre-treatment to prepare it for the hot-dip galvanizing can eliminate or significantly reduce the impact of contaminants due to the mechanical cleaning, pickling and fluxing. The surface quality of the galvanized casting usually means this part of the surface layer of the product which is directly subjected to the hot-dip galvanizing treatment.

2. Research methodology

To evaluate the effect of casting surface roughness on the kinetics of zinc coating growth, two sets of “Y” wedges were cast (Fig. 1). The first set was cast under industrial conditions in furan sands (denoted as "S") and the second one in oil sands (denoted as "O").

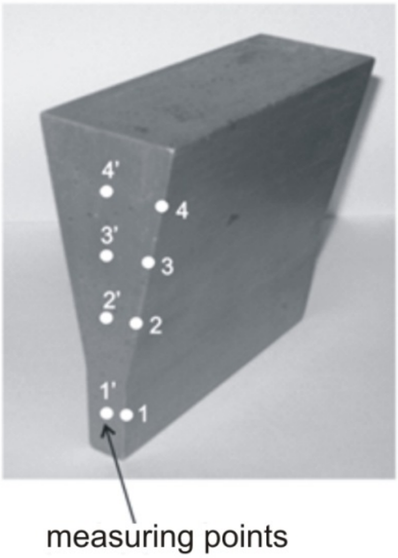


Fig. 1. Microstructure obtained in different places of a “Y” test casting made of the ductile iron, grade EN-GJS-600-3

Moulds were next poured with the ductile iron of EN-GJS-600-3 grade, made in a single melt to obtain a pearlitic matrix in the surface layer of casting. The effect of nodular graphite precipitates was neglected, since it was discussed in [3]. From the lower part of the cast "Y" wedge (points 1 and 1' in Fig. 1) samples were cut out. From these samples, metallographic sections were prepared to examine the resulting microstructure of the surface layer (Fig. 2). It was assumed that the surface layer, i.e. the area of possible reaction between the liquid zinc and ductile iron, is maximum 100 µm.

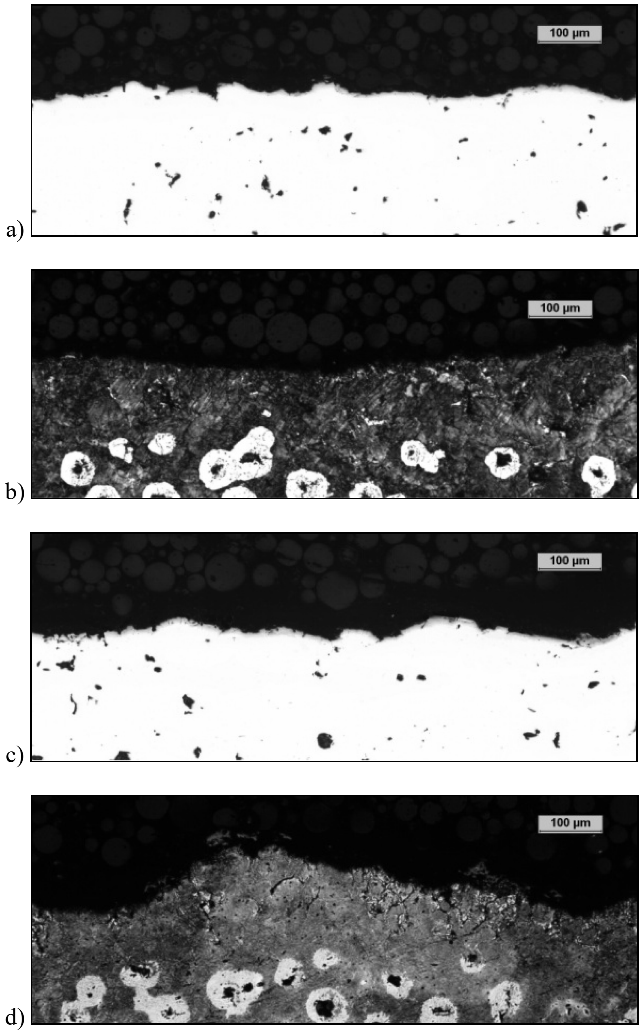
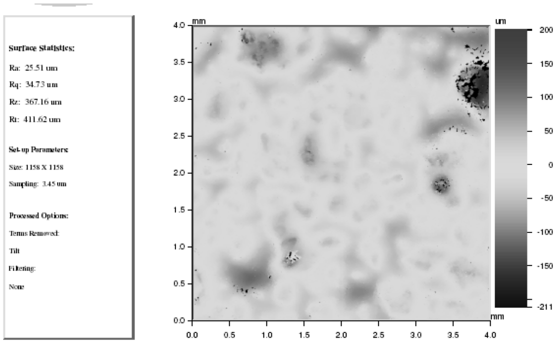
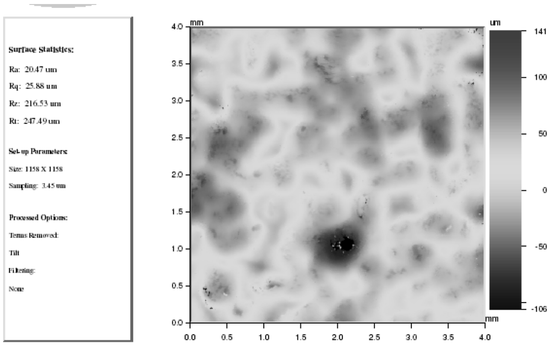


Fig. 2. Microstructure of the surface layer of EN-GJS-600-3 ductile iron samples obtained from castings made in oil sand (O): unetched - a), etched with nital - b), and in furan sand (S): unetched - c), etched with nital - d)

As a next step, roughness was measured with a Wyko NT 9300 profilometer made by Veeco, which is available in the Department of Materials Science and Engineering, Warsaw University of Technology. The results are shown in Figure 3 and compared in Table 1.



a)



b)

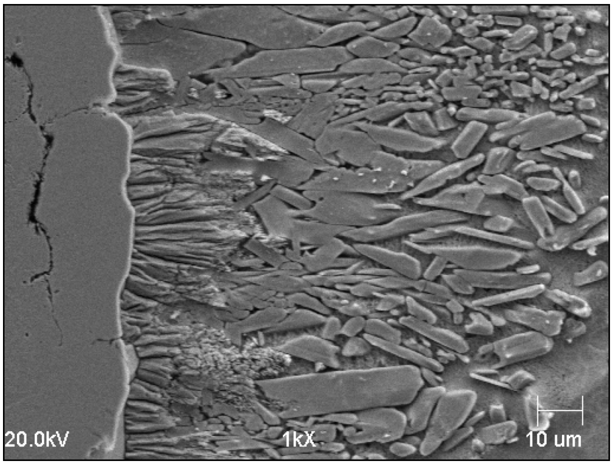
Fig. 3. Visualization of the surface geometry of casting made in mould of: O type - a), S type - b)

Table 1.
Different values of surface roughness parameters compared for the examined castings

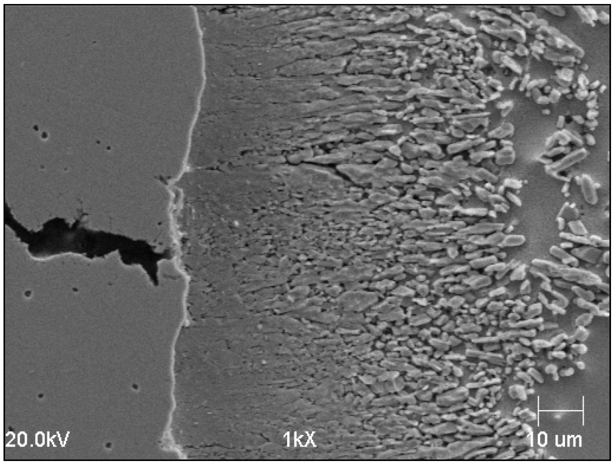
Mould type	R_a	R_q	R_z	R_t
	µm			
O	**25.51**	**34.73**	**367.16**	**411.62**
S	**20.47**	**25.88**	**216.53**	**247.49**

Designations:
R_a – the arithmetic mean of the roughness profile ordinates
R_q – the root mean square of the roughness profile ordinates
R_z – the average height of the roughness profile
R_t – the total height of the roughness profile

After determining the roughness parameters. samples were subjected to the chemical surface treatment including mechanical cleaning. degreasing. pickling and fluxing. Then the samples were undergoing a hot-dip galvanizing carried out at 450°C under the laboratory conditions of Surface Engineering Laboratory in the Department of Casting Alloys and Composites Engineering. Faculty of Foundry Engineering. AGH University of Science and Technology in Krakow. The process duration was from 60 to 600 seconds. From the samples. metallographic sections were prepared. They were etched in Vilella's reagent and thickness of the obtained zinc coating was measured. Examples of the SEM microstructure of the resulting zinc coatings are shown in Figure 4.



a)



b)

Fig. 4. The alloy layer obtained in the time of 300s on the ductile iron sample surface of O type- a) and S type - b) SEM microstructure

The surface layer - in accordance with the PN-M-04250:1987 standard - is the outer layer of material. determined by the actual shape of object comprising this layer. and a volume of material extending from this surface layer inside the object. which exhibits altered physical and sometimes also chemical properties compared to the properties of the core material. The general characteristics include the measurable parameters such as the surface roughness. the load carrying capacity. hardness. residual stresses in the zones of the surface layer. and features that can be presented in a descriptive form. including the appearance of the surface in a macroscopic magnification. the appearance of the metallographic section (or fracture) of the surface layer in a microscopic magnification (1500x). In the case of castings in which the application of machining is in accordance with the production process guidelines reduced to a minimum. it is the surface roughness that is responsible for the surface quality and as such it will be linked to the manufacturing process of product undergoing the hot-dip galvanizing treatment.

3. Results

The results of measurements of the thickness of zinc coating formed on castings with the varying surface roughness are compared in Figure 5.

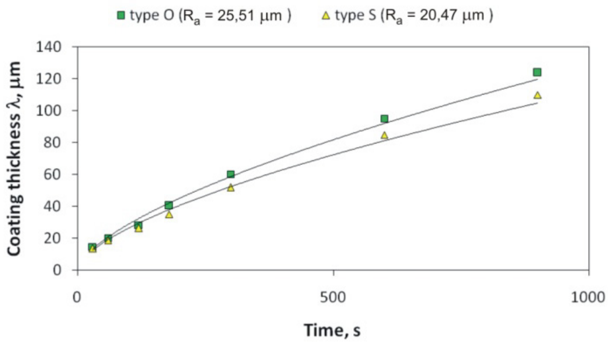


Fig. 5. The kinetics of growth of the Fe-Zn alloy layer in zinc coating formed on the surface of samples cut out from iron castings made by different mould technologies

On the basis of the measured values of the zinc coating thickness. some relationships were derived. which determine the kinetics of the zinc coating growth on the casting with the known surface roughness subjected to the technological process of hot-dip galvanizing in the time interval from 60 seconds to 600 seconds. On casting characterized by the roughness parameter R_a of 25.51 µm. the zinc coating will be growing according to Equation (1):

$$\lambda_O = 1.430t^{0.650}\text{; } R^2 = 0.99 \quad (1)$$

In contrast. the growth of coating on the casting surface of the roughness R_a = 20.47 µm will be controlled by equation (2).

$$\lambda_S = 1.406t^{0.633}\text{;} R^2 = 0.99 \quad (2)$$

4. Conclusions

Based on the conducted tests and studies it can be concluded that surface roughness of the galvanized casting made from the EN-GJS-600-3 grade ductile iron has a significant impact on the resulting thickness of the zinc coating.

After 60 seconds of the treatment. the protective coating was by 8.6% thicker on the cast iron sample with the surface roughness of R_a = 20.02 µm than on the sample made from the same alloy and hot-dip galvanized for the same period of time. but with the surface roughness of R_a = 18.6 µm. The thickness of the coating was increasing with the longer time of the galvanizing treatment and in the 600^{th} second of the treatment was thicker by 12% on the surface with a lower value of the R_a parameter.

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