The aluminizing in powder technology of AISI 304 steel

D B Băitanu¹, D G Gălușcă¹, D C Achiței¹,², M G Minciună¹,², Mohd Mustafa Al Bakri Abdullah²

¹Department Technologies and Equipments for Materials Processing, Gheorghe Asachi Technical University of Iasi, D Mangeron Street, no 41A, Iasi
²Center of Excellence Geopolymer & Green Technology (CEGeoGTech), School of Materials Engineering, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia

E-mail: doru_baitanu@yahoo.ro, dangalusca@yahoo.com, dragos_adc@tuiasi.ro, mirabela.minciuna@yahoo.ro

Abstract. The paper presents a study about the aluminizing treatments applied to AISI 304 stainless steel, with the purpose to improve the corrosion resistance. The aluminizing is realized in a powder medium, composed by aluminium powder (with 99.95 % purity), aluminium oxide Al₂O₃ and ammonium chloride NH₄Cl. The structural characterization was made by scanning electronic microscopy to highlight the structure of layer after aluminizing, at different magnitudes.

1. Introduction

The aluminizing represents a superficial saturation process of steel or cast iron, with aluminium, which imprint to these a high resistance to oxidation and atmospheric corrosion. Steel and cast iron, after aluminizing, are used like substitutes of steels or alloyed materials, which resist to oxides formation at 800–900°C, and in some cases up to 950–1000°C.

Can be subjected to aluminizing the cylinders of high pressure of turbines made by pearlite steels which work at 560-585°C, gases turbine blades, guide disks of gas turbines and shafts of plant by gases turbine made from austenite refractory steels. There are cases by aluminizing of alloys with complex composition and on metals (like Ti, Cu, Co). Aluminizing is made at 700–1100°C and can obtain a thickness of aluminized layer between 0.02-0.8 mm limits.

The superficial zone of aluminized layer has a high hardness (up to 500HV). However, the aluminized layer has a small usage resistance. The aluminized layer is distinguished by fragility, if the aluminium content is high. To decrease the fragility of this layer, can apply a diffusion annealing. If in superficial zone of aluminized layer, the content of aluminium is 20-30%, the layer has a good tenacity.

The aluminized layer presents noncorrosive properties, with high values for some mediums, like air. A good corrosion resistance in air is possessed by aluminized steels in melting by aluminium and iron and it is used for protection of wires, bands, household items, parts for automotives. The aluminized steel is much resistant against atmospheric corrosion and corrosion in sea water, than galvanized steels in melting zinc. After aluminizing, the parts must be cleaned and oiled.

The minimum content in aluminium from ferro-aluminium alloy, which ensures a high resistance at oxide formation, is by 8%. But in the aluminizing case, in the superficial layers of steel it is realizing a higher content of aluminium. The heating of aluminized layer in oxidizing medium leads to formation
of a thin film on steel surface, but resistant, by aluminium oxide, which protect the steel against oxidation.

The resistance of parts in work conditions it is conditioned by the thickness of aluminized layer and his content in aluminium. In the exploitation process of thin parts at high temperature, the aluminium has time to diffuse until their mid and from this reason, the decrease of aluminium content in the superficial layer is slowed.

The advantages of aluminizing parts at high temperature is bigger at working in hydrogen sulphide medium, which favourite discarding of steel parts, inclusive the parts made from steels resistant to oxides formation.

2. Experiments

2.1. Determination of chemical composition for base material

The analysis of chemical composition was made on Foundry Masters Spectrometer, 01J0013 model, manufactured by WAS Worldwide Analytical Systems AG. With WASLAB software and the expandable calibration soft, were obtained the analysis bulletins, which present the determined values.

The analyzed samples was cut, and after, polished on abrasive papers, using cooling water, for not overheat the samples in the processing time.

The average values determined for alloying elements, are present in table 1 and fall the material in the stainless steel class.

| Table 1. Chemical composition determined for the analyzed samples |
|------------------|---|---|---|---|---|---|---|---|
| Fe   | C   | Si  | Mn  | P  | S  | Cr  | Mo  |
| 64.60 | 0.16 | 2.28 | 1.01 | < 0.01 | < 0.01 | 18.90 | 0.33 |
| Ni   | Al  | Co  | Cu  | Nb | Ti | V   | W   |
| 12.10 | 0.02 | 0.12 | 0.15 | 0.02 | 0.01 | 0.07 | 0.04 |

From the industrial applications of AISI 304 steel can remember: chemical equipment, food processing equipment, equipments for beer processing, cryogenic dishes, gutters, and downpipes.

2.2. Structural modifications induced by thermo-chemical treatment

The aluminizing consists by the pieces heating in boxes which contain a mixture by aluminium powder (figure 2.a), ammonium chloride (NH₄Cl) (figure 2.b), aluminium oxide (figure 2.c). At the temperature between 900-1100°C take place the reactions: NH₄Cl → NH₃ + HCl; 6HCl + 2Al → 2AlCl₃ + 3H₂; AlCl₃ + Fe → FeCl₃ + Al activ; 2NH₃ → 3H₂ + 2 N activ

The aluminium diffuse in steel, and nitrogen and hydrogen form an unoxidized atmosphere. The aluminium oxide is designed to not form the powder agglomerations of aluminium. The thickness of alloyed layer, which contain 40-50 % aluminium is 0.1-1 mm and depends by temperature and maintaining time.

The aluminizing was made at a maintaining temperature T = 1000°C, conformable the diagrams from figure 1.

Before aluminizing treatment, the samples were polished on abrasive papers, to obtain a good surface quality and remove any impurities.

The aluminizing was made in a steel recipient, with thick walls (figure 2.d). The samples are placed inside recipient, ensuring a mixture aluminizing layer around these. The precinct was sealed with a metallic cover, in which are provided some exhausted holes for reaction gases.

The aluminizing was made in iron or chrome-nickel boxes. After casting the first layer of powder, this is slightly beaten. Between the pieces is placed the control piece.

The ammonium chloride NH₄Cl (figure 2.b) is used like reaction accelerator of deposition process. The aluminium oxide doesn’t participate at the process, but prevent the particles melting and implicit, the adherence to the pieces surface or recipient.
After aluminizing, it is recommend a diffuse annealing for aluminium, at 900–1050°C, for 4-5 hours, when the layer thickness increase with 20-40% and layer fragility (due to the presence of Al₄C₃ carbide) decrease. The structure of layer, after aluminizing, consist by a solid solution by alloyed ferrite with aluminium, rich in Fe₂Al₅, Fe₃Al, Fe₂Al₅ and Al₄C₃.

2.3. Structural analysis by scanning electronic microscopy

The analysis is made on SEM model VEGA II LSH, manufacturing by TESCAN Cehia, coupled by a EDX detector, type QUANTAC QX2, manufactured by ROENTEC Germany.

The chemical composition of steel resistant at corrosion is established in function of medium in which the pieces will work. The principal mode to increase the corrosion resistance is to adding the elements which form on surface thin layers which protect the base material, preventing the contact between the piece and the aggressive medium.

The experiments were made on samples with small dimensions. The alloyed steel is part of austenite stainless steels.
The increase of oxidation resistance is obtained especially by adding Cr, Al and Si, elements which are dissolved in Fe and which form in time of heating the protector layers of oxides (Cr, Fe)$_2$O$_3$; (Al, Fe)$_2$O$_3$.

In the equilibrium state, the microstructure of these steels is formed by austenite, ferrite and carbides (figure 3). These steels are characterized by an acceptable breaking resistance, small yield strength, and good characteristics of ductility, tenacity and high corrosion resistance in oxidant mediums.

After immersion and maintaining of steel samples in aluminizing recipient, it is developed the formation of a aluminium layer, with 1 mm thickness, at the exterior of piece (figure 4 a,b). The aluminium layer which is adherent to the piece, present a small roughness (figure 4 c).

By applying a diffusion heat treatment, in the superficial layer of sample are placed an increase of aluminium content, fact that provided that the thermo-chemical treatment of aluminizing is reached the goal.

3. Conclusions
The principal mode to increase the corrosion resistance is the addition of elements which form on surface the thin films which protect the base material, preventing the contact between the piece and the aggressive medium.

The aluminizing thermo-chemical treatment is a solution to improve the corrosion resistance of pieces, which work in automotive industry.

The aluminium layers obtained by powder aluminizing that adheres to the pieces, is thin and slightly rough and ensure a good corrosion resistance in different aggressive mediums.

References
[1] A. S. Podder, A. Bhanja, 2013 Advanced Materials Research, Vol. 794, pp. 731-740.
[2] D. Moore, 2001 Heat Treating Progress, pp. 29-33.
[3] D. Scott MacKenzie, 2001 Heat Treating Progress, pp. 37-43.
[4] G. E. Totten, H. M. Tensi, 2002 Heat Treating Progress, pp. 01-04.
[5] N.I. Kobasko, G.E. Totten, G.M. Webster and C.E. Bates, 1998, 18th Heat Treating Society Conference Proceedings, ASM International, Materials Park, OH, pp. 559-567.
[6] G. Negrea, A. Molinari, 1998, Procede avansate in ingineria suprafetelor, Editura U.T.Pres, Cluj-Napoca.
[7] L. Shuqing, S. Daxim, C. Yihing, C. Zhuyou, 2000, Chemical Journal of Chinese Universities, vol. 21, (3), pp. 339.
[8] K. Leclere, C. Briens, T. Gauthie, J. Bayle, P. Guigon, M. Bergougnou, 2004 Chemical Engineering and processing, vol. 43, pp. 693.
[9] S. Bruhns, J. Werther, 2005 AIChE Journal, vol. 51 (3), pp. 766.