



THE EFFECT OF ALUMINUM COATING ON STAINLESS STEEL 316L AND ALPHA IRON

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Abstract

Hot-Dip-Aluminizing, is a versatile technique for protection of iron and steel from harsh environments. Morphology, profile as well as growth of the intermetallics formed on the interface of aluminium coating and the substrate are affected by varying the dipping time and even the substrate that is stainless steel 316L or alpha iron. This effect has been investigated using optical and scanning electron microscopy and diffusion mathematical laws. Hot-dip-aluminized alpha iron exhibits a tongue like interface growth and a thick interlayer with successively increasing dipping time, whereas in case of stainless steel 316L, the thickness of the interlayer decreases and the interface between the interlayer and the substrate successively becomes 'smoother'. Micro Vickers hardness tester was used for testing hardness on three different areas of cross-sectional aluminized samples it was carried out on coating, inter-layer and on substrate. These results showed that the hardness of the interlayer was maximum as it contains the brittle intermetallic compounds formed during aluminizing process.

Keywords: Hot-Dip-Aluminizing, Coating Thickness, Hardness and Diffusion

1. Introduction

Majority of the Engineering failures originates from the surfaces and components degrade in service leading to failures such as wear and fatigue etc. That's why surface modifications had always been a hot research topic in the engineering background. Surface modifications by coatings has become an essential step to improve the surface properties by altering physical, chemical or electrical characteristics of a material surface, such as resistance to wear, creep, fatigue or making the material hard enough to with-stand high values of load. Various conventional techniques are utilized for depositing the desired material onto the surface to achieve surface modification. The aluminized steel structures were mostly used for telecommunication towers, oil transportation tanks, browsers, and electricity towers [1]. Shiev *et al.* [2] performed experiment regarding corrosion of 316L stainless steel by modifying its structure. They modified the sample having composition C= 0.023%, Si= 0.042%, Mn= 1.715% Ni=11.01%, Cr= 17.26%, Mo= 2.06% and trace amounts of P, S, V and titanium.. Awan *et al.* [3] has studied the influence of coating thickness on the formability and ductility of hot-dip-aluminized steel using a 3-point bend test and optical metallography. Their research showed that the measured ductility of the sheet sample increased with increasing the

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amount of silicon in the aluminizing melt. A hot dip aluminizing (HDA) process has been used to increase the oxidation and corrosion resistance and the hardness of the steel substrate [4, 5].

Zhong-xiang *et al.* [6] studied Al-Si coated boron steel with Gleeble-3500, in comparison with the uncoated one and used optical microscope to investigate the effect of deformation conditions on the coating integrity. Ultimate tensile strength and ductility of the Al-Si coated boron steel were found are lower than those of the uncoated steel. It was found that Al-Si coating formability could be optimized by controlling the phase transformation of the ductile Fe-rich intermetallic compounds. Khazraji *et al.* [7] took stainless steel rods of different diameters and dipped them in pure aluminum for different time and temperature. The result found by response surface methodology (RSM) showed that optimum dipping conditions for hot aluminizing was 807°C and 3min. Yao *et al.* [8] used hot dipping method to deposit three types of coating (Zn-Al-Mg-Cu) ZAM on mild steel substrates. The results showed that the microhardness as well as impedance of ZAM was improved. The present study focus on the two areas: firstly the determination of coating thickness secondly the diffusion analysis of coating on stainless steel 316L and alpha iron with varying time. Diffusion study was based on the comparative study of the diffusion of Al into the alloy steel 316L and the ferritic iron. Optical microscope, scanning electron microscope and micro-Vickers were used for the optimisation of properties.

2. Materials and Methods

Stainless steel 316L and alpha iron substrate sheets were cut into six samples having dimensions 1.5 inches length, 0.5 inches width and 1.1 mm thickness, 3 inches length, 1 inch width and 2 mm thickness respectively. Samples were given name and numbers for the ease in experimentation. The surfaces of stainless steel 316L and alpha iron were cleaned and treated with a 50% diluted solution of nitric acid, rinsed in running water and then in ethanol. Molten bath of pure aluminium was prepared for aluminizing the substrate. The specimens for hot dip treatment were drilled and hung by steel wires. The samples were pre heated during the melting of pure aluminium and when the required melt temperature of 765°C was reached, the samples were lowered into the molten flux, for few minutes and then immersed in the melt. The specimens for hot dipping were immersed in the bath at 765°C for 3 minutes, 5 minutes and 7 minutes respectively. When hot dipping experiment was completed, the samples were taken out from the melt and cooled in air as shown in Figure 1(a, b) respectively.

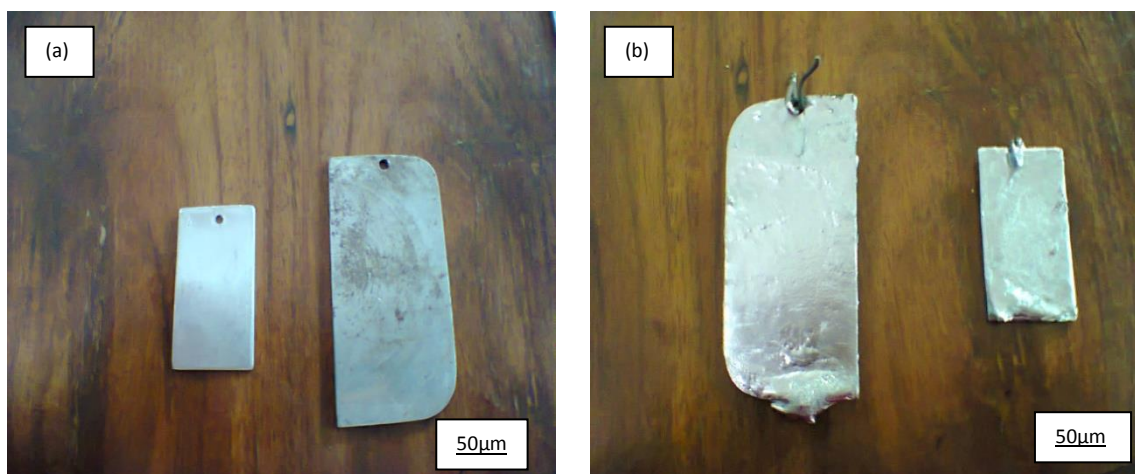


Figure 1. (a) Samples of SS before Aluminizing (b) Samples Alpha Iron after Aluminizing

The coated samples were hot mounted using Bakelite powder and were grinded manually using emery paper varying grit size, started from 120µm to 1000µm. The polishing was performed by nylon cloth impregnated with 1 micron diamond paste lubricated with lapping oil. The samples were etched using HF as etchant

3. Results and Discussion

3.1 Emission Spectroscopy Analysis Stainless Steel 316L Composition

The chemical composition of the stainless steel 316L was checked using emission spectrometer and composition was given in table 1. The composition of alpha iron was as Fe 98.45% and C 0.02%.

Table 1. Composition of 316L stainless steel

Element	%	Element	%	Element	%
Fe	70.11	C	0.03%	Ni	8.126
Si	0.471	Mn	1.800	Mo	0.300
Ti	0.007	Al	0.019	Cu	0.443
Cr	18.704	V	0.104	Nb.	0.03

3.2 Coating Thickness of Aluminized Samples

Coating thickness for all samples was analyzed using optical microscope. An almost uniform and adherent coating of pure aluminium was obtained on all samples. The relationship between different substrate, dipping time and coating thickness is given in Table 2 and Table 3. In case of comparison between different substrates, coating thickness of stainless steel 316L is less as compared to alpha iron. The reason is the presence of silicon, chromium and nickel in the substrate which actually occupies the

vacant sites during diffusion and hinders the diffusion process [9]. As 316L has more carbon content than alpha iron, that's why it's coating thickness is less as compared to alpha iron. In case of increasing time, the coating thickness as well as intermetallic layer thickness increases following the relationship ($x = kt^{0.5}$), i.e. the growth rate increases [10].

Table 2. Coating thickness calculation for Al on stainless steel 316L

Sample ID	Dipping Time (minutes)	Coating Thickness (μm)
Al-SS-3	3	60.3
Al-SS-5	5	71.5
Al-SS-7	7	79.8

Table 3. Coating thickness calculation for Al on alpha iron

Sample ID	Dipping Time (Min)	Coating Thickness (μm)
Al- α -Fe-3	3	54.7
Al- α -Fe-5	5	89.8
Al- α -Fe-7	7	99.3

3.3 Interlayer Thickness of coating of stainless steel 316L and Alpha iron

The interface between the steel substrate and coating is smooth and with increasing the dipping time its thickness increases. But if a comparison is made between alpha iron and steel the interlayer thickness for alpha iron is more than that of stainless steel. The reason behind this is that the stainless steel is an alloy of steel having Ni, Cr, Si, and P which resist the inward growth of aluminum. Whereas alpha iron is simple carbon steel having no alloying elements. So for diffusion of aluminum is more and thick interlayered as well. The interlayer thickness of coating also increases with time as shown in table 5 and table 6 for both stainless steel 316L and alpha iron.

Table 5. Interlayer thickness calculation for Al on stainless steel 316L

Sample ID	Dipping Time (minutes)	Coating Thickness (μm)
Al-SS-3	3	10.6
Al-SS-5	5	14.4
Al-SS-7	7	16.5

Table 6. Interlayer thickness calculation for Al on alpha iron

Sample ID	Dipping Time (minutes)	Coating Thickness (μm)
Al- α -Fe-3	3	34.8
Al- α -Fe-5	5	47.4
Al- α -Fe-7	7	58.4

3.4 Micrograph of Interlayer Thickness on stainless steel 316L

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3.5 Study of Diffusion Morphology using SEM

The morphology of the diffusion can be understood through the formation of intermetallics during diffusion. The morphologies of stainless steel 316L is shown in Figure 2 (a, b, c) and the morphology of alpha iron is shown in Figure 3 (a, b, c). It was observed that intermetallics formed in alpha iron show tongue like structure while in stainless steel 316L show smooth structure. This is also due to the presence of silicon in stainless steel while absent in alpha iron. When Si atom occupies the vacancy site, it blocks easy diffusion path and results in the disappearance of tongue-like morphology.

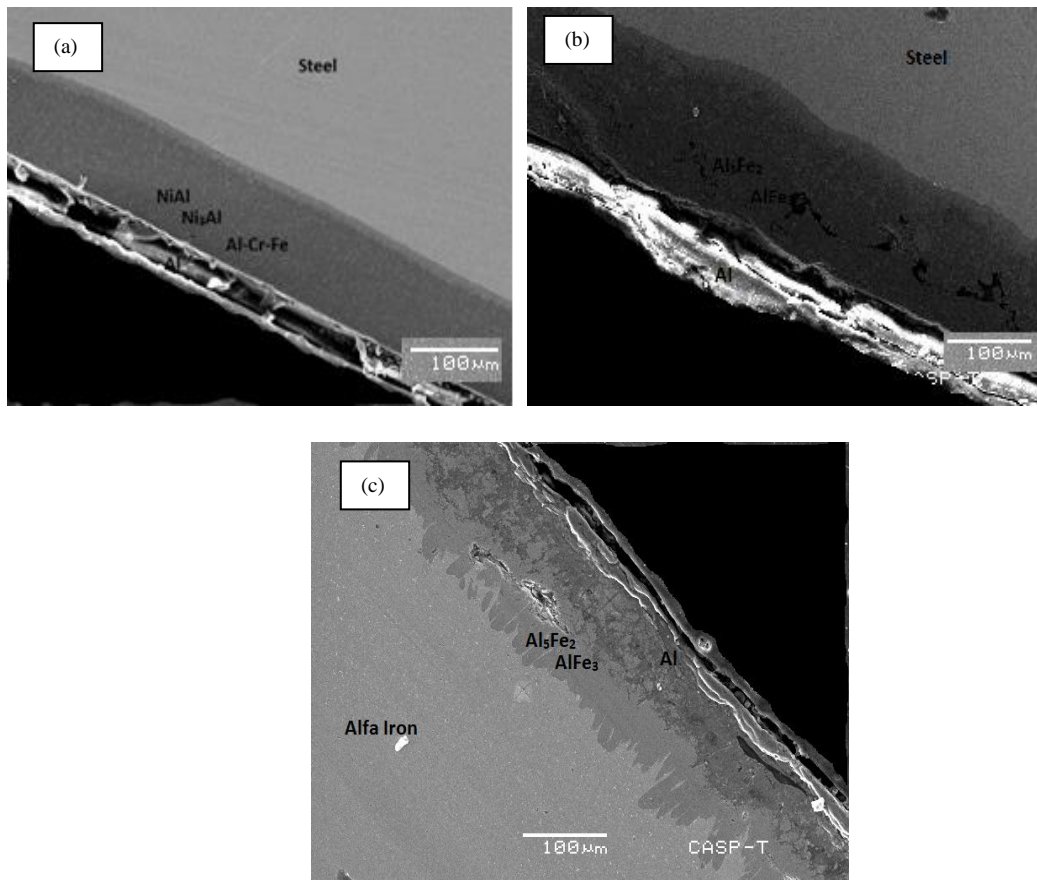


Figure 2. (a) Al-SS-3 diffusion, (b) Al-SS-5 diffusion, (c) Al-SS-7 diffusion

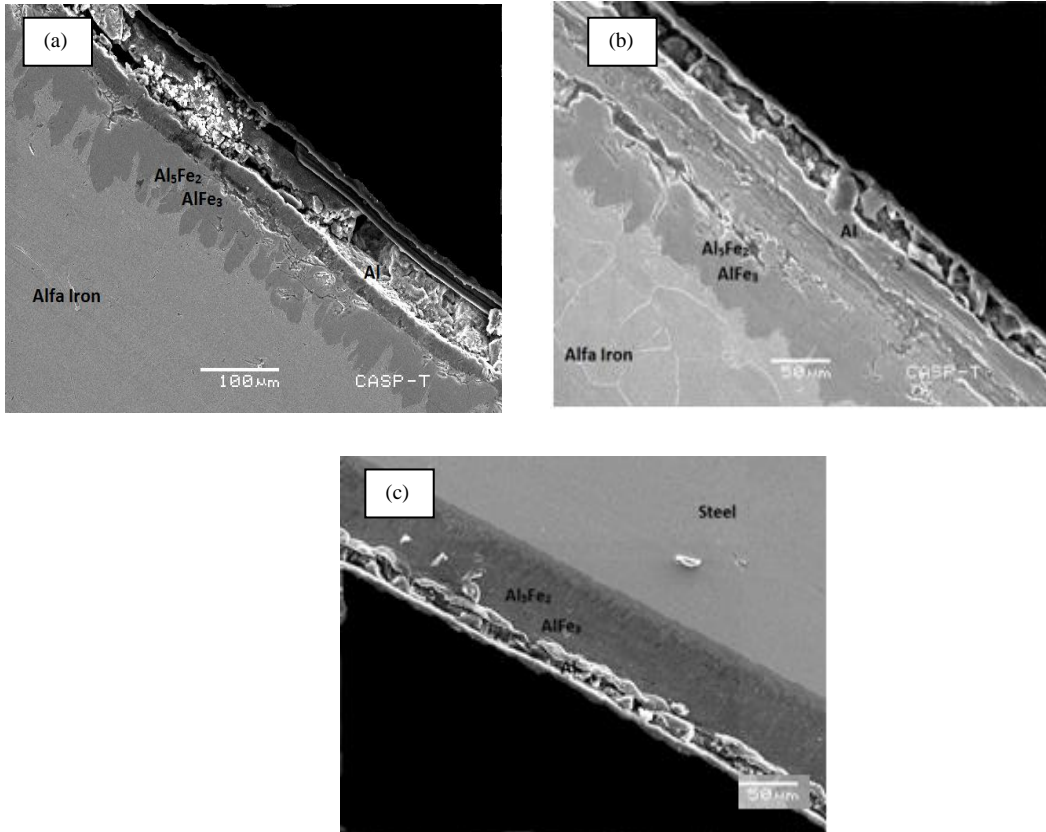


Figure 3. (a) Al- α -Fe-3, (b) Al- α -Fe-5 Al-SS-5 diffusion, (c) Al- α -Fe-7

3.6 Microhardness of the Intermetallics and Coated samples of stainless steel 316L and alpha iron

By applying coating through hot dipping method their hardness values are increased as the coating is diffused in the substrate resulting in the formation of brittle intermetallics which are hard. The values of Micro hardness (Hv) from case to core for both substrates of stainless steel 316L and alpha iron are given in Figure 4 and Figure 5. It is further observed that by increasing time hardness increases, as more time will encourage more diffusion, hence thicker layer of intermetallics and more hardness as shown in Figure 6.

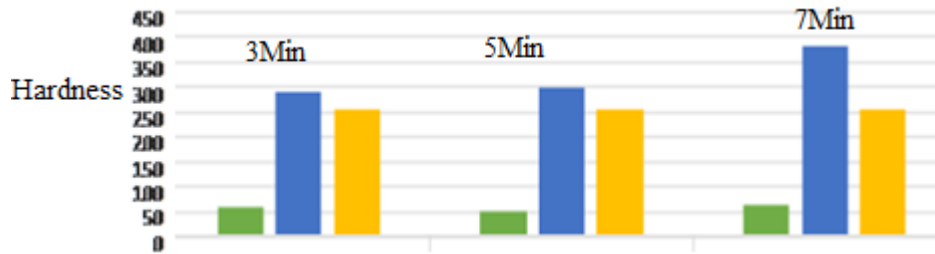


Figure 4 Hardness Values from case to core (stainless steel 316L)

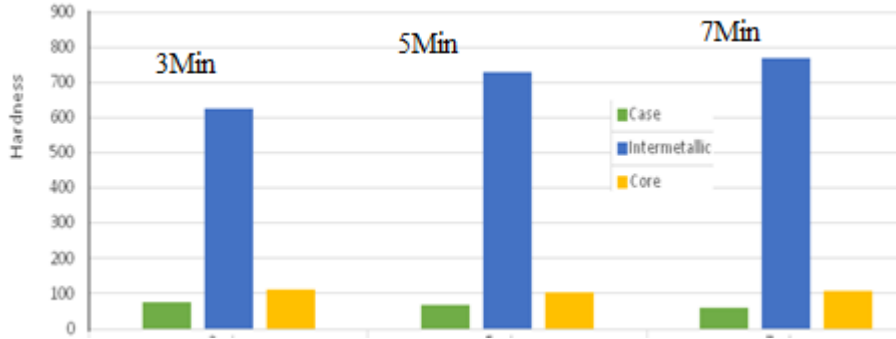


Figure 5 Hardness Values from case to core (alpha iron)

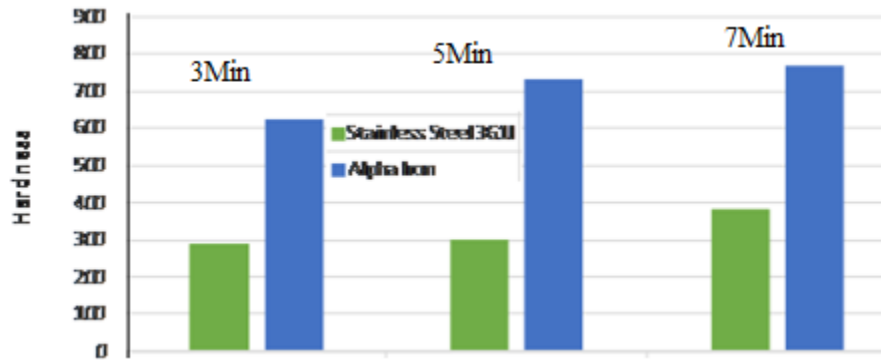


Figure 6 Hardness Vs Time trend for both substrates

3.7 Diffusion Analysis of coated samples of 316L Stainless Steel and Alpha Iron

Diffusion analysis was evaluated using Fick's second law of diffusion as given in equation 1.

$$k = x/2(\sqrt{DT}) \quad (1)$$

Where x is the thickness of the interlayer i.e. the distance where the diffusion takes place. By putting the values in this equation, we can find the constant k. Then using this equation 2, the diffusion can be calculated for every time (as the diffusion is totally non steady state) and shown in Figure 7 and Figure 8. The results showed that aluminium has more diffusion in stainless steel due to alloying elements which occupy the vacant sites of intermetallics resulting in thin diffusion layer [11].

$$D = x^2 / 4kt \quad (2)$$

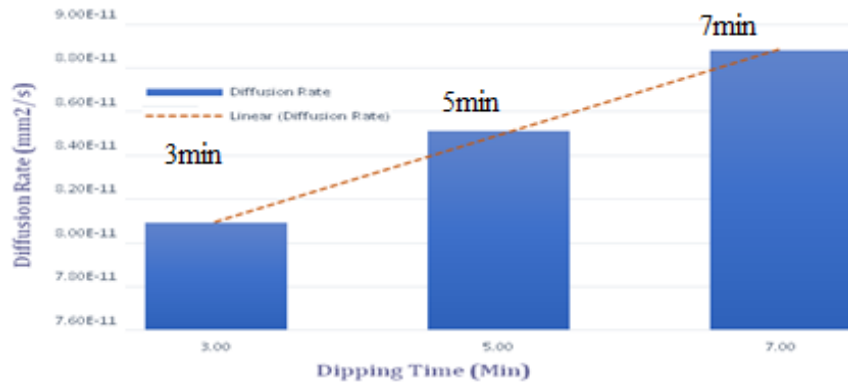


Figure 7 Diffusion vs Dipping Time (Stainless Steel 316L)

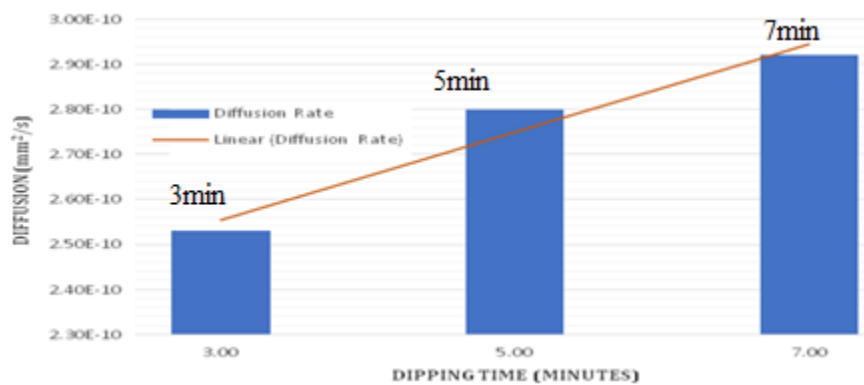


Figure 8 Diffusion vs Dipping Time (Alpha iron)

4. Conclusion

Alpha Iron and Stainless steel samples were effectively coated using hot dipping technique in commercially pure aluminium at 765°C by using different dipping times. It was found that coating thickness was increased from 10.6µm to 16.5µm for steel and for alpha iron from 34.8µm and 58.8 µm respectively as the time was increasing. Hardness of coated samples of steel and alpha iron was found increase for intermetallic layers for both cases. The hardness of coating samples of steel and alpha iron was also found increased from 292 Hv to 385Hv for steel and 625Hv to 769 Hv by increasing time from 3 Min to 7Min. It was found that the thickness of the coating was normally seemed to increase with increase in dipping time as shown in SEM analysis of both 316L stainless steel and Alpha iron. It was concluded that aluminizing can be employed as a useful technique to improve the surface characteristics of Alpha Iron and steel compound.

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