5ème Conférence Internationale des Energies Renouvelables (CIER– 2017)
Proceeding of Engineering and Technology –PET
Vol.29 pp.24-28

Study of the behavior of a high temperature aluminum coated steel

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***Abstract*---This work studies the feasibility of obtaining steel aluminide coatings on mild steel substrate by aluminizing treatment (HDA) especially at the temperature of 800°C and 1000°C. The mild steel was coated for 90 min in air. Detailed optical, scanning electron microscope (SEM), energy dispersive X-ray spectroscopy (EDS) and electron backscatter diffraction (EBSD) investigations were performed to characterize the phases identified during aluminizing. After aluminizing, three layers were formed, external aluminum layer, intermetallic layer and steel substrate. The results showed that the intermetallic layer growing toward the steel substrate possessed a tongue-like morphology which delimited by a strong concentration of pearlite at the temperature of 800°C. But this morphology tends to disappear and takes on a planar aspect after aluminizing at 1000°.However, the interface intermetallic layer /external aluminum layer evolved under an irregular profil with a tongue-like morphology in the temperature of 800°C and 1000°C. The intermetallic layer of the hot dipped was composed of minor monoclinic $FeAl_3$ and major orthorhombic Fe_2Al_5 according to the EDS and EBSD analysis at the temperature of 800°C and 1000°C. But at the interface intermetallic/steel, the intermetallic compounds formed in this level are FeAl and Fe_3Al of cubic crystal structureat the temperatures of 1000°C and 800°C respectively. These intermetallic compounds which appear in very thin layer, at the interface, are tangent toward the steel.**

***Keywords:* Mild steel, Hot-dipping, intermetallic Compounds, Aluminide layer, EBSD.**

I. INTRODUCTION

Aluminizing in aluminum melt is an effective method used to form a thin layer of aluminum on the surface of steel substrate for improving oxidation and corrosion resistance [1-4]. Aluminizing is usually carried out by the hot-dip process in which the component to be coated is treated in an aluminum molten bath. The interface between the substrate and the intermetallic layer appeared tongue-like morphology in most cases. In the process, Al diffuses into steel to form intermetallic compound between the outer aluminum coat and the substrate steel [5, 6]. This compound layer may be composed of one or more of the intermetallic compounds between iron and aluminum, like Fe_2Al_5 and Fe_3Al. This compounds are very brittle in nature [5, 6], and cause cracking and peeling during bending and machining [7]. Thus, the present paper is to present the results of an experimental study on the effects of time aluminizing during aluminizing at temperature of 800°C on the microstructure of Fe-Al coated steel substrate.

II. Experimental

A. Materials

The substrate material used for the investigation was a medium carbon cubic steel with a nominal composition Fe-0,4C (wt %). Commercial grade pure aluminum with a purity of 99, 5 % was used as the molten aluminum bath.

B. Sample preparation

Aluminum ingot was melted in a graphite crucible in a resistance furnace, and the melt was maintained at 800°C and 1000°C. After being degreased in 100 g/l sodium hydrate solution at 50 °C for 5 min, rinsed with water, and then descaled in a 20% hydrochloric acid solution, rinsed with water again, and pretreated in a potassium salt solution at 92 °C for 2 min, the steels substrates were immersed in the molten aluminum bath for a period of time, 180min. Then the samples were taken out from the melt and cooled in air.

ISSN 2356-5608

C. Microstructure and property characterization

After hot-dip aluminizing, Microstructure and chemical composition of the cross-section of the coated specimens were analyzed using scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) and back scattered diffraction (EBSD). The different phases of the surface layers were determined with EBSD technique analysis.

TABLE I. EDAX RESULTS

	Fe (At%)	Al (At%)	Phase
A	98.32	/	Fe
B	72.71	23.35	Fe_3Al
C	25.75	74.25	Fe_2Al_5
D	00.17	99.83	Al
E	21.86	78.14	$FeAl_3$
F	47.40	52.60	FeAl

II. Result and discussion

By aluminizing the samples in pure aluminum, typical microstructure of samples aluminized of medium carbon steel in the temperature on 800°C and 1000°C, for 90min dipping times, are shown in Figure1and 2(a and c). Three distinct regions which could be easily identified in these microstructures include; the outer aluminum layer, the intermetallic compound layer, and the substrate steel. It can be observed that the thickness of intermetallic layers increases with increasing temperature. It can also be observed that the morphology of intermetallic layer appears irregular with a finger like orientated towards the iron in the temperature of 800°C but this morphology tend to become planar and uniforme at the temperature of 1000°C.

Figure (1a) and (2c) can be divided into three areas with different brightness, the bright area at the high side is steel, the dark one at the low side is Al, and the grey one with tongue like pattern located in between is iron aluminides. The intermetallic layer (about 3-4 mm thick) formed by Al diffusion into the steel substrate. The intermetallic layer mainly consisted of the brittle compound Fe_2Al_5. The composition found with EDX point analyses was 74.25 at.% Al, 25.75 at.% Fe. In the external layer showed in Figure (1b and 2d), there are ramifications in forms of crystals globular and lamellar ramifications which correspond to intermetallic compounds of $FeAl_3$. The composition found with EDX point analysis was 21.86% at Fe and 78.14 at%Al. which dispersed in the aluminum matrix.

But in the transition zone between the intermetallic layer and the steel substrate, a thin layer of the compound Fe_3Al could be detected at 800°C. An EDX point analyses was 23.35at% Al, 72.71at% Fe. But at 1000°C, the phase formed at the interface is FeAl. An EDX analysis was 47.40%At Fe and 52.60%Al. These intermetallic compounds were detected by EBSD analysis. The EDAX analysis at different positions in the microstructure is concluded in Table 1.

Additionally, cracks and voids could be observed in the intermetallic layer (Figure (1a and 2(c, d)) which were caused by grinding and polishing indicating the brittle nature of the aluminized layer. The voids were also attributed to the Kirkendall effect. The different diffusion rates between Fe and Al caused a net flux of vacancies to form voids at the interface between the aluminide layer and the steel substrate [9].

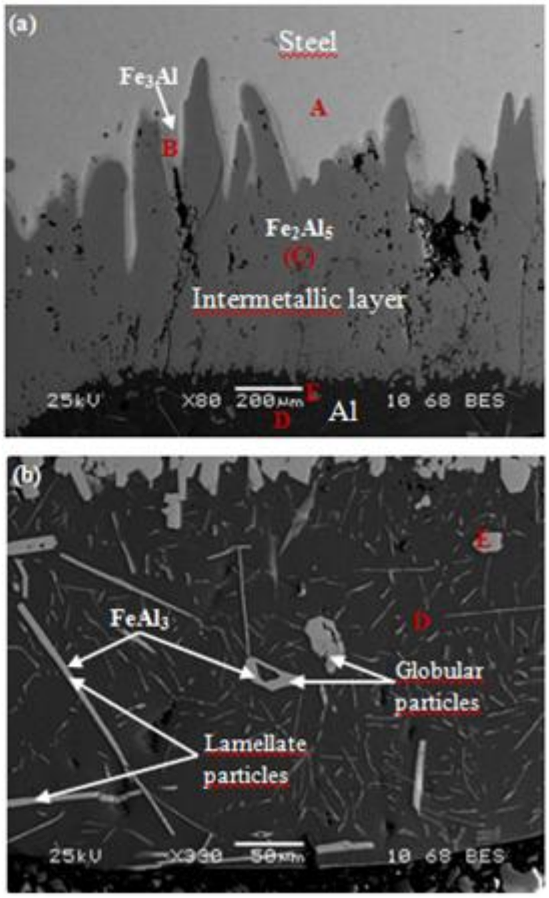

Fig.1. cross section micrographs of steel aluminized for 90mn at 800°C, (a) 200µm, (b) external layer.

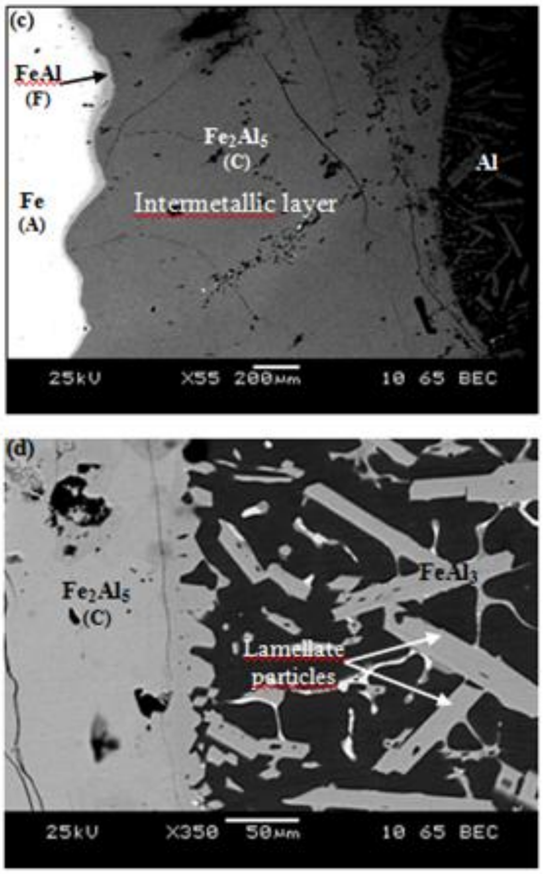

Fig.2. cross section micrographs of steel aluminized for 90mn at 1000°C, (c) 200µm, (d) external layer

In the intermetallic layer, the aluminum intensity appears more important by comparing it has that of iron, which is confirmed with analyses EDS and EBSD showing that the intermetallic layer is composed of intermetallics Fe_2Al_5 and Fe_3Al. The point of intersection between iron and aluminum located has a distance from 9µm confirms the interdiffusion of these two elements. While approaching towards the heart of steel, the aluminum intensity decreases whereas that of iron tends has to increase, it is the phase rich in iron.

According to the chemical compositions and crystallographic structures of the intermetallic phases in the aluminide layers which were acquired by means of EDS, there were Fe_2Al_5 and $FeAl_3$ formed in the aluminide layer on 0.4%C steel after hot-dipping into a pure aluminum molten bath for various immersion times at 800 ◦C and 1000°C. But at the interface intermetallic/steel, the intermetallic compounds formed in this level are FeAl cubic and Fe_3Al at the temperatures of 1000°C and 800°C respectively.

For a further verification of the phase constitution of the aluminide layers, EBSD analysis were applied for identifying each crystallographic structure of the intermetallic phases and the phase distributions in the aluminide layers after hot-dipping for various times. Figure (4(a, b, c)) are the experimental lines of Kikkuchi and their indexed results of the A, B and C phases in the steel

was revealed that the crystallographic structures of the A, B and C phases; are cubic; iron of the steel, space group(Oh) [m3m], a=2.87 Å, cubic Fe_3Al, space group (Oh) [m3m], a=5.78Å and orthorhombic Fe_2Al_5, space group[D2h]mmm, a=7.656 Å, b=6.415 Å, c=4.218 Å, respectively, as showed in figure (3).

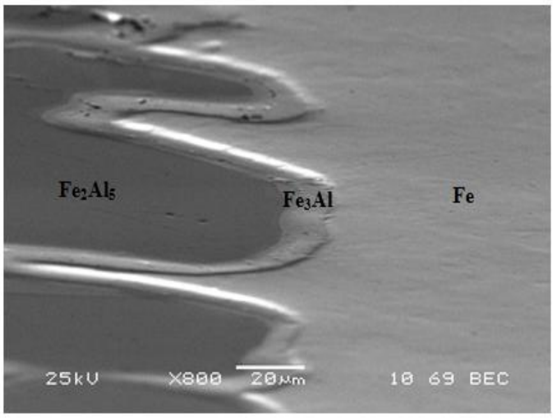

Fig.3. EBSD analysis showing the phase distribution of specimens aluminized in air at 800°C for 90mn

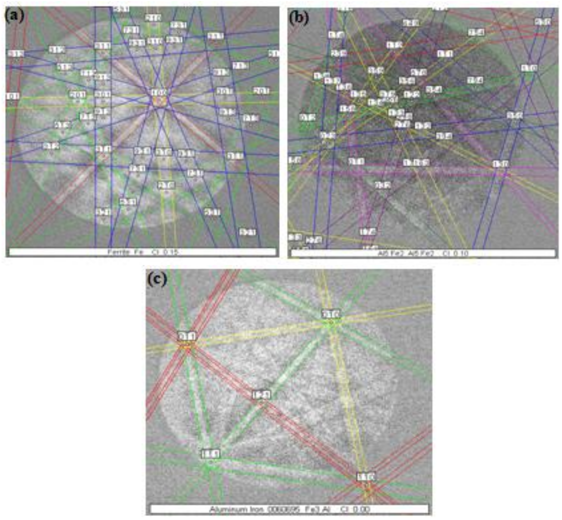

Fig.4. representative experimental EBSD pattern of different phases in the steel aluminized. (a) phase indexing as cubic Fe, (b) phase indexing as orthorhombic Fe2Al5and (c) phase indexing as cubic Fe3Al.

But at the temperature of 1000°C as shown in figure (6c), It was revealed that the crystallographic structures of the F (figure 2c) phase is the cubic FeAl, space groupe Pm3m, a=2.9030Å.

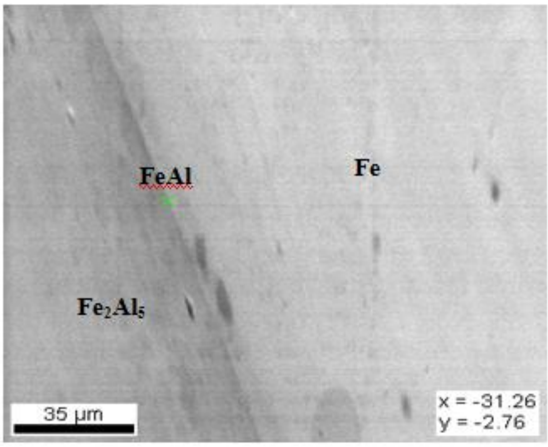

Fig.5. EBSD analysis showing the phase distribution of specimens aluminized in air at 1000°C for 90mn

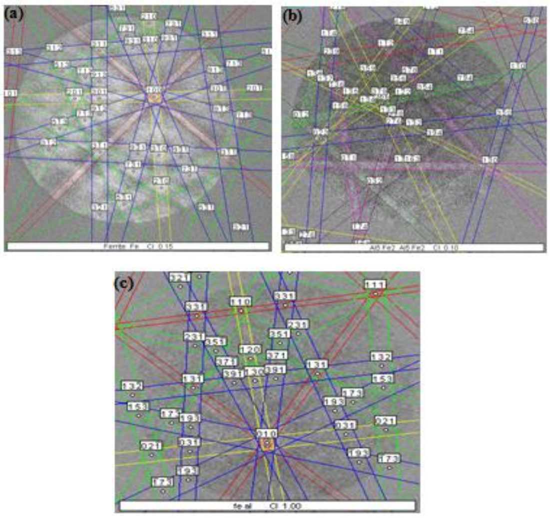

Fig.6. representative experimental EBSD pattern of different phases in the steel aluminized. (a) phase indexing as cubic Fe, (b) phase indexing as orthorhombic Fe_2Al_5 and (c) phase indexing as cubic FeAl.

IV.CONCLUSION

Hot-dip aluminizing coating was investigated in the temperature from 800 °C and 1000°C in air for 90min. The results may be summarized as follows:

The thickness of the intermetallic layer in the steel substrate increase with increasing temperature and the morphology of intermetallic layer appear irregular with a finger like orientated towards the iron at 800°C, but this morphology tend to become planar and uniforme at the temperature of 1000°C.

The EDX and EBSD analysis revealed that the intermetallic layer was composed of minor monoclinic $FeAl_3$ and major orthorhombic Fe_2Al_5 at the temperature of 800°C and 1000°C. But at the interface intermetallic/steel, the intermetallics compounds formed in this level are FeAl cubic and Fe_3Al at the temperatures of 1000°C and 800°C respectively.

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