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Effect of Hot-Dip time on Mechanical Properties of Low Carbon Steel in molten Al-Si alloy at 850 °C

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ABSTRACT

Carbon steel is one of the materials widely used in industries due to its low price and mechanical properties; however, it needs improvement to provide corrosion resistance in industrial applications. The Al-Si coatings on low carbon steel were modified by the hot dipping technique and inspect the effects of the dipped time on the thickness of the coating in molten Al-Si alloy at 850°C for 15,30, 60, 90, and 120 sec. Two layers appeared outer coating as a thick Al-Si phase and inner coating as a thin Al-Fe phase. The thickness and hardness of the coating layers increase with immersion time increased. The lower micro hardness was (130~250HV), and the higher micro hardness was (490~ 900HV) due to the increase of the Al- Fe inter metallic layer. However, Al-Fe inter metallic prolonged growth, which 900 HV was a higher micro hardness and 140µm thickness values for120 sec.

.**Keywords:** Al-Si alloy, Hot dipping, Low carbon steel, Mechanical properties, Surface treatment.

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تأثير زمن الغمس الساخن على الخواص الميكانيكية للفولاذ منخفض الكربون في سبيكة الالومنيوم والسليكون المنصهر عند درجة حرارة 850 درجة مئوية

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الملخص

الصلب الكربوني هو أحد المواد المستخدمة على نطاق واسع في الصناعات بسبب انخفاض سعره وخصائصه الميكانيكية؛ وبالرغم من ذلك، فإنه يحتاج إلى تحسين خصائصه لمقاومة البلي والتآكل في التطبيقات الصناعية. تم تحسين مقاومة البلي والتآكل للصلب الكربوني بواسطة الطلاء بالغمر على الساخن في مصهور الالومينيوم-السليكون عند 850 درجة مئوية لمدة 15 ، 30 ، 60 ، 90 ، و 120 ثانية. ظهرت طبقتان طبقة خارجيه سميكة من Al-Si وطبقة داخليه رقيقة من Al-Fe. ومن خلال فحص تأثيرات زمن الغمر، فإن زيادة سمك وصلابة طبقات الطلاء تزداد مع زيادة زمن الغمر. حيث كانت الصلادة الأدنى (130 ~ 250 HV)، والصلابة الأعلى (490 ~ 900 HV) نتيجة لزيادة طبقة Al-Fe بين المعادن. ومع ذلك، فإن نمو طبقة Al-Fe زادت عند 120 ثانية، حيث أعطت أعلى صلابة 900 HV وسماكة 140 ميكرون.

الكلمات المفتاحية: سبيكة القصدير والالومنيوم، الغمس الساخن، فولاذ منخفض الكربون، الخصائص الميكانيكية، المعالجة السطحية.

1. Introduction

Materials take importance in any industrial development or technological progress. In addition, many research programs are underway to develop efficient materials and less expensive, such as composites, ceramics, polymers, etc. However, metal still alloys are the most commonly used in industrial applications, as scientists improve their characteristics. Given the importance of metal alloy applications, it is necessary to protect it against corrosion. Several techniques can be used, namely the addition of corrosion inhibitors, coatings, and surface treatments [1]. The various corrosion resistance techniques depend on the exposed environment. The coating deposition methods (hot-dip coatings are more economical than coatings obtained by electroplating and vacuum) are part of a physical process that improves mechanical properties [2-4].

Carbon steel is widely used in various industrial applications such as automotive, oil, gas, and construction due to its ease of form and low price. It provides low material costs while having material characteristics accepted by most industries [5-7]. However, carbon steels are easily corroded and easily oxidized when exposed to certain conditions [2,8,9]. Nevertheless, carbon steel is readily oxidized by forming a less dense iron oxide layer on the steel surface, making it unsuitable for corrosion resistance [10]. These oxidizing (corrosion) properties have deteriorated carbon steels' strength, serviceability, and aesthetic value. Therefore, corrosion resistance is an essential aspect of corrosion prevention. Carbon steel needs to be improved by using techniques to ensure that it can provide corrosion resistance in specific applications [11].

Aluminum is a very active metal that has resistance to corrosion by forming a protective layer of alumina (Al_2O_3), which Aluminum hot dip is a surface treatment to produces an aluminide layer on the surface of carbon steel to enhance oxidation resistance and protection of carbon steels in normal and high-temperature environments [12]. Moreover, the aluminum hot-dip coatings technique is the most effective and lowest cost method for modifying carbon steel surfaces [13]. This technique consists of immersing the carbon steel surface in a liquid bath involving reactive diffusion between the compounds in the bath and the iron in the steel. In addition, Aluminum hot dipping coating is a traditional technique because it involves metallurgic ally chemical bonding with higher bond strength between the coating and the

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substrate metal produced [7].

Aluminum in the pure formal has weak mechanical characteristics making it impossible to construct mechanical structures. Therefore, additives and the application of heat treatments cause precipitation of certain phases in the aluminum matrix. Generally, the hot-dip coatings technique gets the widespread attention of scientists because of its cheap, better resistant, and attractive properties than pure aluminum. Moreover, Al-Si alloy hot-dip coatings of low carbon steels are economical and of good quality. They combine the advantages of the corrosion resistance of aluminum (barrier effect) and the advantages of the mechanical behavior of steel [14].

Many studies were done in the Al-Si alloy hot-dip coatings of low carbon steels because of its ability which Fe-Al system formed that has the outstanding corrosion protection for low carbon steels at high temperatures and is economical with good quality [4,7,15,16]. The Fe-Al intermetallic phase helps increase the bond strength between the coating and the substrate required specific parameters and feasibility factors. The factors influencing intermetallic bond formation are coating material's nature, surface substrate, dipping time, heating temperature, and dipping speed [17,18]. Nevertheless, temperature and dipping time play a significant role in intermetallic formation because the diffusion mechanism of atoms directly affects the formation of intermetallic phases [19]. However, the high-temperature oxidation behavior of Al-Si aluminized layers on low carbon steel is not yet understood well [18, 20]. Through this study, the effect of various dipping times on the specimen surface in Al-Si alloy molten bath at 850 °C. This study aims to characterize the microstructure and surface properties of the specimen by changes in chemical construction and shape.

2. Experiment

2.1. Specimens

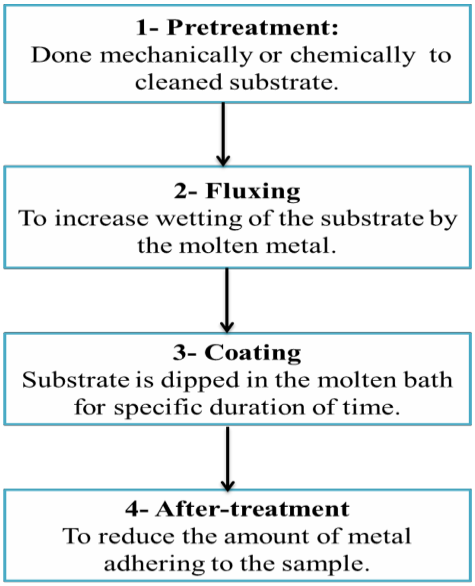
The corrosion specimens used were a steel sheet ASTM A463/A463M with the following dimensions: 81 mm x 22 mm x 3 mm and 3 mm thick sheet steel. The specimens were drilled to make one hole using a computer numerical control (C.N.C.) machine for hot dipping operation. The chemical composition of specimens used in this work is given in table (1).

Table 1. Chemical compositions in wt. % of carbon low alloyed steel grade

Elements (weight%)							
C % bgf	Mn %	Si %	P %	S %	Ni %	Cr %	Fe %
0.14	0.20	0.10	0.01	0.01	0.17	0.03	Balance

2.2 Surface Treatment Preparation

To investigate the microstructure and phase evolution of coating aluminide layers. The hot-dip aluminizing process involves four significant steps shown on the flow chart in figure (1).



1- Pretreatment:
Done mechanically or chemically to cleaned substrate.

2- Fluxing
To increase wetting of the substrate by the molten metal.

3- Coating
Substrate is dipped in the molten bath for specific duration of time.

4- After-treatment
To reduce the amount of metal adhering to the sample.

Figure 1. Flowchart of surface treatment preparation

- **PreTreatment**

The surfaces of specimens were subjected to surface treatment consisting of mechanically cleaned to remove scales or flatten; and chemically cleaned to remove oil, grease, or white corrosion products, as shown in figure (2). In addition, to increase the ability to produce a uniform adherent aluminum coating.

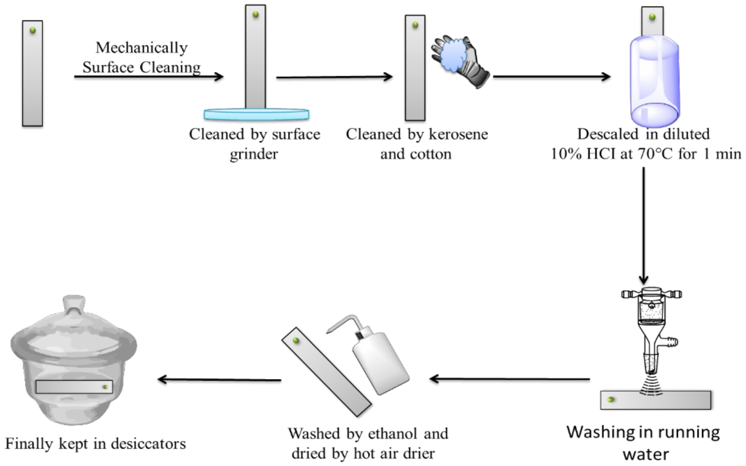


Figure 2. Schematic specimens surface cleaning procedures.

- **Fluxing**

The fluxing was a procedure for further cleaning by immersing the specimens in a molten salt flux floating on top of the molten bath before immersion into the coating bath [21]. The fluxing solution was prepared by adding the amounts of (44% LiCl, 30% NaCl, 16.7% NaF, and 9.3% KCl) to the water forming a 25% weight percent solution and heated to 350 °C [17]. The temperature was kept constant during the dipping process. Each sample was hanged by special wire was prepared and immersed in the fused flux to cover the surfaces with the flux for 3 min. It was taken out and dipped immediately while hot into the aluminum bath. The flux evaporated at the aluminum bath temperature to provide a clean and fresh surface to simplify contact with materials in the molten bath.

- **Coating**

The coating materials were; pure aluminum blocks Al-Si (89-11wt

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%). The Ovens manufactured by Germany Company) was used to maintain the aluminum bath at a constant temperature with a digital reader to achieve this work. After the aluminum wholly melted in the crucible, three substances (68% $ZnCI_2$, 20% NaCl, and 12% NH_4CI) of aluminizing flux were added to the molten aluminum alloy

The system of aluminizing flux was added to improve the oxide coating on the specimens in the molten alloy bath by keeps low surface tension and low density for a smooth reaction, good wettability, and dissolution. The temperature of the aluminum bath was set at 850 °C and specimen dipping time was in the range of 15-120 sec.

- **After-treatment**

After aluminizing specimens by hot dipping, the mounted specimens were subjected to grinding and polishing using classical preparation methods until the surface became cleaning and flashing to reveal the microstructure examination [21].

2.3 Characterization methods

The following measurements were carried out to study the aluminizing of low carbon steel:

- Thickness layer measurements and microstructure examinations were carried out by using a scan electron microscope (S.E.M.).

- The hardness profile of the aluminized specimen was performed using Vickers microhardness tester following ASTM E-384 -89 standard, under an indentation loading of 100 g in 15 sec.

Surface topography is critical in specifying the function of specimen surfaces in hot-dip aluminizing coating. The influence of coating thickness on the formability and ductility of hot-dip-aluminized steel has been determined using a 3-point bend test conducted on a bending machine

3. Results and Discussions

The photographed coated specimens were taken after being

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transferred out of the molten bath and cool at room temperature. The results of photos taken for samples after specimens cooled showed a constant rise of the uniform coating layer and covered the specimens. The specified requirements for the appearance of the aluminizing coating on low carbon steel are continuous, free from gross imperfection, free from sharp points, free from uncoated areas, relatively smooth, uniform in texture, and distributed. Figure (3) shows hot-dipped specimens at 15, 30, and 60-sec show poor uniform coating layer formed on the surface; also dark spots were visible to the naked eye, andthespecimenshot-dippedat90and120secshow the uniform coating layer formed and the brightness start to present.

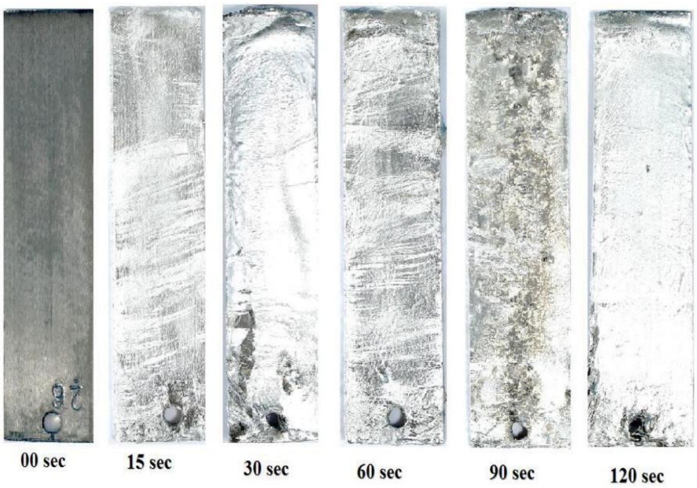

Figure 3. Photograph of specimen aluminizing at 850°C with varying aluminizing time 00, 15, 30, 60, 90, and 120 sec in molten.

3.1 Microstructure Examination

The effect of thickness on the phase structure in the FeAl alloy layer was displayed. The diffusion of the Al atom determined the thickness of the FeAl alloy layer. The Al atom is continuously diffused in the coating through a series of FeAl inter metallic compounds. The metallographic analysis indicated that the thickness of the FeAl alloy layer on the surface of the hot-dip aluminized steel was about 140 µm for a 120-sec figure (4).

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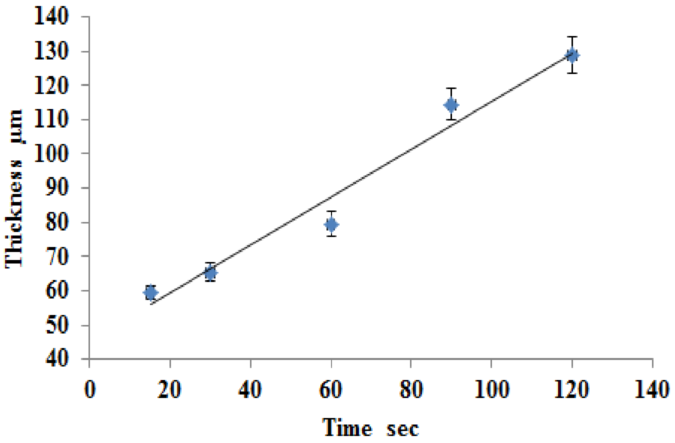

Figure 4. The thickness of the aluminized specimen layers at 850°C for different aluminizing times 15, 30, 60, 90,

To clarify the phase constitution of the FeAl alloy layer and whether or not there is a precipitation of solid aluminum chloride in the coating. Al concentration gradient and the thickness direction of the FeAl alloy layer after the aluminized sample made Al atoms diffuse to the base metal through the diffusion layer, and Al content in the FeAl alloy layer reduced gradually from the surface layer the inside. The FeAl alloy layer's growth depends on the Al-Si alloy's viscosity, maintenance of the diffusion temperature dipping time, and the speed with the part is withdrawn from the bath [9,18].

3.2. Microhardness Characterization

The effect of hot dipping time at 850 °C on the hardness distribution of each specimen coating/substrate interface was investigated at different points from the surface to the substrate layer, and the average value from 10 readings was taken for each specimen coating/substrate interface. In general, increasing dipping time leads to increases in the hardness of the intermetallic layer. For example, according to the Vickers microhardness result in figure (5), three layers first layer on the surface was a lower microhardness value (130 ~ 250 HV); the second layer of the sub-surface was a higher microhardness value (HV 490 ~ 900 HV), and then reduced gradually microhardness value by the third layer. The test results in figure (5) indicated that the microhardness increased to a maximum of 900 HV for 120 sec.

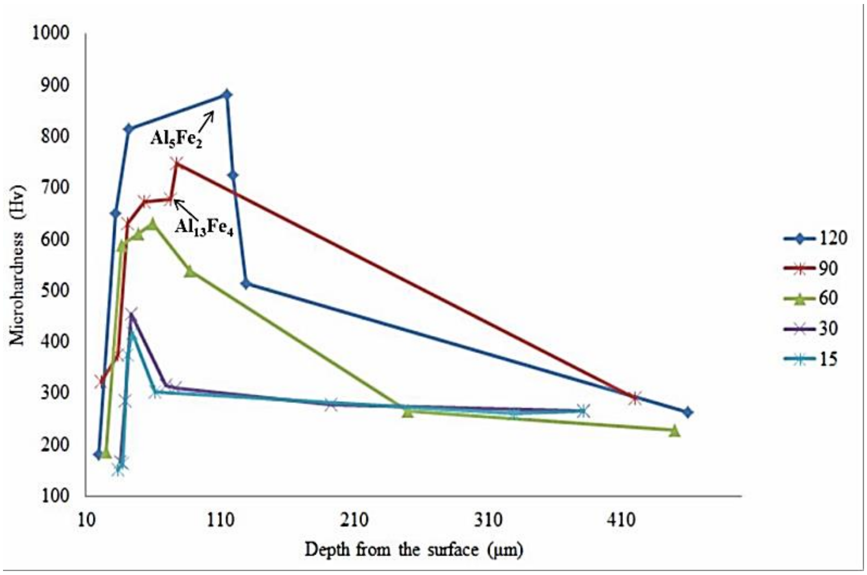

Figure 5.Vickers micro hardness from surface to steel substrate at 850°C for variation time (15, 30, 60, 90, and 129 sec).

Three phases have been (I, II, III) confirm in figure (6) that there is a similarity in the Vickers microhardness results. Figure (6) determines three phases in S.E.M. pictures from surface to steel substrate, from the surface (zone I) the lowest microhardness value due to Al-Si alloy adhered to the coating after, followed by the highest microhardness value (zone II) due to the pickup of aluminum during aluminizing and formation of AlxFey complex layer during diffusion, and (zone III) the steel substrate [12,22,23].

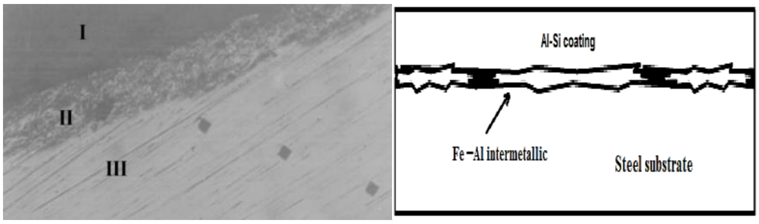

Figure 6. Cross-sectional morphology and illustration of hardness distribution of three phases from surface to steel substrate after the aluminized sample at 850 °C for120 sec

3.3 Scan Electron Microscope Examination

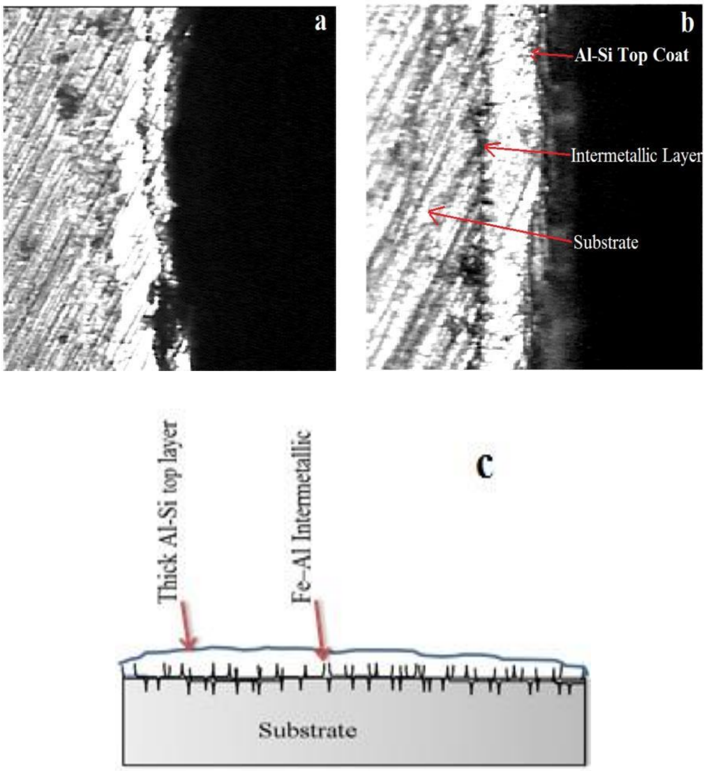

Figure7.Micrograph of cross-section coating samples at 850°C for (a) 90 sec (b) 120 second (c) two layers of coatings through the aluminum hot dipping process at 850 °C for 120 sec

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In general, an analysis of the cross-sectional microstructure shows two layers of coatings through the aluminum hot dipping process as observed in Figure (7); Al-Si alloy as the outer layer has a more porous structure and Fe-Al intermetallic as inner layer characteristic as a tongue-like morphology. In the process of hot-dip aluminizing coating, Al begins to dissolve into a steel substrate immersed in molten. Therefore, the melting of Al has flooded into the steel substrate to form FeAl intermetallic compounds [24,25]. However, the hot dipping time increased by 90 to 120 sec, leading to the continuous creation of new hard phases, the new hard phase's characteristic of a tongue-like morphology. Moreover, aluminizing time for 120 sec indicates that the FeAl alloy layer and the performance of some FeAl intermetallic compounds, perhaps phases in the FeAl alloy layer were Fe_3Al, Fe_2Al_5 present in substantial amount near the surface of the specimen, this makes 120 sec a better choice for aluminizing time [21,26].

During the 3-point bend test surface of the aluminized samples, 15, 30, 60 sec on the outer side was closely observed from the start of the formation of cracks, and the angle at which the cracks just began to appear was noted. In general, the obtained results from the bending test of the samples had been aluminized in the molten aluminum bath at different times; it is clear from visual inspection that with long hot-dipping times, some properties such as flexural strength and fatigue strength increased. In addition, dipping time was affected by the Fe-Al interlayer's thickness since the intermetallic layer is slower growth in the Al-Si alloy [27].

4. Conclusions

Based on the study results, it can be concluded regarding the effect of immersing time in the molten bath on the growth of Fe-Al intermetallic layers that come into contact with the specimens in the interface area. The coatings of low-carbon steel have been successfully produced through hot dipping techniques. Aluminizing coating shows two main layers: Al-Si as a thick outer layer and Fe-Al as thin inner layers consisting of $FeAl_3$ and Fe_2Al_5. The Fe-Al intermetallic layers are characterized as a tongue-like morphology and higher microhardness value. The thickness and higher

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microhardness value increased with increase specimens immersing time in the molten bath.

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