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Study of some Mechanical Properties of Galvanized 4140 Steels

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Abstract— *The effect of three different galvanizing processes on the microstructure and tensile behavior and hardness of galvanized AISI 4140 steels was investigated. The thicknesses of the galvanized layers were measured as 34 μm, 90 μm and 140 μm for the electro galvanized, zinc-rich coated and hot dip galvanized AISI 4140 steels, respectively. No significant increase in tensile strength was observed with the galvanizing process. It was even observed that there was a decrease in tensile strength compared to the samples that were not galvanized. It is concluded that galvanizing processes is not effective in improving the tensile performance of AISI 4140 steels.*
Keywords— galvanizing, steels, microhardness, tensile behaviour.

I. INTRODUCTION

Steels have always been among the most favored and widely used materials because of their strength, formability, and the economics of production. However, Alcantara et al. (2017) reported that the atmospheric corrosion of carbon steels is an extensive topic that has been studied over the years by many researchers. Baboian (1995) and Pistofidis et al. (2006) proposed that the most popular and most widely process used for the protection of steel against corrosion is galvanizing.

The most commonly used methods for galvanization is hot dip galvanizing and electro galvanizing. On the other hand, zinc-rich paints (ZRPs) coatings are also one of the most effective coatings used in order to protect steel from corrosion. Marchebois et al. (2004) indicated that ZRPs are used in many aggressive media: sea water, marine and industrial environments. Corresponding to this, Bin Sofian (2014) showed that ZRPs are one of the most effective anticorrosion coatings for plain carbon steels, acting simultaneously as a very adherent barrier layer and providing galvanic protection. In addition, Feng et al. (2016) obtained that the ZRPs present on electro-galvanized steel is finer, denser, thinner, more uniform and has better corrosion resistance than the hot-dip zinc coating. Di Giovanni et al. (2017) reported that the hot dip galvanizing bath not only activated temper embrittlement, but also caused the thermal stresses in the structure which were the driving force for the cracking in welded steel platform structures.

Over the past few decades, many articles have already been published on some mechanical properties in addition to corrosion behavior of galvanized steels. To summarize, Sirin obtained that the fatigue strength of AISI 4340 steel decreases from 327 MPa to 207 MPa after hot dip galvanizing with a 36,7% decrement. Khosravi et al. (2013) showed that with the increase in welding current, grain size increases and results into the increase of brittle fracture in electrogalvanized steel sheets. Lazik et al.(1995) indicated that cracking in zinc coatings depends not only on the overall texture with respect to macroscopic stress or strain state, but also on the local grain misorientation, and the inherent grain boundary strength. Especially in the hot dip zinc coatings. The intensity of cracking increases with an increasing thickness of the intermetallic layer. Safaeirad et al., (2008) reported compared to uncoated steel, low-carbon steel sheets coated by hot dipping have slightly less ductility because of the thermal effects of the coating process. However, there is no paper deal with the direct study of mechanical properties such as tensile properties and hardness behavior of galvanized 4140 steels. The purpose of this study is to investigate and compare the structure and properties of galvanized and ZRP-coated AISI 4140 steels.

II. EXPERIMENTAL METHOD

AISI 4140 steel plates (diameter: 12.9 mm) were industrially electrogalvanized using a cyanide-free alkaline bath containing Zn^{2+} (12.5 g/L), KOH (170 g/L), K_2CO_3 (50 g/L), additive (10 ml/l), brightening agents (1 ml/l), and conditioner (10 ml/l). The following conditions were used: room temperature and cathodic current density of 3 A/dm^2 for 40 min. A second group of AISI 4140 plates was hot dip galvanized into a zinc bath at a temperature about 560 ^{0}C for 3 min. A third group of AISI 4140 plates was coated with ZRP. Tensile tests were conducted at room temperature using an electro-servo

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hydraulic testing machine with 250 kN capacity. Tensile load and strain were monitored during the tensile tests using a commercial load cell and strain gauge, respectively, where tensile loading was conducted at a crosshead speed of 0.1 mm/min to fracture. To determine the hardness of the samples, a Vickers micro hardness tester with a load of 100 g and dwell time 10 s was used. Many indentations were made on each coating film under each experimental condition to check the reproducibility of hardness data. Microstructural characteristics were investigated for each of the different coatings using an optical microscope.

III. RESULTS AND DISCUSSION

Cross section morphologies of the hot dip galvanized, electro-galvanized and ZRP-coated AISI 4140 steels examined by optical microscopy are given in Fig 1 a-c.

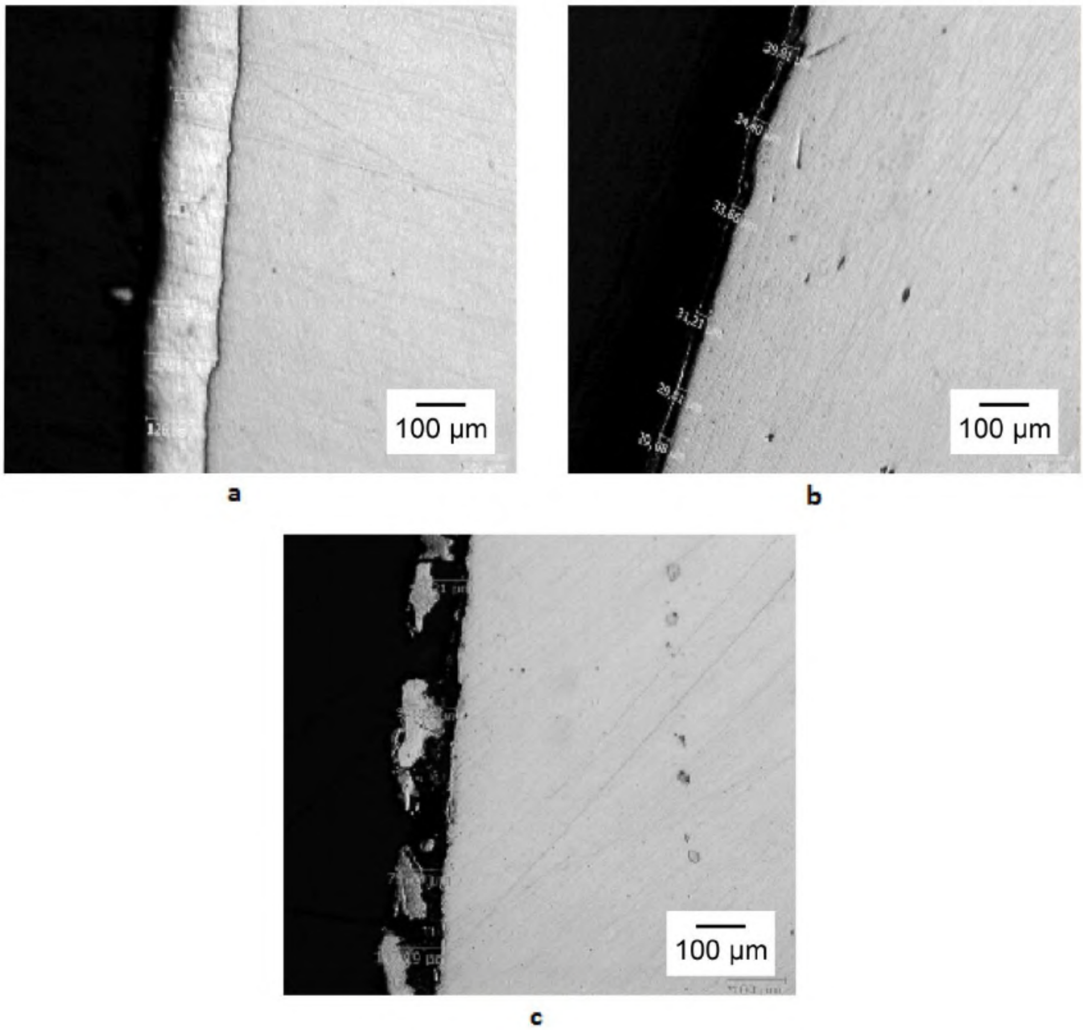

Fig. 1. Cross sections of galvanized layers of the (a) hot-dip galvanized, (b) electrogalvanized and (c) ZRP coated AISI 4140 steels.

As shown in the figure, the coating on the hot-dip galvanized AISI 4140 steel has greatest thickness among the three coatings. The thicknesses of the coating thicknesses are compared, the thickness of the coating in the electrogalvanized AISI 4140 steels is 34 µm, whereas the thicknesses are 90 µm and 140 µm for ZRP-coated and hot dip galvanized AISI 4140 steels, respectively. The boundary between the coating and substrate is clear. We say that holding on the surface of the material is weak and unstable due to the weakness between the activation energy and the diffusion energy in the material surface for this galvanizing process. On the contrary, the surface adhesion is more stable in electro-galvanized and ZRP-coated AISI 4140 steels. There is no a transition region in these galvanized steels. The unstable different phase structures were obtained in the coating layer of ZRP-coated AISI 4140 steels. In addition, the dark regions were obtained especially in the coating layers of electro-galvanized and ZRP-coated AISI 4140 steels due to etching effect (Fig. 1 b and c).

Table 1. Tensile and microhardness values for the galvanized and ZRP-coated AISI 4140 steels

Galvanizing processes	σ_{UTS} (MPa)	σ_{YS} (MPa)	Elongation ϵ (%)	Hardness (HV)
Untreated	1188	1099	15.0	360
Electrogalvanized	1195	1093	17.2	357
ZRP	1169	1079	16.4	365
Hot-dip galvanized	1117	1032	15.9	352

Table 1 shows the tensile properties (ultimate tensile strength σ_{UTS}, yield strength σ_{YS}, and percent elongation ϵ (%)) and micro hardness values of the steels coated with the three different processes. As seen from the table, the σ_{UTS} and σ_{YS} values for the galvanized and ZRP-coated AISI 4140 steels are more or less the same as that of the untreated steel. The slight decrease observed in the hot-dip galvanized steel can be attributed to the annealing effect of the Zn bath. Similar behavior is observed in the hardness values from the indentations, where the hot-dip galvanized steel is softest. The percent elongation values are again very similar; however the slightly higher ductility of the electrogalvanized sample can be attributed to the presence of a smooth continuous coating on the surface.

IV. CONCLUSIONS

Three coating methods were applied to the AISI 4140 steels. The changes observed in ultimate tensile strength, yield strength and hardness were negligible. A slight increase in elongation values were observed compared to untreated AISI 4140 steel. The results showed that while galvanized and ZRP coatings can be used to protect the surfaces of steel against corrosion, they cannot be used to improve mechanical properties.

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