Full Length Research Paper

Effect of some process variables on zinc coated low carbon steel substrates

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This work investigates the effect of some essential plating variable of zinc electro-deposition on low carbon steel substrates. The variation of plating parameter, the depth of immersion, distance between the anode and the cathode on voltage, plating time and coating thickness was considered. The steel substrates were immersed into solution of zinc electroplating bath for varying voltage between 0.5 and 1.0 V. It was discovered that the sample plated at 0.8 V for 20 min gave the best plating properties and it was also observed that increase in applied voltage, plating time, depth of immersion and decrease in distance of the object (cathode) from the anode increases weight gained. Microstructural studies with SEM/OPM however, revealed fine grained deposit of the deposited zinc and the inclusion of addition agent.

Key words: Substrate, electroplating, coating, zinc anode, weight gain, plating variables.

INTRODUCTION

The growing interest in zinc and zinc alloy deposition is enormous in the manufacturing industry for the protection of steel products in corrosion environment (Popoola et al., 2011). Electroplated zinc coatings are considered as one of the main methods used for the corrosion protection of steel. The extensive usage in automotive and other industrial sectors as a protective coating for large quantities of steel wires, strips, sheets, tubes and other fabricated ferrous metal parts have lead to the development of his alloys (Pedrode et al., 2007). Zinc deposits offer good protection and decorative appeal at low cost. Since zinc is anodic to steel, it protects the base metal even if the deposit is porous. An acid zinc bath is used where it is desirable to have a high plating rate with maximum current efficiency (Popoola et al., 2011; Shivakumera et al., 2007). However, the critical pretreatment requirements and the poor throwing power of these solutions restrict their use to plate only on regular shaped articles. Considering pollution hazards and high industrial effluent treatment costs, non-cyanide zinc baths have been introduced in place of cyanide

solutions (Shivakumara et al., 2007). Zinc coatings are obtained either from cyanide, non-cyanide, alkaline or acid solutions. Good deposition depends mainly on the nature of bath constituents, the substrate surface, and time of plating. Generally, a plating bath contains conducting salts, buffering agents, complexing agents and metal ions. Among these, the complexing agents effectively influence better deposition through optimization of current density, pH and temperature. The throwing power and current efficiency of the solution were also determined at various current. Few developed addition agent are surface active and changes the characteristics of metal solution interface properties to form complex with metal ions and are adsorbed on a cathode surface (Popoola et al., 2011; Abdullahi et al., 2008).

Most of the addition agents possess electro active functional groups, usually the electroplating baths are associated with two or more addition agents and are essential to obtain a quality deposit. Too many ingredients cause difficulties in maintaining the operating parameters of the bath solution during the plating process. Some of these agents smoothen the deposit over a wide current density range and the other addition agents influence the production of bright deposits (Joo et al., 2004; Haqua et al., 2005). However, there is

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increasing fear that someday coating of metals will be subdue by these interacting stresses, hence the aim of the present work is to study the effect of 'plating variables on a zinc-coating low carbon steels to forestall such occurrence. The effect of varying time of plating on mass, thickness of the deposit and the effect of voltage and depth of immersion on weight deposition will be study.

EXPERIMENTAL METHODS

The low carbon steel substrate of dimension 20 mm diameters by 1 m long was obtained and the spectrometer chemical composition analysis is examined in percentage.

Chemical composition of low carbon steel

The investigation was carried out in three processes; pre plating process, plating process and the post plating process (Kurt, 1996); in the pre plating process, the surface preparation was done on the polishing machine with different grades of emery paper in order of 60, 120, 360 and 400 um grades. Water was added intermittently so as to cool down the metal samples. During the grinding operation, the metal samples were rotated at an angle of 90 or 180° at intervals so as to erase previous marks which arose due to the initial grinding. The pickling of the samples was done in diluted H_2SO_4 acid solution; this was done to remove all organic contaminants and oxides, followed by electrolytic degreasing. This was carried out by treating the surface of samples with alkaline solution by passing current into the solution for about 5 min and subsequent cleaning in water, to remove all grease or oily contaminants. In the plating process, the electrolytically degreased metal substrate was immersed in a solution containing dissolved zinc salts and made the cathode by connecting it to the negative terminal of the rectifier of the electroplating bath. The anode was also immersed and connected to the positive terminal of the rectifier. The anode is made of pure Zinc rod about 99.98%. The following plating parameters were varied, the voltage was varied between the ranges of (0.5 to 1.0 V), the substrates were plated at time variation of 10 to 35 min and the plating distance from the anode to the cathode also varied between 10 to 30 cm respectively. More so the immersion depth was varied by varying the length of the copper wire used as the cathode connection. Finally, the samples were rinsed in water to wash the salt solution off the samples plated immediately after the electroplating process.

The rinsing was done in distilled water for 5 s before transferring the plated sample to the passivation tank which was done with blue passivation as to increase the resistance of zinc against corrosion in 2 min, then water rinsed and later air dried.

RESULTS AND DISCUSSION

The results are given in Tables 2 to 6 and Figures 1 to 12.

Effect of applied voltage on weight gained of zinc coated low carbon steel substrate

Figure 1 shows general increase in weight gained as the voltage increases, except for the voltage range between 0.5 and 0.6 V which was due to the fact that the plating bath was not stirred before electroplating the sample at 0.6 V. The 0.8 V was chosen at the best plating voltage, this is due to the fact that the 0.8 V presents the best physical properties such as colour brightness, fineness, streak and adhesion as shown in Table 1. At the 0.9 V, sample became dull in appearance while at 1.0 V deposition became poor due to patchy films of coat on the surface of the steel sample.

Effect of plating time on weight gained for zinc coated low carbon steel:

Figure 2, 3 and 4 shows the plot of weight gained versus time of plating by varying distance of depth of immersion ranging from 10, 20 and 30 cm. It was observed that for the 10, 20 and 30 cm distance, weight gain increases as the plating time increases at constant depth of immersion. However, there are increases and decreases in value of weight gained as the plating time increases for the varying depth of immersion. This may evaluate the proof that the deeper the length of immersion, the more the weight gained by the substrate and the better the deposited surface finish as indicated in Figure 5, 6 and 7.

Effects of distance from the anode on zinc coated low carbon steel

Figure 8 shows the plot of weight gained versus time of plating at different distances from the anode. It shows that the distance increases from the anode the weight gained decreases, while the same phenomenon was observed in Figure 9 for the thickness from the anode.

Effect of immersion depth on weight gained and thickness of coated film

Tables 4 and 6a gave the vivid representation of the effect of immersion depth on weight gained and thickness of coated film. It was observed that as the depth of immersion increases, the substrate weight gain increases. However, at 20 minutes when the immersion depth was kept constant at 45 cm and when it was varied between 35 and 50 cm, there is a slight change in co-deposition on the substrate. This observation is in conformity with resistivity relation, that as the length of conductor (wire) increases its resistivity reduces, thereby favoring the rate of electro-deposition. Surface morphology of the plated sample in Figure 13, established the fine grain structure of the deposited plated sample and the increases in the thickness value.

However, perfect crystal and uniform arrangement on the deposit were observed (Figure 14).

Table 1. Chemical composition of low carbon steel.

Symbol of elements	C	S	Si	P	Mn	Ni	Cu	Mo	V	Ti	Al	Mg	Sn	Fe
% Composition	0.18	0.08	0.10	0.62	0.75	0.010	0.23	0.082	0.005	0.002	0.006	0.004	0.008	97.60

Table 2. Visual appearance of plated samples for constant plating time at various voltages.

Samples	Plating effects
A (0.5 V) (10 min)	Diffused reflection
B (0.6 V) (10 min)	Diffused reflection
C (0.7 V) (10 min)	Diffused reflection
D (0.8 V) (10 min)	Bright reflection
E (0.9 V) (10 min)	Dull reflection
F (1.0 V) (10 min)	Dull reflection

Table 3. Trial samples.

Initial weight (g)	Final weight (g)	C-Area of sample (mm^2)	Thickness (µmm)	Voltage volt)	Time (min.)
22.22	22.26	10.97	0.10	0.50	10
22.73	22.76	10.97	0.08	0.60	10
21.07	21.13	10.97	0.16	0.70	10
22.89	22.99	10.97	0.26	0.80	10
23.60	23.72	10.97	0.31	0.90	10
22.76	22.90	10.97	0.36	1.00	10

Table 4. Readings obtained for cathode to anode distance of 10 cm at 20 cm constant depth of immersion.

Initial weight (g)	Final weight (g)	C-area of sample (mm^2)	Thickness (µmm)	Voltage (volt)	Time (min.)
22.86	22.92	10.97	0.156	0.80	10
22.59	22.69	10.97	0.234	0.80	15
22.99	23.13	10.97	0.364	0.80	20
22.24	22.42	10.97	0.468	0.80	25
22.42	22.62	10.97	0.520	0.80	30

Table 5a. Readings obtained for cathode to anode distance of 20 cm at varying depth of immersion.

Initial weight (g)	Final weight (g)	C-area of sample (mm^2)	Thickness (mm)	Voltage (volt)	Time (min.)
22.46	22.52	10.97	0.156	0.80	10
23.17	23.25	10.97	0.208	0.80	15
22.70	22.82	10.97	0.312	0.80	20
22.69	22.90	10.97	0.534	0.80	25
22.49	22.61	10.97	0.312	0.80	30

CONCLUSION

After careful study of electroplating and experimental analysis of electroplating variables, the following conclusions were drawn. Increase in applied voltage, plating time, depth of immersion and decrease in distance of object (cathode) from the anode increases the weight gain and thickness of deposit. However, it was

Table 5b. Readings obtained for cathode to anode distance of 20 cm at 30 cm constant depth of immersion.

Initial weight (g)	Final weight (g)	C-area of sample (mm^2)	Thickness (mm)	Voltage (volt)	Time (min.)
22.49	22.53	10.97	0.10	0.80	10
23.47	23.54	10.97	0.18	0.80	15
23.45	23.57	10.97	0.31	0.80	20
23.30	23.45	10.97	0.39	0.80	25
22.30	22.48	10.97	0.47	0.80	30

Table 6a. Readings obtained for cathode to anode distance of 30 cm at varying depth of immersion.

Initial weight (g)	Final weight (g)	C-area of sample (mm^2)	Thickness (mm)	Voltage (volt)	Time (min.)
21.27	21.45	10.97	0.47	0.80	10
21.65	21.69	10.97	0.10	0.80	15
21.46	21.54	10.97	0.208	0.80	20
21.87	21.97	10.97	0.260	0.80	25
21.37	22.53	10.97	0.416	0.80	30

Table 6b. Readings obtained for cathode to anode distance of 30 cm at 40 cm constant depth of immersion.

Initial weight (g)	Final weight (g)	C-area of sample (mm^2)	Thickness (mm)	Voltage (volt)	Time (min.)
21.43	21.45	10.97	0.052	0.80	10
21.64	21.69	10.97	0.130	0.80	15
21.46	21.54	10.97	0.208	0.80	20
21.87	21.97	10.97	0.260	0.80	25
21.37	22.53	10.97	0.416	0.80	30
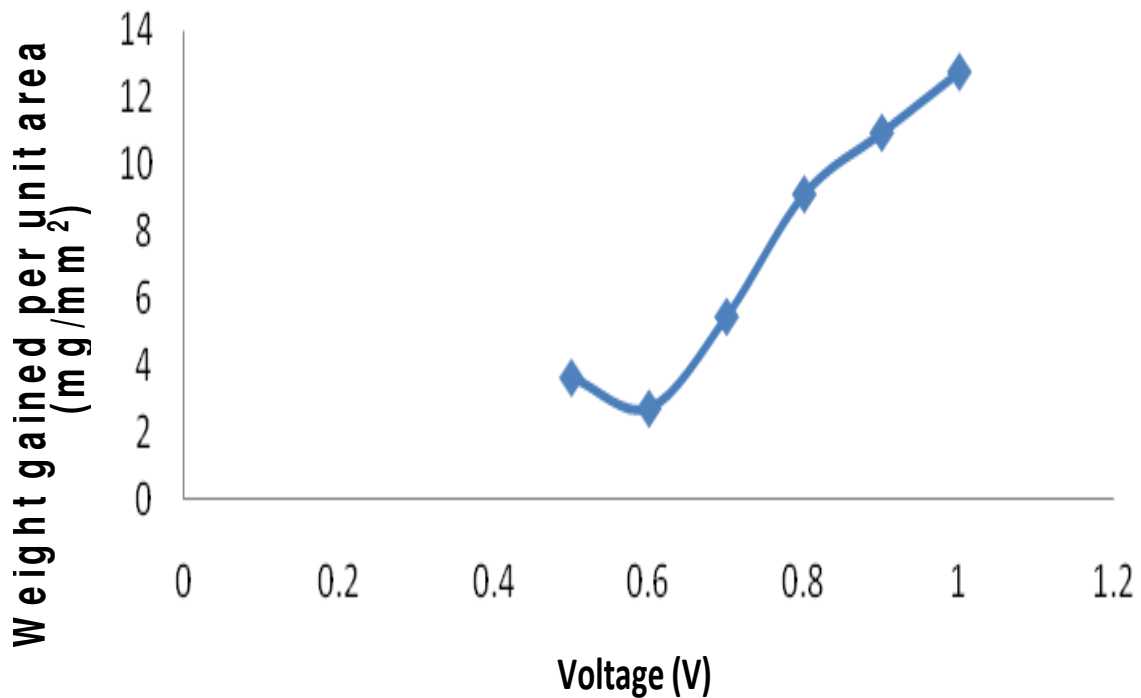
Figure 1. Plot showing weight (mg/mm^2) of zinc electrodeposited on low carbon steel against voltage (volts) at 10 min and distance 10 cm from the anode.
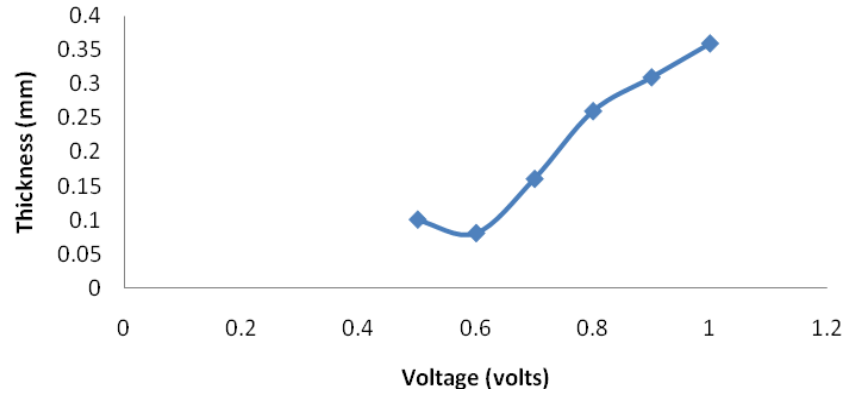
Figure 2. Plot showing the thickness (mm) of zinc electrodeposited on low carbon steel against voltage (volts) at 10 min and distance 20 cm from the anode.\
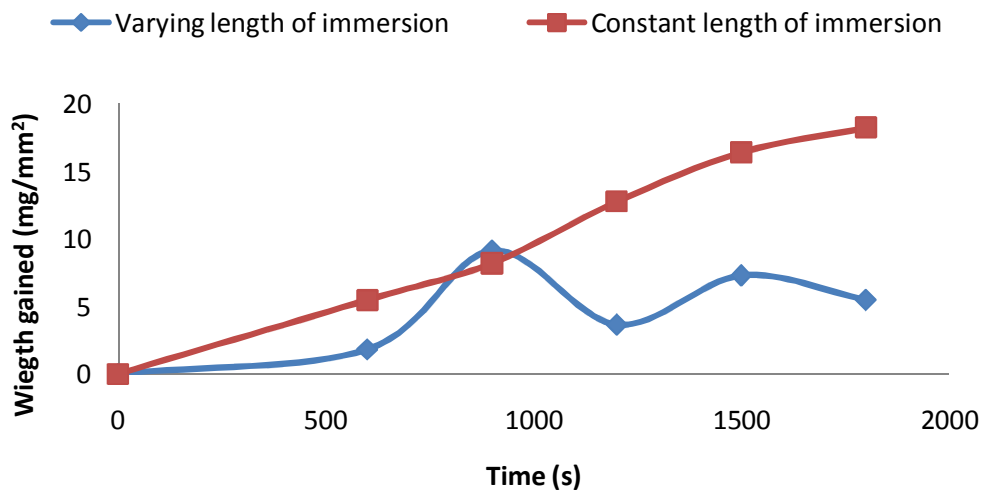

Figure 3. Plot showing the weight (mg/mm^2) of zinc plated on carbon steel gained per time (s) at cathode to anode distance of 10 cm.
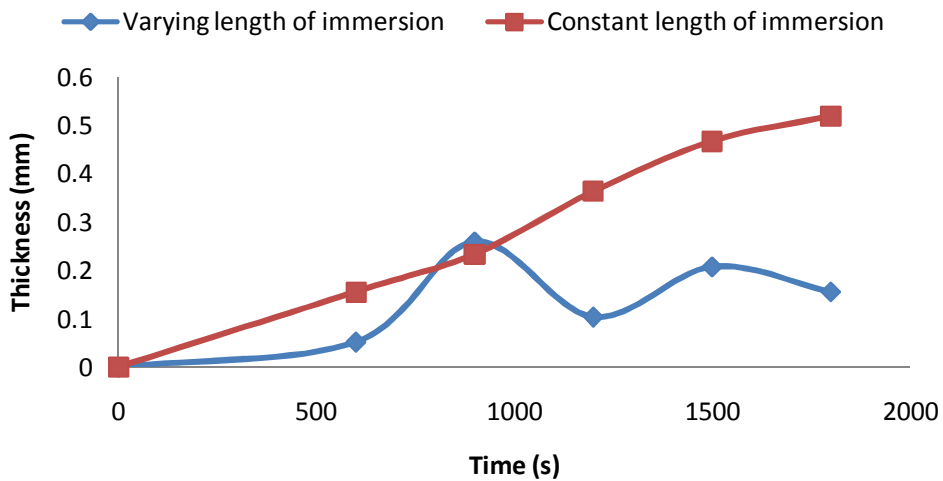

Figure 4. Plot showing the thickness (mm) of zinc plated on carbon steel per time (s) at cathode to anode distance of 10 cm.
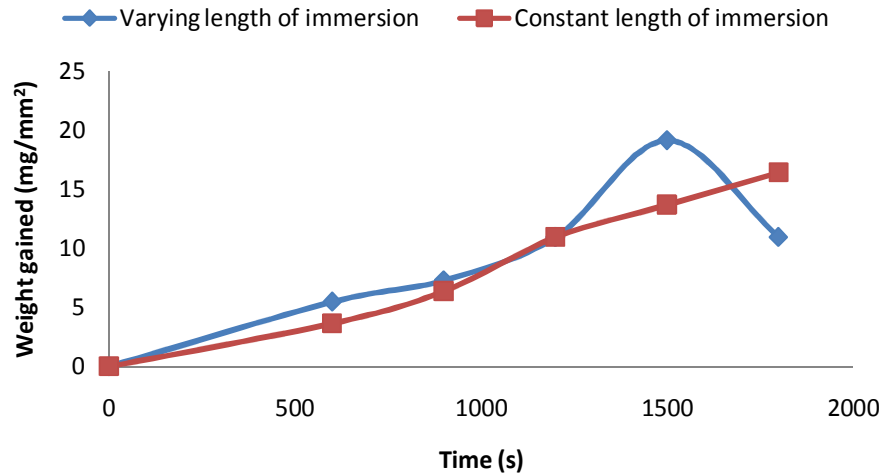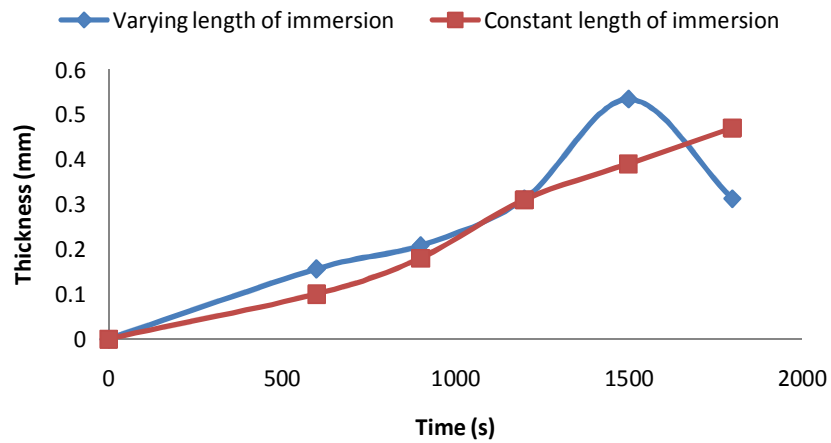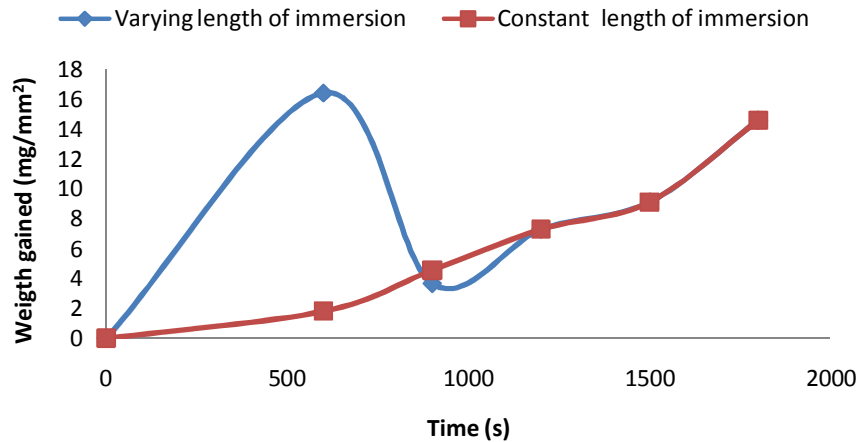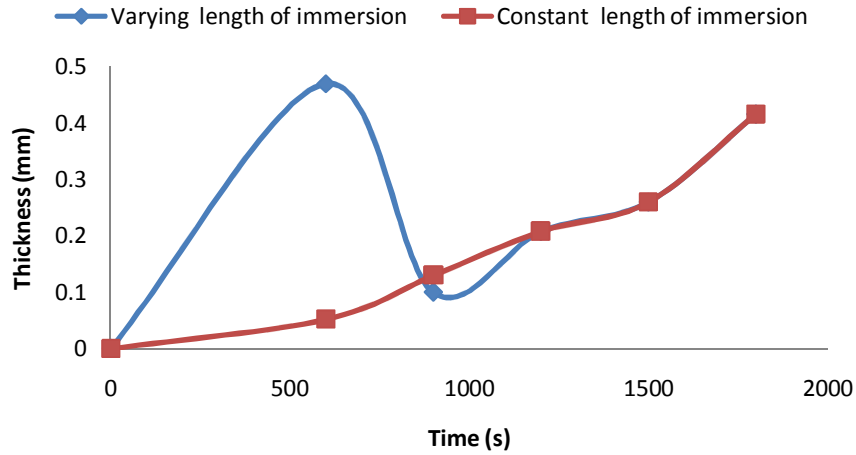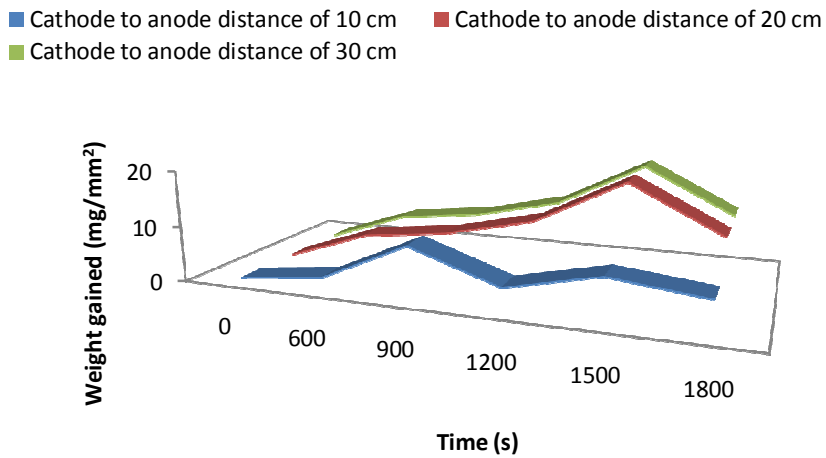
Figure 5. Plot showing the weight (mg/mm^2) of zinc plated on carbon steel gained per time (s) at cathode to anode distance of 20 cm.

Figure 6. Plot showing the thickness (mm) of zinc plated on carbon steel per time (s) at cathode to anode distance of 20 cm.

Figure 7. Plot showing the weight (mg/mm^2) of zinc plated on carbon steel gained per time (s) at cathode to anode distance of 30 cm.

Figure 8. Plot showing the thickness (mm) of zinc plated on carbon steel per time (s) at cathode to anode distance of 30 cm.

Figure 9. Plot showing the effect of cathode to anode distance on the weight of zinc plating gained per time when the length of immersion was varied.
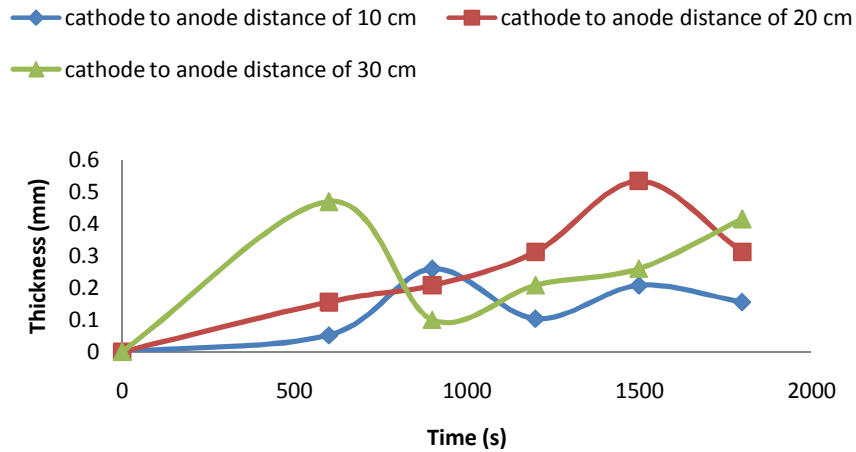

Figure 10. Plot showing the effect of cathode to anode distance on the thickness of zinc plating per time when the length of immersion were varied.
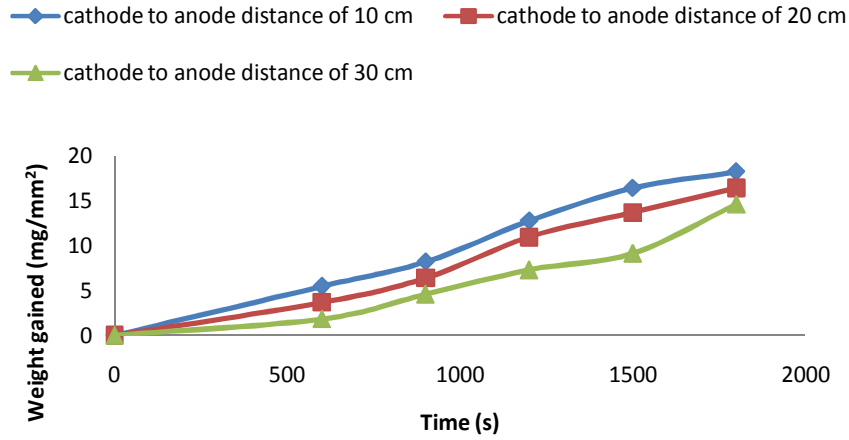
Figure 11. Plot showing the effect of cathode to anode distance on the weight of zinc plating gained per time when the length of immersion were kept constant.
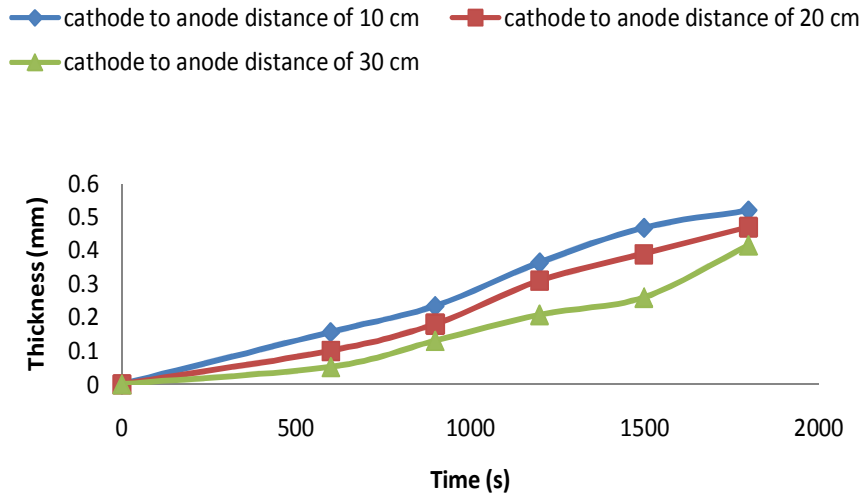

Figure 12. Plot showing the effect of cathode to anode distance on the thickness of zinc plating per time when the length of immersion were kept constant.
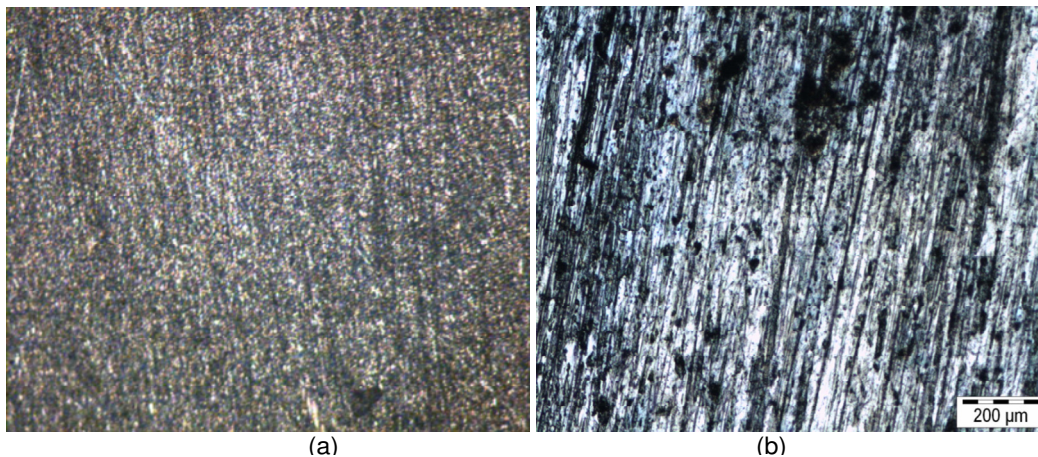

Figure 13. Optical microscope photographs of the surface of the low carbon steel (a) before and (b) after plating respectively.
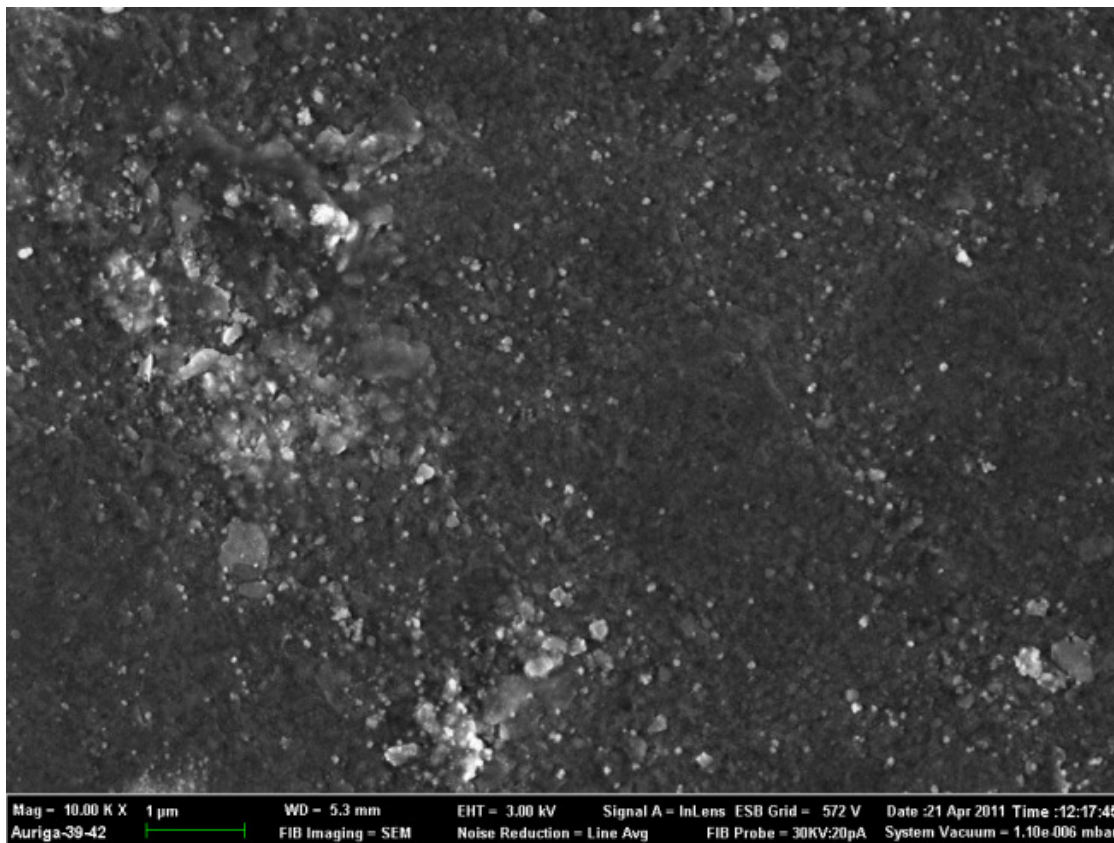
Figure 14. SEM photograph of the deposit obtained from Zn electrodeposition.

observed that sample plated for 20 min, distance of 20 cm from the anode, 45 cm depth of immersion at 0.8 V gave the best plating properties. The improved mechanical and physical properties obtained for plating of zinc on low carbon steel at the aforementioned reference indicate that homogeneity of diffuse plating efficiency is achieved.

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