

Investigating Corrosion Characteristics of Electroplated Medium Carbon Steel in Sodium Carbonate Environment for Decorative Objects Applications

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ABSTRACT

The main objective of this study is to investigate the corrosion resistance characteristics of electroplated Medium Carbon Steel (MCS) in 0.5mol/dm³ Sodium Carbonate environment. Nickel plating of MCS was done in watts solution for 25 minutes with a current density of 3 A/dm³ at 60°C. The nickel plated MCS was later gold plated for 20 minutes with a current density of 0.2 A/dm³ at 50°C . The plated and unplated MCS were exposed to sodium carbonate environment for 360 hours. The weight loss was taken every 24 hours in order to estimate corrosion penetration rate (CPR). The results obtained showed that plated MCS generally showed a better corrosion resistance than the unplated one. Although gold plated MCS has a slightly better corrosion resistance characteristic than nickel plated one, the conclusion that can be drawn from this study is that Nickel and Gold plated medium carbon steels are found to be both reliable materials for decorative objects applications in sodium carbonate environment.

Keywords: MCS, Nickel plating, Gold Plating, CPR, Sodium Carbonate

1. INTRODUCTION

The costly problem of corrosion in manufacturing, oil and gas, food, processing and decorative industries is enormous. There is need to regularly ascertain the corrosion characteristics of materials being used in these industries in order to determine the most appropriate corrosion control and prevention strategy. Carbon steel is very important in decorative and many manufacturing industries because of its unique mechanical properties and inexpensiveness. Quite a number of research efforts have been made in the corrosion study of steels and electroplated alloy materials. The study on corrosion behaviour of welded mild steel- bar in soil media around the coastal area of the university of Lagos has been evaluated by Adeosun et al, 2011. The corrosion rates of plain and welded mild Steel coupons (both the fusion and heat affected zones) were determined using gravimetric method. The weld was done using shielded metal arc welding process. According to the authors, ten (10) samples each (for plain and welded mild steels) were cut and their initial thicknesses and weights were recorded. The soil environment, water content, pH, chloride and sulphur ions concentration were determined. The steel coupons were buried in two selected soil locations and weight losses were measured at regular intervals for a period of six months (180 days). The corrosivity of these soil media varied widely depending on the level of potency of its constituents. The results show that soil medium with the lowest pH and highest chloride ion concentration was found to be highly corrosive in its

attack on the coupons. The paper concluded that the welded mild Steel corroded at a faster rate than the plain mild steel in the studied locations. More also, the medium resistivity is a strong factor affecting the rate of corrosion penetration. Afolabi (2007) studied the corrosion behaviour and Stress Corrosion Cracking (SCC) of low and medium carbon steels in cassava and cocoa extracts by weight loss measurement and constant extension to fracture method respectively. The results obtained revealed that medium carbon steel is more susceptible to corrosion than low carbon steel in both media. SCC is also more in medium carbon steel than low carbon steel in the two media under study. These deductions are due to higher carbon content in medium carbon steel coupled with various aggressive corrosion constituents contained in these media. The author concluded that Hydrogen embrittlement, as well as carbon cracking is responsible for SCC of these materials in the agro-fluid media. Influence of flow on corrosion behaviour of stainless steel, brass and aluminum was studied using electrochemical measurement techniques (Kazi, 2010). Flow effect was identified by comparing erosion-corrosion with pure corrosion studies. For this purpose, open circuit potential (OCP) measurements were performed in both quiescent and flow conditions. OCP transient for the metals/alloys (stainless steel, brass and aluminum) indicated the nature and extent of corrosion on the sample by the environment (seawater and sodium carbonate). Three distinct types of curves were found for all metal-environment combinations. Increasing OCP indicated noble metal behaviour while decrease in OCP

indicated corrosion of material in the exposed environment. The shape of these curves provides information about the extent of metal environment interaction. The authors' experimental observations have really showcased the applicability of open circuit measurements for on-line corrosion monitoring. Carbonate environments is one of the important environments both in the domestic and industrial sectors. Efforts are now being geared towards investigating the corrosion characteristics of alloy materials in carbonate media. Olorunfoba et al (2009) work studied the comparative corrosion behaviour of Al 3103 and galvanized steel roofing sheets in 1 M, 0.5 M and 0.3 M solutions of sodium carbonate and sodium chloride. Samples of the aluminium and galvanized sheets were subjected to the different environments for thirty days. The electrode potentials, in mV (SCE), were measured every day. Electrode potential measurements were taken every day for thirty consecutive days. Weight loss or gain measurements were taken every three days for the duration of the exposure period. The results showed sodium chloride environment had higher corrosive effect on the galvanized roofing sheet than sodium carbonate environment while the reverse was true for aluminium sheets. Also, galvanized steel roofing corroded more than aluminium roofing in both carbonate and chloride environments. Corrosion of galvanized steel roofing was continuous throughout the exposure period in all the environments used. The conclusions drawn by the authors is that galvanized steel roofing sheet is not a suitable material for roofing in carbonate and chloride environments or in industrial environments where chloride or carbonate contamination is possible. Habsah et al (2008) investigated the effect of temperature on corrosion behavior of AISI 304 stainless steel in the presence of magnesium carbonate ($MgCO_3$) salt at 900°C, 950°C and 1000°C for 24–120 h. The results obtained showed that the initial carbonate coating caused acceleration in oxidation, resulting in the formation of scales, followed by the decreased in oxidation rate due to evolution of CO/CO_2 gas. The mass change of metal increased as the temperature and time exposure increased. The morphological structures of deposits were analyzed by using a scanning electron microscopy (SEM). Hu et al (2011) investigated the corrosion behaviour of carbon steel in model alkaline medium in the presence of very low concentration of polymeric nanoaggregates (0.0024 wt % polyethylene oxide -PEO-113-b-PS70 micelles). The steel electrodes were investigated in chloride-free and chloride-containing cement extracts. The electrochemical measurements, electrochemical impedance spectroscopy and potentiodynamic polarization indicate that the presence of micelles alters the composition of the surface layer and influences the electrochemical behaviour of the steel. Authors' observation shows that micelles initially improved the corrosion resistance of the steel whereas no significant improvement was observed within longer immersion periods. Surface analysis, performed by environmental scanning electronic microscopy, energy-

dispersive x-ray analysis and x-ray photoelectron spectroscopy supports and elucidates the corrosion performance characteristics of carbon steel in simulated pore solution in the presence of Micelles. Ciubotariu et al (2010) studied the electrochemical corrosion behaviour of carbon steel X60 using the electrochemical impedance spectroscopy and potentiodynamic polarization methods. 0.5M test solutions of sodium chloride, sodium sulphate and sulphuric acid were used in a three electrode open cell. The findings of the authors showed that the rate of corrosion penetration is higher for carbon steel X60 in 0.5M sulphuric acid and smaller in 0.5M sodium sulphate. The electrochemical and transport properties and thermal stability of epoxy coatings electrodeposited on hot-dip galvanized steel and steel modified by Zn–Ni alloys were investigated by Bajat et al (2000) during exposure to 3% NaCl solution. Zn–Ni alloys were electrodeposited on steel by direct and pulse current. From the time dependence of pore resistance, coating capacitance and relative permittivity of epoxy coating, diffusion coefficient of water through epoxy coating and thermal stability, it was shown that Zn–Ni sublayers significantly improves the corrosion stability of the protective system based on epoxy coating. As long as 1982, Dibari studied the corrosion performance of chromium-electroplated, decorative nickel and nickel-iron alloy electrodeposits in marine and industrial atmospheres and by means of copper-accelerated acetic acid-salt spray testing (CASS). Decorative nickel coatings, 15 and 30 μm thick gave better overall corrosion performance than comparable decorative nickel-iron alloy coatings. Because of the rapid staining that occurs in marine and industrial atmospheres, nickel-iron alloy deposits are not suitable for decorative applications involving moderate and severe corrosion service. Decorative nickel-iron alloy deposits, 7.6 μm thick, appear suitable for mild corrosion service on the basis of CASS test results, but results were affected by iron content and type of electrodeposited chromium. The relatively good performance of thin alloy deposits accounts for established applications in mildly corrosive environments. In the article of George (1994), the nickel plating process is used extensively for decorative, engineering and electroforming purposes because the appearance and other properties of electrodeposited nickel can be varied over wide ranges by controlling the composition and the operating parameters of the plating solution. Decorative applications account for about 80% of the nickel consumed in plating; 20% is consumed for engineering and electroforming purposes. The annual worldwide consumption of nickel for electroplating, including nickel consumed as plating salts, is approximately 180 million pounds (81,700 metric tons), and accounts for 11 to 12 percent of world nickel consumption. Decorative and corrosion resistant coatings for the surface refinement of Mg-Alloys by plasma-based methods was examined by Hoche et al 2008. The authors was able to examine the economic potential of PVD-coatings for the surface refinement and protection of Mg-alloys. The research efforts consists of the introduction of

new pre-treatment methods by electro and plasma polishing followed by a corrosion inhibiting PVD-primer coating and a thin decorative PVD-finish-film. Anodic oxidation of the PVD finish guarantees the full colour palette by interference effects. It was observed that it is possible to completely remove impurities from the surfaces. The finding of this study shows that TiMgAlN coatings with a certain composition seem to be a relief in PVD coating of Magnesium. They withstand the 96 h salt spray test without corrosion damage. Interference colouring by anodic oxidation of Nb thin films on AZ31hp and AZ91hp remarkably improve the decorative appearance. It is also observed that interference colouring works as a stable process for Mg substrates. In Ivan et al 2010 paper presentation on corrosion protection by coatings and base material in decorative and aerospace applications, extensive explanation was given on the decorative applications of PVD technology as corrosion protection technique. The presenters further explained how coatings of non-electroplated parts can be developed. The authors concluded that HIPIMS technology clearly manifests its potential for corrosion protective coatings. More also, multilayer metal/oxide stacks in combination with HIPIMS technology is the next step in corrosion protection strategy.

2. MATERIALS AND METHODS

The materials, equipments and methods used for experimentation are respectively stated in sections 2.1 and 2.2

2.1 Materials and Equipments

Sections 2.1.1 and 2.1.2 gives a list of materials and equipments used in this study.

2.1.1 Materials and Equipment used for Nickel Plating

Electroplating tank (Plastic in lined tanks), MCS to be electroplated (10cm x 20cm), Nickel Anode, Drying tray and Electrolyte. The following are the features of the electrolyte used for the experiment:

- (i) Nickel Sulphate (300 g)
- (ii) Nickel Chloride (30 g)
- (iii) Nickel brightener (30g)

2.1.2 Materials and Equipments used for Gold Plating

Rectifier, Plating tank ,Gold potassium cyanide ,Gold Anode, Drying tray Gold potassium cyanide (30g),Gold metal anode (12.5g) and Nickel plated MCS samples(weight of 3.3g and Area of 4.56cm²).

2.2 Methods

2.2.1 Chemical Composition Analysis

The MCS used was procured from FIIRO (Federal Industrial Institute of Research, Oshodi), Lagos state. The composition analysis of the MCS was carried out at the universal steel, Ikeja, Lagos state.

2.2.2 Procedures for Plating MCS

MCS substrate was plated with purified base solution inside a plating tank followed by the necessary additional agents. A prepared nickel salt was used to prepare high sulphate nickel base solution for Gemini and other bright and semi-bright nickel plating solutions. A standard solution of nickel salts for electroplating of MCS was first prepared. A rubber lined tank was properly cleaned and filled approximately with two-third capacity of clean water. After heating the water to 60 to 70°C, the required weight of prepared nickel Salts was added gradually and thoroughly stirred. When dissolution of the prepared nickel salts was completed, the bath is then diluted with clean water of approximately 5/6ths of the final required volume. At this stage, the solution was purified to remove any traces of metallic impurity or organic contamination before the addition of the brightener additives. The base MCS material (10cm × 20cm) was polished and the plastic in lined tank was hot washed with dilute acid and properly rinsed out with cold water. Polished base metal (10cm × 20cm) was suspended with wires and later pickled in a hydrochloric acid. MCS samples were immersed in tanks of dilute hydrochloric cleaning solutions to remove dirt and solid soil from them. The weight of sample was taken before the treatment of the sized polished specimen .This was properly rinsed in water and anodically cleaned in order to avoid drag out of the electrolyte on the material sample. The nickel plating was done for 25 minutes at a temperature of 60°C and constant current density of 0.3A/dm³.After the specimen was removed from the plating tank, it was immersed into de-ionised water to avoid drag out and clogging of electrolyte on specimens. Material Sample's final weight was determined in order to know the mass of the electrolyte deposited on the base sample material. This helps in determining the thickness of the nickel plating of the sample MCS used in this study. The nickel plated MCS was cut into three samples of dimension (24cm x 1.9cm).The three samples were used in carrying out the gold plating experiments. A little pre-treatment was done, due to the nickel undercoat that has been done on base-metal. Proper hammering and straightening were carried out on these samples to give proper edging and smoothing. This was done in order to avoid blur and hole on the work pieces which can later result to corrosion and instability of electrolyte on work samples .This was followed by thorough washing of the nickel coated

samples in water and then caustic soda in order to dissolve unwanted agents like hammering and working particles on the work samples that can interfere with the results of the experiment. After the clogs were dissolved away, the samples were suspended into the electroplating tank containing gold potassium cyanide (30g), gold metal anode (12.5g) and nickel plated samples (weight of 3.3g and Area of 4.56cm²).The samples were electroplated for 20 minutes to give enough coating thickness. All these specimens were quickly dipped in water immediately they were removed from the bath and later displayed in the drying tray for cooling. Weight of each specimen was taken by scout pro-balance in order to determine the mass of gold material deposited on the nickel plated MCS.

2.2.3 Corrosion Penetration Rate (CPR) Determination Using Weight Loss

The unplated, Nickel plated and Gold plated (with nickel undercoat) MCS coupons were immersed in 0.5mol dm⁻³ Na₂CO₃ environment for a period of 360 hours (15days).The corrosion coupons were removed from the corrosion environment with the aid of a tong . These were then properly cleaned in distilled water and dried with cotton wool. The dried samples were weighed with the

electronic digital weighing balance and recorded. Weight loss measurements of coupons were recorded at interval of 24 hours. The corrosion penetration rate (CPR) were calculated from weight loss analysis using the equation (1)

$$CPR = \frac{87.6W}{\rho At}$$

Where;

CPR – Corrosion Penetration Rate in mm/yr

W – Weight Loss in mg

ρ is density in g/ cub.cm

A is Area of exposed specimen in cm²

t is exposure time in hr.

3. RESULTS AND DISCUSSION

3.1 Results

Table 1: Chemical Analysis of MCS

Run	C	Si	S	P	Mn	Ni	Cr				
(1)	0.3397	0.2191	0.0573	0.0620	0.8294	0.0960	0.1242				
(2)	0.3426	0.2204	0.0605	0.0597	0.8343	0.0961	0.1245				
Avg	0.3411	0.2198	0.0589	0.0609	0.8318	0.0960	0.1244				
Mo	V	Cu	W	As	Sn	Co	Al	Pb	Ca	Zn	Fe%
0.0188	0.0057	0.2066	0.0035	0.0056	0.0252	0.0088	-0.0007	0.0001	0.0001	0.0035	97.9951
0.0191	0.0058	0.2077	0.0035	0.0059	0.0262	0.0088	-0.0007	-0.0000	0.0001	0.0038	97.9816
0.0189	0.0058	0.2071	0.0035	0.0058	0.0257	0.0088	-0.0007	0.0001	0.0001	0.0036	97.9883

Table 2: Nickel Plating Parameters

Weight(initial) (g)	Time in solution (min)	Weight (final) (g)	Temperature (°C)	Current amp/dm ³
281.5	25	325.7	60	3.0

Table 3: Gold Plating Parameters

Weight(initial) (g)	Time in solution (min)	Weight (final) (g)	Temperature (°C)	Current A/dm ³
15.4	20	15.9	50	0.2

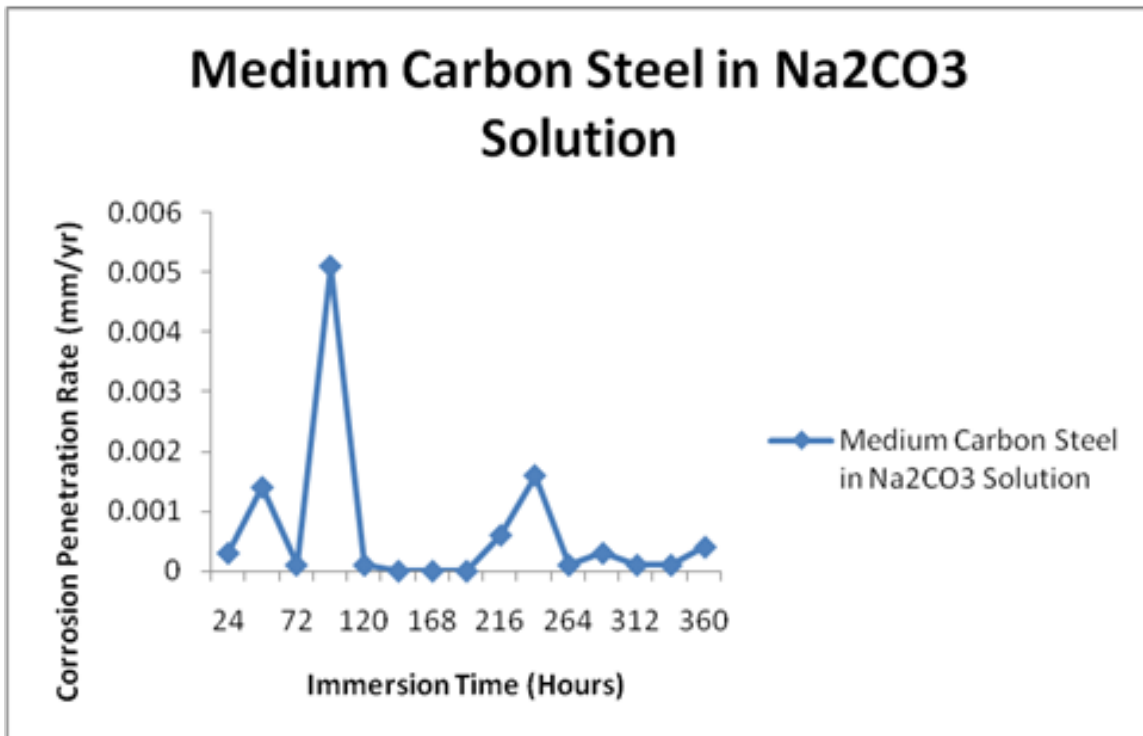


Fig.1: CPR of MCS in Sodium Carbonate Environment

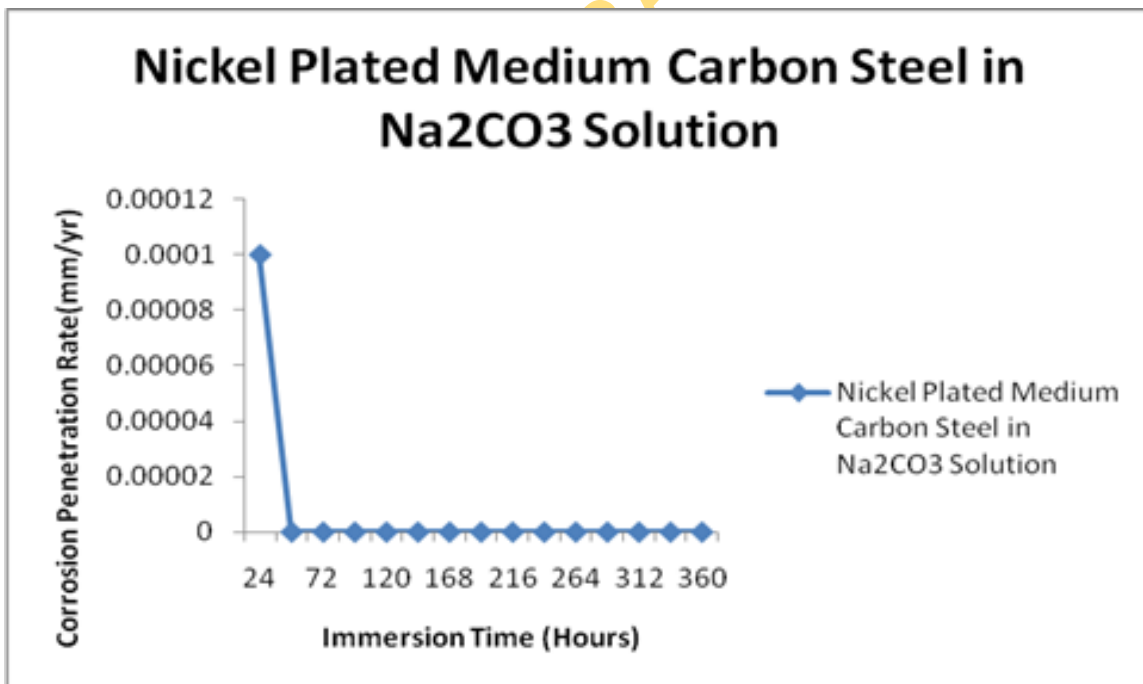


Fig.2: CPR of Nickel Plated MCS in Sodium Carbonate Environment

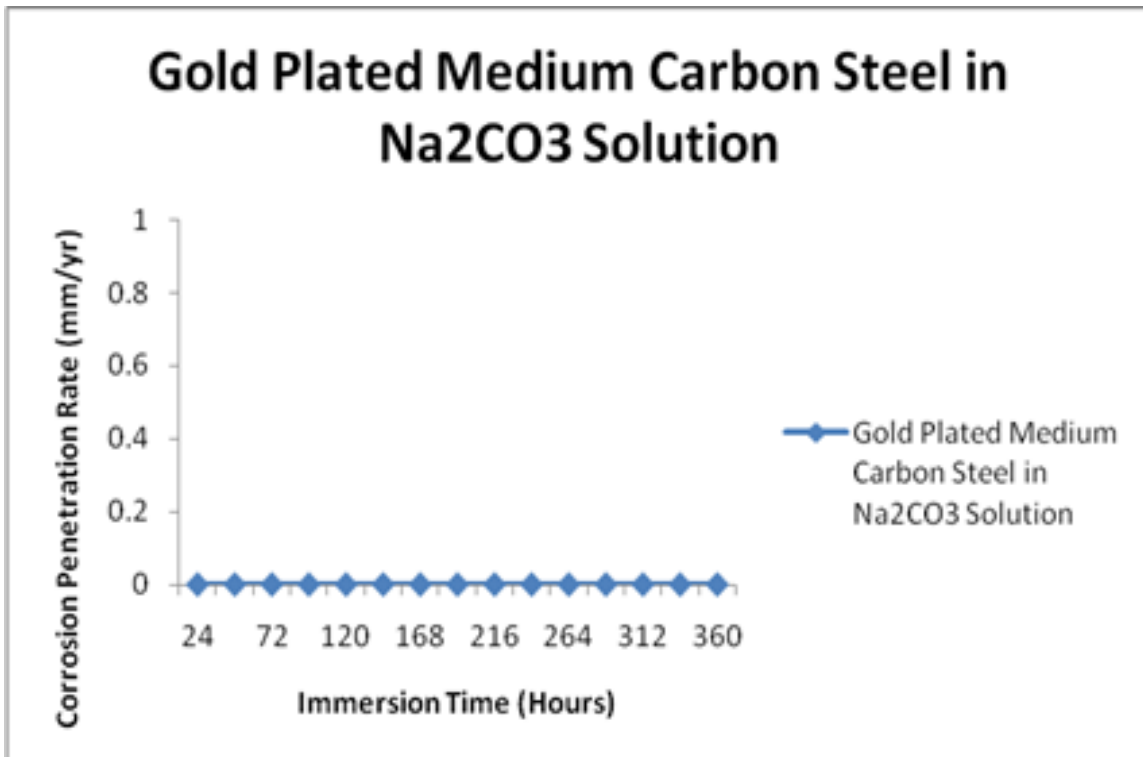


Fig.3: CPR of Gold Plated MCS (with nickel preplate) in Sodium Carbonate Environment

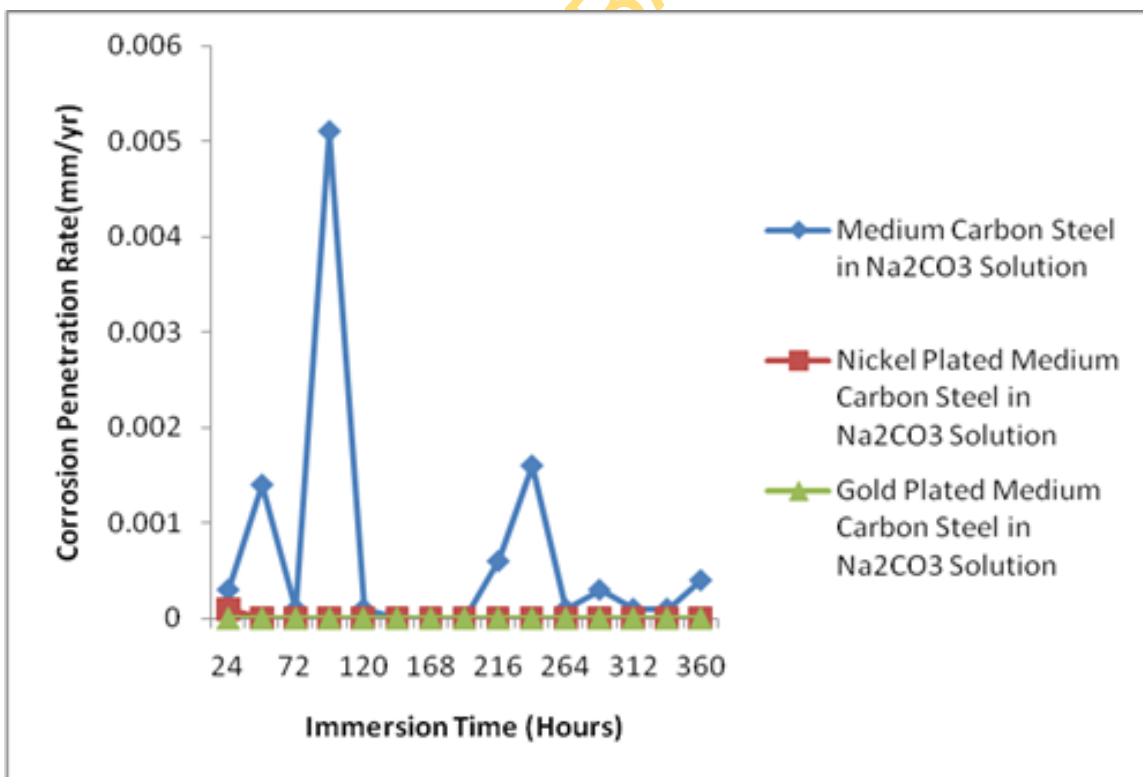


Fig.4: Different CPR of Unplated and Plated MCSs in Sodium Carbonate Environment

3.2 Discussions

Table 1 shows the results of composition analysis of MCS carried out at the Universal steel Limited, Lagos state, Nigeria. The average percentage of carbon content is 0.34% which indicated medium carbon steel (MCS). Tables 2 and 3 give the current density, plating time and increase in weight during nickel and gold plating of MCS. An increase in weight of 44.2g and 0.5g were obtained for nickel and gold plated MCS respectively. Fig.1 describes the corrosion behaviour of MCS in 0.5mol dm⁻³, 100ml sodium carbonate solution for 360 hours study duration. At the end of 24th hour, the CPR was 3×10^{-4} mm/yr. This further increased to 1.4×10^{-3} mm/yr at the end of 48th hour and thereafter reduced to 1.0×10^{-4} mm/yr at the end of 72nd hour. The CPR again picked up to 5.1×10^{-3} mm/yr which was the highest throughout the study period. Between 120 hours and 192 hours, MCS experienced insignificant corrosion deterioration rates. The formation of a passive film is responsible for these insignificant corrosion penetration rates. The CPR once again resumed at the 216th as a result of breakage in the earlier formed passivating layer. This trend however continued till the end of the 360th hour when the CPR recorded was 4.0×10^{-4} mm/yr. In summary, MCS experienced high corrosion degradation in 0.5mol dm⁻³ Na₂CO₃ medium throughout the 360 hours experimentation period. No doubt, MCS is not a reliable material in Na₂CO₃ solution due to its low corrosion resistance. Fig.2 shows the corrosion resistance behaviour of nickel plated MCS in the same concentration of Na₂CO₃ solution as in fig.1. Apart from the first 24 hours when it experienced an infinitesimal CPR with its peak value as 1.0×10^{-4} mm/yr, nickel plated MCS experienced an approximate no corrosion degradation throughout the 360 hours experimentation duration. The formation of passivating layer of nickel oxide is mainly responsible for this very high corrosion resistance of nickel plated MCS in sodium carbonate medium. Fig.3 shows that Gold plated MCS (with nickel undercoat) experienced an approximate no corrosion degradation throughout the study duration of 15 days. The formation of a very strong protective layer is greatly responsible for the high corrosion resistance of gold plated MCS in Na₂CO₃ Solution. Fig.4 illustrates a comparative analysis of corrosion characteristics of unplated, nickel plated and gold plated Medium Carbon Steels (MCSs). Clearly, it is shown in fig.4 that the unplated MCS exhibited the worst corrosion resistance while plated ones have a very high resistance to corrosion degradation. More also, fig.4 revealed that gold plated MCS has a slightly better corrosion resistance characteristics than nickel plated MCS in sodium carbonate solution.

4. CONCLUSION

The following conclusions can be drawn from this experimental study:

- (1) The results of this experimental study have shown that unplated MCS is generally unreliable material in sodium carbonate solution due to its low corrosion resistance characteristics.
- (2) Nickel and Gold plated MCSs generally have high corrosion resistance behaviour in Na₂CO₃ environment. Although gold plated MCS has a slightly better corrosion resistance characteristic than nickel plated one, they are both reliable alloy materials for fabrication of decorative objects that will be utilized in sodium carbonate environment.
- (3) As electroplating time, bath concentration and current density increases, there is a corresponding increase in the corrosion resistance characteristics of electroplated MCS. This is in qualitative agreement with the recent literatures.

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