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Development of Pulse/Direct Electrodeposition, Characterisation and Mineralised Antibacterial Activity of Platinum Coatings on SS304

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Abstract

The current investigation meticulously tracks the advancement, metallurgical delineation and deployment of Platinum 5Q solution onto the SS304 matrix, harnessing its mineralised prowess as a potent antibacterial agent. Pulsed Electrodeposition (PC) with platinum bath solution was used to develop coatings on a substrate with different duty cycle PC 25%, 50% and 75% and Direct Current (DC) source as a comparative study for the electrodeposition performance against the bacterial activities. Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM) were used to observe the newly developed platinum on the substrate. Utilising the broth culture and agar petri plate technique, the antibacterial activity of Pt using DC and PC methods was tested against Gram-negative E. coli and Gram-positive bacteria such as Staphylococcus saprophytieus, Bacillus stilis and Enterococcus faecalis. Platinum metal ions activity was compared to platinum solution and platinum-coated samples in terms of mineralised efficacy. The platinum coating obtained from PC 75% has significant antimicrobial activity against Enterococcus faecalis microorganisms experienced, according to the findings. As the concentration of platinum metal ions increased, so did the antibacterial activity. The study's discoveries indicate that electrodeposited platinum metal ions hold promise as prospective mineralised antibacterial defenders in the times ahead.

Keywords: *Antimicrobial Effect, Atomic Force Microscope, Electrodeposition, Platinum, Scanning Electron Microscope*

1.0 Introduction

Metal-based drugs have more competencies to counter metals' negative effects on various diseases, such as bacteria and cancer, research and development in advanced medicine are identified and long-established to increase the actions of metals[1-4]. One of the epidemiological surveys from Australia, Europe and North America reports that there are the most susceptible way diseases spread from person to person caused by bacteria and

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viruses[5]. One way to spread bacteria or viruses is by direct contact with dirty metallic surfaces (e.g., shops, grocery shopping carts, handrails on buses, and metallic structures in recreational parks). Bus railings and supermarket shopping carts are two of the five locations with the highest heterotrophic-bacteria contamination. To be adaptable and avoid the drawbacks of using organic-based medications, transition metals, which are d-block metals with distinctive electronic configurations, help monitor various disorders[6]. Long back 150 ago, the patent was received in the name of Elkington in the year 1837[7], Then, as technology evolved, Bijttger created the initial experiments using the electrolytic deposition of platinum group metals[8]. The electrodeposition procedure is supposed to be a rapid, easy, efficient and economical way to create a noble metal coating. It is created by briefly immersing it in a simple metal salt solution. Platinum (Pt) is a pricey metal, but the electrodeposition approach quickly creates a thin, adhering coating for a range of uses[9,10].

With an atomic mass of 195.084 and an atomic number of 78, Pt is a transition metal and is denoted by the symbol Pt. Pt is suitable since, due to its nobleness, its ion elution is strictly limited (or high standard electrode potential). Pt has anticancer and antimicrobial properties[11-13]. Due to its metallurgical characteristics, platinum has also found several uses in medicine, such as an antibacterial in defibrillators, hip and knee replacements and catheters[14]. Additionally, collections of platinum atoms between 1 and 100 nm in size possess platinum metal ions that are given more importance because of catalytic behaviour[15].

Utilising methods like Field Emission Scanning Electron Microscopy (FESEM) and Atomic Force Microscopy (AFM), the prepared electrodeposited-aided platinum metal ions on the substrate were analysed. Platinum shows very good antibacterial activity for Gram-negative bacteria in both the broth culture and the agar Petri plate method. This was the first laboratory study of bactericidal activity against selected pathogenic bacteria using a noble metal such as Pt developed by the electrodeposition method.

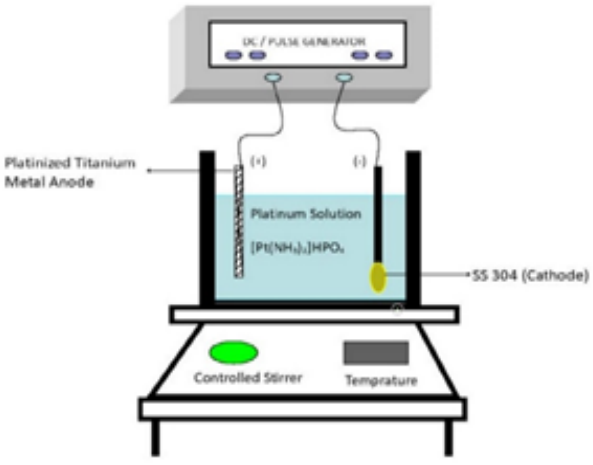


Figure 1. Schematic representation of electroplating of platinum on SS304.

2.0 Resources and Techniques

2.1 Compound

In this study, a platinum 5Q plating solution was given by Arora Matthey Limited, in Kolkata. Agar media for antibacterial action was provided by Mueller-Hinton and nutrient broth for bacterial culture was delivered by Hi-Media, India.

2.2 Electrodeposition Process

The Platinum 5Q bath is based on a complex formula [Pt $(NH_3)_4$] HPO_4 (Platinum Tetra Amine Hydrogen Phosphate) in phosphate buffer at a pH of 10.5. Pt bath solution used for electroplating was diluted with distilled water several times. The solution was made basic by the addition of 10% NaOH.

2.3 Surface Pre-Treatment and Polishing

Pt was layered on SS304 round cathodes with a 15mm diameter and a 1mm thickness (Figure 1). Mechanical polishing of samples was done with SiC abrasive papers

Table 1. Bath solution ingredients that have undergone optimisation

Components	Parameters
Solution of Platinum [Pt $(NH_3)_2$] HPO_4	0.2 g/l
Temperature	50°C
pH	10.5
Current density	2.5 A/dm^2
Deposition time	12 min
Duty cycle	DC and PC at 25%,50%75% duty cycle

to achieve a near-mirror finish. (METCO polishing machine, Chennai, India). The optimal bath composition is shown in Table 1 [16]. By weighing the cathode specimens before and after thorough studies, the amount of platinum coated throughout the electrodeposition procedure was determined.

2.4 Coating Characterisation of Platinum

2.4.1 SEM Analysis

Different platinum-coated samples were characterised for their surface morphology and porosity using an instrument (FESEM Carl ZEISS sigma, Netherlands). 5.00 kV and 15.0 voltage were adjusted while taking SEM pictures.

2.4.2 AFM Analysis

AFM tests (Nanosurf® EasyScan 2 AFM and STM) are used to analyse the coatings' surface roughness.

2.5 Bacterial Pathogens

The following bacteria were obtained from the Sapthagiri Institute of Medical Science and Research Centre (SIMSRC) in Bengaluru, Karnataka, South India: *S. saprophytieus*, *E. coli*, *B. Stilis* and *E. faecalis*. The bacteria stayed placed on gradients of nutrient agar that were kept at 4°C.

2.5.1 Preparation of the Pt-Coated Disc and Solution using the Agar Petri Plate Method

In a 250ml conical flask, nutrient agar and petri plates were created and autoclaved at 121°C and 15 pounds. Nutrient agar was placed onto petri dishes under sterile circumstances. Using test tubes with 24-hour-fresh cultures of four different bacterial species, solidified nutritional agar was used to inoculate petri plates.

Table 2. Composition of nutrient agar media

Constituent/Parameter	Amount
Peptone	5 g
Yeast Extract	2 g
Sodium chloride	5 g
Agar	15 g
pH	7.0 to 7.2
Distilled water	1000 ml make up

2.5.2 Preparation of a Pt-Coated Disc using a Broth Culture Approach to Combat Escherichia coli

Individual, Pt-coated sterile discs were used for the screening. In each test tube, 100µL of fresh *E. coli* culture was injected for 24 hours using around nutrients of 10mL broth that had been autoclaved at 121°C and 15 pounds.

2.6 Antibacterial Study Analyses

2.6.1 Pt-Coated Disc and Solution Using the Petri Plate Method

All three platinum-coated samples, DC, PC 50% and 75%, were loaded into agar petri plates, and additionally, Pt solution trials were loaded with the consecutive various concentrations of 5L, 10L and 15L to test the level enhancement theory for the antibacterial study. Each petri plate received around 100L of culture acquired by the inoculation of the platinum solution. Then, spread plate technology was used. Following inoculation, duplicate plates of each bacterial species were kept and cultivated for 24 hours at 37°C. The petri dishes were checked and documented for bacterial growth suppression after 24 hours[17].

2.6.2 Pt-Coated Disc in Broth Culture

A calorimeter was used to assess the culture's OD and an *E. coli* culture with a 0.6 OD was thought to be suitable for injection. As shown in Figure 6, triplicates for both the experimental and control were measured and the experimental condition was established in the absence of the Pt disc containing only *E. coli*. A test blank was kept without adding any *E. coli* to the broth. Appropriate sterile procedures were followed for the experiment, which was incubated for 24 hours at 37°C. Each sample's absorbance was determined using a UV-Vis spectrophotometer set to 600nm.

3.0 Results and Discussions

3.1 Electrodeposition

By maximising all variables, including bath composition, pH, current density, temperature, and duration, Pt metal was coated on SS304. To determine the amount of Pt

coated after electrodeposition, the weight difference between the cathode specimen before and after coating was employed.

3.2 FESEM

Pictures from FESEM were captured and Figures 2a, 2b, 2c and 2d show the deposit as it was derived from DC and PC changes. As we have seen, 2.5 A/dm^2 offers both a better look and a better distribution of metal ions in the form of smaller particle sizes. This is the optimal circumstance for our studies because Pt exhibits outstanding antibacterial characteristics at small particle sizes and only a minimal concentration of Pt metal ions on the surface is necessary to show an antimicrobial effect[18]. Increases in dispersion and particle size are recorded in PC 25% (Figure 2b) and PC 50% (Figure 2c). However, DC-coated samples function reliably across a wide variety of sizes and have a highly crystalline structure. The PC 75% duty cycle (Figure 2d) sample has a smaller grain size than the PC 25% and 50% models. It is clear from a comparison of all coating photos that coatings with a 75% duty cycle are more uneven, leading to less particle size dispersion in the natural world.

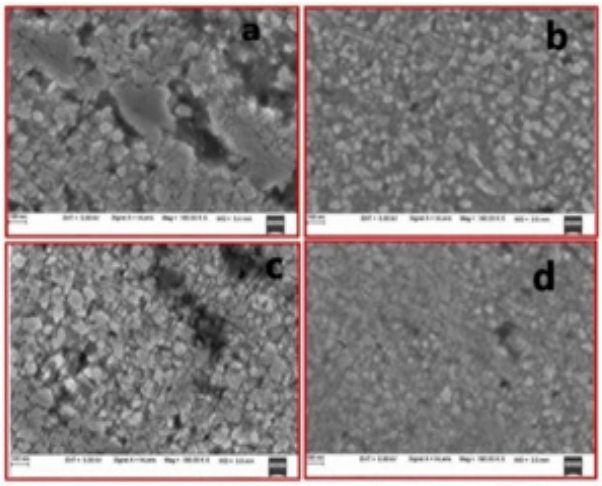


Figure 2. SEM images of Platinum coated on SS304, **A.** DC, **B.** 25% PC, **C.** 50%PC and **D.** 75% PC.

3.3 AFM

The Pt coating's average roughness was evaluated by AFM and was depicted in Figure 3. 3D images of Pt coatings obtained are shown in Figures 3a, 3b, 3c and 3d respectively. The surface roughness was increased at

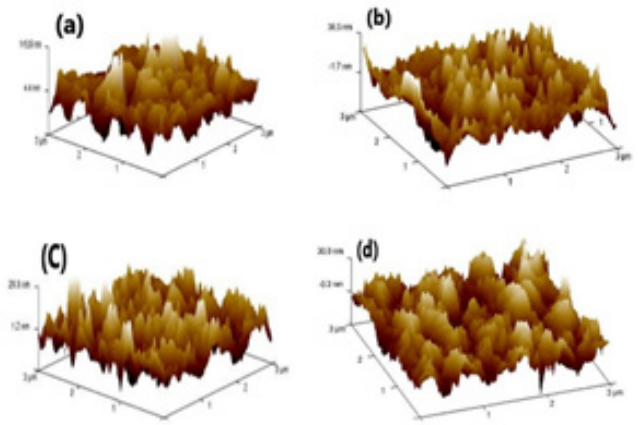


Figure 3. Coatings in 3D images obtained by AFM analysis.

a DC, PC 25%, PC 50% and PS 75% by a factor of 25%. This result was attributed to that obtained by the SEM images in Figures 2a to 2d. A smaller grain size results in a lower roughness at 75% PC duty cycle, which later raises the roughness value. As a result of the analysis above, it can be concluded that the coating is less rough the smaller the crystallite particle size. Pt metal ions with smaller crystalline sizes exhibited greater antibacterial activity, albeit this activity improvement was also influenced by the level and Pt greater surface zone. The duty cycle variation significantly affected how their measurements of crystallites looked from the outside[19].

4.0 Antimicrobial Action

Gram-negative *E. coli* and other gram-positive bacteria, including *S. saprophyticus*, *E. faecalis* and *B. subtilis*

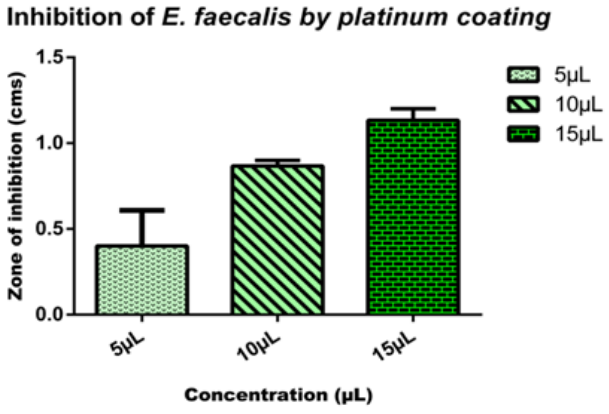


Figure 4. Antimicrobial activity of *E. faecalis* by Pt solution.

Table 3. Antimicrobial activity of platinum coating.

Microorganisms	DC	50%	75%	Antimicrobial resistance
Escherichia coli	-	-	-	No
Staphylococcus saprophyticus	-	-	-	No
Enterococcus faecalis	+	+	+	**Yes**
Bacillus subtilis	-	-	-	No

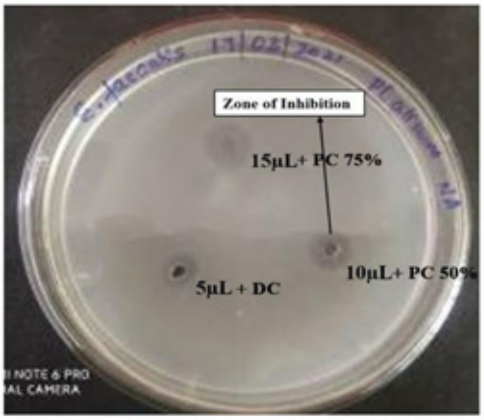


Figure 5. Zone of inhibition formed by platinum coating against the *E. faecalis*.

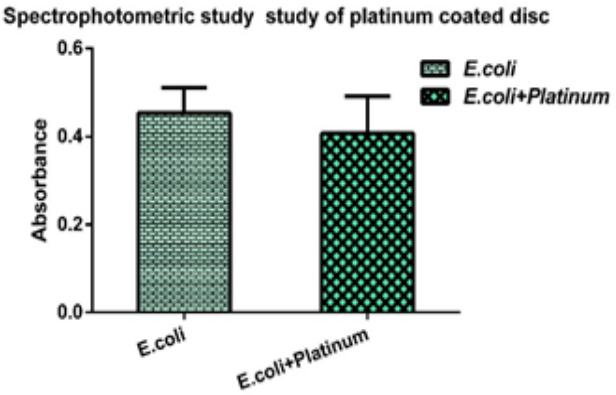


Figure 7. Platinum-coated disc on *E. coli* by spectrophotometric.

species, were tested for electrodeposited Pt-coated samples generated from DC and PC techniques. According to Table 3, Pt showed antimicrobial resistance against *E. faecalis* and fitting proof of zone of inhibition was shown in Figure 5. The rest of the three species were not susceptible to Pt. According to Figure 4, there was a considerable, significant inhibition zone as the Pt content rose.

The sample broth was thoroughly scrutinised for any external contamination and the Pt-coated disc was contrasted with the test control, which contained solely an *E. coli* inoculum. Pt-coated disc inoculation

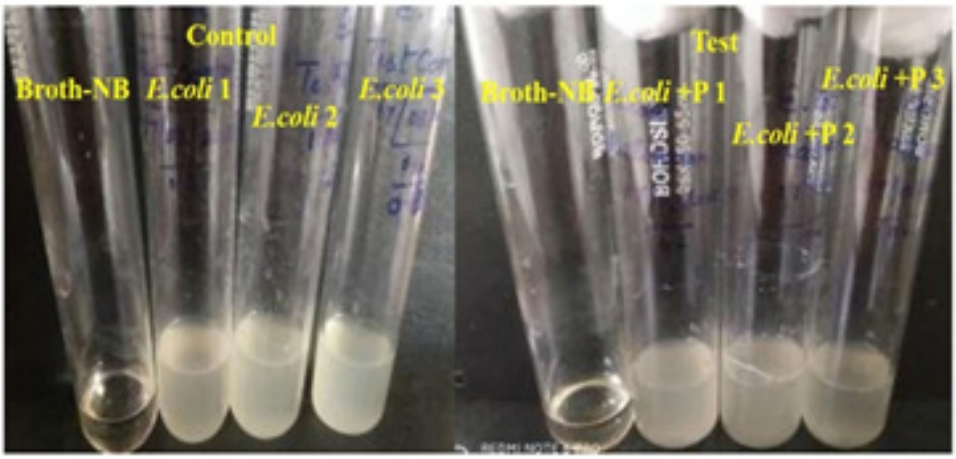


Figure 6. Spectrophotometric study of platinum coated (P) disc on *E. coli* (n=3) in broth culture.

test samples showed modest antibacterial activity at 600nm, as shown in Figure 7. With an average SEM of 0.45±0.93 and 0.45±1.23 for test control and test sample respectively[20].

5.0 Conclusion

As per the research results, platinum metal ions coatings on SS304 by PC method compared to DC method have better effective antibacterial activity against all pathogens tested. SEM and AFM investigations corroborated the data on crystalline size and deposition capability. As the particle size/grain size reduced and the number of Pt metal ions enhanced, the antibacterial levels increased. As determined by the zone of inhibition seen against Gram-positive bacteria, platinum metal ions may be promising antibacterial agents. As a result of their extensive pharmaceutical properties, platinum metal ions have been identified as a safe metal ions form of platinum that has the potential to be useful therapeutic agents. Further investigation is warranted to elucidate the mechanism through which antimicrobial activity is amplified in the presence of Pt metal ions.

6.0 Acknowledgement and Funding

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