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Comparative Study on A Novel Local Electroplating Method Using High-Density Paste Versus Traditional Electrolytic Solutions: An Examination of Copper Coating Thickness and Corrosion Resistance on Iron Samples

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Abstract

This paper presents a study on a new method of electroplating, using a high-density paste instead of traditional electrolytic solutions. The method was tested on iron samples, which were coated with copper. The thickness of the copper layer was measured using a leoi-44 experimental ellipsometer, revealing a thickness of 318 nm for the sample treated with the paste method, and 400 nm for the sample treated traditionally. The external view test of the samples was also tested, comparing the microscopic im-ages of the samples' surfaces, we notice that there is a great similarity between surface of sample A and surface of sample B, which indicates that the coating process with local electroplating paste in sample A is successful because it gave results similar to the traditional coating process used in sample B. The paper concludes that this new meth-od could be useful for treating specific areas of large or fixed metal objects.

Keywords: Electroplating, high-density electrolyte paste, copper coating, local electroplating, traditional elec-troplating, Dimi and Helms method.

الخلاصة: يقدم هذا البحث دراسة عن طريقة جديدة للطلاء الكهربائي وهي طريقة طلاء كهربائي موضعي باستخدام عجينة عالية الكثافة بدلا من المحاليل الاليكتروليتية التقليدية. تم اختبار الطريقة على عينات الحديد والتي تم طلائها بالنحاس في هذه الدراسة . تم قياس سمك الطبقة النحاسية باستخدام مقياس القطع الناقص التجريبي leoi-44، حيث كشف عن سمك 318 نانومتر للعينة المعالجة بطريقة الطلاء الكهربائي الموضعي ، و400 نانومتر للعينة المطلية حسب الطريقة التقليدية . كما تم اختبار اختبار المنظر الخارجي للعينات، ومقارنة الصور المجهرية لأسطح العينات، لاحظنا وجود تشابه كبير بين سطح العينة (A) وسطح العينة (B)، مما يدل على أن عملية الطلاء الكهربائي الموضعي المستخدم في العينة (A) ناجحًا لأنه أعطى نتائج مشابهة لعملية الطلاء التقليدية المستخدمة في العينة (B). ويخلص البحث إلى أن هذه الطريقة الجديدة يمكن أن تكون مفيدة لمعالجة مناطق محددة من الأجسام المعدنية الكبيرة أو الثابتة.

1. INTRODUCTION

1.1.History of electroplating

Electroplating is a process of producing a metal coating on a solid object by using an electric current. The object to be coated acts as the negative electrode (cathode) of an electrolytic cell, while the metal to be deposited acts as the positive electrode (anode) or is dissolved in the electrolyte solution. Electroplating can improve the appearance, durability, conductivity, or corrosion resistance of the object. Electroplating was invented in 1805 by Italian chemist Luigi Brugnatelli, who used a voltaic pile (an early battery) to deposit gold on silver medals. However, his work was not widely recognized until later, when other scientists improved and patented the process[1, 2].

Some of the important developments in the history of electroplating are:

In 1839, Russian and British scientists independently discovered methods to copper plate printing press plates[3].

In 1840, George and Henry Elkington, cousins from Birmingham, England, obtained patents for electroplating and established the first electroplating company. They also bought the patent rights to John Wright's process of using potassium cyanide as an electrolyte for gold and silver plating[3, 4].
In 1857, electroplating was first applied to costume jewellery, making it more affordable and fashionable[3].
In the late 19th and early 20th centuries, electroplating was used to produce metal plates with complex shapes, a technique called electroforming[2].

In the 20th and 21st centuries, electroplating became widely used in various industries, such as electronics, automotive, aerospace, and medical. Electroplating was also used to purify metals, such as copper, and to create new alloys and composite materials[2].

1.2 Types of electroplating

The process of metal plating can consist of electroplating, which makes a deposition of metal ions on the surface of the substrate by making use of an electric current[2]. Electroless plating applies metal ions on the workpiece as well without making use of any electrodes[5]. There are different types of coatings which can either be industrial or commercial. Commercial decorative coating is utilized on items that are used every day to provide them with improved appearance and strength[6]. Most commercial coatings are used on certain tools, silverware, and jewellery. Industrial coatings are applied to metal parts to give them endurance and to improve their wear resistance so that they can withstand harsh conditions. This helps in protecting and strengthening machine parts and truck parts. Coatings are also capable of improving the solderability and strength with reduced friction to reduce potential wear[5, 7].

A. The various metal plating processes include:

Electroplating Process: A process where electrodeposition is utilized to coat the workpiece in a thin layer of metal. Controlled electrolysis is utilized by engineers for the transfer of the desired metal coating from the anode (the part that contains the metal that will be made use of as the plating) to the cathode (the part that is to be plated). Both the cathode and the anode are immersed in an electrolyte chemical bath and a continuous electrical charge is applied. The electric current causes the movement of negatively charged ions (anions) to the anode and the movement of positively charged ions (cations) to the cathode, forming a thin layer around or plating the desired workpiece in an even metal coating[2].

Electroless Plating: A process where metal ions are applied on the workpiece without making use of any electrodes. This process is used to coat non-conductive materials with a thin layer of metal. The process involves the use of a reducing agent and a metal salt solution. The reducing agent reduces the metal ions in the solution to form a thin layer of metal on the workpiece[8].

Immersion Plating: A process where the workpiece is immersed in a solution containing the metal ions that are to be deposited on the surface of the workpiece. The process is simple and does not require any electrical current. The metal ions in the solution are attracted to the surface of the workpiece and form a thin layer of metal on it[2].

B. The types of metal plating based on the metal used include:

Nickel Plating: A process where a thin layer of nickel is deposited on the surface of the workpiece. It is used to improve the corrosion resistance of the workpiece[2, 8].

Zinc Plating: A process where a thin layer of zinc is deposited on the surface of the workpiece. It is used to protect the workpiece from corrosion.

Rhodium Plating: A process where a thin layer of rhodium is deposited on the surface of the workpiece. It is used to improve the appearance of the workpiece and to protect it from scratches and tarnish[2, 8].

1.3 Theoretical expectations for paste of topical electroplating process

The idea of this study focuses on replacing the traditional electrolytic solution used in the electroplating process with another medium with a higher density consistency (paste).

The importance of this method is that it enables the electroplating process to be carried out locally and for specific areas of metal objects without the need to immerse the entire metal object completely in the electrolytic solution as is the case in the traditional method.

This method gives a high possibility of maintaining and sustaining industrial equipment, which increases its operational life.

This method is also useful in increasing the effectiveness of welding work, as if we assume that we weld two pieces of galvanized iron together, we will obtain a welding area that is not galvanized and therefore susceptible to corrosion or interaction with the medium in it. The idea of the local electroplating paste depends on trapping the ions released from the anode surface and not allowing them to reach the cathode surface, using a special membrane, which causes these ions to collect and remain in their critical state, forming the local electroplating paste, which is collected and used in other places after being stimulated with an appropriate electrical current.

2. EXPERIMENTAL WORK

To conduct a practical test on this method, iron was chosen to be coated with copper because iron is one of the metals most susceptible to corrosion and also because “copper is widely used in plating because copper gives a theoretical benefit in increasing the effectiveness before the plating process with other metals, as the surface treated with copper will be in a consistent manner[9]. The copper layer serves to protect the iron from corrosion[10]. This is especially important for objects that are exposed to the elements or are in regular contact with moisture[11, 12]. The copper plating layer is also considered an intermediate layer in some other iron plating processes[11]. Such as nickel plating of iron, Nickel has a much better affinity for copper than iron. This means that nickel adheres better to a surface that has been copper-plated, which can result in a more durable finish[4].

2.1 Materials and Methodology

The process of topical electroplating is carried out in two stages.

2.1.1 The first stage: preparing the paste of topical electroplating

This is done using an electroplating paste preparation cell, which consists of a beaker containing a cathode electrode (iron) and an anode electrode (copper).

Figure 1: The cell's electrodes are the anode (copper) and the cathode (iron).

The two electrodes are separated using cotton fibers, then these fibers are saturated with the electrolyte solution prepared according to the “Dimi and Helms” method, which is considered the standard method for preparing copper plating solutions[9].

Table 1. The electrolyte solution components according to the “Dimi and Helms” method

Component	Quantity
Copper sulphate, pentahydrate	0.375 g/l
Hydrochloric acid	37% v/v

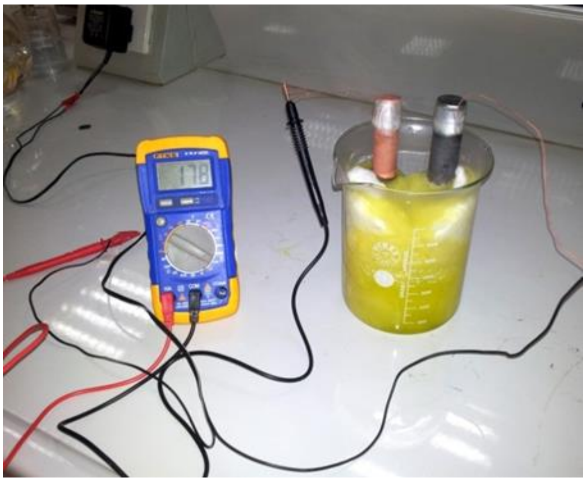


Figure 2: Cell of topical electroplating paste preparation

Overview of cell for preparing paste of local electroplating during work. The cell is connected to an electric current proportional to the diameter of the anode electrode and according to the formula (4 - 6 A/dm²)[9], where 50 mm of the anode electrode is immersed. To find the current, the surface area of the anode is calculated.

According to the formula (4 - 6 A/dm²)[9], since every 10,000 mm² requires approximately 5 A, so an electrical current source of 2 A was used.

For a period of 3 hours, the ions are released from the anode and collect on the cotton fibers, which prevents these ions from reaching the cathode, forming a paste that is collected and used in the next stage.

According to this method, 215 ml of local paint paste is produced from every 1000 ml of electrolyte solution, as shown in the figure 3.

Figure 3: High-density electrolyte solution (paste of topical paint) and as shown in the figure in dark color.

2.1.2 The second stage: painting the metal surface

After obtaining the paste from the first stage, the paste is stimulated with an appropriate electric current of 0.2 A for three minutes and using the "stimulating electrode" tool, which is made by wrapping a foil of pure copper around a glass rod. The edge of the glass rod protrudes from the copper foil by 3 mm to ensure that there is no contact between the surface of the iron sample and the copper foil.

The copper ions in the paste, which are in a critical state, which moves to the iron surface, causing the plating process, leaving behind an inert paste that is removed by rinsing with water and the metal surface is cleaned from it to obtain a clean painted surface.

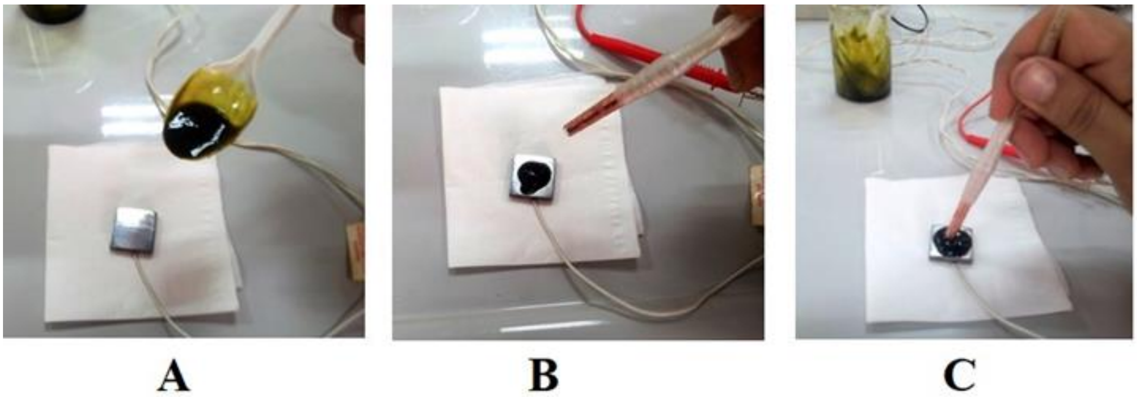


Figure 4: Stages of the laboratory experiment for the second stage of using local electroplating paste on the surface of the iron sample.

Figure 5: Iron sample after the end of the laboratory experiment using topical electroplating paste.

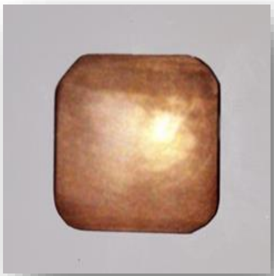
3. RESULTS AND DISCUSSION

The iron sample after the plating and washing process, where a layer of copper was deposited on the surface of the iron piece. It was noted that the shape of the painted area took the shape of the area that was covered with the local electroplating paste.

To find the effectiveness of the electroplating paste method. The principle of comparison was adopted between the method of this study and the traditional method of plating iron with copper (The “Dimi and Helms” method), where three test Samples were made of the same metal (iron) with the same dimensions (25mm x 25mm), and the surfaces of these Samples were prepared (cleaning and polishing) in the same grinding method in order to prepare the surface of the metal in order to obtain the best plating process.

The Samples are named A, B, and C

Table 2. Comparison between the method of paste of local electroplating and the "Dimi and Helms" method of plating iron with copper

Sample name	Sample shape	Sample description
A		A well-cleaned surface of a sample of iron, part of its surface electroplated with copper, according to the method (paste of local electroplating method)
B		A sample of iron that was cleaned well and electroplated with copper by immersing it in an electrolyte solution according to the traditional method[9]
C		A surface of a sample of iron was cleaned well by grinding method, as in the previous samples

To test the effectiveness of the paste of local electroplating method, three tests were performed. Microscopic images test to show the microstructure of surfaces. Calculated the thickness of the copper layer by analysis of the change in polarization by using LEOI-44 experimental ellipsometer.

A. *Microscopic images test*

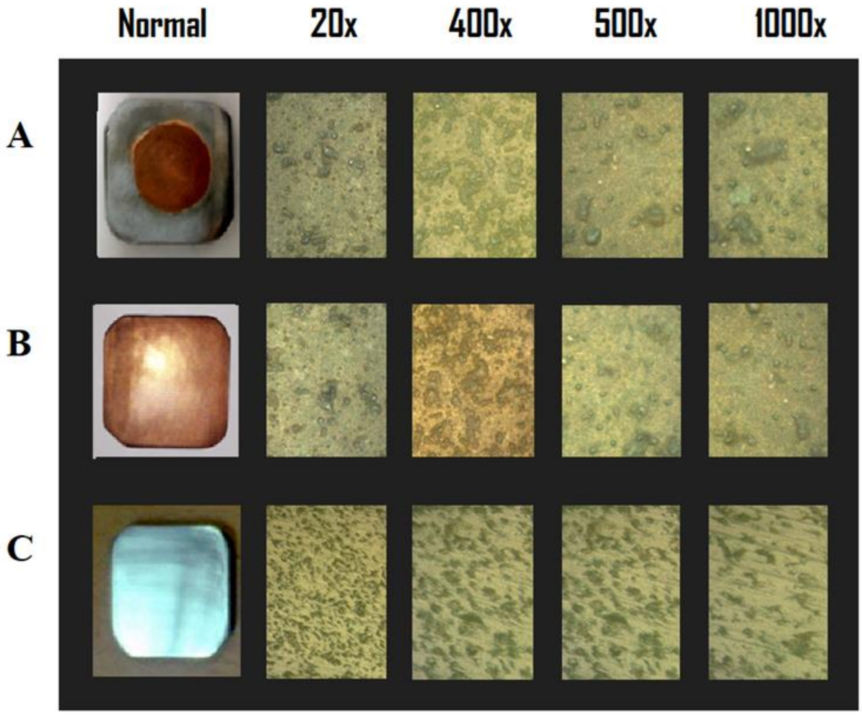


Figure 6: Microscopic images to show the microstructure of surfaces at different magnifications,

Where nx symbolizes the number of times of magnification, for example,20x means the image is magnified 20 times larger than its actual size.

When comparing the microscopic images of the samples' surfaces, we notice that there is a great similarity between surface of sample A and surface of sample B, which indicates that the coating process with local electroplating paste in sample A is successful because it gave results similar to the traditional coating process used in sample B.

B. Calculated the thickness of the copper layer

Figure7: LEOI-44 experimental ellipsometer

The thickness of the copper layer was calculated by using LEOI-44 experimental ellipsometer (as shown in the picture) it was found that the thickness of the paint layer (copper layer) with local electroplating paste method in sample A was (318 nm), while in sample B, which was painted in the traditional method, the thickness of the paint (copper layer) was (400 nm).

4. CONCLUSIONS

The conclusion of the paper states that the local electroplating paste method is effective for copper coating on iron surfaces. The method allows for specific areas of large or fixed metal objects to be treated, which is beneficial when traditional electroplating is not feasible. The study found that the copper layer thickness achieved with the paste method was 318 nm, compared to 400 nm with the traditional method. Despite the slight difference in thickness, the surface quality of the copper coating was similar between the two methods. The paper suggests that the local electroplating paste could be a useful alternative for electroplating in certain applications.

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