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A Comparative study of Electro- Deposition of Copper and Zinc on High-Carbon Steel

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Abstract—*Electroplating is a n electrochemical process that involves a chemical response of the constituents in an aqueous mixture, due to galvanic excitation that causes the formation of thin film layers i.e. the coating, on the substrate of the material. Very few surface finishing techniques exist that serve the purposes of various functional applications and aesthetic appeal. Electroplating stands out as one of those surface finishing techniques that impact peculiar properties. This paper presents an overview of the comparisons between the electro- deposition of copper and Zinc on high carbon steel.*

Keywords: *Electroplating, Electrochemical, Coating, Chemical, Environments*

Introduction: Electroplating, which is also known as electro deposition, isa process in which the deposition of a material is done on a work-piece using anelectric current. It is a process by which a thin layer of metal is deposited on work-piece known as the substrate.

Electroplating is primarily used to change the physical properties of an object. This process can be used to give objects increased wear resistances, corrosion protection or aesthetic appeal.

Moreover, Electroplating also increases the metal's hardness and thickness, prevents it from getting corroded and it may also provide the metal with specific electrical properties and solder-ability. Though this process may seem as an advanced technology,it is actually centuries old.

This process of applying protective and decorative coatings has so greatly advanced that properties, dimensions of coats and coating rates can be strictly controlled. As a result of these properties, T h e electroplating market size is estimated to be valued at USD 20 billion in 2023 and is expected to surpass USD 30 billion by 2033. The adaptation of electroplating is likely to advance at a CAGR of 4.1% during the forecast period. - "Electroplating Market Outlook (2023 to 2033)" 2023

Tin(*Sn*), Silver(*Ag*), Rhodium (*Rh*), Platinum(*Pt*), Palladium (*Pd*), Zinc(*Zn*), Iridium(*Ir*), Lead (*Pb*), Gold(*Au*), Nickel(*Ni*), Chromium(*Cr*), Copper(*Cu*), Brass (an alloy of *Zn +Cu*), and Aluminium(*Al*) are the most used coatings on a variety of metal substrates.

History of Electroplating: It is remarkable that practical and technological phases of electroplating matured even before 'Faraday's Laws' of electrolys is were pronounced.

Electroplating was invented in 1805 by Italian inventor Luigi V.Brugnatelli. He did this by linking a wire between a

dissolved gold solution and a battery, also known as a Voltaic pile. - *"A Brief History of Electroplating" 2019*

Moreover, Until World War 1, electroplating was considered anart because appearance and appeal of electroplated surfaces were considered instead of the physical and chemical propertiesof the coat.

It was around World War 2, that electroplating was considered aTechnological advancement fromits art status.

Applications of Electroplating: To day, electroplating is a part of advanced science an d engineering due to advancement in metallurgy and physical Electro-Chemistry. The use of Direct current (D.C) as a source of energy for electroplating processes and thermocouples for controlling temperature rise in the process, has m a d e electroplating highly reliable. Electronics, automobiles and various other industries have demands for electroplated products. Electroplating is also used in the making of jewellery and facilitating conduction in

circuit boards. A few more practical applications and uses ofthis process are as follows:

- *Aesthetics:*

Some metals are more expensive, rare, and valuable than the others, silver and gold being the most obvious examples. Through the process of electroplating, an extremely thin layer of gold or silver can be used to coat a less valuable metal so that the final product has all the beauty andlustre at a minimal cost. Electroplating, being one of the widely implemented applicationstoday, is extensively used for designing jewellery and otherornaments. Moreover, thin layers of chromium are also used on automobiles and appliances to give them an attractive and shinyappearance.

- **Commercial Applications:** Electroplating is also used on carp arts to give as moot appearance and texture with the help of a thin layer of chromium, at the car owner's request. Electroplating can also be done on various other appliances as well.

- *Prevention of Corrosion:*

As some metals are more proneto natural processes such as corrosion (conversion of a metal into a chemically stabilised form like oxide, hydroxide, carbonate, or sulphide), electroplating protects their surface by coveringthem with a thin layer of metal, which shall be corrosion resistant. Copper, chromium, and nickel, which are the non- corrosive metals, are spread over corrosive metals like iron and steel to prevent corrosion.

- **Conduction of Electricity:** Metals like silver and gold are indeed excellent conductors of electricity; however, they are prohibitively expensive. Through the techniques of electroplating, little amounts of these highly conductive and precious metalscan be incorporated into the integrated circuits and electrical components like computers, cell phones, amongst many others, to help in the conduction of electricity.

Reducing Friction: Electroplating can reduce the built-up friction of some materials such as the electrical connectors to a great extent byintroducing a certain kind of metal plating on them. For instance – nickel plating improves performance and reduces friction and wear and tear.

- *Protection from Radiation:*

Electroplating also helps to protect the materials from various other natural phenomena, including radiation and abrasion, simply by imparting the desired features or characteristics to the surface of the metals, which in general, lack them.

4. Principles of Electroplating: Electroplating is an application of the first (1st) Law of Faraday that the charge Q (Coulomb) passed through an e Electrolyte is directly proportional to the mass of metaldeposited m (g) on cathode.

Mathematically,

$Q \propto m$

or

$m \propto it$ because $Q=it$

therefore,

$m=Zit$

where:

m = Mass in grams (g) of metaldeposited

Z = Electrochemistry equivalent of metal (ECE)

i = Current in amperes

t = Time in seconds

The Factors affecting the rateof electroplating are:

1. The voltage applied by theexternal circuit.
2. The surrounding bath temperature and the chemical composition of the electrolyte .
3. The time duration ofelectroplating.
4. The spacing between the anode and the cathode.

5. Setting up the required Apparatus for Electroplating and making an Electroplating Cell: Apparatus required:

1. 2 beakers
2. 50 g of (aq) Copper sulphate
3. 50 g of (aq) Zinc Sulphate
4. 1 L of distilled water
5. 2 1.5V dry cells
6. 2 3V batteries
7. 2 4.5V batteries
8. 2 6V batteries
9. 2 9V batteries
10. 10 2 feet long and insulatedCopper wires.
11. 2 Multimeters
12. 2 pure Copper plates
13. 2 pure Zinc rods
14. 16 (4/6 inch) plates of High-Carbon Steel
15. 1 Stopwatch

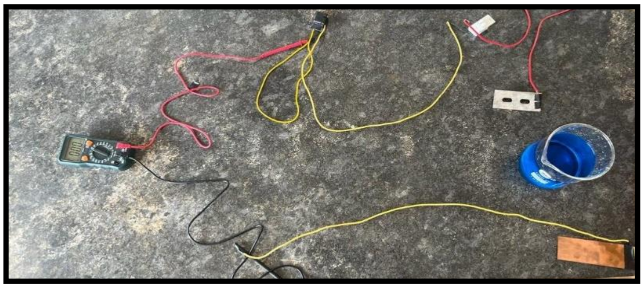
Making an Electroplating Cell:

1. First, measure 50 grams of(aq) Copper Sulphate and 50 grams of (aq) Zinc Sulphate on an electrical balance separately.
2. Then put each of the solutes in 2 separate 1L beakers.
3. Measure 500 ml of distilledwater in 2 measuring cylinders and pour the 500ml of the distilled water intoe ach of the beak e r srespectively.
4. After that, stir the mixture in both the beakers until the solutes dissolve and the solutions of Copper Sulphateand Zinc Sulphate form.
5. These will be the electrolytes.
6. After that, connect a 9V battery to a Multimeter, the Copper anode, and the steel cathode by copper wires and a 9V battery to a Multimeter, the Zinc anode and the steel cathode respectively for each of the two experiments.

Note : 1. (Positive terminal ofthe battery to be connected to the positive terminal of the Multimeter whose negative terminal will be connected to the Copper/Zinc anode. While the negative terminal of the battery has to be connected to the steel cathode.)

2. (The batteries of different volts to be changed after each experiment if your are examining the effect of change in Voltage on the amount of Copper or Zinc deposited on High- Carbon Steel)

After this, the Apparatus is set upand the Electroplating Cell is made.



(Picture of the copper electroplating cell)

6. The Experiment:

1. Copper Plating: The anode ismade of a plate of pure *Cu* is coated on the cathode made from High - Carbon Steel. The Electrolyte is dilute $CuSO_4$ solution (50 *g* per 500 *ml* of distilled water)(0.62 *M*).

When current is passed through the electrolyte, it dissociates into Cu^{2+} and SO_4^{2-} ions. The anode dissolves and Cu^{2+} ions from the solution move to the cathode andget reduced to form *Cu* atoms which get deposited on the steel cathode.

The reactions involved hereare:

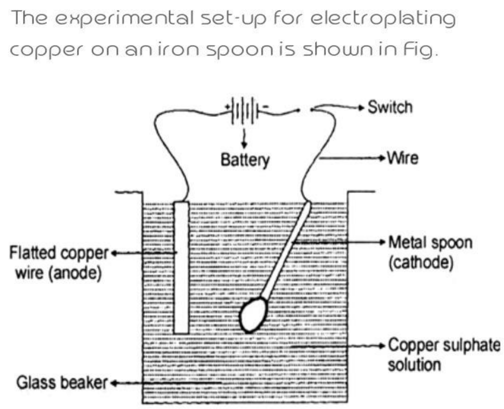
At Anode: (Oxidation)

Cu (S) $\rightarrow Cu^{2+}$(aq) + $2e^-$

At Cathode: (Reduction)

Cu^{2+}(aq) + $2e^-$ $\rightarrow Cu$ (S)

(Electroplating of Copper)



Experiment 1:

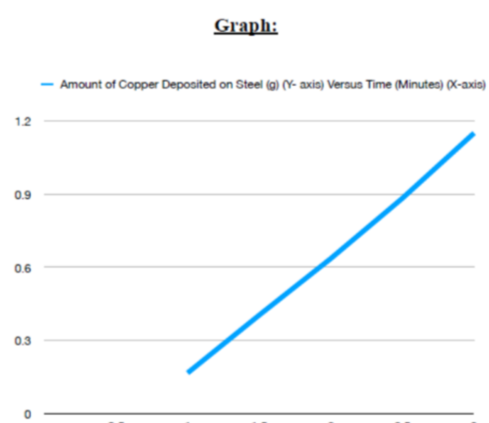
Topic: Examining the effect of change in the time of electroplating on the amount of Copper electroplated on high carbon steel.

Hypothesis: Time of electroplating is directly proportional to theamount of Copper electroplated on high carbon steel i.e. As the time of electroplating increases, the amount of copper electroplated on highcarbon steel also increases.

Observation Table:

S.NO	Time (Minutes)	Initial mass of Copper plate(Anode) (g)	Initial mass of Steel (Cathode) (g)	Final mass of copper plate (Anode)(g)	Final mass of Steel (Cathode) (g)	Differencein mass of Anode (g)	Differencein mass of Cathode (g)
1	1	17.440	31.761	17.270	31.930	0.170	0.169
2	1.5	17.270	29.313	16.861	29.719	0.409	0.406
3	2	16.861	29.313	16.221	29.951	0.640	0.638
4	2.5	16.221	33.088	15.333	33.973	0.888	0.885
5	3	15.333	31.585	14.178	32.737	1.155	1.152

Graph:



Experiment 2:

Topic: Examining the effect of change in the Voltage on the amount of Copper electroplated on high carbon steel Cathode.

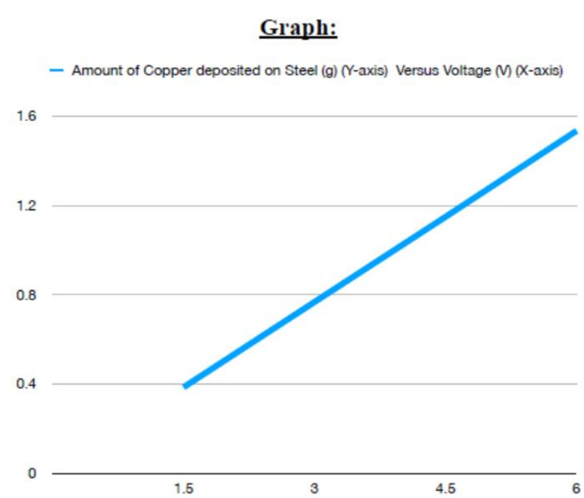
T (Time) = 2 minutes.

Hypothesis: Voltage is directly proportional to the amount of Copper electroplated on high carbon steel i.e. As the Voltage increases, the amount of copper electroplated on high carbon steel also increases.

Observation Table:

S.NO	Voltage (Volts)	Initial massof Copper plate (Anode)(g)	Initial massof steel(Cathode)(g)	Final massof Copper plate (Anode)(g)	Final massof steel(Cathode)(g)	Differencein mass of Anode(g)	Differencein mass of Cathode(g)
1	1.5	16.886	33.913	16.501	34.296	0.385	0.383
2	3	16.501	32.627	15.735	33.392	0.766	0.765
3	4.5	15.375	30.325	14.229	31.471	1.146	1.146
4	6	14.229	29.539	12.698	31.070	1.531	1.531

Graph:



1. **Zinc Plating:**
The anode is made of a rod of pure *Zn* which is coated on the cathode made of High-Carbon Steel. The electrolyte is dilute *$ZnSO_4$*

solution (50 *g* per 500 *ml* ofdistilled water)(0.619 *M*).

When current is passed through the electrolyte, it dissociates into Zn^{2+} and SO_4^{2-} ions. The anode dissolves and Zn^{2+} ions from the solution move to the cathode and get reduced to form Zn atoms which get deposited on the High-Carbon Steel cathode.

The reactions involved hereare:

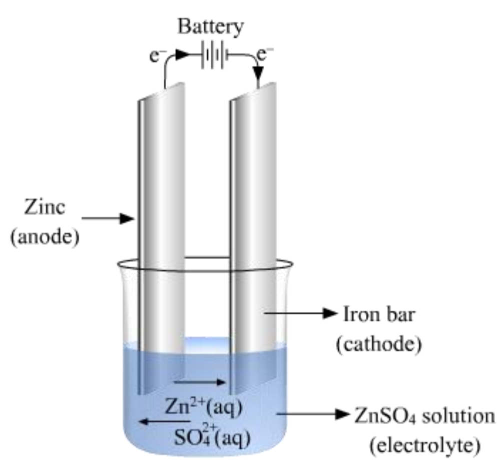
At Anode: (Oxidation)

$Zn\ (S) \rightarrow Zn^{2+}(aq) + 2e^-$

At Cathode: (Reduction)

$Zn^{2+}(aq) + 2e^- \rightarrow Zn\ (S)$

(Electroplating of Zinc)



(Image by mrmcw.edu.in)

Experiment 3:

Topic:

Examining the effect of change in the time of electroplating on the amount of zinc electroplated on high carbon steel.

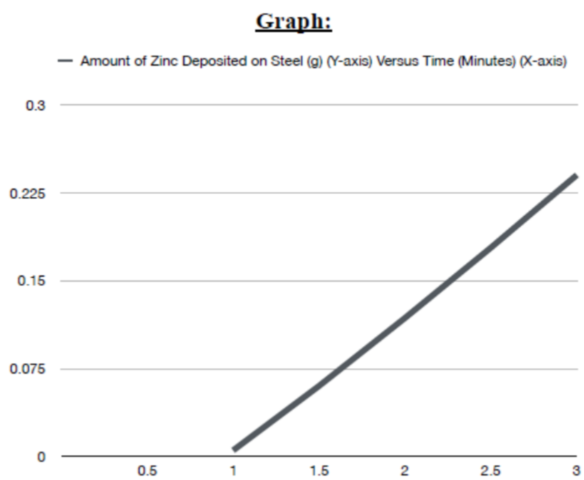
T (Time) = 2 minutes.

Hypothesis: Time of electroplating is directly proportional to the amount of Zinc electroplated on high carbon steel i.e. As the time of electroplating increases, the amount of Zinc electroplated on highcarbon steel also increases.

Observation Table:

S.NO	Time (Minutes)	Initial mass of Zinc Rod (Anode) (g)	Initial mass of steel(Cathode) (g)	Final mass of Zinc Rod (Anode)(g)	Final mass of steel(Cathode)(g)	Differencein mass of Anode (g)	Differencein mass of Cathode(g)
1	1	47.819	25.625	47.813	25.700	0.006	0.005
2	1.5	47.813	26.284	47.751	26.344	0.062	0.060
3	2	47.751	26.110	47.631	26.228	0.120	0.118
4	2.5	47.631	25.962	47.453	26.140	0.178	0.178
5	3	47.453	26.149	47.213	26.389	0.240	0.240

Graph:



Experiment 4:

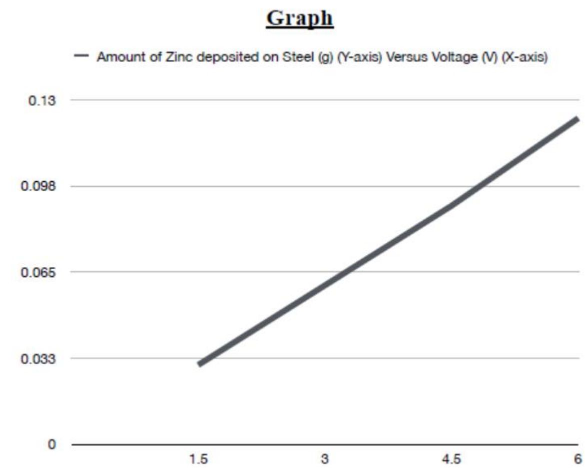
Topic: Examining the effect of change in the Voltage on the amount ofzinc electroplated on high carbon steel Cathode.

Hypothesis: Voltage is directly proportional to the amount of Zinc electroplated on high carbon steel i.e. As the Voltage increases, the amount of Zinc electroplated on high carbon steel also increases.

Observation Table:

S.NO	Voltage (Volts)	Initial mass of Zincl Rod (Anode)(g)	Initial mass of steel(Cathode)(g)	Final mass of Zinc Rod (Anode)(g)	Final mass of steel(Cathode)(g)	Differencein mass of Anode (g)	Differencein mass of Cathode(g)
1	1.5	47.813	30.570	47.783	30.600	0.030	0.030
2	3	47.783	29.798	47.723	29.858	0.060	0.060
3	4.5	47.723	30.588	47.631	30.678	0.092	0.090
4	6	47.631	33.472	47.508	33.595	0.123	0.123

Graph



6. Discussions and Result:

The results obtained from the above experiments are as given below:

Experiment 1:

(Copper Coating)Mass Versus Time
$m \propto t$i.e.
as the time is increased the mass increases.

Experiment 2:

(Copper Coating) Mass Versus Voltage
$m \propto V$i.e.
as the Voltage is increased the mass increases.

Experiment 3:

(Zinc Coating) Mass Versus Time
$m \propto t$i.e.
as the time is increased the mass increases.

Experiment 4:

(Zinc Coating) Mass Versus Voltage
$m \propto V$i.e.
as the Voltage is increased the mass increases.

7. Conclusion:

The above observations and conclusions prove the First Law Of Faraday.

8. Precautions:

1. The surface of the metal or the substrate which has to beelectroplated must be smooth and uniform.

2. The surface of the material should be free from any impurity.
3. The electrolyte should have high solubility in water.
4. The electrolyte should not have any side reactions duringdissolution in water.

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