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(RESEARCH ARTICLE)

Analysis of hydrogen embrittlement in zinc electroplating

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Abstract

Electrodeposition is the method of plating metal into another by hydrolysis generally to protect against corrosion of metal. In Zinc Electroplating, Zinc is deposited on steel, where Zinc acts as a sacrificial element that enhances Steel's life. The zinc electroplating methods are mostly affected by process parameters such as current, temperature, voltage, etc. Hydrogen is absorbed in the plated Zinc layer and later it causes cracking, which is known as hydrogen embrittlement. Hydrogen De Embrittlement is a process that removes Hydrogen. Various test methods are used to qualify a part after hydrogen de-embrittlement. One of them, the Silicon oil test was used to detect it earlier and now we have used paraffin oil for the same, thus making it cost-efficient.

Keywords: Zinc electroplating; Hydrogen embrittlement; Silicon oil test; Paraffin oil test; Cost-efficient; De-embrittlement

1. Introduction

For the purpose of preventing corrosion on plated items, zinc electroplating serves as a barrier and sacrificial coating. Since zinc rusts more quickly than mild steel, protecting the steel substrate, the zinc covering rusts first. A thin zinc coating can make mild steel less durable since zinc rusts at a rate that is at least ten times slower than that of mild steel. [1].

In order to extend the life of another material by shielding it against corrosion, a procedure called electroplating employs electric current to remove cations of a suitable substance from a solution. Because there is atomic hydrogen present, a process called hydrogen embrittlement takes place on a plated surface that causes a reduction in a metal's toughness or ductility.

The removal of hydrogen from the plated parts can be accomplished using a procedure called "hydrogen de embrittlement," as the presence of hydrogen is not good. [2]. In this article, we will focus primarily on the paraffin test method, one of the testing techniques used to determine whether parts have undergone hydrogen de-embrittlement.

2. Zinc electroplating

The most often utilized metal for electrodeposition is zinc. It has always been the element that is responsible for shielding ferrous substances from corrosion. This property is the outcome of two defense mechanisms. The first is physical; although this metal oxidizes readily when in contact with air, it passivates, generating a layer of compact and insoluble oxide that prevents atmospheric agents from penetrating the underlying material [5].

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Levelers and brighteners are two categories of often utilized additives in electroplating baths. These additives alter the plating procedure to produce electrodeposits with the required qualities for the applications they are intended for. It is challenging to maintain control of the plating process since these additives gradually degrade during plating and the electrodeposition process is sensitive to the additive concentration [10].

A single electrode and an external source of electric current are used in the electroplating process. In the Electroplating process, the metal to be coated is made as an electrolyte [4]. The electroplating process typically uses an electrolysis cell, which is made up of two electrodes, an electrolyte, and an external source of current [4]. The cations associate with the anions in the electrolytic solution. Furthermore, these cations are reduced at the cathode to deposit on the Anode (i.e., Base Metal). In Zinc Plating over Steel, Zinc is made of the anode, while Steel is made of the cathode. So, with the passing of current, Zn2+ from ZnSO4 will be deposited on Steel, and the remaining SO42- will react with Zn2+ in the regeneration tank to form ZnSO4 again and the process continues.

The reactions involved are:

At anode: $Zn \rightarrow Zn^{2+} + 2e^{-}$

(Oxidation reaction)

At cathode: $Zn^{2+} + 2e^{-} \rightarrow Zn$ (Reduction reaction)

$Zn^{2+} + SO_4^{2-} \rightarrow ZnSO_4$ (Regeneration Tank)

3. Hydrogen embrittlement

Hydrogen embrittlement (HE) is a phenomenon in which the mechanical properties of metals and alloys are significantly reduced due to the presence of atomic hydrogen and it causes a loss of ductility and strength, which makes the plated surface brittle.[3] HE can occur during a variety of processes, including manufacturing, cleaning, plating, pickling, and electroplating [7].

Hydrogen can enter the metal lattice in a variety of ways, such as through corrosion, cathodic protection, or exposure to hydrogen gas. Once inside the lattice, the hydrogen atoms can combine to form molecular hydrogen, which can cause the metal to become brittle and fracture easily, even at low stresses.

HE is a significant concern in a wide range of industries, including aerospace, automotive, and energy production, as it can lead to catastrophic failures of critical components such as aircraft parts, pipelines, and pressure vessels. Prevention and mitigation strategies typically involve minimizing exposure to hydrogen during manufacturing and storage and designing components with materials that are less susceptible to HE. The presence of hydrogen can weaken the bonds between the atoms in the lattice, leading to reduced ductility and toughness, and an increased likelihood of fracture [9].

In post-treatment methods such as heat treatment and baking can be used to remove hydrogen from the material and reduce the risk of, HE. Inspection and testing methods such as ultrasonic testing and X-ray diffraction can also be used to detect the presence of hydrogen and identify potential areas of concern. Thermal desorption analysis was used to study the microstructural and strength changes in the presence of hydrogen as well as the mechanism for hydrogen trapping [6].

4. Salt spray test

The salt spray test, also known as the salt fog test or salt corrosion test, is a widely used corrosion testing method that evaluates the resistance of a material or coating to corrosion caused by salt exposure. The test involves exposing the material or coating to a continuous spray of a saltwater solution (usually a 5% sodium chloride solution) in a controlled environment for a specified period of time. The salt spray test is conducted according to various international standards such as ASTM B117, ISO 9227, and JIS Z 2371. The test duration and other parameters may vary depending on the specific standard and application.

5. Experimental procedure

During the salt spray test, the sample being tested is usually placed in a test chamber or cabinet, where a saltwater solution is continuously sprayed onto the surface of the sample at a constant rate and temperature. The chamber is usually sealed to prevent any external contamination. The test can range from a few hours to several weeks or even months. After the test period is completed, the sample is inspected visually for signs of corrosion, such as rust or discoloration. The degree and extent of corrosion can be evaluated using various techniques such as microscopy. At a microscopic level, the salt spray test can lead to the formation of various types of corrosion products, such as rust, oxides, and other compounds. The formation of these products can depend on the composition of the metal being tested, the specific testing conditions, and the duration of the test.

6. Paraffin test method

Test procedure

A dehydrogenation check is made by an immersion test in paraffin oil at a high temperature.

Used instruments:

The test must be done by using the following.

- Heater plate
- Thermometer (min 250°C)
- Beaker of 500 ml
- Paraffin oil (about 300 ml)

Method

- On the heater and place the Beaker (with the oil inside) in the center.
- Check the temperature of the oil to rise until 185°C.
- Stabilize the temperature to maintain it constantly.
- Drop the plated part inside the oil for a maximum time of 3 minutes.
- The presence of effervescence needs to be observed and high or excessive effervescence-producing parts are rejected.

Effervescence grade (GE) by Picture

- GE = 1 inexistent effervescence
- GE = 2 low or irrelevant
- GE = 3 medium effervescence
- GE = 4 high effervescence
- GE = 5 excessive effervescences

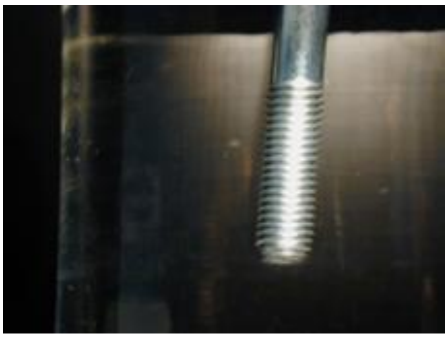

Figure 1 Paraffin test -Grade = 1 OK

Figure 2 Paraffin test -Grade= 2 OK

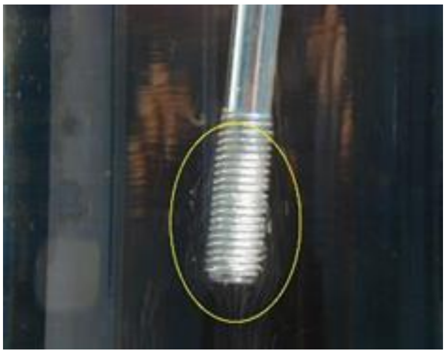

Figure 3 Paraffin test -Grade = 3 SUSPECT

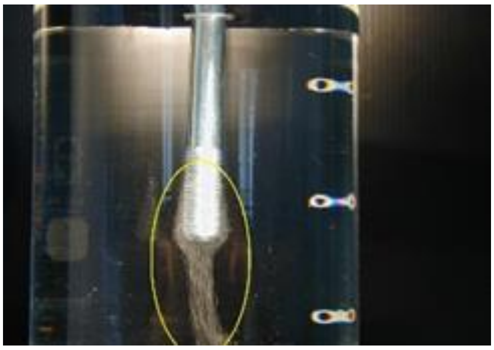

Figure 4 Paraffin test -Grade = 5 NO GOOD

Microscopic structure

Study on hydrogen embrittlement is made along with the SEM microstructure. The microstructure of zinc coating was observed by scanning electron microscope [11].

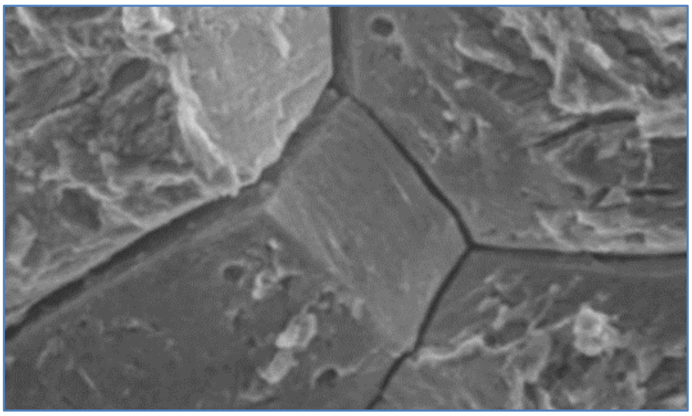

Figure 5 SEM microstructure of hydrogen embrittlement at 1500X

7. Conclusion

The conclusion of an analysis of hydrogen embrittlement in zinc electroplating would depend on the specific findings and observations made during the analysis. Hydrogen embrittlement can occur in zinc electroplating due to the absorption of hydrogen gas by the metal. Hydrogen embrittlement can lead to reduced strength and ductility of the metal, which can cause cracks, fractures, and other forms of mechanical failure. The risk of hydrogen embrittlement can be mitigated by controlling the electroplating process parameters such as current density, temperature, and pH levels. Post-plating baking or heat treatment can be effective in removing hydrogen from the plated metal and improving its mechanical properties. The Paraffin Oil test has been validated and the results were found satisfactory. As the Silicon oil per liter is 23% higher than paraffin oil, the usage of paraffin oil over silicon oil makes the Hydrogen De embrittlement test cost-efficient.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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