Corrosion and Surface Finishing

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Abstract Surface finishing is very important to most industries for a variety of reasons. The finishing process could be used for reflectivity, improving hardness, or for decorating a finished product to attract potential buyers. However, from an engineering point of view, its main purpose is to prevent corrosion. Corrosion is actually a process whereby manufactured metals return to their natural oxidation states. Corrosion is of economic importance because it limits the life time of metal structures (example: bridges) and can result in accidents or incidents of pollution. This chapter describes corrosion and discusses how various surface treatments are used to prevent it. The topics covered include electroplating, electroless plating, spray coating, galvanization, painting, anodizing, physical vapor deposition (PVD), and chemical vapor deposition (CVD).

1 Introduction

Treatments to the surfaces of metals and other materials are very important in most industries. They are used for purposes such as decoration, reflectivity, improving hardness, and preventing corrosion. From an engineering point of view, the primary purpose of surface finishing is to prevent corrosion. Corrosion involves electrochemical reactions of a metal with an oxidizing agent in the environment. It is of economic importance because it limits the life time of metal structures, and can result in accidents or incidents of pollution. This chapter describes corrosion and discusses various surface treatments to prevent it. Plating and painting are identified

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as common coating methods to prevent corrosion. They provide a protective film between the substrate and its surrounding environment. Galvanization is another technique that is mentioned. It is the process of applying a protective zinc coating to steel or iron to prevent rusting. Individuals need to select an appropriate coating and coating process for specific metals and their applications. In order to properly do this, various factors must be considered. These include the composition and properties of the substrate and the film that is to be applied to it. Also the coating process and the corrosive environment (where the metal item will be located and used) must be taken into account.

2 Corrosion

Corrosion can be considered the deterioration of materials (especially metals) as a result of their chemical reactions with the surrounding environment. Corrosion destroys the useful properties of a material such as the strength and structure of iron in bridges. It can cause environmental pollution resulting from a leak in an oil pipeline or a large loss of transported water from corrosion leaks in buried pipes for water distribution. Corrosion is a process whereby manufactured metals return to their natural oxidation states. A reduction-oxidation reaction takes place in which the metal is oxidized by its surroundings (example: oxygen in air). A common form of corrosion is rust, a reddish-brown compound, known as iron oxide (Fe_2O_3). See Fig. 1 [1]. This reaction is possible when iron (Fe) is in the presence of water and oxygen.

Fig. 1 Iron rust sample

Corrosion can affect an entire surface of a metal or just local spots. Uniform corrosion of the complete surface usually only happens in acidic conditions [2]. This generally results in overall thinning and causes no major damage. On the other hand, a very detrimental form of corrosion is pitting. This type is found at a single location on the surface and creates a pit or cavity which is difficult to prevent and often hard to detect. It can result in structural failure (example: a cracked pipe).

Corrosion occurs on exposed surfaces. Therefore, these surfaces should be coated to provide a protective barrier between the metal and its surroundings. Surface finishing is applied to protect metals from corrosion. Some industrial treatments are presented and described in this chapter. In order for them to be successful, one needs to recognize the type of metal and corrosive environment involved and to determine the appropriate coating process for that situation. In all cases, surface preparation is an essential first step before any coating is applied. This is because the performance of a coating is greatly influenced by its ability to properly adhere to a material's surface. Consider the corrosion of steel, an alloy containing mostly iron and about 1 % carbon. Steel stored inside a dry, clean, heated building has a low risk of corrosion. However, a steel structure exposed to a harsh environment of moisture, oxygen, air pollution, etc. needs to be protected so that the iron isn't oxidized to rust.

3 Electroplating to Control Corrosion

Electroplating can be defined as the application of a metal coating to a metallic or other conducting surface using an electrochemical process. The item to be plated serves as the cathode (negative electrode) and the anode is usually the metal to be plated on the item. Both components are placed in an aqueous (aq.) solution, called an electrolyte, containing dissolved metal salts and other ions to allow for a flow of electricity. A power source provides a direct current to the anode and oxidizes its metal atoms so they are able to dissolve in the solution. These dissolved metal ions are then reduced at the cathode and deposited there as a metal coating.

Electroplating is widely used in various industries to coat metal objects with a thin layer of another metal. Since chromium is very corrosion resistant, it is electroplated on to car parts, wheel rims, and other items. Nickel plating, tin plating, and their alloys are used for corrosion protection on nuts, bolts, brackets, and other metal components [3]. Gold electroplating is also very good for corrosion and tarnish protection, but it is rather expensive. In addition, a sacrificial coating can be electroplated to a metal surface. For example, zinc serves as a sacrificial coating for iron and is used up in the reaction. This protects the iron from rusting (corrosion).

4 Electroless Plating to Control Corrosion

Electroless plating uses a redox reaction without an electric current to deposit metal on an object or workpiece. The electroless plating solution generally includes the following: a source of metal, a reducer, a complexing agent (which holds the metal in solution by forming coordinate bonds with the metal atom or ion), and buffers along with other chemicals to stabilize the bath [4]. One form of this process is electroless nickel plating. It can be used to produce a nickel phosphorus alloy coating, which helps prevent corrosion. For this process a reducing agent such as hydrated sodium hypophosphite ($NaPO_2H_2$. H_2O) reacts with the metal ions to deposit metal. The phosphorus content in these coatings can vary from about 2 to 14 %. Low phosphorous electroless nickel provides excellent resistance to alkaline, corrosive environments [5]. On the other hand, high phosphorous electroless nickel finishing is used in industries (like oil drilling and coal mining) requiring resistance to strongly acidic corrosive environments and to those industries needing a pore free finish [6].

5 Spray Coating to Control Corrosion

Spray coating is a process in which materials are sprayed onto a surface. It is widely known as the use of spray cans (or spray guns) by artists and as an industrial process for car body painting. For this method, the functional fluid or ink is atomized at the nozzle of the spray head, which makes a continuous flow of droplets. This system uses a stream of pressurized air or gas (such as argon or nitrogen) to break up the liquid into droplets at the nozzle [7]. These droplets of ink (paint) are then carried onto the surface of a particular substrate. Spray coatings protect metals from corrosion by providing them with a barrier from the atmosphere and surrounding environment. Drawbacks to this process are that it is a line-of-sight technology (which makes it impossible to coat small cavities, etc.) and the coatings have pores/cracks that need to be sealed for certain applications [7].

Another form of this coating process is called Thermal Spraying, where melted (or heated) materials are sprayed onto a surface. This technique consists of an electrical (examples: plasma and arc) or chemical (ex. combustion flame) heat source and a coating material in the form of powder or wire which is melted into tiny droplets and sprayed at high velocity onto surfaces [8, 9]. Thermal spraying can produce thick coatings over a large area at a high deposition rate as compared to other coating processes. This technique also allows for versatile substrates and coating materials. Substrates include metals like aluminum, steel, stainless steel, copper, and bronze, as well as some plastics. The coating materials can be metals, alloys, ceramics, plastics, and composites [10].

6 Galvanization to Control Corrosion

Galvanization is a process for coating iron and steel with zinc to prevent them from rusting. The most common form of galvanizing is Hot-dip Galvanization [11]. For this method, metals such as iron and steel are coated with a layer of zinc by being submerged in a bath of molten zinc. The coating forms a barrier between the substrate and corrosive substances in the atmosphere. Its effectiveness depends on factors such as the coating thickness and coating corrosion rate which is influenced by the composition of the atmosphere as well as the type of coating.

Zinc also serves as a sacrificial anode (where there is a loss of electrons), so that if the coating is scratched the remaining zinc protects the exposed steel. Galvanized steel is widely used for applications requiring corrosion resistance without the cost of stainless steel. Galvanized steel is used in roofing, handrails, consumer appliances, automotive body parts, metal pails, and in most heating and cooling duct systems in buildings.

7 Painting to Control Corrosion

Painting can be defined as the coating of a surface with paint (which includes pigment or color). The paint coating can be applied by using brushes, rollers, and spray methods (which are described in chapter "Industrial Surface Treatments"). Industrial paint is used to protect metal, wood, and a variety of other materials. It provides a barrier between the substrate's surface and its surroundings.

Paint and galvanized steel (steel coated with zinc) can be used together to provide superior corrosion control than either method used alone. This technique, known as a "duplex system," consists of painting steel that has been hot-dip galvanized after fabrication [12]. The paint serves as a barrier protecting the galvanized steel from the atmosphere. It slows down the rate at which zinc is consumed and therefore extends the life of the galvanized steel.

In order for this method to be successful, the metal's surface must be properly cleaned and prepared, before an appropriate paint is applied. To start, the galvanized surface is cleaned to remove any dirt, grease, or oils, as well as other surface contaminants and zinc corrosion products. Then the surface is profiled to allow for a good adhesion of the paint. Therefore, it must be free of protrusions and slightly roughened. In any case, remove the least amount of zinc as possible during the cleaning and profiling steps. Otherwise, the corrosion protection (of the item) will be reduced. Finally, an appropriate paint should be selected and applied. Individuals are encouraged to contact paint manufacturers to obtain specific information regarding the suitability of paints for use on galvanized steel.

8 Anodizing to Control Corrosion

Anodizing is an electrolytic passivation process that increases the thickness of natural oxide layers on the surface of metals [13]. It basically forms an anodic oxide finish on a metal's surface to increase corrosion resistance. For the anodizing process, the metal to be treated serves as the anode (positive electrode, where electrons are lost) of an electrical circuit. Anodized films are most often applied to protect aluminum alloys. An aluminum alloy is seen on the front bicycle wheel in Fig. 2 [14]. For these alloys, aluminum is the predominant metal. It typically forms an alloy with the following elements: copper, magnesium, manganese, silicon, tin, and zinc [15]. Two main classifications for these alloys are casting alloys and wrought alloys, both of which can be either heat treatable or non-heat treatable.

Almost 85 % of aluminum is used for wrought products such as rolled plates, foils, and extrusions [16]. Cast aluminum alloys provide cost-effective products but usually have lower tensile strengths than those of wrought alloys. Aluminum alloys are used in engineering, the aerospace industry, and for components where corrosion resistance or light weight is needed. If left unprotected their surfaces are anodized, which means that they form a white protective layer of the corrosion product, aluminum oxide.

Fig. 2 Aluminum alloy displayed in the front bicycle wheel

9 Physical Vapor Deposition (PVD) to Control Corrosion

Physical Vapor Deposition (PVD) includes various methods for depositing thin films onto a substrate by the condensation of a desired vapor. For this process the coating material changes from the solid phase to the vapor phase and back to the solid phase (as it builds a film on the substrate). The PVD technique involves physical processes like the use of high-temperature vacuum evaporation of a coating material that is then condensed onto a substrate. It is carried out in a vacuum at temperatures between 150 and 500° C and provides coatings with an average thickness of 2–5 μm [17]. This method can be used to deposit thin films onto items for corrosion control. Some of these films are titanium nitride (TiN), titanium carbon nitride (TiCN), zirconium nitride (ZrN), and chromium carbide (CrC). They are hard, have a low coefficient of friction, and are chemically resistant, which makes them good chemical and thermal barriers when applied to surfaces [18]. ZrN provides a decorative, corrosion resistant coating for brass. TiN coatings extend the life of cutting tools and surgical instruments used in the medical industry.

PVD is an alternative to the processes of electroplating and to some painting applications because it generates less hazardous waste and uses smaller amounts of hazardous materials since no plating baths, etc. are involved [19]. Also in some cases, PVD coatings are harder and more corrosion resistant than those of the electroplating process. Most of these coatings do not require protective topcoats because they are durable and have good impact strength. The PVD method allows many different substrate materials such as metals, alloys, ceramics, glass, polymers, etc. to be coated. Also the coating properties such as hardness and adhesion can be accurately controlled. Therefore, these coatings have a wide range of applications. They are used in the aerospace, medical, automotive, optics, firearm industries, just to name a few.

10 Chemical Vapor Deposition (CVD) to Control Corrosion

Chemical Vapor Deposition (CVD) is a chemical process to produce solid thin films on surfaces. Typically one or more precursor gases flow into a chamber containing heated objects that need to be coated. Chemical reactions take place on or near the hot surfaces. See Fig. 3 [20]. As a result, thin films are deposited on these surfaces. The coatings serve many purposes but can also provide protective barriers from the surrounding atmosphere.

Several benefits of the CVD process include the following. A variety of materials can be deposited with high purity. These films generally display uniform thickness on the insides and outsides of elaborately shaped objects. Also the CVD process has a relatively high deposition rate.

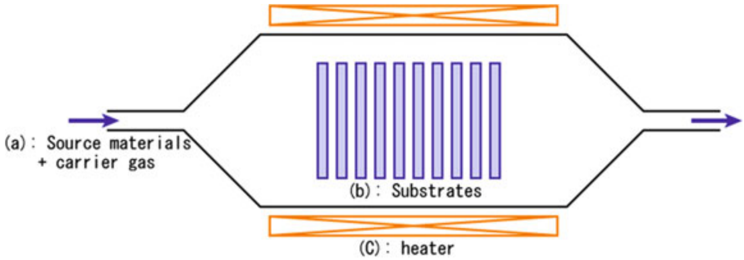

Fig. 3 A schematic diagram for the chemical vapor deposition process

In contrast, the physical vapor deposition method (PVD) generally requires a line of sight between the source and the surface to be coated. Also the PVD process often requires a higher vacuum than the CVD process.

Disadvantages exist for the CVD technique [21, 22]. The precursors can be toxic or corrosive. They can be expensive too. Also as a result of using this method, most of the films are deposited at high temperatures. This restricts the type of substrates that can be coated. Substrates with different thermal expansion coefficients can cause the deposited films to have mechanical instabilities. Therefore, this coating method has some limitations in regards to corrosion control.

11 Conclusion

This chapter described corrosion and discussed various surface finishing treatments to prevent it. It mentioned that corrosion involves electrochemical reactions of a metal with an oxidizing agent in the environment. Corrosion is actually a process whereby manufactured metals return to their natural oxidation states. We were also reminded of the economic importance of corrosion because it limits the life time of metal structures (example: bridges) and can result in accidents or incidents of pollution.

Industrial treatments for corrosion control were discussed too. Plating and painting were identified as common coating methods to prevent corrosion. They provide a protective film between the substrate and its surrounding environment. Galvanization is another technique that was described. Galvanization is the process of applying a protective zinc coating to steel or iron to prevent rusting. Individuals need to select an appropriate coating and coating process for specific metals and their applications. In order to properly do this, various factors must be considered. These include the composition and properties of the substrate and the film that is to be applied to it. Also the coating process and the corrosive environment (where the metal item will be located and used) must be taken into account.

The topics that were covered in this chapter include electroplating, electroless plating, spray coating, galvanization, painting, anodizing, physical vapor deposition (PVD), and chemical vapor deposition (CVD).

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