

N4

Mechanotechnics

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What is covered?

This module will help you understand how corrosion affects a lot of metals, and how it is prevented. It further provides information on the various classes and forms of corrosion, the types of corrosion tests, surface preparation methods, and the various painting processes in use.

Learning outcomes

After studying this module, you should be able to:

Unit 1

- Describe corrosion as the destruction of a material as a result of chemical, electrochemical, or metallurgic interaction between the material and the environment.

Unit 2

- Explain the two main classes of corrosion.

Unit 3

- Explain the following forms of corrosion: Surface corrosion:
 - Stress corrosion
 - Galvanic corrosion
 - Inter-crystalline corrosion
 - Pitting corrosion.

Unit 4

- Explain the most common types of corrosion tests.

Unit 5

- Describe what each of the following metal-protection processes involves:
 - Cathodic protection
 - Electroplating
 - Anodising
 - Phosphating.

Unit 6

- Describe the following processes that we use to prepare steel for spray painting: Sandblast cleaning, Descaling, and Grease removal.

Unit 7

- Explain the following painting processes: Air spray painting, Airless spray painting, Electrostatic spray painting, and Dip painting.
- List the advantages and disadvantages of using each of the painting processes.

Unit 1: Introduction to corrosion and its prevention

LEARNING OUTCOMES

- Describe corrosion as the destruction of a material as a result of chemical, electrochemical, or metallurgic interaction between the material and the environment.

Introduction

In 2013, it was estimated that the world was losing roughly 3% of its total annual production value to corrosion. Experts claimed that if corrosion-control practices had been put in place, this would have saved the world between 15% and 35% of these costs. As can be seen, corrosion is a major problem on a global scale, and it is every engineer's duty to put control measures in place.

Corrosion

Corrosion is the destruction of a metal as a result of the chemical, electrochemical, or metallurgic interactions it has with the environment. Metals are generally unstable in their purified forms, so they tend to go back to their natural ore state by means of corrosion.

To prevent corrosion, it is important to know the factors that influence the process, i.e. the type of metal, the type of environment it is exposed to, and how the metal surface is treated. Corrosion generally occurs in the presence of moisture and oxygen, so most metal protection methods work by isolating either or both of these agents from the metal. However, the challenge of corrosion is that it is a very slow but continuous, self-perpetuating process. Thus, once the metal starts corroding, it will continue doing so even if the corrosive agents are eliminated from the environment.

ACTIVITY 2.1

Corrosion research

1. In pairs, do internet research about the global cost of corrosion.
2. As an individual, find definitions for chemical, electrochemical, and metallurgic.

Unit 2: Classification of corrosion

LEARNING OUTCOMES

- Explain the two main classes of corrosion.

Introduction

Corrosion can be divided into two main subclasses that are:

- Chemical corrosion
- Electrochemical corrosion.

1. Chemical corrosion

Also referred to as oxidation, chemical corrosion occurs when a metal reacts chemically with oxygen in the air. A good example is the formation of rust in iron, and in its alloys such as steel. The metals react with oxygen to form a typical red or orange coating of iron oxide on its surface. Atmospheric corrosion of metals and their alloys, which is very common in industrial cities, also falls under chemical corrosion. This results when hydrogen sulphate, nitrogen, sulfur dioxide and carbon dioxide, released from factories in fumes, combine with moisture in the atmosphere to form acids such as sulfuric acid, nitric acid, and carbonic acid. These acids then attack metals through their powerful oxidising natures.

2. Electrochemical corrosion

Electrochemical corrosion consists of two surface reactions – oxidation and reduction reactions. The electrochemical circuit consists of three basic components, namely an anode, a cathode, and an electrolyte.

- Anode – The electrode that provides electrons. It is usually the site for corrosion.
- Cathode – The electrode that receives electrons. It is usually made up of a metal that needs protection from corrosion.
- Electrolyte – It provides the environment for electrochemical reactions. Electrolytes can be an acidic or alkaline aqueous solution, or even just water.
- Return current path – provides an electrical link between the two electrodes.

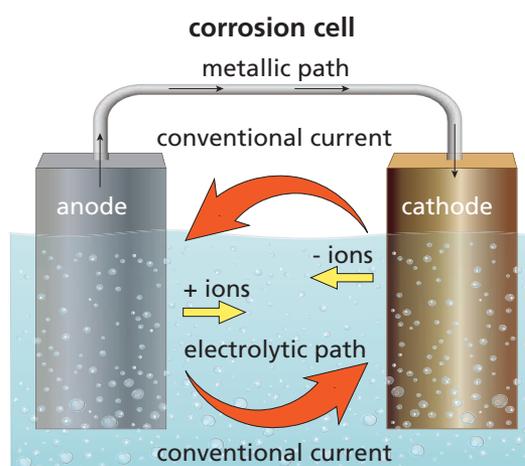


Figure 2.1 Elements of electrochemical corrosion

ACTIVITY 2.2

Electrochemical corrosion

1. Copy the corrosion cell diagram in your notebook and label all the main parts. Now explain in your own words how the cell works.
2. Compare and contrast the anode and the cathode.

Unit 3: Forms of corrosion

LEARNING OUTCOMES

- Explain the following forms of corrosion:
 - Surface corrosion
 - Stress corrosion
 - Galvanic corrosion
 - Inter-crystalline corrosion
 - Pitting corrosion.

Introduction

There are five main forms of corrosion that we will be dealing with in this module. Let us consider each form in greater detail.

1. Surface corrosion

Surface corrosion is the most common form of corrosion, and it mainly involves an electrochemical reaction that proceeds uniformly over the entire exposed surface of a metal. Due to **adverse** weather conditions, especially humidity, anode and cathode spots form on the metal surface where they constantly change position. This form of corrosion causes the most damage to metals, in terms of the total mass loss, and is very hard to detect since it even occurs beneath a protective layer of paint or grease.

2. Stress corrosion

When a force for example a dead weight is suddenly applied on a metal, stress corrosion may result. This can even occur to structures in **inert** surroundings, so humidity is not a big factor. Many metal-working processes – activities such as welding, cold-welding, or forming – are major players in stress corrosion; so, if metals are subjected to these processes, normalising processes should be performed soon after to strengthen the metal back to its original form. If normalising processes are not done, the corrosion can commence without being visible – cracks only appearing just before **catastrophic failure** of the structure.

3. Galvanic corrosion

When two dissimilar metals are dipped in a liquid that can act as a suitable electrolyte, the more reactive metal corrodes first – thereby protecting the other metal. In most cases, the humid atmosphere acts as the electrolyte. Depending on the position of the metal on the galvanic ladder, the metal with the lesser resistance corrodes before and to a greater degree than the other.

Keywords

adverse of weather conditions; meaning harsh, e.g. high temperatures or humidity

inert of the environment, meaning chemically inactive

catastrophic failure total failure, which cannot be repaired



Figure 2.2 The galvanic ladder

4. Inter-crystalline corrosion

Due to various physical and chemical processes, metal particles can gain a charge. Usually the metal grains may start behaving like a cathode, whilst the boundaries separating the grains may then behave like an anode. This greatly weakens the grains and usually results in catastrophic failure. Inter-crystalline corrosion is very common in stainless steels, and is sometimes called intergranular corrosion.

5. Pitting corrosion

In the presence of moisture, imperfections on a metal surface such as scratches may form small anodes, whilst the rest of the metal surface acts as the cathode. As the pitting continues, the scratches ultimately develop into tiny holes all over the surface. During pitting, the affected areas do not move as they do in surface corrosion. As a result, pitting corrosion is very hard to predict.

ACTIVITY 2.3

Forms of corrosion

1. In groups, come up with similarities and differences between all the five main forms of corrosion.
 2. As an individual, try to memorise the galvanic ladder.
-

Unit 4: Corrosion tests

LEARNING OUTCOMES

- Explain the most common types of corrosion tests.

Introduction

There are several factors that affect the corrosion rate of metals. These include humidity, temperature, air pollution, salt water content, acids, or the type of contact between dissimilar metals.

1. Corrosion tests

Corrosion tests are done to ensure the performance of metals, metal platings, and coatings. There are several factors that affect the corrosion rate of metals. These include humidity, temperature, air pollution, salt water content, acids, or the type of contact between dissimilar metals. In most tests though, only temperature, humidity, and salt water content are varied. Tests are comparative, which means that the workpiece is compared with a standard workpiece of known corrosion-resisting properties. When the tests are complete, we then consider:

- Changes in mass of the workpiece, i.e. weight loss after removing rust.
- Changes in visual appearance of the workpiece.
- Changes in **mechanical** properties such as hardness and strength.
- Changes in the corrosive medium.
- Changes in the depth of corrosion.
- Changes in electrical resistance.

Keywords

mechanical using physical force

atomise break into fine particles or droplets

1.1 The salt-spray test

A salt solution of 5% table salt (NaCl) by weight is **atomised** and sprayed as fog on workpieces hanging at angles of 15°–30° from the vertical. The temperature of the spray chamber is maintained at 35 °C using thermostats. The period of exposure varies from test to test, depending on the type of workpiece.

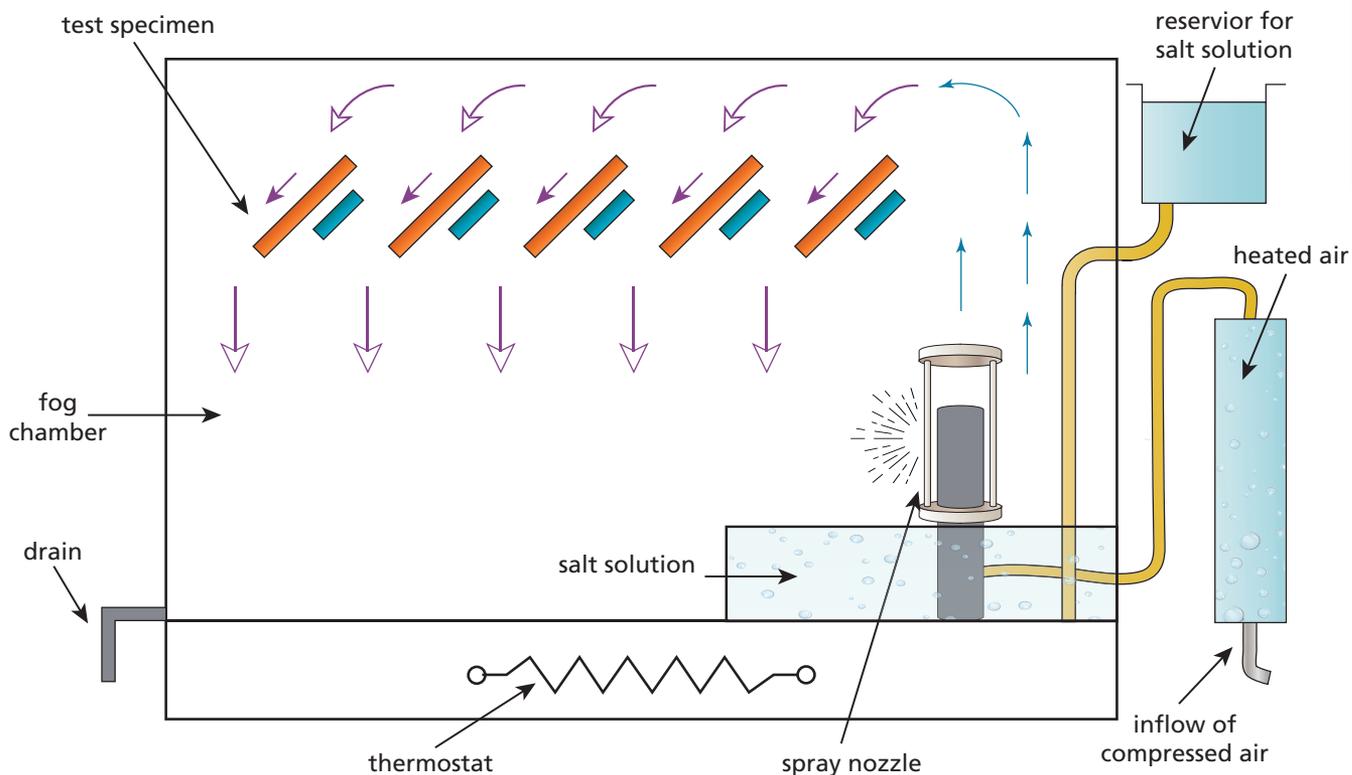


Figure 2.3 The salt-spray test

1.2 The humidity test

In the standard humidity test, workpieces are placed in a humidity chamber at 100% humidity. They are hung perpendicularly, and distilled water is usually used instead of salty water. After 24 hours, the workpieces are removed from the chamber and the water is poured out. The workpieces are then evaluated.

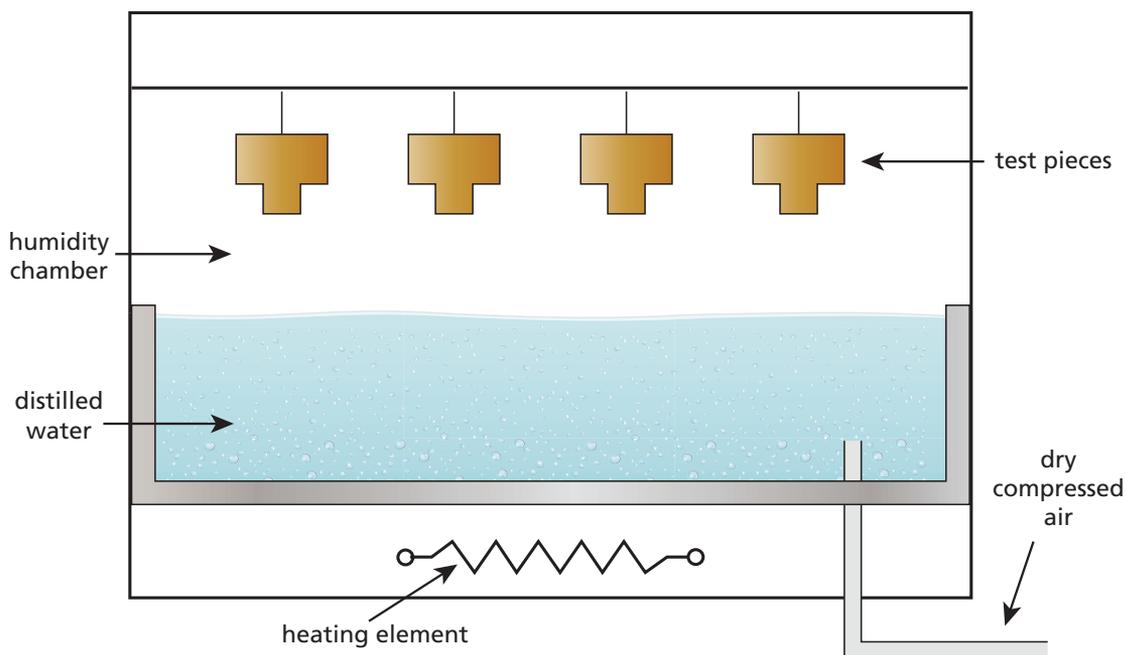


Figure 2.4 The humidity test

1.3 The sulfur dioxide test

Keyword

simulate imitate the properties of

Also called the Kesternich test, this test is very popular as it takes significantly less time to obtain results compared to the other two tests. There are similarities with the other two test chambers in terms of design. In addition to distilled water, a controlled volume of sulfur dioxide is released inside the chamber to **simulate** acid rain. The temperature is then maintained at 40 °C for a period of 8 hours. The heating system is then switched off and the chamber is left open for a further 16 hours. The test can then be repeated until the required results are obtained.

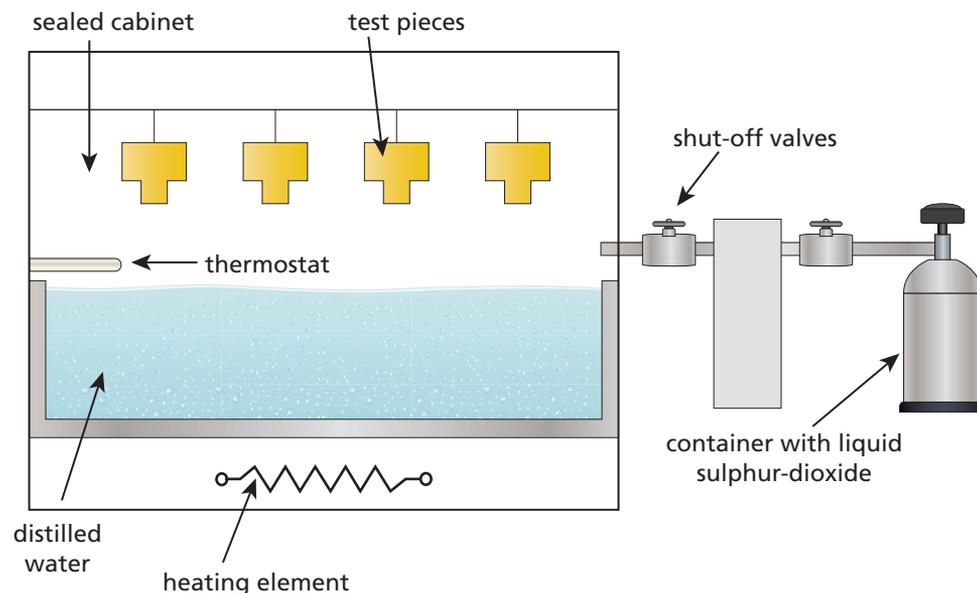


Figure 2.5 The sulfur dioxide test

ACTIVITY 2.4

Corrosion tests

1. Draw a fully-labelled diagram of the salt-spray test.
2. What are the similarities and differences between the humidity test and the sulfur dioxide test? Discuss in pairs.

Unit 5: Metal protection processes

LEARNING OUTCOMES

- Describe what each of the following metal-protection processes involves:
 - Cathodic protection
 - Electroplating
 - Anodising
 - Phosphating.

Introduction

When metal structures corrode, they can collapse and cause accidents. The two easiest ways to avoid corrosion are either to replace a metal with one that does not corrode easily, e.g. aluminium and stainless steel, or else you can apply a protective coat of paint to the metal, where applicable. Otherwise, more sophisticated methods of protecting the metal need to be applied. These include:

- Cathodic protection
- Electroplating
- Anodic protection
- Phosphating.

1. Cathodic protection

Otherwise known as sacrificial protection, cathodic protection involves the following steps:

- The metal requiring protection is made the cathode.
- A metal higher than it on the galvanic ladder (see Figure 2.2) is made the anode.
- The two electrodes are then placed in a suitable electrolyte and are joined by an electric conductor.

A special case of cathodic protection is called galvanizing. This process uses zinc metal to coat iron and steel parts. Since zinc is higher than iron on the galvanic ladder, it corrodes first – thereby forming zinc-oxide. This zinc-oxide layer then inhibits the corrosion of the iron or steel. Cathodic protection is very useful in the production of steel pipelines for carrying water or fuel. It is also used in the production of ship hulls, water heater tanks, and even offshore oil platforms.

2. Electroplating

This involves electronically depositing a metal onto another metal. Usually, a thin layer of nickel, tin, or chromium is deposited on steel in an electrolytic bath. In most cases, the electrolyte consists of a water solution containing salts of the metal to be deposited.

Again, the metal requiring protection is made the cathode and a low-voltage direct current is turned on. Electroplating can also be done, not for protection purposes, but for decorative purposes in jewellery making. Different types of electrolytes give different finishes; for example, an acidic electrolyte normally gives a thick and shiny finish whilst an alkaline electrolyte gives a dense, fine-grain deposit and a smooth, reflective finish.

3. Anodic protection

Anodising is a corrosion control method developed from observing how aluminium behaves in nature. When pure aluminium metal is exposed to air, it forms a thick layer of aluminium oxide on its surface which then prevents it from further reaction. When anodising a metal surface, the following steps should be observed:

- The metal requiring protection is made the anode.
- Lead, tin, or graphite is made the cathode.
- The two electrodes are then dipped in an acidic electrolyte usually made of chromic acid, sulfuric acid, or oxalic acid. The circuit is completed using a direct current power source.

When the current flows, oxygen particles are released on the surface of the anode and they form an oxide there. Steam is then applied to the metal afterwards so as to seal the pores on the metal, thereby creating a more durable layer. This protection method is mostly applied to carbon steel tanks for storing sulfuric acid and 50% caustic soda. In this case, cathodic protection cannot be used since it cannot withstand extremely high currents.

4. Phosphating

Phosphate coatings are used to prepare steel, aluminium, zinc, and galvanised steel for corrosion resistance, lubrication, or as a foundation for painting. Usually, the parts to be processed are dipped in a dilute solution of phosphoric acid and phosphate salts, such as iron phosphate or crystalline zinc phosphate. The solution then reacts with the surfaces of the parts to form a layer of insoluble, crystalline phosphates. The parts are later washed and dried; if further protection is required, they can then be sent for chromating.

ACTIVITY 2.5

Protecting metal

1. How is cathodic protection different from electroplating?
 2. What are the similarities between anodising and phosphating?
-

Unit 6: Surface preparation for painting

LEARNING OUTCOMES

- Describe the following processes that we use to prepare steel for spray painting: Sandblast cleaning, Descaling, and Grease removal

Introduction

To ensure the quality and durability of metal coatings subjected to corrosion, sufficient surface preparation is very important. There are five steps that need to be carried out:

- Thoroughly clean the surface.
- Remove old paint if present.
- Remove rust using sandpaper.
- Fill holes and dents using epoxy filler.
- Prime the surface.

1. Sandblast cleaning

To smooth out and clean the metal surface, compressed air is used to force sand grains across the surface at high speeds. To make the process more effective, materials such as grit, aluminium oxide, or even steel balls may be used in place of sand. Other factors that can influence the effectiveness are:

- Air pressure
- Size of grains
- Weight of grains
- Speed of grains
- Size of the nozzle.

2. Descaling

This involves the removal of oxide deposits from heated metal surfaces before or during forging operations. During heat treatment processes, scales may form on a metal surface, thereby discolouring it and reducing its quality. After cleaning, stripping and pickling, a smooth surface remains. There are three main descaling methods that you can use.

2.1 Sandblast cleaning (mechanical cleaning)

Sandblast cleaning is a mechanical cleaning method which not only cleans the metal surface, but also removes scales. Other mechanical methods include scrubbing using wire brushes, and waterjet spraying.

2.2 Flame cleaning

This method involves flame washing the metal surface using an extremely hot oxyacetylene flame. The flame has a reducing effect which removes both scales and rust, leaving the surface ready for wire brushing and painting.

2.3 Acid pickling

Acid cleaning on metal surfaces is used to remove scale deposits, and to also neutralise any remaining alkaline deposits from previous cleaning processes. This cleaning method is mainly used on ferrous metals, and aluminium and copper alloys. The metal parts are dipped in an acid bath of between 5% and 10% sulfuric acid concentration for 15 to 20 minutes at 60 °C. Afterwards, the metal parts are washed with warm water before dipping them in a 2% phosphate acid solution for 3 to 5 minutes. A primer coating is then applied while the parts are still warm.

3. Grease removal

For a thin grease layer on a metal surface, there are several methods of removal that include applying caustic soda (sodium hydroxide), paint solvents, detergents, rubbing alcohol, or even household vinegar in some cases. However, in severe cases, the parts are scrubbed with hot solvent vapours and placed in a vapour room. The vapours condense on the part to form a liquid flow, which dissolves and washes the grease away as the liquid drains with gravity. Solvents in use include trichloroethylene, methyl chloroform, and also methylene chloride.

ACTIVITY 2.6

Descaling metal surfaces

1. Write a paragraph explaining what descaling involves.
 2. In pairs, research additional ways that make sandblasting more effective.
-

Unit 7: Painting processes

LEARNING OUTCOMES

- Explain the following painting processes: Air spray painting, Airless spray painting, Electrostatic spray painting, and Dip painting.
- List the advantages and disadvantages of using each of the painting processes.

Introduction

There are four painting processes we need to know about, namely: air spray, airless spray, and dip and electrostatic spray painting. Let us look at each process in greater depth.

1. Air spray painting

Conventional spray painting is done using a device that sprays a coating through the air onto a surface. The device consists of a compressor, an air-pressure tank, a paint container, a paint spray gun, and flexible piping. Compressed air sucks up and atomises paint particles using the Venturi principle, and then directs them to the spray nozzle which controls the shape and density of the spray. Spray guns can be automated or manual, and may come with a range of heads to allow for different spray patterns.

1.1 Advantages of air spray painting

- It is fairly cheap.
- Uniform thickness of paint is easily achievable.
- Air spray painting can reach uneven and hard-to-reach surfaces.
- It is very easy to change the paint colour.
- The operator can easily adjust the spraying width to suit the workpiece requirements.
- Its excellent atomisation ability makes it highly favoured in the automotive industry.
- There is a low risk of orange peel effect.
- The equipment is very easy to operate and repair.
- It rarely produces air bubbles in the solvent.
- It provides a smooth paint finish.

1.2 Disadvantages of air spray painting

- Overspray results in high paint wastage.
- A large quantity of thinners is necessary.
- The spraying time is relatively long, and so is the drying period.
- It evaporates more in cold systems due to the use of more diluent.
- It is difficult to paint overhead because of the cumbersome paint container.

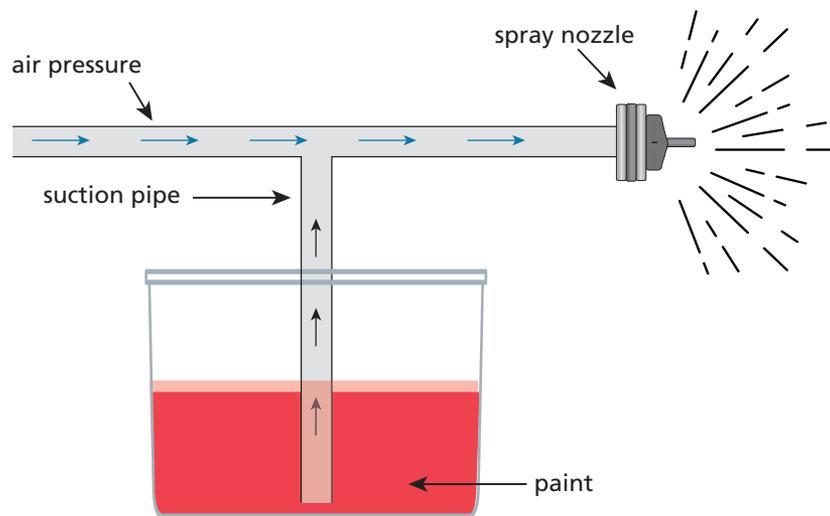


Figure 2.6 (a) The principle of air spray painting

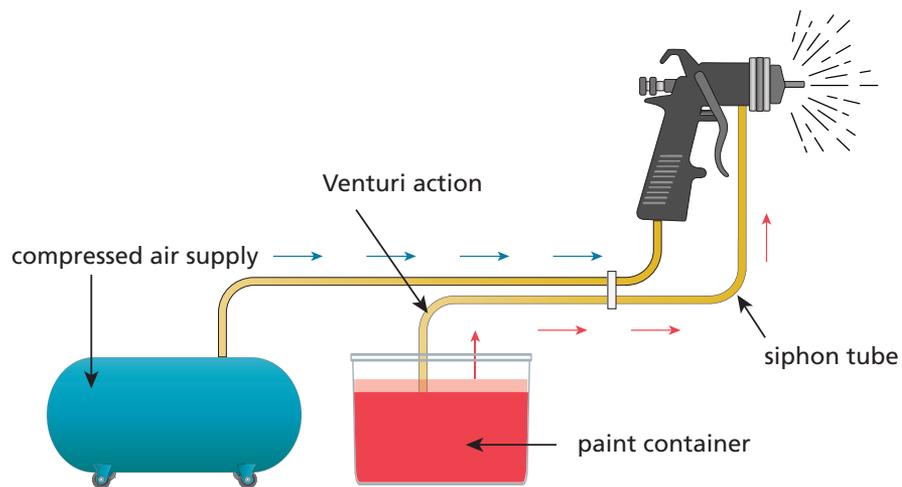


Figure 2.6 (b) Air spray painting

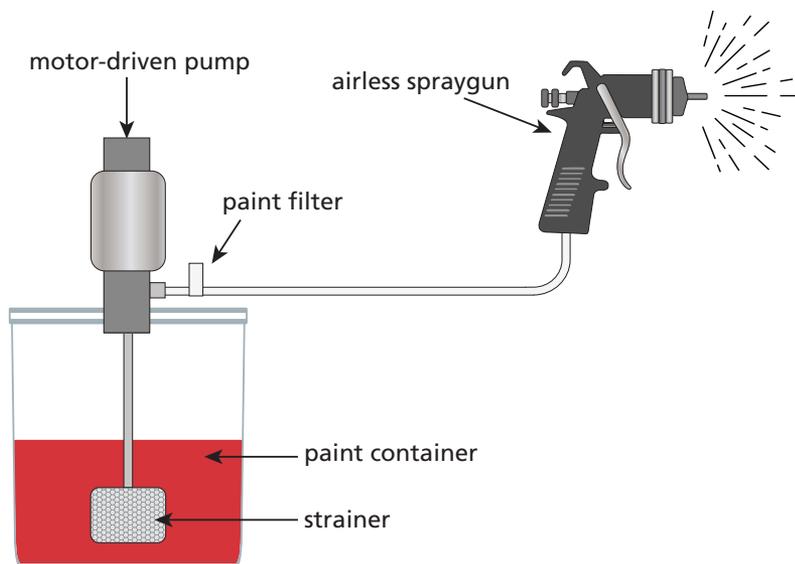


Figure 2.7 Cold airless or high-pressure spray painting

2. Airless spray painting

Airless spray painting or high-pressure spray painting is done using a device that forces paint up a hose and then out of the spray gun through a minute tip. The nozzle then creates a fan-shaped pattern of paint onto the surface; to vary the flow rate, the tip size and the pressure may be altered. To achieve atomisation when using viscous fluids with high surface tension, a heater can be installed between the pump and filter. This results in temperatures in the range of 70 °C to 80 °C, which keeps the paint thin and thus reduces the need for thinners. This also reduces the risk of sagging.

2.1 Advantages of airless spray painting

- Very versatile since it can be used for the interiors and exteriors of different kinds of material.
- It is very fast.
- The gun lays paint on a surface evenly, unlike brushes or rollers.
- Can be applied on rough, textured and damaged surfaces, for example where paint is peeling.
- The coating made is thick, so there is no need to overspray.
- It gives a flawless finish.
- Water-based paints or paints containing metallic particles can be applied using this method, as opposed to the electrostatic method.
- An airless sprayer's coating is very 'wet' and thus there is good adhesion with the material.
- The coating is very durable.
- There is no need to buy huge quantities of thinners.
- Overhead spraying is possible.

2.2 Disadvantages of airless spray painting

- There is high wastage of paint since between 20% and 40% of the paint droplets do not end up on the metal surface.
- There is a need to cover items which are in close proximity to the metal surface.
- It requires some effort to clean the pump, hose, filters, and the spray gun itself.
- It is not easy to control the thickness of the coat.
- It is not possible to overlap paint strokes.

3. Electrostatic spray painting

Electrostatic spray painting has the advantage that it can be done with both liquid and powdered paint. The paint particles can be electrostatically charged in several ways. A negative charge can be applied to the paint while it is still in the reservoir or in the barrel of the spray gun. When the paint is propelled through the gun, it gains a static electric charge as it moves through the barrel. The metal object to be painted has a positive charge, and hence it attracts the negatively-charged paint particles (opposite charges attract). Since the paint particles are all negatively charged, they repel each other and distribute themselves evenly on the metal surface, thus giving it a uniform coverage.

3.1 Advantages of electrostatic spray painting

- It creates a strong bond, which produces a highly durable coating.
- Powder coating is highly resistant to corrosion.
- Powder coating does not use a solvent, hence it does not cause water pollution.
- It covers a three-dimensional object evenly, giving it a good edge and wrap-around coverage.
- It has a high paint transfer efficiency of about 95%, which saves paint and cuts costs.
- Not only does the powder have a high utilisation rate, it can also be recycled.

- It has a better looking finish compared to other methods, because it produces a uniform paint thickness.
- It is portable and can be applied onsite; thus, large architectural metal items do not need to be dismantled for recoating as this can be done electrostatically.

3.2 Disadvantages of electrostatic spray painting

- The equipment is expensive to acquire.
- It is mostly applicable to metals only.
- It is not suitable for uneven surfaces.
- Poor management can result in electric shock and fires.

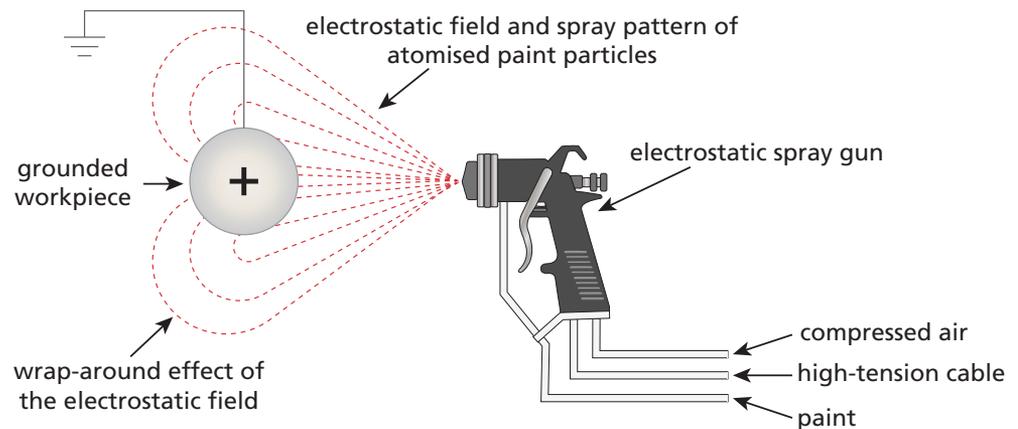


Figure 2.8 Electrostatic spray painting

4. Dip painting

Dip painting involves **immersing** metal parts in a tank of paint, and then draining off the excess paint in a solvent-saturated atmosphere before drying or curing. Before immersion, the surface is cleaned using a solvent, a phosphate bath, or sandblasting. This method is very quick and is most suited for mass production of parts which need coating on all surfaces. The process is usually highly automated, and thus the parts are moved on conveyors. The thickness of coating can be controlled by varying the viscosity of the paint and the rate of withdrawal of parts from the tank. To reduce wastage, it is also possible to modify the system and incorporate electrostatic spray painting principles.

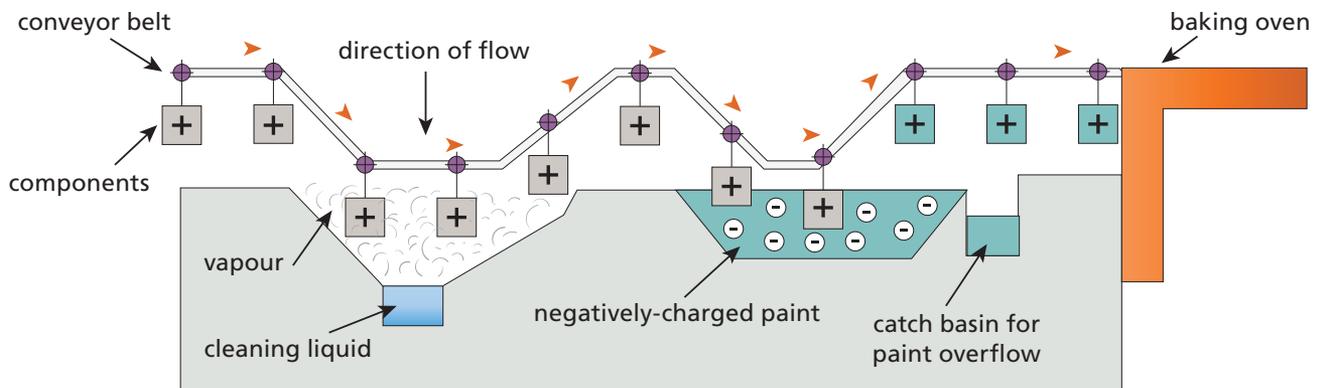


Figure 2.9 Dip painting

4.1 Advantages of dip painting

- Metal parts with challenging geometries, for example wheels and pipes, can be painted.
- It is a much simpler and cheaper process.
- Provides a way cheaper alternative, where powder coating is deemed too expensive.
- It is very quick.
- It is highly resistant to corrosion.
- It can increase the friction or grip of cutting tools such as pliers and shears.
- It also gives aesthetics to metal surfaces.

4.2 Disadvantages of dip painting

- If metal parts are too light compared to the paint, they may float on the paint surface instead of being immersed.
- A wedge effect may result. This is when the film thickness is not uniform, i.e. with the lower bottom edges of parts being more heavily coated.
- Dip painting is prone to sags forming due to gravity during curing.
- There are large capital requirements due to high levels of automation and huge quantities of paint.

ACTIVITY 2.7

Painting processes

1. Compare and contrast airless and air spray painting.
2. Copy the dip painting diagram in your notebook and label the main parts.

Module summary

- Corrosion causes huge economic losses worldwide and thus needs to be prevented. There are various metal protection processes available that can be used to solve the problem of corrosion.
- There are two subclasses of corrosion, namely chemical and electrochemical. At times, both chemical and electrochemical corrosion take place on the same metal. In such a case, stringent measures need to be taken so that the metal can be saved.
- There are five main forms of corrosion, namely: surface, stress, galvanic, inter-crystalline, and pitting. If any one of them is left acting on a metal without preventative measures being taken, the structure will fail.
- The salt-spray test, the humidity test, and the sulfur-dioxide test are the three main tests done to check a metal's performance against corrosion. Each test has its own unique pros and cons.
- There are four main metal protection methods, namely: cathodic protection, electroplating, anodising, and phosphating. Each method has its own strengths and weaknesses.
- Surface preparation is essential before applying a coat of paint; otherwise the paint may fail to stick to the metal surface. Before applying paint, a surface must be clean without any dirt or grease on it.

- There are several methods of applying paint on a metal surface. Each method of paint application has its advantages and disadvantages that must be noted before selection.
- Corrosion is a major problem worldwide. For it to be controlled, there is a need to understand its various classes and forms.
- Different tests have been designed to evaluate the performance of workpieces in corrosion environments. The main methods are the salt-spray test, humidity test, and sulfur-dioxide test.
- The most applicable corrosion prevention method is painting metal surfaces. Thus, several painting methods need to be understood – taking note of their advantages and disadvantages.

Exam questions

1. There are two main classes of corrosion, namely chemical and electrochemical corrosion.
 - a) Describe chemical corrosion (2)
 - b) Explain electrochemical corrosion (5)
 - c) Draw a fully-labelled diagram of electrochemical corrosion. (5)
2. Name and describe all five forms of corrosion. (10)
3. Briefly explain the salt-spray test. (5)
4. Make a labelled drawing of the salt-spray test. (5)
5. How is electroplating different from cathodic protection? (4)
6. Describe the following components of an electrolytic circuit:
 - a) Anode (1)
 - b) Electrolyte (1)
 - c) Cathode. (1)
7. Briefly describe galvanising. (3)
8. Explain why sandblasting is very useful in corrosion prevention. (2)
9. What are the differences and similarities between conventional spray painting and high-pressure spray painting? (10)
10. Discuss the electrostatic method of painting, clearly outlining its pros and cons. (6)
11. Name three popular corrosion tests which are carried out in industry. (3)
12. State three possible causes for each of the following faults that can happen in the spray process:
 - a) Excessive paint spray (3)
 - b) Uneven spray painting (3)
 - c) Sagging surface (3)
 - d) Speckle or orange peel effect. (3)
13. State six advantages and four disadvantages of airless spray painting. (10)
14. Explain the dip painting method. (5)
15. Draw a fully-labelled diagram of this method. (5)

Total: 95 marks