Hot Corrosion

Introduced by:

Hajir Ali Kadhim

Fatima Dheyaa

Supervised by:

Dr. Ali Hubi

Introduction

Hot corrosion is a type of corrosion that occurs in materials due to the effects of high temperatures. It causes the material to react with oxygen or other compounds in the surrounding environment, which leads to the deterioration of the material's properties and loss of its quality or strength. Hot corrosion often occurs at temperatures above 300 °C, and may be accompanied by additional effects such as the material interacting with corrosive gases such as sulfur or chlorine.

Introduction

When a metal is exposed to high temperatures, surface oxidation occurs, leading to the formation of an oxide layer on the surface of the metal. In some cases, this oxide may react with the surrounding gas, causing faster corrosion. Hot corrosion is a major problem in industries that deal with high temperatures, such as the energy, metallurgy, and automotive industries, as it reduces the life of equipment and increases costs

Mechanism of Hot Corrosion:

1. Oxidation and Surface Oxidation:

At high temperatures, the metal reacts with oxygen in the air to form metal oxides on the surface. This protective layer of oxide is initially durable, but over time, it may become porous or unstable, allowing oxygen or other gases to penetrate into the metal and thus accelerate corrosion.

2. Effect of corrosive gases:

In some hot environments, there may be pollutant gases such as sulfur or chloride that react with the metal. For example, sulfur may react with the metal to form metal sulfides, which increases the surface deterioration of the metal and reduces its resistance.

Mechanism of Hot Corrosion:

3. Advanced Chemical Reactions:

As the temperature increases, other chemical reactions may occur such as the oxidation of aluminum or iron that forms solid oxides, but they do not provide the necessary protection for the metal. This can lead to theloss of mechanical properties of the metal such as strength and hardness.

Factors affecting hot corrosion

1. Temperature:

The higher the temperature, the faster the chemical reactions, which enhances the corrosion process. At temperatures above 300 °C, the material becomes more susceptible to hot corrosion.

2. Chemical composition of the metal:

Different metals have different ability to resist corrosion in hot environments. For example, stainless steel has better resistance to hot corrosion than ordinary steel, due to its composition containing high amounts of chromium.

Here is an educational and explanatory image that illustrates hot corrosion, highlighting the effects of high temperatures and corrosive environments on metal surfaces. It shows oxidation, cracking, and material degradation with labels explaining the process.

Factors affecting hot corrosion

3. Surrounding gases:

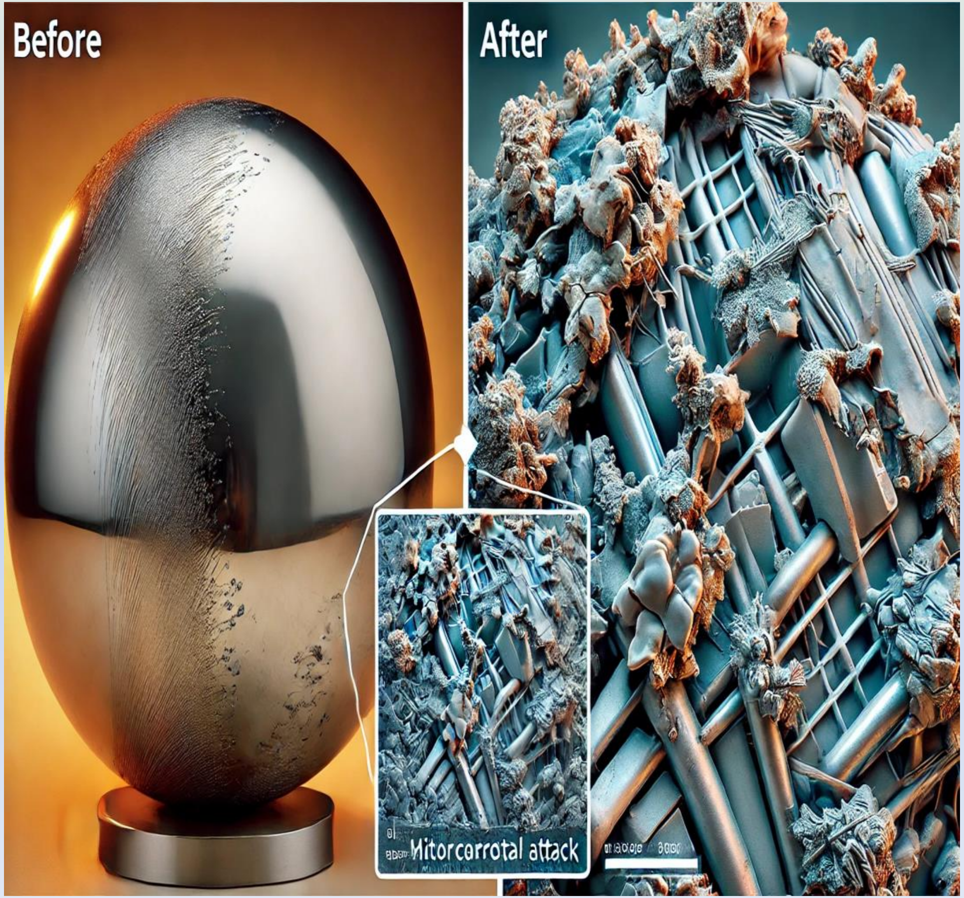
Oxygen is one of the main factors in hot corrosion, but gases such as sulfur, chlorine, and nitrogen can also contribute to increased corrosion speed. Sometimes, toxic compounds are formed that can affect the overall performance of the metal.

4. Interaction with fluids:

In industrial environments where fluids are present at high temperatures, a reaction may occur between the fluids and the metal. This contributes to the deterioration of the metal surface more quickly, especially in the presence of acid or alkaline materials.

Appearance of Hot Corrosion

Here is a visual representation of materials affected by hot corrosion. The image illustrates the material's condition before and after exposure, highlighting features like surface pitting, flaking, and the formation of crusty deposits. A close-up inset showcases the microscopic intergranular attack and phase changes in the microstructure for detailed analysis.



Types of Hot Corrosion

A. **Corrosion by Oxidation**
B. **Corrosion due to sulfur**
C. **Corrosion due to chlorine**

A. Oxidative corrosion

Oxidative corrosion is a type of corrosion that occurs when a metal reacts with oxygen in the atmosphere or in an oxygen-rich environment, resulting in the formation of a metal oxide on the surface of the metal. This process is one of the most common forms of corrosion and usually occurs at low to moderate temperatures, but may increase in hot environments.

How oxidative corrosion occurs?

1. Metal reacts with oxygen:

When the metal is exposed to oxygen in the air, oxygen atoms begin to react with the metal atoms on the surface. For example, in the case of iron, oxygen reacts with iron to form iron oxide (Fe_2O_3), commonly known as rust.

The chemical equation for the formation of iron oxide:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

How oxidative corrosion occurs?

2. Formation of the oxide layer:

Initially, a thin layer of oxide forms on the surface that is cohesive and acts as a protective shield against the subsequent reaction of oxygen with the metal. But over time, this layer may become brittle or porous, allowing oxygen to reach the inner metal, leading to further corrosion.

3. Effect of heat:

When metals arrapid, increasing the rate e exposed to high temperatures, the oxidation process may accelerate. At high temperatures, chemical reactions become more at which metal oxides are formed. Some metals may react more quickly with oxygen at high temperatures, such as aluminum, which forms aluminum oxide (Al_2O_3) when reacting with oxygen.

Effects of Oxidative Corrosion

- **Surface deterioration:** The formation of oxide layers results in the deterioration of the metal surface, reducing the strength and hardness of the metal.
- **Weight gain:** Oxidation corrosion causes oxide to accumulate on the surface of the metal, increasing its weight.
- **Loss of mechanical properties:** Metals become more brittle and weak as a result of oxygen reacting with their surface.

Prevention of Oxidative Corrosion

- **Protective coating:** The use of protective coatings such as oil coatings or metal coatings can protect the surface from reacting with oxygen.
- **Use of oxidation-resistant metals:** such as stainless steel with a high chromium content, which reacts with oxygen to form a protective oxide layer that prevents reaction with the base metal.
- **Environmental control:** Reducing exposure to oxygen in the environment can reduce the rate of oxidation corrosion.

Etiology of Hot Corrosion

Corrosion Factors:

- High operating temperatures that accelerate oxidative reactions.
- Contaminants such as sodium, sulfur, and chlorine, which can lower the melting point of oxide scales, leading to accelerated degradation.

Mechanisms:

- Oxidation: Formation of oxides at high temperature, which can spall off, exposing fresh metal beneath.
- Eutectic Formation: The melting of corrosive contaminants at elevated temperatures that can lead to liquid-phase sintering and flow across surfaces.

B. Sulfur Corrosion

Sulfur corrosion occurs when metal reacts with sulfur compounds in the environment, such as sulfur dioxide (SO_2) or other sulfur compounds. At high temperatures, sulfur reacts with metals to form metal sulfides on the metal surface, causing the material to deteriorate faster than normal corrosion.

How sulfur corrosion occurs?

1. Sulfur reacts with metals:

Sulfur reacts with metals such as iron or nickel to form sulfide compounds, such as iron sulfide (FeS) or nickel sulfide (NiS). These compounds accumulate on the surface of the metal, causing the metal to weaken and reduce its durability.

2. Sulfide layer formation:

Over time, a layer of sulfide forms on the surface of the metal. This layer may not be cohesive enough, allowing gases or other substances to react with the metal from the inside, accelerating the corrosion process.

3. Heat and its effect:

At high temperatures, the reaction of sulfur with metal accelerates. This reaction is faster in environments where metals

Effects of Sulfur Corrosion

- **Increased deterioration:** Sulfur corrosion reduces the metal's resistance to pressure and tension, weakening the material and reducing its lifespan.
- **Accelerated reaction:** Sulfur can also react with oxygen, forming both oxide and sulfide compounds, which accelerates the corrosion process.

Prevention of Sulfur Corrosion

- **Use resistant metals:** Some metals, such as stainless steel, exhibit better resistance to sulfur corrosion due to the formation of oxide layers that protect the metal.
- **Protective coatings:** Corrosion-resistant coatings can be used to help protect the metal from the reaction of sulfur with it.
- **Control of sulfur in the environment:** Reducing the concentration of sulfur in the air or using filters can reduce the effects of sulfur corrosion.

C. Chlorine Corrosion

Chlorine corrosion occurs when metal reacts with chlorine gas or other chlorine compounds in the environment. This type of corrosion is very dangerous because it can lead to rapid deterioration of the metal, especially in environments with high temperatures or humidity.

How chlorine corrosion occurs?

1. Chlorine reacts with metal:

When metal is exposed to chlorine gas (Cl_2) or chlorine compounds such as sodium chloride ($NaCl$) or hydrogen chloride (HCl), chlorine begins to react with the surface of the metal, forming compounds such as metal chlorides. These compounds quickly react with the metal, causing the surface to corrode.

For example, chlorine can react with steel to form iron chloride ($FeCl_2$ or $FeCl_3$): **$Fe + Cl_2 \rightarrow FeCl_2$**

How chlorine corrosion occurs?

2. Formation of a layer of chloride compounds:

Chlorine reacts with the metal to form a layer of chloride compounds that can be porous and loose. This layer does not protect the metal but rather facilitates continued interaction with chlorine, leading to faster deterioration of the metal.

3. Combined effect with humidity:

In some environments, such as coastal areas where the winds contain a high percentage of chloride, chlorine can react with moisture in the air to form hydrochloric acid (HCl), a strong acid that accelerates the corrosion process: $Cl_2 + H_2O \rightarrow 2HCl + O_2$

Effects of chlorine corrosion

- Loss of mechanical strength: Chlorine corrosion causes the metal to become weak and brittle, reducing its resistance to loads and pressure.
- Formation of holes or cracks: Chlorine corrosion may lead to the formation of holes or cracks in the metal, especially in metals that contain elements that are less resistant to chlorine, such as iron and steel.
- A faster effect at high temperatures: At high temperatures, the rate of chlorine reaction with the metal increases, leading to faster corrosion.

Prevention of chlorine corrosion

1. Use of chlorine-resistant materials:

Stainless steel, which has a high percentage of chromium, can provide good resistance to chlorine corrosion, as it forms an oxide layer on its surface that protects it from reacting with chlorine.

2. Protective Coating:

Protective coatings such as ceramic coatings or metallic coatings can be used to protect the metal from direct interaction with chlorine.

3. Environmental Control:

Reducing the concentration of chlorine in the surrounding environment can help reduce corrosion. In industrial settings, filters or systems can be used to reduce corrosive gases.

Prevention of chlorine corrosion

4. Using Anodes for Grounding:

In some cases, electrolytic anodes can help reduce the effects of chlorine corrosion by attracting negative ions away from the metal surface.

- Overall, chlorine corrosion is a rapid and destructive type of corrosion that requires advanced preventive measures to preserve metals in environments where they are exposed to chlorine

Key Environments Where Hot Corrosion Occurs

Industries Affected:

- Aerospace: Gas turbines exposed to high-temperature combustion gases containing sodium and sulfur compounds.
- Energy Production: Gas and steam turbines, where high thermal and corrosive stress can lead to performance loss.
- Marine Environment: Salt-laden air can contribute to hot corrosion in components like exhaust systems and propulsion systems.

Components Prone to Hot Corrosion:

- Turbine blades, combustion chambers, heat exchangers, and exhaust manifolds.

Sodium-Sulfur Interaction

Chemical Interactions:

- Sodium compounds can interact with sulfur dioxide to form molten salts at high temperatures, leading to detrimental effects on protective oxide layers.

Eutectic Formation:

- Low-melting-point eutectics that form in the presence of sodium can lead to liquid droplets that infiltrate oxide layers, disrupting integrity and causing enhanced material loss.

Prevention:

- Understanding these interactions is crucial to designing coatings and barriers that can withstand these corrosive conditions.

Prevention Strategies Overview

- **Importance of Preventive Measures:**

Cost-effective strategies are key to extending the lifespan of components and reducing downtime.

- **Key Strategies:**

Proper material selection, application of protective coatings, and regular inspection regimes help fight hot corrosion.

- **Empirical Evidence:**

Share success stories or data that demonstrate reduction in failures through effective strategies.

Coating Techniques

❑ Types of Protective Coatings:

Thermal Barrier Coatings (TBCs): Insulate components and reduce thermal stress, thereby lowering hot corrosion susceptibility.

Oxidation-Resistant Coatings:

Coatings that can withstand aggressive environments, often made from advanced ceramics or metal-based compounds.

Material Selection

- **Guideline Considerations:**

Material selection must factor in long-term exposure to operating conditions, understanding both thermal and corrosion resistance.

- **Data Analysis:**

Emphasis on utilizing performance data from real applications to inform choices and predict material behavior in specific environments.

- **Alloy Innovations:**

Highlight novel alloy systems being developed to combat hot corrosion challenges.

Chemical Inhibitors

Inhibitor Types:

A. **Organic Inhibitors:** Contain molecules that adsorb onto metal surfaces, reducing corrosion rates.

B. **Inorganic Inhibitors:** Typically salts or minerals that form protective layers on metal, such as phosphates or chromates.

C. **Volatile Corrosion Inhibitors (VCIs):** Release vapors that condense on surfaces, offering protection in enclosed spaces.

Application Examples of Chemical Inhibitors

- **Aerospace:** Zinc phosphate coatings are utilized to safeguard metals in jet engines from hot corrosion.
- **Marine Industry:** Vapor Corrosion Inhibitors (VCIs) are integrated into packaging materials to protect metal components during shipping and storage.
- **Power Generation:** Organic inhibitors are added to cooling water systems to minimize corrosion in heat exchangers.

Design Changes

- ✓ **Structural Considerations:**

Engineering designs should avoid features that promote hot corrosion, like uncoated surfaces and sharp interior angles prone to stress concentration.

- ✓ **Thermal Cycling Management:**

Design components to accommodate thermal expansion and contraction, reducing stress and potential crack formation.

Monitoring Techniques

- **Advanced Monitoring Methods:**

Deploying non-destructive testing (NDT) techniques to regularly assess component integrity.

- **Early Warning Systems:**

Implementing systems that can provide alerts about changes in performance or detectable corrosion.

References

1. Khanna, A. S. (Ed.). (2016). High temperature corrosion. World Scientific.
2. Prashar, G., & Vasudev, H. (2020). Hot corrosion behavior of super alloys. Materials Today: Proceedings, 26, 1131-1135.
3. Prashar, G., & Vasudev, H. (2020). Hot corrosion behavior of super alloys. Materials Today: Proceedings, 26, 1131-1135.
4. Gurrappa, I., Yashwanth, I. V. S., Mounika, I., Murakami, H., & Kuroda, S. (2015). The importance of hot corrosion and its effective prevention for enhanced efficiency of gas turbines. Gas Turbines-Materials, Modeling and Performance, 1, 55-102.

Thank you for your listening