Use of Epoxies as Protective Coatings against Corrosion for Metals
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Metals are ubiquitous in a wide array of structural applications and corrosion is of paramount concern in this regard. Corrosion can occur when metals are exposed to the environment along with reactions to water, acids, salts, and other chemicals. Whether the metal is used in aerospace, oil and gas production, petrochemical manufacturing facilities, or electronic devices, among others, corrosion will lead to a reduction of the mechanical properties, structural integrity and overall functionality of the final product.

One of the best approaches to preventing and inhibiting corrosion is to create a barrier over the metal surface, which can be achieved using protective coatings. These coatings will protect against corrosion, moisture and other chemicals from attacking the metal. With their excellent adhesion, convenient application, mechanical strength and toughness, thermal, electrical, and chemical resistance profile, epoxies are highly effective as corrosion protection coatings for numerous applications.

Types and sources of corrosion

The type and rate of corrosion are determined by the metal, the types and concentrations of the reactive chemicals, along with the environment, e.g. temperature and humidity. For example, in oil and gas production, there are corrosion issues. Sweet and sour corrosion occurs when carbon dioxide (CO₂) and hydrogen sulfide (H₂S) are dissolved in water generating acidic solutions that attack the metal. Both can result in pitting, or the formation of small cavities or holes in the metal surface. The presence of oxygen accelerates this process. Another example is galvanic corrosion which occurs when two metallic materials with different electrochemical potentials are in contact in the presence of an electrolyte. Crevice corrosion generally occurs in areas where the surface is partially hidden from the environment and narrow, deep cracks are present, such as where two parts meet or underneath a screw head. There are numerous other scenarios where corrosion can occur. Still another important example is erosion and fretting (constant wear due to movement against another surface).

Prevention through protection

With so many possible mechanisms by which corrosion can occur, it is imperative to consider it in the design phase. Obviously, it is easier to prevent corrosion rather than dealing with it after it has occurred. Epoxies are highly effective entities for preventing corrosion. In addition, their performance properties, such as their resistance to moisture, acids, and temperature, can be tailored to meet the needs of different applications.

Epoxies offer high bond strength and long term protection for metal surfaces against chemical attacks.

There are a number of different industries where corrosion can be a major issue. Below we have outlined just a few of the industries where corrosion can be a problem:

- With offshore production in the oil and gas industry, platforms are exposed to salt water, and oil drilling components must resist attack by CO₂, H₂S, and free water at high temperatures. Pipelines are also exposed to crude oil, natural gas, and other hydrocarbons.
- Reactors, pipelines, and storage tanks used in the petrochemical industry are exposed to a very wide range of harsh chemicals, including strong acids and bases, oxidizing agents, solvents, salt solutions, various gases, hydrocarbons, and water.
• Storage tanks used for general industry applications must resist corrosion due to possible exposure to solvents, acids and bases, fuels, hydrocarbons, and water.

• Metallic structures used in military and aerospace applications are exposed to extreme temperatures and a range of chemicals, including jet and other fuels, water, hydrocarbons, degreasers, and deicing fluids.

• Electronic systems of all types, from the smaller handheld consumer devices to the most sophisticated sensors, for example, are exposed to flux residues, processing plasmas, gases, cleaners, solvents, other coatings, salts, acids, and other ionic elements.

• Medical implants and other devices are exposed to bodily fluids, oxidizers, highly concentrated saline solutions with other complex substances such as amino acids, proteins, and plasma. Exposure to sterilants like H2O2, glutaraldehyde, alcohol and steam can also result in corrosion.

• Optical, electro optical, fiber optic systems must also guard against corrosion. Operating conditions can create a corrosive environment and epoxies are widely used to prevent this occurrence.

Selecting the right epoxy system

The successful performance of epoxy-based systems depends on proper selection and formulation of the key components: the epoxy resin and the curing agent.

In epoxy resins, the epoxy ring reacts readily with curing agents to yield crosslinked films that act as effective barriers against reactive chemicals and moisture. Aromatic groups impart toughness, rigidity, and high temperature resistance, while the oxygen substituents provide enhanced adhesion performance. Bis A and Novolac are some of the commonly used epoxy resins. Multifunctional epoxies are attractive because they have additional sites for crosslinking, leading to higher crosslinking densities and even greater thermal and chemical resistance properties for coatings based on these resins.

Choosing the best curing agent

The selection of the curing agent for an epoxy coating intended for a specific application is probably the most critical in the selection of the epoxy system. Curing agents not only affect the viscosity and reactivity of a formulation, they are incorporated into the applied coating and determine the type of crosslinking bonds that are formed, which has a direct impact on the properties of the coating. There are numerous types of curing agents that are effective for epoxy resins, thus allowing the formulator to tailor the properties of the coating system to meet the corrosion protection needs of many different applications.

The most important types of curing agents for epoxy coatings include nitrogen-based compounds (aliphatic amines, polyamides, cycloaliphatic amines, aromatic amines) polysulfides, and catalyzed systems such as imidazoles.

• Aliphatic amines cure readily at room temperature and impart both toughness and chemical resistance for good corrosion protection, but are not typically used on coatings greater than ¼ inch in thickness.

• Polyamides are the easiest to use and also cure readily at room temperature. They can cure in thicker sections and impart toughness to epoxy coatings, while their chemical resistance may not be quite as robust as that provided by aliphatic amines. However they are still widely used and highly effective.

• Cycloaliphatic amines can be more effective than the aforementioned two groups in selective environments. They work best when post cured at moderate temperatures.

• Aromatic amines provide epoxies with the best corrosion resistance performance, but require curing at up to 150°C and post-curing at up to 200°C.

• Polysulfides are special polymers that serve both as curing agents and flexibilizers. As a curing agent they do not require heating. They impart excellent toughness and good corrosion resistance particularly to fuels, oils and water.

• Imidazoles are catalytic curing agents that provide outstanding temperature and chemical resistance, and thus are ideal for corrosion protection coatings, but they do require heating to 80-120°C.

Solvent free epoxy systems are formulated in a wide range of thicknesses to provide efficient easy application and enhanced performance.
There are a wide range of one part and two part systems available depending on the type of epoxy resin and curing agent selected. One part systems do not require mixing but typically require heat for curing, generally at 125 to 175°C.

**The role of heat in optimizing corrosion resistance**

Although in many instances epoxy resin compositions can be cured at room temperature, often in order to achieve optimum corrosion-protection properties of epoxy coatings, curing at elevated temperatures is required. Most importantly, post-curing with heat is imperative because it enhances the crosslinking of epoxies.

**Epoxy coatings from Master Bond**

Master Bond offers a wide range of epoxy-based corrosion protection coatings for use in the oil/gas, petrochemical, aerospace, electronic, and medical industries. The important properties and curing agent used for each epoxy coating system are listed in Table 1.

**In closing**

With the growing demand for new age applications, corrosion has become an inherent problem in oil & gas, electronics, medical, optical, and many other industries. As illustrated in this paper, in order to prevent corrosion in such situations, epoxies are widely utilized. Not only do they confer excellent corrosion resistance, they are also easy to handle and process. However, one must be mindful of selecting the right epoxy system along with the appropriate application techniques for best results.

In order to improve the corrosion resistance properties of epoxy systems, constant research is being carried out. One such area of interest is the addition of various fillers in epoxy systems. Some specialized nanofillers have attracted particular attention in this regard.

Going forward, the objective for formulators is to enhance the capacity of such materials to withstand even more aggressive chemicals, temperatures and different hostile environments.

For further information on this article, for answers to any adhesives applications questions, or for information on any Master Bond products, please contact our technical experts at Tel: +1 (201) 343-8983.

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**Table 1: Epoxy-based corrosion protection coatings from Master Bond**

<table>
<thead>
<tr>
<th>Product</th>
<th>Chemistry</th>
<th>Primary Function</th>
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<tbody>
<tr>
<td>EP21ARHT</td>
<td>Cycloaliphatic based</td>
<td>Acid resistance especially to sulfuric, hydrochloric, phosphoric acids</td>
</tr>
<tr>
<td>EP21TPLV</td>
<td>Polysulfide based</td>
<td>Protection from fuels, oils, hydrocarbons and hydraulics</td>
</tr>
<tr>
<td>EP41S-1HT</td>
<td>Cycloaliphatic based</td>
<td>Withstands fuels, alcohols. and solvents, including gasohol</td>
</tr>
<tr>
<td>EP62-1</td>
<td>Imidazole</td>
<td>Protection from acids, bases, many solvents, even at elevated temperatures</td>
</tr>
<tr>
<td>SUPREME 45HTQ</td>
<td>Aromatic amine</td>
<td>Resistant to downhole chemicals, high temperatures and a combination of both</td>
</tr>
<tr>
<td>EP30-2</td>
<td>Aliphatic</td>
<td>Good general purpose epoxy that protects against environmental conditions. Provides resistance to water, salts and many common chemicals. Optically clear.</td>
</tr>
<tr>
<td>EP42HT-2Med</td>
<td>Cycloaliphatic based</td>
<td>Particularly resistant to heat, steam and chemical sterilants</td>
</tr>
<tr>
<td>EP21ND</td>
<td>Polyamide</td>
<td>Good general purpose “go-to” material for standard type corrosion resistance</td>
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