INSIDE:

- MOTION CONTROL: Why is preload necessary in some bearing applications? PAGE 56
- MATERIALS: Make the right choice for metal coating for the right application PAGE 70
- MECHATRONICS: Five keys to mechatronic success PAGE 80
Materials

Metals make it possible to have a variety of products, such as industrial production equipment, automobiles, aircraft, or consumer electronics. The corrosion metals are subject to, however, is a problem. Preventive measures, such as the right coating, can delay or eliminate corrosion.
The annual cost of corrosion worldwide is equivalent to 3 to 4% of the global gross domestic product, or more than $3.0 trillion. Historically, in non-critical industries, corrosion was treated as a repair and maintenance issue. More recently, however, preventive measures significantly reduce corrosion costs. These measures include appropriate material selection, careful component design, and corrosion control.

Active corrosion control involves the use of a sacrificial material (often zinc) that participates in corrosion reactions rather than the metal substrate. Passive protection involves the application of a barrier material that prevents corrosive reagents and water from reaching the surface of the metal substrate. These coatings and films also often provide additional protection against impact, abrasion, and other mechanical damage.

Given the very broad use of metals and the wide range of metal types, the performance expectations differ significantly, as do the acceptable cost/balance ratios. Different coating technologies meet the varied requirements; selecting the best coating technology for an application can be challenging. Here are several guidelines.

**Conventional technology: epoxies**

There are two major classes of coating technologies recognized for protective properties: epoxies and polyurethane-type systems, which include polyurethanes, polyureas and hybrids of these two chemistries. Epoxies are widely used as corrosion protection coatings for factory-applied metal applications because they exhibit excellent adhesion to metals and offer high moisture-, chemical-, and impact-resistance. They continue to be widely used as primers (sometimes zinc-rich) in multi-coat systems, including those with different topcoat chemistries (acrylics for light-duty applications, epoxies, silicones, polyurethanes and polyureas for medium- to heavy-duty applications). Most epoxy coatings used today are high-solids or 100%-solids formulations that meet strict environmental regulations concerning the emission of volatile organic compounds (VOCs).

There are, however, limitations to epoxy coatings that have driven interest in alternative technologies for corrosion control. In particular, epoxy coatings are not very flexible and can crack in applications that

---

**Cast iron pipe coated** with polyurethane coating to protect against undersea exposure. *Photo: Chemline*
Materials

Involves substrate movement, high wear, or heavy impacts. They also do not perform well at low temperatures (become brittle) and yellow over time in exterior applications due to degradation upon exposure to UV radiation.

For these reasons, polyurethane and derivative coating technologies are increasingly used as corrosion control coatings for OEM metal applications due to their greater flexibility combined with high adhesion and high resistance to moisture, chemical attack, and impact.

**Chemistry of polyurethanes and polyureas**

Isocyanates are used to synthesize both polyurethane and polyurea resins. Polyurethanes are obtained when diisocyanates (or polyisocyanates) react with polyols, while polyureas are generated when they react with amines. In hybrid systems, isocyanates are reacted with a mixture of amines and polyols. For many polyurethanes (except moisture-cured systems, for example), a catalyst is required to ensure rapid reaction of the isocyanate and polyl components. On the other hand, isocyanates react rapidly with amines, and thus no catalyst is required for the formation of polyureas.

A range of isocyanate, polyl and amine reactants are available for the synthesis of polyurethanes, polyureas and hybrids. Isocyanates can be aliphatic or aromatic. Aromatic compounds (such as, diphenylmethane diisocyanate (MDI) and toluene diisocyanate (TDI)) contain bonds that can absorb UV radiation, which leads to their breakdown and the undesirable yellowing of the coatings. As a result, aliphatic isocyanates (such as, hexamethylene diisocyanate (HDI) and isophorone diisocyanate (IPDI)), which do not have these bonds, are often preferred for the synthesis of polyurethane/polyurea binders intended for the formulation of exterior coatings.

Polyethers, polyesters, and polycarbonates are the polyol types most widely used for polyurethane and hybrid polymer production. In some cases, the polyol contains more than one type of linkage. Specialized polyols, such as polycaprolactones, are preferred for some applications. The length of the polyol chain has a significant impact on the hardness (short) and flexibility (long) of the coating, while the type of polyol impacts properties such as chemical and moisture resistance.

The diamines used for the preparation of pure polyureas and hybrids are typically polyamines. Often two different types are used: amine-terminated polymer resins, typically polyetheramines, and amine-terminated chain extenders, generally pure polyamines. Both primary and secondary amines can be used, with secondary amine reacting more slowly. Hybrids can be formed by reacting isocyanates with a physical blend of polyols and diamines, or by incorporating hydroxyl groups into the polyamine (often the chain extender).

**Polyurethanes**

While traditionally solvent-based, two-component (2K) coating systems, polyurethanes are also available as 1K water-based PU dispersions, 2K waterborne systems,
Materials

Initial water-based systems did not perform as well as their solvent-based counterparts and also suffered from application issues. Advances in PU technology have, however, led to the development of many PU dispersions that have application properties closer to those of solvent-based systems. The 100% solids systems also initially presented application difficulties, but here again advances in application techniques and equipment have overcome these challenges.

The crosslinking that occurs during PU film formation imparts specific properties to these coatings. They exhibit excellent gloss and color retention (for pigmented formulations; clear topcoats are also possible), combined with good chemical and moisture resistance, even for thin film builds, which is crucial for applications where weight is a concern (such as in automotive and aerospace industries). Aliphatic PUs also resist UV light for exterior applications. PU coatings’ mechanical properties include high impact, abrasion, and scratch resistance.

Because polyurethanes comprise two distinct components—the polyisocyanate and polyol portions—their properties are tunable through selection of different isocyanate and polyol building blocks. As a result, it is possible to achieve PU coatings that range from very flexible (elastomeric) to very rigid. In addition, PU coatings can be formulated with a unique combination of flexibility/elongation and harness that is not possible to achieve with epoxy acrylic systems. They also have excellent adhesions to different substrates, including metal. Thus, one product line can often be used for multiple applications, which can reduce carrying costs in inventory. Furthermore, for light- to medium-duty applications, polyurethanes can be used as single, direct-to-metal coatings, eliminating the need for a primer, which also reduces material and labor costs.

Polyurethane coatings cure fairly rapidly, even at lower temperatures, but most require a catalyst. The exception is moisture-cured systems, in which the water in the air acts as the catalyst. These systems are suitable for use in humid conditions. On the other hand, most 100%-solids PU coatings are more sensitive to moisture (susceptible to blistering) than other technologies, including epoxies, polyureas and PU/polyurea hybrids due to the need for a catalyst. Solvent-based PU coatings are typically applied as thin films (< 5 mil dry film thickness) using conventional airless sprayers, while 100% solids systems can be applied at thicker film builds (> 20 mil dry film thickness), but require the use of plural component spray technology, which automatically mixes the resin and catalyst components prior to spraying. Operation of this complex equipment requires trained/licensed applicators.

OEM applications for polyurethane coatings cover a broad swath of industries. Factory-applied, solvent-based systems (including high-solids formulations) are widely used in the furniture, cabinetry, and flooring industries. PU coatings are also used to some extent in the automotive industry in underbody, interior, and exterior (primer, base, topcoat) applications, as well as for truck-bed liners (both factory-applied and aftermarket). All types of PU coatings find use in general industrial metal, heavy equipment and plastic primer, topcoat and clear-coat applications. Direct-to-metal rigid PU systems are used for OEM pipe coating and steel storage tank applications, while elastomeric systems applied as a foam hardcoat are for waterproofing and durability in architectural trim, themed entertainment applications, and occasionally building panels.

Polyurea elastomers

Polyurea coatings are 100% solids, zero-VOC formulations that cure rapidly (as little as 30 seconds) without the need for a catalyst or heat, even at low temperatures (down to ~20°C). Due to the nature of the urea linkage, they are not sensitive to moisture; no blistering occurs, even when polyureas are applied on substrates in the presence of liquid water. As with polyurethanes, the formation of crosslinked networks in polyurea films imparts excellent mechanical properties, but the improved hardblock/
softblock segmentation in polyureas results in enhanced hardness/stiffness, tear and abrasion resistance and weathering, thermal shock and impact resistance. The urea linkages also contribute to enhanced chemical and water resistance. The combination of isocyanate and amine-terminated polyol segments delivers an attractive combination of flexibility and hardness.

Unlike polyurethanes, polyureas can be applied at very high film builds. As a result, they can serve not only as protective coating layers, but also contribute to the structural integrity of a substrate. They adhere to a range of substrates, including concrete, metals, wood, composites, foam and others.

There are challenges to working with polyureas, however. When first introduced, polyureas often suffered from substrate wetting, intercoat adhesion and surface defect issues. Developments in both raw materials and application equipment have helped overcome these shortcomings. Even so, proper mixing is crucial for optimum film formation and adhesion. As with 100%-solids PUs, high-pressure, plural component sprayers are required for the application of polyureas, and applicator training is necessary to ensure that operators understand how to identify optimum mixing and spray conditions. Polyurea elastomers are typically unsuitable for applications requiring thin (< 5 mil) coatings.

In general, polyurea coatings are preferred as topcoats for rapid curing applications (fast turnaround times), the coated substrate will be exposed to extreme conditions and appearance is not a key concern. In addition, they are used in applications where a thinner topcoat (PU or otherwise) may be damaged, leading to potential problems with corrosion and degradation. Polyureas are also often selected to replace epoxies in applications where elongation and impact resistance are important, because epoxies often crack and delaminate under such conditions. Examples include OEM waterproofing applications and rail and barge coatings. In general, polyureas are frequently used in the field due to their insensitivity to moisture and temperature. On-site applications include roof, pipe and tank coatings, truck-bed liners, liners for large tanks (freight ship lines, bulk transport wagons), car parking decks, bridges and offshore protection.

Polyaspartic ester-based polyurea coatings represent a newer technology based on the reaction of isocyanates with aliphatic polyaspartic esters (aliphatic diamines). These coatings generally cure more slowly than polyureas and can be applied at thinner film builds. Like polyurethanes, they are applied using conventional airless sprayers. Thus, they are often used in the same applications that can use PUs.

**Hybrids – the best of both**
The use of blends of amine- and hydroxyl-terminated polyols creates even more opportunities for fine-tuning the properties of hybrid coatings. Not only the appearance, hardness/flexibility and mechanical properties, but also the reactivity of these coatings can be adjusted by choosing different isocyanates, polyetheramines and polyols. Controlling the curing time lets you...
Unlike polyurethanes, polyureas can be applied at very high film builds. As a result, they can serve not only as protective coating layers, but also contribute to the structural integrity of a substrate.

Develop smooth to textured films with the desired surface appearance combined with the higher performance of polyureas.

Hybrids are typically 100%-solids formulations that cure rapidly (catalyst required) and can be applied in high film builds. They have good elongation and flexibility combined with excellent chemical and solvent resistance and resistance to abrasion and impact. Like polyureas, they can be applied at low temperature. However, the application of hybrid coatings is less complex (easier impingement mixing) than that of polyureas, although plural component spray equipment and applicator training are still required.

The customizability of polyurethane/polyurea hybrid coatings has led to their use in a variety of applications where the high performance of polyureas and an attractive finish are both desired. Consequently, they are often preferred over polyureas because hybrids can meet these requirements and still offer rapid turnaround times, and do so at a lower cost than pure polyurea coatings. The most common OEM uses are corrosion control and waterproofing applications where the high performance of polyureas is not required and hybrids provide more attractive solutions on a cost-performance basis. In some cases, hybrids are preferred because they offer a unique set of properties that cannot be achieved with a pure PU or polyurea system. Hybrids are also finding use in secondary containment application over concrete and geotextiles.

Making the right choice

There are polyurethane, polyurea, and PU/polyurea hybrid coating technologies available for practically every OEM coating application imaginable. These chemistries offer a range of properties suitable for different application conditions and performance needs. The factors to consider when selecting a protective coating for a given application include: the type of substrate, the application technology, the conditions under which the coating must perform, the cure time, the desired film thickness and the performance requirements (adhesion, appearance, and mechanical and resistance properties).

Cost is also clearly a key driver in the selection of a coating technology. Polyurethane coatings are the least expensive, polyureas the most costly, and hybrid coatings fall in between. Polyurethanes are often considered to offer the best compromise between cost and performance. Hybrids, on the other, offer 80% of the benefits of polyureas at approximately 50% of the additional cost compared to polyurethanes.

Thin-film polyurethanes suit applications where performance and a high-quality finish are required. In less demanding applications, they can be applied as a single coat (for example, direct-to-metal), but are often used as the topcoat when the coated substrate must be protected from more extreme conditions.

Polyureas, which can be sprayed in poor conditions including extreme temperatures and high humidity, are commonly used for outdoor or on-site applications. Polyurethanes and hybrids, which require catalysts for curing, are not suitable here. Less-expensive hybrids are preferred for OEM applications where the higher-performance curing properties of polyureas are not required, but similar applied-film properties are desired.

Chemline Inc.  
[chemline.net](http://chemline.net)

Reprinted from Design World for Chemline, Inc © 2016 WTWH Media, Inc.