TURNING THE SCREW

New standards for coating technologies are helping to ensure the integrity of structures from buildings to aircraft to bridges – and more.

By Kathy Hunt

For the average consumer, what coats a spoon, screw, or door handle makes little difference. As long as the item doesn't rust or corrode, most people never consider how or why a metal product resists wear and maintains its smooth surface. Nor do they think about how long humans have applied coatings to tools, utensils, vehicles, and other items to protect against nature and slow degradation. Since ancient times, organic substances such as beeswax, clay, tar, and lacquer have been employed to seal, waterproof, and safeguard objects.

With time, the materials used as coatings have changed. The 18th century saw the introduction of metal coatings after French chemist and physician Paul Jacques Malouin presented his method for creating a protective zinc covering for iron in 1742. By dipping a piece of iron into a bath of molten zinc, he supplied the iron with a corrosion-resistant coating and gave the world hot-dip galvanization.

In 1805, coatings took another leap forward with the introduction of electroplating or electrodeposition. Although other scientists had worked on this approach, Italian chemist Luigi Brugnatelli often receives credit for the first successful attempt at using an electrical current and metallic solution to coat another metal. With electroplating, a variety of elements, including nickel, chromium, copper, gold, and silver, could be applied as coatings.

Over two centuries later, electrodeposition continues to evolve, reflecting innovations as well as increased knowledge about the environmental and health impacts of coating materials. ASTM International's committee on metallic and inorganic coatings (B08) assists in this evolution. Established in 1941, the committee focuses on coatings created by such processes as electroplating; autocatalytic or electroless plating; immersion plating; vacuum processes such as vacuum metalizing, sputtering, and ion plating; chemical conversions such as chromating, phosphating, and black oxide; anodic oxidation; hot dipping; thermal coating such as flame spray, chemical vapor deposition, plasma spray, and detonation; and porcelain enamel and ceramic-metal coatings fused at temperatures greater than 427 degrees Celsius (800 degrees Fahrenheit). Sheet, wire, and tin mill products do not pertain to the committee's work.

ELECTRODEPOSITED NANOSTRUCTURED COATINGS

Presently, the subcommittee on engineering coatings (B08.03) is working on a new specification for electrodeposited nanostructured zinc-nickel coatings (WK29468). The work item addresses the performance requirements for a nanostructured zinc-alloy coating comprised of nanoscale grains of zinc or nanoscale layers of zinc alloy, both of which contain at least 95% zinc. It looks at unfabricated and fabricated products, steel forgings, and iron castings and will provide a foundation for identifying nanostructured zinc alloy coatings for steel substrates.

"The proposal for a new standard specification was prompted by the superior corrosion resistance achieved with nanostructured coatings compared to the standard zinc-nickel coatings specified by B841 [standard specification for electrodeposited coatings of zinc-nickel alloy deposits, Class 2], whether sacrificial or barrier coatings," says Oscar Garcia, metallurgist at Sigma Fasteners and B08 member. "This enhanced corrosion resistance results from two interrelated effects: the development of a unique microstructure and the application of adjusted electrodeposition parameters."

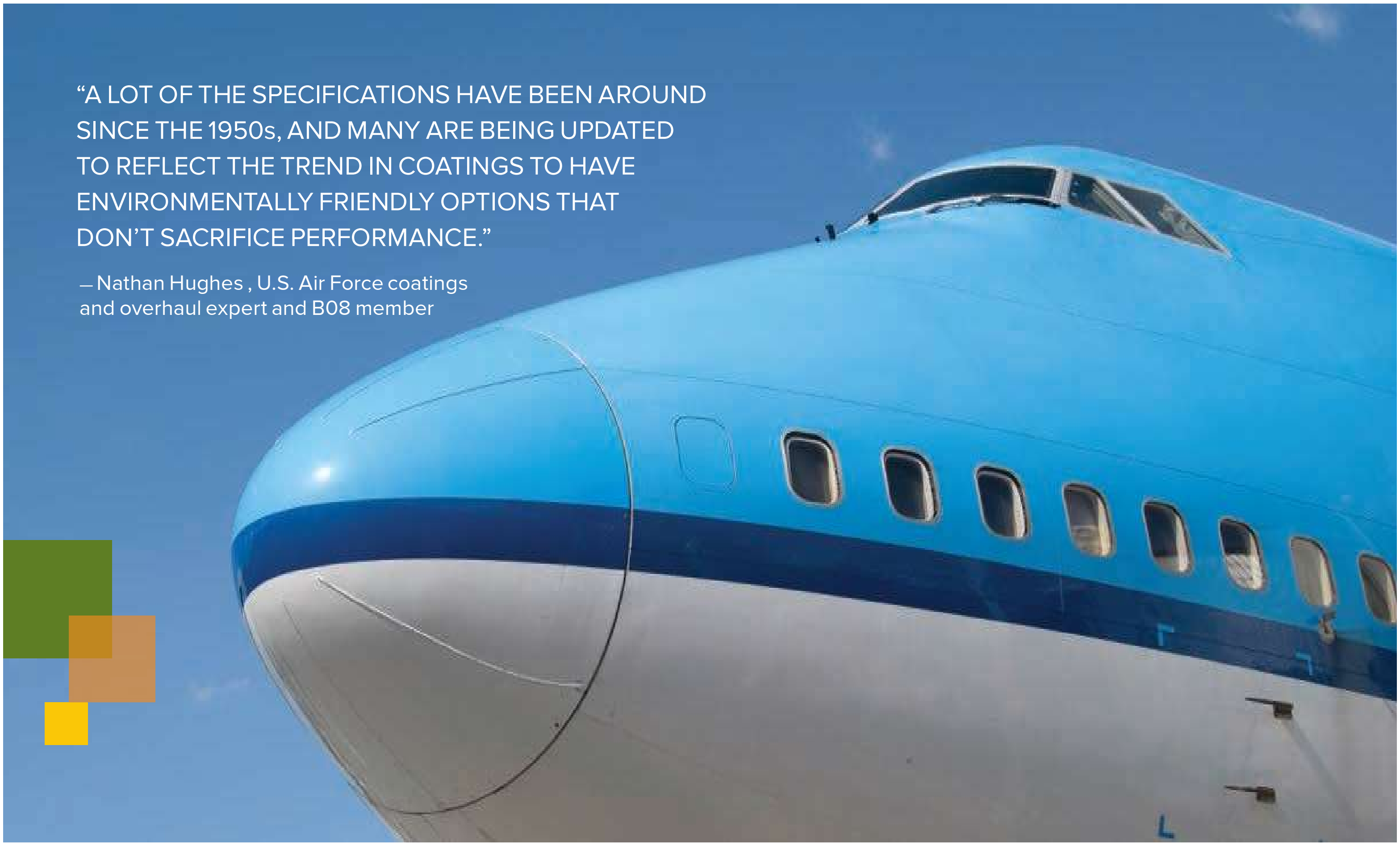
Ensuring corrosion resistance is essential. If fasteners or other essential pieces of hardware corrode, they could become deformed, break, or fail, compromising the structural integrity of the item of which they're a part. Buildings, bridges, automobiles, aircraft, pipes, and more may collapse as a result.

TWO CENTURIES AFTER THE INTRODUCTION OF METAL COATINGS, ELECTRODEPOSITION CONTINUES TO EVOLVE, REFLECTING INNOVATION AND KNOWLEDGE ABOUT THE ENVIRONMENTAL AND HEALTH IMPACTS OF COATING MATERIALS.

"Nanostructured zinc-nickel has the performance benefits of nanometer-sized layers of zinc and nickel — increased durability and corrosion resistance — that exceed the benefits of the original single-layer coating of zinc and nickel," says U.S. Air Force coatings and overhaul expert and B08 member Nathan Hughes. "For highly corrosive environments like offshore oil and gas platforms, aircraft carriers, or anything dealing with naval, aerospace, or marine operations and exposure to saltwater – nanostructured zinc-nickel provides the best corrosion protection."

The standard will be applicable not only to marine but also to industrial and high-humidity environments. Automotive and aerospace components such as fasteners, brackets, and housings, among other industrial applications, will benefit from it.

Herman Amaya is the chief metallurgist for Modumetal LLC and worked for Schlumberger for 15 years as principal engineer and metallurgy corrosion manager. According to him, the proposed standard for nanostructured zinc-nickel



WK29468

A new specification for electrodeposited nanostructured zinc-nickel coatings, WK29468 addresses the performance requirements for a nanostructured zinc-alloy coating comprised of nanoscale grains of zinc or nanoscale layers of zinc alloy, both of which contain at least 95% zinc.

having the same composition ranges as specified in B841 class 2 composition " ...demonstrates a corrosion resistance at least an order of magnitude higher than the standard processed equivalent composition B841." He adds that this enhanced corrosion resistance is validated by extensive field tests done over more than five years. It is also quantified by B117 Salt Fog testing with time to "red" corrosion exceeding 7,000 hours for coatings in the range of 8 to 12 microns (µm), using the criterion of reporting first "red " corrosion incidence. This process involves placing test pieces in a chamber that periodically sprays a salt solution and then studying the pieces for signs of rust or corrosion.

Amaya, who has been an active member of B08 for eight years, says the distinction between the process in the proposed standard and the one in B841 is the modulation of the electrodeposition process into a high-current component followed after a defined time period by a lower current component level. "This type of process is referred to as nanolaminar, pulse and reverse pulse electrodeposition and results in a microstructure of nanoscale grains generally less than 25 µm arranged in a layered or laminar deposition pattern," he says. "The combination of these two factors enhances the electrochemical properties of the zinc-nickel and by doing so improves the overall corrosion resistance."

Amaya notes that this process has been under development for the past 20 years or so, but it is only in the last five years that it has moved from development labs into the commercial setting with the opening of dedicated production facilities in Houston. Field testing in offshore facilities has resulted in the incorporation of the nanostructured zinc-nickel coatings into the specifications of various oil and gas companies. This prompted the suggestion that the process be reflected in a separate ASTM standard.

UPDATING COATING STANDARDS

In addition to its work on the nanostructured zinc-metal specification, the metallic and inorganic coatings committee is revising several existing standards, including the standard specification for electrodeposited engineering chromium coatings on ferrous substrates (B650). The specification covers the requirements for electrodeposited chromium coatings, which are occasionally referred to as functional or hard chromium, applied to ferrous alloy substrates for engineering applications. They are used to increase wear, abrasion, fretting, and corrosion resistance; to reduce galling or seizing and static and kinetic friction; and to build up undersized or worn parts. This standard does not attempt to address the safety concerns associated with its use. The user must establish proper safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

"A lot of the specifications have been around since the 1950s, and many are being updated to reflect the trend in coatings to have environmentally friendly options that don't sacrifice performance," Hughes says. He adds that chrome plating on steel is still used throughout the aerospace world.

“Keeping that in mind, when you’re trying to find a chrome-free plating alternative for B650, such as spray-applied tungsten carbide cobalt or a different electroplated coating, whatever you’re choosing that’s environmentally friendly also has to be as good as the benchmark,” Hughes says.

Two standards that minimize the risk of hydrogen embrittlement are likewise under revision. They are the standard specification for pre-treatments of iron or steel for reducing the risk of hydrogen embrittlement (D849) and the standard guide for post-coating treatments of steel for reducing the risk of hydrogen embrittlement (D850). Hydrogen embrittlement refers to the damage a metal sustains when hydrogen penetrates the metal and causes a loss in pliability and tensile strength.

The pre-treatment specification covers procedures done before electroplating, autocatalytic plating, porcelain enameling, and other chemical-coating operations. The post-treatment guide concerns heat-treatment procedures done after plating but before a secondary conversion coating. Both focus on substrates that have a high hardness level and include high-strength fasteners used in the automotive, oil, and gas industries.

MEETING THE U.N. SDGs

In September 2015, the United Nations agreed on the 2030 Agenda for Sustainable Development, an action plan that features 17 sustainable development goals (SDGs) to be accomplished globally by 2030. Of the 17 goals, the new specification for electrodeposited nanostructured zinc-nickel coatings meets two: Goal 3, which focuses on good health and well-being; and Goal 12, which addresses responsible consumption and production.

Hexavalent chromium, or chromium 6, is a toxic form of chromium widely used in electrodeposition. When released into the air, hexavalent chromium affects the liver, kidneys, respiratory system, skin, and eyes. When ingested in drinking water, it has caused tumors in rats and mice. The Occupational Safety and Health Administration (OSHA) considers all hexavalent chromium compounds to be carcinogenic, noting that the risk of respiratory cancers, specifically lung and paranasal sinus and nasal cavity, increases the longer workers are exposed to it.

The new specification for electrodeposited nanostructured zinc-nickel coatings cites the use of trivalent chromium passivate instead of hexavalent chromium. The Environmental Protection Agency (EPA) states that little evidence exists that trivalent chromium poses any toxic or carcinogenic risk to humans. By employing trivalent chromium, WK29468 mitigates the health risks of hexavalent chromium and aligns with sustainable development Goal 3, which strives to ensure healthy lives and promote the well-being of everyone at any age.

The work item may also lead to the replacement of cadmium electroplating. Cadmium generates toxic fumes during the plating process.

The Centers for Disease Control (CDC) has indicated that breathing high levels of cadmium can result in lung damage and death while ingesting lower levels in the air, water, and food can cause kidney disease, brittle bones, and cancer. Worldwide, many are concerned about the health effects of cadmium and some have called for a reduction in the amount of cadmium plating taking place.

The composition and performance levels of the nanostructured zinc-nickel indicate the coating could be a feasible alternative to cadmium. As a result of technological advances, Garcia says, a nanostructured zinc-nickel coating can be achieved that even outperforms cadmium coatings in corrosion resistance and operates at higher temperatures. By offering nanostructured zinc-nickel as a substitute for cadmium coatings, WK29468 meets SDG 12: responsible consumption and production.

“The need to replace these plating methods is due to several considerations, such as human health, environmental protection, regulatory compliance, sustainability, and meeting consumer expectations,” Garcia says. “This move highlights the industry’s commitment to embracing alternatives, meeting performance standards while minimizing negative impacts on health and the environment. Ultimately, the adoption of WK29468 signifies a conscious step toward sustainability and responsible practices within the coating industry.”

For additional information or to join the committee on metallic and inorganic coatings (B08), please contact staff manager Jennifer Tursi at: jtursi@astm.org. ■

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