Feature

UV-Curable Powder Coatings with Robotic Curing for Aerospace Applications

By Christopher W. Geib

The United States military depends on the effectiveness and reliability of the various weapons systems they use every day. These systems must function in extremes of temperature, humidity, corrosive atmospheres, blowing dust and sand, as well as possible chemical, biological and radiological agents. Virtually all weapon systems have some form of protective coating on them. Of the various parameters that these coatings must meet, the single most important is corrosion resistance. It is reported that the cost of corrosion to the Department of Defense (DOD) is in excess of $20 billion.

To protect their assets, the DOD continues to use coatings containing hexavalent chromium, a known carcinogen, and volatile organic solvents in liquid paint systems. Recently, the DOD added isocyanates to their list of emerging contaminants. These compounds are commonly found in the two-component polyurethane topcoats used on everything from aircraft to ground support equipment. Industry efforts to reduce these hazards are funded through DOD grant programs such as the Environmental Security Technology Certification Program (ESTCP) and the Strategic Environmental Research and Development Program.

Powder coatings offer one possible way to eliminate the hazardous materials and solvents. Developed in the 1960s as an alternative to wet-applied coatings, powder coatings contain no solvents and emit no toxic or hazardous gases when cured. The technology for powder coatings has advanced immensely since those times. The early powders were based on epoxy-type materials and required high temperatures (400°F plus) to cure. In addition, these early powder coatings were designed to act as barrier protection only. The durable finishes were mar- and abrasion-resistant, but would not protect the underlying substrate if the coating was cut down through to the metal below. Because of the cure temperatures, early powders

Figure 1

Typical photoinitiator for UV cure

IRGACURE 819 and IRGACURE 819 DW

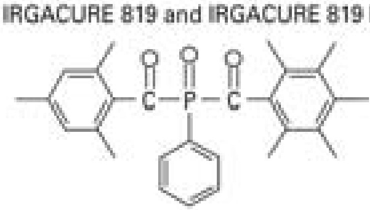

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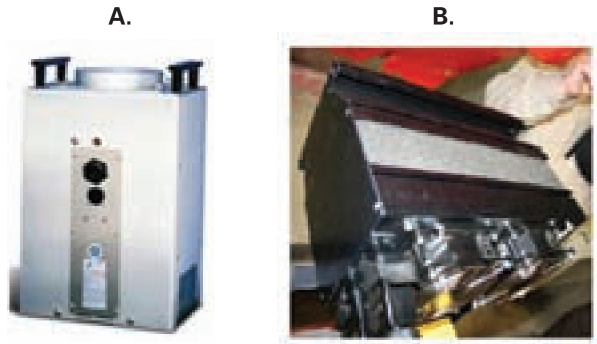
FIGURE 2

Typical UV lamps



A) Typical microwave-induced UV lamp made by Fusion® UV Systems
B) Mercury-arc based lamp made by Nordson® UV

could only be used on mainly steel as alloyed aluminum and composites could not manage the high heat applied.

Much has changed since those early days and many of today's thermal-cured powder coatings can be melted and cured at temperatures between 250°F and 350°F. Powder coatings can and are formulated with corrosion-inhibitor packages, most not containing chromium that addresses the weakness of powder coatings being used only as barrier coats. In addition, more recently, radiation-curable coatings using either Ultraviolet (UV) light or Electron Beam (EB) functionality have been added to powder coatings, further reducing the energy required to cure the coating and allowing powder coatings to be applied to articles of literally any size.

UV-cured chemistry is based on resins crosslinking by light-induced reactions rather than heat (as in the thermally cured powders). A compound referred to as a photoinitiator absorbs a UV photon at a certain wavelength that, in turn, causes the photoinitiator to break down into a free-radical containing species. Although there are other UV-cure mechanisms, such as cationic UV cure, the most common cure chemistry is based on the free-radical method. Photoinitiators today are generally phosphine compounds such as Ciba® Specialty Chemicals' IRGACURE® 819DW shown in Figure 1.

The UV light source is typically provided by high-energy mercury lamps. Typical configurations are high-voltage electric arc or microwave induced. Figure 2 shows typical UV lamps.

These lamps can employ straight mercury vapor. However, many lamps in use are doped with different metals to alter the UV spectrum to be more efficient for different photoinitiators and coating systems. A common lamp configuration is referred to as the "V bulb," this is a lamp that has been doped with a small amount of gallium. Figures 3 and 4 show the unmodified spectrum of mercury and a modified spectrum.

Advances in the light-emitting diode (LED) arena show great promise to eventually provide power and irradiance levels unheard of from solid-state devices in the past. Using liquid cooling, new UV-LED sources are starting to approach the energy density of the medium-pressure, mercury lamps without the heat and without the mercury. These advances will ultimately further bring down the cost of using UV-curables in many manufacturing areas where protective coatings are used. Figure 5 shows a prototype of one of these advanced UV-LED sources.

UV-cure resins contain reactive groups—typically acrylates, methacrylates, vinyls and unsaturated di-acids such as maleic anhydride. The more common examples are unsaturated polymers such as acrylate or methacrylate end-capped

FIGURE 3

Un-doped mercury-arc spectrum

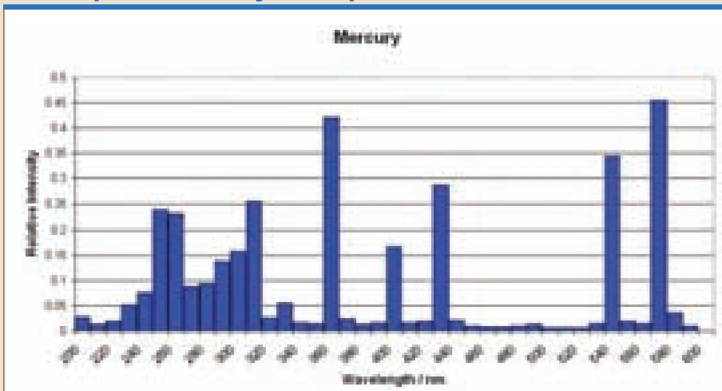
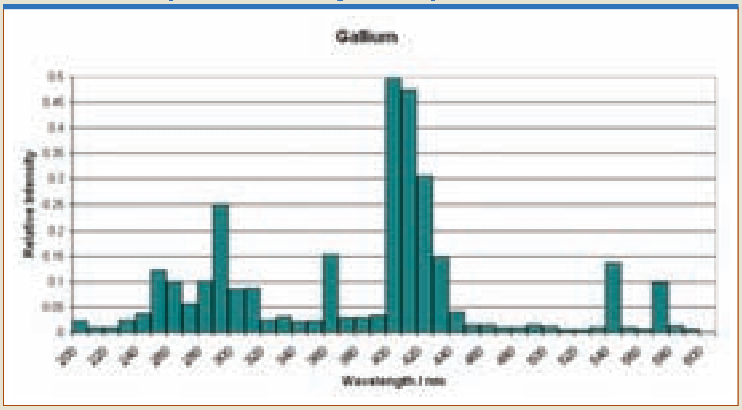


Figure 4

Gallium-doped, mercury-arc spectrum



polyesters, polyurethanes, epoxies, acrylics and hybrids, and blends of the previous. Figure 6 shows an example of a polyurethane end-capped with methacrylate.

These resins—along with photoinitiators, flow additives, pigments, corrosion inhibitors and other additives—are blended and then extruded. From there, they are ground to a particle size that gives the powder its ability to take on an electrostatic charge. Most of these resins are made without solvents meaning that UV-cure powders are VOC-free from cradle to grave. In general, no hazardous air pollutant (HAP) compounds are used in the powder formulation; therefore, it can be said that most UV-cure powders are both VOC- and HAP-free.

Application of powder is typically done using an electrostatic spray process. Two types of spray guns are used. One is a high-voltage electrostatic gun that uses a fine electrode in the powder stream to impart a charge to the powder. The second typical type of gun is called a tribo gun that has a pattern inside the gun that causes the powder to rub against itself and the walls, and imparts a charge to the powder in much the same way sliding your feet across a wool carpet imparts a static charge. The substrates for powder coating are typically metallic and grounded. The charged powder seeks the grounded part and adheres until it melts. Non-metallics can also be powder coated, but the process requires that the substrate be treated with a substance that temporarily imparts conductive properties to the substrate, or the substrate is pre-heated to a temperature that causes the powder to partially melt and stick to the substrate.

Once the powder has been applied to the substrate, heat is applied from either a convection oven or infrared (IR) lamps, or a combination of both. In the case of thermal-cure powders, the substrate is brought up to the cure temperature of the powder and held for some period of time. However, with UV-cure powders, only the powder needs to be heated using shortwave IR lamps to its melting temperature. By using shortwave IR, the powder is rapidly heated and the substrate barely sees any of the heat energy. Once the powder has melted and has flowed to a smooth finish, UV light is applied causing the powder to cure rapidly, usually in a matter of seconds. Figure 7 graphically describes the process.

The advantages of using a UV-cured powder over a wet solvent-based

Figure 5

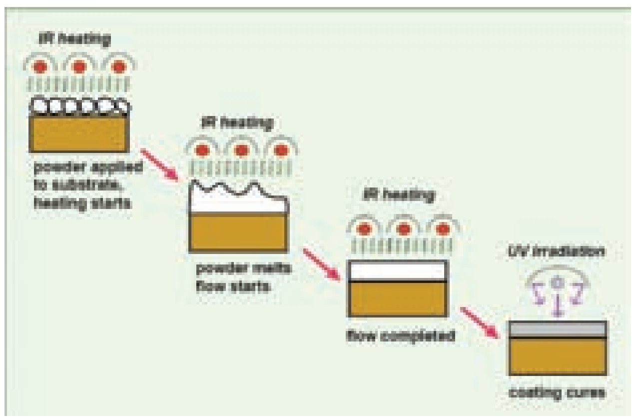
Prototype UV-LED lamp

Figure 6

Polyurethane di-methacrylate (typical)

FIGURE 7

UV powder-curing process



paint or even thermally cured powder coatings are significant. Use of UV-cure powder eliminates both VOCs and HAPs. This greatly reduces the amount of hazardous waste generated as part of the painting operation. Transfer efficiencies for UV powder are typical of all powder coatings that are up to 95% with reclaim. Color changes are fast, not requiring a major clean out of paint lines and pots. There is a decrease in thermal exposure since only the powder is actually heated. In essence, there is no oven. This means substrates that are sensitive to heat (such as tempered metals, composites or even rubber compounds) can be powder coated using UV-cure technology. Because there is no oven, UV-cure powder can be applied to objects of literally any size up to and including a ship exterior. Finally, UV-cure powders require less energy overall as the IR and the UV energy is focused on a specific part for only as long as it is needed.

Robotics use has been around for more than 20 years. However, the marriage of robotics and UV curing is relatively new. In the past, UV curing was limited to mostly two-dimensional, mostly flat surfaces. More recently, UV curing has moved into curing coatings on complex three-dimensional shapes such as custom automotive wheels. Because UV curing requires that UV light must reach every square inch of the shape, curing the UV coating on something like a car body, automotive radiator or custom wheels can be a daunting challenge. In the past, attempts were made to use a light tunnel approach. In Figure 8 you can see a typical auto body inside a light tunnel.

But in looking at this light tunnel, one can begin to see the drawbacks of such an approach. The number of the lamps, the amount of power (~600 W/in. of lamp), cooling and fixtures create high capital costs. Lamps wear out and must be replaced periodically, and this creates downtime for the production line. Generally, to keep power levels consistent around the tunnel, when one lamp wears out, it is best to change all the lamps at the same time. The biggest drawback one can see with this approach is line changes. If, instead of the apparent Mercedes in the image, the vehicle was replaced with a Volkswagen, all the lamps would be required to be readjusted, test runs performed and so on. The light tunnel approach does not lend itself well to mixed products. This is exactly the case on parts paint lines at military depots. A paint line might only do aircraft wheels; however, these could be from a large assortment of different aircraft or vehicles. Batching just one size at a time is virtually impossible, making the downtime a major factor for the light tunnel approach.

This is exactly where a robotic approach shines at its best (see Figure 9). A robot can be programmed with a "map" of the target surface. Once stored in the memory system of the robot, every time a particular component is presented to the robot

FIGURE 8

UV-curing light tunnel approach

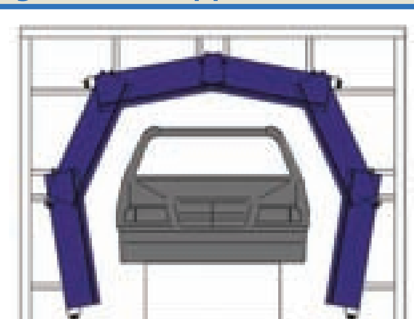


Figure 9

Robotic curing system

for curing, a few clicks of a mouse or a sensor that reads a bar code on the part carrier can cause the robot to instantly reprogram. Because of the "map," the robot system ensures repeatability from part to part. Product mix is no longer a disadvantage because numerous maps can be stored. The lamp moves on the arm of the robot eliminating the need for many lights. Robots can maintain extremely close target distances, ensuring a full and complete cure. Finally, robotic curing is ideally suited to cure large, bulky and complex parts. In essence, anything from the nose wheel of an F-16 fighter jet to an entire KC-135 aircraft, or even a large warship can be UV-cured using robotic curing systems.

As mentioned at the beginning of this article, the U.S. DOD spends large amounts of money each year to protect corrosion-sensitive components and weapon systems. Many of the current coatings continue to rely on the use of hexavalent chromium-containing pigments to provide corrosion protection. In addition, new emerging contaminants such as diisocyanate-containing materials are still in widespread use. Solvent-based coatings, although at higher solids levels, still introduce volumes of volatile air pollutants to the atmosphere. All of these hazards pose significant risk to human health and the environment. Hazardous waste storage and disposal costs are a significant amount of the protective coatings budget. Because these coatings take hours or days to fully cure, weapon systems are unavailable for days. Additionally, these same weapon systems must remain in controlled atmospheric environments to ensure proper cure and elimination of dust contamination. Maintaining these environmental conditions requires a significant amount of electrical power. And, finally, wet paint in the form of two-component formulations are wasteful as, on average, only about 60% of the paint used actually successfully transfers to the workpiece. The rest of the paint must be cleaned up and disposed of as hazardous waste.

One solution to this dilemma is to replace, where possible, wet coatings with powder coatings. Ideally, use of a UV-curable powder coating should be considered for all its advantages. The ESTCP has funded a demonstration of UV-curable powders applied to DOD weapon systems. The objectives of the project are to demonstrate a VOC- and HAP-free, UV-cure powder coating. Further, the project intends to demonstrate the use of state-of-the-art robotics to perform curing of the powder. The requirements the powder needs to meet to be qualified for military use is to meet or exceed the performance metrics of the current MIL-PRF-23377 chromated epoxy primer, and the performance metrics of the current MIL-PRF-85285 polyurethane/polyester topcoat. Additionally, a military UV-curable powder coating (UVCPC) should also be able to come in the full spectrum of military color schemes and in gloss, semi-gloss and flat finishes.

Until very recently, it has been relatively easy to produce a gloss or semi-gloss powder coating finish in the thermal cure area. These can be accomplished at temperatures much greater than 325°F. Melt and flow temperatures for UV-cure powders are typically between 250° and 300°F, resulting in finishes that are generally only capable of high gloss or semi-gloss. What has been accomplished as part of this project so far are both high gloss (>90 @ 60°F) and true semi-gloss (> 15 and < 45 @ 60°F) finishes. Typical semi-gloss gray coatings are measuring out at a 38.5 average at 60° incidence. A flat-finish prototype UVCPC has just begun initial qualification testing. The initial prototype's low gloss is encouraging with a gloss less than 4.6 at 60°F incidence and under 7 at 85°F. This now opens up a wide vista of possibilities for UV-curable powders. All of the powders for this project (including the new flat-finish powder) are currently being provided by a single vendor, Powder Coating Research Group (PCRG), in Columbus, Ohio. Through various commercial arrangements, PCRG can provide batches of UVCPC from 10 pounds to thousands of pounds. For the ESTCP demonstration, a gloss white meeting FED-STD-595 color 17925, a semi-gloss gray color 26173, and a flat gray color 36173 are planned. However, virtually any color the military currently uses is possible. As will be seen for several of the operational components, a Coast Guard white color 17860 and possibly a Navy torpedo green color 24108 will be required as well.

In addition to demonstrating no VOC and HAP, and meeting military performance metrics, the UVCPC project will demonstrate curing using state-of-the-art robotics. Figure 9 shows the UV-curing subsystem as delivered for the project carrying both the UV and IR lamps. The robot is a standard commercial Fanuc® Model M-710i C50 robot. The UV lamp is a mercury-arc lamp system manufactured by Nordson® in England and the IR lamp is made by ITW BGK®. The mounting bracket was designed and fabricated for this project by UV Robotics®. The robotic curing system, as this is known, will be set up in a facility at Whidbey Island Naval Air Station that recently was updated to meet current environmental, fire and safety codes. Figure 10 shows the curing facility. The structure inside the curtained area is the robotic curing cell and to the right behind the curtains are the powder coating booths. Both booths/cells are 12 foot high, 14 feet wide and 25 feet deep—a more than adequate size to powder coat and cure very large components.

The operational components that the demonstration intends to powder coat include wheels from the Navy EA-6B, P-3, EA-18G, and the main landing gear doors from a Coast Guard HC-130 aircraft. The Navy asked that the project powder coat a section of a Mk. 48 torpedo, an interior hatch from a submarine, and various ammunition cases and periscope storage cases.

Figure 10

Curing facility

Finally, the project will powder coat as a proof-of-concept demonstration, a scrap wing from an A-10 or scrap flap from a KC-135, and a façade of an HH-65 Coast Guard helicopter.

In-depth validation testing is underway at the Coatings Technology Integration Office at Wright-Patterson AFB. UVCPC test panels have been set out for outdoor exposure testing at Kennedy Space Center. Corrosion testing in an SO_2 corrosive environment is also underway. All of the validation testing must be completed prior to obtaining approvals from the various military agencies authorizing the powder coating of operational military components. At present, it is expected that all of the required testing will be complete by early May 2011. Powder coating of proof-of-concept parts could begin as early as June or July 2011, with operational parts later in calendar 2011. Completion of the initial ESTCP project WP-0801 is slated for April 2014.

Expected follow-up efforts include demonstrating a flat, UV-cure powder coating as a Chemical Agent Resistant Coating. UV-cure powder, along with proven high performance liquid UV primers and rare earth pretreatments, are ready to be demonstrated as a true zero-chrome coating system under the MIL-PRF-32239 (Advanced Performance Coating) specification. UV-cure powder is also ready to demonstrate itself as an above-the-waterline marine coating, replacing the current high-VOC, epoxy-polyamides. Integrating a U.S. Army Research Lab powder application technology with a high-energy UV-LED light source is also very close to demonstration. This is just a snapshot of future applications for UV-curable coatings, both powder and liquids, that will be realized on military hardware in the next five to 10 years. The future of UV-cure coatings for use in the DOD is a very bright future indeed.

For more information on the project, contact William Hoogsteden, Principal Investigator, Air Force Research Laboratory at 937-656-4223 or william.hoogsteden@wpafb.af.mil; *or Christopher W. Geib, Co-Principal Investigator, Science Applications International Corporation, at 937-431-4332 or* geibc@saic.com.

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