UV-Curable Aerospace Primer and Topcoat

By Mark Bowman

Aerospace coatings encounter a variety of challenging environments. The exterior aerospace coating must maintain its flexibility and adhesion over a temperature range of -65°F to 350°F. High in the stratosphere, the coatings experience harsh UV radiation and on the ground they must resist the inevitable exposure to hydraulic and lubricating fluids, and jet fuel. The coatings must protect the high-strength aluminum alloys used in aerospace which are susceptible to corrosion.

Exterior primers are usually epoxy resins and commonly contain strontium chromate to help control corrosion. The topcoats are usually solvent-borne 2K urethanes cured at ambient temperatures with dry-to-fly times of 6-72 hours. The primers require several hours of cure before application of a topcoat. The humidity and ambient temperature strongly affect the curing of aerospace primers and topcoats.

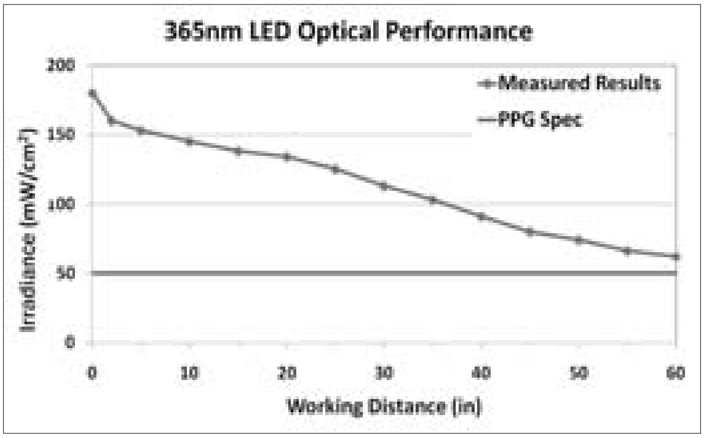
PPG Industries recently completed a project with the U.S. Air Force to develop prototype UV-cured aerospace coatings to overcome the long cure times encountered with aerospace coatings. Additionally, it was hoped that UV-cure coating technology would enable volatile organic compounds (VOCs) to be lowered and avoid the use of isocyanates.

Expected Benefits of UV Cure

- Very fast cure
- No "dry-to-touch," "dry-to-tape," "dry-to-fly" restrictions
- Cure independent of temperature and humidity

Figure 1

UV-LED Lamp and 365 nm LED Optical Performance chart



- Lower VOCs
- Isocyanate-free
- Longer pot life

UV radiation exposure from high-irradiance sources or from low-irradiance sources for long durations or repeated exposures is a health and safety concern when handling portable UV devices. Therefore, to reduce the risk of injury to users, the decision was made not to use light sources that emit in the UV-B and/or UV-C bands, which are higher energy and more damaging than UV-A.

It is difficult at this point to picture a practical way to use UV lamps to cure coatings over an entire plane. At one square foot per minute, it would take days to cover the entire surface of an aircraft. So, it was decided to first focus on the use of UV-cure aerospace coatings for small area repair. This would be for spot repair using a portable UV-A lamp.

Rapid Field Repair

- Spot repairs (12” x 12” or smaller)
- Portable, durable UV-A lamp
- Rapid cure, one hour or less
- Hand-spray application
- Ambient cure conditions
- Avoid exposure to isocyanates, UV-B, UV-C

Figure 2

Fluid resistance tests on 3-layered coating systems on aluminum (2024-T3)

Metal Treatment / Primer	All topped with a grey UV topcoat				
	Sanded	Silane-Zirconium Sol-Gel	TCP (Cr III)	Alodine 1200S	De-Ox
UV Urethane Primer (for Cr)	Failed #2	Failed #1,#2,#3,#4	Failed #1,#3,#5	Pass	Failed #2
Commercial Chromated Primer	Pass	Pass	Failed #1,#2,#3,#4	Failed #1,#2,#3,#4,#5	Not Tested
Commercial Chrome Free Primer I	Failed #2	Pass	Failed #1,#2	Failed #2,#3,#4,#5	Failed #1,#2
Commercial Chrome Free Primer II	Pass	Failed #2	Failed #1,#2,#4,#5	Failed #1,#2,#4	Not Tested
UV Epoxy Primer (for Cr)	Failed #1,#2	Failed #1,#2,#3,#4	Failed #1,#2,#3,#4	Failed #1,#2,#4	Failed #2

Test #1- Dry adhesion, ASTM D-3359
Test #2- Water Immersion [49/C for 96 hrs] ASTM D 3359
Test #3- Hydraulic Fluid Royco 782 [49/C for 24 hrs] ASTM D 3359
Test #4- Hydraulic Fluid Royco 756 [49/C for 24 hrs] ASTM D 3359
Test #5- Mobil Jet Oil 2 [121/C for 24 hrs] ASTM D 3359

Figure 3

UV topcoat over various primers

System ID	Pretreatment	Primer	Topcoat
System A	None	Chromated Primer	UV Topcoat
System B	None	Chrome Free Primer A	UV Topcoat
System C	Zr-Si	Chrome Free Primer B	UV Topcoat
System D	Alodine 1200S	UV Primer	UV Topcoat
Control	None	Chromated primer	APC Grey Topcoat

Test	Chromated Primer (System A)	Chrome Free (System B)	Chrome Free (System C)	Chrome Pretreatment (System D)	Control
JP8 Jet Fuel -- [Ambient for 7 Days][A]	Fail	Fail	Pass	Pass	Fail
Skydrol – [30 Days][A]	Fail	Fail	Pass	Pass	Pass
- 43°C Cylindrical Bend[B]	Pass	Pass	Pass	Pass	Pass
Salt Spray – [1000 hours][C]	Pass	Fail	Fail	Pass	Pass

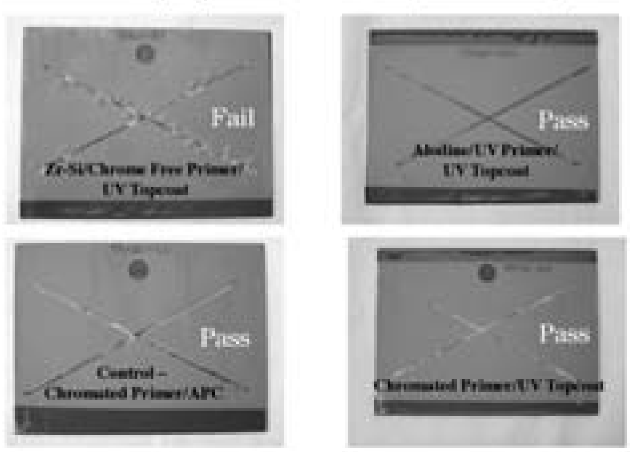
[A] Crosshatch adhesion ASTM D-3359-08 as per MIL-PRF-32239
[B] 4-Inch Cylindrical Mandrel Bend
[C] ASTM B117, as per MIL-PRF-32239

- Minimize use of heavy metals such as chromium or cadmium

For field repair use, a UV lamp should be portable, robust and safe (UV-A only). Additionally, the lamp should emit a parallel beam of UV-A light and be capable of rapidly curing a coating from five feet away. To do so, a 365 nm, UV-LED lamp from Clearstone Technologies was chosen with an irradiance ≥50 mW/cm^2 from a distance of five feet. The photo shows the UV-LED lamp curing a panel from several feet away (See Figure 1).

Figure 4

Salt spray—1,000 hours (Al 2024-T3)



In three significant ways, the use of a UV-LED lamp impacts the development of a UV coating system. First, the absence of UV-C and UV-B make overcoming the effect of oxygen inhibition on surface cure even more challenging. Typically, UV-B and UV-C generate large numbers of free radicals at coating surfaces to overcome the rate at which atmospheric oxygen inhibits the propagation of cure. Second, since UV-LED lamps do not emit infrared radiation, the coating will need to rapidly cure at near ambient temperatures during UV irradiation. Third, since UV-LED lamps emit a fairly narrow spectral band of UV light, one is limited in the choice of photoinitiators that can be used.

Additionally, curing primers and colored topcoats is complicated by the presence of pigments such as carbon black and titanium dioxide that strongly absorb and/or scatter UV-A light.

Figure 5

UV primer

Application	Test Method	Test Condition	Objective	Comment
Condition in Container	Fed-Std-141D Method 3011.3		Homogeneous liquids free from skins, lumps and gelled or coarse particles.	Passes
VOC	ASTM D5403			3.02 lbs/gal
Pigment			0 wt.% Lead 0 wt.% Chromium 0 wt.% Cadmium	0 wt.% Lead 0 wt.% Chromium 0 wt.% Cadmium
Viscosity	ASTM D1200	Ambient		Successfully sprayed with HVLP many times
Pot Life	ASTM D1200	Number of hours after mixing under ambient conditions; closed container	24 hour pot life	Has been successfully sprayed after one week
Surface Appearance	Visually inspect	No grit, crater, blister, sagging, running, orange peel.		Passes
Dry-to-Topcoat	Test after UV lamp exposure			Coating is dry and not tacky
Wet Tape Adhesion	FED STD 141D Method 6301.3	Fully cured coatings at ambient conditions after 24 hours soak in ambient water	Rating of 4A or better	Rated at 5A
Chemical Resistance	ASTM D5402 (using 25 double rubs)	Fully cured coatings	No change when exposed to MEK	Passes

Figure 6

UV topcoat

Application	Test Method	Test Condition	Objective	Comment
Condition in Container	Fed-Std-141D Method 3011.3		Homogeneous liquids free from skins, lumps and gelled or coarse particles.	Passes
VOC	ASTM D5403		Zero VOC with no exempt solvents utilized	**Zero VOC, 100% solids**
Pigment			0 wt.% Lead, 0 wt.% Chromium	0 wt.% Lead, 0 wt.% Chromium
Viscosity	ASTM D1200	Ambient	18-35 seconds on #4 Ford cup	23 seconds on #4 Ford cup
Pot Life	ASTM D1200	Number of hours after mixing under ambient conditions; closed container	24 hours pot life	>72 hours, has been successfully sprayed after 3 days
Color	ASTM D2244	Ambient	ΔE <1 from Standard	Close to standard.
Opacity	ASTM 2805	Ambient	Contrast ratio >.99	Contrast ratio >.99
Dry-to-Fly	Test after UV lamp exposure			Coating is dry and not tacky
Wet Tape Adhesion	FED STD 141D Method 6301.3	Fully cured coatings at ambient conditions after 24 hours soak in ambient water	Rating of 4A or better	Rated at 5A

Coating the exterior aluminum surfaces of aircraft typically consists of a treatment of the aluminum surface followed by application of a primer and then a topcoat. Various coating stacks with five different aluminum treatments and five different primers were topped by a gray UV topcoat and screened with adhesion and fluid resistance tests. Any coating stack that passed all five tests is indicated with a pass in Figure 2.

The four most promising coating stacks that passed the fluid resistance tests were tested further. The coating stack with the UV primer and UV topcoat passed 1,000-hour salt spray , jet fuel, Skydrol and cryogenic bend tests (See Figures 3 and 4).

In summary, a highly pigmented, zero-VOC, 100% solids, UV-aerospace topcoat was developed that can be rapidly cured with a portable UV-A lamp. A UV primer that is compatible with the UV topcoat was also developed. The coatings have sufficient crosslink density to pass fluid resistance tests while still maintaining flexibility and adhesion at very low temperatures. Due to the practical limitations of applying UV light over the entire surface of an aircraft, the first commercial applications of UV aerospace coatings may be for small area repair.

Additional development work is needed before these UV cure coatings will pass all the requirements of the military or commercial aviation markets. Radiation-cure aerospace coatings show potential to reduce cure times and deliver isocyanate-free formulations with low- or zero-VOC content (See Figures 5 and 6).

Acknowledgements

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—Mark Bowman
is a research associate at PPG
in Allison Park, Penn.