Development of UV-A Curable Coatings for Military Aircraft Topcoats

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Abstract

UV-A curable coatings are investigated as an alternative to traditional two-component polyurethane aerospace topcoats due to their rapid cure rates, low VOC, low VHAPs and high performance properties. The development of a formulation that approaches military specifications for aircraft topcoats will be described in this paper, and this paper will also review the results of recent field trials of a UV-A curable stencil coating after 600 service hours on a C-130 aircraft.

Introduction and Background

Developments in UV-A light sources and photoinitiators has allowed for significant progress of site applied markets such as automotive refinish[1] and flooring. Footprint limitations are still an issue in the automotive refinish markets (Figure 1) and are expected to be the bottleneck in the application of UV-A curable coatings to large surfaces.

Figure 1 - Curing of stencil coating on C-130

Recently, there has been a government initiative to develop UV curable aerospace coatings in an effort to decrease the return to service time while still maintaining high performance properties.[2] Conventional coatings in this market are based upon two component polyurethanes that require 72 hours to fully develop their physical properties. The development of UV curable aerospace coatings would significantly decrease refurbishing time.

Property	MIL-PRF-85285 Specification	Stencil Coating
Flexibility – GE Impact Test	40%	2%
Chemical Resistance	Jet fuel, hydraulic fluid, or oil – softening no more than 2 pencils	Pass
Crosshatch / Wet tape Adhesion	>4A	Pass
Gloss	85° ≤ 9 60° < 5	85° = 39
Accelerated Weathering	ΔE < 1 after 500 hrs	ΔE = 0.9 at 500 hrs

Table 1 - Salient properties of camouflage coatings that conform to MIL-PRF-85285 and properties of stencil coating

The physical properties of aerospace topcoats for military applications are currently defined by military specification 85285 (MIL-PRF-85285), and the critical properties in this specification are outlined in Table 1. Coatings that qualify to these standards are based on high performance industrial resins that yield a good balance of physical properties including chemical resistance, flexibility, adhesion, and weathering. Since the cost of the coating is only a fraction of the overall painting cost, high quality raw materials are used in aerospace coatings resulting in these coatings being some of the highest performance systems found in the market.[2]

Coating	ΔE 7 months	ΔE 14 months	Δ 60° Gloss 7 months	Δ 60° Gloss 14 months
Black UV Stencil	1.56	0.87	(-5.2)	(-4.8)
2K Gray Fluorourethane	0.57	1.23	(-0.13)	0.00

Table 2 - Weathering properties of coatings on C-130

UV curable coating formulations were developed at Bayer MaterialScience-Deft and evaluated by the Air Force's Coatings Technology Integration Office in 2007.[3] These coatings displayed promising physical properties with room for improvement in the areas of flexibility and gloss (Table 1). This formulation was used as stencil coatings on a C-130 and F-16, and has been periodically evaluated for color change and gloss retention. After 600 flying hours (14 months), the stencil coatings on the C130 had ΔE values comparable to the conventional polyurethane fluoropolymer (Table 2).

UV curable coatings based on oligomeric chemistry are typically hard and chemically resistant, which imparts deficiencies in flexibility. Furthermore, gloss reduction can also be challenging with this type of chemistry due to the lack of shrinkage of the polymer upon solvent evaporation. The stencil coating was reformulated to address the aforementioned performance issues and approach military aerospace specifications.

Coating Formulations and Results

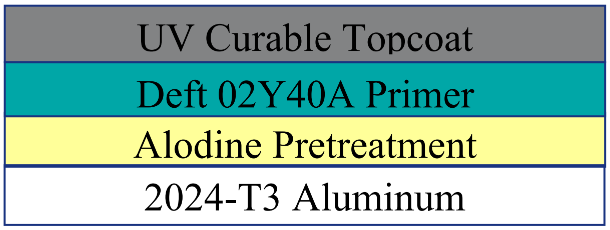

Figure 2 – Coating stackups diagram

Coatings were applied at two dry mills film thickness and UV cured for eight minutes at eight inches standoff distance using a H&S Autoshot 400W light unless otherwise specified. All coatings were evaluated on freshly primed, Alodine treated 2024-T3 aluminum panels (Figure 2) with the exception of flexibility that was tested on 2024-T0 aluminum panels. Evaluations were performed immediately after curing using the guidelines provided in MIL-PRF-85285.

Resin / Reactive Diluent	GE Flexibility (%)	MEK Double Rubs	Average Acrylate Functionality	Pencil Hardness
Resin 1 (20% HDDA)	<2	>100	3.8	2H
Resin 2	20	>100	3.2	HB
Resin 3	60	>100	2	4B
Soft Reactive Diluent	60	39	1	<6B

Table 3 - Stencil coating properties made with different resins

Typically, UV curable coatings lack flexibility and give superior chemical resistance due to their high crosslink density. Aerospace coatings require a compromise of both chemical resistance and flexibility while maintaining hardness. These properties are primarily dictated by the filler concentrations and the resin(s) functionality / glass transition temperature. Three urethane acrylate resins and a reactive diluent were evaluated for their flexibility in the stencil formulation by preparing the formulation using only one resin. The results are shown in Table 3. The data shows an inversely proportional relationship between average acrylate functionality and flexibility, as expected. Both the monofunctional reactive diluent and difunctional resin both show improved flexibility although at the expense of hardness. This data indicates that a mixture of hard and soft resins along with reactive diluents is required to get the balance of flexibility, hardness, and chemical resistance required to meet MIL-PRF-85285.

Curing Conditions	60° Gloss	85° Gloss
Fusion Full Spectrum Light	47	81
H & S UV-A Metal Halide Light	3	26
Quantum UV-A Fluorescent Light	4	27
H&S UV-A Light + 10% Reactive Diluent	3	3

Table 4 - Effect of curing conditions on gloss

Low gloss in UV coatings is typically accomplished by adding micron-sized silica or crosslinked polymer particles to form a rough surface that scatters light. The formulation of very low gloss coatings that meet MIL-PRF-85285 standards requires a large concentration of flatteners, which is detrimental to the coatings flexibility. Alternative strategies were explored to maintain a balance of physical and aesthetic properties. Table 4 shows the effect of curing conditions on gloss for the same formulation. Higher gloss values are obtained when the full spectrum Fusion UV light is used compared to when UV-A lights are used to cure the coatings.

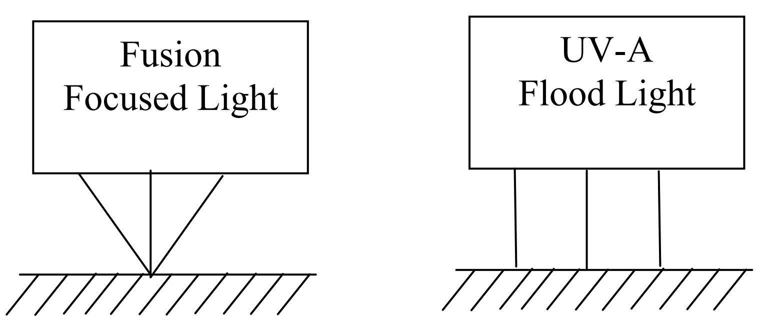

Figure 3 – Focused versus flood UV lights

Fusion UV lamps have higher intensity and are focused lights as compared to the flood style UV-A lights that emit lower intensity light. The focused light and higher intensities allows the coatings to cure more uniformly since oxygen inhibition is overcome at a much faster rate because the consumption of oxygen is faster than oxygen diffusion. On the other hand, the lower intensity UV-A light cures the coating from the bottom up since the surface has a high oxygen concentration that inhibits the free radical reaction. Eventually, the photoinitiators reduce the oxygen concentration to a level that allows polymerization to occur at the surface.[4] This explanation is further supported by the observation that lower gloss values are obtained when a higher monomer concentration is present in the formulation. An increased concentration of acrylate groups produces increased inhibition of polymerization at the surface causing the cure of the surface to occur well after the bottom layers have polymerized.

Gloss reduction using full spectrum lights can be obtained by curing with a 172 nm excimer lamp followed by a mercury arc lamp.[5,6] Reduced penetration by the 172 nm lamp limits the crosslinking to near the surface producing wrinkled structures. Through cure is obtained with the mercury arc lamps, yielding a matte finish. The oxygen inhibition method of reducing gloss works in a similar manner, curing the bottom layers first then the surface, which also produces a wrinkling effect.

Test	MIL-PRF-85285 Specification	BMS UV Topcoat
GE Impact Test	40%	40%
Chemical Resistance	Jet fuel, hydraulic fluid, or oil – no softening	Softened with jet fuel
Crosshatch / Wet Tape Adhesion	>4A	Pass
Gloss	85° ≤ 9 60° < 5	85° = 10
Accelerated Weathering	ΔE < 1 after 2000 hrs.	ΔE = 0.6 at 500 hrs.

Table 5 – Critical properties of UV topcoat – preliminary evaluations

Improved accelerated weathering has been a focus of the military over the past decade and these properties are typically ameliorated via the introduction of UV-A absorbers and hindered amine light stabilizers (HALS). Unfortunately, these additives can interfere with the absorbance of UV-A light by the photoinitiators resulting in partially crosslinked coatings. UV-A curable formulations can permit a low level of HALS additives, however they are especially sensitive to the presence of UV-A absorbers. Raw material selection is especially critical to obtain good weathering properties since the traditional weathering additives can not be used at the recommended level.

Conclusions

Overall the performance of UV-A curable coatings has been shown to rival that of conventional polyurethane coatings. Formulations that yield a balance of chemical resistance, flexibility, and hardness were obtained using a combination of hard and soft urethane oligomers and reactive diluents. Gloss reduction of these coatings was achieved by a combination of flatteners and oxygen inhibition, leading to flexible, low gloss formulations. Weathering of UV-A aerospace systems is another critical property that can be chiefly controlled by raw material selection. The stencil coating reformulation efforts have resulted in significant progress towards formulating a UV-A coating that meets MIL-PRF-85285, and these coatings are currently being evaluated for their performance against the full specification.

Acknowledgements

Bayer MaterialScience would like to acknowledge Concurrent Technologies Corporation and Environmental Security Technology Certification Program for partially funding this research.

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