Progress in the Development of UV Curable Topcoats for Military Aircraft

S. Sarmah, A. Tortorello and T. Bishop
DSM Desotech
Elgin, Illinois, USA

Abstract

Two prototype UV curable coatings, a gloss white and a camouflage matte gray, were evaluated according to performance standards for military topcoats. The coatings were benchmarked against two conventional USAF topcoats representing typical performance properties. The two coatings were evaluated especially for hardness, adhesion, cold temperature flexibility, fluid resistance, color, gloss and accelerated weathering. Based on the evaluations, further developmental work was undertaken to improve the performance of the gloss white coating. This paper will summarize the performance properties of each prototype coating. Strengths and properties which need improvement relative to military specifications will be discussed.

Background

The United States Air Force (USAF) had contracted Concurrent Technologies Corporation (CTC) to conduct a project to demonstrate if commercially available UV-curable coatings can meet performance, application, and environmental requirements of selected military aircraft applications. UV-curable coatings have the potential to reduce the negative environmental impact associated with current solvent-borne coatings operations while improving production schedule and cost. CTC had solicited participation from a number of UV curable coatings suppliers, including DSM Desotech, to submit samples of commercial coatings for testing. The first phase was testing of coated panels submitted for a preliminary round of evaluations. The second phase included submission of liquid coatings for a more complete round of testing by CTC. Coating samples from DSM Desotech showed strong promise in these preliminary testing phases which included UV-curable topcoats from several vendors. Key strengths as well as needed improvements were identified in a summary report by CTC. Additional developmental work was carried out by DSM Desotech with support from CTC targeting further improvements in coating performance for this aerospace application.

Initially DSM Desotech had submitted a camouflage (camo) matte gray (DD-A) and a gloss white (DD-B) coating for testing to CTC. Based on initial evaluations, CTC requested follow-up development of only the gloss white topcoat since the submission by Desotech was the best of all the submitted gloss white candidates. This paper summarizes the findings of the preliminary rounds of testing as well as the follow-up development effort to achieve the needed improvements.

Summary of Initial Testing

The two DSM Desotech candidates, DD-A camo gray and DD-B gloss white, were tested by CTC along with two conventional 2K urethane control coatings, Deft 03-GY-312 camo gray (representing desired minimum performance) and Deft 99-GY-001 camo gray (representing desired optimum performance). The coatings were applied on aluminum test panels which were already primed with MIL-PRF-23377 standard solvent-borne primer. The coated panels were tested according to USAF and Navy performance standards for topcoats by following the Joint Test Protocol (JTP) prepared by CTC in conjunction with Air Force Research laboratory. The test results were evaluated with emphasis on areas of improvement needed to meet the performance requirements per military specification MIL-PRF-85285D.

A. Color and Gloss

Fed-STD-595C requires that color matches be made against approved individual color chips obtained from General Services Administration (GSA). However, in this case CIELAB values obtained, based on ASTM D 2244, from DSM Desotech coatings and relevant color chips were compared, as shown in Table 1. The two coatings were compared to approved color chips 17925 and 17860 (both white) and 36173 (gray). Table 2 shows the gloss values (ASTM D 523) for the two coatings as well as those for the approved color chips. The very low gloss values for the DD-A camo gray are very impressive since low gloss is quite difficult to achieve in 100% solid UV curable coating.

Table 1. Measured CIELAB Values

Coating	Color of System				Fed Std 595C Color to match				ΔE
	Color	L*	a*	b*	Color	L*	a*	b*	
DD-B	Gloss White	78.80	-5.24	16.44	17925	93.24	-0.41	5.16	19.0
					17860	91.38	-3.15	3.92	17.9
DD-A	Camo Gray	47.44	-1.06	-3.26	36173	49.96	-1.59	-4.35	2.8

Table 2. Gloss Readings of Coatings and Color Chips

Coating	Color	Gloss at 60°	Gloss at 85°
DD-B	Gloss White	71.2	Not recorded
DD-A	Camo Gray	2.6	4.5
17925	Gloss White	90 (minimum)	No requirement
17860	Gloss White	90 (minimum)	No requirement
36173	Camo Gray	5 (maximum)	9 (maximum)

B. Adhesion and Hardness

Both coatings passed the wet tape adhesion test (ASTM D 3359, Method A) but DD-B gloss white marginally failed the cross hatch adhesion test. Even though there is no specific requirement for pencil hardness, DD-A was slightly below the desired B, HB, or F range and required improvement in hardness.

C. Flexibility

Both coatings passed the low temperature flexibility test (ASTM D 522) and all coatings, including the controls Deft 03-GY-321 and Deft 99-GY-001, failed the GE impact test (ASTM D 6905). It should be noted that these coatings were applied on already primed panels which might have resulted in the unexpected failure of the control coatings. However, improvement in flexibility is still needed for DSM Desotech coatings.

D. Fluid Resistance

The coated panels were exposed to water, lubricating oil, JP-8 jet fuel, hydraulic fluid, and Skydrol LD-4, a hydraulic fluid based on tributyl phosphate, for various durations. The two DSM Desotech coatings exhibited good overall fluid resistance by passing the minimum fluid resistance standards per MIL-PRF-85285D even though some improvements were needed per the optimum requirements of MIL-PRF-32239. Table 4 shows the results after 24 hour immersion in lube oil at 250 ± 5°F. The two coatings met the minimum requirements for pencil hardness (ASTM D 3363), adhesion, blistering. However, the gloss white DD-B did not meet the optimum color change requirement of ΔE less than 3.

Table 4. 24 Hour Lube Oil Resistance @ 250 ± 5°F

Coating	Color	Initial Hardness	Final Hardness	Initial Wet Tape Adhesion	Final Wet Tape Adhesion	Blistering	ΔE Color Change
Deft 03-GY-321 (control)	Camo Gray	HB	HB (pass)	4B	4B	None (pass)	0.7 (pass)
Deft 99-GY-001 (control)	Camo Gray	HB	HB (pass)	4B	4B	None (pass)	0.9 (pass)
DD-B	Gloss White	HB	HB	3B	5B	None (pass)	7.3 (fail)
DD-A	Camo Gray	2B	4B	4B	5B	None (pass)	1.8 (pass)

The coatings also passed the 24 hour and 7 day immersion in hydraulic fluid without adhesion loss, blistering or loss of pencil hardness by more than two units. Again, DD-B exhibited greater color loss (ΔE = 7.7) after immersion for 7 days. Similar results were also observed after 7 day and 30 day immersion in jet fuel. This time DD-B showed a color change of ΔE = 3.9, slightly worse than the optimum acceptable loss of ΔE = 3.

Table 5 shows the results after 30 day immersion in Skydrol in relation to optimum performance requirements per MIL-PRF-32239. DD-A gray as well as the two control coatings suffered pencil hardness loss of more than 2 units, but DD-B did not. The two DSM Desotech coatings as well as one of the controls also exhibited blisters, but all four coatings did not show loss of adhesion or color change of greater than ΔE = 3.

Table 5. 30 Day Skydrol Resistance

Coating	Color	Hardness Softening Amount	Blistering	Initial Wet Tape Adhesion	Final Wet Tape Adhesion	ΔE Color Change
Deft 03-GY-321 (control)	Camo Gray	5 pencils (fail)	None (pass)	4B	4B (pass)	0.8 (pass)
Deft 99-GY-001 (control)	Camo Gray	5 pencils (fail)	Blisters (fail)	4B	4B (pass)	0.3 (pass)
DD-B	Gloss White	2 pencil (pass)	Blisters (fail)	3B	4B (pass)	1.4 (pass)
DD-A	Camo Gray	4 pencils (fail)	Blisters (fail)	4B	4B (pass)	0.3 (pass)

Table 6 presents the performance of the coatings after 30 day immersion in deionized water. Relative to optimum performance requirements, both DSM Desotech coatings displayed unacceptable loss in pencil hardness and adhesion; DD-B also exhibited blistering and color change greater than 3 ΔE.

Table 6. 30 Day Deionized Water Resistance

Coating	Color	Hardness Softening Amount	Blistering	Initial Wet Tape Adhesion	Final Wet Tape Adhesion	ΔE Color Change
Deft 03-GY-321 (control)	Camo Gray	0 (pass)	None (pass)	4B	4B (pass)	0.3 (pass)
Deft 99-GY-001 (control)	Camo Gray	0 (pass)	None (pass)	4B	4B (pass)	0.4 (pass)
DD-B	Gloss White	4 pencil (fail)	Blisters (fail)	3B	2B (fail)	4.4 (fail)
DD-A	Camo Gray	>4 pencils (fail)	None (pass)	4B	2B (fail)	0.9 (pass)

E. Heat Resistance

The results of heat resistance testing at 250°F (1 hour) and 350°F (4 hours) are shown in Table 7. Both coatings did not show loss of adhesion; however color change was worse than the optimum requirement of ΔE = 3 for DD-A after exposure at 350°F and for DD-B after exposure at both temperatures. DD-B also did not meet the low temperature flexibility requirement after exposure at 350°F.

Table 7. Heat Resistance of Coatings

Coating	Color	ΔE Color Change at 1hr 250°F	ΔE Color Change at 4hr 350°F	Low Temp Flex at 4hr 350°F	Initial Adhesion	Adhesion at 4hr 350°F
Deft 03-GY-321 (control)	Camo Gray	0.0 (pass)	0.4 (pass)	None (pass)	4B	4B (pass)
Deft 99-GY-001 (control)	Camo Gray	0.1 (pass)	0.6 (pass)	None (pass)	4B	4B (pass)
DD-B	Gloss White	4.5 (fail)	15.1 (fail)	Cracking (fail)	3B	4B (pass)
DD-A	Camo Gray	0.9 (pass)	4.3 (fail)	None (pass)	4B	5B (pass)

F. Accelerated Weathering

Prolonged UV exposure under a Xenon arc was used for accelerated weathering (ASTM G 155) of the coatings. MIL-PRF-85285D requires that, as minimum performance requirements after 500 hours of Xenon arc accelerated weathering, the coatings should not suffer color loss of more than one ΔE, gloss change of more than one while meeting low temperature flexibility and GE impact requirements. MIL-PRF-32239 requires the same criteria to be met after 3000 hours of weathering for optimum performance. Table 8 shows the performance of the coatings after 500 hours of weathering. The DSM Desotech coatings passed or almost met the minimum requirements for color change but did not meet the gloss retention requirements. DD-B also failed to meet the low temperature flexibility and GE impact requirements. Table 9 shows weathering results after 3000 hours of UV exposure. Unacceptable gloss retention is still a problem for both DD-A and DD-B while color change was marginal for DD-B. Both coatings also failed low temperature flexibility test. GE impact testing could not be performed on exposed DD-B due to severe degradation during 3000 hours of UV exposure.

Table 8. 500 Hour Accelerated Weathering

Coating	Color	ΔE Color Change at 500 hours	Initial Gloss	60º Gloss at 500 hours	Low Temp Flex at 500 hours	GE Impact at 500 hours
Deft 03-GY-321 (control)	Camo Gray	0.3 (pass)	1.4	1.3 (pass)	No cracking (pass)	5%
Deft 99-GY-001 (control)	Camo Gray	0.0 (pass)	1.3	1.2 (pass)	No cracking (pass)	5%
DD-B	Gloss White	1.7 (fail)	71.2 (fail)	63.9 (fail)	Cracking (fail)	1%
DD-A	Camo Gray	0.4 (pass)	2.6 (pass)	5.7 (fail)	No cracking (pass)	2%

Table 9. 3000 Hour Accelerated Weathering

Coating	Color	ΔE Color Change at 3000 hours	Initial Gloss	60º Gloss at 3000 hours	Low Temp Flex at 3000 hours	GE Impact at 3000 hours
Deft 03-GY-321 (control)	Camo Gray	1.7 (fail)	1.4 (pass)	1.3 (pass)	No cracking (pass)	5%
Deft 99-GY-001 (control)	Camo Gray	0.2 (pass)	1.3 (pass)	1.2 (pass)	No cracking (pass)	5%
DD-B	Gloss White	3.8 (fail)	72.8 (fail)	9.7 (fail)	Cracking (fail)	Coating destroyed
DD-A	Camo Gray	0.5 (pass)	2.4 (pass)	7.6 (fail)	Cracking (fail)	1%

G. Needed Improvement in Properties

Initial round of evaluations revealed that retention of color and gloss, particularly after extended fluid immersion and weathering, should be improved. These tests also identified improvements needed in low temperature flexibility, degradation during long duration weathering, and loss of hardness during immersion in water and Skydrol. The follow-up development would focus on achieving these improvements.

Further Development of Gloss White Coating

As mentioned before, DSM Desotech, with support from CTC pursued further technical effort to achieve the needed improvements only in gloss white topcoat. Necessary reformulation and testing were undertaken to assess if the improved coating formulations meet the minimum performance requirements per test standards in JTP. The first round of testing was conducted by CTC whereas testing during this follow-up development was conducted in the laboratories of DSM Desotech. The following were the key targets for the next round of development effort:

- Flexibility: exceed 10 in-lbs in Gardner reverse impact test
- Gloss: exceed 90 at 60° viewing angle
- Color: meet Fed-STD 595C requirements relative to color chip 17860
- Weathering: improve gloss retention after 1000 hours in QUV weathering machine
- Fluid resistance: reduce drop in pencil hardness after immersion in water and Skydrol
- Adhesion: maintain consistent 4/5 rating

The following sub-sections summarize the experimental aspects and results and analysis from the follow-up development stage.

A. Experimental

Primer Preparation and Application

A one-gallon kit of MilSpec PRF-23377J primer from Deft Coatings, Inc., designated 02-Y-040A was purchased. The kit consisted of a pigmented base (component A) and a clear catalyst (component B). Instructions in the technical data sheet included mixing the two components in a 3:1 volume ratio, applying the admixed primer to the substrate using suitable spray equipment, and allowing the primer to cure dry-to-topcoat for five hours maximum.

The admixture of the primer was allowed to stand for 30-60 minutes prior to application. Generally, the dry-to-topcoat instructions of allowing a 4-5 hour delay before topcoating was followed, but dry times of 24 hours and one week were also utilized. The primer was then spray applied using an HVLP gun to 2024-T3 aluminum panels treated with an alodine conversion coating. The alodine-treated panels were prepared by and received from CTC. Also tested were pre-primed panels received from CTC and reactivated according to the procedure recommended by CTC, i.e., light sanding with 320 grit sandpaper followed by a light wipe with MEK to remove any primer dust.

UV Curable Gloss White Topcoat Candidates

Two UV curable high gloss topcoat candidates meeting Fed-STD-595C color number 17860 were developed. The coatings were designated as DD-C and DD-D. The liquid viscosity of the two coatings can be compared to previously tested submission, DD-B, as a benchmark. Viscosity measurements were run on a Physica MC-10 viscometer at 25°C using the Z3 system and a shear rate of 50 sec^{-1}.

Table 10. Viscosity of Reformulated Liquid Coatings

	DD-B	DD-C	DD-D
Viscosity, mPa·s (25°C)	210	173	465

As a point of reference, viscosity effective for spray application is typically considered to be 25 seconds on a number 2 Zahn cup. This translates to about 125 mPa·s. However, it had been previously observed that it was possible to effectively spray coatings with viscosity up to about 500 mPa·s as an upper limit. In the case of coating DD-D, it may be possible to achieve more effective spray atomization by heating the coating to 30°C (86°F) or by adjusting the nozzle orifice and/or increasing the pressure at the spray gun in order to achieve a better finish.

The above coatings were spray applied at room temperature to suitable panels using a HVLP spray gun. The liquid films were cured in an air atmosphere with an H&S Auto Shot lamp set 10 inches above the horizontal substrate for a period of 10 minutes. It had been previously determined that a distance of 10 inches produced a UVA irradiance of about 67 $\text{mW}\cdot\text{cm}^{-2}$.

B. Results and Discussion

Crosshatch Adhesion

During the course of this work it was very difficult to obtain cured film adhesion that was adequate, consistent, and repeatable. It was postulated that this difficulty was due in large part to aged pre-primed panels, even when reactivated according to the recommended procedure. It was also learned that intercoat adhesion between a conventional primer and a UV topcoat was influenced by stress relaxation in the topcoat. This conclusion can be seen by comparing the crosshatch adhesion, measured according to ASTM D 3359, of the three subject coatings in Table 11. Stress relaxation is reflected by the number of days in which the topcoat is allowed to age before being tested.

Table 11. Crosshatch Adhesion after Various Durations of Topcoat Aging

Primer type	Old (reactivated)		Freshly Applied	
Topcoat aged, days	<1	>4	<1	>4
DD-B	0B	0-4B	0B	3-4B
DD-C	0B	0B	0-1B	4-5B
DD-D	NT	NT	0-1B	4-5B

As indicated, intercoat adhesion was at best poor for all coatings over old primer. However, when the primer was freshly applied, adhesion of the topcoat was poor initially but gradually improved as the topcoat aged. In fact, adhesion could be seen to incrementally improve on a daily basis. It is postulated that the combination of continued primer crosslinking (curing) coupled with stress relaxation in the topcoat accounts for the improved intercoat adhesion. The fact that this is an intercoat phenomenon can be seen by the fact that unprimed anodized aluminum panels used for flexibility testing demonstrated near perfect immediate adhesion without stress relaxation.

Adhesion was also tested after allowing the primer to dry between 1 and 7 days before topcoating. Up to about 24 hours, intercoat adhesion was acceptable but got worse beyond about 2 days. Given the above results, topcoating the primer within 24 hrs dry time is recommended because intercoat adhesion between the primer and topcoat degraded when the primer was allowed to dry much longer than 24 hrs. Furthermore, allowing the topcoat to age at least 4 days before testing is also recommended.

Gloss & QUV Weathering Resistance

Achieving both high gloss and gloss retention after weathering is a challenge for UV coatings in general and for this application in particular. High gloss UV cured pigmented coatings can be easily achieved by using curing lamps with full spectrum high UV irradiance and curing under an inert (nitrogen) atmosphere to prevent inhibition of cure by oxygen at the coating surface. Unfortunately, the H&S Auto Shot lamp produces a very low irradiance (as indicated above) in the UVA region only and blanketing with inert atmosphere to eliminate oxygen inhibition is not an option for this application. Similarly, retention of gloss is influenced by the completeness of surface cure.

Despite these challenges, the two high gloss white coatings developed during this work demonstrated good gloss and one (DD-D) has been found to weather rather well. Gloss was measured using a BYK Gardner micro-TRI-gloss meter. Accelerated weathering was tested with Q-Panel Co. Model QUV/SE Weather-o-Meter according to ASTM G-154 Cycle 4. Table 12 shows 60° viewing angle gloss both initially and after exposure in a QUV-A Weather-o-Meter for the indicated interval. Gloss retention upon weathering is critically influenced by the spectral distribution of the curing lamp and the UV light irradiance the lamp produces. This influence was demonstrated using coating DD-C cured with three different lamps: the H&S Auto Shot (UVA at 66 $mW \cdot cm^{-2}$), Fusion Systems H lamp (UVA, UVB, UVC at about 200 $mW \cdot cm^{-2}$), and Fusion Systems D lamp (UVA, UVB, UVC at about 700 $mW \cdot cm^{-2}$). Table 13 shows the 60° viewing angle gloss initially and after weather-o-meter exposure for the indicated time. The indicated time intervals in the Table 13 vary for each lamp type because exposure of the coatings was not begun all at the same time. Nevertheless, this experiment clearly indicated that use of full spectrum UV lamps for curing as opposed to low irradiance UVA lamps resulted in considerably improved weathering resistance.

Table 12. Change in 60° Gloss of UVA Cured Coatings during Weathering

Weathering Time	DD-B	DD-C	DD-D
Initial	69	90	92
117 hrs	31	-	-
125 hrs	-	50	-
190 hrs	-	-	82
322 hrs	-	-	80
358 hrs	-	46	-
476 hrs	-	-	79
617 hrs	17	-	-
672 hrs	-	47	-
960 hrs			73
1203 hrs			70

Table 13. 60° Gloss of DD-C Coating Cured with Different UV Lamps

60° Gloss of DD-C during QUV weathering		
H&S Auto Shot	**Fusion H Lamp**	**Fusion D Lamp**
90 (initial)	90 (initial)	87 (initial)
50 (125 hrs)	87 (263 hrs)	88 (334 hrs)
46 (358 hrs)	85 (597 hrs)	89 (466 hrs)
47 (672 hrs)	85 (729 hrs)	89 (620 hrs)
50 (804 hrs)	85 (883 hrs)	-
52 (958 hrs)	-	-
57 (1442 hrs)	79 (1442 hrs)	83 (1442 hrs)
42 (1685 hrs)	69 (1685 hrs)	74 (1685 hrs)

The degree of cure in the coatings after UV exposure by these three lamps was examined by estimating reacted acrylate unsaturation (RAU) using a Nicolet 4700 FT-IR spectrophotometer in the attenuated total reflection (ATR) mode. The residual acrylate functionality on the top surface of the cured coatings was compared to the initial amount of functionality in the corresponding liquid coatings. Table 14 shows the comparative degree of cure in the two coatings after exposure from different lamps. It is evident that degree of crosslinking after exposure to only UVA radiation is less than that after exposure to broad spectrum UV lamps of much higher irradiance. Low UVA irradiance along with oxygen inhibition resulted in less than desirable surface cure. Degree of crosslinking has a direct impact on retention of gloss and chemical resistance. Since UVA only radiation does not result in very

Table 14. Degree of Cure in Coatings after Exposure to Different UV Lamps

Coating	Curing Lamp & UV Irradiance	UV Exposure	% Reacted Acrylate Unsaturation
DD-C	H&S Autoshot, UVA, 67 $mW\cdot cm^{-2}$	10 min.	86.2
DD-C	Fusion 600W D lamp, UVA/UVB/UVC 700 $mW\cdot cm^{-2}$	1 J/cm^2, air	97.6
DD-C	Fusion 300W H lamp, UVA/UVB/UVC 200 $mW\cdot cm^{-2}$	1 J/cm^2, air	98.2
DD-D	H&S Autoshot, UVA, 67 $mW\cdot cm^{-2}$	10 min.	86.5

high degree of crosslinking even after prolonged exposure, it will be difficult to retain gloss at the high expected level in the long term or after exposure to fluids.

Color

Development of a high gloss white matching Fed-STD-595C color number 17860 can be determined by measuring the CIELAB values. Table 15 shows these values for the subject coatings as recorded on a Macbeth Color-Eye colorimeter running Color iControl software. The values compare with those for a color chip of 17860 purchased from GSA and DD-B as a benchmark.

Table 15. CIELAB values for New Coatings

Coating	L*	a*	b*	ΔE
17860	91.63	-1.64	4.49	0
DD-B	83.71	-4.28	12.03	11.25
DD-C	88.51	-1.95	1.47	4.35
DD-D	89.01	-2.34	3.97	2.76

Both newly developed coatings are found to be better color matches to the 595C color standard than the previously tested DD-B. Change in color values after exposure in the QUV weather-o-meter is shown Table 16. The two new coatings are seen to better maintain their original L*, a*, and b* values than is the benchmark coating DD-B.

Table 16. Coating Color Change during QUV Weathering

Coating (weathering hours)	ΔL*	Δa*	Δb*	ΔE
DD-B (617 hrs)	-2.87	3.45	-1.11	4.62
DD-C (958 hrs)	-1.16	0.30	1.02	1.57
DD-D (190 hrs)				1.04
DD-D (322 hrs)				1.44
DD-D (476 hrs)	-0.43	0.66	-1.52	1.71
DD-D (960 hrs)				2.35
DD-D (1203 hrs)				2.40

Pencil Hardness and Fluid Resistance

Fluid resistance of a coating candidate was measured in terms of pencil hardness after immersion in the subject fluid for a predetermined time. Pencil hardness was measured according to ASTM D3363 using mechanical pencils and no sled. Depending upon the type of fluid, the change in hardness from the originally recorded pencil rating was used as the acceptance criteria. Limited fluid resistance testing was conducted on the two candidates following immersion in deionized water (14 days) and Skydrol LD-4 (21 days). The appearance of cured film blistering after immersion was also used as an acceptance criterion. Table 17 shows the water and Skydrol resistance for coatings DD-C and DD-D. The fluid resistance values for DD-B were obtained from previous testing by CTC as shown in Tables 5 and 6. Both coating candidates experienced gloss reduction after immersion in water but did not exhibit blistering. The same was true for immersion in Skydrol however, both coatings suffered severe hardness reduction in this fluid.

Table 17. Water and Skydrol Resistance of New Coatings

Fluid (Duration)	DD-B	DD-C	DD-D
Initial	HB	B	B
Deionized water (14 days)	<4B (blisters)	B (no blisters)	2B (no blisters)
Skydrol LD-4 (21 days)	2B (blisters)	<4B (no blisters)	<4B (no blisters)

Flexibility

Because DSM Desotech has the capability to design and synthesize unique oligomers, the potential to dramatically influence the balance between chemical resistance (which usually causes brittleness) and flexibility exists. Table 18 presents the influence of reactive functional groups present in the oligomer on cured film flexibility. Flexibility was recorded using a Gardner impact tester following ASTM D 6905 with a 2 pound weight. The coatings were applied to anodized 2024-0 aluminum that had no MilSpec primer coating. Coating DD-C was seen to be more flexible than either DD-B or DD-D. Both DD-C and DD-D are based on the same oligomer whereas DD-B is based on an oligomer having higher acrylate functionality. However, coating DD-D was formulated with different monomers in order to exhibit faster cure at low irradiance. Apparently, the effect of monomers causing good cure speed has caused a decrease in film flexibility.

Table 18. Results of Gardner Impact Testing

Coating	**Direct impact (in·lbs)**	**Reverse impact (in·lbs)**
DD-B	10	<4
DD-C	20	6
DD-D	6	<4

Conclusions

Two prototype high gloss UV curable white coatings matching Fed-Std-595C color 17860 were developed. Both coatings represented an overall dramatic improvement over previous prototypes and met most of the requirements for military aerospace topcoats. A lower degree of surface cure, after UVA irradiance at low intensity, due to oxygen inhibition has been postulated to result in lower gloss retention after weathering compared to cure under broadband UV exposure with high irradiance. Earlier prototypes had shown good overall fluid resistance; however improvement was needed in resistance to water and Skydrol. Following further development, gloss white coatings were capable of passing water soak resistance whereas both still failed immersion in Skydrol LD-4. Further improvement is also needed in impact flexibility.

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