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FLEXIBLE PRIMER EVALUATION

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ABSTRACT

A flexible primer was tested with four topcoats for adhesion, flexibility, salt spray resistance, and the effect on the UV resistance of the topcoats. Stack-ups with the flexible primer were generally more flexible than analogous stack-ups made with a MIL-PRF-23377 control, and the flexible primer did not adversely affect salt spray resistance or weatherability. Dry-to-recoat times were good. Coatings stack-ups containing the flexible primer, however, were very soft with a pencil hardness <6B. It was also noted that a number of samples prepared under low humidity conditions had poor wet adhesion. This information has been shared with coating developer and they are working to improve the hardness and wet adhesion of the coating.

Keywords: flexible, primer, corrosion, barrier

INTRODUCTION

Primers are usually more brittle than the topcoats that cover them. As a result, when cracks form in the topcoat they tend to propagate from the topcoat into the primer. When the primer cracks, it exposes the substrate and leads to corrosion. This problem was less severe when the Air Force used a flexible polysulfide primer. Because the primer was more elastic than the topcoats that covered it, the primer often protected a substrate when the topcoat cracked. This was especially useful around fasteners where the topcoat cracks due to pressurization cycles. When the Air Force discontinued use of the polysulfide coating due to volatile organic compound (VOC) considerations, corrosion resistance was adversely affected.

Flexible, low VOC primers previously tested by the Air Force suffered from two defects: 1) The dry-to-topcoat time was too long; and 2) The primers had a detrimental effect on the weather resistance of the topcoat. A major objective of this trial was to determine if a flexible candidate primer also suffered from these two drawbacks.

EXPERIMENTAL PROCEDURE

Unless otherwise specified, panel preparation, priming, curing and testing were conducted under ambient conditions (approximately 77°F and 50% relative humidity).

Substrate Type and Pretreatment Protocol

Coatings were applied to aluminum alloy 2024. Panels used in flexibility testing (GE Impact Resistance and Low Temperature Bend) were 0.020" thick untempered aluminum while the panels used for all other testing (dry-to-recoat, wet tape adhesion, salt spray resistance, and xenon arc resistance) were 0.032" thick T3 temper. Panels were pretreated with chromate conversion coating or non-chrome alternative as described in **Table 1**.

Table 1: Summary of Primer Conditions and Test.

Pretreatment	Primer	Primer Cure Conditions	Topcoat	Dry to Recoat*	Wet Tape Adhesion	GE Impact	Low Temp Mandrel	Salt Spray	Xenon Arc
Chromate Conversion Coating	**MIL-PRF-23377 (control)**	77°F/50%RH	Mfg 1 – MIL-PRF-85285	√	√	√	√	√	√
			Mfg 1 - APC	√	√	√	√	√	√
			Mfg 2 - APC	√	√	√	√	√	√
			Mfg 3 - APC	√	√	√	√	√	√
	Candidate Flexible Primer	60°F/30%RH	Mfg 1 – MIL-PRF-85285	√	√				
			Mfg 1 - APC	√	√				
			Mfg 2 - APC	√	√				
			Mfg 3 - APC	√	√				
		60°F/90%RH	Mfg 1 – MIL-PRF-85285	√	√				

			Mfg 1 - APC	√	√				
			Mfg 2 - APC	√	√				
			Mfg 3 - APC	√	√				
		90°F/30%RH	Mfg 1 – MIL-PRF-85285	√	√				
			Mfg 1 - APC	√	√				
			Mfg 2 - APC	√	√				
			Mfg 3 - APC	√	√				
		90°F/90%RH	Mfg 1 – MIL-PRF-85285	√	√				
			Mfg 1 - APC	√	√				
			Mfg 2 - APC	√	√				
			Mfg 3 - APC	√	√				
		77°F/50%RH	Mfg 1 – MIL-PRF-85285	√	√	√	√	√	√
			Mfg 1 - APC	√	√	√	√	√	√
			Mfg 2 - APC	√	√	√	√	√	√
			Mfg 3 - APC	√	√	√	√	√	√
Nonchrome Pretreatment	**Candidate Flexible Primer**	77°F/50%RH	Mfg 1 – MIL-PRF-85285		√	√	√	√	
			Mfg 1 - APC		√	√	√	√	
			Mfg 2 - APC		√	√	√	√	
			Mfg 3 - APC		√	√	√	√	
*Dry to Recoat included topcoat application to 3 panels @ 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 & 24 hours cure. Dry to Recoat panels were tested for gloss and cross hatch adhesion.									

Primer Application

Prior to application, the candidate flexible primer was mixed (1 part A, 1 part B, and 1 part C, equal parts by volume) and shaken (5-10 minutes) according to manufacturer specifications. The mixed viscosity was measured using a #4 Ford Cup. The candidate primer was applied using standard spray techniques, with a target dry film thickness of 1.7-2.1 mils. Measured viscosities and film thicknesses are given in Appendix A.

For controls, a smaller number of panels were primed with a MIL-PRF-23377 epoxy primer.

Dry-to-Recoat Time. Atmospheric conditions greatly affected the dry-to-recoat time of previously tested low VOC flexible primers. Because of this history, an extensive dry-to-recoat series was included in this study. Panels pretreated with chromate conversion coating were primed under five conditions: ambient (79°F/46%RH), dry and cool (60°F/30%RH), wet and cool (62°F/95%RH), dry and warm (92°F/25%RH), and wet and warm (92°F/62%RH).

Topcoats were applied to the primed panels after the primer had cured for 1.5 hours, 2.0 hours, 3.0 hours, 4.0 hours, 5.0 hours, 6.0 hours, and 24 hours. After the topcoats had cured for at least 7 days, they were tested for gloss (ASTM D 523) and crosshatch adhesion (ASTM D 3359, Method B). The

ambient cure set of panels was later duplicated because of issues discussed in the RESULTS AND DISCUSSION section.

Topcoat Application on Standard Test Panels

Four topcoats were used in this study: a MIL-PRF-85285 topcoat from Manufacturer 1, an Advanced Performance Coating (APC) type topcoat from Manufacturer 1, APC-type topcoat from Manufacturer 2, and APC-type topcoat from Manufacturer 3. Color for all panels was 36173 of FED-STD-595b. Standard application conditions were used, with the topcoats being applied 2 hours after application of the primer (except panels used in the dry-to-recoat series).

Testing of Fully Cured Panels

Testing was done in triplicate except where otherwise noted.

Wet Tape Adhesion. Panels were placed back to back in beakers full of deionized water for at least 24 hours under ambient conditions. Within 10 minutes of removal from the water, a razor blade was used to cut two parallel lines 1 inch apart and approximately 1.5 inches long were cut into the coating. An X scribe was then cut in the middle of the parallel cuts. After brushing away debris, the tape adhesion test was conducted using the procedure described in ASTM D 3359, Method A.

GE Impact. The elongation of a primer/topcoat combination was measured with a GE Impact tester using a method consistent with ASTM D 6905. The impact sites were examined optically with the aid of a 10x lens to determine the GE impact elongation score. The impact site was also tested with an Elcometer pinhole detector using a procedure consistent with ASTM G 62. The Elcometer data determined if cracks had propagated through the primer to the metal substrate or if the primer blunted the crack growth.

Low Temperature Flexibility. The ASTM D 522 procedure was used to test low temperature flexibility of coating stack-ups containing the flexible primer. Three panels of each stack-up were placed in a freezer at -51°C for 24 hours before testing. While still in the freezer, the panels were bent 180° over a 2” diameter mandrel. The coating on the bent panels was then examined for cracks.

Weatherability. Previous flexible primers adversely affected the weather resistance of polyurethane topcoats. To determine if the current candidate affects weatherability, panels were tested for xenon arc weatherability using a method consistent with ASTM G 155. Color and gloss of the panels were measured before exposure and after each 504 hours of exposure up to a total of 2009 hours.

Salt Spray Resistance. Coated panels were exposed to 1996 hours of salt fog using the protocol described in ASTM B 117. During this process, the panels were rated for corrosion approximately every 500 hours.

RESULTS AND DISCUSSION

The data discussed below are in the appendices at the back of this paper.

Primer Application

The flexible primer sprayed well in all environmental conditions. As seen in the data found in Appendix A, film thicknesses were within the target thickness window of 1.7 – 2.1 mils.

Although the coating applied well under all conditions, the data obtained from one set of panels was considered too suspect to be used. The exception was the ambient (78°F and 46%RH) dry-to-recoat series where the measured viscosity of the mixed primer was about 60% higher than the other applications. The higher viscosity coating sprayed well, but the adhesion performance of the primer was not consistent with data collected from samples sprayed at other events. Because of these anomalies, the spray event was repeated. The coating viscosity at the repeat event was consistent with the larger body of data as was the adhesion performance (Appendix E).

Gloss

Appendix B contains 60° gloss data. Gloss was a function of the dry-to-recoat time. Specifically, gloss was higher if recoat time exceeded 3 or 4 hours, with several stack-ups having 60° gloss values above 5 (the allowable maximum) at the 24-hour mark. On average, higher gloss inversely correlated to application humidity, although humidity variation was smaller than dry-to-recoat variation.

On average, stack-ups topped with topcoat from Manufacturer 2 had the lowest gloss regardless of whether the stack-up included the flexible primer or the control primer.

Pencil Hardness

Most stack-ups containing the flexible primer were unable to withstand even the softest pencil in the authors' collection (6B), and all were too soft for aerospace use. The data in Appendix C show that stack-ups including topcoat from Manufacturer 2 were the least soft, but even these were much too vulnerable to gouging. Although most Air Force coating specifications do not have a specific pencil hardness requirement, experience has shown that coatings softer than about 2B tend to have problems. For reference, the coatings tested here were easily damaged with a fingernail.

Adhesion

Some flexible primer stack-ups coated at low humidity failed the wet tape test (that is, they received a rating less than 4A). Adhesion failures were observed when the topcoat did not stick to the primer. The area of failure of several panels was large, including the entire triangle between the center of the X scribe and the parallel line approximately ½" below the center. The affect of humidity on adhesion was not anticipated and this data is being discussed with the developer of the flexible primer.

Dry adhesion, as measured by the cross-hatch test, was generally good (Appendix E). Excluding data from the high viscosity batch, stack-ups averaged at least a 4B, or passing rating. For all stack-ups, the

system that included the flexible primer performed at least as well as the analogous system that included the control epoxy primer.

Flexibility

The GE Impact data are important to this analysis since it is the primary metric for determining if the flexible primer is more flexible than the traditional primer.

Stack-ups that included the flexible primer and topcoats from Manufacturers 1 and 3 were more flexible than stack-ups made with those topcoats and the traditional MIL-PRF-23377 epoxy primer (control). Surprisingly, improved flexibility was not observed when the topcoat from Manufacturer 2 was applied to the flexible primer. It is interesting to note that these data correlate to the pencil hardness data where stack-ups including Manufacturer 2's topcoat were noticeably harder than the stack-ups with other topcoats.

Weatherability

Previously tested versions of polysulfide primer were found to have a very adverse effect on the xenon arc resistance of topcoats. The flexible primer tested in this trial, however, does not affect the topcoat weatherability. After 2009 hours of xenon arc exposure, topcoats applied to the flexible primer had similar changes in color and 60° gloss to the same coating applied to MIL-PRF-23377. The data in Appendix G shows stack-ups made with either primer were largely within tolerance ($\Delta E<1$ unit and <1 gloss unit change) after exposure. (Note: The changes for some stack-ups made with the MIL-PRF-85285 topcoat from Manufacturer 1 were slightly larger, but since this is a non-APC formula the larger values are expected.)

Salt Spray Resistance

Salt spray performance of stack-ups that included the flexible primer passed 1996 hours of salt spray exposure with no more than an acceptable amount of corrosion. Appendix H has the data.

SUMMARY

This report includes the results from the first stage of an effort to evaluate new flexible primers for aerospace use. The trial consisted of tests for chemical resistance (pencil hardness and dry crosshatch adhesion before and after exposure to MIL-L-23699), flexibility (GE reverse impact and -51°C mandrel bend), adhesion (wet X scribe tape pull), dry-to-recoat time (gloss measurements of topcoat applied at timed intervals after primer application), salt spray resistance, and xenon arc exposure resistance.

The results given in this report are generally good, although two issues were observed. The primer appeared to have a wide dry-to-recoat window, although the gloss of the topcoat increased if more than 4 hours passed between application of the primer and application of the topcoat. The flexible primer did form a more flexible coating stack-up when teamed with most topcoats. The stack-up performed well in dry adhesion, salt spray and xenon arc. Unfortunately, the pencil hardness of samples that contained the flexible primer material was much too soft, most failing under the 6B (softest) pencil. Also, wet adhesion of stack-ups prepared at low humidity was a problem as many of the topcoats did not stick to the primer.

These results have led the authors to request modified versions of the flexible primer tested. Some of the key tests will be redone. A new test will be accomplished to quantify the toughness of these coatings rather than just the softness. This will likely be a rain-erosion test. If the new versions of this coating perform adequately well enough to warrant field trials, the coating system will be applied to select areas of a KC-135 aircraft at Tinker AFB.

APPENDIX A - PRIMER VISCOSITIES AND FILM THICKNESSES

Primer	Environmental Conditions	Ford #4 Cup Viscosity	Average Primer Dry Film Thickness
Control (MIL-PRF-23377)	77°F and 50%RH	21.8 seconds	0.8 mils
Flexible Primer	79°F and 46%RH	15.6 seconds	1.6 mils
Flexible Primer	77°F and 51%RH	15.6 seconds	1.6 mils
Flexible Primer	92°F and 62%RH	15.0 seconds	1.9 mils
Flexible Primer	92°F and 25%RH	15.7 seconds	1.8 mils
Flexible Primer	62°F and 95%RH	15.6 seconds	2.0 mils
Flexible Primer	60°F and 30%RH	14.5 seconds	1.8 mils
Flexible Primer *	78°F and 46%RH	24.2 seconds	1.6 mils
Flexible Primer (Repeat)	78°F and 46%RH	15.1 seconds	2.2 mils

* Because the viscosity of the paint at this event was 60% higher than at the other events, data collected from panels sprayed with at this event was discarded and the work was repeated.

APPENDIX B - 60° GLOSS DATA

Dry to Recoat 60º Gloss									
	23377 Controls		**Stackups with Candidate Flexible Primer**						Avg
Hours to Topcoat	Topcoat	ºF/%RH	Topcoat	ºF/%RH					
		77/50		*60/30*	*60/90*	*77/50*	*90/30*	*90/65*	
1.5	Mfg 2 - APC	2.1	Mfg 2 - APC	1.8	0.7	0.9	1.0	0.9	2.0
	Mfg 1 - 85285	2.6	Mfg 1 - 85285	7.9	1.4	2.0	2.5	1.2	
	Mfg 1 - APC	3.9	Mfg 1 - APC	1.3	1.3	2.1	2.7	1.6	
	Mfg 3 - APC	4.2	Mfg 3 - APC	4.7	0.9	3.6	1.7	0.9	
2.0	Mfg 2 - APC	1.9	Mfg 2 - APC	1.3	0.7	0.9	1.1	0.8	1.9
	Mfg 1 - 85285	2.5	Mfg 1 - 85285	5.5	1.3	2.2	2.7	1.6	
	Mfg 1 - APC	4.1	Mfg 1 - APC	1.5	1.1	2.6	3.0	1.7	
	Mfg 3 - APC	4.3	Mfg 3 - APC	2.0	0.8	3.9	1.6	0.9	
3.0	Mfg 2 - APC	1.8	Mfg 2 - APC	1.3	0.7	1.1	1.1	0.9	2.0
	Mfg 1 - 85285	2.6	Mfg 1 - 85285	4.4	1.5	2.4	3.3	1.9	
	Mfg 1 - APC	4.0	Mfg 1 - APC	1.7	1.3	2.7	3.8	2.2	
	Mfg 3 - APC	4.1	Mfg 3 - APC	2.3	0.8	4.5	2.2	0.9	
4.0	Mfg 2 - APC	1.6	Mfg 2 - APC	1.3	0.7	1.0	1.3	1.0	2.1
	Mfg 1 - 85285	2.5	Mfg 1 - 85285	4.1	1.8	2.5	3.9	2.4	
	Mfg 1 - APC	4.0	Mfg 1 - APC	1.8	1.2	2.8	5.1	2.4	
	Mfg 3 - APC	1.8	Mfg 3 - APC	2.7	0.8	1.6	2.5	1.1	
5.0	Mfg 2 - APC	1.7	Mfg 2 - APC	1.4	0.8	1.1	1.6	1.1	2.3
	Mfg 1 - 85285	2.7	Mfg 1 - 85285	4.3	1.8	2.6	4.6	2.9	
	Mfg 1 - APC	2.5	Mfg 1 - APC	2.0	1.7	1.4	5.9	2.9	
	Mfg 3 - APC	1.9	Mfg 3 - APC	2.7	0.9	1.9	3.0	1.2	
6.0	Mfg 2 - APC	1.8	Mfg 2 - APC	2.5	0.7	1.1	1.4	1.2	2.7
	Mfg 1 - 85285	2.6	Mfg 1 - 85285	4.3	1.9	2.7	2.7	3.6	
	Mfg 1 - APC	2.3	Mfg 1 - APC	2.1	1.9	1.5	3.4	4.4	
	Mfg 3 - APC	1.9	Mfg 3 - APC	13.3	0.9	2.5	1.0	1.3	
24	Mfg 2 - APC	1.7	Mfg 2 - APC	2.2	1.1	1.4	1.4	0.9	3.5
	Mfg 1 - 85285	3.3	Mfg 1 - 85285	4.9	2.7	4.5	5.1	2.1	
	Mfg 1 - APC	4.0	Mfg 1 - APC	11.3	5.0	4.4	5.8	3.3	
	Mfg 3 - APC	6.0	Mfg 3 - APC	2.8	1.1	4.8	4.7	1.3	
Averages		2.9		3.5	1.3	2.4	2.8	1.7	

Stack-ups with topcoat from Manufacturer 2 had an average gloss of 1.1, stack-ups with MIL-PRF-85285 topcoat from Manufacturer 1 had an average gloss of 3.0, stack-ups with APC topcoat from Manufacturer 1 had an average gloss of 2.9, and stack-ups with topcoat from Manufacturer 3 had an average gloss of 2.4.

APPENDIX C - PENCIL HARDNESS

Controls	Before 23699 Exposure	After 23699 Exposure	Flexible Stack- ups	Before 23699 Exposure	After 23699 Exposure
23377/ Mfg 2 - APC	F	F	Flex Primer/ Mfg 2 - APC	5B	6B
	HB	2H		6B+	5B
	F	F		6B+	6B
23377/ Mfg 1 - 85285	HB	2B	Flex Primer/ Mfg 1 - 85285	6B+	6B+
	HB	2B		6B+	6B
	HB	HB		6B+	6B+
23377/ Mfg 1 - APC	2B	HB	Flex Primer/ Mfg 1 - APC	6B+	6B+
	2B	2B		6B+	6B+
	B	2B		6B+	6B+
23377/ Mfg 3 - APC	2B	2B	Flex Primer/ Mfg 3 - APC	6B+	6B+
	2B	2B		6B+	6B+
	2B	3B		6B+	6B+
6B < 5B < 4B < 3B < 2B < B < HB < F < H < 2H < 3H <4H < 5H < 6H					
<——— Softer ——————————— Harder ———>					

APPENDIX D - WET TAPE ADHESION

Controls	°F/%RH	Flexible Stack- ups	°F / % Relative Humidity				
	77/50		60/30	60/90	77/50	90/30	90/65
23377/ Mfg 2 - APC	5A	Flex Primer/ Mfg 2 - APC	5A	5A	5A	5A	5A
	4A		5A	4A	5A	5A	5A
	4A		5A	4A	5A	5A	5A
23377/ Mfg 1 - 85285	4A	Flex Primer/ Mfg 1 - 85285	4A	4A	5A	5A	4A
	4A		2A	5A	5A	4A	4A
	4A		4A	4A	4A	5A	4A
23377/ Mfg 1 - APC	4A	Flex Primer/ Mfg 1 - APC	2A	5A	5A	5A	5A
	5A		2A	4A	4A	3A	5A
	4A		2A	4A	4A	5A	5A
23377/ Mfg 3 - APC	4A	Flex Primer/ Mfg 3 - APC	4A	5A	5A	3A	5A
	5A		4A	5A	5A	3A	4A
	5A		2A	4A	5A	3A	5A

Ratings of 4A and 5A meet most Air Force coating specifications.

APPENDIX E – CROSSHATCH DRY ADHESION

Dry-to-Recoat Crosshatch Adhesion									
Hours to Topcoat	**Controls**	**°F/%RH**	**Flex Stack-ups**	**°F / % Relative Humidity**					
		77/50		**60/30**	**60/90**	**~~77/50*~~**	**77/50**	**90/30**	**90/65**
1.5	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B*~~**	**4.0B****	**4B**	**5B**
		4B		**4B**	**5B**	**~~5B*~~**		**4B**	**5B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**5B**	**~~4B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**4B**	**~~4B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 3 - APC	**5B**	Flex Primer/ Mfg 3 - APC	**4B**	**4B**	**~~3B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
2.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~5B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**4B**	**~~3B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**5B**	**4B**	**~~4B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 3 - APC	**4B**	Flex Primer/ Mfg 3 - APC	**5B**	**5B**	**~~4B*~~**	**4.0B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~4B*~~**		**4B**	**4B**
3.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B*~~**	**5.0B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~5B*~~**		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**4B**	**~~5B*~~**	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~5B*~~**		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**5B**	**~~4B*~~**	**5.0B****	**4B**	**4B**
		4B		**5B**	**4B**	**~~4B*~~**		**4B**	**4B**
	23377/ Mfg 3 - APC	**5B**	Flex Primer/ Mfg 3 - APC	**4B**	**5B**	**~~5B*~~**	**5.0B****	**4B**	**4B**
		4B		**5B**	**4B**	**~~4B*~~**		**4B**	**4B**

* Data from this spray event is suspect because primer viscosity was 60% higher than normal after mixing. The data was ignored in the analysis.

** Average of readings from three panels.

APPENDIX E – CROSS-HATCH DRY ADHESION (CONTINUED)

Dry-to-Recoat Crosshatch Adhesion									
Hours to Topcoat	**Controls**	**°F/%RH**	**Flex Stack-ups**	**°F / % Relative Humidity**					
		77/50		**60/30**	**60/90**	**~~77/50~~***	**77/50**	**90/30**	**90/65**
4.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**4B**	**~~5B~~***	**5.0B****	**4B**	**4B**
		3B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**4B**	**~~1B~~***	**5.0B****	**4B**	**4B**
		4B		**5B**	**5B**	**~~2B~~***		**4B**	**4B**
	23377/ Mfg 3 - APC	**4B**	Flex Primer/ Mfg 3 - APC	**4B**	**5B**	**~~1B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~2B~~***		**4B**	**4B**
5.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B~~***	**4.3B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**4B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**4B**	**~~0B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~0B~~***		**4B**	**4B**
	23377/ Mfg 3 - APC	**5B**	Flex Primer/ Mfg 3 - APC	**4B**	**4B**	**~~4B~~***	**4.7B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
6.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**5B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**4B**	**~~1B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~0B~~***		**4B**	**4B**
	23377/ Mfg 3 - APC	**4B**	Flex Primer/ Mfg 3 - APC	**4B**	**4B**	**~~2B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**5B**	**~~4B~~***		**4B**	**4B**
24.0	23377/ Mfg 2 - APC	**4B**	Flex Primer/ Mfg 2 - APC	**4B**	**4B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - 85285	**4B**	Flex Primer/ Mfg 1 - 85285	**4B**	**4B**	**~~4B~~***	**5.0B****	**4B**	**4B**
		4B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**
	23377/ Mfg 1 - APC	**4B**	Flex Primer/ Mfg 1 - APC	**4B**	**4B**	**~~2B~~***	**5.0B****	**4B**	**4B**
		4B		**5B**	**4B**	**~~2B~~***		**4B**	**4B**
	23377/ Mfg 3 - APC	**2B**	Flex Primer/ Mfg 3 - APC	**4B**	**5B**	**~~3B~~***	**5.0B****	**4B**	**4B**
		2B		**4B**	**4B**	**~~4B~~***		**4B**	**4B**

*Data from this spray event is suspect because primer viscosity was 60% higher than normal after mixing. The data was ignored in the analysis.

**Average of readings from three panels.

APPENDIX F - GE IMPACT RESISTANCE

Controls	77°F and 50% Relative Humidity		Flex Stack-ups	77°F and 50% Relative Humidity	
	Cracking % Elongation Passed	Pin hole Detection % Passed		Cracking % Elongation Passed	Pin hole Detection % Passed
23377/ Mfg 2 - APC	10%	10%	**Flex Primer/ Mfg 2 - APC**	5%	5%
	10%	10%		5%	10%
	10%	10%		10%	10%
23377/ Mfg 1 - 85285	20%	20%	**Flex Primer/ Mfg 1 - 85285**	40%	20%
	20%	20%		40%	20%
	20%	20%		40%	40%
23377/ Mfg 1 - APC	20%	20%	**Flex Primer/ Mfg 1 - APC**	40%	40%
	20%	20%		40%	40%
	20%	20%		60% (no crack)	40%
23377/ Mfg 3 - APC	40%	40%	**Flex Primer/ Mfg 3 - APC**	60% (no crack)	60+%
	40%	40%		60% (no crack)	60+%
	40%	40%		60% (no crack)	60+%

APPENDIX G - XENON ARC RESISTANCE

Stack-Up Compositions		Panel Identification	504 hours		1008 hours		1512 hours		2009 hours	
			Δ E	Δ 60° gloss	Δ E	Δ 60° gloss	Δ E	Δ 60° gloss	Δ E	Δ 60° gloss
Includes Control Primer	23377/ Mfg 2 - APC	848C1A007	**0.35**	**0.13**	**0.24**	**0.18**	**0.18**	**0.25**	**0.21**	**-0.38**
		848C1A008	**0.34**	**0.10**	**0.26**	**0.18**	**0.20**	**0.23**	**0.20**	**-0.33**
		848C1A009	**0.39**	**0.03**	**0.27**	**0.15**	**0.23**	**0.20**	**0.26**	**-0.20**
	23377/ Mfg 1 - 85285	848C1B007	**0.74**	**0.35**	**0.85**	**0.88**	**1.19**	**1.35**	**1.79**	**-1.58**
		848C1B008	**0.63**	**0.33**	**0.77**	**0.70**	**0.84**	**1.10**	**1.21**	**-1.43**
		848C1B009	**0.50**	**0.31**	**0.90**	**0.68**	**0.90**	**1.10**	**1.19**	**-1.43**
	23377/ Mfg 1 - APC	848C1C007	**0.56**	**0.05**	**0.66**	**0.40**	**0.60**	**0.65**	**0.65**	**-0.78**
		848C1C008	**0.51**	**0.30**	**0.58**	**0.48**	**0.53**	**0.68**	**0.57**	**-0.83**
		848C1C009	**0.60**	**0.25**	**0.65**	**0.38**	**0.62**	**0.63**	**0.67**	**-0.73**
	23377/ Mfg 3 - APC	848C1D007	**0.16**	**0.08**	**0.14**	**0.18**	**0.12**	**0.30**	**0.20**	**-0.40**
		848C1D008	**0.13**	**0.05**	**0.12**	**0.15**	**0.11**	**0.25**	**0.18**	**-0.35**
		848C1D009	**0.10**	**0.08**	**0.09**	**0.23**	**0.13**	**0.73**	**0.20**	**-0.43**
Includes Flexible Primer	Flex Primer/ Mfg 2 - APC	848C1E007	**0.26**	**0.03**	**0.10**	**0.08**	**0.08**	**0.10**	**0.26**	**-0.18**
		848C1E008	**0.25**	**0.05**	**0.08**	**0.10**	**0.10**	**0.15**	**0.39**	**-0.25**
		848C1E009	**0.33**	**0.00**	**0.15**	**0.08**	**0.09**	**0.10**	**0.18**	**-0.15**
	Flex Primer/ Mfg 1 - 85285	848C1F007	**0.55**	**0.45**	**0.40**	**1.08**	**0.34**	**1.40**	**0.66**	**-1.50**
		848C1F008	**0.55**	**0.45**	**0.37**	**0.93**	**0.37**	**1.20**	**0.86**	**-1.25**
		848C1F009	**0.55**	**0.85**	**0.51**	**1.55**	**0.73**	**1.75**	**1.35**	**-1.83**
	Flex Primer/ Mfg 1 - APC	848C1G007	**0.43**	**0.18**	**0.24**	**0.43**	**0.19**	**0.55**	**0.34**	**-0.65**
		848C1G008	**0.58**	**0.15**	**0.42**	**0.38**	**0.35**	**0.48**	**0.42**	**-0.55**
		848C1G009	**0.57**	**0.08**	**0.51**	**0.33**	**0.58**	**0.55**	**0.40**	**-0.65**
	Flex Primer/ Mfg 3 - APC	848C1H007	**0.46**	**0.45**	**0.63**	**0.93**	**0.53**	**0.73**	**0.41**	**-0.90**
		848C1H008	**0.26**	**0.20**	**0.29**	**0.50**	**0.35**	**0.65**	**0.39**	**-0.73**
		848C1H009	**0.20**	**0.30**	**0.30**	**0.53**	**0.34**	**0.65**	**0.41**	**-0.78**

APPENDIX H - SALT SPRAY RESISTANCE

Flex Stack-ups	Panel Identification	504 hours		944 hours		1512 hours		1996 hours	
		In Scribe	Under-cut	In Scribe	Under-cut	In Scribe	Under-cut	In Scribe	Under-cut
Flex Primer/ Mfg 2 - APC	848A2A004	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
	848A2A005	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
	848A2A006	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Flex Primer/ Mfg 1 - 85285	848A2B004	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**
	848A2B005	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**
	848A2B006	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**
Flex Primer/ Mfg 1 - APC	848A2C004	**0**	**0**	**1**	**0**	**1**	**0**	**2**	**0**
	848A2C005	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**
	848A2C006	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Flex Primer/ Mfg 3 - APC	848A2D004	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
	848A2D005	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
	848A2D006	**0**	**0**	**1**	**0**	**1**	**0**	**1**	**0**

Scribe Ratings

0	Bright and clean
1	Staining, minor corrosion but no build up
2	Minor/moderate corrosion product build up
3	Moderate corrosion product build up
4	Major corrosion product build up
5	Severe corrosion product build up

Undercut Ratings

0	No lifting of coating
1	Lifting or loss of adhesion up to 1/16"
2	Lifting or loss of adhesion up to 1/8"
3	Lifting or loss of adhesion up to 1/4"
4	Lifting or loss of adhesion up to 1/2"
5	Lifting or loss of adhesion beyond 1/2"

Blistering away from the scribe was not observed on any panels.