

Cryogenic Testing – Prepared for Highland International, LLC December 2014

Short Term Cryogenic Testing Procedure

Designated panels were subjected to 4 x 24 hour cycles of cryogenic temperatures (-300°F). All panels were removed mid cycle and submerged in boiling water. The immediately cooled water bath was allowed to return to a boil for 5 minutes, afterwards, the panels were placed back in the cryogenic chamber (-300°F) for the remainder of each 24 hour cycle. At the end of each cycle, the panels were allowed to return to ambient temperatures (approx 72°F) for 24 hours.

All testing was conducted by 300° Below Cryogenic Tempering Services, 2999 E. Parkway Drive, Decatur IL 62526.

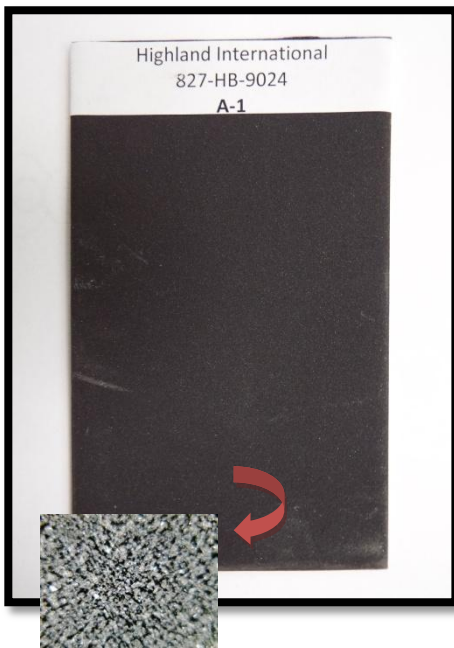
All test panels (304L Grade Stainless Steel) were prepared and provided by Highland International, Inc.

Short Term Panel Preparation

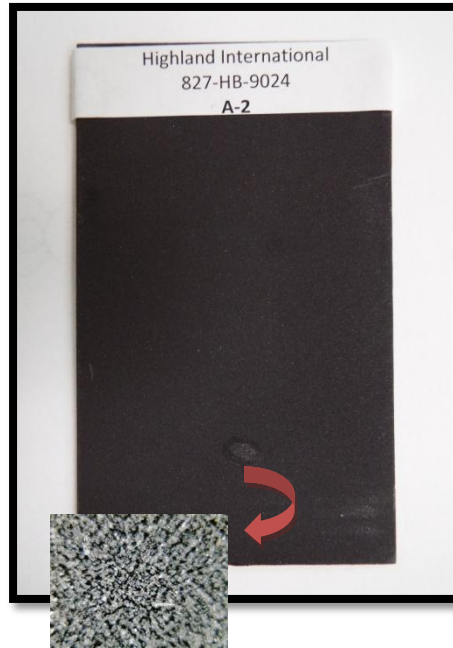
Short Term Test Panel Grid					
Group	Panel ID	Surface Prep (On 304L SS)	Coat 1	Coat 2	Cure
Highland 827-HB Series	A1	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	A2	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	A3	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	A4	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	24 Hours @ 500°F
	A5	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	24 Hours @ 500°F
	A6	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	24 Hours @ 500°F
Competitor #1	B1	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	B2	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	B3	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	24 Hours @ 500°F
Competitor #2	C1	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	C2	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	C3	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	24 Hours @ 500°F

Short Term Post-Test Panels

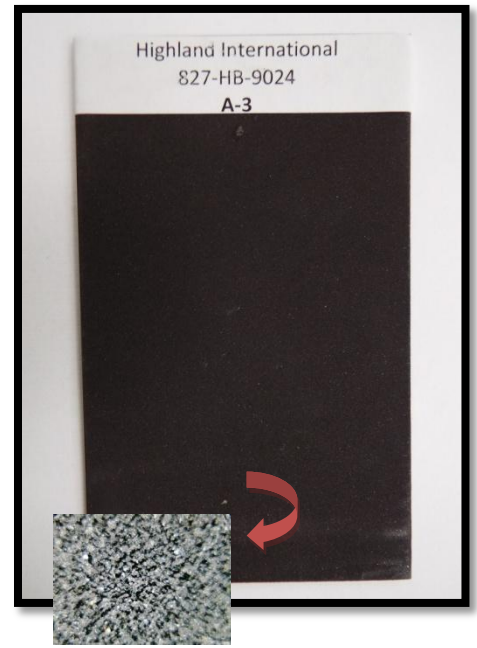
Group “A” Panels Represent Highland International, Inc. 827-HB Series
(Magnification represents x20 zoom)



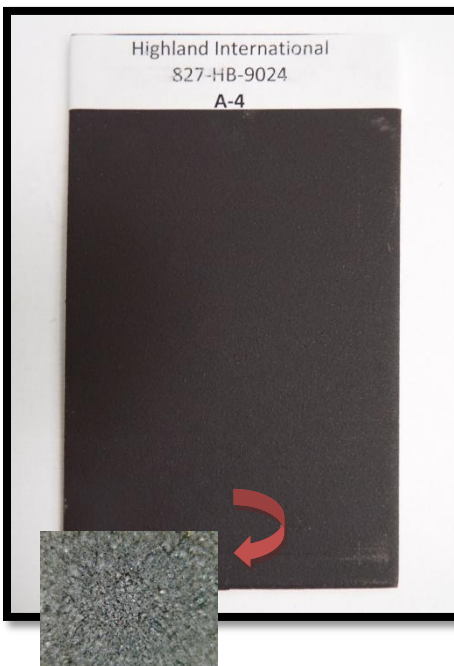
A1 – Highland 827-HB
Ambient Cure



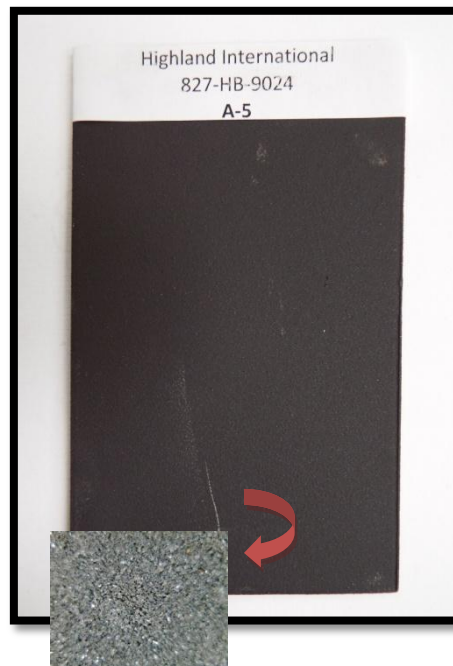
A2 – Highland 827-HB
Ambient Cure



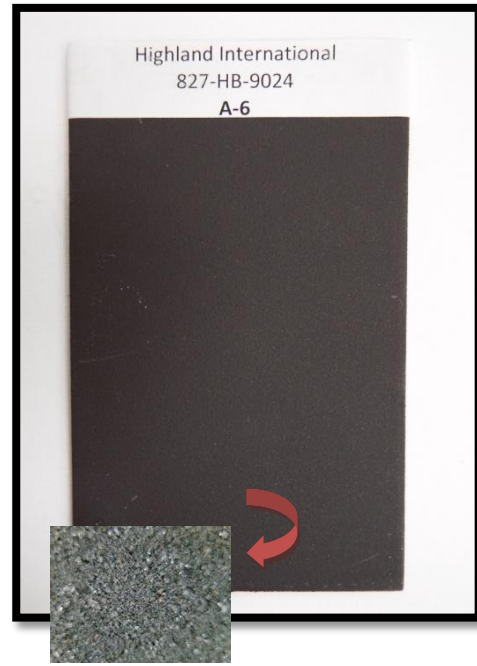
A3 – Highland 827-HB
Ambient Cure



A4 – Highland 827-HB
Heat Cured @ 500°F



A5 – Highland 827-HB
Heat Cured @ 500°F

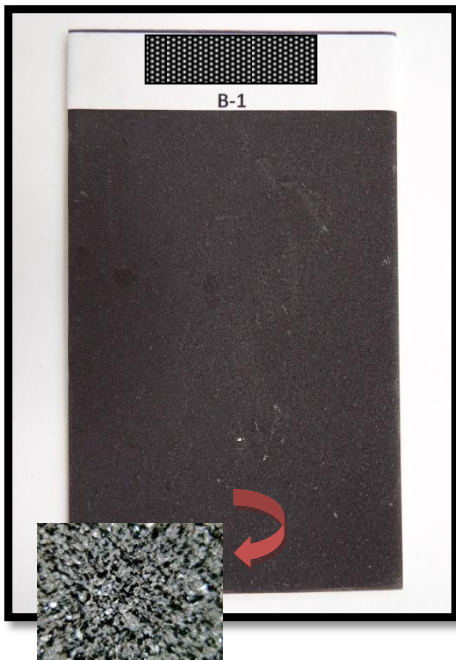


A6 – Highland 827-HB
Heat Cured @ 500°F

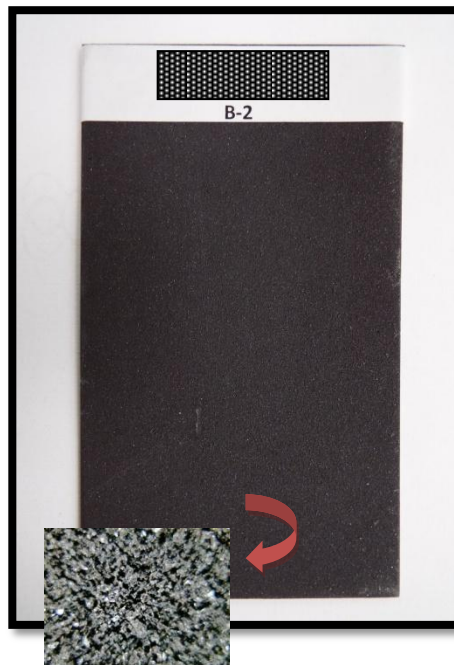
Short Term Post-Test Panels (Continued)

Group "B" Panels Represent Competitor #1 Multipolymeric Matrix Coating

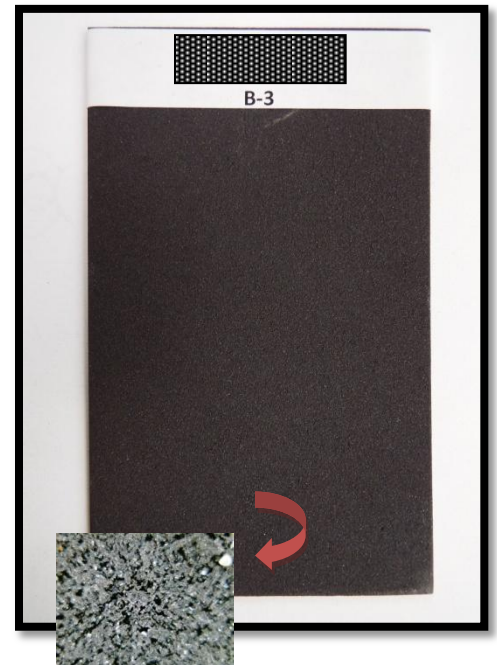
(Magnification represents x20 zoom lens)



B1 – Competitor #1
Ambient Cure



B2 – Competitor #1
Ambient Cure



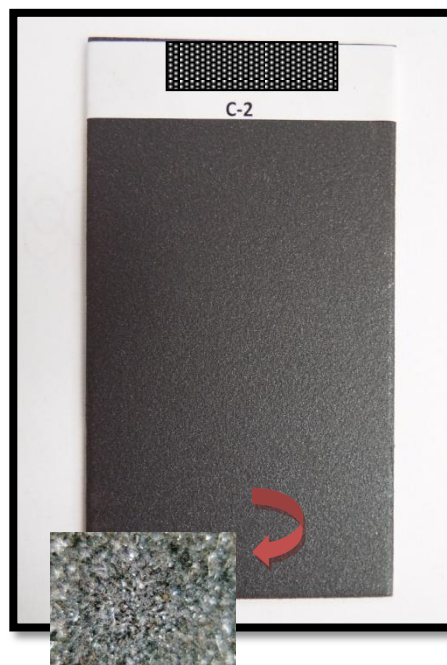
B3 – Competitor #1
Heat Cured @ 500°F

Group "C" Panels Represent Competitor #2 CUI Coating

(Magnification represents x20 zoom lens)



C1 – Competitor #2
Ambient Cure



C2 – Competitor #2
Ambient Cure



C3 – Competitor #2
Heat Cured @ 500°F

Short Term Post-Test Panels (Adhesion Results)

ASTM D4541 Test Method for Pull-Off Strength Using Portable Adhesion Tester

ASTM D3359 Test Method for Measuring Adhesion by Tape Test

Group "A" Panels Represent Highland International, Inc. 827-HB Series

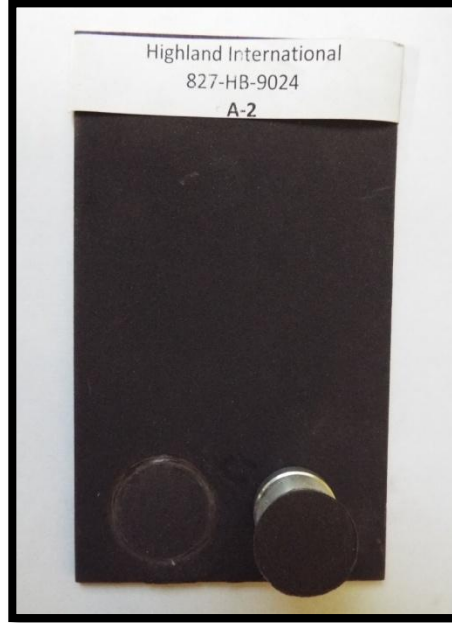
All pull offs were noted as 100% cohesive failure at given psi.



A1

Pull Off: 350 PSI

Cross Hatch: 3A



A2

Pull Off: 400 PSI

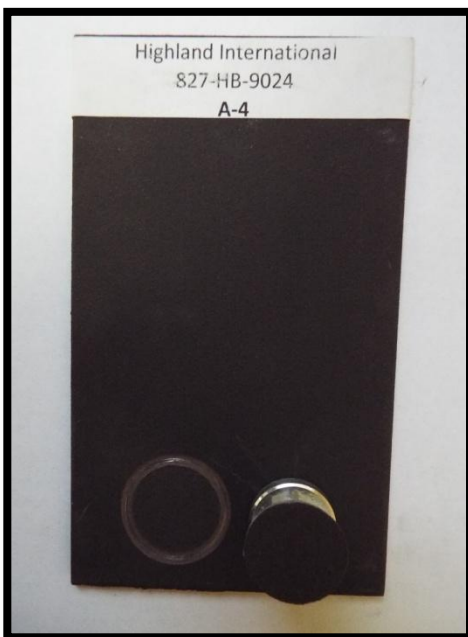
Cross Hatch: 3A



A3

Pull Off: 300 PSI

Cross Hatch: 4A



A4

Pull Off: 450 PSI

Cross Hatch: 3A



A5

Pull Off: 450 PSI

Cross Hatch: 3A



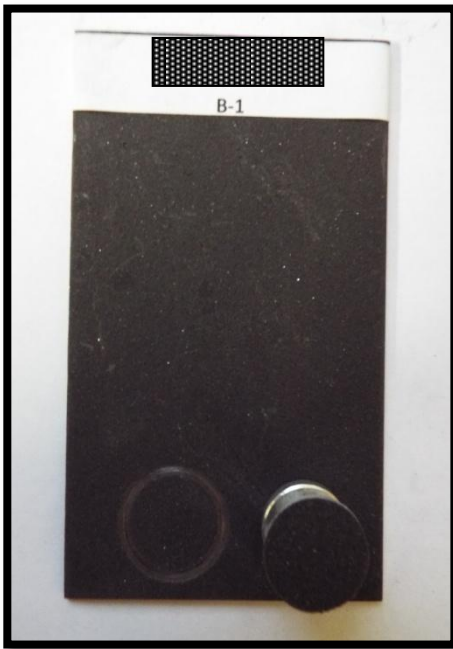
A6

Pull Off: 450 PSI

Cross Hatch: 3A

Group "B" Panels Represent Competitor #1 Multipolymeric Matrix Coating

All pull offs were noted as 100% cohesive failure at given psi.



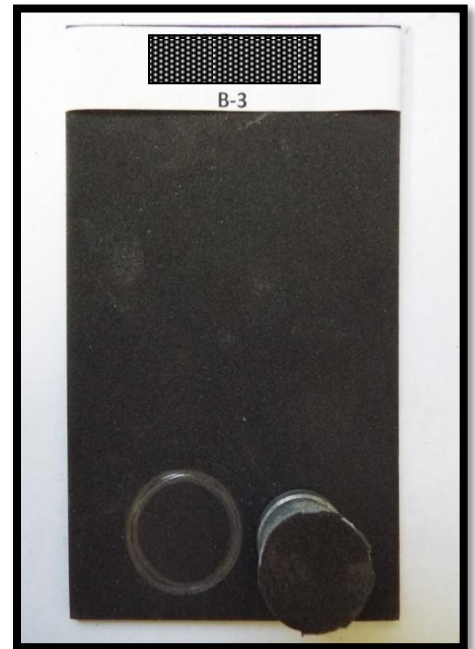
B1

Pull Off: 50 PSI
Cross Hatch: 3A



B2

Pull Off: 50 PSI
Cross Hatch: 4A

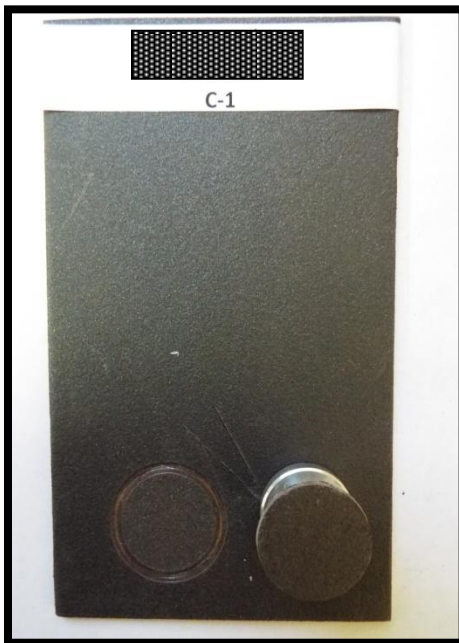


B3

Pull Off: 50 PSI
Cross Hatch: 3A

Group "C" Panels Represent Competitor #2 CUI Coating

All pull offs were noted as 100% cohesive failure at given psi.



C1

Pull Off: 400 PSI
Cross Hatch: 3A



C2

Pull Off: 100 PSI
Cross Hatch: 3A



C3

Pull Off: 400 PSI
Cross Hatch: 4A

Short Term Post-Test Panels (Salt-Fog Results)

ASTM B117 Practice for Operating Salt Fog

Group "A" Panels Represent Highland International, Inc. 827-HB Series

(Top and bottom areas of each panel have been taped to protect from salt-fog affect)



A1

No rusting in the field



A2

No rusting in the field



A3

No rusting in the field



A4

No rusting in the field



A5

No rusting in the field



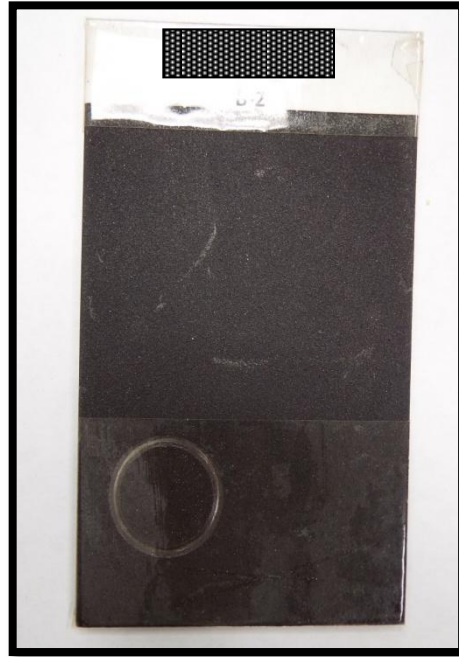
A6

No rusting in the field

Group "B" Panels Represent Competitor #1 Multipolymeric Matrix Coating



B1
No rusting in the field



B2
No rusting in the field



B3
No rusting in the field

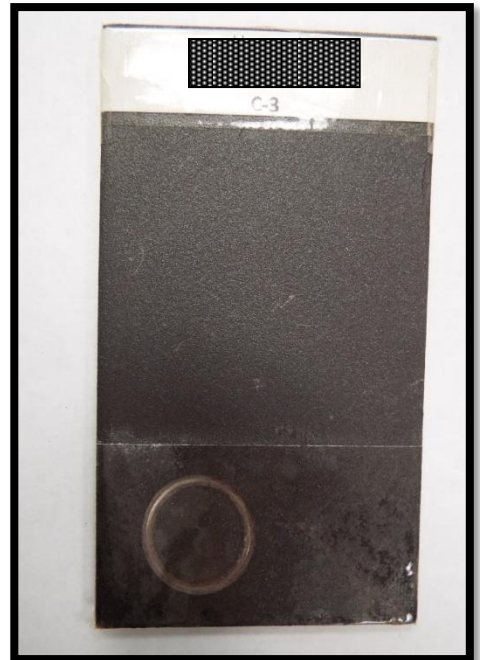
Group "C" Panels Represent Competitor #2 CUI Coating



C1
No rusting in the field



C2
No rusting in the field



C3
No rusting in the field

Short Term Cryogenic Evaluation

After the cryogenic test procedure was complete, all panels were evaluated for micro-cracking (via visual and magnified inspection), adhesion differences, and performance in salt fog to further evaluate effects, if any, from cryogenic and thermal shock cycles.

Short Term Cryogenic Testing - Summary

Short Term Test Panel Grid							
Group	Panel ID	Visual Inspection	Micro-cracking (20 x zoon inspection)	Micro-cracking Pass/Fail	Adhesion (via Elcometer)	Adhesion (via Tape Test)	Salt-Fog
Highland 827-HB Series	A1	Excellent	None	Pass	350 psi	3A	Pass
	A2	Excellent	None	Pass	400 psi	3A	Pass
	A3	Excellent	None	Pass	300 psi	4A	Pass
	A4	Excellent	None	Pass	450 psi	3A	Pass
	A5	Excellent	None	Pass	450 psi	3A	Pass
	A6	Excellent	None	Pass	450 psi	3A	Pass
Competitor #1	B1	Excellent	None	Pass	50 psi	3A	Pass
	B2	Excellent	None	Pass	50 psi	4A	Pass
	B3	Excellent	None	Pass	50 psi	3A	Pass
Competitor #2	C1	Excellent	None	Pass	400 psi	3A	Pass
	C2	Excellent	None	Pass	100 psi	3A	Pass
	C3	Excellent	None	Pass	400 psi	4A	Pass

Excellent = No visual abnormalities

Good = Some visual abnormalities, no visual failure

Poor = Visual abnormalities and visual coating failure

All panels passed visual and magnified inspections for micro-cracking as well as salt fog testing. Adhesion for all coatings evaluated via cross-hatch (ASTM D3359) averaged between a 3-4A. Adhesion evaluated via Elcometer Pulls (ASTM D4541) showed the following averages/rankings:

#1 – Highland 827-HB Series with average pull-off strength of 400psi

#2 – Competitor #2 with average pull-off strength of 300psi

#3 – Competitor #1 with average pull-off strength of 50psi

Long Term Cryogenic Testing Procedure

Designated panels were subjected to 4 x 1 week cryogenic cycles (1 week = 7 days @ -300°F). All panels were removed from the cryogenic chamber on the 3rd day of each cycle to be submerged in boiling water. The immediately cooled water bath was allowed to return to a boil for 15 minutes, afterwards, the panels were placed back in the cryogenic chamber (-300°F) for the remainder of each 1 week cycle. At the end of each 1 week cycle, the panels were allowed to return to ambient temperatures (approx 72°F) for 24 hours.

All testing was conducted by 300° Below Cryogenic Tempering Services, 2999 E. Parkway Drive, Decatur IL 62526.

All test panels (304L Grade Stainless Steel) were prepared and provided by Highland International, Inc.

Long Term Panel Preparation

Long Term Test Panel Grid					
Group	Panel ID	Surface Prep (on 304L SS)	Coat 1	Coat 2	Cure
Highland 827-HB Series	A-L7	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
	A-L8	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
Competitor #1	B-L4	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient
Competitor # 2	C-L4	SSPC-SP 1 w/ MEK	5-6 mils DFT	5-6 mils DFT	7 Days Ambient

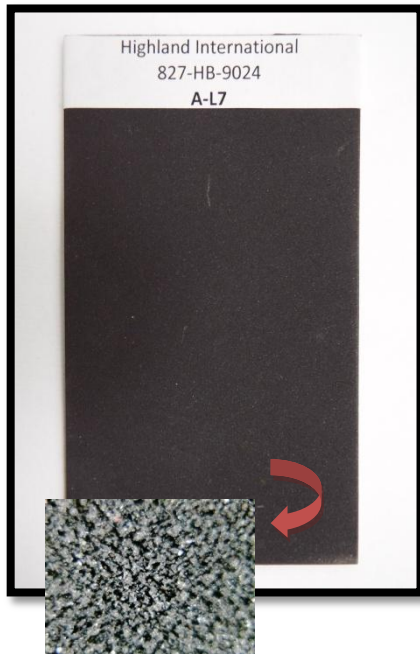
Long Term Panel Evaluation

After the long-term test procedure was complete, all panels were evaluated for microcracking (via visual and magnified inspection), adhesion differences, and performance in salt fog to further evaluate effects, if any, from longer term cryogenic cycles.

Long Term Post-Test Panels

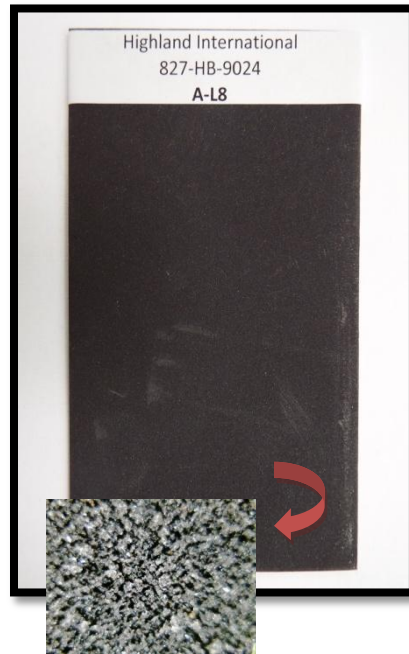
Group "AL" Panels Represent Highland International, Inc. 827-HB Series

(Magnification represents x20 zoom)



A-L7

Ambient Cure

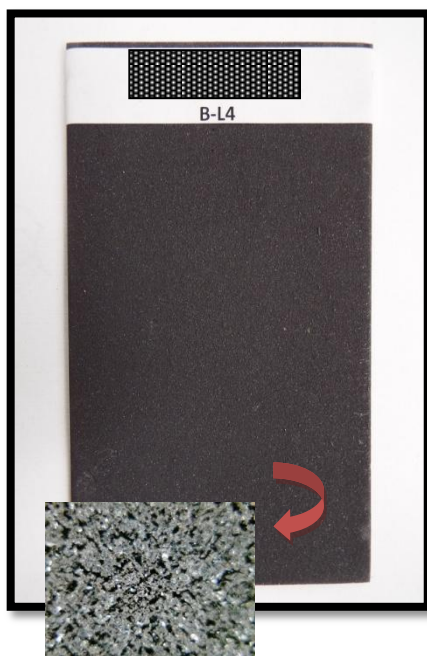


A-L8

Ambient Cure

Group "BL" Panel Represents Competitor #1 Multipolymeric Matrix Coating

(Magnification represents x20 zoom)



B-L4

Ambient Cure

Group "CL" Panel Represents Competitor #2 CUI Coating

(Magnification represents x20 zoom)



C-L4

Ambient Cure

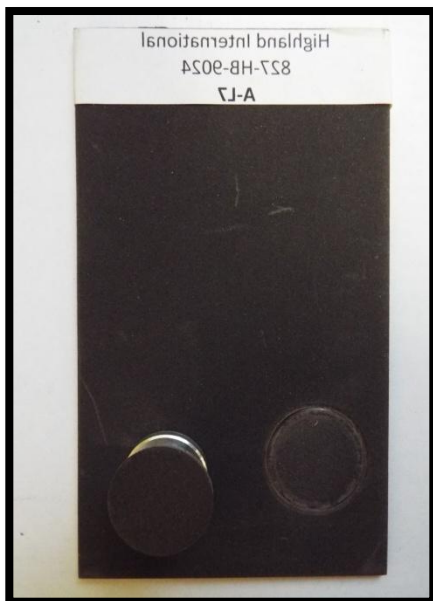
Long Term Post-Test Panels (Adhesion Results)

ASTM D4541 Test Method for Pull-Off Strength Using Portable Adhesion Tester

ASTM D3359 Test Method for Measuring Adhesion by Tape Test

Group "AL" Panels Represent Highland International, Inc. 827-HB Series

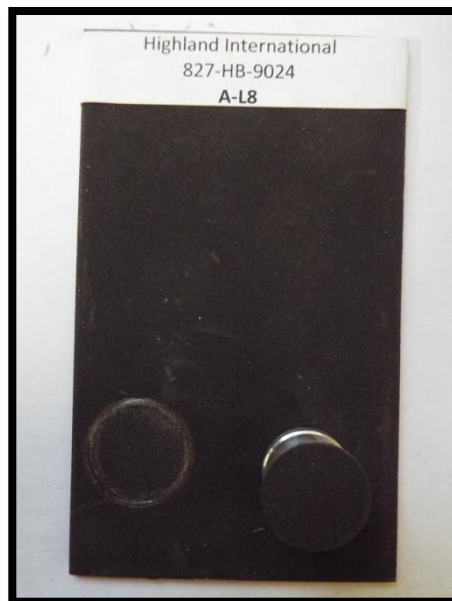
All pull offs were noted as 100% cohesive failure at given psi.



A-L7

Pull Off: 300 PSI

Cross Hatch: 3A



A-L8

Pull Off: 300 PSI

Cross Hatch: 3A

Group “BL” Panel Represents Competitor #1 Multipolymeric Matrix Coating

All pull offs were noted as 100% cohesive failure at given psi.



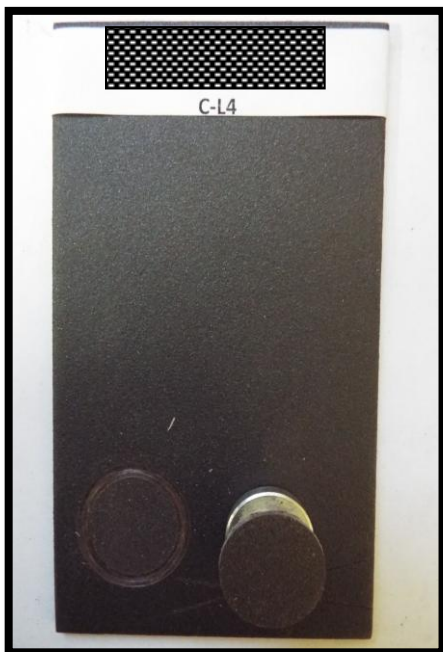
B-L4

Pull Off: 0 PSI

Cross Hatch: 3A

Group “CL” Panel Represents Competitor #2 CUI Coating

All pull offs were noted as 100% cohesive failure at given psi.



C-L4

Pull Off: 300 PSI

Cross Hatch: 3A

Long Term Post-Test Panels (Salt-Fog Results)

ASTM B117 Practice for Operating Salt Fog

Group “AL” Panels Represent Highland International, Inc. 827-HB Series

(Top and bottom areas of each panel have been taped to protect from salt-fog affect)



A-L7

No rusting in the field



A-L8

No rusting in the field

Group “BL” Panel Represents Competitor #1 Multipolymeric Matrix Coating

(Top and bottom areas of each panel have been taped to protect from salt-fog affect)



B-L4

No rusting in the field

Group "CL" Panel Represents Competitor #2 CUI Coating

(Top and bottom areas of each panel have been taped to protect from salt-fog affect)



C-L4

No rusting in the field

Long Term Cryogenic Testing - Summary

Long Term Test Panel Grid							
Group	Panel ID	Visual Inspection	Microcracking (20 x zoon inspection)	Microcracking Pass/Fail	Adhesion (via Elcometer)	Adhesion (via Tape Test)	Salt-Fog
Highland 827-HB Series	AL-7	Excellent	None	Pass	300 psi	3A	Pass
	AL-8	Excellent	None	Pass	300 psi	3A	Pass
Competitor #1	BL-4	Excellent	None	Pass	0 psi	3A	Pass
Competitor #2	CL-4	Excellent	None	Pass	300 psi	3A	Pass

Excellent = No visual abnormalities

Good = Some visual abnormalities, no visual failure

Poor = Visual abnormalities and visual coating failure

All panels passed visual and magnified inspections for micro-cracking as well as salt fog testing. Adhesion for all coatings evaluated via cross-hatch (ASTM D3359) was found to be equal at 3A. Adhesion evaluated via Elcometer Pulls (ASTM D4541) showed the following averages/rankings:

#1 – Highland 827-HB Series & Competitor #2 with average pull-off strengths of 300psi

#2 – Competitor #1 had 0 psi pull-off strength

Cryogenic Testing Conclusions

Highland 827-HB Series is suitable for cryogenic service temperatures, in that such temperatures reached in these tests do not affect the overall performance of the product. Furthermore, it can be inferred that while all coatings tested may be suitable for cryogenic services, Highland 827-HB may perform as well or better than the 2 competitor products tested alongside 827-HB in these trials.