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Hexavalent-Chromium-Free Aluminum Sacrificial Paint Validation

A Paper based on a Presentation given at NASF SUR/FIN 2022 (Rosemont, Illinois)*
by
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Editor's Note: The following is a paper based on a presentation given at NASF SUR/FIN 2022, in Rosemont, Illinois on June 7, 2022, in Session 1, Aerospace / Defense Response to REACh. This is the second of two papers on the development of hexavalent-chromium-free aluminum sacrificial paints, this one from the user point-of-view – the process validation. The first, by McMordie, available at http://short.pfonline.com/NASF23Feb1, addresses the developer point-of-view.

ABSTRACT

Hexavalent chromium is a known carcinogen, repro-toxin and mutagen. Its elimination is of high importance to the aerospace industry, which has struggled to find high performing alternatives. Legacy aluminum sacrificial paints have traditionally utilized hexavalent chromium to prevent corrosion and coatings which are equal to or better than have been difficult. Many attempts have resulted in failure. In this paper, a body of results will be shared substantiating efficacy of a leading replacement. Performance testing included cyclic-synthetic-seawater (salt spray/humidity/ambient) corrosion testing, continuous neutral salt spray corrosion testing, cyclic salt spray / humidity corrosion testing, cyclic salt spray / heat / humidity corrosion testing, heat resistance testing, fluid resistances testing, adhesion testing, conductivity/resistivity, metallography, quality, stripping, and touch up.

Introduction and background

Hexavalent chromium is a known carcinogen, repro-toxin, and mutagen. Its elimination is of high importance to the aerospace industry which has struggled to find high performing alternatives. Legacy aluminum sacrificial paints have traditionally utilized hexavalent chromium to prevent corrosion and oxidation of steels. Due to the high performance nature of these coatings, work to approve alternate coatings has been difficult. To date, most attempts have failed. A concurrent paper by McMordie, available at http://short.pfonline.com/NASF23Feb1, addresses the work involved in the product development of a leading replacement, a novel proprietary hexavalent-chromium-free aluminum sacrificial paint, Alseal 5KGT, developed by Coatings For Industry, Inc. (CFI), of Souderton, Pennsylvania. This paper covers the work toward successfully validating the product by the user, Rolls Royce Corporation.

Aluminum Sacrificial Paints (ASPs) have been used by the aerospace industry for decades to protect steel from corrosion and oxidation. A hexavalent chromium-free alternate to the traditional ASP systems (traditionally containing hexavalent chromium as a critical part of their binder system) has been a challenge for materials engineering in the aerospace industry for decades. Rolls-Royce Corporation has evaluated alternates; however, the latest data is promising that this challenge can be met. Coatings for Industry's Alseal 5KGT, and its historical progenitors, have been evaluated over the years by Rolls-Royce Corporation. This paper summarizes the trials performed by Rolls-Royce Corporation and the favorable data it has generated.

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Traditional ASPs are a layer of aluminum powder held against steels by a ceramic binder system. In many instances, this "base coat" is aided by an additional "sealer" layer, which is the binder system (only) applied over top as a barrier. Notably, it also acts to passivate the base coat. This system allowed for improved protection as well as providing coloration if desired. Given that hexavalent chromium is one of two components in the inorganic polymeric binder architecture, a novel binder system has been very challenging, not just within the base coat system but also with respect to the ability of the seal coat to passivate. Coatings for Industry's novel approach to provide a base coat polymer architecture but also to overcome the challenges associated with the seal coat and its important function as a passivating layer has been a boon.

Rolls-Royce recognizes that the nature of the novel coating requires the base and seal coats to perform as a system; that they not be used independently and specifies this. Rolls-Royce tested this novel coating system against typical performance requirements required to approve traditional ASPs (containing hexavalent chromium) and to demonstrate results which exceed these requirements.

The performance tests focus on corrosion resistance but must include full characterization of the thermal limits of the coating. The tests performed include:

- Adhesion
- Corrosion resistance:
  - Continuous neutral salt spray per ASTM B 117
  - Cyclic synthetic sea-water humidity (US Navy test)
  - Cyclic salt spray and heat
  - Cyclic salt spray, humidity, and heat
  - Throwing power
- Thermal resistance testing followed by continuous neutral salt spray testing
- Electrical properties (conductivity of base coat and non-conductivity of seal coat)
- Metallography
- Touch up
- Strip and recoat
- "Throwing Power"

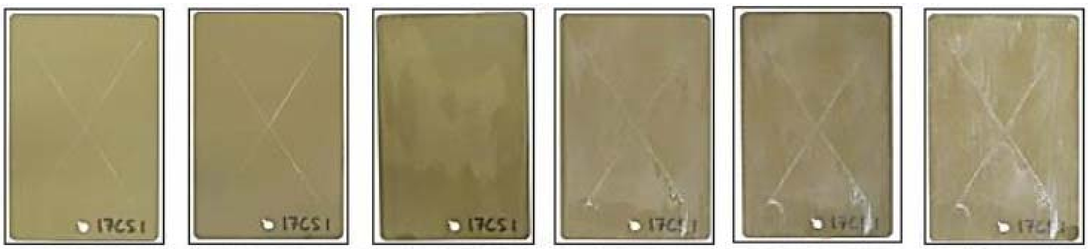
			Corrosion Tests						Fluid Resistance			Adhesion		Electrical			
		Qual	Navy CRD[1]	SS	BiCyc	TriCyc	TP	Heat	Hyd	Fuel	Oil	Xcut	Bend	Cond	Res	Met	
	Report Section:	3.2	3.3.1	3.3.2	3.3.3	3.3.4	3.3.5	3.4	3.5.1	3.5.2	3.5.3	3.6.1	3.6.2	3.7.1	3.7.2	3.8	Panel sub-tota
	Coating Config	Panel ID															
Legacy System	Base Scribed	all	NLB1 NLB2	--	--	--	--	--	--	--	--	--		(NLB1 NLB2) b4 CRD	--	--	2N
Legacy System	Base + Seal Scribed	all	NLS1 NLS2	--	--	--	--	LH850 LH900 LH950 LH1000 LH1050 LH1100 LH1150 LH1200	--	--	--	--		--	(NLS1 NLS2) b4 CRD	(extra)	2N + 8Q
Legacy System	Base + Seal Scribed & Touched-up	all	NLT1 NLT2	--	--	--	--	--	--	--	--	--		--	--	--	2N
Candidate System	Base Not Scribed	all	--	--	--	--	--	--	--	--	--	--		CBCo	--	--	1Q
Candidate System	Base + Seal Not Scribed	all	--	--	--	--	TP1 TP2	--	--	--	--	--		--	--	--	2Q
Candidate System	Base + Seal Scribed	all	NCS1 NCS2 NCS3 NCS4	17CS1 17CS2 17CS3 17CS4	Bi1 Bi2 Bi3	Tri1 Tri2 Tri3	--	CH850 CH900 CH950 CH1000 CH1050 CH1100 CH1150 CH1200	HF1 HF2	F1 F2	TO1 TO2	AD1	AD2	--	(NCS1 NCS2) b4 CRD	(AD1 AD2)	4N + 26Q
Candidate System	Base + Seal Scribed & Touched-up	all	NCT1 NCT2	17CT1 17CT2	--	--	--	--	--	--	--	--		--	--	--	2N + 2Q
	Panels sub-total:	0	12N[1]	6Q[3]	3Q	3Q	2Q	16Q	2Q	2Q	2Q	1Q	1Q	1Q	0Q	0Q	12N +

Figure 1 - Test matrix used to evaluate performance of legacy Al sacrificial paint with Alseal 5KGT paint.

The test matrix is shown in Figure 1. The testing was designed to compare the legacy aluminum sacrificial paint containing hexavalent chromium with the chromium-free Alseal 5KGT candidate system. While the pass/fail performance data for the legacy system was well established in industrial practice, a number of the more rigorous military and aerospace specifications required concurrent side-by-side comparison.

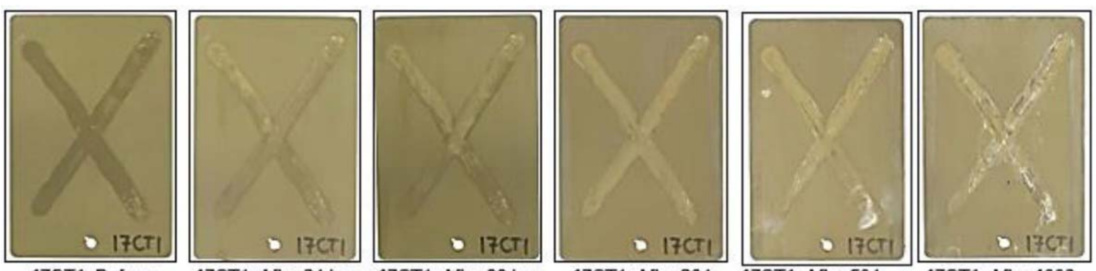
Corrosion testing

Corrosion test results are shown in Figs. 2 thru 6. The ASTM B-117 continuous neutral salt spray (Column "SS" in Fig. 1) was run for 1,008 hours, or 42 days. Scribed Alseal 5KGT panels were examined at intervals of 24, 96, 204, 504 and 1008 hours of exposure, and passed inspection. The results for panel 17CS1 are shown in Fig. 2. Additional scribed panels were touch up after scribing and subject to the 42-hour NSS; the results for panel 17CT1 are shown in Fig. 3.



17CS1: Before exposure | 17CS1: After 24 hrs of exposure | 17CS1: After 96 hrs of exposure | 17CS1: After 204 hrs of exposure | 17CS1: After 504 hrs of exposure | 17CS1: After 1008 hrs of exposure

Figure 2 – ASTM B-117 42-day neutral salt spray performance result for scribed Alseal 5KGT, examined at specified intervals.



17CT1: Before exposure | 17CT1: After 24 hrs of exposure | 17CT1: After 96 hrs of exposure | 17CT1: After 204 hrs of exposure | 17CT1: After 504 hrs of exposure | 17CT1: After 1008 hrs of exposure

Figure 3 – ASTM B-117 42-day neutral salt spray performance result for scribed and touched-up Alseal 5KGT, examined at specified intervals.

Referring to Figure 1, the "BiCyclic" corrosion test involved 20 days of salt spray and thermal cycling, while the "TriCyclic" corrosion test involved 10 days of salt spray, humidity, and thermal cycl~~ic~~ing. The test specimens were examined at several intervals and passed both tests satisfactorily. The BiCyclic and TriCyclic test results are shown in Figs. 4 (Sample Bi1) and 5 (Sample Tri1), respectively.

Bi1: Before bicyclic exposure | Bi1: After 24 hrs of exposure | Bi1: After 96 hrs of exposure | Bi1: After 204 hrs of exposure | Bi1: After 336 hrs of exposure | Bi1: After 480 hrs of exposure

Figure 4 – BiCyclic corrosion / thermal cycling performance result for scribed Alseal 5KGT, examined at specified intervals.

Figure 5 – TriCyclic corrosion / thermal cycling performance result for scribed Alseal 5KGT, examined at specified intervals.

Navy corrosion testing was performed against the standard US Navy Components Requirements Document which instructs for a complex 50-day cyclic test including ambient, heating, humidity and synthetic sea water salt spray. Figure 6 shows the comparative results for both the legacy and Alseal 5KGT paints for (1) base coat with no seal, scribed, (2) base coat plus seal, scribed, and (3) base coat plus seal, scribed, and touched up. Alseal 5KGT performance was equal or better than the legacy system.

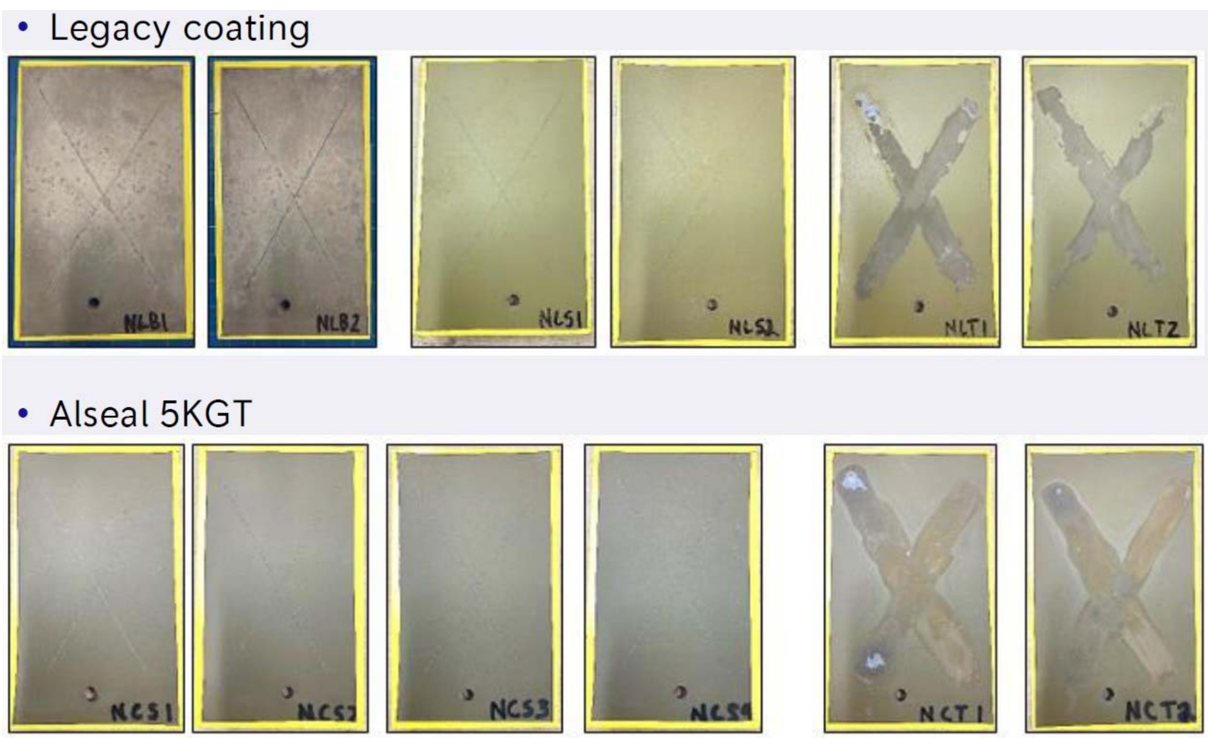


Figure 6 – Coated steel panels after 50-day U.S. Navy cyclic test. The first pair of panels in each row were coated with sacrificial basecoat alone (with no seal coat) and scribed, the second pair of panels were coated with sacrificial base coat and seal coat and then scribed, the third pair of panels were coated with sacrificial base coat, sealed, scribed and then touched up. Performance of Alseal 5KGT (lower row) was equal to or better than that of the legacy system (top row)

A Throwing Power corrosion test was developed by the author to attempt to determine the extent of protection afforded to the un-coated base metal surfaces due to adjacent coating. A triangular segment of the coating was stripped from a panel coated with Alseal AKGT. The panel was then subjected to salt fog. The novel coating prevented corrosion of bare steel up to ~0.030" from the coating edge.

Thermal resistance

The thermal resistance study for the legacy coating involved a 42-day (1008-hr) thermal exposure at 1100°F. followed by neutral salt spray exposure. The results are shown in Fig. 7, for various intervals over the heat exposure process. The neutral salt spray exposure was 21 days (504 hr). Increasing the exposure temperature to 1150°F caused deterioration of the coating and the salt spray exposure was terminated at 48 hr (Fig. 8).

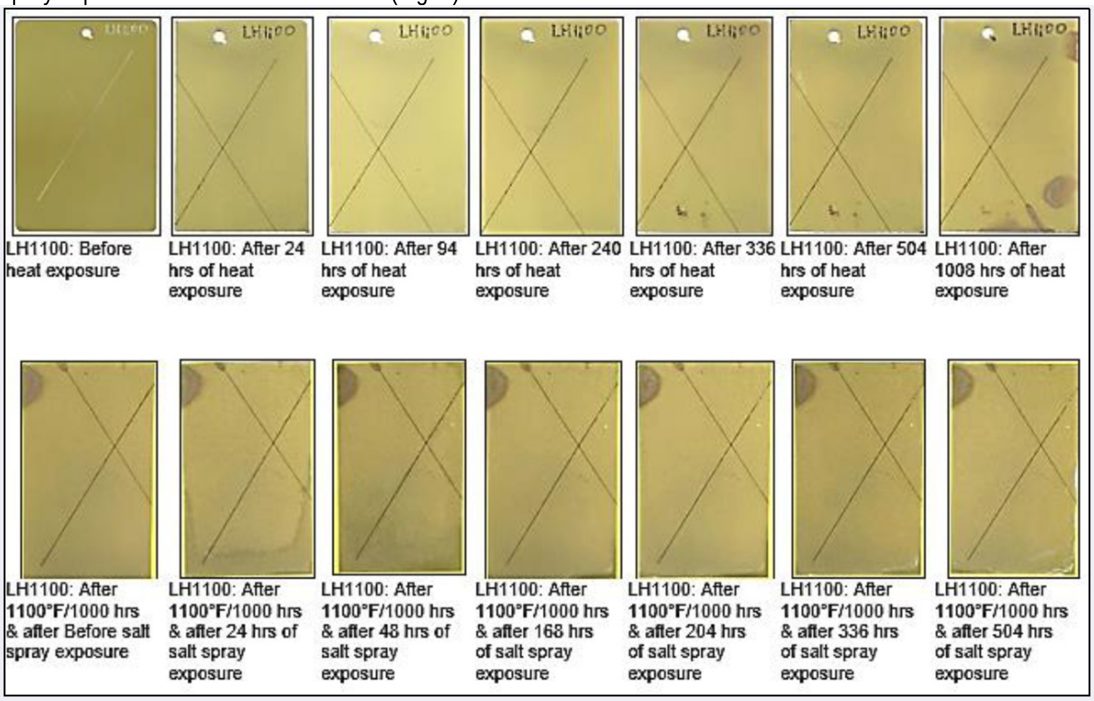


Figure 7 – Thermal resistance study of the legacy coating at 1100°F.

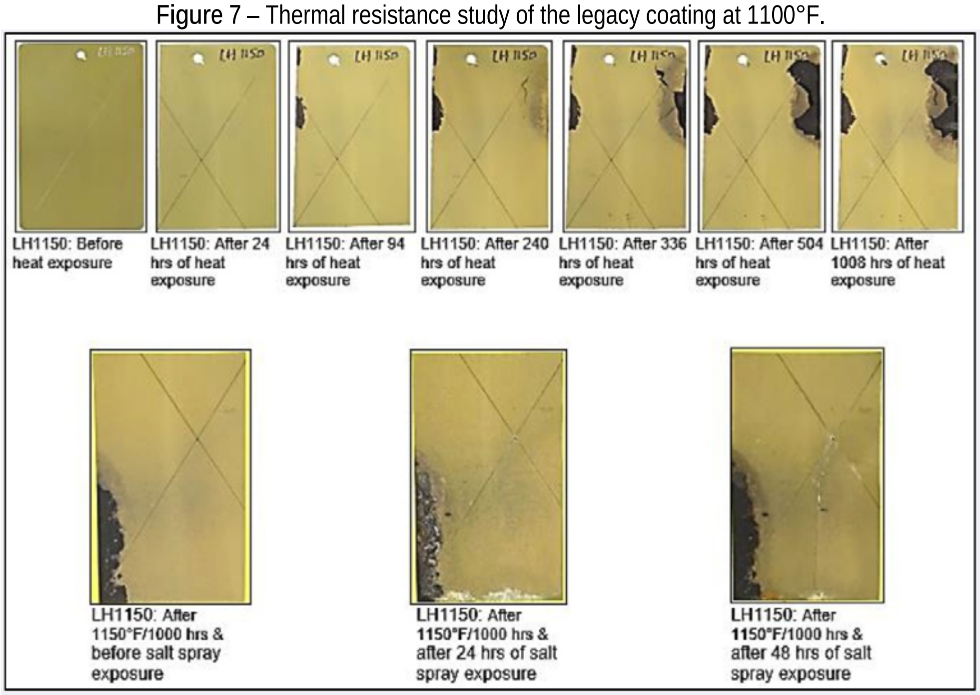


Figure 8 – Thermal resistance study of the legacy coating at 1150°F.

Thermal resistance performance of the Alseal 5KGT is shown in Figs. 9 and 10, for exposure temperatures of 1000°F and 1050°F, respectively. As before, the salt spray for the higher temperature was discontinued after 48 hours, with deterioration of the coating.

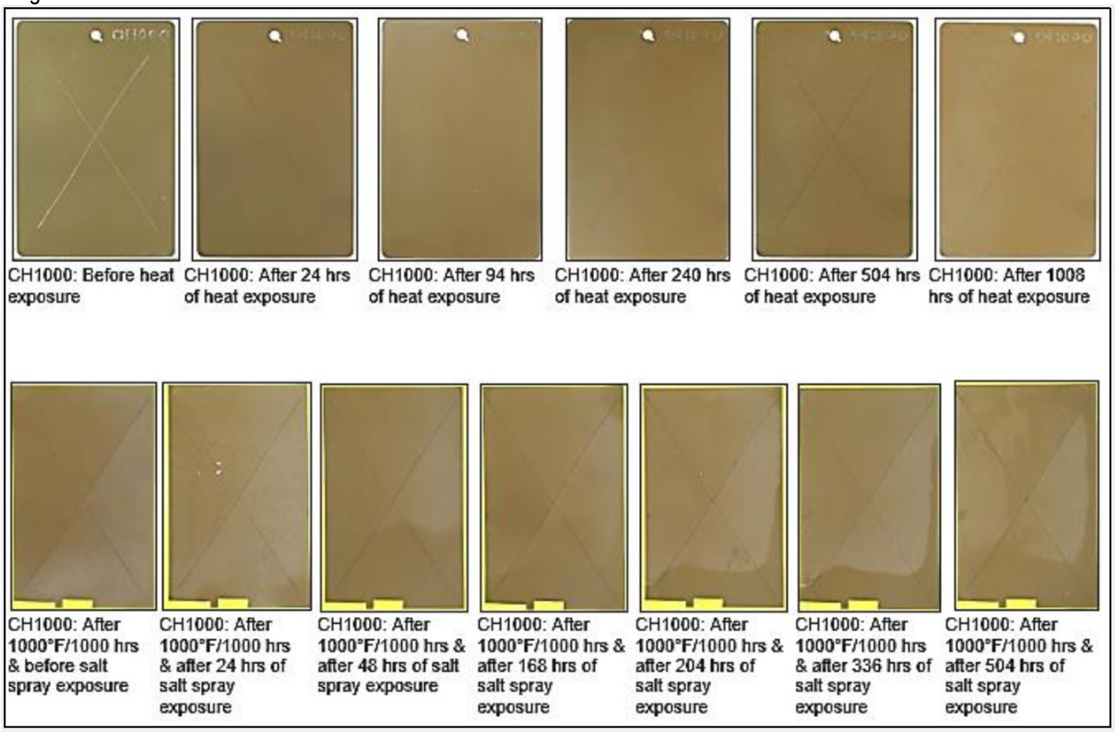


Figure 9 – Thermal resistance study of the Alseal 5KGT coating at 1000°F.

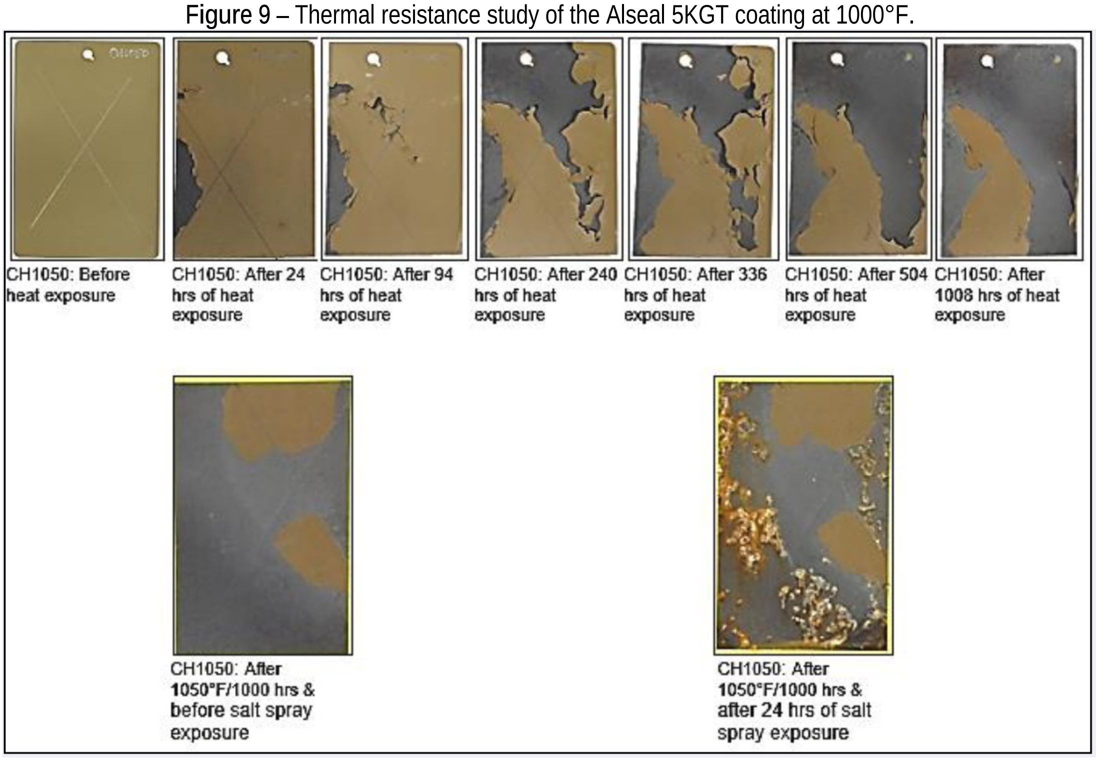


Figure 10 – Thermal resistance study of the Alseal 5KGT coating at 1050°F.

Results summary

The complete test results are summarized in Fig. 11. Where the Alseal 5KGT passed performance requirements, the novel hexavalent chromium-free was shown to have met the established criteria for visual quality, corrosion resistance, fluid resistance, adhesion and electrical properties. The other results, including heat resistance, are reported for information. In general, the results indicate success for many applications.

Table 1a: Results Summary of Alseal 5KGT Testing

Test Category	Test Names	Result
Quality	Visual Inspection Criteria	Pass
Corrosion	USN/LF CRD (Cyclic Synthetic Sea Water Salt Spray / Heat / Humidity)	Pass
	Salt Spray, Continuous Neutral	Pass
	Cyclic Salt Spray / Heat ("Bi-Cyclic")	Pass
	Cyclic Salt Spray / Humidity / Heat ("Tri-Cyclic")	Pass
	Throwing Power	Info
Heat Resistance	Bake + Salt Spray	Info
Fluid Resistance	Hydraulic Fluid	Pass
	Fuel	Pass
	Oil	Pass
Adhesion	Cross Cut Tape	Pass
	Bend	Pass
Electrical Properties	Conductivity	Pass
	Resistivity	Pass
Metallography	Cross Section	Info
Fatigue Debit	RR Moore Rotating Beam	Info
Thickness of panel coating	ISO 2808 or ASTM B244 or ASTM D1005 or RRMS 30037-5	Info

Table 1b: Other Data Summary

Coating Touch-Up Method	Info
Coating Strip Method	Info

Figure 11 – Summary of test results.

About the author

Brad Wiley is Chemical Process Specialist and member of the Materials Technology Center within Materials Engineering at Rolls-Royce Corporation, Indianapolis, Indiana. He began his career as a plating chemist, has been a metallurgist, a chemical process engineer, repair engineer within the aftermarket validating repair and overhaul of engine components, and in 2010 moved to his current position as a researcher responsible for chemical processes as well as Rolls-Royce's global paint strategy.