Silicone ice-release coatings

Rob Thomaier, Sr. Technical Sales Representative Danielle Peak,
Technical Writer, NuSil Technology LLC, Carpinteria, CA, USA

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Ice adhesion is a major concern in the aircraft industry because ice buildup affects many aspects of flying. Ice build-up on rotary aircraft blades can affect efficiency by reducing the aerodynamics of the blades.

WHITE PAPER

INTRODUCTION

Ice adhesion is a major concern in the aircraft industry because ice buildup affects many aspects of flying. Ice build-up on rotary aircraft blades can affect efficiency by reducing the aerodynamics of the blades. When ice builds up on the leading edges of aerodynamic surfaces, it decreases lift and increases drag; wind tunnel tests show very thin ice sheets can reduce lift by as much as 30% and increase drag by 40%.1 Ice can add additional mass to the blades, putting stress on the aircraft which can culminate in catastrophic failure. The sudden release of ice through centripetal force can result in dangerous ice projectiles that can damage the aircraft. Uneven release of ice can unbalance helicopter rotor system, resulting in unwanted vibration. Ice-release coatings aid in the release of ice and can even reduce ice build-up.

A variety of solutions exist, modeled after many of the solutions used for aircraft: heaters to melt the ice, fluids to lower the freezing point of water, and coatings to minimize ice adhesion. Ice-release coatings aid in the release of ice and can reduce ice build-up. Applying coatings that reduce ice adhesion is a practical and economical choice for rotorcraft manufacturers.

In recent years, silicone coatings have gained popularity in many aircraft applications due to their broad operating temperature range, resistance to many different aviation fluids, and effective ice-release performance. In general, silicones are elastomeric and flexible at extreme temperatures, making them excellent coatings and sealants; some silicones have a glass transition temperature (Tg) of -142°C.

Currently, many materials are commercially available and marketed as ice-release. Many of these materials were tested and ranked in a study by Haehnel and Mulherin in 1998.5 More recently, another round of materials was tested and reported in Laboratory Ice Adhesion Test Results for Commercial Ice-release Coatings for Pratt & Whitney at the Cold Regions Research and Engineering Laboratory (CRREL) –including a silicone coating from NuSil Technology LLC. Further testing was conducted to compare the anti-icing performance of various silicone ice-release coatings. Several materials were evaluated using the Zero Degree Cone Test at CRREL. These silicone materials performed very well, significantly better than the control material, Teflon®.

Besides more evaluations via the Zero Degree Cone Test at CRREL, additional testing consisted of an experimental ice adhesion test by NuSil Technology and an icing rotor test using silicone-coated airfoils in an icing chamber.

PRATT & WHITNEY ICE ADHESION TEST

The initial phase of the ice adhesion testing discussed here involved twelve replicates, each of six different ice-release coating sprays applied to aluminum test pins. Each sample was rinsed at least two times with isopropyl alcohol (except the coatings by Microphase based on this company's recommendation prior to performing ice adhesion tests2).

The adhesion strength of ice to these ice-release coatings was tested and compared using a test method developed by CRREL. The method measures the bond strength of ice to a coated pin. An image and schematic of the test stand is shown in Figure 1. Water is added to a mold surrounding the coated pin and then frozen. An O-ring placed at the bottom of the inner cylinder keeps any water from leaking out before it freezes. After spending eight hours at -10°C, the samples were allowed to rest for another 40 hours at freezing temperatures before being tested. The force required to push each pin out of the ice mold was quantified to determine the adhesive strength of the ice.

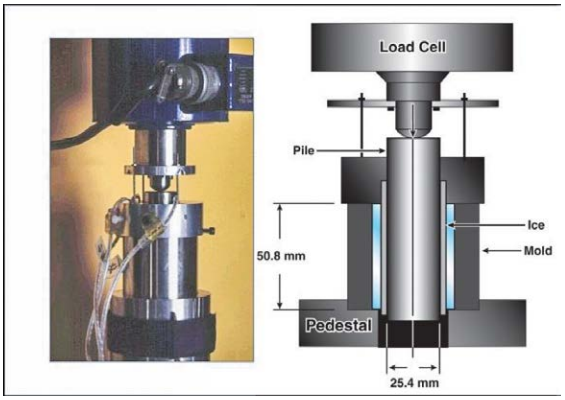


Figure 1. Instrumental sample pile and mold in testing machine (left) and Zero-Degree cone test stand configuration (right).

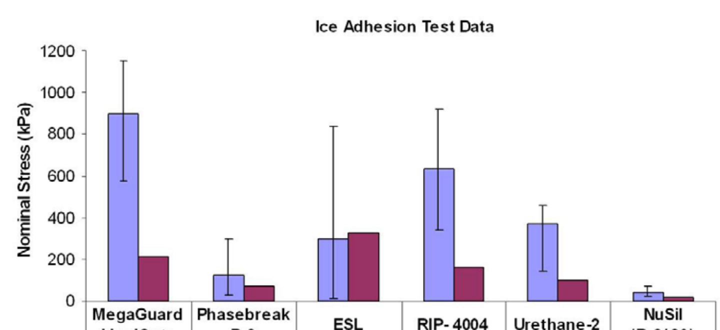
[1] Mulherin, N.D., Haehnel, R.B., Jones J.F., "Toward developing a standard shear test for ice adhesion". Proceedings, 8th International Workshop on Atmospheric Icing Structures, Reykjavik, Iceland, 8-11 June 1998. IWAIS 1998.

[2] Laboratory Ice Adhesion test Results for Commercial Ice phobic Coatings for Pratt & Whitney, May 2004, CRREL.

RESULTS AND DISCUSSION

Load-displacement plots for each test performed were collected and are available with the CRREL report. Figure 2 summarizes these results. The Y-axis describes the shear stress required for ice releaseâ€"the value calculated from the average load required to remove the ice from the surface. The mean and standard deviation were derived from 12 replicates. The error bars indicate the range in stress values for each group of samples.

Prior to this study, TeflonÂ® consistently exhibited the lowest failure values, at 238 kilopascals (kPa). However, it is apparent that the silicone R-2180 demonstrates the least amount of nominal stress, 37 kPa, when compared to the other commercially available ice-release coatings tested. Phasebreak B2 and ESL also had low adhesion strength, at 117 and 295 kPa, respectively. However, both coatings show high variability and standard deviation. These discrepancies are associated with the observation that the ice was in various states of solidification. It was observed in the CRREL report that several of the replicates from both Phasebreak B-2 and ESL exhibited traces of unfrozen water on the top and bottom of the samples. These materials are subject to inconsistencies due to solutes leaching from the coatings into the water that lower the freezing point of the surrounding water.



	MegaGuard LiquiCote	Phasebreak B-2	ESL	RIP- 4004	Urethane-2	NuSil (R-2180)
Mean	898	117	295	637	374	37
Std Dev	210	72	322	160	96	14

Figure 2. Laboratory Ice Adhesion test Results for Commercial Ice-release Coatings for Pratt & Whitney, May 2004, CRREL.

The US Army Corps of Engineers of the Department of the Army conducted a study to evaluate the adhesion strengths of several commercially available materials, coatings, and paints known to have low friction or non-stick properties (See Figure 3.)3 Similar to results from the Pratt & Whitney study, R-2180 performed better than the other coatings and materials tested. In fact, it decreased the adhesion strength over bare steel by a factor of 40.

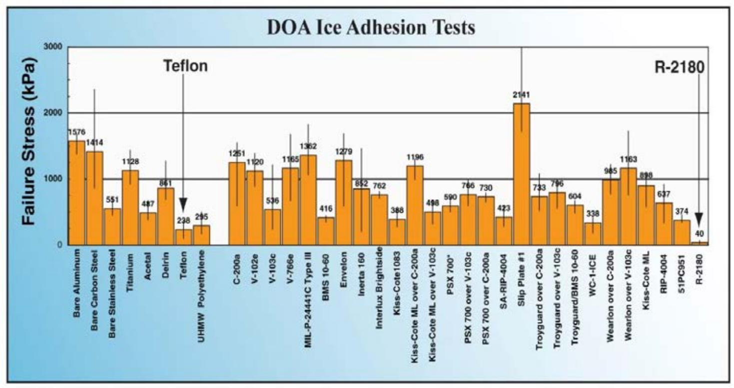


Figure 3. Ice adhesion test results for construction materials and commercial coatings from DOA Manual; R-2180 is on the far right. Error bars represent the range in data.

Zero degree cone test on silicone ice-release coatings

Following the release of the test results for Pratt & Whitney, more silicone coatings were tested using the Zero-Degree Cone test to further investigate their ice adhesion. Two basic types of silicone coatings were tested: fluorosilicones (fuel resistant) and dimethyl silicones (low Tg). These coatings are listed in Table 1, below.

Sample Name	Material Type
R-1009	RTV Silicone Coating (dimethyl silicone)
R-1082	RTV Silicone Coating (dimethyl silicone)
R-3930	RTV Fuel Resistant Silicone Coating (fluorosilicone)
R-3975	RTV Fuel Resistant Silicone Coating (fluorosilicone)
R-2180	Heat Curing Silicone Coating (dimethyl silicone)

Table 1. Coating Names and Descriptions

[3] EM 1110-2-1612, Engineering and Design – Ice Engineering, U.S. Army Corps of Engineers, Department of the Army, 20 October, 2002, UPDATED VERSION: September 2006.

Results and Discussion

The additional silicone coatings all resulted in a mean stress value of less than 47kPa as shown below in Figure 4.

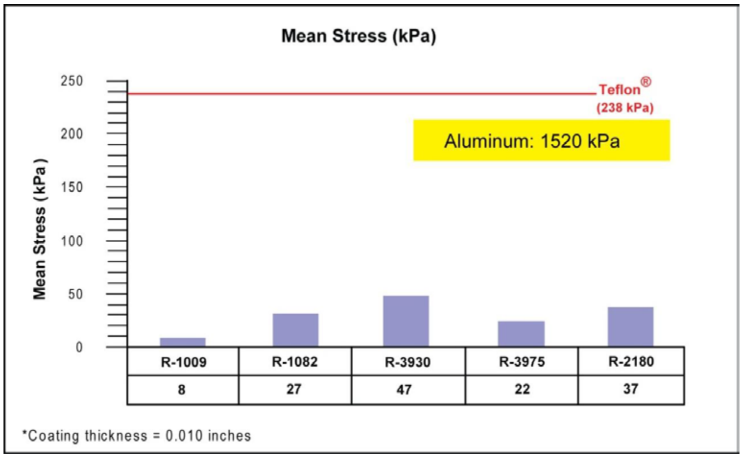


Figure 4. Ice adhesion test results for additional silicone coatings relative to Teflon® and bare aluminum4.

Addressed in this test was the effect of environmental conditions and wear on the coatingsâ€™ de-icing abilities. Figure 5 shows how R-2180 performs after exposure to various environmental conditions, including physical wear, thermal cycling, humidity cycling, and salt spray. The durability of R-2180 coated aluminum pins was tested by roughening the surface with sand paper prior to the Zero-Degree Cone Test to simulate the influence of wear. Figure 5 shows that although the worn R-2180 surface did not perform as well as a freshly applied coating of R-2180, it still outperformed the TeflonÂ®. Furthermore, when coated pins were exposed to extreme thermal conditions, humidity cycles, and sprayed with a salt-water solution prior to ice adhesion testing; R-2180 continued to outperform TeflonÂ®.

[4] Laboratory Ice Adhesion test Results for Commercial Ice-release Coatings for Pratt & Whitney, June 2009, Robert B. Haehnel, CRREL.

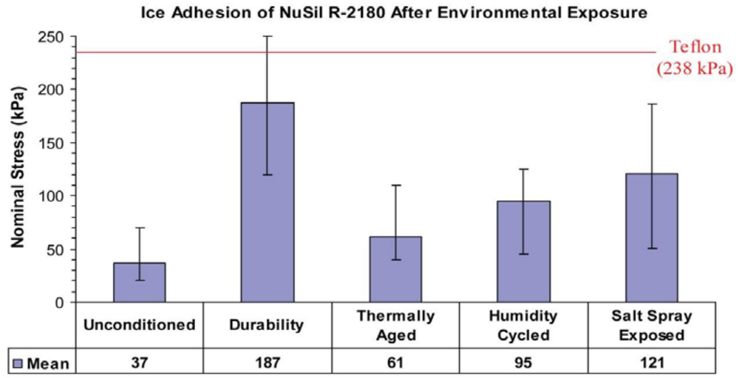


Figure 5. Post Conditioning Ice Adhesion Pin Testing at CRREL.5

The graph below displays Zero Degree Cone Test ice-release performance results for R-2180, R-3930, R-3975, R-1009, and R-1082. These silicone coatings were evaluated alone as well as in combination with R-1182, a one-part, fast cure RTV complementary silicone coating that prevents the silicone from being a particle gatherer.

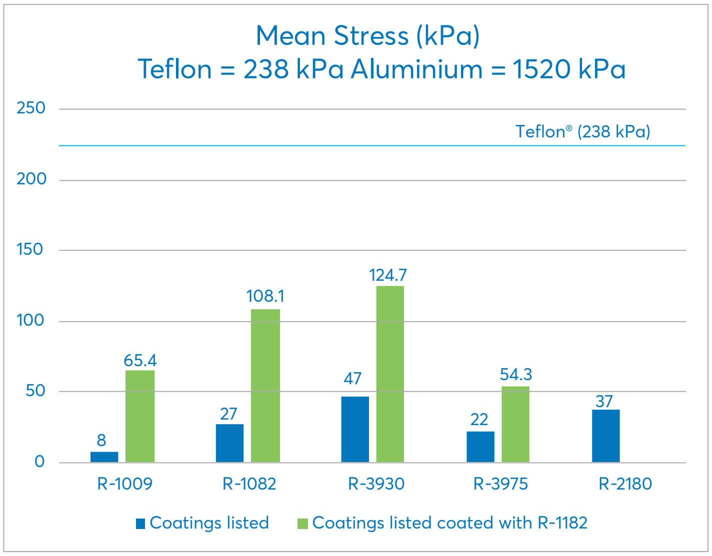


Figure 6. Ice adhesion results for silicone ice-release materials with and without R-1182 on bare 2024 aluminum.

cR-3975 had the lowest ice adhesion strength of the two fuel resistant coatings, as well as the lowest overall result when the coatings were tested in combination with R-1182. R-3975 also showed the lowest discrepancy in ice adhesion strength from being tested neat versus evaluated with R-1182 topcoat.

Experimental Ice-release coating evaluation test

After the Zero Degree Cone Test, the materials in Table 1 were also tested using an experimental NuSil Technology test method. For this test, ice-release coatings were applied to primed aluminum panels. A Teflon ring was securely clamped to each coated panel and placed in the freezer then the Teflon rings were filled with water. After 24 hours in the freezer, the test samples were individually transferred to a force tester in a cold chamber (See Figure 7.) and the ice adhesion strength to the panels tested at -10°C. The panels were tested in triplicate per coating, and the averaged result for each was calculated in pounds per square inch (psi).

Figure 7. The panel and filled Teflon ring apparatus inside the environmental chamber prior to being tested.

RESULTS AND DISCUSSION

Unlike the Zero Degree Cone Test, this ice-release coating test quantifies ice adhesion on a flat surface to more closely simulate practical applications. The normalized data is depicted in Figure 8. Bare aluminum panels were used as controls. Note that the force required to remove ice from panels coated with R-1082/R-1182 is listed at zero psi. This is because all three ice blocks fell off the test panels, with gentle handling, prior to testing; the ice didn't adhere at all to this coating.

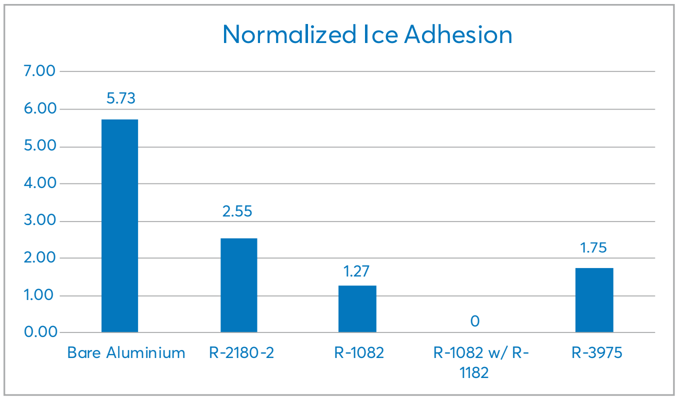


Figure 8. Normalized ice adhesion using NuSil's new experimental test method.

Icing environment rotor test

The icing rotor test was conducted at Penn State's Adverse Environment Rotor Test Stand to expand NuSil's ice-release evaluation. R-1082 and R-1082 coated with R-1182, the low coefficient of friction complimentary coating, were tested. Samples were 10" x 4" aluminum airfoils coated with silicone at 3–5 mils thick. Testing was conducted at Penn State Vertical Lift Research Center of Excellence. A photo of the test apparatus is shown in Figure 9.

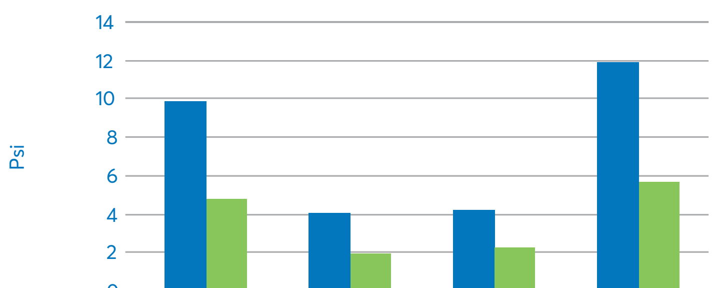
Figure 9. Adverse Environment Rotor Test Stand at Penn State Vertical Lift Research Center of Excellence.

The airfoil samples are attached to the outer edge of the blades and tested at two different temperatures: -8°C to generate glaze ice and -12°C for rime ice. The mass of the ice accretion is calculated by the voltage required to spin the airfoils on the rotating blades.

RESULTS AND DISCUSSION

The two different temperatures illustrate the adhesion difference between glaze and rime ice: the 4° decrease in temperature bore significant effect on the ice adhesion to each of the coatings. In correlation with the results from CRREL and NuSil's experimental test, the R-1082 dimethyl silicone performed very well, reducing the ice adhesion by more than half compared to the control, uncoated aluminum. The R-1082A and R-1082B are replicates of the same coating. The discrepancy between the results for R-1082/R-1182 topcoat from the NuSil test and the wind tunnel test suggests some of the difficulty of evaluating ice-release coatings in the laboratory. It would be especially beneficial to further evaluate the ice-release performance of these formulations in the field.

Ice Adhesion Strength



	Control	R1082A	R1082B	R1082/R1182
-12 °C	9.84	4.06	4.24	11.93
-8 °C	4.74	1.92	2.27	5.65

Figure 10. Icing rotor test adhesion results.

CONCLUSIONS

The implications of ice buildup have resulted in multiple efforts to understand and improve ice-release coatings. Tests performed by CRREL, NuSil Technology and Pennsylvania State University have shown that silicone coatings significantly reduce ice adhesion compared to uncoated surfaces and even other commercially marketed ice-release materials. The results of the Zero Degree Cone Test, NuSil Technology's experimental ice adhesion test, and the wind tunnel test further attest to the overall efficacy of silicone materials as ice-release coatings. These coatings are not deicing technologies but they are ice-releasing; in other words, they do not prevent ice formation, but they do allow ice to break easily from surfaces.

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