Spring 2019

Requalification of Coated Fabrics using Chemlok 2332 in place of Chemlok 233

Daniel Madler
djm190@zips.uakron.edu

Requalification of Coated Fabrics using Chemlok 2332 in place of Chemlok 233

Daniel Joseph Madler

Department of Chemical and Biomolecular Engineering

Honors Research Project

Submitted to

The Honors College

Approved:

Bi-min Zhang Newby Date 4-16-19
Honors Project Sponsor (signed)

Bi-min Zhang Newby
Honors Project Sponsor (printed)

Tina Darnell Date 10-30-18
Reader (signed)

Tina Darnell
Reader (printed)

Madeline M. Busch Date 10/30/18
Reader (signed)

Madeline Busch
Reader (printed)

Accepted:

H M Cheung Date 23 APR 2019
Department Head (signed)

H. MICHAEL CHEUNG
Department Head (printed)

Bi-min Zhang Newby Date 4-16-19
Honors Faculty Advisor (signed)

Bi-min Zhang Newby
Honors Faculty Advisor (printed)

__________________ Date _________
Dean, Honors College

Requalification of Coated Fabrics using Chemlok 2332 in place of Chemlok 233

4200:497-002

Recipients:
Dr. Bi-min Zhang Newby
Tina Darnell
Madeline Busch

Author: Daniel Madler

Date: 4-2-2019

Table of Contents

Executive Summary

Problem Statement

The intended purpose of this project is to qualify an environmentally friendly replacement for the discontinued Chemlok 233 adhesive cement used in natural rubber coated fabric applications at UTC Aerospace Systems. Lord Corporation discontinued Chemlok 233 because it contained trichloroethylene, TCE, and was deemed environmentally unsafe by the EPA. UTC Aerospace Systems uses Chemlok 233 in various applications in their deicer product line, including coated fabrics, which add strength to the deicers. A previous co-op, Madeline Busch, helped UTC find a suitable replacement in base cement usage at the manufacturing plant in Union, WV. The work done by Madeline only covered internal cement usage, and that left the externally manufactured coated fabrics unchanged and still in need of a replacement. Three coated fabrics produced by external manufacturers use Chemlok 233 in the primer cement as per UTC specifications. The objective was to compare the current coated fabric to an alternate coated fabric that used Chemlok 2332 in place of Chemlok 233. The breakdown for deicer builds can be found in **Table 1** and it is recommended to view this table to help alleviate confusion when reading the results. It should be noted that Deicer B and C are both made using the same materials in question, but the build style, amounts, and other materials used vary enough to create to unique products.

Results

The three coated fabrics, defined as Coated Fabric A, Coated Fabric B, and Coated Fabric C, were tested against their counterparts; Exp Coated Fabric A, Exp Coated Fabric B, and Exp Coated Fabric C, respectively. Coated Fabric A is made using Cement A, and Exp Coated Fabric A is made using an experimental version of Cement A which replaces Chemlok 233 with Chemlok 2332. Coated Fabrics B and C are both made using Cement B, and Exp Coated Fabrics

B and C are made with the experimental version of Cement B, which again replaces Chemlok 233 with Chemlok 2332. Each coated fabric is made up of a nylon fabric that is coated in primer cement and then a rubber compound is calendered into the fabric to adhere to the fabric. The primer cements currently have Chemlok 233 in their formulations. Adhesion data from the supplier and manufacturing facility showed Coated Fabric A to have average values of 20.56piw (or lbf/inch) and 17.51piw, respectively, compared to Exp Coated Fabric A having values of 18.04piw and 22.42piw, respectively. Deicer A, built with Coated Fabric A, had an average flex life of 13,369 cycles, compared to Exp Deicer A, built with Exp Coated Fabric A, with an average flex life of 16,542 cycles.

Coated Fabric B had average adhesion values of 16.61piw and 22.57piw and Exp Coated Fabric B had values of 51.37piw and 35.50piw. Deicer B, built with Coated Fabric B and Coated Fabric C, had an average flex life of 8,656 cycles and Deicer C, built with Coated Fabric B and Coated Fabric C, had an average flex life of 8,800 cycles. Exp B Deicer B (built with Exp Coated Fabric B and Coated Fabric C) had an average flex life of 5,767 cycles, and Exp B Deicer C (built with Exp Coated Fabric B and Coated Fabric C) had an average flex life of 17,970 cycles.

Lastly, Coated Fabric C had average adhesion values of 23.76piw and 25.46piw, while Exp Coated Fabric C had values of 34.05piw and 39.52piw. Exp C Deicer B (built with Coated Fabric B and Exp Coated Fabric C) had an average flex life of 6,096 cycles, and Exp C Deicer C (built with Coated Fabric B and Exp Coated Fabric C) had an average flex life of 12,419 cycles. Each experimental deicer also passed a burst test where the deicer inflates to three times the standard operating pressure as specified.

Conclusions

All three experimental coated fabrics matched or surpassed their respective control counterpart in adhesion values. Adhesion data alone gives strong justification to the alternative fabric, but raw adhesion data is not enough to draw a full conclusion. The fit, form, and function of the deicers are the top priority for the company. Looking at the average flex life for each deicer is not enough to determine the performance of the coated fabrics, and the failure mode must be examined. Upon inspection of the failures, it was found that all deicers tested to failure did not involve a delamination of the coated fabric in question. Each experimental coated fabric passed adhesion testing as well and showed cohesive delamination. This information allows for the conclusion to be made that Exp Cement A, quantitatively and qualitatively speaking, qualifies as a suitable replacement for Cement A and Exp Cement B as a suitable replacement for Cement B. By approving Exp Cements A and B, Coated Fabrics A, B, and C will be updated, and subsequently Deicers A, B, and C.

Broader Implications

The main purpose of this project was to replace an obsolete cement primer used in production at UTC Aerospace Systems. It is important to note this primer contained an environmentally hazardous material (TCE) and by replacing this cement, UTC was able to continue production with no interruption.

Technical skills gained through this project include Instron machine testing and Pneumatic Deicer construction. Additionally, technical aptitude in problem solving and data analysis was improved as well as technical communication through working with the suppliers of the coated fabrics. Technical report writing skills and design techniques were also improved.

Recommendations

Moving forward, it is recommended that UTC continue testing alternate cement primers, as they become available, to optimize the performance and processing of the coated fabrics. Also, further investigation into the deicer design is considered, when new programs allow for optimization, to address known historical failure modes to increase flex life and performance.

Introduction

The objective of this project was to qualify 3 coated fabrics for UTC Aerospace Systems that would replace current coated fabrics that are no longer available for production. These coated fabrics can no longer be manufactured due to the discontinuation of Chemlok 233 adhesive cement. On August 31, 2016 Lord Corporation, the manufacturers of the Chemlok adhesive family, discontinued Chemlok 233 due to the use of TCE (Trichloroethylene) in this adhesive cement. TCE is a common solvent in the adhesive industry that has been found to be environmentally hazardous as well as toxic. Lord Corporation decided to move away from using TCE and stopped the production of Chemlok 233. UTC uses coated fabrics that are produced by external suppliers. The suppliers were advised to make a last time purchase of Chemlok 233 so as to have 1 years' worth of adhesive for qualification tests to be completed and evaluated.

Coated fabrics are an essential material used in production at UTC's manufacturing plant for reinforcement and carcass builds. UTC's manufacturing facility in Union, West Virginia, specializes in the production of pneumatic deicers for use on private and commercial airplanes. Pneumatic deicers are primarily made with rubber compounds and the use of coated fabrics provides structure to the part. The coated fabrics used by UTC are woven fabrics, typically treated with an RFL dip, that are coated with primer cement, and a rubber compound is then calendered onto the fabric. The purpose of this process is to create a reinforced rubber compound that can easily bond to other rubber compounds while also adding strength to the part.

This project focused on three coated fabrics that are currently in production at UTC suppliers, each of which utilize Chemlok 233 in the primer cement formulation. The primer cement formulations are owned by UTC. Due to proprietary issues, the names and formulas for the cements, coated fabrics, and deicers were changed for this project.

One coated fabric, Coated Fabric A, uses Cement A as the primer cement and was used in the production of Deicer A. Cement A has Chemlok 233 in the formulation, and so must be changed in order to be produced. Exp Cement A was created as a replacement for Cement A and will not have Chemlok 233 in the formulation, but rather Chemlok 2332, an adhesive that does not contain TCE, has been recommended by Lord Corporation, and was selected as a suitable replacement in UTC's in-house cement applications (Busch). This experimental cement was used to create Exp Coated Fabric A, and subsequently Exp Deicer A, each of which was tested to prove equivalency to their control counterpart.

Cement B, which also contains Chemlok 233, is used in the production of the other two coated fabrics, Coated Fabric B and Coated Fabric C. Additionally, Coated Fabric B and Coated Fabric C are both used in the manufacturing of Deicer B and Deicer C. Cement B had an experimental version made using Chemlok 2332 instead of Chemlok 233, this was named Exp Cement B. Exp Cement B was then used to make Exp Coated Fabric B and Exp Coated Fabric C. In order to test each deicer individually for the coated fabrics, two experimental deicers were built for each control. Exp B Deicer B will be Deicer B made using Exp Coated Fabric B and Coated Fabric C.

Exp C Deicer B was Deicer B made using Exp Coated Fabric C and Coated Fabric B. Exp B Deicer C was Deicer C made using Exp Coated Fabric B and Coated Fabric C. Lastly, Exp C Deicer C was made using Exp Coated Fabric C and Coated Fabric B. Please refer to **Table 1** for clarification of each variable that is referenced throughout the rest of the document.

Table 1 shows breakdown of each control and experimental variable that will be used in this project.

Name	Made using
Cement A	Chemlok 233
Coated Fabric A	Cement A
Deicer A	Coated Fabric A

Name	Made Using
Exp Cement A	Chemlok 2332
Exp Coated Fabric A	Exp Cement A
Exp Deicer A	Exp Coated Farbic A

Name	Made using
Cement B	Chemlok 233
Coated Fabric B	Cement B
Deicer B	Coated Fabric B & Coated Fabric C
Deicer C	Coated Fabric B & Coated Fabric C

Name	Made Using
Exp Cement B	Chemlok 2332
Exp Coated Fabric B	Exp Cement B
Exp B Deicer B	Exp Coated Fabric B & Coated Fabric C
Exp B Deicer C	Exp Coated Fabric B & Coated Fabric C

Name	Made using
Cement B	Chemlok 233
Coated Fabric C	Cement B
Deicer B	Coated Fabric B & Coated Fabric C
Deicer C	Coated Fabric B & Coated Fabric C

Name	Made Using
Exp Cement B	Chemlok 2332
Exp Coated Fabric C	Exp Cement B
Exp C Deicer B	Exp Coated Fabric C & Coated Fabric B
Exp C Deicer C	Exp Coated Fabric C & Coated Fabric B

The project was conducted primarily at the UTC support engineering site in Uniontown, Ohio. Data that was compiled for evaluation in this project include: physical properties of the cements from the supplier, adhesion data for the coated fabrics from both the supplier and receiving inspection at the manufacturing facility, standard acceptance test data for manufactured deicers at the production facility, flex life data and failure inspection from Uniontown, and burst test data and failure inspection from Uniontown. The data was compared and the results will define the next course of action to take with the obsolete materials. If the experimental materials prove to have equal or greater properties, then the experimental cements were approved for production use, and UTC will remove Chemlok 233 from its coated fabric production.

Background

Chemlok 233 is a rubber-to-substrate adhesive manufactured by Lord Corporation. The Chemlok family, consisting of 233, 2332, and many other variants are adhesives and primers that all are used for rubber-to-substrate bonding (2). On August 31, 2016 Lord Corporation stopped production of Chemlok 233 due to the presence of trichloroethylene, TCE. TCE is a common solvent used in industrial practices around the world, but the EPA has deemed TCE as environmentally dangerous and a known carcinogen (3). In order to move away from using this hazardous material, Lord Corporation decided to discontinue the production of Chemlok 233.

UTC Aerospace Systems has used Chemlok 233 in many production parts in the past, and has done extensive work to replace all instances of Chemlok 233. Previously, UTC was able to successfully replace all internal usage of Chemlok 233 at their manufacturing facility. Chemlok 233 was used directly as adhesive cement, and it was also used as a component in adhesive formulations for some deicer builds. Depending on internal usage, Chemlok 2332 or Chemlok 402 was used as the replacement (1). Based on the work completed prior to the coated fabrics project, Chemlok 2332 was selected as the best alternate to begin testing in coated fabric constructions.

Coated fabrics are primarily used in deicer systems built at UTC Aerospace Systems. A coated fabric is any form of woven fabric coated in a primer or material, such as lacquer, varnish, or rubber. Historically, coated fabrics have been used for over a thousand years for the purpose of waterproofing bags and covers (4). In the case of this project, the coated fabrics focused on were Nylon fabric that has been coated in a primer cement formulation made from Chemlok 233 or Chemlok 2332. Once the fabric has been coated in the primer cement, the fabric is then calender coated with a rubber compound and allowed to adhere together. The coating procedure gives strength and structure to the rubber compound that is adhered to the fabric. With the strengthened compound, the deicers are able to be built lightweight, but still be flexible and durable enough to withstand the conditions at high speeds and altitudes.

Deicers manufactured by UTC are essential safeguards present on aircraft wings. The function of the deicer is to prevent or remove any ice buildup along the wings or stabilizers on an aircraft. In order to break any ice buildup that may have formed on the wing, the deicer is built with a series of tubes that can be inflated with air that will break apart ice that has been forming. Pneumatic deicers are very complex to build, requiring many layers of coated fabrics and rubber compounds each tied together with cements. Additionally, each deicer is shaped to fit the form of the wing perfectly and each layer is cut and laid by hand before it is cured in an autoclave.

Experimental Methods

There are three major experimental methods used in this report: Adhesion building and testing, deicer burst testing, and deicer flex life testing. This section will go into further detail about each of these tests. Adhesion building and testing is the initial test used to determine if the material can be a suitable replacement to the current. Adhesion samples, built per the specifications outlined in the material's Standard Practice Specification (SP), are tested with each incoming shipment of material and it was determined whether the batch would be accepted for production. Additionally, suppliers will test the material per quality procedures prior to shipping by using an adhesion build outlined in the Material Procurement Specification (MPS). MPS and SP builds can and usually differ in schematics because internal testing (SP) can build the adhesion sample to mimic the final product with internal materials readily available for the build. MPS's use material approved and supplied by UTC to the suppliers for adhesion builds and quality testing. For this project, MPS adhesion data was reported from the suppliers and compared to the controls for each of the three coated fabrics. SP adhesion data from the manufacturing facility was also collected and compiled for review. Coated Fabric A, Coated Fabric B, and Coated Fabric C will each have MPS and SP data to compare to the experimental variants of each coated fabric. The following figures show the adhesion builds for both MPS and SP for each coated fabric that were tested.

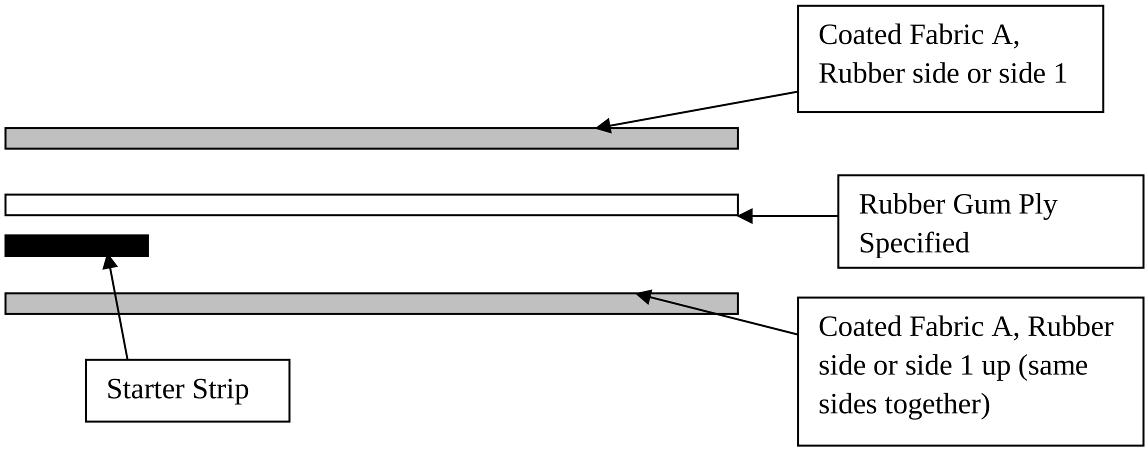


Figure 1 shows the MPS adhesion build for Coated Fabric A and Exp Coated Fabric A.

Coated Fabric A SP Build for Adhesion to side 1:

```
---------------- 6" min--------------
XXXXXXXXXXXXXXXXXX          Coated Fabric A side 1 down
--------------------------------------          Tie in Cement (2 coats on Fabric)
XXXXXXXXXXXXXXXXXX          Rubber Gum Ply Specified
                                  ----          2" Starter Strip
--------------------------------------          Tie in Cement (2 Coats on Fabric)
XXXXXXXXXXXXXXXXXX          Coated Fabric A side 1 up
///////////////////////////////////////////////          Building Metal
```

Figure 2 shows the SP adhesion build for side 1 of Coated Fabric A and Exp Coated Fabric A. The samples cured were made 6" long minimum, and the building metal was as large as needed to fit the entire sample build within the area of the metal.

Coated Fabric A SP Build for Adhesion to side 2:

------------- 6" min-----------------	
XXXXXXXXXXXXXXXXXX	Coated Fabric A side 1 down
--------------------------------------	Tie in Cement (2 coats on Fabric)
XXXXXXXXXXXXXXXXXX	Rubber Gum Ply Specified
-----	2" Starter Strip
--------------------------------------	Tie in Cement (2 Coats on Fabric)
XXXXXXXXXXXXXXXXXX	Coated Fabric A side 1 up
///	Building Metal

Figure 3 shows the SP adhesion build for side 2 of Coated Fabric A and Exp Coated Fabric A. The samples cured were made 6" long minimum, and the building metal was as large as needed to fit the entire sample build within the area of the metal.

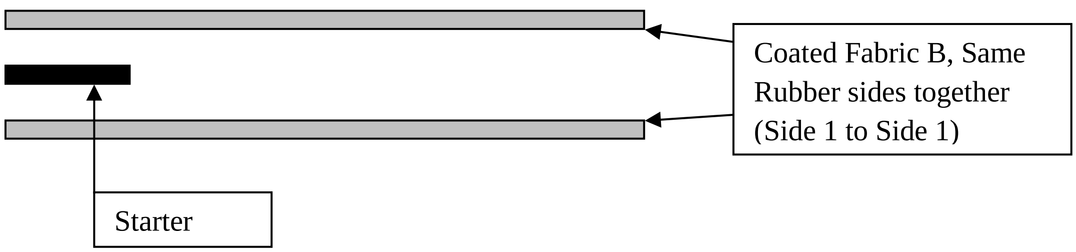


Figure 4 shows the MPS adhesion build for Coated Fabric B and Exp Coated Fabric B

Coated Fabric B SP Build for Adhesion

------------- 6" min-----------------	
XXXXXXXXXXXXXXXXXX	Coated Fabric B side 1 down
-----	2" Starter Strip
XXXXXXXXXXXXXXXXXX	Coated Fabric B side 2 up
///	Building Metal

Figure 5 shows the SP adhesion build for Coated Fabric B and Exp Coated Fabric B. The samples cured were made 6" long minimum, and the building metal was as large as needed to fit the entire sample build within the area of the metal.

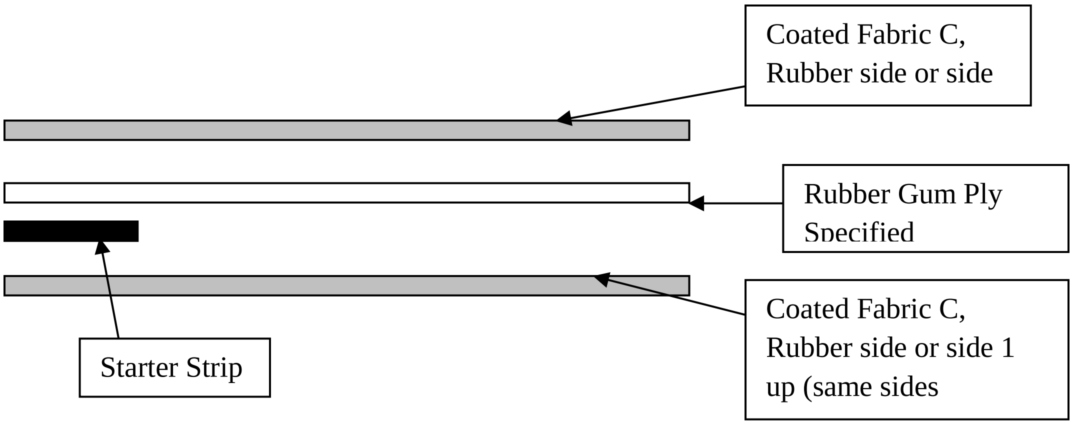


Figure 6 shows the MPS adhesion build for Coated Fabric C and Exp Coated Fabric C

Coated Fabric C SP Build for Adhesion to side 1:

-------------- 6" min-----------------	
XXXXXXXXXXXXXXXXXX	Coated Fabric C, side 1 down
--	Tie in Cement (1 coat on fabric)
XXXXXXXXXXXXXXXXXX	Rubber Gum Ply Specified
-----	2" Starter Strip
--	Tie in Cement (1 coat on fabric)
XXXXXXXXXXXXXXXXXX	Coated Fabric C, side 1 up
//	Building Metal

Figure 7 shows the SP adhesion build for side 1 of Coated Fabric C and Exp Coated Fabric C. The samples cured were made 6" long minimum, and the building metal was as large as needed to fit the entire sample build within the area of the metal.

Coated Fabric C SP Build for Adhesion to side 2:

-------------- 6" min-----------------	
XXXXXXXXXXXXXXXXXX	Coated Fabric C, side 2 down
--	Tie in Cement (1 coat on fabric)
XXXXXXXXXXXXXXXXXX	Rubber Gum Ply Specified
-----	2" Starter Strip
--	Tie in Cement (1 coat on fabric)
XXXXXXXXXXXXXXXXXX	Coated Fabric C, side 2 up
//	Building Metal

Figure 8 shows the SP adhesion build for side 2 of Coated Fabric C and Exp Coated Fabric C. The samples cured were made 6" long minimum, and the building metal was as large as needed to fit the entire sample build within the area of the metal.

The adhesion samples were built according to the appropriate schematics and cured in an autoclave at specified time, temperature, and pressure. After being cured, the samples were removed and cut to desired dimensions, five 1" x 8" samples from a 6" x 8" piece. The samples were tested using a "T-Peel" method on the Instron machine. The data obtained from the Instron machine is compiled and compared for the qualification process of determining the viability of the replacement cements.

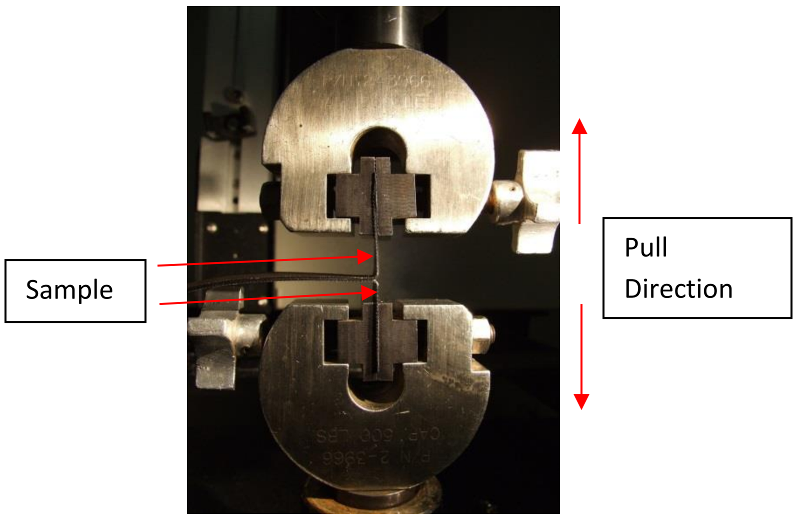


Figure 9 shows the Instron "T-Peel" test fixture. This method was used for all adhesion tests in the project.

Once the coated fabrics have passed adhesion testing, the next phase of testing will begin. The deicer burst test follows a fairly simple procedure utilizing pressurized air. Each deicer is tested individually in a chamber that will contain the explosive force from the test. For this project, an autoclave is used for the testing chamber. The deicer is placed in the autoclave and attached to a pressure hose. The deicer is then filled with air and the pressure in the deicer is increased by 1 psi per second until the deicer bursts. A device is used that monitors the pressure in the deicer and reports the maximum pressure achieved. Passing the burst test requires that the deicer reaches three times its operating pressure before burst. Only one deicer will be burst tested for each coated fabric. Upon failure, each deicer will be inspected for the cause of failure.

The last phase of testing is the deicer flex life test. This test consists of operating the deicer at standard pressure as defined by the customer under ambient conditions and observing the number of cycles prior to the deicer failing. The deicers are mounted onto plywood boards using 1300L cement and are then connected to the PPEC test machine. The PPEC regulates the pressure and time of inflation for each deicer. PPEC allows for up to 16 separate air channels to be regulated at all times. For this project, each deicer is flexed at operating pressure for 6 seconds and deflates/rests for 18 seconds, meaning the time for one flex cycle is 24 seconds. Deicers are flexed continuously from start to failure. Failure is defined by a deicer's inability to operate within 2 psi of standard operating pressure and usually takes the form of a hole leaking air on either the bondside or breezeside of the deicer. The failed deicers are then inspected further, and the cause of failure is defined and documented for data analysis. The number of cycles a deicer can reach before failure is defined as the flex life, and while this is an easy way to determine quality, it is not always accurate or consistent. Each deicer can have slight differences that can drastically affect the flex life, so the mode of failure is very important to understand. In this project, if the mode of failure is not related to the coated fabric used - i.e. the deicer's failure area does not contain the coated fabric of interest – then the results are reviewed with design engineering and manufacturing for approval. The deicer failures are observed using a Dino-Lite microscope and results are recorded. If the failure area of the deicer does not involve the coated fabric of interest, and if there is no delamination or separation of the coated fabric in the part, then the coated fabric would be considered equivalent to the control.

Figure 10 shows the PPEC flex machine. The computer controls the settings for each channel. The deicers are mounted to boards and the top right one is shown mid flex.

<u>Data and Results</u>

Table 2 shows the receiving information for Coated Fabric A and Exp Coated Fabric A from the supplier.

Coated Fabric A (MPS)		
Name	Cement A % Solids	Adhesion (lbf/in)
Coated Fabric A	18.0	20.56
Exp Coated Fabric A	19.3	18.04

Table 3 shows the receiving information for Coated Fabric A and Exp Coated Fabric A from the plant.

Coated Fabric A (SP)		
Name	Adhesion Side 1 to 1 (lbf/in)	Adhesion Side 2 to 2 (lbf/in)
Coated Fabric A	17.91	17.12
Exp Coated Fabric A	17.58	27.26

Table 4 shows the deicer flex life data for Deicer A which used Coated Fabric A.

Deicer A				
Name	Test Type	Date started	20psi Dry Cycles	Failure Mode
Deicer A 1	FLEX	2/1/2018	11,249	Breezeside Blowout at carcass edge
Deicer A 2	FLEX	2/1/2018	17,361	Breezeside Blowout at carcass edge
Deicer A 3	FLEX	2/1/2018	11,498	Breezeside Blowout at carcass edge
Deicer A Burst	BURST	2/28/2018	93.85 psi BURST	Breezeside Blowout at carcass edge
Deicer A Extra	FLEX	not tested	not tested	not tested

Table 5 shows the deicer flex life data for Exp Deicer A which used Exp Coated Fabric A.

Exp Deicer A				
Name	Test Type	Date started	20psi Dry Cycles	Failure Mode
Exp Deicer A 1	FLEX	2/19/2018	14,931	Breezeside Blowout at carcass edge
Exp Deicer A 2	FLEX	2/19/2018	10,822	Breezeside Blowout at carcass edge
Exp Deicer A 3	FLEX	2/19/2018	23,874	Breezeside Blowout at carcass edge
Exp Deicer A Burst	BURST	2/28/2018	89.2 psi BURST	Bondside Blowout at carcass edge

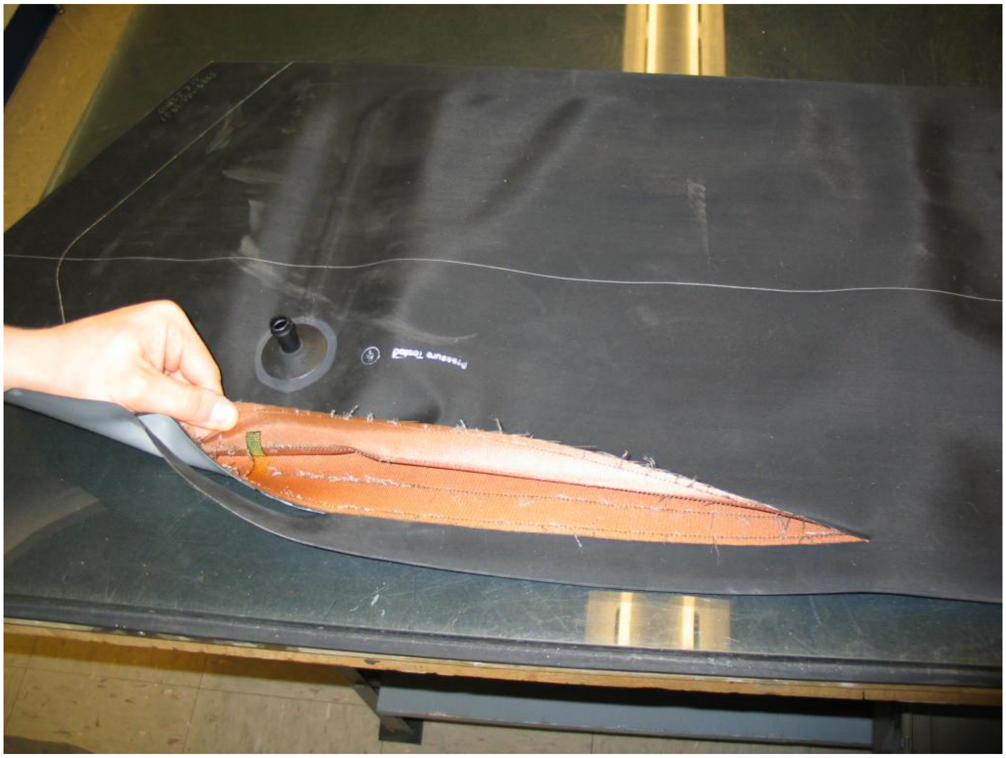


Figure 11 shows Deicer A Burst test bondside failure

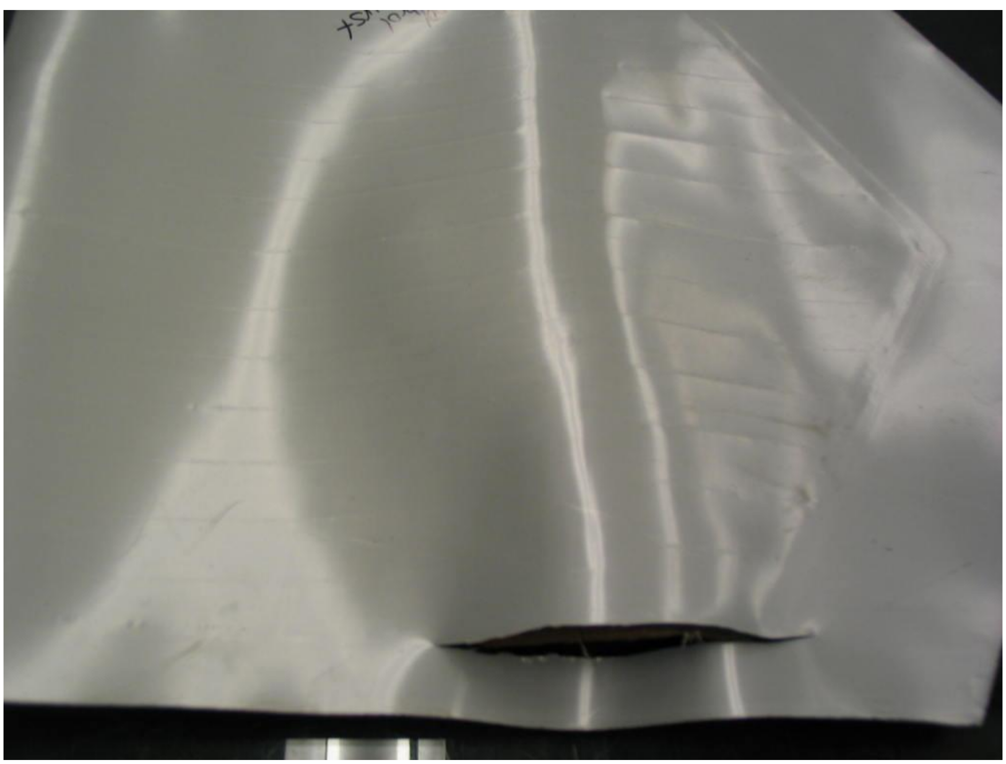


Figure 12 shows Deicer A Burst test breezeside failure

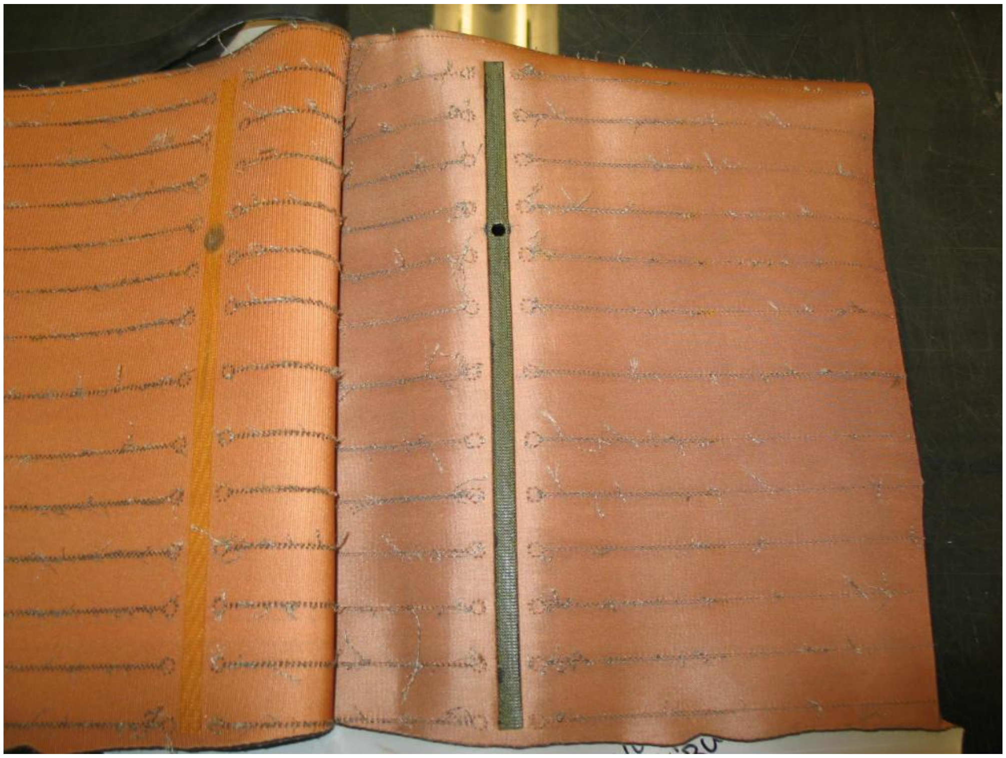


Figure 13 shows Deicer A Burst test manifold inspection

Figure 14 shows Exp Deicer A Burst Bondside failure

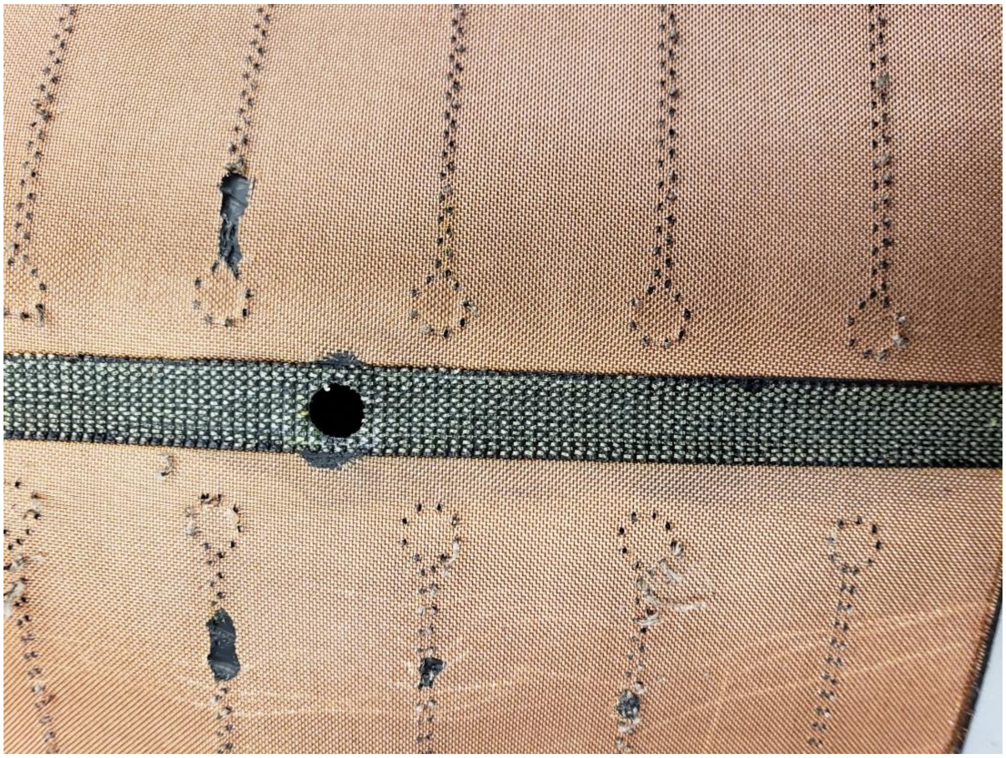


Figure 15 shows Exp Deicer A Burst manifold inspection

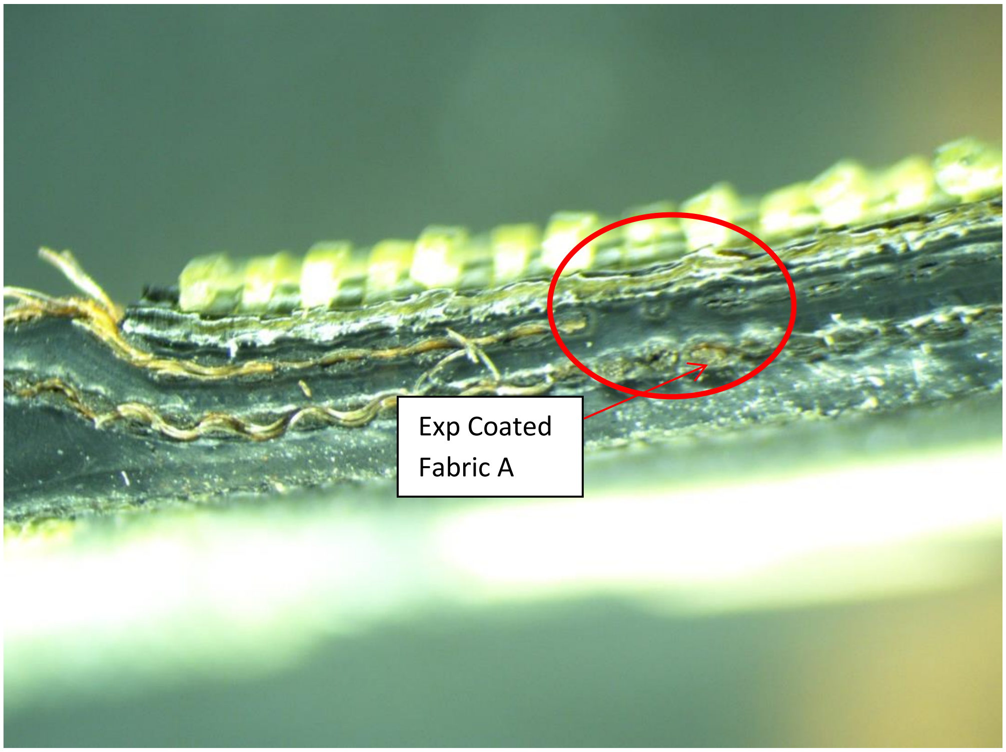


Figure 16 shows Exp Deicer A Burst cross-section of manifold. As shown, there is no delamination in the layer containing Exp Coated Fabric A.

Table 6 shows the receiving information for Coated Fabric B and Exp Coated Fabric B from the supplier.

Coated Fabric B (MPS)		
Name	Cement B % Solids	Adhesion (lbf/in)
Coated Fabric B	18.1	16.65
Exp Coated Fabric B	18.49	51.39

Table 7 shows the receiving information for Coated Fabric B and Exp Coated Fabric B from the plant.

Coated Fabric B (SP)	
Name	Adhesion (lbf/in)
Coated Fabric B	18.26
Exp Coated Fabric B	27.64

Table 8 shows the receiving information for Coated Fabric C and Exp Coated Fabric C from the supplier.

Coated Fabric C (MPS)		
Name	Cement B % Solids	Adhesion (lbf/in)
Coated Fabric C	18.6	23.76
Exp Coated Fabric C	19.34	34.05

Table 9 shows the receiving information for Coated Fabric C and Exp Coated Fabric C from the plant.

Coated Fabric C (SP)		
Name	Adhesion Side 1 to 1 (lbf/in)	Adhesion Side 2 to 2 (lbf/in)
Coated Fabric C	18.51	26.53
Exp Coated Fabric C	26.07	26.6

Table 10 shows the deicer flex life data for Deicer B which used Coated Fabric B and Coated Fabric C.

Deicer B				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Deicer B 1	FLEX	11/27/2017	8656	cross inflation
Deicer B 2	FLEX	11/27/2017	8656	cross inflation
Deicer B Burst	BURST	CONTROL	not tested	not tested
Deicer B 3	FLEX	11/27/2017	8656	cross inflation
Deicer B 4	FLEX	11/27/2017	8656	cross inflation

Table 11 shows the deicer flex life data for Exp B Deicer B which used Exp Coated Fabric B and Coated Fabric C.

Exp B Deicer B				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Exp B Deicer B 1	FLEX	6/19/2018	3977	breezeside blowout
Exp B Deicer B 2	FLEX	6/19/2018	6109	cross inflation
Exp B Deicer B Burst	BURST	6/27/2018	79.90 psi/ 75.65 psi BURST	breezeside blowout not near the manifold (2 air connections)
Exp B Deicer B 3	FLEX	6/19/2018	6109	cross inflation
Exp B Deicer B 4	FLEX	6/19/2018	6873	cross inflation

Table 12 shows the deicer flex life data for Exp C Deicer B which used Coated Fabric B and Exp Coated Fabric C.

Exp C Deicer B				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Exp C Deicer B 1	FLEX	7/25/2018	4369	breezeside blowout
Exp C Deicer B 2	FLEX	7/26/2018	6718	cross inflation
Exp C Deicer B Burst	BURST	7/19/2018	81.85 psi/ 80.75 psi BURST	breezeside blowout at tube end
Exp C Deicer B 3	FLEX	8/8/2018	6649	cross inflation
Exp C Deicer B 4	FLEX	8/8/2018	6649	cross inflation

Figure 17 shows Exp B Deicer B 2 cross-inflation inspection.

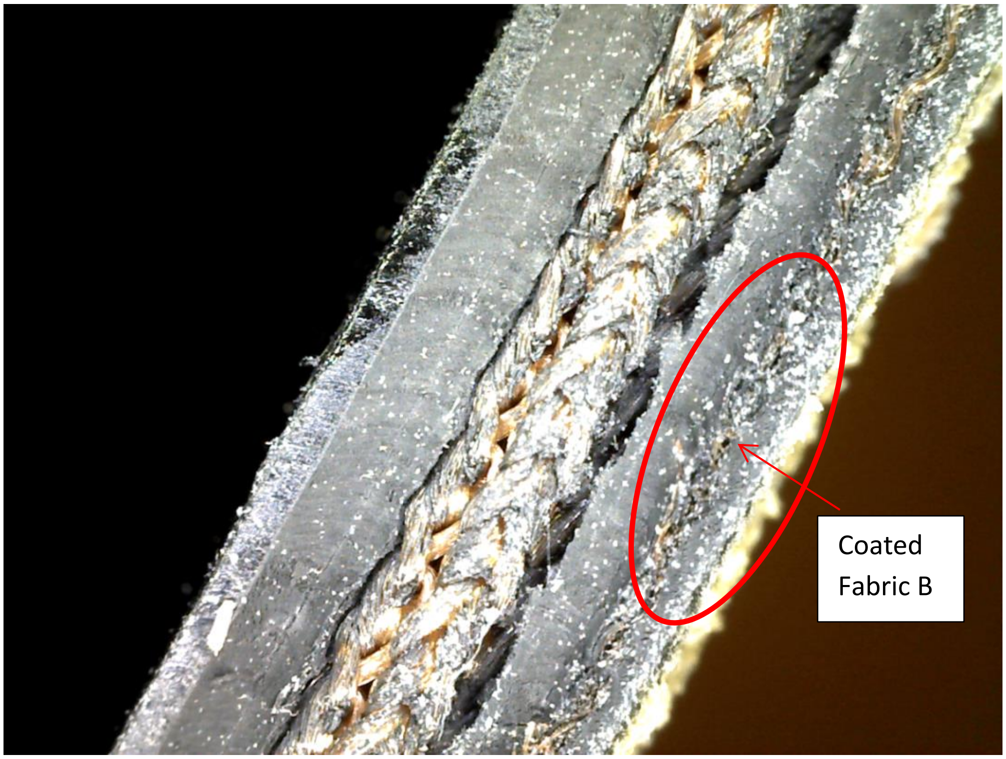


Figure 18 shows Deicer B 1 cross-section. As shown, there is no delamination in the layer containing Coated Fabric B.

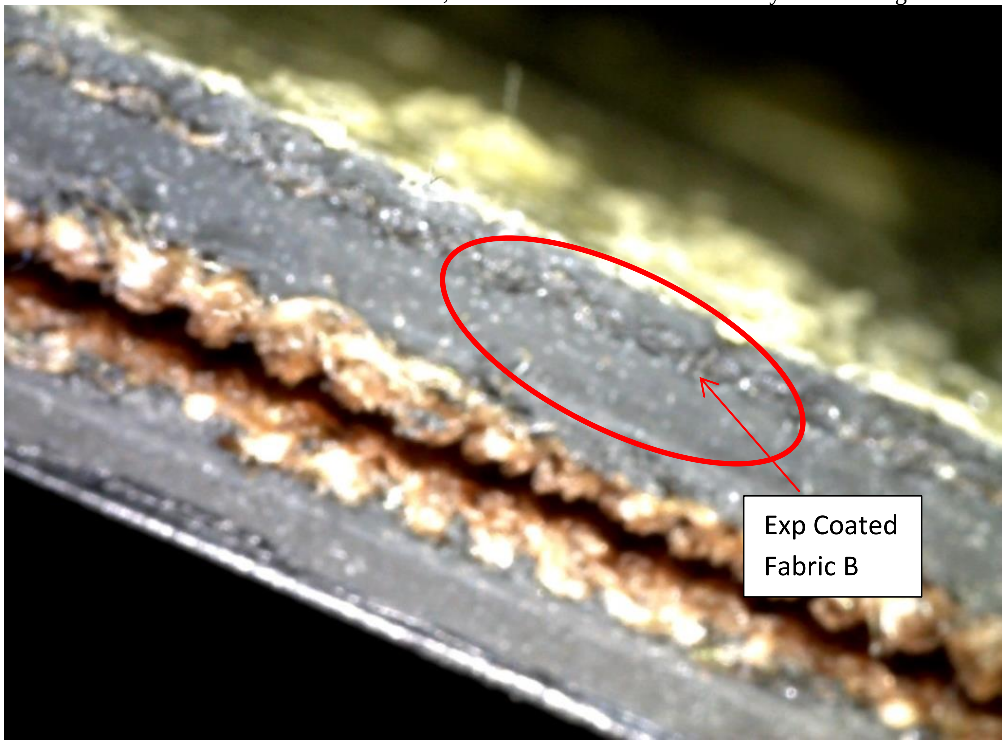


Figure 19 shows Exp B Deicer B 2 cross-section. As shown, there is no delamination in the layer containing Exp Coated Fabric B.

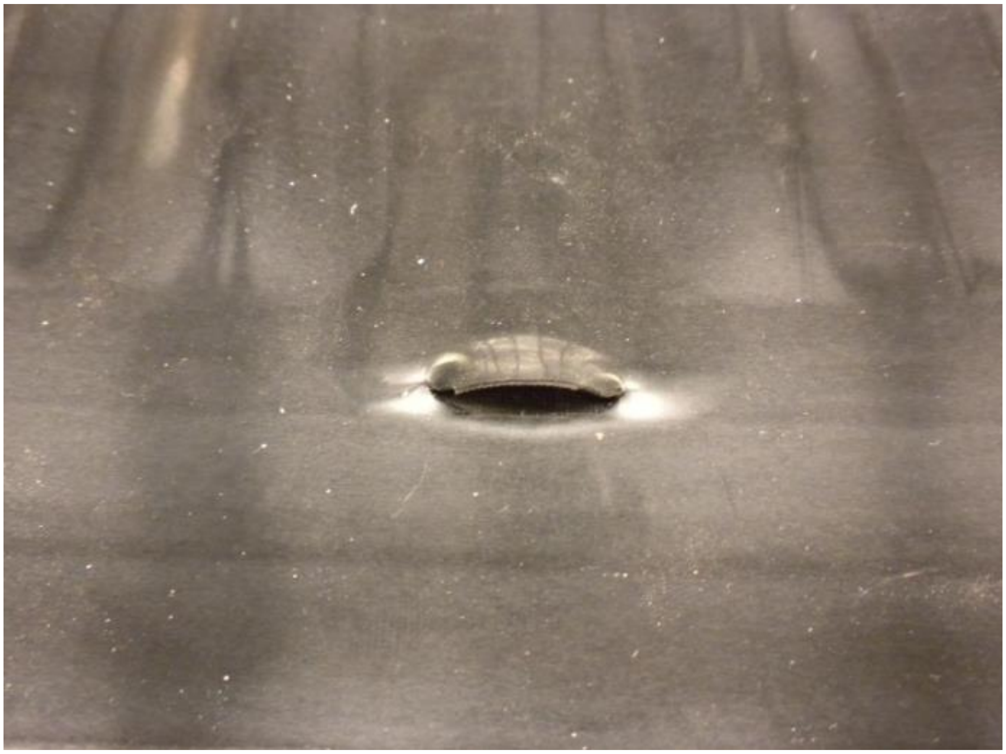


Figure 20 shows Exp C Deicer B Burst bondside failure.

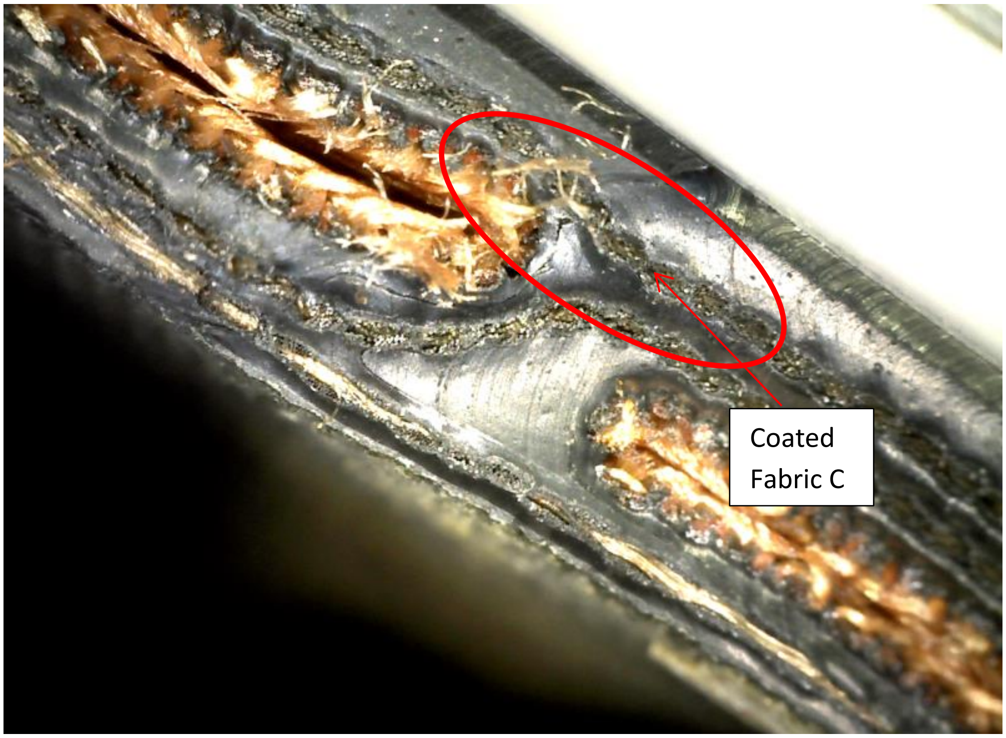


Figure 21 shows Deicer B 1 cross-section. As shown, there is no delamination in the layer containing Coated Fabric C.

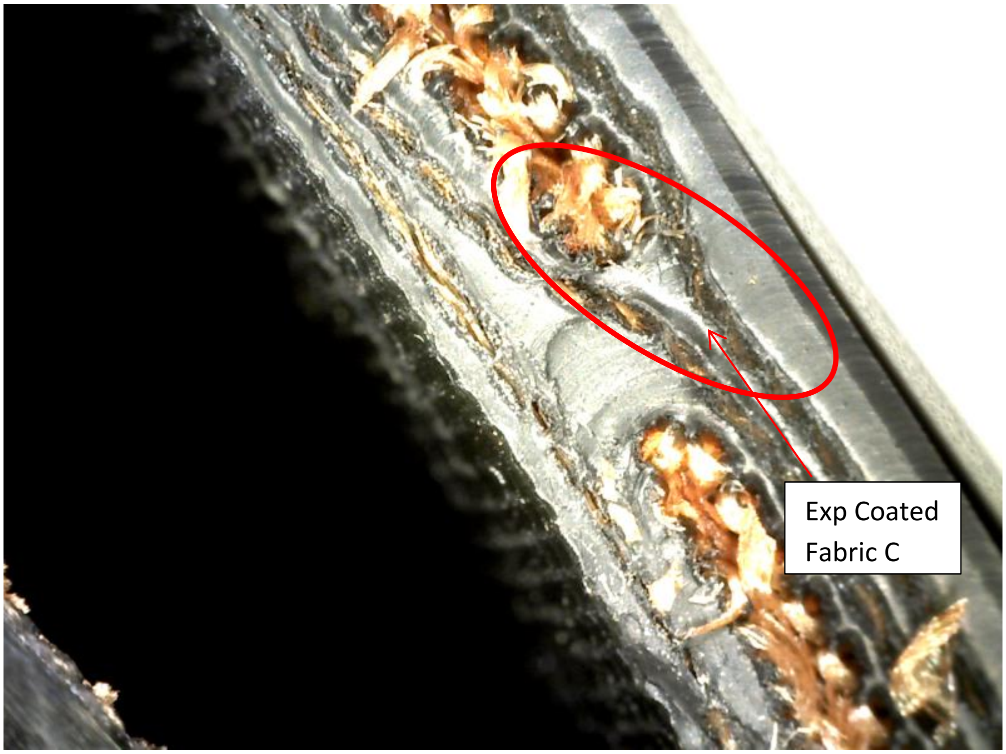


Figure 22 shows Exp C Deicer B 3 cross-section. As shown, there is no delamination in the layer containing Exp Coated Fabric C.

Table 13 shows the deicer flex life data for Deicer C which used Coated Fabric B and Coated Fabric C.

Deicer C				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Deicer C 1	FLEX	12/4/2017	14016	Bondside delamination
Deicer C 2	FLEX	12/4/2017	9917	Bondside blowout
Deicer C 3	FLEX	12/4/2017	6569	A/C Leak bondside delam
Deicer C 4	FLEX	12/4/2017	4700	A/C Leak bondside delam
Deicer C Burst	BURST	CONTROL	not tested	not tested

Table 14 shows the deicer flex life data for Exp B Deicer C which used Exp Coated Fabric B and Coated Fabric C.

Exp B Deicer C				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Exp B Deicer C 1	FLEX	6/25/2018	14243	Bondside leaks not near manifold
Exp B Deicer C 2	FLEX	6/25/2018	18374	Bondside leaks not near manifold
Exp B Deicer C 3	FLEX	6/25/2018	25739	Bondside leaks not near manifold
Exp B Deicer C 4	FLEX	6/25/2018	13525	Bondside leaks not near manifold
Exp B Deicer C Burst	BURST	6/27/2018	71.8 psi BURST	Bondside blowout not at manifold

Table 15 shows the deicer flex life data for Exp C Deicer C which used Coated Fabric B and Exp Coated Fabric C.

Exp C Deicer C				
Name	Test Type	Date Started	20psi Dry Cycles	Failure Mode
Exp C Deicer C 1	FLEX	7/25/2018	19361	Bondside leaks along manifold
Exp C Deicer C 2	FLEX	7/16/2018	2204	Bondside leaks at carcass egde
Exp C Deicer C 3	FLEX	7/24/2018	17335	Bonside leak at air connection
Exp C Deicer C 4	FLEX	7/19/2018	10776	Bondside leaks
Exp C Deicer C Burst	BURST	7/19/2018	74.3 psi BURST	Bondside blowout at carcass edge

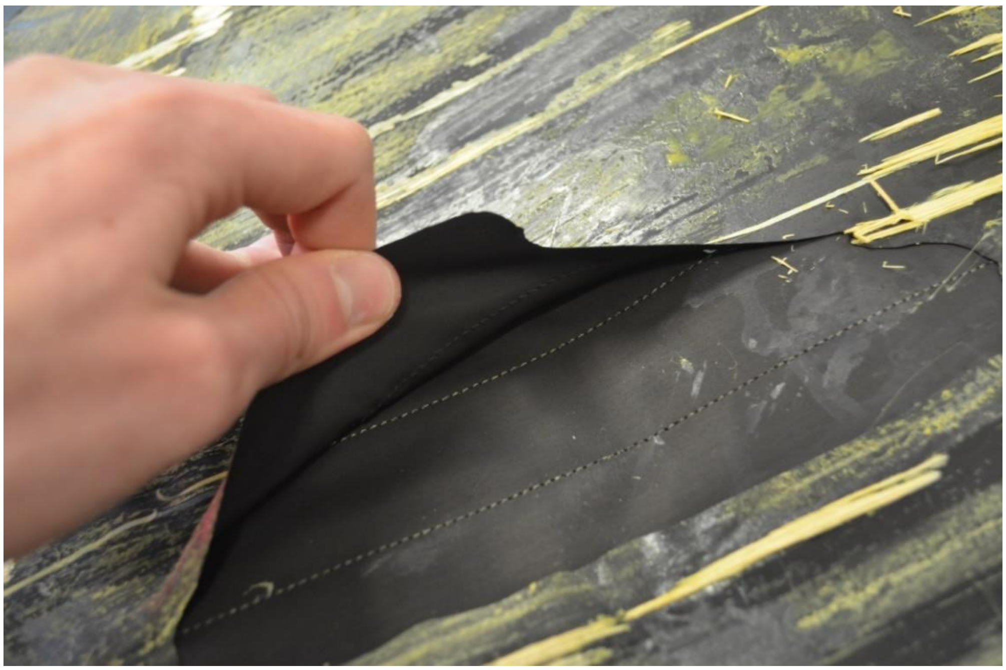


Figure 23 shows Deicer C 3 bondside failure.

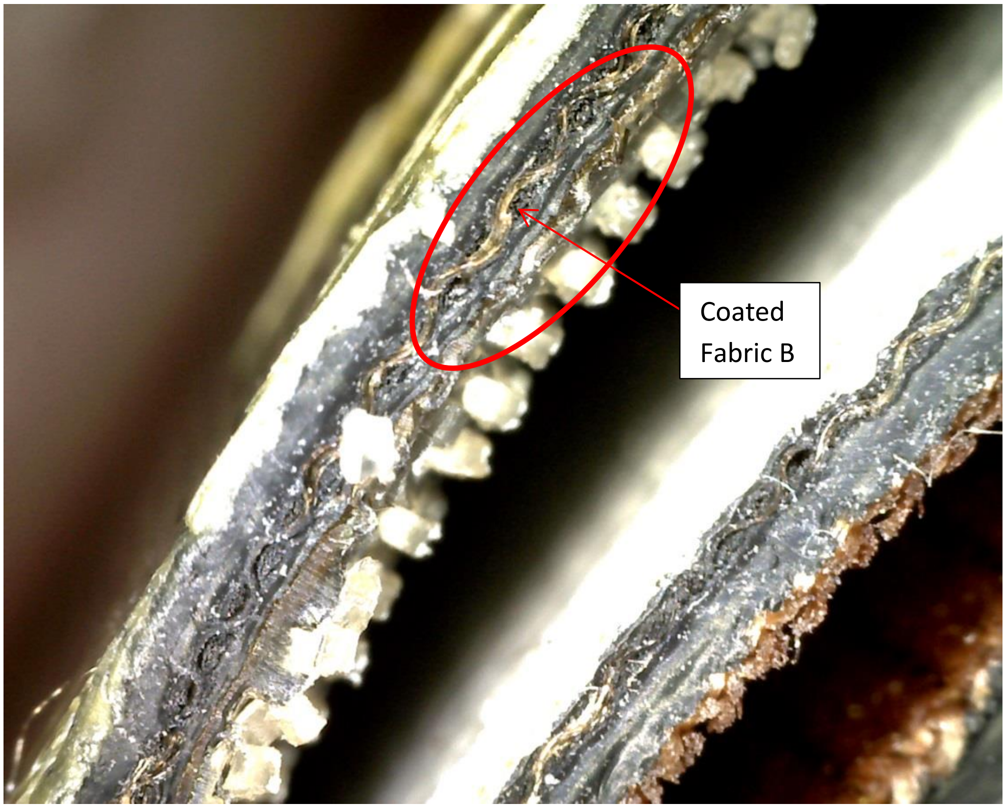


Figure 24 shows Deicer C 1 cross-section of manifold. As shown, there is no delamination in the layer containing Coated Fabric B.

Figure 25 shows Exp B Deicer C 4 bondside failure.

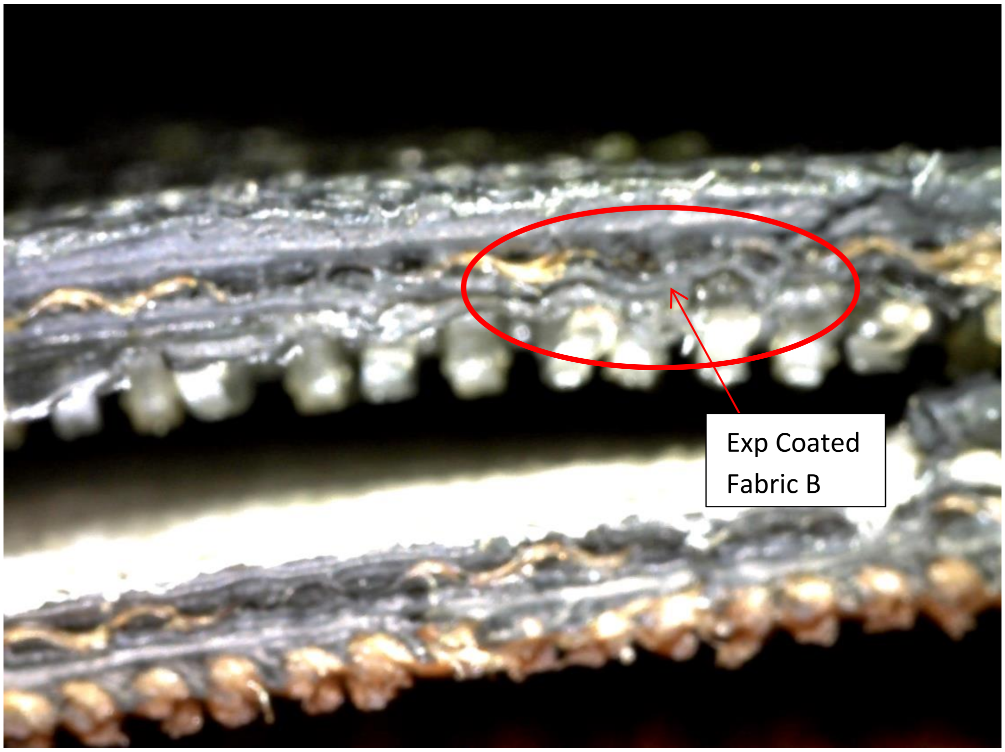


Figure 26 shows Exp B Deicer C 2 cross-section of manifold. As shown, there is no delamination in the layer containing Exp Coated Fabric B.

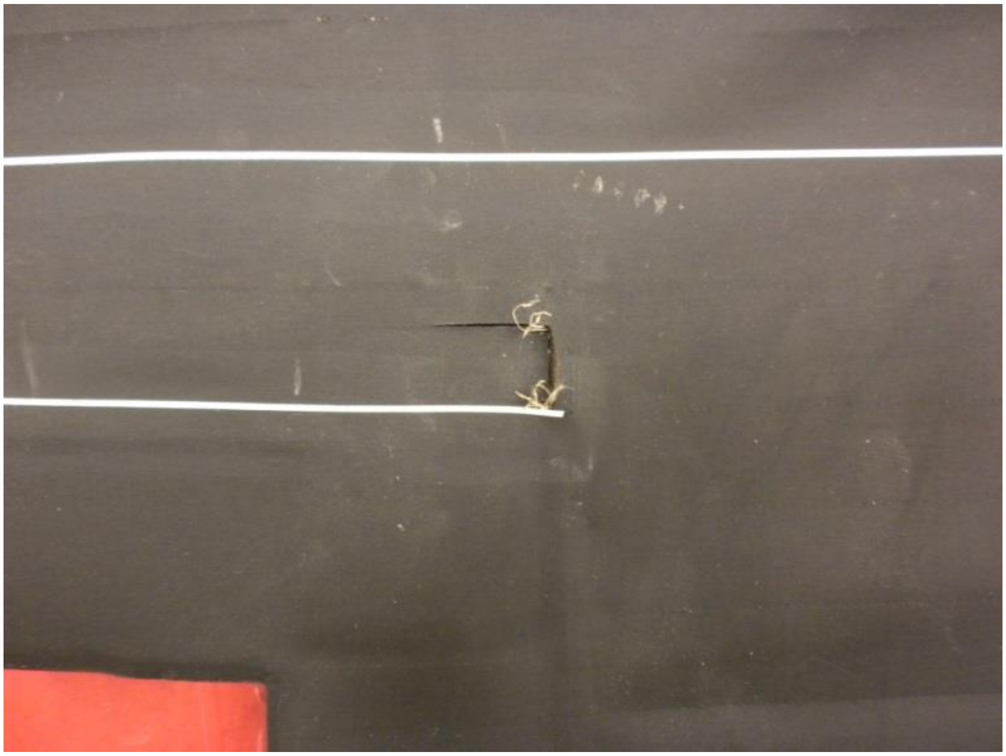


Figure 27 shows Exp C Deicer C Burst bondside failure.

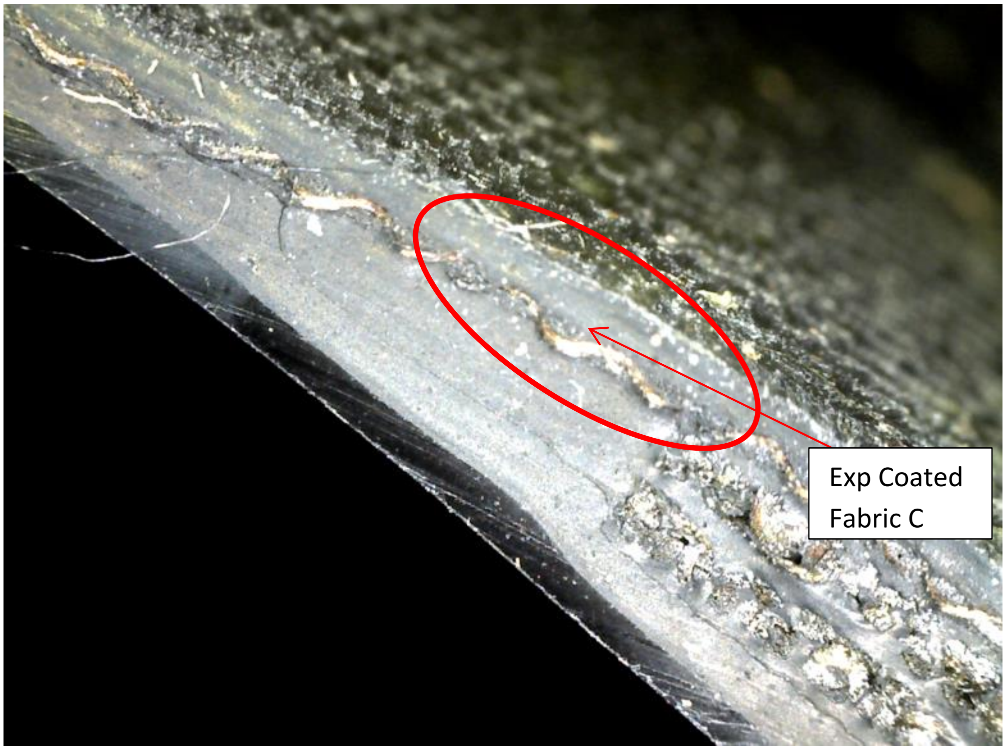


Figure 28 shows Exp C Deicer C a cross-section. As shown, there is no delamination in the layer containing Exp Coated Fabric C.

<u>Discussion/Analysis</u>

The receiving inspection data collected from the suppliers and the plant give the first set of results for this project. The physical property of the adhesive reported by the supplier is the percent solids. This property has a specification range given in the MPS and is tested prior to coating the fabrics. The percent solids range for Cement A is 15.3%-19.3% and according to **Table 2**, both the control and experimental adhesives pass. Cement B has a range of 15.5%-19.5%, and both trial runs using Cement B and Exp Cement B show passing values, as shown in **Tables 6 and 8**. Once the coated fabrics were made, the suppliers then tested adhesion according to the MPS builds, **Figures 1, 4, and 6**, and reported values. **Table 2** shows that Coated Fabric A had a slightly higher adhesion value than Exp Coated Fabric A, but not enough to stop further testing. **Tables 6 and 8** report that Exp Coated Fabric B and C had adhesion values much higher than the control counterparts. Since all experimental coated fabrics proved to be similar or better than the controls, the suppliers were able to send the products and the results to the manufacturing plant in WV for further testing.

Upon receiving the products, the plant then tests the fabrics using the SP build to better understand how the material will perform in the final deicer. Following the builds outlined in **Figures 2, 3, 5, 7, and 8**, the coated fabrics were tested and data was reported. Exp Coated Fabric A was found to have very similar adhesion values once again, with a larger value in the Side 2 build, according to **Table 3**. **Table 7** shows that Exp Coated Fabric B has higher adhesion and **Table 9** shows that Exp Coated Fabric C has higher adhesion on Side 1 and similar adhesion on Side 2. Once more, the experimental materials proved to have similar capabilities as the controls and thus the next phase of testing could be started.

Each coated fabric was then used to create a set of deicers for flex life and burst testing. By far the longest phase in testing, production of the test deicers so as to not disturb commercial production took a long time, as well as testing the parts also took up to a week before failure. Deicer A and Exp Deicer A both passed the burst test, and the flex life testing resulted in an average of 13,369 cycles for Deicer A and 16,542 cycles for Exp Deicer A. A higher average flex life was a good indication, but the inspection of the failures was the true final result of this test. From **Tables 4 and 5**, along with **Figures 11-16**, the results can be seen that Exp Deicer A did not have any failures due to a delamination of Exp Coated Fabric A. Since Exp Cement A, Exp Coated Fabric A, and Exp Deicer A all proved to have equivalent or better performance to their control variant, Exp Cement A can be qualified as a suitable replacement for Cement A, and thus change Coated Fabric A and Deicer A.

Burst tests for Deicer B and Deicer C were not conducted due to time constraints and the justification was that parts made for production are already proven to be acceptable and do not require a burst test. Exp B Deicer B and Exp B Deicer C both passed the burst test as shown in **Tables 11 and 14**. When compared to Deicer B in flex life testing, Deicer B had an average flex life of 8,656 cycles while Exp B Deicer B had 5,767 cycles. Again, the flex life number is not the final say in the performance of the coated fabric, and so the inspection of the failures was conducted. **Tables 10 and 11**, as well as **Figures 17, 18, and 19**, show that although the flex life was shorter, the reason it failed had nothing to do with Exp Coated Fabric B. No delamination of Exp Coated Fabric B was found in any deicer, coupled with the high adhesion values from both MPS and SP gives justification that Exp Coated Fabric B can be deemed equivalent to Coated Fabric B in Deicers B and C. The average flex life for Deicer C was 8,800 cycles, and compared to Exp B Deicer C with an average flex life of 17,970 cycles. **Tables 13 and 14**, along with **Figures 23-26**, show that there is no delamination in Exp Coated Fabric B. From the data and results, Exp Cement B can be qualified as a suitable replacement to Cement B for uses in Coated Fabric B and Deicers B and C.

Lastly, Coated Fabric C and Exp Coated Fabric C were tested in Deicers B and C. Again, Deicers B and C were not burst tested, but Exp C Deicer B and Exp C Deicer C did pass the burst test. Comparing average flex life times, Deicer B had an average of 8,656 cycles, while Exp C Deicer B had an average of 6,096 cycles. When inspected further, no delamination in the layers containing Exp Coated Fabric C were found, as seen in **Tables 10 and 12** and **Figures 20-22**. The average flex life of Deicer C was 8,800 cycles, and the average flex life for Exp C Deicer C was 12,419 cycles. Again, upon inspection, no delamination was found in the layer of concern; shown in **Tables 13 and 15** and **Figures 27 and 28**. Once more, when taking in to account the adhesion and results of the flex testing failures, Exp Cement B can be justified as a suitable replacement for Cement B and subsequently Coated Fabric C and Deicers B and C.

Over the course of this project, many different ideas for improvement were brought up and taken into consideration. Unfortunately, due to time constraints, most ideas were cut short or removed entirely in order to finish replacing Cements A and B. Ideally, testing multiple different replacement cements and choosing the best performing one would have been the most accurate course of action. Additionally, due to the somewhat low average flex life of the testing parts, determining the weakest link in the deicer and optimizing the part would make for a good project in the future.

Literature Cited

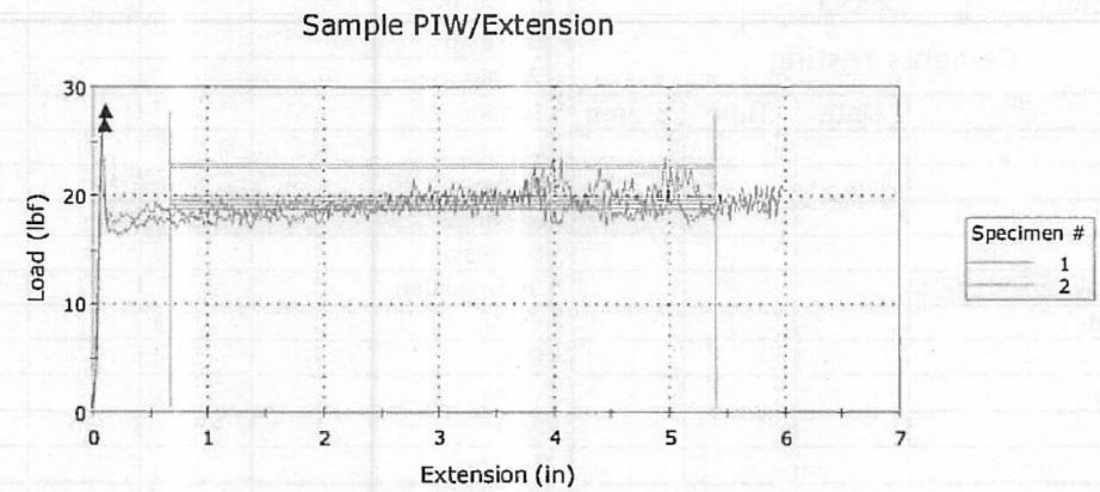
(1) Busch, Madeline M., "Environmentally Friendly Alternates to Chemlok 233 Adhesive Cement" (2018). *Honors Research Projects*. 649. https://ideaexchange.uakron.edu/honors_research_projects/649

(2) Rubber-to-Substrate Adhesives for Automotive Assembly Applications | LORD Corp EMEA https://www.lord.com/emea/products-and-solutions/adhesives/rubber-to-substrate-adhesives-for-automotive-assembly-applications

(3) Safety Data Sheet Trichloroethylene SDS http://www.tnstate.edu/nanobio/documents/Trichloroethylene.pdf

(4) Scott R.A. (1995) *Coated and laminated fabrics*. In: Carr C.M. (eds) Chemistry of the Textiles Industry. Springer, Dordrecht

<u>Appendix A:</u> Example of Adhesion Data from Manufacturing Plant in Union, WV.



	Average Load/width at Average Value (5 Peaks) (lbf/in)	Average Load/width at Average Value (Integral) (lbf/in)	Average Load at Average Value (Integral) (lbf)	Average Load at Average Value (All Peaks) (lbf)
1	22.59	18.81	18.81	19.19
2	22.86	19.59	19.59	19.95
Coefficient of Variation	0.8261	2.8785	2.8785	2.7449
Mean	22.72	19.20	19.20	19.57
Median	22.72	19.20	19.20	19.57
Minimum	22.59	18.81	18.81	19.19
Maximum	22.86	19.59	19.59	19.95
Standard Deviation	0.19	0.55	0.55	0.54
Mean - 3 SD	22.16	17.55	17.55	17.96
Mean + 3 SD	23.29	20.86	20.86	21.18

Figure 29 shows an example of raw adhesion data that would be collected from incoming SP testing at the plant in Union, WV.