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Rust Preventative Spray Varnish Verification and Nozzle Development

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SENIOR DESIGN FINAL REPORT: RUST PREVENTATIVE SPRAY VARNISH

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Abstract

This report details the testing of five different corrosion preventatives to be used in an e-motor product as well as the design of a self-contained, automated spray varnishing unit for Schaeffler Transmission. Results from material testing showed that DEI HI-TEMP Silicone Coating deteriorated rapidly and did not provide adequate corrosion resistance. The Seymour 620-1525 Tool Crib Red Insulating Varnish did not show any visible deterioration; however, it is out of safe operating temperature and therefore was not selected as a viable option. The MG Chemicals 4228-55ML Red Insulating Varnish performed better than both DEI and Anti-Seize during testing, but due to being a brush-on only application, was not chosen as the best option for this application. The results show that two of the five coatings tested had acceptable performance; both the Seymour 620-1525 Tool Crib Red Insulating Varnish and the Sprayon EL609 Green Insulating Varnish performed adequately. Further testing and analysis should be completed prior to any final decisions on the best varnish for the application.

After this material selection occurred, the team started to focus on sprayer design. Due to circumstances surrounding communication between the team and Schaeffler, the team decided to focus specifically on designing a new nozzle on a off-the-shelf ready spray can for Sprayon to better optimize material use and to try to improve upon the application of the material to a sample stator lamination. The team researched and designed several iterations of nozzles and analyzed them by applying the material to stator samples and analyzing them under three major criteria; application, coating thickness, and the provided Saltwater Test from the material testing. Based on these criteria the team was able to design 4 nozzles that passed testing, nozzles #2 (a replica of the manufacturer's nozzle), #8 (a converging elongated head nozzle with a circular exit), #10 (a continuously converging nozzle with an oval exit), and #13 (a 15-degree flat fan nozzle). We also recommend these four nozzles to be considered as candidates for future testing and further development to better improve coating quality and uniformity.

Contents

1. Introduction

Our team conducted research on rust preventative spray varnish for Schaeffler Transmission in Wooster. Five materials were selected for this rust preventative analysis. The project is based on the concept of varnishing electric steel stator lamination stack; they constitute a stator for an electric motor, known as an e-motor, as shown in Figure 1. To maintain the safety of all end-users, e-motors have international standards that they must meet. These standards are ISO 12103-1[1] and ISO 20653[2]. The first pertains to the Arizona Dust Test[1] and the second defines the degree of protection that the motors must have. The spec that Schaeffler must meet is IP6K7[2]. This means that the internal protection must be dust tight and that the system must be able to survive temporary immersion.

Figure 1: Example of Lamination Stacks Used in e-motors

These stacks are epoxied together along all of the external edges. These stacks must be varnished along the inside diameter because they are exposed to the elements. They cannot be epoxied as the electrical current needs a medium(air) to travel through. The varnishes need to be of the NEMA class F spec[3]. Class F means that the stacks will have a maximum temperature of 155 °C. In addition, the maximum temperature rise is 105 °C.

This problem brings about two significant questions:

1. What varnish is the best?
2. What is the best way to varnish the steel?

To better address these questions, our group decided to follow guidance from Schaeffler and conduct testing on samples of the lamination stacks. Information on the rationale behind material choices as well as testing procedure and processes will be explained in detail under section 2: Material Selection.

2. Material Selection

After months of preparation for testing, our group was finally able to gather all of the resources needed to conduct testing. These would range from gathering the needed materials and samples, finding much technical and field expertise in the forms of advising, and a proper physical testing location. Even though Schaeffler recommended using home ovens to complete the testing portion of this project, our group and the many advisors that have contributed to this project could not stress enough the importance of proper use and following best practice procedures when conducting research on these products. Therefore, all testing and analysis was conducted in a supervised laboratory setting. All information on materials and laboratory procedure will be explained in sections 2.1 and 2.2.

2.1 Material Analysis

This section contains information for the materials used during the rust preventative spray varnish verification. The reasons for the selection of each product, product descriptions, price of each material, operating temperatures, and other important information are described below.

2.1.1 MG Chemicals 4228-55ML Red Insulating Varnish[4]

The MG Chemical varnish (Figure 2) is a highly insulating coating with low viscosity. It's mainly used to protect industrial and electrical parts against arc, corona, corrosion, and moisture. This material is applied by brush and is not a spray varnish.

- Operating Temperature: 180 ℃ (Above Class F)
- Price/bottle: $14.52 (2 oz)
- Price/oz: $7.26

This material was selected because it is a brush-on varnish with an operating temperature above the testing procedure requirement. This material will provide a better understanding of the difference between brush-on and spray-on applications of varnishes.

Figure 2: MG Chemicals 4228-55ML Red Insulating Varnish[5]

2.1.2 Seymour 620-1525 Tool Crib Red Insulating Varnish[6]

The Seymour varnish (Figure 3) is an insulating material that is designed to protect against deterioration caused by exposure to oil, moisture, acid, and alkali. This product is a spray-on varnish.

- Operating Temperature: 155 ℃ (Class F)
- Price/can: $8.23 (16 oz)
- Price/oz: $0.51

This product was selected because its application is spray on and its operating temperature is above the testing procedure requirement. We expect this material to not deteriorate under our testing conditions and have little corrosion form during the experiment.

Figure 3: Seymour 620-1525 Tool Crib Red Insulating Varnish[7]

2.1.3 Anti-Seize Technology Red Insulating Varnish[8]

Anti-Seize Red insulating varnish (Figure 4) strongly adheres to metal and other insulating components. The protective coating is used for many different electrical and industrial applications. This product is a spray-on varnish.

- Operating Temperature: 121 ℃
- Price/can: $15.80 (16 oz)
- Price/oz: $0.99

This product is a spray-on varnish with an operating temperature that is below our testing procedure requirement. This material will provide a better understanding of how the operating temperature of a varnish affects the results.

Figure 4: Anti-Seize Technology Red Insulating Varnish[9]

2.1.4 Sprayon EL609 Green Insulating Varnish[10]

Sprayon (Figure 5) is an insulating varnish that creates a hard, tough surface that is oil resistant and waterproof. The product is used to insulate motor windings and electrical components. This product is a spray-on varnish.

- Operating Temperature: 155 ℃ (Class F)
- Price/can: $12.27 (15.25 oz)
- Price/oz: $0.80

This product was selected because its application is spray-on and its operating temperature is above the testing procedure requirement. We expect this material to not deteriorate under our testing conditions and have little corrosion form during the experiment.

Figure 5: Sprayon EL609 Green Insulating Varnish[11]

2.1.5 DEI HI-TEMP Silicone Coating[12]

The High-Temp silicone coating (Figure 6) is used to protect hot surfaces from abrasion, oil, and grime. This product is a spray-on silicone coating.

- Operating Temperature: 815 ℃
- Price/can: $11.27 (12 oz)
- Price/oz: $0.94

This is the only silicone coating that was selected. It will give us a better understanding of the difference between varnishes and silicone coating. Silicone coatings are used to withstand high temperatures, but not repetitive immersion.

Figure 6: DEI HI-TEMP Silicone Coating[13]

2.2 Testing Procedure

To test the effectiveness of the rust preventive varnishes, samples are to be collected and subjected to saltwater exposure representative of conditions it will have in Schaeffler products. After numerous iterations of exposure, the samples are to be compared to determine the varnish most suitable for production purposes. Table 1 represents all miscellaneous test information.

Table 1: Material Test Report Details	
Test Description:	Saltwater Rust Preventative Spray Varnish Comparison Test
Test Requester:	Schaefer Group
Test Location:	UA Corrosion Labs, ASEC 471
Tentative Start Date:	7/10/2021
Products Tested:	MG Chemicals 4228-55ML Red Insulating Varnish, Seymour 620-1525 Tool Crib Red Insulating Varnish, Anti-Seize Technology Red Insulating Varnish, Sprayon EL609 Green Insulating Varnish, DEI HI-TEMP Silicone Coating
Sample Size:	5
Sample Size Rationale:	A sample size of 10 units shall be used for each material. The test is to be conducted for evaluation of surface / edge condition with an applied coated material. Since this is a low-risk test for observation purposes, a sample size of 5 is used.
Objective	To determine whether the above listed products will protect and adhere to a sample of an eMotor stator lamination.
Test Type:	Evaluation

2.2.1 Sample Preparation

1. Find Schaeffler provided eMotor samples. Make sure that there is enough material to provide for 60 sample coupons in total.

2. Find a safe work area to spray samples with varnish, make sure that use of PPE such as gloves and respirators is used during the spraying process. **Caution, these products are harmful to touch / consume. DO NOT breathe or touch material before curing. If material comes in contact with skin, immediately wash exposed area, and consult Appendix B for chemical information of material.**

3. If needed, setup a small spray-booth using packing plastic to contain material during application. See Figure 7.

4. Apply each material as directed by manufacturer onto the samples. Ensure that 10 samples can be created from the provided parts.

Figure 7: Example Spray Booth

5. Allow material to cure as directed by manufacturer.

6. Cut samples into 10 coupons, label containers for each material and segregate samples based on material type.

7. This portion of the procedure is now complete.

2.2.2 Test Procedure

1. Prepare Oven for test, ensure oven is clear of other materials, set to 140 C, instructed use as directed by manufacture. See Figure 8 for pictures of oven used.

Figure 8: Oven used in Experiment

2. Prepare batches for test. Use a baking sheet with a liner to protect oven from corrosion. Set samples on baking sheet in rows according to their material. Record orientation of the tray and which samples belong to which material. See Figure 9 for example setup.

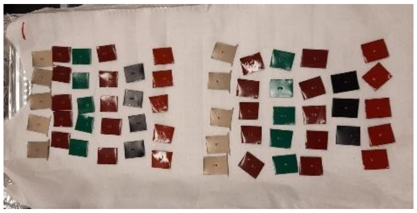


Figure 9: Example Tray Layout

3. Prepare 5% NaCl solution using deionized water for sample immersion.

4. Setup a timer, set to 10 Minutes. This test will run for 40 cycles.

5. For each cycle;

    a) Quickly and fully submerge each sample in the saltwater solution for at least 1 second.

    b) Place neatly back on tray.

    c) Open oven and insert tray into oven. Start Timer.

    d) Monitor the oven, open door at 141 C, close door at 140 C, reset heater at 138 C. Ensure oven stays at 140 +-5 C.

    e) After timer ends, reset timer and pull tray out of oven.

    f) Take macro pictures of tray every 10 cycles.

    g) Repeat steps a through f 40 times.

6. After last cycle, set tray on counter to cool for 10 minutes.

7. Turn off oven and clean off workspace(s).

8. Setup Olympus stereo microscope at 20x magnification (see Figure 10) and analyze 1 sample of each material from each batch.

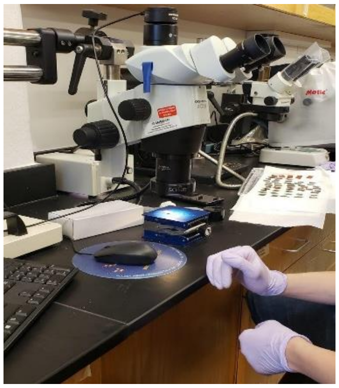


Figure 10: Olympus Microscope

9. Record observations.

10. The test is now complete.

2.2.3 Deviations

Each varnish had 10 samples with 5 in each set. The DEI HI-TEMP Silicone Coating (samples colored black as seen in Figure 9) were limited to 7 total samples due to sample preparation issues at Schaeffler.

2.2.4 Materials Used in Saltwater Corrosion Test

- Varnished coupon-samples of eMotor Stator (materials listed above)
- Paper Towel
- Baking Sheet
- Oven that can hold 140 C
- Oven Mitts
- PPE; safety glasses, gloves, respirator.
- Olympus microscope
- 5% NaCl saltwater bath

3. Material Testing Results

This section is an in-depth analysis of the research behind the chosen testing chemicals, the testing methodology, and the ranking system. It also delves into the observations and analysis from the day of testing and a second look at the samples.

3.1 Preliminary Test Results

The results were analyzed on two separate occasions, July 10th, and July 25th. Figure 11 shows the samples prior to testing. The samples were split into two groups for testing, each handled by a separate operator.

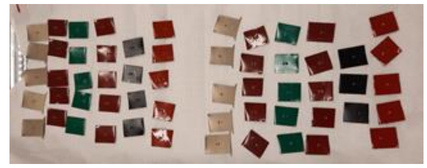


Figure 11: Samples Prior to Testing

On July 10th, our team performed the varnish corrosion test. During this testing procedure, the team recorded observations of what happened to the samples after each cycle of testing. The standard samples look similar to Figure 12. They are not perfectly flat. The “notch” mentioned later is located in the center of the sample.

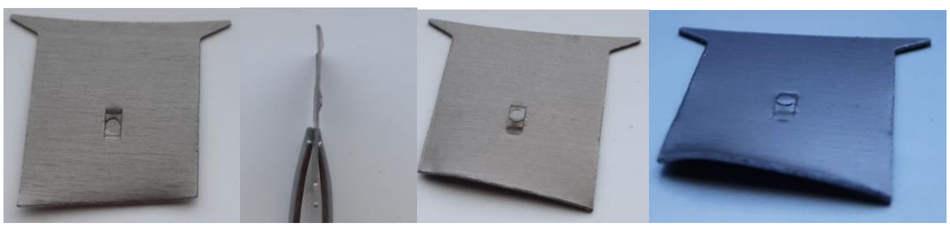


Figure 12: Standard Uncoated Sample

When the parts were taken out of the oven, salt deposits were noticed on the center of all the coating surfaces and can be seen in Figure 13. These salt deposits were found after each cycle.

A: 10 Cycles *B: 20 Cycles* *C: 30 Cycles*

Figure 13: Samples During Testing

The first amount of visible rust was noticed on the notches of the control samples, and this was recorded after the 7th cycle. Degradation of the DEI silicone coating was noticed throughout the testing, as seen in Figure 14. The fibers seen are most likely insulation from the furnace.

The anti-seize red insulating varnish (Figure 15), which was the material that was above its operating temperature, showed no visible breakdown during testing.

Figure 14: Center and Edge images of two samples of DEI Silicone (x20 zoom)

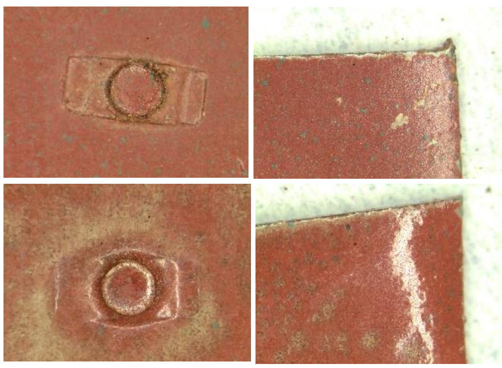


Figure 15: Center and Edge images of two samples of Anti Seize (x20 zoom)

The team performed an analysis of the samples on the day of testing and the observations were recorded. Visible rust was observed on the edges of all the samples. Coating loss was evident on all the samples, as was the glossy sheen finish. Overspray wasn't noted prior to testing, but after testing it was clearly visible that the samples had overspray. A common observation was that most if not all the samples had some level of visible corrosion on the center notches. The DEI silicone coating samples (Figure 14) shared one characteristic, unlike the other varnishes. Their coating degraded significantly more than others, and fibers from the oven seemed to have embedded themselves into the coating.

3.2 Research and Ranking Considerations

To properly assess the sprays' efficacy, we needed to narrow down the criteria upon which we were going to judge them. After extensive research, the team determined that the two best criteria to use were coating adhesion and the amount of corrosion found on the samples after the test. We used objective methods to quantify and qualify coating performance in terms of adhesion and amount of corrosion.

3.2.1 Coating Research

The following explains what constitutes effective rust preventatives as well as effective coatings. Schaeffler needs the coating to be affordable and durable as it is a one-time application that cannot be replaced. In addition, the coating needs to provide chemical resistance, heat resistance, close to zero moisture permeability, and significant adhesion as it will be constantly attacked. Coatings protect substrates through three basic mechanisms: barrier protection, chemical inhibition, and galvanic (sacrificial) protection.[14]

Barrier protection (Figure 16), which is the type of coatings in this project, is the complete isolation of the substrate from the environment.[14] These coatings are non-porous layers that once they are damaged, are no longer able to protect the substrate.[15]

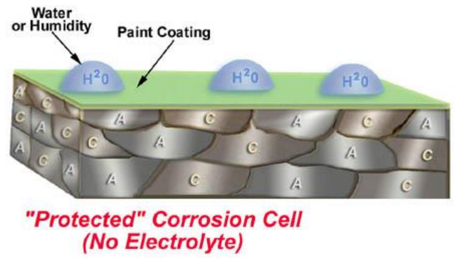


Figure 16: Graphic of Barrier Protective Coating[16]

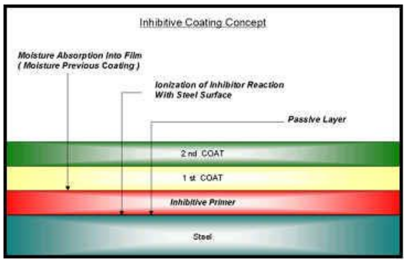


Figure 17: Graphic of an Inhibitive Coating[17]

Chemical inhibition (Figure 17) is the addition of inhibitive pigments to the coating. Inhibitive coatings form a porous passive layer over the substrate that will offer significantly reduced protection over time.[15] Sacrificial protection is coating the substrate with another metal.[15]

Sacrificial coatings (Figure 18) are still effective after wear but depend on the amount used and the substance binding it to the substrate.[15] Sacrificial coatings can be very expensive and will not be the most cost-efficient solution. Barrier protection is preferred as it tends to be cheaper, and its effective period has the potential to last longer than the inhibitive coating.

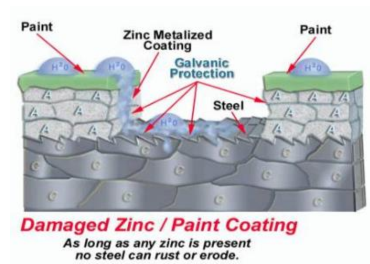


Figure 18: Graphic Showing an Example of Galvanic Coating[16]

3.2.2 Coating Adhesion

To accurately judge coating adhesion, we needed to examine multiple areas throughout the samples using various methods. We examined the cut edges of the samples and compared them to the machined edges using the Olympus Stereoscope. Second, we checked for bubbles, non-uniformity, and bare spots. We performed a visual inspection of the surface area covered by the varnishes. We checked the coating for undercutting wherever rust developed. Figure 19 shows the control samples with no protective coating. Here we noticed significant corrosion, especially along stamped edges.

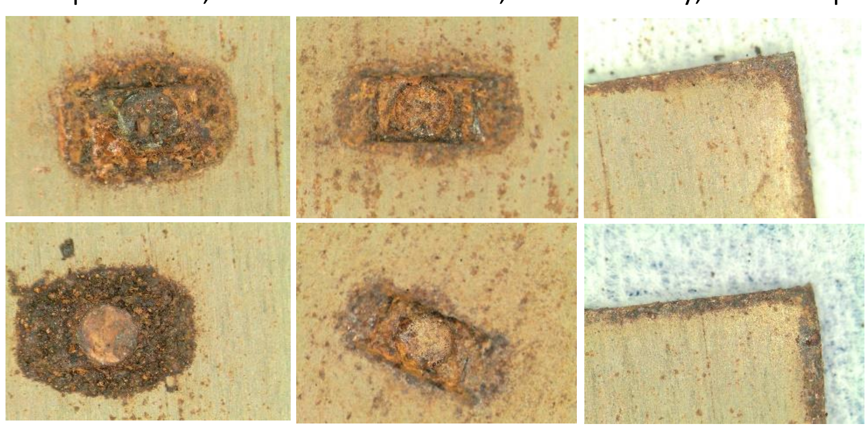


Figure 19: Center (Top and Bottom) and Edge images of two Control Samples (x20 zoom)

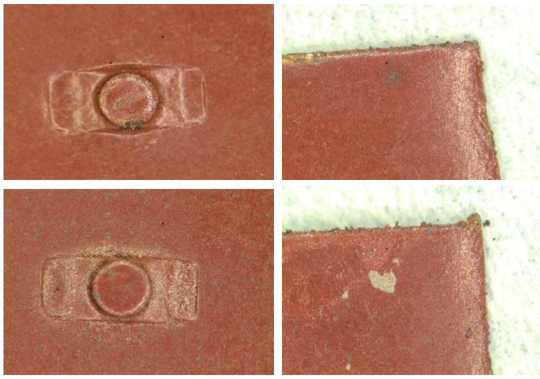


Figure 20: Center and Edge images of two samples of Seymour (x20 zoom)

One of the most definitive methods of testing the coating adhesion was through a knife test. The test is usually performed by cutting two lines in an “x” shape at a 30-45 degree angle and then the coating is lifted away.[18] A standardized version of this test can be found in ASTM D6677.[19] During this test, we attempted to lift the coating away from the substrate on multiple locations: bare spots, rust developments, edges, and on the unaffected varnish. It should be noted that this test is extremely subjective and its value is directly related to the operator’s experience. These results are all relative to each other and have no baseline to compare to.

With that said, the DEI silicone coating performed the worst. The Anti-Seize coating performed the worst out of all of the *varnishes*, but better than DEI. Seymour and MG Chemicals performed very similarly during the knife test; however, the Seymour coating was more difficult to lift off which indicates better adhesive strength (Figure 20). The Sprayon varnish performed the best (Figure 21).

3.2.3 Coating Corrosion Performance

After seeing the results of the adhesion test, the team decided to move forward in the analysis with the top three samples: Sprayon, Seymour, and MG Chemicals. The other two coatings were still inspected, just not considered as contenders. We decided the best way to assess the coating performance was through the center notch of the samples, as they all seemed to be completely coated. This area of the sample is more subjected to rust because of cold working. It deforms the grains and elongates them. Cold working creates residual stress in the sample at this location, making it more susceptible to stress-corrosion cracking.[14] We took one sample of each coating from each testing group and examined the center notches under the Olympus Stereoscope.

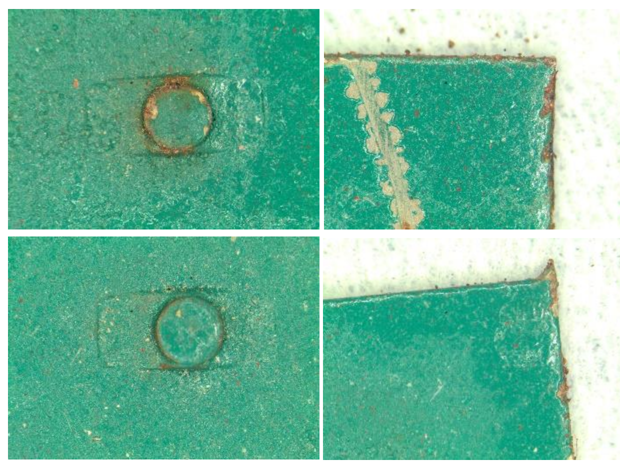


Figure 21: Center and Edge images of two samples of Sprayon (x20 zoom)

A base 20X magnification was used initially to perform a visual inspection, but on the Sprayon and Anti-Seize samples, there was some heterogeneity noticed in the surface finish. To study this further, A 40X magnification was used to analyze this further. Small corrosion “volcanoes” (Figure 22a) were seen at this level on the Anti-Seize samples, and an extremely rough surface was found on the Sprayon samples (Figure 22b).

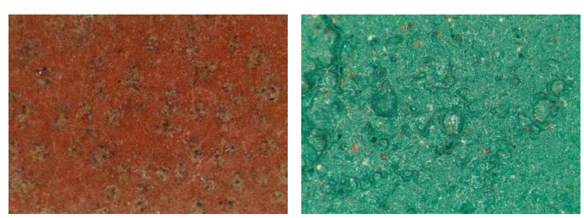


Figure 22: x40 Zoom images of: A. Anti-Seize (red) and B. Sprayon (green)

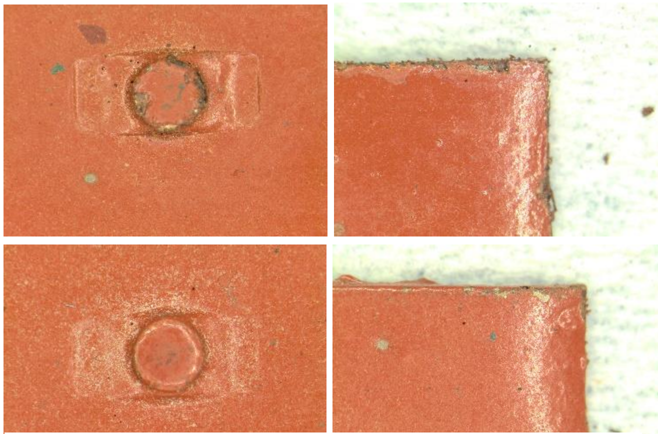


Figure 23: Center and Edge images of two samples of MG Chemical (x20 zoom)

The MG Chemicals samples (Figure 23) showed less corrosion than the Sprayon and Seymour, but only slightly. Due to its method of application(brush) and lack of adhesion compared to the Sprayon and Seymour, it was not pursued as a viable option. The Sprayon and the Seymour coatings were also very similar in the amount of corrosion present, but the team decided that the Sprayon showed less overall corrosion among *all the samples*.

3.3 Additional Analysis and Observations

Further analysis of the samples was completed on July 25th and aided in the final ranking of the coatings. The control samples were examined first. The majority of the rust was found on the center notch and edges of these samples. This was noted for further examination of the coated parts. The topside of the notches showed a larger surface area of rust compared to the downside of the notches. The topside of the notch is in the direction of the impression made by the stamping process. Refer to Figure 19 for the orientation of the notches. On the controls' surfaces, the visible rust formed in flow lines. These flow lines formed along the cold working/machining.

The edges of the coatings were examined for undercutting and flaking of material. It should be noted that there was no undercutting on any of the examined samples, but visible rust was observed on the edges of each coating. Undercutting is the corrosive loss of adhesion between the coating and the substrate, an indication of poor coating performance.[20] No quantitative analysis could be made of the corrosion on the edges, so no comparison could be made between the samples. The center notches of the coated samples generally had the most visible rust. Two samples of each coating were examined for rust on this area of the part. Each sample that we examined had a fair amount of cross-contamination from the overspray of other coatings.

The DEI Silicone coating (Figure 14) deteriorated rapidly during testing. The DEI samples showed the most corrosion relative to the other coatings. During the adhesion analysis, this coating was removed the easiest. Due to its relatively poor adhesion and rapid deterioration, it was not selected to be in the top 3 coatings.

The Anti-Seize coating, which was above operating temperature, did not show any visible signs of deterioration. This does not mean that it did not break down; rather, we only saw it start to peel from the edges (Figure 15). These samples showed random corrosion spotting throughout. Due to this coating being out of operating temperature and having relatively poor adhesion, it was not selected to be in the top 3 coatings.

The MG Chemicals (Figure 23) coating displayed flaking around the edges, specifically on the corners. This coating had the worst flaking out of all the coatings, but it was not as easily removed as the DEI or the Anti-Seize during the adhesion test, granting it a spot in the top three.

The Seymour (Figure 20) and the Sprayon (Figure 21) coating samples seemed to be relatively similar in their corrosion levels. However, the Sprayon coating was harder to remove during the adhesion test. However, the Sprayon coating showed more overspray than other samples, as shown in Figure 21. These two were selected to be in the top three, above the performance of the MG chemicals.

4. Material Selection Recommendations

A barrier type coating was selected as the preferred method due to cost and effective period. With this said, the chosen criteria to rank the coatings on are coating adhesion and coating performance. We ranked the coatings using the above criteria. The rankings below are resultant of both the coating adhesion and coating performance.

1. Sprayon
2. Seymour
3. MG Chemicals
4. Anti-Seize
5. DEI Silicone

The Sprayon, Seymour, and MG Chemicals varnishes all had acceptable performance and would meet Schaeffler's needs. The Anti-Seize varnish and the DEI Silicone coating did not perform adequately enough to meet their needs. It should be noted that these rankings do *not* mean that Sprayon is the best coating for this application, due to other considerations that will be addressed in the design phase of the project. Further testing and analysis should be completed prior to any final decisions. These results are simply what was seen in our experiment and should not be taken as fact.

5. Nozzle Research and Design

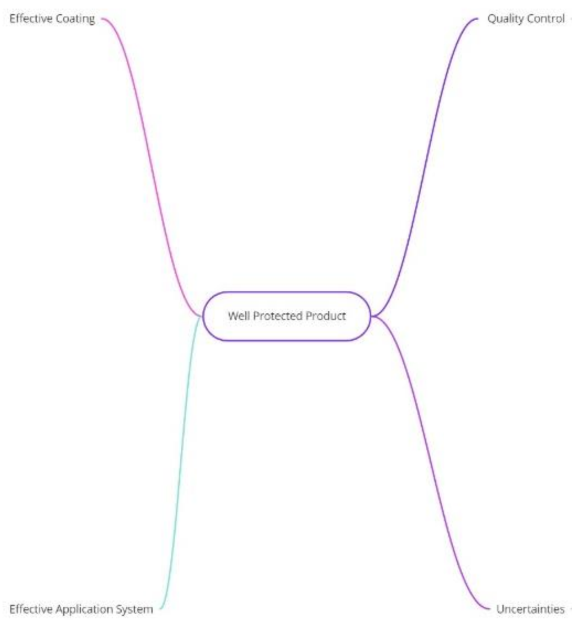


Figure 24: Mind Map

The outcome the design portion of the project is to produce well-protected parts for Schaeffler motors. The team has broken down this design into four categories: an effective coating, an effective application system, quality control, and project uncertainties. These have been expanded upon in a visual mind map seen in Figures 24 through 28. The effective coating has already been discussed. The rest of this report will focus on the effective application system, specifically, an ideal nozzle design.

An effective coating needs to consider the application the coating is needed for, the coating type used, the resulting coating characteristics, and the substrate characteristics. The application for Schaeffler is corrosion prevention. The coating type for this project is a varnish (a form of barrier protection) as opposed to silicone or paint. The varnish needs to be adhesive to perform adequately, as well as durable to meet Schaeffler's needs. The substrate is an E-Steel with the characteristics according to material NO 27-15 (DIN EN 10303: 2016-02).[21]

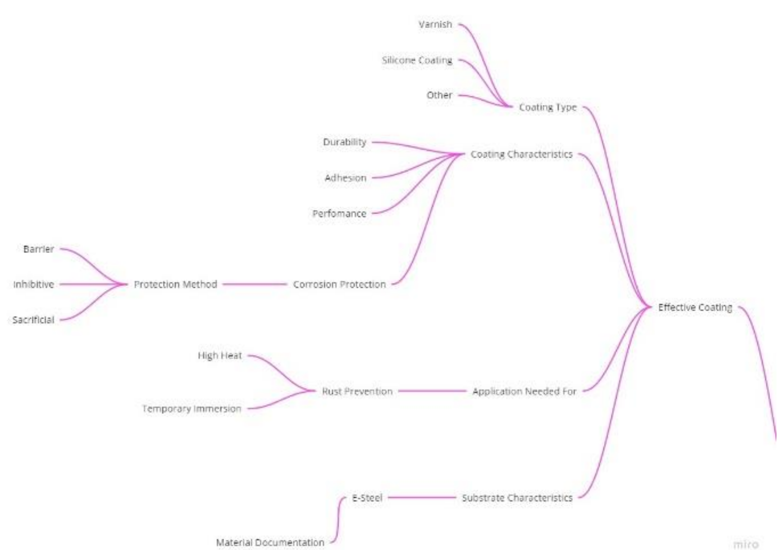


Figure 25: Mind Map – Effective Coating

The application system consists of four main components: propulsion, applicator, environment, and automation. Each of these needs to be conscious of cost as well as safety. The propulsion system will most likely be a form of safely contained compressed gas, but the decision is open for discussion. The applicator will have to be able to spray the varnish, as brushing is not an option that will work in Schaeffler's fast-paced industrial environment. The application system needs to be self-contained, as well as safe for employees (e.g., must have some sort of HVAC). Finally, the system needs to be automated and easily able to be integrated into Schaeffler's lines. Due to the team's limited time, funding, lack of communication from Schaeffler, and lack of extra resources, the effective application system will focus *solely* on an ideal nozzle design.

Figure 26: Mind Map – Effective Application System

Quality control is of the utmost importance for Schaeffler as it reduces scrap, increases profits, and ensures the overall safety of their products for their customers. The system will need both an initial inspection of the parts as well as the system components. The parts should first be checked for material defects and cleanliness. The system should be checked for proper operating conditions both physically and electronically. The parts post coating should be checked for coating quality in terms of uniformity, thickness, and coverage.

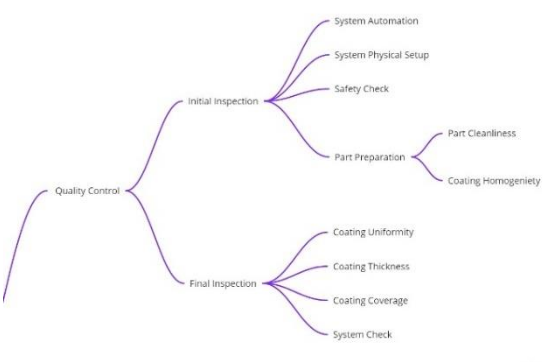


Figure 27: Mind Map – Quality Control

With all designs, some uncertainties will arise. Material defects are a real possibility when it comes to both the substrate and the coatings. The environment in the design will be controlled but may not be in Schaeffler's plant. As for automation, coding bugs can prove to be aggravating and problematic. Costing factors such as supply and demand are subject to market change and are therefore out of the design's feasible control.

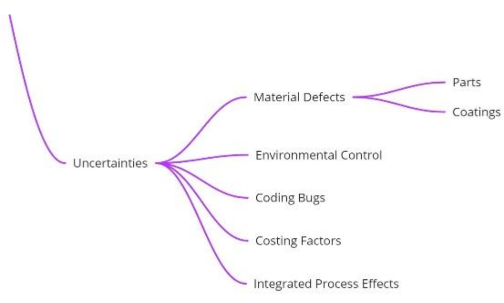


Figure 28: Mind Map – Uncertainties

Due to a lack of input and communication from the Schaeffler team, we were unable to coordinate the development of a final assembly system. Instead of developing a system that might not work in Schaeffler's setting, our team decided to focus on a key aspect of manufacturing the final product: The application of the rust preventative to the stator surface. This mainly entails the ability of an operator to use the shelf-available spray can versions of the material product. Our team decided to pursue a design application that will work homogeneously within the constraints of the available spray can product. After studying the available spray can products, specifically, Sprayon, we found that the spray nozzle could be easily removed from the propellant assembly. This would allow our team to begin research on and designing new nozzles to better optimize the end result of applying the material to the available stator samples.

5.1 Nozzle Design Research

The basic function of an aerosol can is one fluid stored under high pressure is used to propel another fluid out of a can. One of the fluids, the propellant, boils well below room temperature, and the other, the product, boils at a much higher temperature. Displayed in Figure 29 there are two ways to configure an aerosol system:

1. The product is a liquid poured into a sealed can, and then a gaseous propellant is pumped in through the valve system.

2. The propellant is a liquefied gas. This means that the propellant will take liquid form when it is highly compressed, even if it is kept well above its boiling point.

An aerosol can is designed to have a curved bottom; the reasons for this is to give the can greater structural integrity and make it easier to use up all the product.[22]

Eight functional parts go into the design of a nozzle/valve system in an aerosol can, which is shown in Figure 30. When the liquid flows through the nozzle, the propellant rapidly expands into gas. This action helps to atomize the product, forming an extremely fine spray.[22]

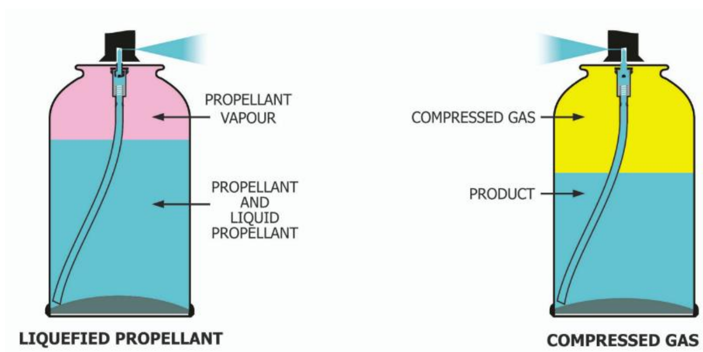


Figure 29: Example Cross Section of a Spray Can[23]

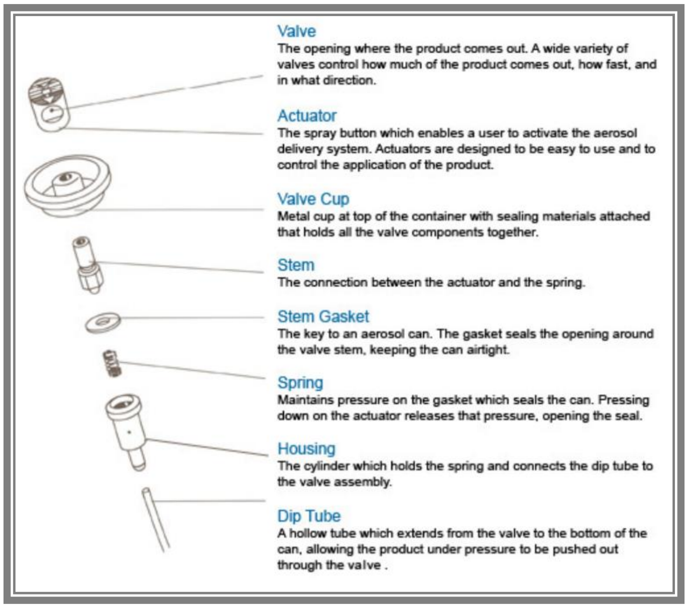


Figure 30: Example Spray Can Nozzle Assembly[24]

The valve system in an aerosol can operates on the principle of applying a pressure difference to the environment; a visual representation can be seen in Figure 31. When the actuator is pressed, it depresses the stem. This interrupts the sealing action of the gasket and exposes the stem orifice to the pressurized flow of product, thus opening the valve. When the actuator is released, the spring returns the stem to the sealed position, closing the valve.[24]

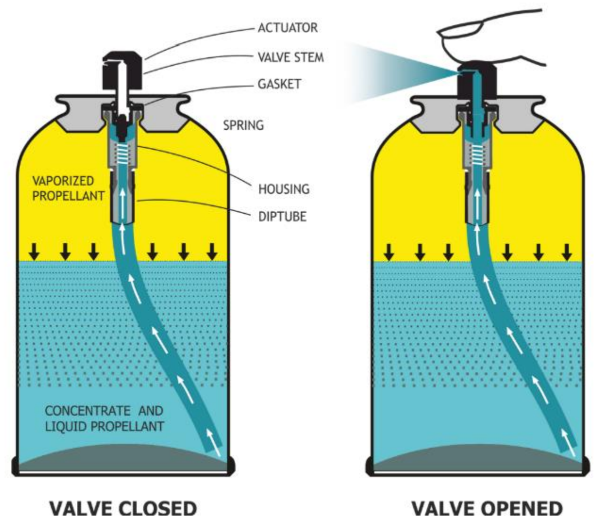


Figure 31: Actuation of a Spray Can Nozzle[26]

These systems revolve around the fundamental theories of fluid mechanics. The team researched Bernoulli's equation (Figure 32), the continuity equation ($A_1V_1 = A_2V_2$), and one-dimensional incompressible flow to better understand how fluid flow is affected in this system. Bernoulli's equation demonstrates how the velocity, area, and pressure of the system are related. The necessary assumptions are steady 1D flow, constant density, and no loss to friction.[25] The continuity equation is represented by the conservation of mass with a constant density for incompressible, one-dimensional flow.

$$p_1 + \frac{1}{2}\rho V_1^2 + \gamma z_1 = p_2 + \frac{1}{2}\rho V_2^2 + \gamma z_2$$

Figure 32: Bernoulli's Equation[25]

The team researched spray patterns to better understand how nozzle design affects them. There are two main categories of nozzle designs: hydraulic nozzles and air atomizing nozzles

Within those two categories you can find the following spray patterns shown in Figure 33:

Figure 33: Spray Patterns: Flat Fan, Mist/Fog Fan, Full Cone, Hollow Cone, Straight Jet[27]

5.1.1 Flat Fan Shaped Orifice - Deflection

The deflection design of a shaped orifice nozzle forms a deflected flat fan. The flat fan patterned formed is high impact and has coarse droplets, shown in Figure 34.[27]

Figure 34: Deflection Nozzle[27]

5.1.2 Flat Fan Shaped Orifice - Standard

The standard design of a shaped orifice nozzle produces fan patterns. Under certain design constraints these nozzles can form a fog or high impact jet. Figure 35 displays a standard fan nozzle with its respective spray pattern.[27]

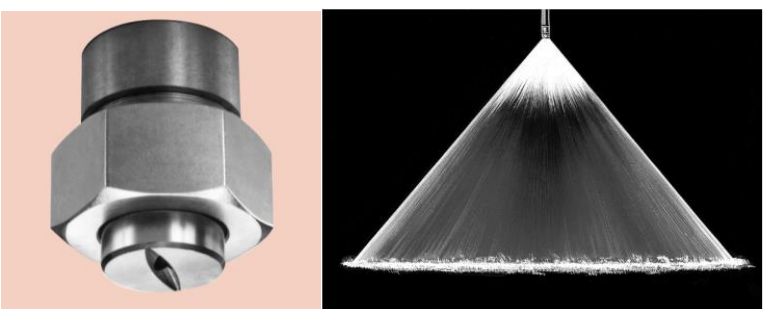


Figure 35: Fan Nozzle[27]

5.1.3 Impingement Orifice – Mist/Fog Fan

Impingement designs produce fog patterns that are typically less prone to clogging compared to other mist/fog nozzles. See Figure 36 for a standard nozzle and its respective spray pattern.[27]

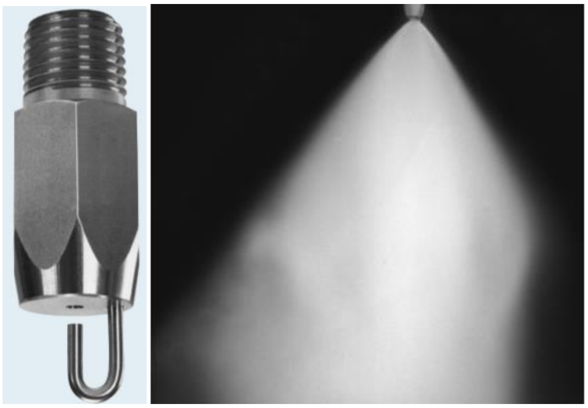


Figure 36: Fog Nozzle[27]

5.1.4 Spiral Orifice- Hollow/Full Cone

Spiral designs can produce either a hollow or full cone pattern, shown in Figure 37. These nozzles are clog resistant and produce smaller droplets compared to other nozzles with similar flow rates.[27]

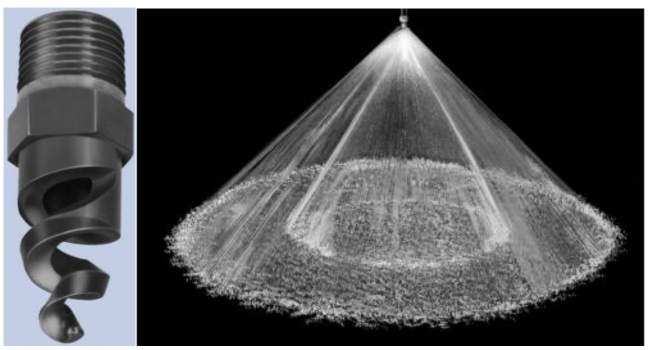


Figure 37: Spiral Nozzle[27]

5.1.5 Whirl – Axial

Axial designs of whirl nozzles form hollow and full cone patterns. An even distribution of fluid across the cone is maintained by these nozzles; reference Figure 38.[27]

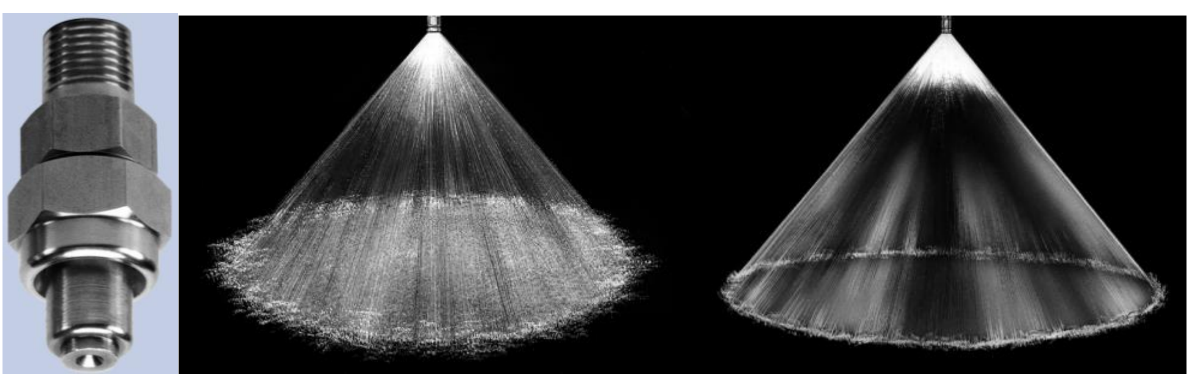


Figure 38: Whirl Nozzle[27]

5.1.6 Whirl Tangential

A tangential design of a whirl nozzle produces both hollow and full cone patterns (Figure 39). The spray pattern is at a 90^{o} to the original fluid flow.[27]

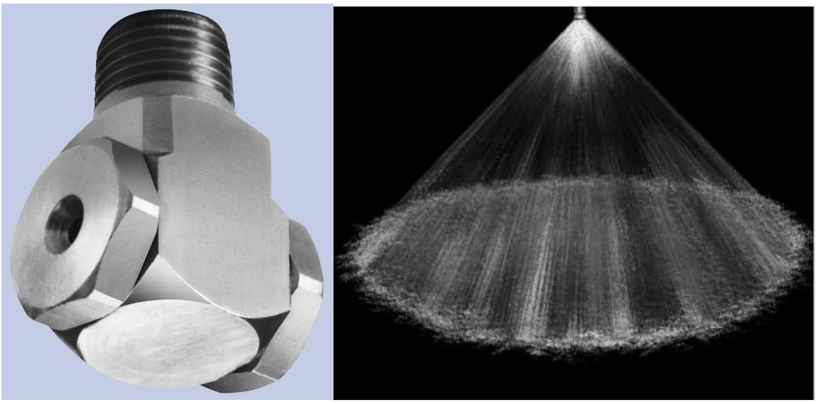


Figure 39: Whirl Tangential Nozzle[27]

5.1.7 Siphon Fed

Siphon fed nozzle designs produce a fan or cone pattern. This nozzle operates at the lowest flow rate of all the designs. Figure 40 is an example of a standard siphon fed nozzle.[27]

Figure 40: Siphon Fed Nozzle[27]

5.1.8 External Mix

External mix nozzle designs produce narrow full cone and fan patterns. The external mixing aids in atomizing viscous flow. Figure 41 is an example of a standard external mix nozzle.[27]

Figure 41: External Mix Nozzle[27]

5.1.9 Internal Mix

Internal mix nozzle designs produce hollow cone, narrow and wide full cone, fan and deflect fan patterns. This design in the most common and versatile air atomizing nozzle. Reference Figure 42 for two different standard internal mix nozzles.[27]

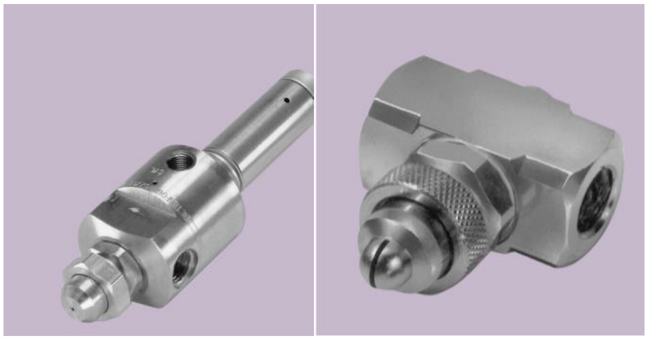


Figure 42: Internal Mix Nozzle[27]

5.2 Manufacturing Process Selection

As the team moved to the manufacturing phase of the project, we were faced with one daunting issue. How were we going to properly fabricate such small, intricate parts? The team decided on additive manufacturing as subtractive manufacturing methods would not be able to meet the size specifications needed for the proper construction of the nozzles. There are seven 3D printing methods defined by ASTM F2792-12A under Committee 42: Vat Photopolymerization (VPP), Powder Bed Fusion (PBF), Material Jetting (MJ), Binder Jetting (BJ), Sheet Lamination (SL), Material Extrusion (MEX), and Directed Energy Deposition (DED).[28] VPP is the process of curing photopolymer-based resins using UV light. There are two methods of curing, projection and scanning. Projection is curing an entire layer at a time by shining the pattern on the resin at once. Scanning is tracing the pattern in each layer. The VPP printing method provides the ability to print in micrometers and nanometers while maintaining structural integrity and high-quality surface finish. Stereolithography (SLA) is the term for the scanning form of VPP printing. SLA prints require post-processing measures to ensure the quality of the prints. The first step is to rinse and soak the print in a solvent (isopropyl alcohol is commonly used) to remove any extra uncured resin. Following the cleaning, the supports will need to be snipped away from the main print. Lastly, the print can be cured in a UV light chamber to fully harden the finalized print. The team chose to 3D print the nozzle designs using the Form 2 Desktop 3D Stereolithography Printer.

5.2.1 Printer

The Form 2 is a stereolithography printer that uses a 250 mW power, 140 micron spotsize, 405 nm wavelength violet laser to cure photopolymer-based resins. It is capable of printing in 25, 50, and 100 microns for its layer thickness (axial resolution). The Form 2 uses a sliding peel process with a wiper to level the resin in between layer printing.[29] The resin used was the Formlabs Clear Resin FLGPCL04.[30,31] Figure 43 shows the Form 2 printer used as well as one of the team members removing the printed nozzles from the substrate. For a physical visualization of the Form 2, see Figure 44.

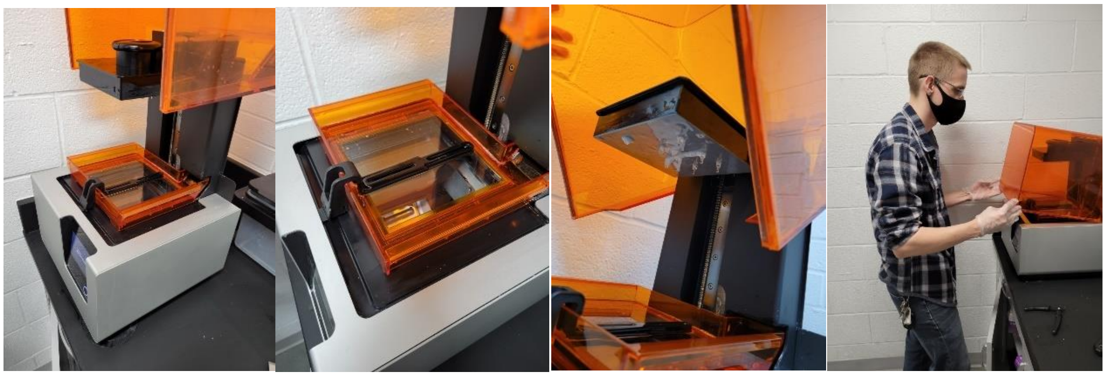


Figure 43: Formlabs Form 2 and Clear Resin FLGPCL04

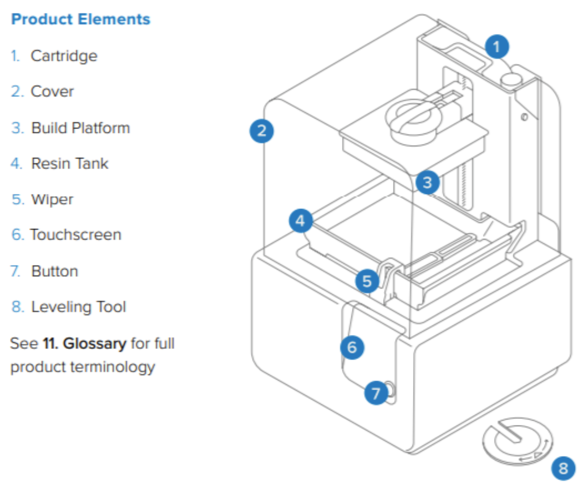


Figure 44: Formlabs Form 2 Subcomponents[29]

5.3 Design

Nozzle designs followed an iterative process. Different exit hole shapes and sizes were modeled and printed to observe and conclude a cause-and-effect relationship between design and spray pattern. This was done in 3 separate iterations focusing on different nozzle designs.

5.3.1 Design Verification

To legitimatize the team's findings, we needed to verify their manufacturing method. The best way to prove that the nozzle designs were comparable was to reproduce Sprayon's stock nozzle. The team used a software that measures microscopic images based on known distances. After obtaining the measurements (Figure 45), the team modeled the stock nozzle replica and printed it using the Form 2. Both the stock nozzle and the replica were tested during each set of testing to establish a control.

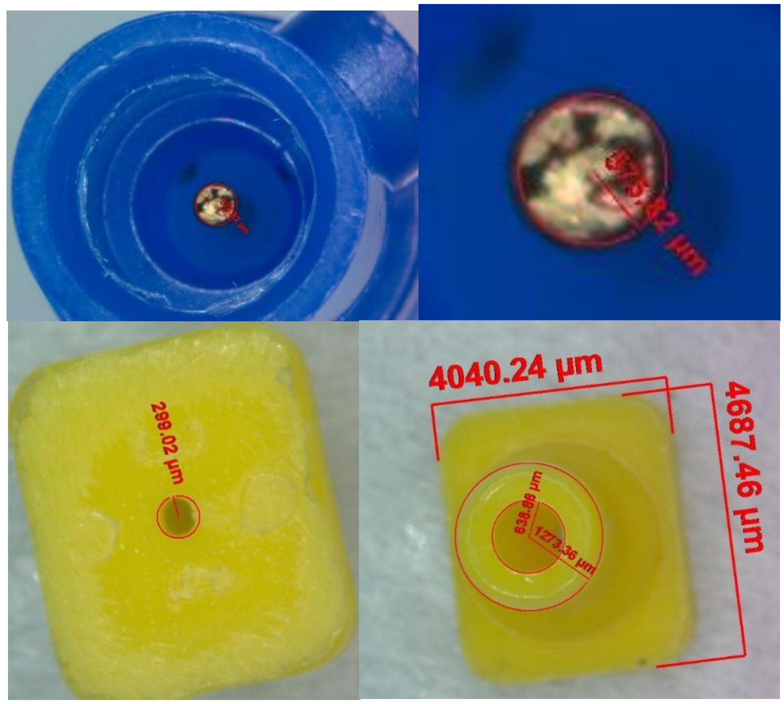


Figure 45: Measurements of the Sprayon Nozzle

5.3.2 Iteration 1 Design Theory

The first iteration of nozzle design attempted various sizes and shapes of exit holes. These designs include one nozzle intended to copy the manufacturer's nozzle dimensions, two rectangular openings intended to spray a flat pattern, two circular openings intended to spray a cone pattern, and a spiral opening intended to spray a spiral pattern.

5.3.3 Iteration 1 Design Application

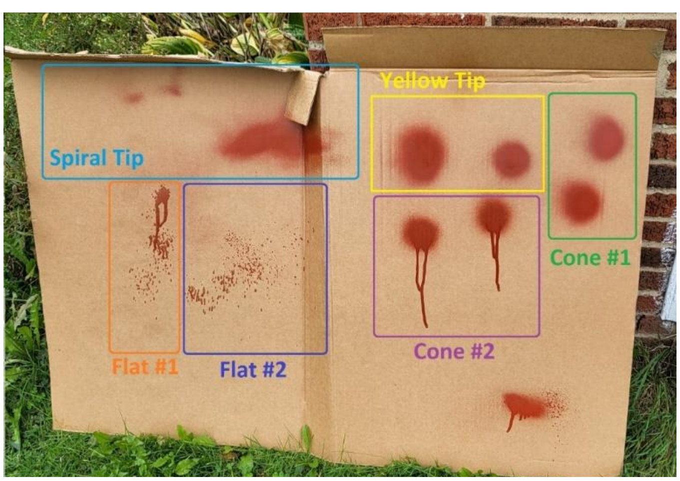


Figure 46: Iteration 1 Results

The spray used in application was Sprayon EL 601. This red colored spray is not seen in later tests as it was ordered incorrectly but was the only available spray at the time. The correct spray, Sprayon EL 609, was used for following iterations. All spraying was done 6 to 8 inches away from the cardboard as specified in application by Sprayon.

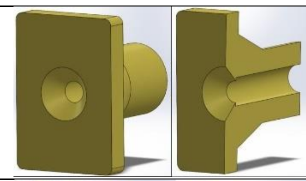
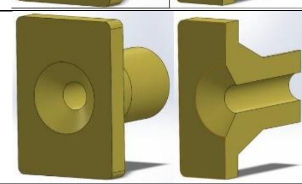
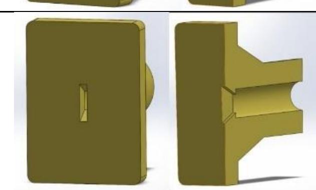
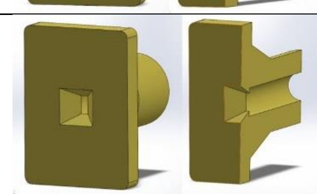
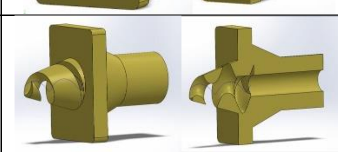
The results can be seen in Figure 46. The pattern labeled yellow tip in all iterations refers to the pattern made by the nozzle provided by the manufacturer. Images of the nozzle tip models can be seen in Table 2. Cone #1 and Cone #2 with a circular exit hole resulted in cone spray patterns. Larger exit holes as seen with Cone #2 atomize less and drip significantly. Cone #1 had slight dripping. Flat #1 and Flat #2 with rectangular openings both clogged when used and sprayed in sporadic spurts. The spiral nozzle tip sprayed in two directions. To the right it sprayed onto the carboard in an elongated pattern. To the left it sprayed in a fine mist at a right angle away from the cardboard. Lastly, the nozzle intended to be a copy of the yellow nozzle failed to print correctly and would be attempted again in Iteration 2. All but three nozzles were clogged after use and needed to be cleaned to be used again.

5.3.4 Iteration 2 Design Theory

In Iteration 1, the nozzles that showed desirable atomization were the yellow nozzle from the manufacturer and Cone #1. From this, Iteration 2 expanded on changing the exit hole shape of the yellow tip while maintaining a similar size. One rectangular exit was made intended to make a flat spray pattern. Another was made with a square exit to observe its effect.

Other nozzles had the head elongated to increase the distance traveled through the exit hole size. One design kept the same hole size of the yellow nozzle, one with a larger rectangular exit hole, and two that converged in a funnel for the length of the head. One converged to a circular opening that was the same size as the yellow nozzle and the other converged to a small square exit hole. Table 2 shows the nozzle models and their respective cross sections.

Table 2: Iteration 1 Nozzle Cross Section

Design Name:	Model View
Cone #1	
Cone #2	
Flat #1	
Flat #2	
Spiral	

5.3.5 Iteration 2 Design Application

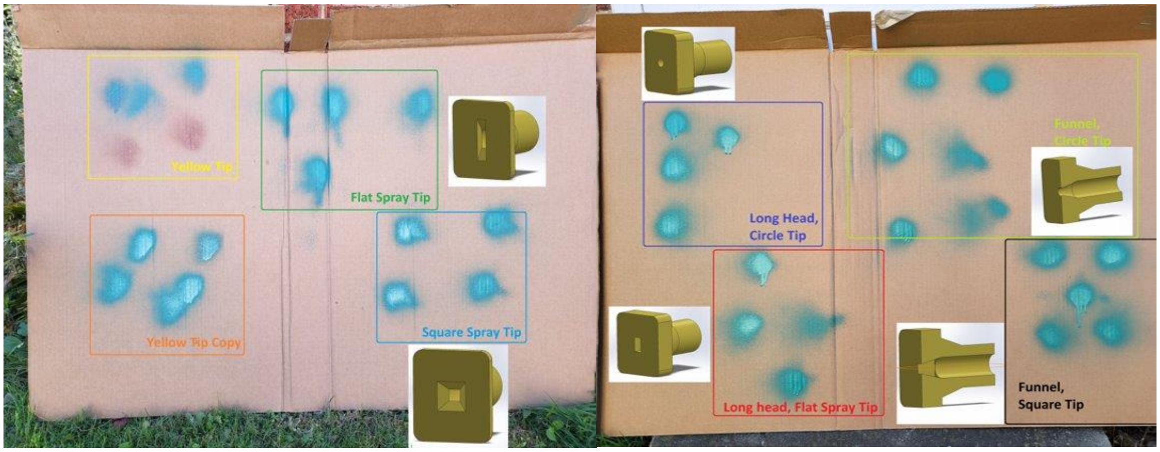


Figure 47: Iteration 2 Results

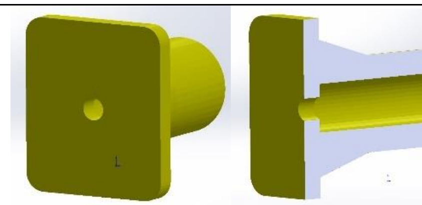
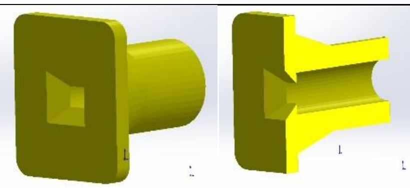
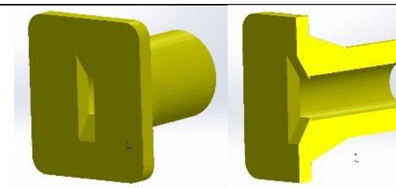
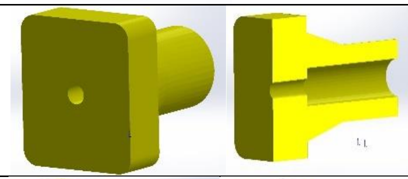
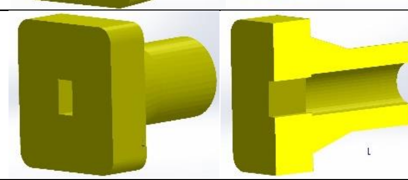
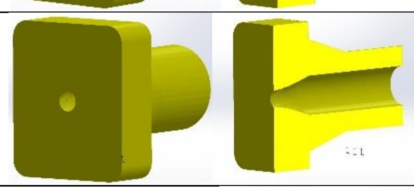
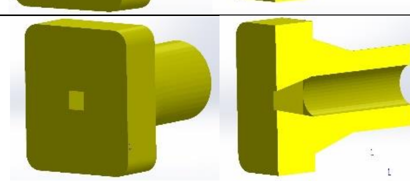
Sprayon EL 609 was used during application. Spraying was performed at both between 6 to 8 inches away and 10 to 12 inches away in each pattern grouping. This was done to check for differences when using nozzles with elongated heads.

All nozzles sprayed cone shaped patterns with variations, shown in Figure 47. The copy of the yellow tip performed similarly, as expected. The rectangular exit hole sprayed a cone shaped pattern with a tail end pointing downward. Most of the spray exited the end with no influence from the tip. This would indicate that nozzles intending to spray a flat pattern would need to be redesigned in Iteration 3. The square spray tip resulted in a cone pattern with distinct rounded corners.

The elongated heads were sprayed from 10 to 12 inches away and 6 to 8 inches away in each grouping. Those that were sprayed closer showed visual dripping. All patterns sprayed in a cone pattern with no notable variation. Converging the exit hole through the elongated head did not produce a visually different result when compared to nozzles that did not converge. Figure 48 shows the nozzles after testing; Table 3 displays the nozzle models and their cross sections.

Figure 48: No Clogging Iteration 2

Table 3: Iteration 2 Nozzle Cross Section

Design Name	Model View
Copy of Original Nozzle (yellow tip copy)	
Square Nozzle (Square tip spray)	
Funneled Rectangle (Flat Spray Tip)	
Long Head, Circular (Long head, Circle Tip)	
Long Head, Rectangle (Long head, Flat spray tip)	
Long Head, Converging Circle (Funnel, Circle tip)	
Long Head, Converging Square (Funnel, Square tip)	

Note: No nozzles clogged after use. Verified with 0.4mm needle

5.3.6 Iteration 3 Design Theory

Design for Iteration 3 focused on creating a flat spray pattern and a deflection nozzle design. Converging the exit hole was also attempted for a circular and oval shaped exit. Adjustments to the flat spray nozzles were done in different angle increments for the angled cut in the nozzle head. This cut caused the spray to hit its slope and deflect in a manner to create a flat spray pattern. Similarly, deflection nozzles were designed with a sloped surface for the spray to deflect in a desired direction.

5.3.7 Iteration 3 Design Application

Sprayon EL 609 was used during application. Spraying was done 6 to 8 inches away from the cardboard. deflection nozzles were oriented so that they spray to the left of where the can is aimed. These spots ae shown in Figure 49.

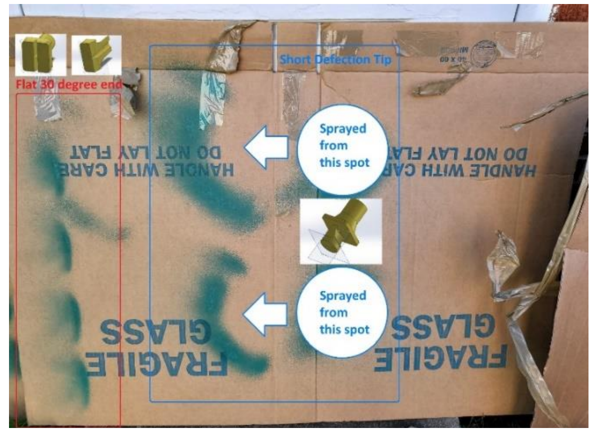


Figure 49: Iteration 3 Deflection Nozzles

The continuously converging circle nozzle tip and the oval counterpart both resulted in a cone spray pattern. The oval nozzle applied thicker and had small amounts of dripping.

The 45-degree, 20-degree, and 15-degree flats all made a flat spray pattern as intended. The 45-degree pattern was the widest and the 15 degree was the thinnest.

The results for Iteration 3 are shown in Figure 51. Deflection nozzles deflected as intended. The short and long tips sprayed in a crescent shape to the left of the position sprayed. The short nozzle with a concave surface formed a wider crescent shape with a mirrored orientation compared to the other deflection tips. None of the nozzles in Iteration 3 clogged after initial testing, proved in Figure 50. Table 4 contains images of the nozzle models and their cross sections.

Figure 50: Iteration 3 No Clogging

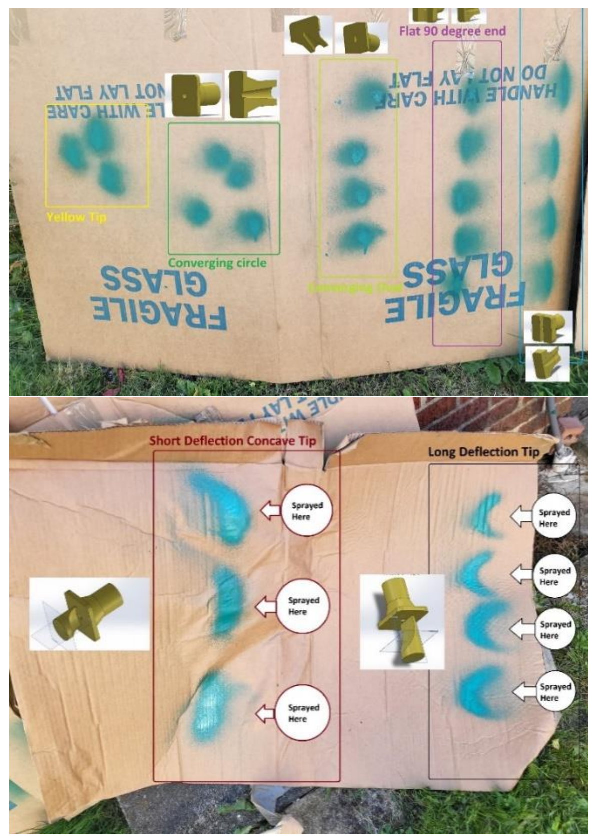
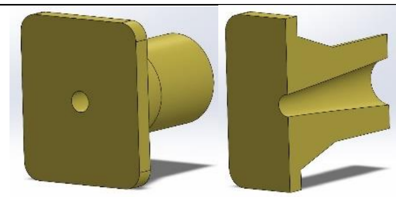
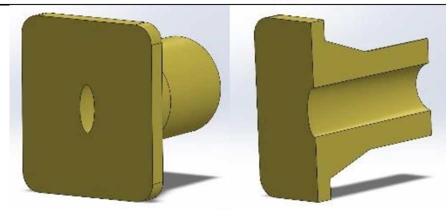
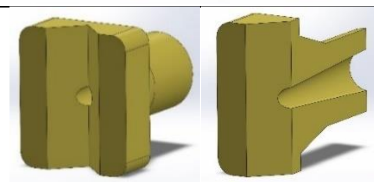
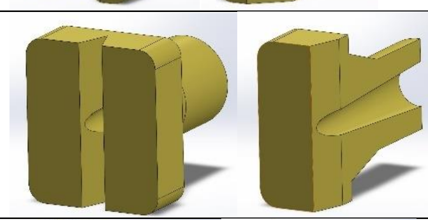
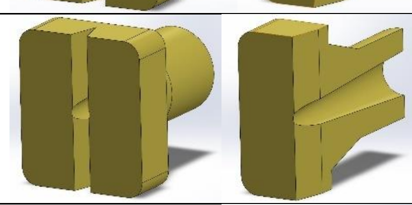
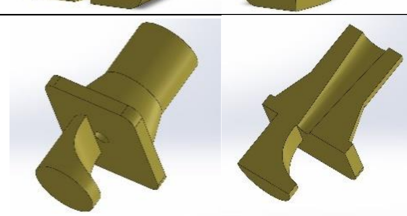
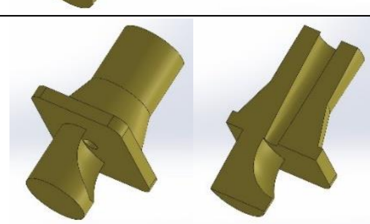
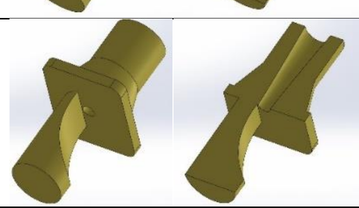


Figure 51: Iteration 3 Results

Table 4: Iteration 3 Nozzle Cross Section

Design Name:	Model View
Continuously Converging Circle	
Continuously Converging Oval	
45 Degree Flat	
20 Degree Flat	
15 Degree Flat	
Short Deflection Tip	
Short Concave Deflection Tip	
Long Deflection Tip	

Note: No clogging occurred after testing.

6. Nozzle Testing Procedure

To test the effectiveness of the nozzles, samples are to be created from the varying designed nozzles and subjected to saltwater exposure representative of conditions it will have in Schaeffler products. After numerous iterations of exposure, the samples are to be compared to determine the varnish most suitable for production purposes. Different methods for testing spray pattern, material adhesion, and coverage on the sample will also be conducted. Table 5 represents all miscellaneous test information. The sample size for this round of testing is limited due to the amount of stator samples left-over from the first rounds of testing.

Table 5: Nozzle Test Report Details	
Test Description:	Sprayon Nozzle Research and Design Comparison Test
Test Requester:	Schaefer Group
Test Location:	UA Corrosion Labs, ASEC 471
Tentative Start Date:	11/13/2021
Products Tested:	Sprayon EL609 Green Insulating Varnish DEI HI-TEMP Silicone Coating, 3D Printed Nozzles
Sample Size:	2
Sample Size Rationale:	A sample size of 2 units shall be used for each Nozzle. The test is to be conducted for evaluation of surface, edge, and adhesion conditions with an applied coated material. Nozzle spray patterns will also be analyzed.
Objective	To determine whether the above listed nozzles will protect and adhere to a sample of an eMotor stator lamination, not compromising protection and/or reducing material loss during application.
Test Type:	Evaluation
Lab Conditions:	72 °F

Figure 52: Nozzle Experimental Setup

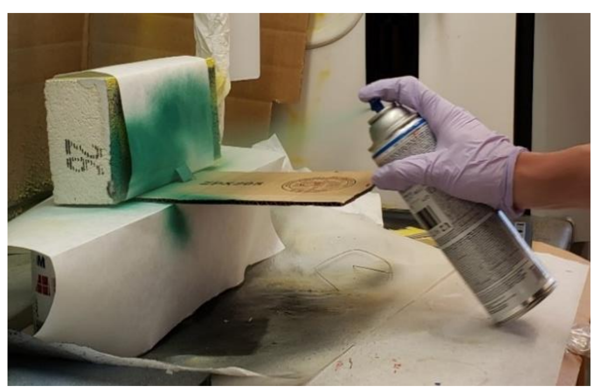


Figure 53: Sample Part Being Sprayed

6.1 Material Application

1. Find Schaeffler-provided eMotor samples. Make sure that there is enough material to provide for 32 sample coupons in total.

2. Find a safe and regulated work area to spray samples with varnish, make sure that use of PPE such as gloves and respirators is used during the spraying process. **Caution, these products are harmful to touch / consume. DO NOT breathe or touch material before curing. If material comes in contact with skin, immediately wash exposed area and consult Appendix B for chemical information of material.**

3. Setup a spray booth in a controlled environment shown in Figure 52 and Figure

53; in this case, a fume hood was used. Ensure that the Sprayon material is applied within a range of 70°F-90°F[10].

Refer to Appendix B for further manufacturer information.

4. Degrease and clean intended samples. Ensure samples are dried before material application.
5. For each Nozzle, spray material onto two sample coupons. Ensure a distance of 8-in is used between the part and the spray can. Ensure that all parts are oriented in a similar fashion when material is applied. Figure 53 is an example of coating application.
6. Label nozzles (Figure 54) and take note of spray pattern, amount of spray passes used, and any unusual events. Separate parts based off of the nozzle used to apply material. See Table 6 for nozzle identification.
7. Allow material to dry on sample for 15 seconds before handling.
8. Analyze samples under a microscope once the material has cured.
9. This portion of the procedure is now complete.

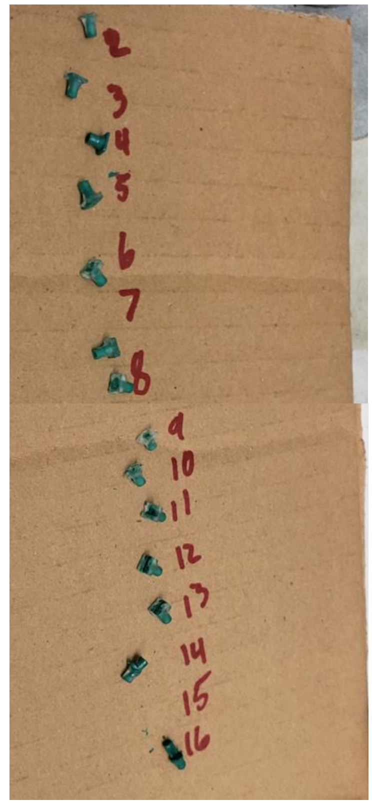


Figure 54: Nozzle Identification

Table 6: Nozzle Identification and Description			
ID #	Description	ID #	Description
1	Original Nozzle	9	Continuously Converging Circle
2	Copy of Original Nozzle	10	Continuously Converging Oval
3	Square Nozzle	11	45 Degree Flat
4	Funneled Rectangle	12	20 Degree Flat
5	Long Head, Circular	13	15 Degree Flat
6	Long Head, Rectangle	14	Short Deflection Tip
7	Long Head, Converging Square	15	Short Concave Deflecting Tip
8	Long Head, Converging Circle	16	Long Deflection Tip

6.2 Saltwater Corrosion Testing

Refer to the test procedure in section 2.2.2. Use same experimental setup to test stator samples with Sprayon material. Make note to capture surface images of samples under a microscope before and after testing them.

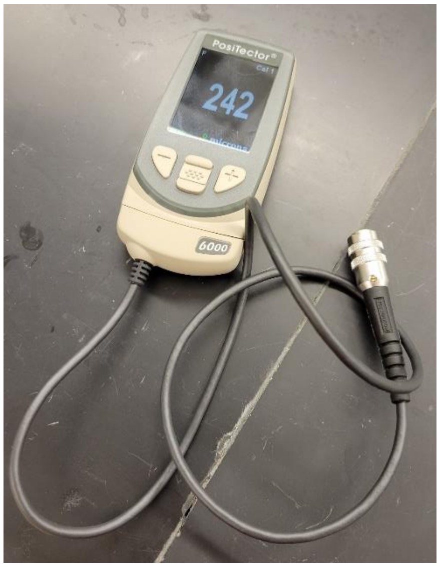


Figure 55: DeFelsko PosiTector with Coating Thickness Instrument

6.3 Material Layer Thickness Testing*

1. Turn on DeFelsko PosiTector Using the Coating Thickness Instrument SN: 343599.
2. Place Intended sample to be measured coating side up on clean, flat work surface.
3. Place Coating Thickness Instrument probe onto desired location of piece to be measured.
4. Press probe into piece and press outer collar onto piece.
5. Take 10 measurements of the coating thickness of the material and average them.
6. Repeat until desired number of samples are measured.
7. This portion of the procedure is now complete.

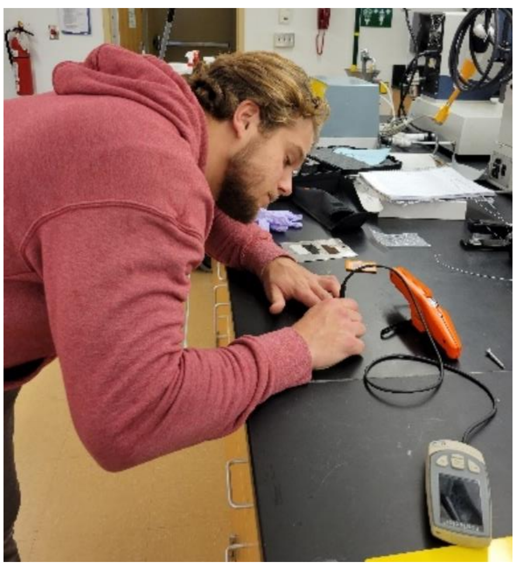


Figure 56: DeFelsko PosiTector in Use

Figures 55 and 56 display the DeFelsko PosiTector with Coating Thickness Instrument and it being used by a team member to measure sample thickness.

*Thickness testing is conducted in accordance with ASTM Standard E376-19, “Standard Practice for Measuring Coating Thickness by Magnetic Field or Eddy Current (Electromagnetic) Testing Methods”.[32]

6.4 Deviations

Most of the testing procedures were followed as previously discussed. However, there were a few minor deviations during testing. First, after the parts were sprayed, they were handled only a few seconds after being sprayed. Per directions from Sprayon, they should have been partly cured before being handled.[33] The oven used for the saltwater testing was inconsistent with holding a temperature of 140 C°, and sometimes approached the high safe temperature of 155 C°. The last nozzle breaking during installation into the spray can was also unintended.

6.5 Materials Used for Nozzle Testing

6.5.1 Material Application

- Sprayon EL609 PPE; safety glasses, gloves
- Spray Booth
- Fume Hood
- 8-inch spacer
- Sample Divider
- Controlled Curing Environment
- Olympus microscope

6.5.2 Saltwater Corrosion Testing

- Varnished coupon-samples of eMotor Stator (Sprayon)
- Paper Towel
- Baking Sheet
- Oven that can hold 140 C°
- Oven Mitts
- PPE; safety glasses, gloves
- Olympus microscope
- 5% NaCl saltwater bath

6.5.3 Material Layer Thickness Testing

- DeFelsko PosiTector Using the Coating Thickness Instrument SN: 343599
- Varnished coupon-samples of eMotor Stator (Sprayon)
- Olympus microscope
- PPE; safety glasses, gloves
- Provided Coating Thickness Calibration Board

7. Nozzle Testing Results

After running multiple tests, the team started a discussion on how to interpret the results of the experiment. In total, the team had three major concerns to analyze. These include nozzle performance during application, material coating thickness, and the comparative saltwater test. To better narrow down the results, the application performance, and coating thickness will be examined.

The results of each test will be explained in the further detailing sections, along with an interesting phenomenon observed during the thickness testing.

7.1 Application

The criteria for a nozzle to have unacceptable application testing is if it clogs, has a non-uniform spray pattern, or is not optimized for an 8-in spray distance. If any of these occur, it would interfere with the application of material. Clogging directly inhibits spray from leaving the nozzle. Non-uniformity in spray pattern is when portions of the pattern have material apply much thicker than other sections. This usually causes dripping in sections of the pattern that receive more particles and other sections receive less. Nozzles are acceptable if they can coat the sample at a distance of 8 inches optimally which means that a few passes of the spraying should be sufficient. All nozzles are acceptable in this regard except for Nozzles #3, 4, 14, and 16. A visual assessment of these nozzle application can be seen below in Table 7.

Nozzles #3 and 4 were considered unacceptable due to non-uniform spray patterns. Nozzle #3 had an irregular cone pattern with rounded corners forming a square like shape. Spray applied thicker near these rounded corners and caused dripping. Unless the object being sprayed was within the center of the square shape, it would receive an uneven amount of material. Nozzle #4 sprayed a cone pattern with a tail. The tail is a vertical line extending below the circle formed from the cone pattern due to the rectangular exit hole shape.

Nozzle #14 was the short deflection tip. It deflected material away from the direction the can was aimed as intended, however it creates a large spray pattern. At 8 inches from the part, only a small portion of particles applied to the surface. 7 passes of the can were needed to apply enough material to cover the part while other nozzles only needed 2 to 3 passes. This nozzle was considered unacceptable because it is not optimized for an 8-in spray distance.

Nozzle #16 was considered unacceptable due to clogging. After attempting to make it functional, parts of the nozzle broke off making it non-functional. All nozzles should be considered when analyzing data with the other testing results.

Table 7: Nozzle Application Observations						
Sample	Description	Number of Passes	Intended Spray Pattern	Actual Spray Pattern	Clogging	Uniform Spray Pattern
1	Original Nozzle	2	Cone	Cone	No	Yes
2	Copy of Original Nozzle	2	Cone	Cone	No	Yes
3	Square Nozzle	2	Experimental	Irregular Cone	No	No
4	Funneled Rectangle	2	Flat	Cone with tail	No	No
5	Long Head, Circular	2	Cone	Cone	No	Yes
6	Long Head, Rectangle	2	Cone	Cone	No	Yes
7	Long Head, Converging Square	2	Experimental	Cone	No	Yes
8	Long Head, Converging Circle	2	Cone	Cone	No	Yes
9	Continuously Converging Circle	2	Cone	Cone	No	Yes
10	Continuously Converging Oval	2	Experimental	Cone	No	Yes
11	45 Degree Flat	2	Flat	Flat	No	Yes
12	20 Degree Flat	3	Flat	Flat	No	Yes
13	15 Degree Flat	3	Flat	Flat	No	Yes
14	Short Deflection Tip	7	Deflection	Deflection	No	Yes
15	Short Concave Deflecting Tip	2	Deflection	Deflection	No	Yes
16	Long Deflection Tip	N/A	Deflection	N/A	Yes	N/A

7.2 Thickness

To ensure DeFelsko PosiTector's accuracy, the team used a calibration board of various materials with predefined thicknesses (shown in Figure 57). This calibration board came from the manufacturer. The instrument seemed to be reading a bit low compared to the calibrated thicknesses. Table 8 shows the expected calibration values and the measured values. Due to the consistently low readings during the calibration, the team decided to correct the values. These corrected values were determined by adding the average percent error (3.2%) to every measured value.

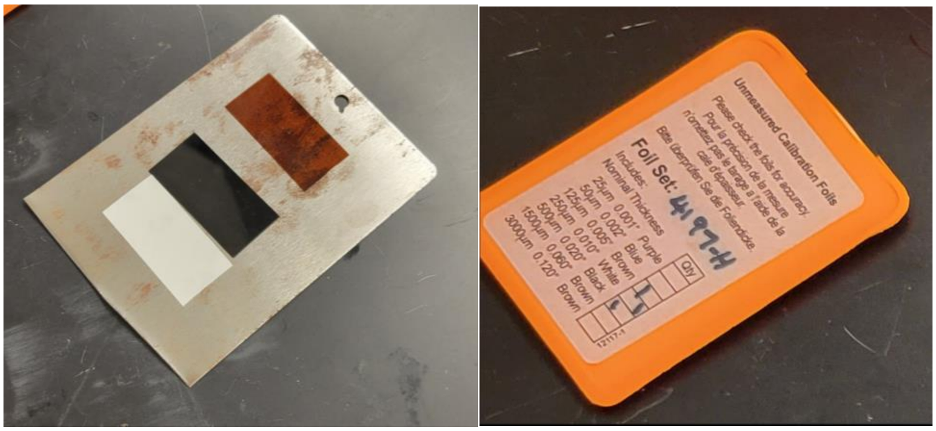


Figure 57: Calibration Card for DeFelsko PosiTector

Table 8: DeFelsko PosiTector Calibration					
Expected (µm)	Measurement 1 (µm)	Measurement 2 (µm)	Measurement 3 (µm)	Measurement 4 (µm)	Average (µm)
125	118	120	122	118	119.5
250	240	240	240	240	240
500	496	492	494	494	494

The thickness test was attempted on the samples after a curing period of 7 days (manufacturer recommended). The material scraped off when the coating thickness measuring instrument made contact with the samples. To ensure the material was completely cured, the samples were baked in an oven at 140° C for two hours. The samples being baked in the separate furnace is shown in Figure 58. Following this baking, the material did not scrape off during the second attempt. Both the tops and bottoms were baked at 140° C; however, the bottoms were subjected to the saltwater test.

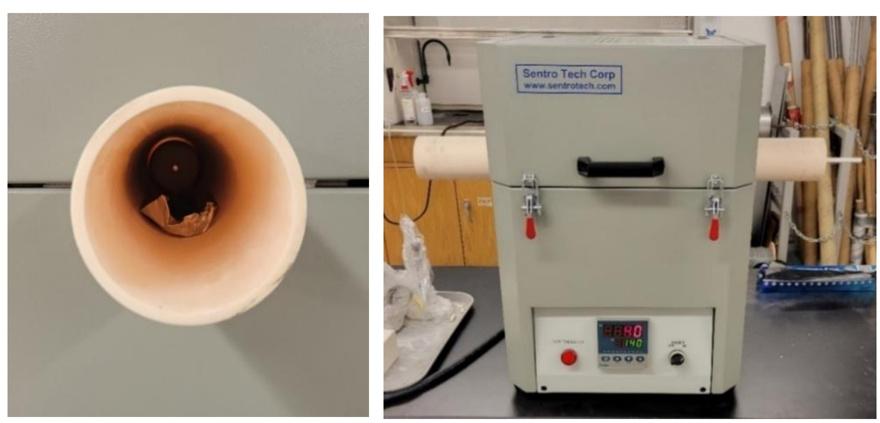


Figure 58: Furnace Used in Thickness Testing

To have a baseline measurement for comparison following the second saltwater test, the team measured the thickness of the SD1 saltwater test samples. There are no measurements of their thicknesses prior to the original saltwater test. These measurements (Table 9) show that the average thickness is approximately 43.5 microns, and the calibrated average thickness (Table 10) is 44.85 microns. This is about 202% thicker than the bottoms' average and 255% thicker than the tops' average. The bottoms before calibration (Table 11) averaged 21.49 microns thick, and the tops before calibration averaged 17.05 microns thick. The average calibrated thickness (Table 12) for the bottoms is 22.18 microns, and the average calibrated thickness for the tops is 17.56 microns. The calibrated tables are color coded according to the specification provided by Sprayon, the rust preventative manufacturer. Green is within specification, and red is out of specification. The recommended dry film thickness is 1 mil (25.4 microns).[33] It should be noted that sample 16 does not have test values as the nozzle failed to spray the sample and broke during sample preparation.

Table 9: Sample Thicknesses from 1st Round of Material Testing

Sample	Average (µm)
1	50.6
2	37.6
3	39.1
4	41.8
5	39.5
6	43
7	41.6
8	40.1
9	45.6
10	55.7

Table 10: Calibrated Thicknesses from 1st Round of Material Testing

Sample #	Average (µm)
1	52.2192
2	38.8032
3	40.3512
4	43.1376
5	40.764
6	44.376
7	42.9312
8	41.3832
9	47.0592
10	57.4824

Table 11: Uncalibrated Thicknesses			
Bottoms		Tops	
Sample	Average (µm)	Sample	Average (µm)
1	12.7	1	23.7
2	26.3	2	19.9
3	23.9	3	17.9
4	27.75	4	24.75
5	28.25	5	16
6	5.5	6	36
7	15.75	7	13
8	19.5	8	14.25
9	25.75	9	16.25
10	24.75	10	13.75
11	24.25	11	15.5
12	16.5	12	6.75
13	23.25	13	9.25
14	22.25	14	13
15	26	15	15.75

Table 12: Calibrated Thicknesses			
Bottoms Calibrated		Tops Calibrated	
Sample	Average (µm)	Sample	Average (µm)
1	13.1064	1	24.4584
2	27.1416	2	20.5368
3	24.6648	3	18.4728
4	28.638	4	25.542
5	29.154	5	16.512
6	5.676	6	37.152
7	16.254	7	13.416
8	20.124	8	14.706
9	26.574	9	16.77
10	25.542	10	14.19
11	25.026	11	15.996
12	17.028	12	6.966
13	23.994	13	9.546
14	22.962	14	13.416
15	26.832	15	15.75

7.2.1 Baking Samples

As stated previously, the samples were baked at 140° C to ensure a full cure. The samples prior to this baking displayed consistent pitting and lack of material coverage. The material scraped away without any intentionally applied force during the thickness testing as well. Seen in Figures 59 through 61, there is a visible difference between pre-bake and post-bake samples. Images were taken at both the center and the edges of the samples. The post-bake samples exhibit much less pitting and much more material coverage. Even some of the largest pits completely closed (Figure 61). The coatings did not scrape off unintentionally after baking either.

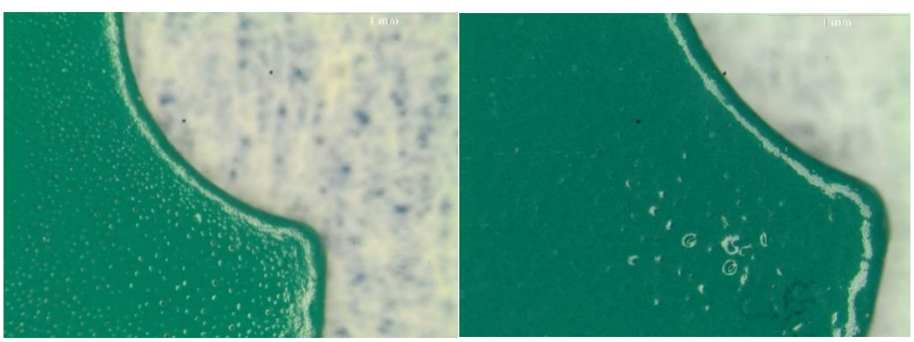


Figure 59: Sample 1 Edge Pre-Bake vs Post-Bake

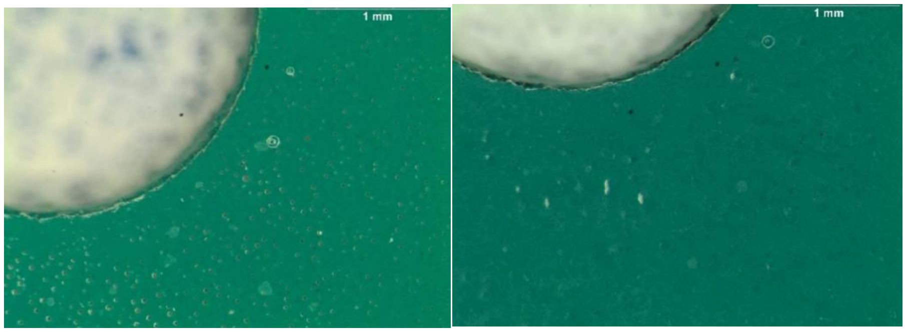


Figure 60: Sample 3 Center Hole Pre-Bake vs Post-Bake

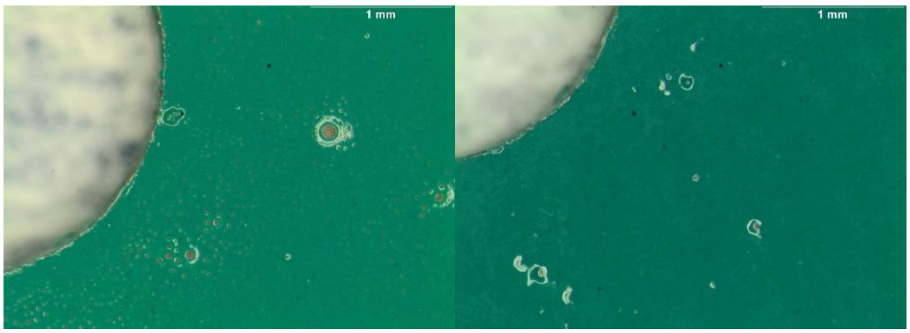


Figure 61: Sample 11 Center Hole Pre-Bake vs Post-Bake

7.3 Saltwater

A second saltwater test was performed on November 13, 2021, with a goal of determining how the different nozzle designs spray patterns hold up against the specification given to the team by Schaeffler. The sample numbers correlate with the identification of nozzle numbers in Table 7. Visual analysis was performed on the center notch, edge, and the surface of all the tested samples. A weight system was created to add in this analysis. This system can be found in Table 13. A visual analysis of the rust prevention performance for each sample is shown in Table 14. The team decided the most important aspect of the visual analysis was the non-uniformities in each area. As seen in Table 15 each sample was given an average score to create a comparison. The scores highlighted in red are considered poor, the score highlight in yellow are sufficient but not ideal, and the scores highlighted in green are good. To see magnified pictures of the samples, please review Appendix C. The compiled results from each analysis are shown in Table 16.

Table 13: Visual Key	
Quality	Weight
None	1
Minimal	2
Moderate	3
Severe	4

Table 14: Saltwater Test Visual Analysis					
Sample	Center Notch			Edge	
	Flaking/Peeling	Rust	Undercut	Rust	Undercut
1	Moderate	Minimal	None	Moderate	Minimal
2	Minimal	Minimal	None	Moderate	None
3	Minimal	Minimal	None	Minimal	None
4	Moderate	Moderate	None	Minimal	None
5	Severe	Severe	None	Minimal	Moderate
6	Moderate	None	None	None	None
7	Severe	Severe	None	Minimal	None
8	Severe	Severe	None	None	None
9	Minimal	Moderate	Severe	None	None
10	Minimal	Minimal	None	None	None
11	Minimal	Moderate	None	Minimal	None
12	Severe	Severe	Moderate	Minimal	None
13	Severe	Severe	None	None	None
14	Severe	Severe	Severe	Minimal	Minimal
15	Moderate	Severe	None	None	None

Table 15: Non-Uniformity Visual Analysis Post-Saltwater Test					
Sample	Center Notch	Edge	Surface	Scores	
	Non-Uniformity	Non-Uniformity	Non-Uniformity	Total	Average
1	Minimal Lack of Material	Severe Lack of Material	Severe Lack of Material	10	3.33
2	Minimal Pitting	Minimal Pitting	Minimal Pitting	6	2
3	Minimal Lack of Material	None	Moderate Cracking	6	2
4	Moderate Cracking	None	Moderate Pitting	7	2.33
5	Minimal Lack of Material	Severe Pitting	Moderate Cracking	9	3
6	Severe Globbing/Lack of Material	Minimal Pitting	Severe Cracking/Pitting	10	3.33
7	Minimal Lack of Material	Moderate Lack of Material	Moderate Cracking	8	2.67
8	Minimal Lack of Material	None	Minimal Globbing	5	1.67
9	Minimal Lack of Material	Moderate Pitting	Moderate Cracking	8	2.67
10	None	None	Moderate Cracking	5	1.67
11	None	None	Severe Cracking	6	2
12	Moderate lack of Material	Minimal Pitting	Moderate Cracking	8	2.67
13	Moderate Cracking	None	Minimal Lack of Material	6	2
14	Severe Lack of Material	Minimal Lack of Material	Minimal Cracking	8	2.67
15	Moderate Lack of Material	Severe Pitting	Minimal lack of Material	9	3

Table 16: Compiled Results				
Sample	Application Test	Thickness Test (Bottom Pieces)	Post Saltwater Test Scores	
		Average (µm)	Total	Average
1	Acceptable	13.1064	10	3.33
2	Acceptable	27.1416	6	2
3	Not Acceptable	24.6648	6	2
4	Not Acceptable	28.638	7	2.33
5	Acceptable	29.154	9	3
6	Acceptable	5.676	10	3.33
7	Acceptable	16.254	8	2.67
8	Acceptable	20.124	5	1.67
9	Acceptable	26.574	8	2.67
10	Acceptable	25.542	5	1.67
11	Acceptable	25.026	6	2
12	Acceptable	17.028	8	2.67
13	Acceptable	23.994	6	2
14	Not Acceptable	22.962	8	2.67
15	Acceptable	26.832	9	3
16	Not Acceptable	N/A	N/A	N/A

8. Discussion and Nozzle Selection Recommendations

8.1 Nozzle Design Discussions

Cone spray patterns are the most common type of nozzles tested in the team's experiment. A cone pattern is caused be a small opening that is large enough to allow spray consistently through and atomizes particles, but not too large as to cause a failure in atomization. Iteration 1 is a decent example of nozzles failing to atomize the spray. Nozzle "Cone #2" from Iteration 1 had a circular exit hole too large to atomize and resulted in thick dripping. The nozzles "Flat #1" and "Flat #2" from Iteration 1, although originally intended to spray a flat pattern, clogged due to the exit hole being too small. The best atomization occurred with the original yellow nozzle provided with the can with an exit diameter of 300 µm. "Cone #1" with a diameter of 500µm performed like the yellow nozzle with slight dripping, indicating the original had an optimized size for atomization.

In Iteration 2, the team saw more influence on the cone patterns, stemming from the nozzle design. Nozzle #3 created a cone pattern with rounded corners that appear to form a square. This occurred due to the nozzle end limiting the full cone pattern by the right corners of the square deflecting small amounts of particles, causing the crude square shape. The crude corners tend to drip and glob as they are receiving more material than the center of the spray pattern. This does not happen to all square shaped exit holes as also seen in the Nozzle #7 in Iteration 2. The team believes that Nozzle #7 does not follow the square spray trend as it is essentially the same size as the yellow tip exit. The only difference is the nozzle is squared off; however, the exit is so small that it overcomes the increased drag. Sharp edges seen in the square/rectangular nozzles increase drag on the fluid, thus decreasing exit velocity. This decrease in exit velocity lowers the pressure and results in a poorly atomized spray.

Converging nozzles would ideally cause a more concentrated spray compared to those that are not converging. Spray patterns of converging nozzles in Iterations 2 and 3 did not appear different to the naked eye. The differences were made clear upon microscopic inspection. This will be elaborated on in Section 8.2.

Flat spray patterns occur when particles exiting the nozzle are deflected from two slopes that redirect the spray to contact the desired surface in a line. Iterations 1 and 2 did not contain a nozzle of this design and the fan attempts failed to produce a flat spray pattern. In Iteration 3, the nozzle heads were elongated to allow enough room for an angled cut. This created two slopes for the spray to deflect against. Results from the iteration show that smaller angles cause tighter flat patterns and larger angles cause wider flat patterns. The 45-degree nozzle produced a wide spray pattern, and the 15-degree produced a long thin spray pattern.

Deflection sprays occur when particles contact a sloped surface and divert from the original direction. This happens when a sloped surface is added to the end of a nozzle. Flat slopes and concave deflection surfaces were compared. Increasing the length of the slope creates a smaller pattern but maintains the crescent shape. The increased length makes the smaller pattern because the spray deflects at a distance further from the exit hole. The shape and size of the pattern is determined by the slope of deflection and how the particles exiting the nozzle interact with it.

8.2 Nozzle Application Discussion

The team performed a microscopic inspection of the test samples at both their center notches and their edges. These images are in Appendix C. These images were scrutinized by the entire team and ranked in accordance with the previously used system from Section 7.3. Their observations are recorded in Table 17. Pitting was the only condition considered as these images were taken pre-saltwater testing and the team felt that it was the best indication of nozzle performance. It should be noted that the pitting is believed to stem from both a chemical issue with the propellant/solvent mix and the atomization of the spray from the nozzle. Rectangular nozzles (#4,6) performed insufficiently in terms of coating uniformity. The deflections (#14,15) performed better than the rectangular nozzle but were still not ideal. Converging nozzles (#7,8,9,10) performed sufficiently in terms of uniformity. Nozzles #11 through 13 were sufficient but not preferred based on uniformity. Nozzles #1 through 3 and Nozzle #5 performed sufficiently, but not ideally. This analysis is based on the sample pieces as wholes, instead of just at their centers or edges.

Table 17: Nozzle Application Analysis

Sample	Observation Pre-Bake	Observation Post-Bake
1	Moderate Pitting	Minimal Pitting
2	Moderate Pitting	Minimal Pitting
3	Moderate Pitting	Minimal Pitting
4	Severe Pitting	Severe Pitting
5	Moderate Pitting	None
6	Severe Pitting	Severe Pitting
7	None	None
8	Minimal Pitting	None
9	Minimal Pitting	None
10	Minimal Pitting	Minimal Pitting
11	Severe Pitting	Minimal Pitting
12	Minimal Pitting	Minimal Pitting
13	Minimal Pitting	None
14	Moderate Pitting	Moderate Pitting
15	Moderate Pitting	Minimal Pitting
16	N/A	N/A

8.3 Nozzle Recommendations

The team combined all the analysis preformed to decide how to rank these nozzles. Three categories were made to rank all the nozzles tested. The results from these rankings can be found in Table 18. The nozzles highlighted in red are insufficient, the nozzles highlighted in yellow are sufficient but not ideal, and the nozzles highlighted in green are recommended.

Table 18: Nozzle Final Assessment

ID #	Description	ID #	Description
1	Original Nozzle	9	Continuously Converging Circle
2	Copy of Original Nozzle	10	Continuously Converging Oval
3	Square Nozzle	11	45 Degree Flat
4	Funneled Rectangle	12	20 Degree Flat
5	Long Head, Circular	13	15 Degree Flat
6	Long Head, Rectangle	14	Short Deflection Tip
7	Long Head, Converging Square	15	Short Concave Deflecting Tip
8	Long Head, Converging Circle	16	Long Deflection Tip

8.3.1 Nozzle Recommendation Explanations

Below are the explanations behind each nozzle rating based on the team's myriad of scoring techniques as well as previously unsaid reasons.

Nozzles #1, 3, 4, 5, 6, 14, 15, and 16 are labeled as "insufficient". Despite Nozzle #1 being the yellow stock nozzle that came from the manufacturer, it did not perform adequately. This is believed to be the case since it was used for all nozzle testing, from design phase to the final saltwater sample application. The team believes that it accumulated residual material buildup and wore the nozzle material down from being loaded and unloaded into the housing unit. Nozzle #3, despite performing adequately in the Non-Uniformity Visual Analysis Post-Saltwater Test (Table 15), it is labeled insufficient as the spray uniformity during design phase proved to be unfit as previously stated in Section 8.1. Nozzles #4 and 6 are insufficient due to their extreme surface non-uniformity (Table 17). Nozzle #5 is insufficient due to scoring a 3 in the Non-Uniformity Visual Analysis Post-Saltwater Test (Table 15). Nozzles #14, and 15 are insufficient as they did not perform adequately during application testing nor the non-uniformity analysis (Table 16). Nozzle #16 failed from the start as it clogged, thus proving the nozzle to be insufficient.

Nozzles #7, 9, 11, and 12 are labeled as "sufficient but not recommended for this application". As stated in Section 8.1, Nozzle #7 is a square exit. It meets the criteria to make the sufficient label, but due to its shape, is not ideal for this application. Any possible excess dripping and rounded corners are not acceptable, which are both possible outcomes of a square exit. Nozzle #9 falls under this category as it scored a 2.67 (Table 15) which means it trends towards moderate/severe non-uniformities. Nozzle #11 exhibited severe pitting, seen during the Nozzle Application Analysis (Table 17). Nozzle 12 scored 2.67 during the Non-Uniformity Visual Analysis Post-Saltwater Test (Table 15), which is not ideal.

Nozzles #2, 8, 10, and 13 were ranked "recommended" by the team. These nozzles were put into this category based off their quality performances in all the analyses performed by the team. The nozzles performed well under the Nozzle Observation Assessment (Table 7) and showed no irregularities during the application process. The nozzles scored 2, 1.67, 1.67, and 2 respectively for the Non-Uniformity Visual Analysis Post-Saltwater Test (Table 15), which were determined by the team to be high-quality scores. These nozzles also showed sufficient results during the Nozzle Application Analysis (Table 17). The team did more visual comparisons between these four nozzles and decided that #8 and #10 performed the best out of all the nozzles selected. It is interesting that Nozzle #2 performed so well compared to Nozzle #1. This nozzle was supposed to be an exact replica of #1, so based off the assumption stated previously #1 would be labeled as recommended if it hadn't been used so much prior to these analyses.

9. Conclusions

9.1 Accomplishments

After two semesters, more than 400 collective hours per member, the team delivered a detailed report and presentation regarding the best rust preventative varnish for Schaeffler's E-motor stator lamination stack and an ideal nozzle design to be used with Sprayon's aerosol can. The team tested 5 different varnishes: MG Chemicals 4228-55ML Red Insulating Varnish, Seymour 620-1525 Tool Crib Red Insulating Varnish, Anti-Seize Technology Red Insulating Varnish, Sprayon EL609 Green Insulating Varnish, and DEI HI-TEMP Silicone Coating. A saltwater test was conducted according to Schaeffler's guidelines to test each coating. They were ranked according to coating adhesion and performance. A knife test was used for ranking adhesion and a thorough microscopic analysis was conducted for rust prevention. Out of these coatings, Sprayon El609 Green Insulating Varnish ranked the best and was used in further testing. Moving forward with this varnish, the team set out to design an ideal nozzle for Schaeffler's application needs. They ran through three iterations of various nozzle types, all manufactured using additive manufacturing methods. They 3D printed the nozzles using the Form 2, an SLA printer. The team had to refresh themselves on fluid dynamics and learn corrosion science as well during this project. At first, nozzle design was trial and error, but over the iterations, the team came to understand the relationships presented to them through Bernoulli's equation, the continuity equation, and other fluid dynamic concepts. Once the team tested all the nozzles, they performed extensive visual analysis and another saltwater test to validate their findings. The team ranked their nozzle designs and narrowed down their findings to four final nozzles. The team deepened their understanding of the fluid dynamics, corrosion prevention, and additive manufacturing methods. Most importantly, they created a start for future students to use in the field of ideal nozzle design and rust prevention.

9.2 Uncertainties

After all experimentation was done, there were a few observations made that could help improve the experimental design of the tests, and the evidence of the results. First observation was majorly constricted by access to materials. The second round of tests only used a sample size of 2. In most cases this is unacceptable, but in regard to the constraints of resources and time that the team had, it was the only sample size that was available. It would be highly recommended to increase the sample size for each nozzle to 10 to provide for a better analysis and avoid any extreme deviant behavior during testing. Other uncontrolled variables include the angle at which the spray can was held at during application. Although the distance from the component was controlled in the second experiment, the angle in regard to the position of the part was not controlled. The furnace used in both saltwater experiments was also unideal for the application, as it was not intended to hold a low operational temperature around 140 degrees Celsius. These uncertainties combined with human error could cause deviations in the experimental results.

9.2.1 Material Selection and Testing

After finishing our testing, we realized that many things could have been done in a more consistent, cleaner fashion. These changes would have provided a more academically suited testing environment. Starting with our test samples, at the time of application we had sprayed the metal outside. We did not provide ample space for individual sample spraying, instead, sprayed in batches. In addition, there was cross-contamination between the sample coatings, and the metal laminations could have been cleaned before spraying. Our champion, Jeremy Silvidi, led the team during the sample preparation, not allowing for much room to converse. Following the coating application, he took the samples and cut them in order to protect company knowledge -- another issue. Samples should have been cut prior to coating application to ensure proper edge coating. The samples need to have a controlled environment for future coating applications to ensure correct adhesion. The samples in this test did not have a humidity controller or even a temperature controller, possibly preventing proper curing of the coatings. Furthermore, there was no "proper coating" guideline. Simply, we sprayed the samples without concern for even application. For future testing, we would need to develop an agreed-upon, design-tested application method. With our current testing method, the samples are being coated on the flat side rather than the edge, per Jeremy's instructions. The real laminations will be stacked, and the ID will be coated. We cannot assume that the same results seen on the flat will apply to what we will see on the ID edges. Individual sample identification could have also been useful during testing, instead of keeping the same order as a quasi-identity. An etching of sorts might have worked for our needs. Beyond our sample preparation, we did not have a controlled furnace. The furnace used for testing was designed for metallurgical work and thus fluctuated in temperature by +/- 5°C.

9.2.2 Nozzle Selection and Testing

During the CAD design and 3D printing phase, uncertainties arose from the measurements of the manufacturer nozzle. This is due to both human error and inaccuracy/imprecision of the instruments used. The possibility of error during the SLA printing should also be considered. The test samples were not sprayed at the exact same angle every time, providing another source of uncertainty towards the nozzle testing results. The samples did not have enough time to cure prior to moving them out of the spraying booth, possibly skewing the results. The oven used in the second saltwater test is the same as the first, providing the same temperature regulation issue. The instrument used in the thickness test did not read 100% accurately, providing another source of uncertainty towards the results. The sample size of the nozzle testing was limited to 2 samples per nozzle, and only 1 per nozzle for the second saltwater test. Ideally, the sample size would exceed 30 per nozzle as to be able to use a Z distribution instead of a T distribution.

9.3 Ethical Considerations

Prior to any scientific progress, the health of the individual and the land must be considered. These tests require any operator to wear the correct PPE: goggles, latex/nitrile gloves, a mask, or possibly a respirator if within a confined space during coating application. These chemicals listed, or others chosen for this corrosion prevention cause are carcinogenic and hazardous to one's health. Safety data sheets for all chemicals should be read and complied with. In addition to personal hazards, these chemicals pose a risk to the health of the nearby environment if not disposed of properly. All hazardous wastes should be handled and disposed of properly according to the local/state/federal regulations. For this test, the Ohio Revised Code Chapter 3734[34] and the Electronic Code of Federal Regulations Title 40 - Chapter 1 -Subchapter 1 - Part 261[35] should be followed.

9.4 Future Work

If students were to continue work from the conclusion provided in this report, a few subjects should be investigated further. These subjects include conducting a similar test that accounts for the listed uncertainties and has a larger sample size. Students could create experiments to measure the flow rate of the particles exiting the nozzle based on nozzle design that could increase the understanding of the nozzle designs influence in application. Another is to conduct tests on other rust preventatives and how their coatings are affected by post-baking and attempt the baking process at various temperatures to find potential optimization for post-bake coatings.

References

1. ISO. "ISO 12103-1:2016(En) Road Vehicles — Test Contaminants for Filter Evaluation — Part 1: Arizona Test Dust." *ISO*, 2016, www.iso.org/obp/ui/#!iso:std:63386:en.
2. ISO. "ISO 20653:2013." *ISO*, 13 June 2018, www.iso.org/standard/58048.html.
3. "NEMA Insulation Classes." *Engineering ToolBox*, www.engineeringtoolbox.com/nema-insulation-classes-d_734.html.
4. MG Chemicals. *4228 Red Insulating Varnish Safety Data Sheet*, MG Chemicals, 2020.
5. "Red Insulating Varnish." *One Company...Many Solutions*, 28 June 2021, www.mgchemicals.com/products/conformal-coating/varnish-for-electronics/red-insulating-varnish/.
6. Seymour of Sycamore. *Red Insulating Varnish Safety Data Sheet*, Seymour of Sycamore, 2021.
7. "TOOL CRIB® RED INSULATING VARNISH." *Seymour of Sycamore*, 22 Apr. 2020, www.seymourpaint.com/product/tool-crib-red-insulating-varnish/.
8. A.S.T. Industries, Inc. *Red Insulating Varnish Safety Data Sheet*, A.S.T. Industries, 2017.
9. "17214, RED INSULATING VARNISH - AEROSOL." *RED INSULATING VARNISH Anti-Seize Technology*, www.antiseize.com/17214-2.
10. Sprayon Products Group. *Safety Data Sheet SC0609000*, Sprayon Products Group, 2021.
11. "EL609 Green Insulating Varnish." *Sprayon*, 21 July 2018, www.sprayon.com/product/el609-green-insulating-varnish/.
12. Design Engineering, Inc. *HT-Silicone-Coating-Black SDS*, Design Engineering, Inc., 2015.
13. "Hi-Temp Silicone Coating Spray - Black." *Design Engineering, Inc*, www.designengineering.com/hi-temp-silicone-coating-spray-black/.
14. Corrosion: Understanding the Basics, edited by J. R. Davis, and JR, Davis, A S M International, 2000. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/uakron/detail.action?docID=3002408.
15. "Anti-Corrosion Coatings Explained: Surface Technology Uk Blog." *Surface Technology*, Surface Technology, 4 July 2018, www.surfacetechnology.co.uk/blog-18-the-three-types-of-anti-corrosion coatings-explained/.
16. "Explanation of Metallizing`s Galvanic Protection." ZincNation, Inc., www.zincnation.com/itWorks.html.

17. “Coating Principles.” Coating Principles, faculty.kfupm.edu.sa/me/hussaini/corrosion%20engineering/06.03.01.htm.
18. “Test Methods for Coating Adhesion: Resources: DeFelsko.” *DeFelsko Inspection Instruments*, www.defelsko.com/resources/test-methods-for-coating-adhesion.
19. ASTM D6677-18, Standard Test Method for Evaluating Adhesion by Knife, ASTM International, West Conshohocken, PA, 2018, www.astm.org
20. “Corrosion Undercutting.” Corrosion Undercutting, corrosion-doctors.org/PaintCoatings/ undercutting.htm.
21. “DIN En 10303:2016-02, Dünnes Elektroband Und -Blech Aus Stahl Zur Verwendung Bei Mittleren FREQUENZEN; Deutsche FASSUNG EN_10303:2015.” DIN EN 10303:2016-02, Feb. 2016, doi:10.31030/2315580.
22. Harris, Tom. “How Aerosol Cans Work.” HowStuffWorks Science, HowStuffWorks, 27 Jan. 2020, https://science.howstuffworks.com/innovation/everyday-innovations/aerosol-can2.htm.
23. Mosil. “Aerosols- Principle, Techniques & Applications: Overview of Aerosol Spray.” Mosil Lubricants, 2 July 2021, https://www.mosil.com/blog/technical-concept-aerosols-principle-techniques-and-application/.
24. “Aerosol Technology.” The Aerosol Can – How an Aerosol Can Works, http://www.threecell.com/client_archives/capco/technology.php?thepage=media.
25. Munson, Bruce R. Fundamentals of Fluid Mechanics. Wiley, 2013.
26. www.mosil.com/blog/technical-concept-aerosols-principle-techniques-and-application.
27. “Spray Nozzles.” Spray Nozzles for All Industries and Applications, https://www.spray-nozzle.co.uk/spray-nozzles.
28. “ASTM Standard F2792 - 12A, Standard Terminology for Additive Manufacturing Technologies.” ASTM International - Standards Worldwide, http://www.astm.org/Standards/F2792.
29. “Form 2 Desktop Stereolithography 3D Printer.” FormLabs, https://media.formlabs.com/m/7253926716b40054/original/-ENUS-Form-2-Manual.pdf.
30. “Clear Resin TDS.” FormLabs, https://formlabs media.formlabs.com/datasheets/Clear_Resin_Technical.pdf.
31. “Clear Resin SDS.” FormLabs, https://formlabs-media.formlabs.com/datasheets/1801037-SDS-ENUS-0.pdf.

32. Standard E376-19, Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy Current (Electromagnetic) Testing Methods.” ASTM International - Standards Worldwide, https://www.astm.org/Standards/E376.htm.
33. EL609 Product Data Sheet. 2010, https://paintdocs.com/docs/webPDF.jsp?SITEID=SO&doctype=PDS&prodno=SC0603000&lang=2.
34. “Rules and Laws Governing Hazardous Waste.” Resource Conservation and Recovery Act Rules, epa.ohio.gov/derr/derrrules/rcra#176626480-chapter-3745-270-land-disposal-restrictions-standards.
35. “Electronic Code of Federal Regulations.” Electronic Code of Federal Regulations (ECFR), www.ecfr.gov/cgi-bin/text-idx?node=pt40.28.261&rgn=div5.

Appendix A: Coating Thickness Instrument Information Sheet

500µm 0.020" Black
1500µm 0.060" Brown
3000µm 0.120" Brown

DeFelsko®

DeFelsko Corporation
800 Proctor Avenue
Ogdensburg, New York 13669-2205 USA

Certificate of Calibration

Certificate Number: 18-530487

Nomenclature: Coating Thickness Instrument
Manufacturer: DeFelsko Corporation
Model: PosiTector 6000 FNS Probe
Probe Serial No: 343599
Note: Probe serial # on connector

Laboratory Environment
Temperature: 23 ± 5°C
Relative Humidity: Up To 95%

Date of Calibration: August 31, 2018

Date in Service†: ______________________
To be completed by the end user, in ink

Test Method: This coating thickness instrument was calibrated to manufacturer's specifications according to procedure MP 2527 using Certified Thickness Standards traceable to PTB through certificates 40151 PTB 11, 74055 PTB 15, 74056 PTB 15, 02759052 D-K-15105 2016-11 and 0591 D-K-19342 2016-11.

Thickness Standard Serial #	Min	Standard Thickness* (microns)	Max	Instrument Reading (microns)
28247	74.18	76.95	79.72	76
25202	244.32	248.81	253.30	250
23511	1478.46	1495.41	1512.36	1498
16527	66.76	69.45	72.14	70
16542	238.42	242.85	247.28	246
17266	1477.10	1494.04	1510.98	1506

*Maximum uncertainty ± 0.43 microns

Calibration Performed by: Autum Hess

Autum Hess

Technician

DeFelsko Corporation operates under Management Procedures intended to implement the requirements of ISO 9001, ISO 10012-1, ISO 17025 and ANSI/NCSL Z540-1. This document certifies that the instrument met published specifications of:

0-50 microns ± (1.0 microns + 1% of reading)
>50 microns ± (2.0 microns + 1% of reading)

†There are no components in this product which have a specific shelf life. Therefore, the calibration interval of this instrument begins on the date that the product is first put into service by the end user. Calibration interval will vary based on usage, handling and storage conditions.

Page 1 of 1
Management Form 2007.2-2/2014

Appendix B: Material Technical Data Sheets

MG Chemicals 4228-55ML Red Insulating Varnish[5]

4228 Liquid

Red Insulating Varnish

4228 is a highly insulating coating with excellent arc and corona resistance. This red, low viscosity, one part varnish coating is easy to use and adheres well to many substrates.

The 4228 insulates transformers, coils, motor windings, and various electric generator parts against arc and corona. As well, it protects these parts from corrosion and moisture.

Features & Benefits

- Insulation Class H—Suitable for service up to 180 °C
- Excellent oil and moisture resistant
- Excellent finish—tough, flexible, glossy, and durable red coat
- Good adhesion
- Good water and salt water resistance

Available Packaging

Cat. No.	Packaging	Net Vol.	Net Wt.
4228-55ML	Bottle	55 mL	58.3 g
4228-255ML	Can	255 mL	238 g
4228-1L	Can	850 mL	901 g
4228-4L	Can	3.60 L	3.81 kg

Contact Information

MG Chemicals, 1210 Corporate Drive
Burlington, Ontario, Canada L7L 5R6

Email: support@mgchemicals.com

Phone: North America: +(1)800-340-0772
International: +(1) 905-331-1396
Europe: +(44)1663 362888

Cured Properties

Dielectric Strength (dry)	3 000 V/mil
(wet)	1 500 V/mil
Service Temperature Range	-40–180 °C

Usage Parameters

Dry Time To Handle	30 min
Minimum Recoat Time	4 h
Recommended Film Thickness	25–38 µm
Theoretical Coverage @ 25 µm	890 000 cm²/L

Uncured Properties

Viscosity @ 25 °C	590 cP
Density	1.1 g/mL
Percent Solids	52 %
Shelf Life	5 y
Calculated VOC	514 g/L

ISO 9001:2015 Quality Management System. Burlington, Ontario, Canada SAI Global File: 004008 09 November 2021 / Ver. 2.1 1

4228 Liquid

Application Instructions
Read the product SDS before using this product (downloadable at www.mgchemicals.com).

Recommended Preparation
Clean the substrate with Isopropyl Alcohol, MG #824, so the surface is free of oils, dust, and other residues.

Recommended Thinner
When thinning is required, use MG #4354 Thinner 4.

Brush
4228 can be applied by brush for rework or touch-ups. Thinning is not required for most brush applications. Desired coating thickness can be achieved in a single application. Applied coating can be cured immediately.

Manual Spray Guns
Use a standard fluid nozzle gun with a minimum tip diameter of 0.8–1.0 mm. The settings listed below are recommendations; however, performance will vary with different brands:

Inlet	Air flow	Air cap
20–40 psi	10–15 SCFM	8–10 psi

1. Dilute the coating with Thinner 4, if required.
2. Stir the coating gently but thoroughly.
3. Spray a test pattern to ensure good flow quality.
4. Tilt the board at 45° and spray a thin even coat from a distance of 20–25 cm (8–10 in). Use spray-and-release strokes with an even motion to avoid paint buildup in one spot. Start and end each stroke off the surface.
5. Wait 4 hours before applying another coat, to avoid trapping solvent.
6. Rotate the board 90° and spray again to ensure good coverage.
7. Apply additional coats until desired thickness is achieved (go to step 3).
8. Let dry 30 min at room temperature before applying heat cure.

Dip Coat
Use a Ford or Zahn cup to monitor the viscosity of the coating, as the solvent will evaporate over time.

1. Hang the PCB on a dipping arm.
2. Slowly lower the PCB into a tank and leave immersed in the coating for 2 min to allow penetration.
3. Slowly withdraw the PCB from the tank at a rate of approximately 6" per minute.
4. Let dry for 4 hours before applying additional coats or 40 minutes before heat cure.

Cure Instructions
Allow to dry at room temperature for 24 hours, or after letting sit for 30 minutes, cure the coating in an oven at 80 °C for 1 hour.

Clean-up
Clean spray system and equipment with MEK or acetone, MG #434.

Storage and Handling
Store between -5 and 25 ˚C in a in a dry area, away from sunlight (see SDS).

Disclaimer
This information is believed to be accurate. It is intended for professional end-users who have the skills required to evaluate and use the data properly. M.G. Chemicals Ltd. does not guarantee the accuracy of the data and assumes no liability in connection with damages incurred while using it.

Seymour 620-1525 Tool Crib Red Insulating Varnish[7]

SEYMOUR — Product Information Sheet

TOOL CRIB RED INSULATING VARNISH

#620-1525

This product is specially designed to protect and insulate surfaces from deterioration caused by exposure to oil, moisture, acid and alkali. The high gloss enamel coating is recommended for use as a finish coat to Class "F" winding or electrical apparatus. Dries quickly, resists cracking, and prevents the passage of electricity into or out of the substrate.

Suggested Uses:

Commutator ends, switchboard parts.
Motor case interiors
Collector rings and shells.
Armatures, bus bars.
Field windings of motors,
Starters, generators

Packaging:

UPC Code	043281007139
Cans per case	6
Shipping weight per case	9 lbs.
Container	20 fluid ounce can
Label weight	16 ounces (454 grams)
Shipping Classification	Consumer Commodity ORM-D, UN 1950
Hazard Class	2.1

Properties:

Coverage	Up to 18 square feet
Cleanup	Paint or lacquer thinner
Flammability	Extremely Flammable
Flash point	-4F
Specific Gravity	0.80
Solids Content	22%
MIR value	0.88, cannot exceed 0.95
HAPs content	15%
Storage Temperature	40-100F
Application Temperature	50-90F
Gas Resistance	Yes
Dielectric Strength	1400 volts per mil when dry
Resin System	Phenolic
Shelf life	Guaranteed for 2 years
Food contact rating	No

Dry Time*:

Tack free 20 minutes

*At 72F, 50% humidity,
1.5 mil thickness

Curing/Recoat time is extended with multiple coats and excessively thick coats

Gloss*:
High gloss, >80

*as measured on a 60 degree gloss meter

12-11-2019

Seymour of Sycamore
917 Crosby Avenue
Sycamore, IL 60178

Phone: 815-895-9101 or 800-435-4482
Fax: 815-895-8475 or 800-343-4258

www.seymourpaint.com

Anti-Seize Technology Red Insulating Varnish[9]

Technical Data Sheet
P/N 17214
Page 1 of 1
Date: April 2010

RED INSULATING VARNISH
Aerosol

WWW.ANTISEIZE.COM

Product Description

Red Insulating Varnish is an excellent choice for protecting electrical components. Our Red Insulating Varnish coats your electrical components with a durable film of Varnish to guard them from the damaging effects of water and moisture that cause corrosion, loss of voltage, and damage to electrical component operating in a wet or humid environment. It strongly adheres to electrical components and protects them against rust and corrosion, seals out moisture, dirt and dust and provides long term protection to your parts.
Our Red Insulating Varnish is highly resistant to water and humidity, greases and oils, acids and alkalis. It protects electrical components operating in wet humid conditions or those parts subject to rain, snow and water spray. It helps to restrict current leakage and aids in the optimal performance of electrical components, contacts, switches, transformers and motor windings and so many other useful ways to use it. Water and corrosion are the two worst enemies of electrical components exposed to harsh environments and account for loss of production and increase maintenance costs. Our Red Insulating Varnish will guard your components, and keep them operating efficiently and reliably. It has many uses and is a great aid in keeping your electronics operating.

Features & Benefits

- Protects electrical components against corrosion caused by exposure to water or high humidity
- High Arch resistance
- Dries quickly to a Glossy Red Transparent film that remains flexible
- Resists oil, grease, acids and alkali environments
- Dielectric Strength of 1,700 volts/ mil
- Seals components
- Sheds dirt and dust
- CFC Free
- VOC Compliant
- RoHS Compliant

Applications include

Motor windings and armatures, Transformers, Field Coils, Switchboard parts, switches, Seals electrical contacts and plugs, protects bus bars, seals terminals, guards against rust and corrosion in Marine electronics and wiring, terminal blocks, help to seal wiring labels against rub off or removal, protects crimp connections against moisture damage, Electrical taps, electrical lugs, fuse blocks and so many more.

Typical Properties

Property	Value
Color	Translucent red
Dielectric Strength	1,700 volts/mil thickness
Upper Temperature limit	250F
RoHS	Compliant

Cautions

This product is not recommended for use in an oxygen system and not as a sealant for chlorine or other strong oxidizing materials. Read all information on labels and Material Safety Data Sheets prior to use. All products should be tested and evaluated for a particular purpose prior to use.

Product Limited Warranty

This information is based on information we believe to be reliable and accurate, but no guarantee of its accuracy is made for a particular application. We urge and recommend that Users pretest their application prior to incorporating the product into use and assume that the User will conduct such testing. Also see warranty statement on website.

Available In:

Size: 16oz net wt. Aerosol Can
P/N: 17214

ANTI-SEIZE TECHNOLOGY
2345 N. 17th AVE. • FRANKLIN PARK, IL 60131–3432
847-455-2300 • www.antiseize.com

Sprayon EL609 Green Insulating Varnish[11]

ELECTRICAL & ELECTRONIC

USES

- Motor Windings
- Field Coils
- Transformers
- Armatures
- Commutator Ends
- Stater Windings
- Rings & Frames
- Bus Bars
- Sealing electrical switch board parts and electronic components

EL609

APPLICATION

SURFACE PREPARATION: Must be applied directly to dry, clean surfaces and not over any other paint or coating. Proper surface preparation contributes to maximum service life of coatings. All contaminates (mill scale, rust, rust scale, chemicals, grease, oil, wax, weld spatter, old paint or other foreign matter) must be removed down to bare metal. APPLICATION: Remove all rust, scale, paint, grease or foreign matter. A good clean surface is necessary. Apply directly to DRY surface and not over any other paint or coating. Product should be sprayed in a well-ventilated area. Use at room temperature (70°F.) for best operation. Turn can upside down. Hit sides lightly while rotating can in 1/4 turns until agitator ball breaks loose. While holding can upright, alternately shake the can up and down and in a circle for 30-60 seconds until the agitator travels freely in the bottom. NOTE: INSUFFICIENT MIXING MAY CAUSE PLUGGING TO OCCUR. Press spray button firmly with the can 8" to 12" away from surface being coated. Move can with short dusting strokes, releasing button at the end of each stroke. Apply several thin coats. To prevent clogging, hold can upside down and spray until only clear gas comes out. CLEAN UP: Acetone.

PERFORMANCE

- **SPECIFICATION: MEETS PERFORMANCE REQUIREMENTS OF ASTM D 115-07 4.2 PERFORMANCE FOR:**
  - 4.2.1 Drainage: 22%
  - 4.2.2 Time of Drying: See drying schedule
  - 4.2.3 Build: 2.9 mm
  - 4.2.8 Oil Resistance: See chemical resitance
- **TEMPERATURE CLASS:** Class F (155°C / 310°F)
- **DRY HEAT RESISTANCE:**
  - Constant: 310°F
  - Intermittently: 400°F
- **DIELECTRIC STRENGTH:**
  (ASTM D 115-07) Green: 2,890 VPM
- **ONE WEEK HARDNESS:**
  (ASTM D 3363 SHORE A 24hr / 1 Week): 6B
- **FLEXIBILITY:** (ASTM D 522) Pass
- **CHEMICAL RESISTANCE:**
  - Aliphatic hydrocarbon solvents: Moderate
  - Alkalis: Moderate
  - Aromatic hydrocarbon solvents: Severe
  - Chlorinated solvents: Severe
  - Salt water: Severe
  - Glycol ethers, alcohols: Severe
  - Inorganic acids: Severe
  - Organic acids: Severe
  - Oils: Severe
- **DRYING TIME @ 70°F @ 50% R.H.:**
  - To Touch: 10 Minuntes
  - To handle: 15-30 Minutes (Tack Free)
  - Full cure: 7 Days

SHIPPING

Refer to section 14 of the material safety data sheet for proper transport information and labeling.

PROPERTIES

APPEARANCE: Green
SHEEN: Semi-Gloss
RESIN TYPE: Epoxy / Phenolic
PROPELLANT: Hydrocarbon Blend
% SOLIDS: 22.83
WT./GAL.: 6.62
SPECIFIC GRAVITY: 0.79
% VOC AEROSOL: 55.17%
MIR: .806
V.O.C. COMPLIANT CALIFORNIA: Yes*
V.O.C. COMPLIANT OTC STATES: Yes*
FLAMMABLE: Yes
FLASH POINT: >0°F
RECOMMENDED FILM THICKNESS: 1 Mil dft
COVERAGE PER AEROSOL (THEORETICAL):
10 sq. ft. @ 1 Mil dft
HAZARD RATING: 2,4,0
SHELF LIFE: 3 years from date of manufacture

*ELECTRICAL AEROSOL COATINGS ARE EXEMPT

PACKAGING

STOCK #: 500609000
UPC CODE: 0-75577-84215-5
FILL WT: 15.25 oz.
PER CASE: 12
CARTON DIMENSIONS:
L 12.00" x W 10.00" x H 13.75"

RESOURCES

MSDS/EDS/PRODUCT DATA
SHEETS: sprayon.com
CUSTOMER SERVICE: 1-800-777-2966
TECHNICAL INFORMATION: 1-800-251-2486

Distributed by:

PRESERVE. PROTECT. PREVENT.

Sprayon® Products
101 Prospect Ave. NW
Cleveland, OH 44115
Sprayon.com
1-800-777-2966

310-PDS-EL609

DEI HI-TEMP Silicone Coating[13]

PERFORMANCE PRODUCTS

Frequently Asked Questions

DEI High-Temp Silicone Coating™

What is the purpose of using HT Silicone Coating ™?

HT Silicone Coating has several beneficial purposes on header wraps and metal surfaces. When applied to an exhaust wrap it increases the wraps thermal isolation and resistance. The silicone agent bonds to the surface of the wrap and increases its integrity which reduces the need to re-wrap headers or piping, just re-apply HT Silicone Coating™ routinely. HT Silicone can also be applied to a prepped metal surface where wrapping is improbable. Because HT Silicone Coating™ is silicone based it also can repell water, dirt and oils from any surface. This is especially usefull on header wrap as keeping it free of debris lessens wear and increases it's durability.

What else can HT Silicone Coating ™ be used for?

Wherever metal heat absorbtion may exist! The intended use for this product is on header wrap as mentioned above, but HT Silicone Coating™ may also be applied to bare metal headers, exhaust pipes, manifolds, engine blocks, heads, valve covers, oil pans, transmission or rear-end housings, differential covers, brake calipers and even on your barbeque grill.

What temperature can HT Silicone Coating ™ withstand?

HT Silicone Coating will effectively withstanding 1500 degees and provide added style.

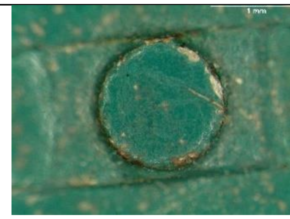
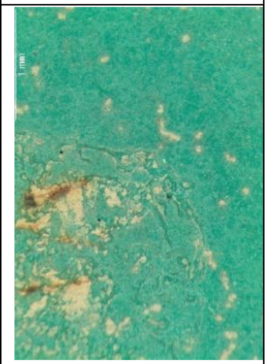
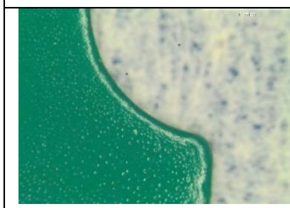
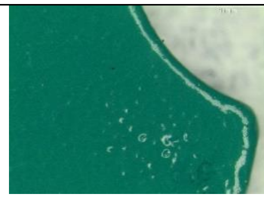
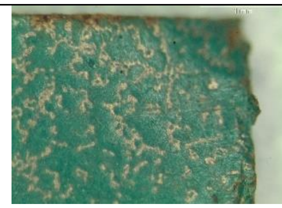
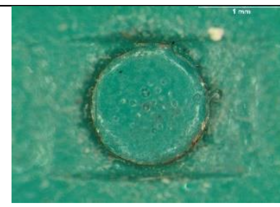
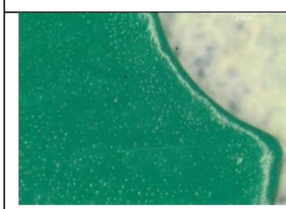
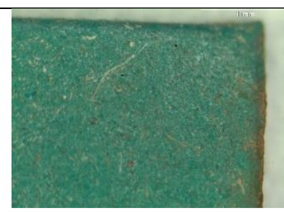
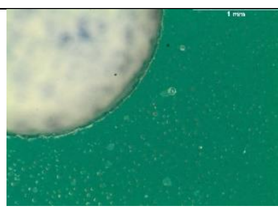
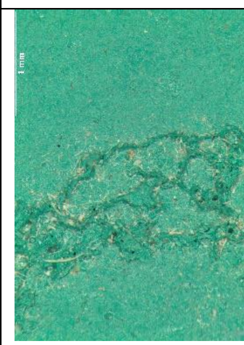
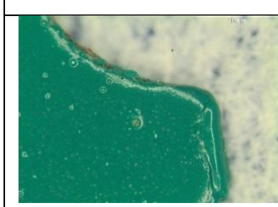
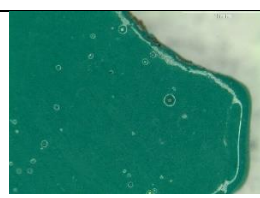
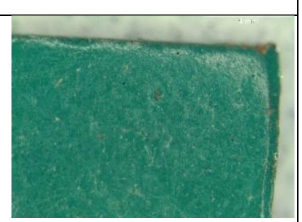
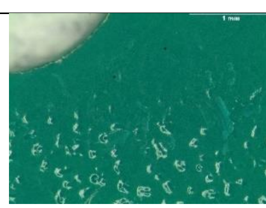
How is HT Silicone Coating ™ applied?

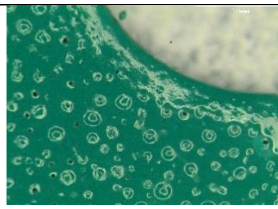
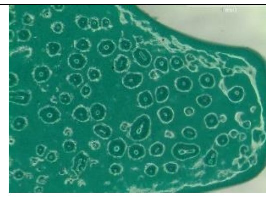
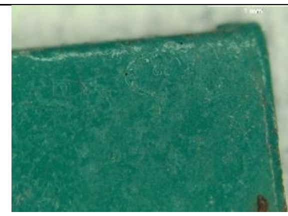
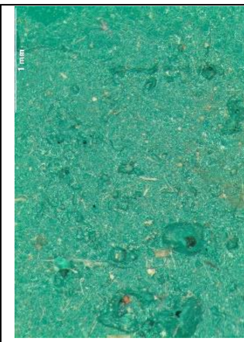
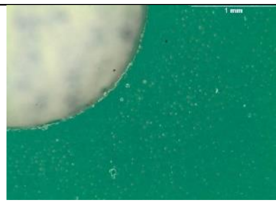
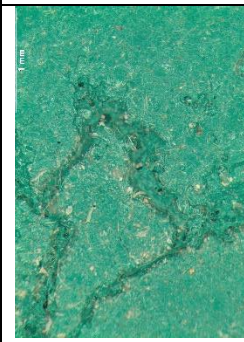
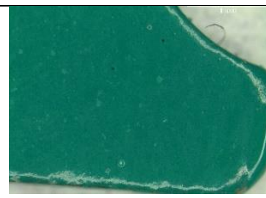
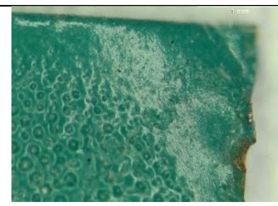
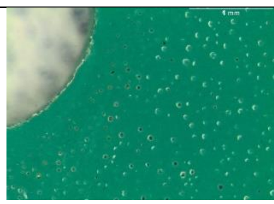
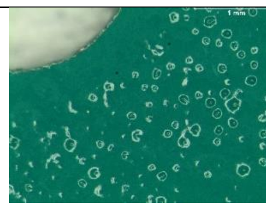
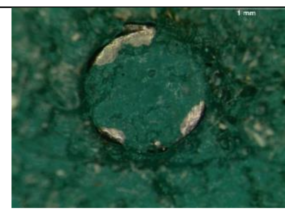
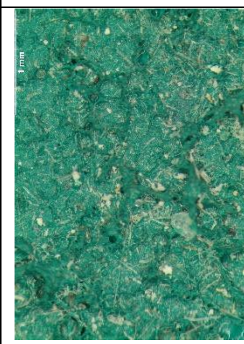
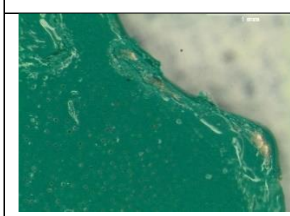
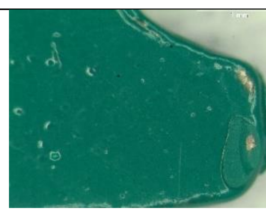
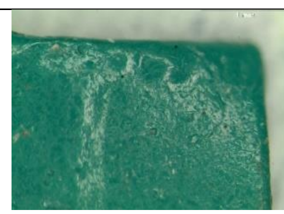
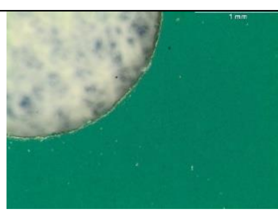
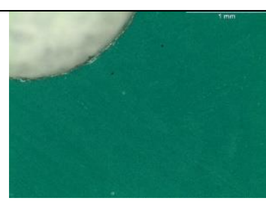
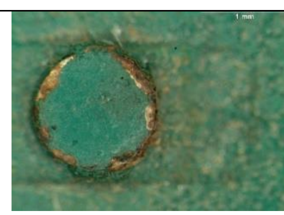
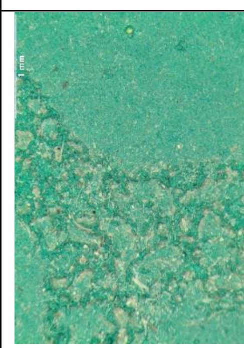
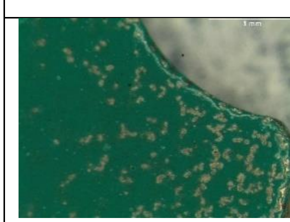
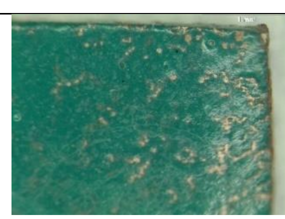
For header wraps it is recommended that HT Silicone be applied in several light coats for optimal thermal performance and cleanliness. For bare metal surfaces it is recommended that the surfaces be properly prepared before applying.

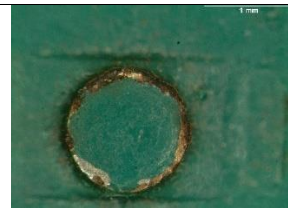
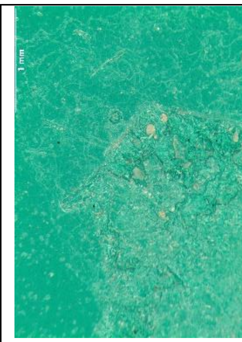
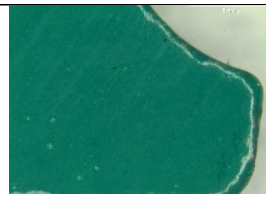
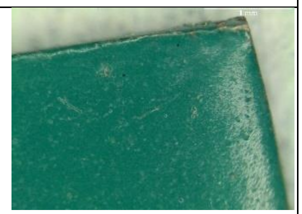
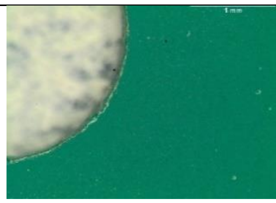
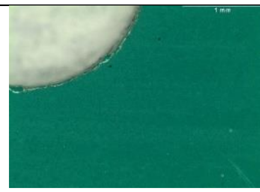
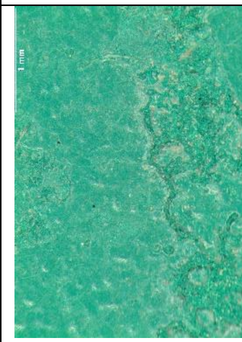
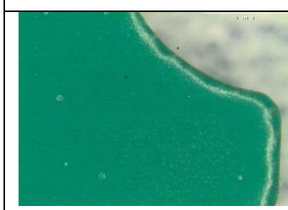
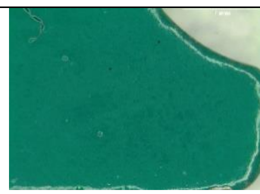
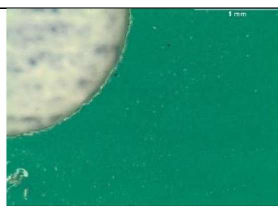
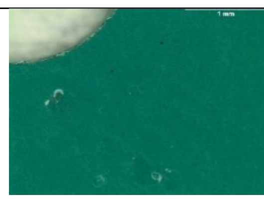
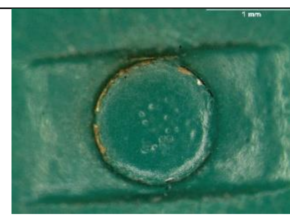
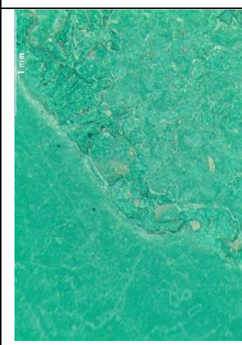
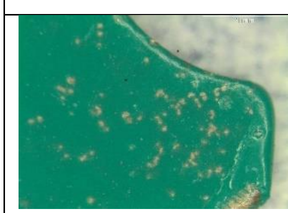
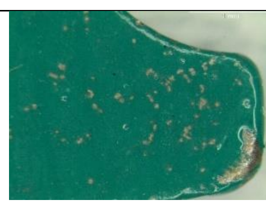
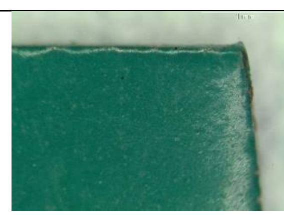
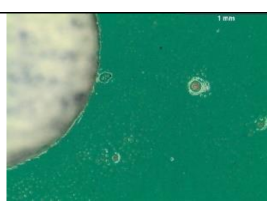
Design Engineering Inc.
604 Moore Road
Avon Lake OH 44012
www.DesignEngineering.com
800-264-9472

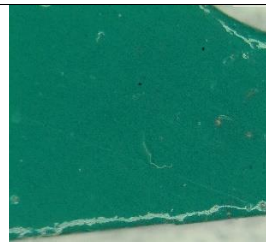
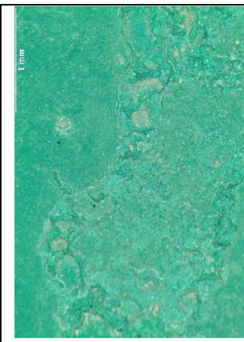
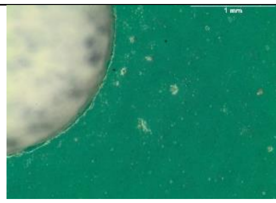
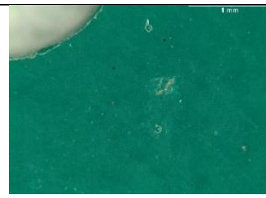
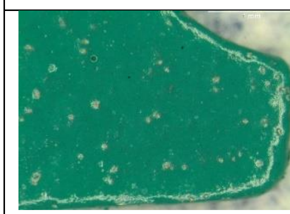
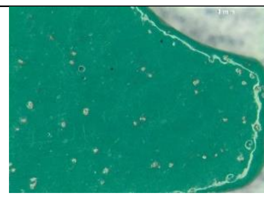
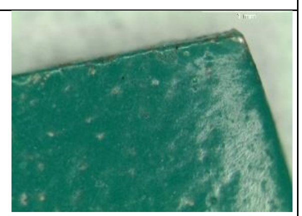
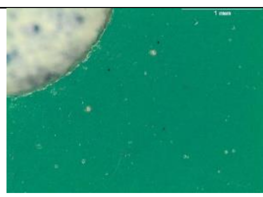
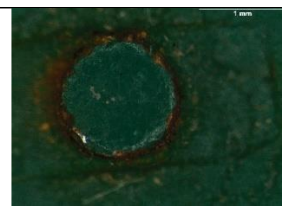
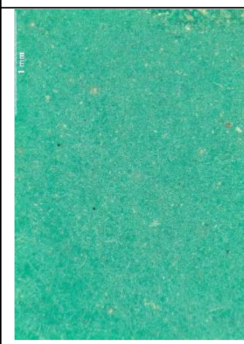
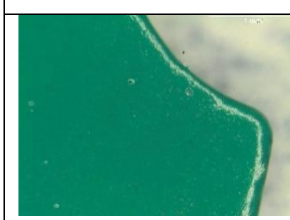
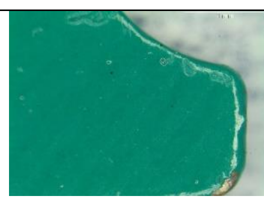
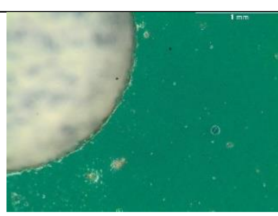
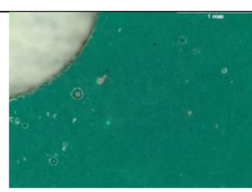
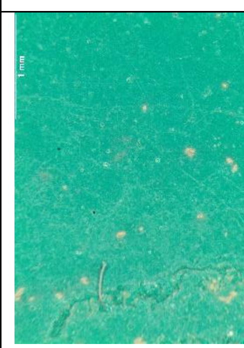
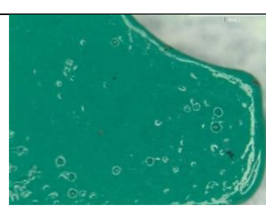
v06.06
FAQ023

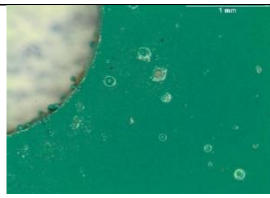
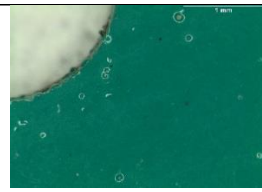
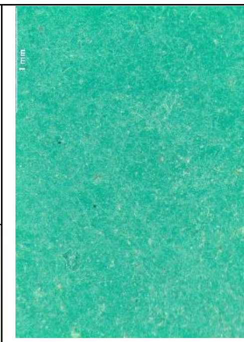
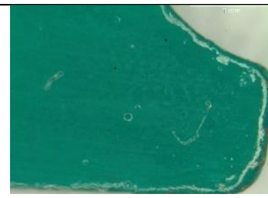
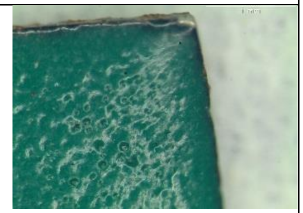
Appendix C: Pictures of Sprayon Samples: Olympus Stereo Microscope

Sample	Pre-Bake	Post-Bake	Post-Saltwater Test	Saltwater Test Surface
1				
				
2				
				
3				
				
4				

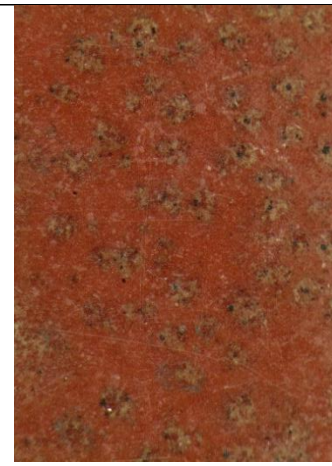
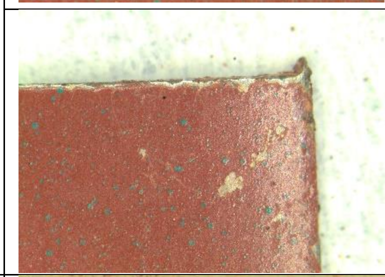
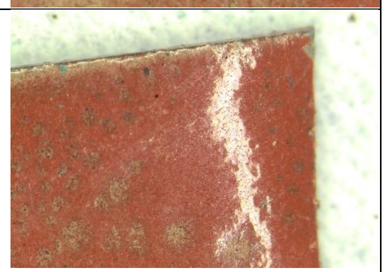
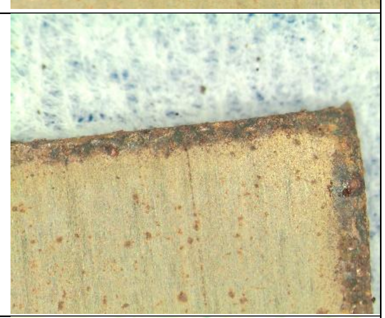
				
5				
				
6				
				
7				
				

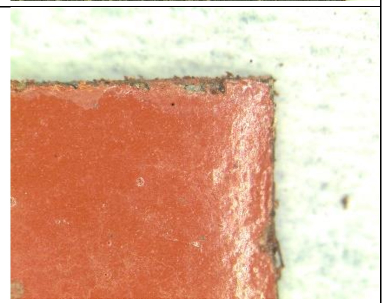
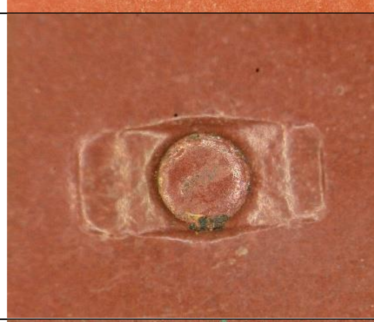
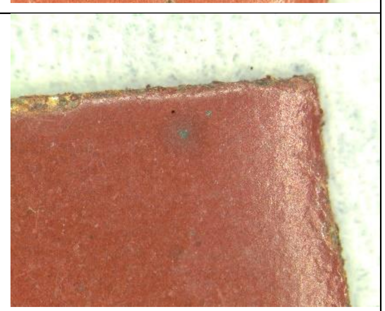
8				
				
9				
				
10				
				
11				

				
12				
				
13				
				
14				
				

15				
				

Appendix D: Pictures of Material Testing Samples:

Anti-Seize			
			
Control Sample			
			
DEI HI-TEMP			

			
MG Chemicals 4228-55ML			
			
Seymour 620-1525			
			

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