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DESIGN AND QUALIFICATION OF A ROBUST POLYURETHANE BASED CONFORMAL COATING PROCESS FOR SODIMMs

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BY

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Abstract

Conformal coatings are a means to protect printed circuit board assemblies, including the electronic components that they are populated with. Selecting a suitable conformal coating product has a significant impact on the nature of ruggedization that can be achieved. A variety of materials and application processes can be used during conformal coating. These materials and processes have an impact on the repeatability of the process and the reliability that can be expected.

Manual spray conformal coating is a method that is widely used. Polyurethanes, a class of organics, is a conformal coating option that provides high degrees of abrasive, temperature and chemical resistance while protecting against the formation of tin whiskers. At the same time, due to its chemical resistance, it is hard to rework the same.

In order to minimize the need for rework and create an efficient, repeatable and reproducible process, the automation of conformal coat spray application may be considered. This research addresses a means of a robust and automated conformal coating spray application on SODIMM type memory modules using a two-component polyurethane based conformal coating material. A variety of methods can be used for conformal coating application which involves spraying, dipping, brushing, and chemical vapor deposition. However, regarding suitability, affordability, and efficiency, automated

conformal coating spray deposition appears to be the appropriate method for the application of the conformal coating on SODIMMs.

Published research on conformal coating process setup is restricted to manual methods of conformal coat spray application. This research aims to improve process quality by observing improvement in yields while preventing observed defects and providing repeatable and consistent output for printed circuit board assemblies that are populated with SODIMMs. This is implemented using a variety of designed experiments to validate optimal input configurations for every sub-process of the overall conformal coating spray process. These optimal configurations are then used across the process for the execution of a controlled lot which is then inspected for visual defects and thickness to analyze process effectiveness.

The sub-processes for the conformal coating process include board wash, ionograph test, masking, plasma cleaning, conformal coating spray, and cure. The board wash sub-process was qualified using three different temperature and time durations as inputs. The wash was conducted for combinations of 25, 35, 45 minutes at 100, 125 and 150 F. The wash solution concentration percentages were kept constant at 20%. When examined under a microscope, white residue was observed for lower temperature configurations. Next, the ionograph tests were conducted to verify ionic contamination levels on the surface of the SODIMM products, and it was observed that all samples passed.

The plasma cleaning process tests involved various gas chemistries, and the effectiveness was verified using contact angles produced by distilled water over on BGA surfaces. It was observed that an oxygen-based plasma cleaning process provided the minimum contact angles of 8° or below. Argon, by itself, performed equally well. The mixture of the two gasses resulted in an angle greater than 8°. Hence, oxygen was decided to be the gas chemistry of choice.

The spray process was experimented with using three different programs. It was observed that the metalized surfaces of the components exhibited thinner deposits of coating than the other areas on board. The final program was modified to accommodate for cross-directional passes and an air tack time of an hour to resolve the observed issue which turned out to be successful as a fix.

The controlled lots processed and five samples were inspected for coating thickness ten times each provided with an average thickness of 84.84 microns with lies within the specification of IPC-CC-610 and customer requirements. No additional defects were observed, and hence the process setup is considered successful. This research has also helped in identifying potential opportunities for improvement which are discussed in the final chapter of this report.

DEDICATION

This research is wholeheartedly dedicated to my beloved parents and grandparents, who have been my source of inspiration, strength and courage whenever I thought of giving up, who continually provided their moral, spiritual and emotional support.

To my brothers, sisters, relatives, mentors and friends, and classmates who shared their word of advice and encouragement to conclude this research.

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CHAPTER 1

Introduction

1.1 Introduction to conformal coating

Conformal coating is a protective film applied on surfaces to protect them from environmental damage and degradation. According to IPC-CC-830B, “Conformal coating is used herein when referring to a type of protective coating for use on printed wiring (or circuit) assemblies. The conformal coating is intended to provide protection from moisture and contamination and provide electrical insulation; not as a sole source of mechanical support” [1].

In the context of this research, the term ‘conformal coating’ would be used about Printed Circuit Board Assemblies (PCBAs). The film thickness is typically from 25-75 μm ($1 \times 10^{-6}\, m$) [2] and ‘conforms’ [3] to the board topography, architecture, and components, covering and protecting solder joints, the leads of electronic components, exposed traces, and other metalized areas from corrosion. Most of the board traces are covered by solder mask. The purpose of cothe nformal coating is to cover all other metalized surfaces, except gold fingers, not covered by solder mask. Conformal coating provides protection against mold growth and electrical failures, allowing for smaller track sizes and greater voltage thresholds. Additionally, it provides significant levels of protection agains tin (Sn) whiskers [4].

Most applications that currently make use of conformal coatings belong to the military, marine, aerospace, automotive, lighting and green energy sectors. As a natural evolution of this form of environmental PCBA protection, healthcare, and consumer electronics industries are accepting conformal coating as it provides significant advantages regarding reliability and miniaturization.

1.2 Types of conformal coating

The type of conformal coating [5] used for an application process is crucial to the product type and requirements for ruggedization. However, it is important to consider additional factors such as demand, supply, process cost (setup and operational), rework capabilities and time to coat. If a suitable match is found for the same, it can be used as a coating of choice for the conformal coat deposition process. Below are some of the common types of conformal coatings.

1.2.1 Acrylic (type AR)

The moisture resistance of acrylics is comparable to that of silicone and polyurethane, but they have reduced resistance to petroleum solvents and alcohols. The dielectric strength of acrylic coating is approximately 1500 volts/mil (1 mil = 0.001 in = $2.54 \times 10^{-5}\ m$) and the temperature range for acrylic coatings is approximate -59ºC to 132ºC. Acrylic conformal coatings are relatively easy to repair and have a low curing time. Good electromechanical properties and a long pot life with little to no shrinkage or heat dissipation during cure are some of the advantages of acrylic conformal coatings. On the other hand, acrylic conformal coatings can be particularly sensitive to solvents (e.g., repair solvents or stripping agents containing chlorine) [4, 6, 7, 8].

1.2.2 Silicone (Type SR)

Silicone coatings tend to have excellent shock resistance. They are easy to apply. Mechanical spot repairs are possible, but overall removal can be difficult due to the solvent and heat resistance of the material. Dielectric strength is approximately 1100 volts/mil (1 volts/mil = 39370.1 volts/m), which is somewhat less than other coatings, but the flexibility of silicone allows for the application of thicker coatings. The temperature range of silicones is about -65ºC to 200ºC. Advantages include higher temperature applications up to 200ºC (392ºF), excellent humidity and corrosion resistance, and excellent thermal endurance, which is suitable for high thermal dissipating components (e.g., power resistors). Disadvantages include limited pot life, high Coefficient of Thermal Expansion (CTE) and difficulty during rework due to solvent and heat resistance [4, 6, 7, 8].

1.2.3 Polyurethane (Type UR)

Polyurethane coatings are rigid and durable, exhibiting high moisture resistance. The relative hardness of polyurethane coatings and cure shrinkage may stress components. Rework of polyurethane coatings in localized regions can be done by thermally softening the material, but the removal of this type of coating from large areas is challenging. The temperature range of polyurethane coatings is approximate -59ºC to 132ºC. Polyurethanes have a dielectric range in between 1500-2500 volts/mil. Polyurethane coatings are available as both one and two-part systems, have excellent humidity and chemical resistance while exhibiting good dielectric properties over time. Disadvantages include difficulty with rework and repair due to chemical resistance. Even selective rework requires heating. Humidity can cause blistering which may lead to electrical failure [4, 6, 7, 8].

1.2.4 Epoxy (Type ER)

Epoxies are thermosetting systems usually containing two parts. They follow the same temperature ranges as polyurethanes. Localized repair is only possible by burning through particular epoxy areas. Removal over large areas is nearly impossible. Advantages include high abrasion and humidity resistance. Disadvantages include short pot-life, repair difficulty and stress on components due to the shrinkage associated with curing [4, 6, 7, 8].

1.2.5 Parylenes (Type XY)

Parylene coatings [7] (poly-para-xylene) require Chemical Vapor Deposition (CVD) to deposit on small polymer segments called dimers that are then broken down into monomers as they travel down in the form of vapor through the chamber that contains the assembly to be coated. A parylene coating is used to produce relatively thin coats as opposed to other coatings. The monomer makes contact with the surface and sticks to it uniformly. There are various types of parylene coatings (Parylene N, C, and D), with varying chemical structures and properties. Advantages of parylenes include exceptional environmental, chemical, and corrosion protection, and excellent dielectric strength (5500 - 7000 volts/mil). Parylenes also have to ability to adhere and conform to most surfaces and provide uniform coating levels. These properties help prevent thin-outs, pinholes, run-offs and sagging. Disadvantages include inconvenient technique, the requirement of specialized equipment (vacuum chamber for parylene deposition), complicated rework and operational costs. (require the use of plasma abrasion or micro blast cleaning) [10, 11].

1.2.6 Others

Other conformal coatings include nano-coatings and hybrids. They range from medium to high costs regarding the operation. Hybrids can provide unique solutions such as security, RF shielding/immunity or selective conductivity but are extremely expensive. Nano-coatings are thin coatings that are very sensitive to abrasion and require a long cure time. Nano-coatings properties vary across industries due to their recent adoption in the market. Both types can be deposited using spraying or dipping. Additionally, nano-coatings allow for low-pressure deposition while hybrids allow for application via dipping and printing (Figure 1.1).

1.3 Conformal coating application methods

Following the choice of the appropriate conformal coating material, it is essential to decide on the method of application of the conformal coating. Based on process and product requirements and complexity, a coat application method is required to achieve a high yield and minimum defects per the requirements. The defects can be defined based on the customer requirements in addition to industrial standards. The variables that will decide the type of process implemented for conformal coat application will be based on the PCB thickness, components on the PCBA, thickness requirements, coverage, and restricted areas on the board.

1.3.1 Spraying

Spraying can be conducted in conjunction with silicone, acrylic, nano-coatings and polyurethane applications. It is the most popular implementation of conformal coating and one of the most affordable options. The coating quality obtained at the end requires less material than other application methods. Acrylic, polyurethanes, silicones, parylene, nano coats, and hybrids are categories that are capable of being applied using spray coating.

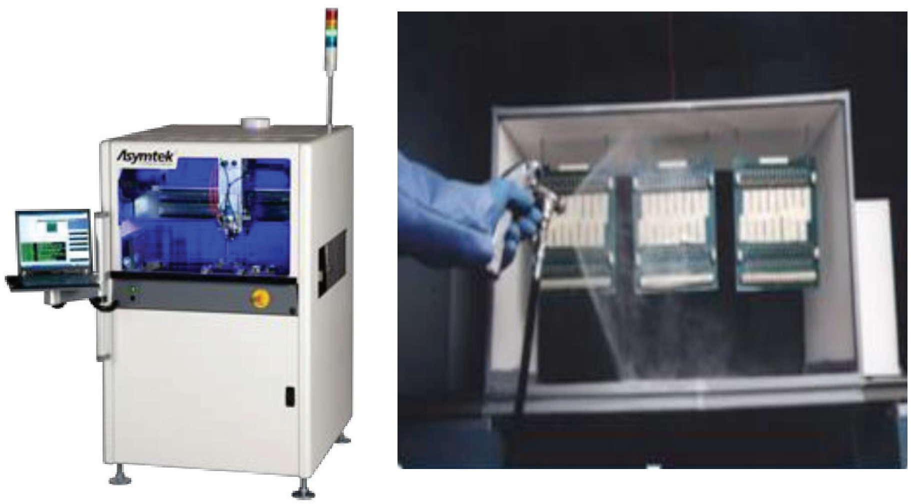


Figure 1.1: Conformal coat spray application a) Automatic b) manual [11]

Spray application may be conducted manually or using an automated setup (Figure 1.1). The factors that make manual spraying useful is the low cost of setup, process simplicity and the ability to coat complex board designs. However, it can be hard to prevent overspray, which can lead to excessive waste of material and harmful emissions. It is also difficult to regulate coating thickness using this method. The method requires multiple coating cycles. Automated spray methods are utilized to avoid the shortcomings of manual spray application methods. They provide material savings, reduced masking requirement and medium to high throughput. This approach is very efficient. However, it is costly and requires regular machine programming and maintenance.

1.3.2 Dipping

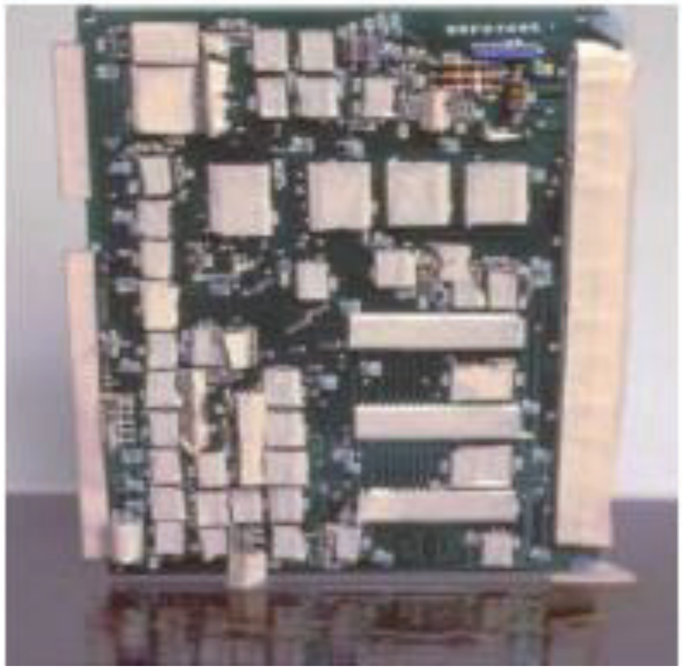


Figure 1.2: Dipping method of conformal coating application [11]

This process is suitable for low volume, high complexity jobs and provides for excellent coverage on complex components, shapes, and parts within the assembly. It requires efficient masking and prepping. Otherwise, the components, substrates or areas of the assemblies may sustain damage. The dipping baths require high degrees of cleanliness, and the temperature and humidity conditions need to be carefully regulated. (Figure. 1.2).

1.3.3 Brushing

This technique is suitable for all applications other than parylene based conformal coatings. The advantages include low investment, no masking, efficient touch-up and rework for low volume jobs. The disadvantages include inconsistent thickness and high variability in

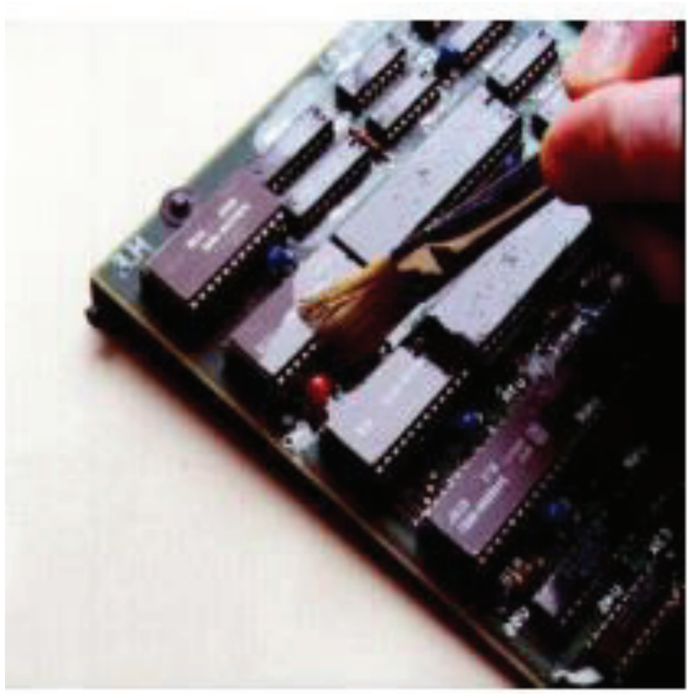


Figure 1.3: Brushing method of conformal coat application [11]

coatings. It is difficult to control voids and bubbles, and it is dependent on operator technique. (Figure 1.3)

1.3.4 Chemical vapor deposition (CVD)

Graphite, silicone or parylenes based conformal coatings are usually deposited through the implementation of CVD. Polymers are vaporized into small segments called dimers that are broken down into monomeric species. The monomers are then deposited on the surface of the substrate via adsorption (Figure 1.4).

1.4 Introduction to SODIMMs

SODIMMs are miniaturized memory modules containing QFNs, passives, resistor packs, BGA devices (flash, EEPROMs) and gold fingers. They are a form of PCBA (Figure 1.5).

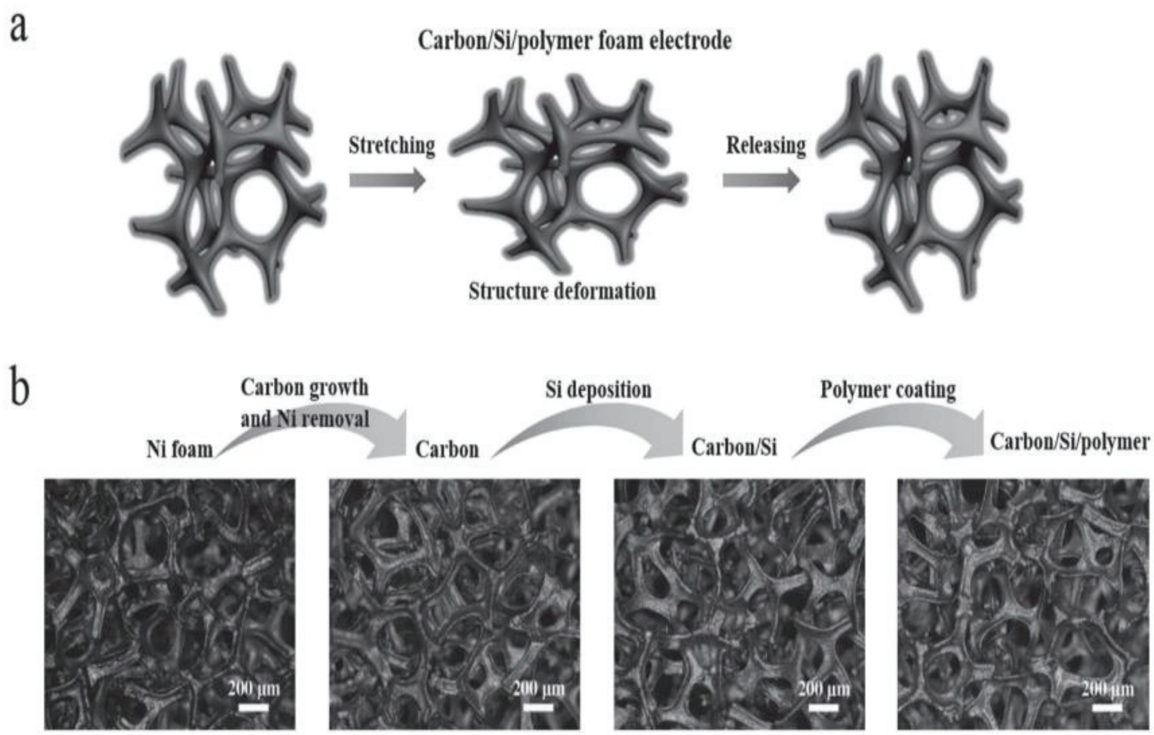


Figure 1.4: Chemical vapor deposition process [23]

Standard SODIMMs range from 100-pins to 260-pins, varying in dimensions and position of notches on the board.

The reader should observe a variety of conformal coating types and their methods of application. For this research, there is a need to focus on polyurethane based conformal coating deposited by an automatic spray method. This process should aim to optimize costs, quality, speed, and efficiency while meeting demands from the customer.

1.5 Risks associated with conformal coating

During the process setup and production phase, it is possible for defects to occur. According to the available literature, the following causes are attributed to most failures as a result of the conformal coating process.

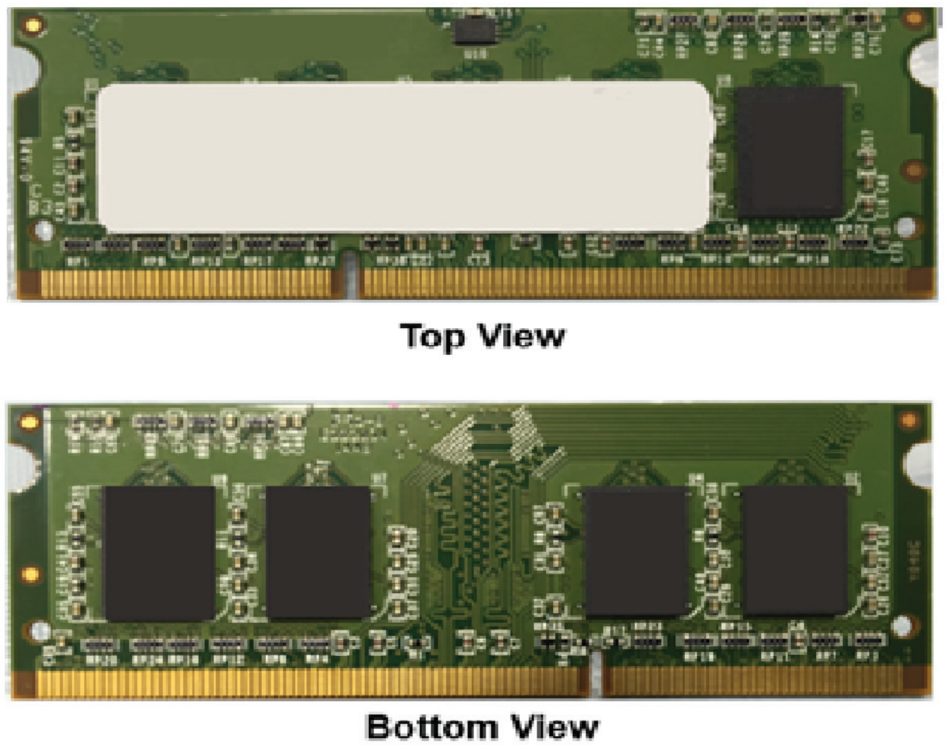


Figure 1.6: Small Outline Dual In-line Memory Modules

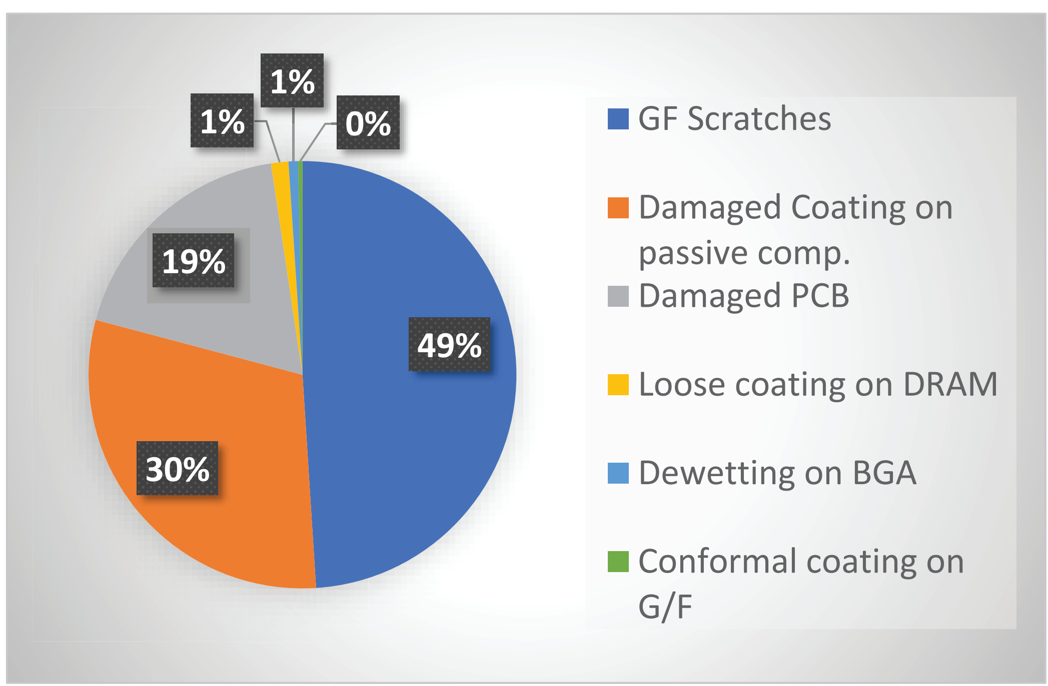


Figure 1.5: Defects sorted by frequency of occurrence

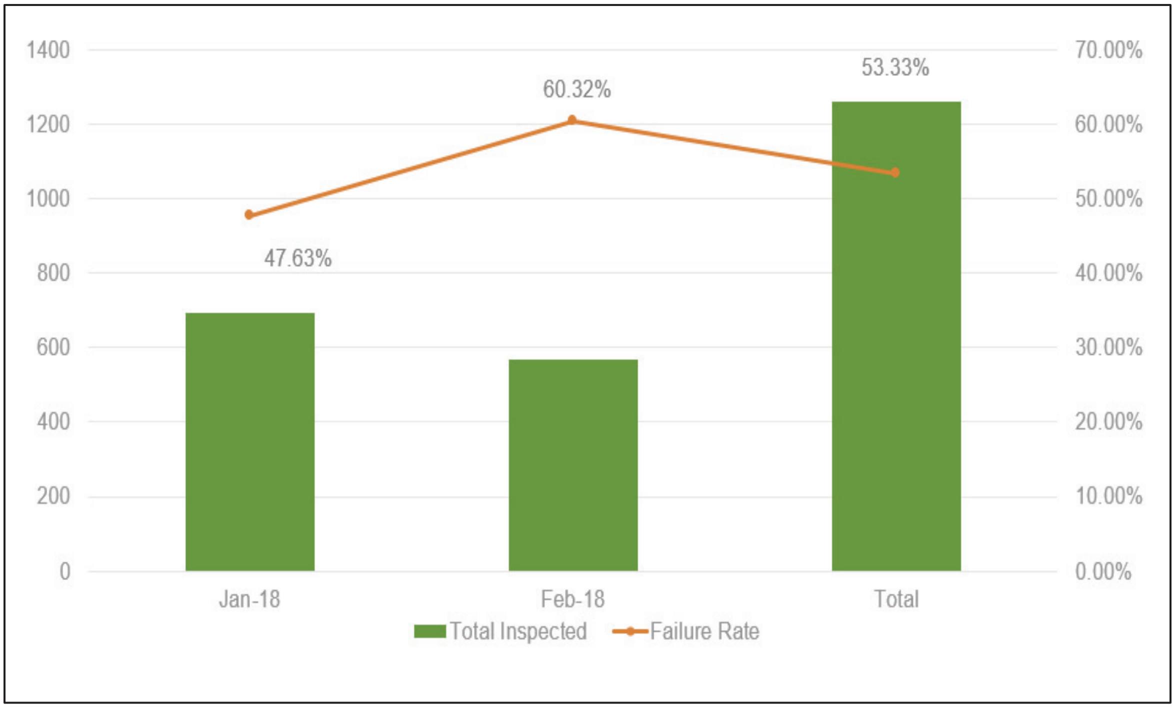


Figure 1.7: Defects observed at supplier end

1.5.1 Mechanical damage to electrical assemblies

During handling of coated modules, it is possible that the conformal coat or the coated components get damaged. Few of such scenarios include flipping or handling of partially cured or uncured boards. It can result in dewetting, damaged coating and other defects. Another situation occurs during the de-masking of areas on the PCBA. De-masking may cause damage to smaller components such as passives, which may be broken or chipped while de-masking [17].

1.5.2 Electrical failures due to stresses induced by coating on solder joints

After curing, the conformal coating shrinks and hence may affect the solder joint integrity, causing stresses due to mismatch of Coefficient of Thermal Expansion (CTE). Parylenes are especially susceptible to such issues. This problem is magnified with an increase in thickness in coating and damage to components. [18]

1.6 Problem and Research Objective

There are numerous issues associated with the conformal coating process at production facilities. Most companies utilize manual spray methods in conformal coat modules. There is inadequate data to provide guidelines for polyurethane conformal coating process, especially for SODIMM type memory modules. This calls for research for an automated atomized polyurethane conformal coating spray application process for SODIMM based

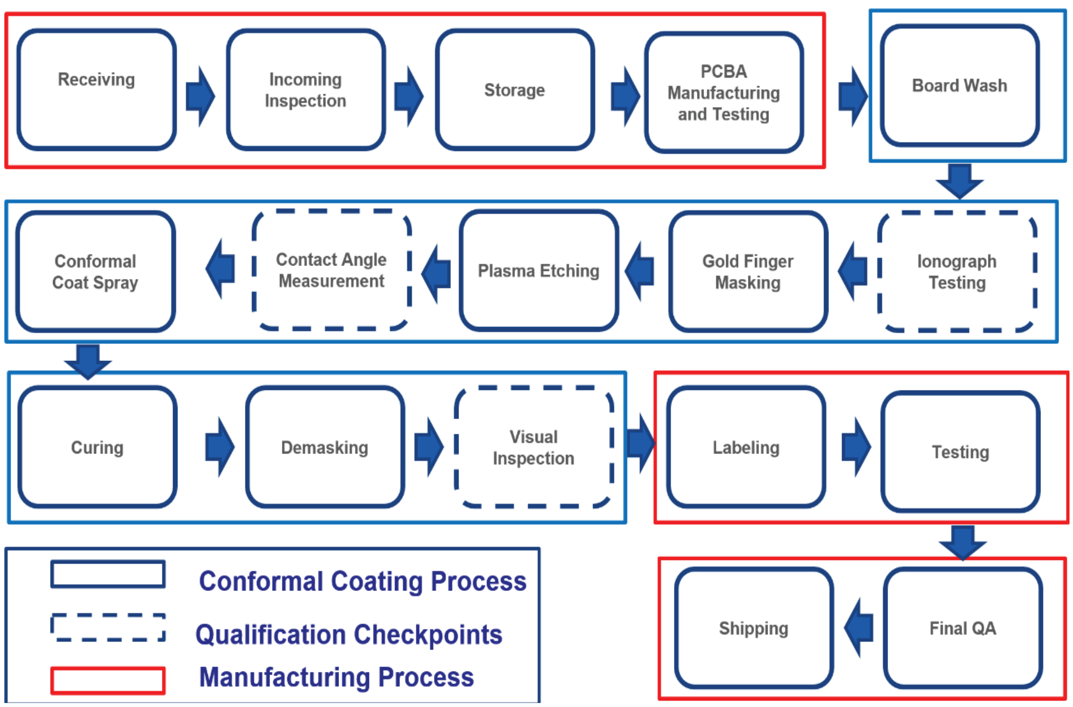


Figure 1.8: SODIMM conformal coating process outline flowchart

memory modules that is repeatable and reproducible with minimum lead time, cycle time and increased yields and minimum defects.

The research objective was to develop a robust polyurethane conformal coating application process using the automated spray application method. The process will be utilized to coat Small Outline Dual Inline Memory Modules (SODIMM) to protect against moisture, mold, chemical exposure, and mechanical damage. The primary coating material is Humiseal 1A33 used alongside Thinner 521 AU.

The conformal coating process contains various steps post PCB assembly in the following order: These include board wash, ionograph testing for surface contamination, masking of gold fingers to prevent damage during plasma cleaning, plasma cleaning for increasing surface energy, contact angle measurement using an optical tensiometer, automated conformal coat spraying, conformal coat curing and contactless measurement of conformal coating thicknesses (Figure 1.8).

The qualification of the process was based on equipment design, installation, and operations, as reflected by the product's quality and functionality. The optimization of the wash process required optimized wash time and concentration levels for board washing. The plasma cleaning process was qualified based on the optimized gas mixture concentration and cleaning time. Thinner to the material ratio of the mix, atomization levels, dispense height, dispense width, amount of material dispensed and dispense speed was collectively optimized to obtain a repeatable and reproducible spray process.

1.7 Summary

The chapter begins with a definition of conformal coating. It then moves on to the purpose of conformal coating. Subsequently, an overview of various types of conformal coating and dispense methods is provided along with a discussion of the respective advantages and disadvantages of the same. Based on the requirement from the conformal coating and the options available, a decision can be made on the suitable type of material. The chapter then details methods that are used to apply the conformal coating and their specialized implementations based on product type and design, process complexity, masking, thickness requirements, cost and time required to coat. It then moves forward to discuss SODIMMs, the PCBA manufacturing process and how conformal coating fits into it. The chapter then provides a brief description of the history of supplier issues observed during the conformal coating process. The problem statement reflects on the issues exhibited by manual spray methods and highlights the importance of an automated conformal coating spray application process for ruggedizing SODIMMs.

CHAPTER 2

Literature Review

2.1 Introduction

It is essential to understand the different components associated with the conformal coating process too understand the dynamics of conformal coatings with SODIMMs. This chapter aims to cover existing studies conducted in the field of conformal coatings specific to the PCBA manufacturing process. It talks about conformal coating after PCBA the manufacturing process. The contents of this chapter describe various research initiatives embarked upon in the field of PCBA conformal coating and the outcomes of associated research identifying potential gaps and highlighting the need for process design, setup and qualification study for the same.

2.2 PCBA conformal coating

Conformal coatings are utilized for ruggedizing electronic assemblies to prevent damage or failures in hostile environments. Some of the examples would include the military, automobile, aerospace and medical applications [16]. The various advantages of conformal coatings include the development of an insulated organic barrier that protects against moisture exposure, potential pollution (electrical leakage), mechanical damage, and mold growth. The level of moisture protection is evaluated using the level of moisture absorption-desorption kinetics. The level of kinetics can be regulated by altering the thickness of the layers.

Additionally, according to Salman [15], conformal coatings can provide chemical protection. The research describes protection for their experimentation on the PCB-based multisensor array to determine the levels of protection provided by the coating. The study also mentions the salt spray resistance test as a means of assessing the reliability of a PCBA. It is difficult for a PCBA to pass the test without coating assistance as salt solutions would accelerate corrosion on copper tracks in conventional cases.

The study [16] addresses conformal coatings that reduce lead-free solder-alloy related problems by mitigating tin (Sn) based whiskers and improving fatigue strength. It is described that these metallic growths can compromise component terminations when it comes to tin that is electroplated. Tin whiskers can compromise the circuits by causing shorts and hence device failure. In this case, the implementation of the conformal coating can reduce product failures on the first plug or infancy. In addition to conformal coating, it is advised to improve tin chemistries and component thermal treatments. Tin whiskers are represented in Figure 2.1 [16].

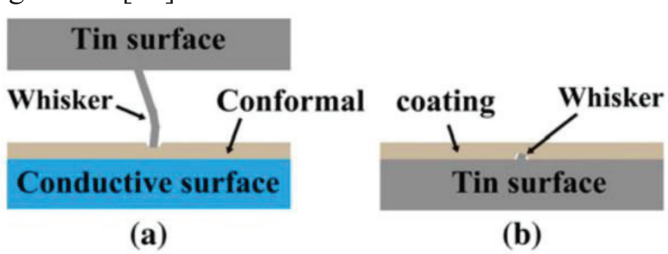


Figure 2.1: Tin whisker growth [22]

Kaldesch [20] experimented with Uralane 5750 conformal coating on tin whisker growth and reported that tin whisker growth is not terminated by using a conformal coating. However, it is significantly reduced. The experimentation included: implementing a delayed onset for tin whiskers, influencing the growth of tin whiskers, affecting their density, preventing tin whiskers from growing through the coating. In their study, a tin whisker managed to grow through a 0.00635 mm thick coating. They also observed that after two years, numerous tin nodules were found growing below the conformal coating. It is stated that tin whiskers are sensitive to electrostatic forces and may result in shorts regardless of conformal coating. Hence, conformal coating by itself may not be able to avoid failures caused due to tin whiskers.

Woodrow et al. [21] presented their continued research for tin whisker mitigation for PCBAs. The results of the experimentation say that conformal coatings can suppress the formations of whiskers and eruptions. With 401 days of exposure to the ambient conditions, tin whisker breakout was contained. However, during high humidity conditions, the effect of conformal coatings was overcome, and the whiskers and growth were able to pass through the conformal coating regardless of the coating thickness which contradicts their previous study of 50°C/50% RH where whisker growth and eruptions were temperature dependent. Auger analysis was conducted that concluded that the surface of the crust was a mixture of tin, tin oxide and zinc oxide for the eruptions.

Dou [19] presented their research on reliability to ensure high insulation impedances of conformally coated assemblies. The cause for this is attributed to be moisture as it combines with solder flux residue on the surface of PCBAs. The ionic or organic contaminants increase the Surface Insulation Resistance (SIR). SIR is defined as the electrical resistance between two conductive materials generated due to the presence of a dielectric material [19]. This research focused on finding relationships between moisture and SIR for conformally coated PCBs by measuring leakage currents on passives in environmental testing chambers while adhering to IPC standards for non-component loaded boards. It was found that damp heat insulation resistance measurements following a procedure similar to IPC standard SIR testing for non-component full boards have been carried out on capacitor loaded PCBs reflowed with a low-solids solder paste and encapsulated with a two-part silicone-based conformal coating. The boards were cleaned to varying levels to allow for the investigation of surface contamination impact on the effectiveness of the conformal coating. The differences were observed despite ionic contamination tests yielding similar or identical levels. Qualitative analysis for the presence of organic resin residues from soldering was found to be a better predictor of the behavior in the damp heat test. Discoloration of solder on comb structures was seen on encapsulated boards after the wet heat tests but not on exposed boards.

When it comes to mechanical fatigue in harsh environments, it is essential to reduce the impact of vibrations, abrasion, and high temperature [18]. The stress produced due to these two factors may contribute to failures. Conformal coatings exhibit improvement in solder joint reliability for BGA and SMT components [19]. It also provides adequate protection against arcing and haloing of the electric discharge. Electrical factors like dielectric strength, resistivity and dissipation factors need to be considered before selecting the suitable conformal coating material.

Han [22] attempted to examine the effectiveness of conformal coating on actual assembled hardware. Six conformally coated samples were analyzed for their effectiveness against tin whiskers when applied to gull-wing specimens and quad flat pack specimens. Gullwing leads show non-uniform coverage of conformal coating. Scanning Electron Microscopy (SEM) was used in backscattered electron mode to aid in quantifying coating coverage.

Tests for tin whiskers were conducted again after specimens were subjected to sequential temperature cycling and increased temperature and humidity conditions as well as corrosive gasses. It was observed that Parylene C was the only coating that was able to survive the effects of the harsh environment and effectively suppress tin whiskers. It was also found that corrosive gas exposure proportional to tin whisker density but not growth, spray processed conformal coatings were found to have minimum coverage in comparison to coatings that were deposited using Chemical Vapor Deposition (CVD). Thinly coated corners showed more susceptibility to whisker growth in comparison to the ones exhibiting greater thickness.

2.3 Conformal coating processes development

Conformal coatings vary by chemical and physical properties, application, removal or rework methods. Curing durations are also different depending on the material and deposition processes [13]. An ideal conformal coating must not crack, exhibit dewetting, low-shrinkage, proper adhesion and environmental friendliness. The conformal coating dispense mechanisms depend on the type of conformal coating being used. Two-component mixtures require maintenance of ratios and vigilance when it comes to concentrations [11]. They also need to be used within a specified time interval of mixing. Inconsistencies observed at this stage of the process may cause quality issues such as dewetting, thin coating, bubbling. Examples of such conformal coating materials are epoxies and urethanes. One component systems, such as acrylics, do not produce this issue as the same batch can be continually used for a longer course of time.

Another important factor while selecting a conformal coating is the ease of rework. There might arise a need to conduct rework for components or the coating itself. This process must not damage the components. The rework on these modules can be done using dissolution in specific compounds, application of heat or shearing. The research, however, does not mention the requirement of ease of rework for smaller assemblies. Two-component systems usually beat other options in these scenarios.

The coatings also vary by cure mechanisms. Curing may be conducted via the exposure of specific coatings to a higher temperature, low humidity or applying normal temperatures would require several hours for the coatings to cure. UV light-cured coatings may get cured as fast as a few minutes.

The coatings are classified in the following significant groups by composition epoxy (ER), acrylic (AR), urethane (UR) and silicone (SR), and poly-para-xylenes (XR). There are however more categories that include composites used for specialized applications. Depending on the type of conformal coating selected, the optimal deposition process may be chosen. It involves either manual deposition processes such as manual spray, dip or brushing or automated dip or spray. Ideally, dipping is considered to be the more reliable method. However, in cases that cosmetic quality is taken into consideration, spraying provides a relatively consistent deposition and avoids run marks and material wastage. Despite the advantages, sprayed PCBAs are more prone to surface defects such as dewetting, fisheyes and bubbling. See Tables 2.1, 2.2. Symbols '+' and '-' indicate the favorability of coating associated with the respective factors.

Table 2.1 Properties of conformal coatings for QFN components [14]

Type	Acrylic	Silicone	Urethane	Parylene
Material cost	+	-	+	-
Ease of application	+	- *	+	-
Repair	+	-	--	--
Temp range	+	++	+	++
Solvent resistance	-	+	++	++
Electrical resistance	+	++	++	++
Abrasion resistance	+	-	++	++
Material pot life	+**	++	-	++

*Contaminates other materials
** in inert atmosphere

Table 2.2 Comparison of dispense process performance [14]

Method	Width control	Thickness control	Minimum coating width
Brushing	-	-	+
Manual spraying	--	+	--
Dipping	---	+	--
Curtain coating	+	+	--
Selective coating	++	+	-

2.4 Conformal coating process flow

The start of the research requires an overview of conformal coating process steps. These steps include PCBA wash, ionograph testing, baking, masking, plasma cleaning, optical tensiometry test, conformal coat application, conformal coat curing, conformal coat thickness measurement, and conformal coat visual inspection. The modules also required to be tested for functionality post visual quality inspection. One of the first prominent studies conducted in the conformal coating process looked at the 'Analysis and

Improvements of an Acrylic Conformal Coating Process' [2]. This research employed the use of masking boots as a replacement for masking tapes and flex masks regarding cost savings. However, it was found that there were no significant differences in cost savings or quality.

Other significant tests conducted include the weight loss tests, optimum air cure and oven times. The research also aimed to study if the cure time can be reduced from 2 hours to a smaller number. The study looked at various types of masking tapes with inconclusive results regarding which masking tape met all the requirements. The study suggests the use of Zahn cup #2 and #3 viscometers determine the amount of error, and it was discovered that Zahn cup #2 shows acceptable readings. Other variables that were analyzed included the operator bias, coating to thinner ratios and alternative flex masks all indicating little to no difference in quality. This study was however only able to look at the two-part (coating and thinner) [2] acrylic conformal coating process specific to a particular instance/application. The flowchart for the method is shown in Figure 2.3.

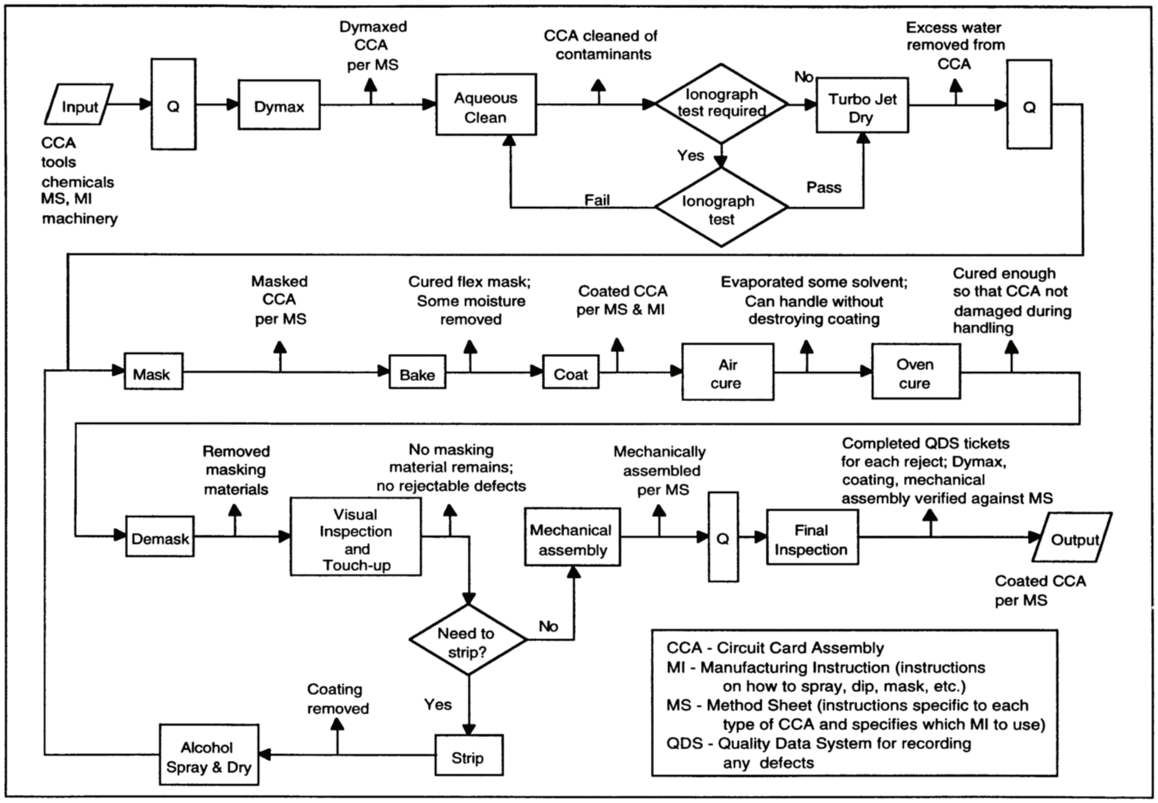


Figure 2.2: Acrylic conformal coating process map [2]

Dymax [2] refers to the epoxy that was cured using UV light to hold wired components to make sure they did not get loose. The use of Dynmax is not required in the existing process. This paper also addresses ionograph testing, drying, masking, and curing. The process will remain same until this point. The air cure before the oven cure is eliminated in this research as existing conformal coatings are capable of receiving accelerated temperature curing using a suitable oven. The partially sprayed boards can be handled safely as physical contact with the boards is prevented. A specialized fixture has been designed for the specific purpose of providing handling flexibility. The coating strip process would also be different from the one described in the study as there are customized materials used to do the strip in-case rework is required. The research paper also discussed spray (manual),

manual dip and auto dip processes for conformal coating. However, this research follows the automatic spray process for dispensing and coating. The study advocates the use of dipping to be the more efficient process of dispensing as it is much faster. On the other hand, inefficient masking may pose the risk of bleeding of the conformal coating into areas that need to be avoided while coating. Spraying avoids this issue and provides better aesthetic quality and hence would be used for this research as the method of choice [2].

The experiments for the research [14] involved the standardization actions for work benches, masking tapes, coating to thinner ratio, viscosity tests, and oven temperature standardization for a cure. The equation for the solvent evaporation rate was presented as follows. 'W' was described as the weight of the coupon, hook, and coating at a given time. 'Wb' and 'We' were the respective weights measured after removing the coupon from the oven for the first time and at the end of ten days respectively.

The humidity temperature and humidity of the room was also measured before conformal coating application

$$\% \text{ solvent evaporation} = (W - Wb)/(We - Wb) \quad (1)$$

The research was able to obtain relationships between the evaporation between curing rate vs. curing temperature. It was also described that masking tapes must not contain silicone, as they leave residues after demasking, lose adhesion when heated, exhibit porosity, tear easily. At the same time, it should be anti-static, self-sticking, easy to remove and clean and must leave a clear, smooth line at the boundaries of the masked areas. The study advocates the use of 3M tapes which would be adhered to during this research. The measurements for viscosity were conducted using the Zahn cup viscosimeter gauge experiments that showed clear operator bias. The suggested coating to thinner ratio was

42% pure coating to 58% thinner for dipping per 1000 mL of the mix. The future scope of this study was to look for weight loss tests to be run at standardized temperatures. Opportunities to look for the improvement of cycle time and throughput, monitoring of the scenarios where the most amount of touch-ups were required and doing a cause analysis of the same.

To understand more about dispense mechanisms, Szuch [13] presented an exhaustive literature survey that covered issues faced by various contract and equipment manufacturers when it comes to shielding electronics from damage caused by harsh environments. The paper discusses multiple dispensing technologies and their properties along with the issues encountered while dispensing them. The dispensing methods described are spraying, dipping, brushing, and needle-dispensing. The paper also talks about automated means of dispensing using robots. The literature review proposes a high flow-rate, tri-mode applicator technology offering wide varieties of automized spray patterns, spot and line modes and coaxial air-assisted monofilament modes. Two such configurations were compared for repeatability, selectivity, and accuracy. As an example, 0805 jet capacitors were described.

In more recent research conducted on the conformal coating dispense processes, newer materials are emerging. These are a mix of acrylic and urethane chemistry [16]. These chemistries are solvent-free one component systems with UV curing properties despite thermal curing to reduce lead time and cycle time for the coating process. It is stated that a couple of days are required at least to achieve full cure and full adhesive functionality. Layer thickness would depend on humidity and diffusion control. Techniques such as brushing, atomization, and curtain coating (high control over thickness as well as width) offer high flexibility and control over coating thickness but require extensive and careful masking. The automated spray is better regarding the ventilation requirement because of atomization. The spray/curtain coating, when automated, provided much better control over the coat thickness and consistency. Additionally, selective coating, such as automated dipping, improves uniformity and provides higher thickness control. The process becomes much more repeatable and reproducible as a result with little to no masking requirement (Ref. Table 2.2).

The behavior of the liquid drops can be described by equations 1-4 below [14],

Bond Number, $$B_o = \frac{\rho g d}{\sigma} \quad (1)$$

Reynold number, $$R_e = \frac{\rho v d}{\eta} \quad (2)$$

Weber number, $$W_e = \frac{\rho v^2 d}{\sigma} \quad (3)$$

Ohnesorge number, $$Oh = \frac{\eta}{\sqrt{\rho \sigma d}} \quad (4)$$

Here, ρ is Density (kg/m3), d: characteristic linear dimension, typically drop diameter (m), σ : superficial tension (in N/m), v: velocity of the fluid with respect to the object (m/s) η : Dynamic viscosity (in Pa.s). Bond number (Bo) is the ratio of gravity force to capillary force.

When Bo <<1, gravitational forces can be neglected, and only capillary forces and inertial forces for mechanical collision need to be considered, i.e., jetting is possible at the top and the bottom of the circuit simultaneously. Reynold number (Re) is the ratio of inertial forces to viscous forces and is useful for predicting the transition from laminar to turbulent flow and Re <2000 is usually the limit to laminar flow targeted. Weber number (We) is the ratio of inertial forces to capillary forces and defines jetting capability, representing the minimum energy needed to pass the nozzle barrier. We >>4 is a representative jetting limit. At the same time, minimum nozzle size can be set for a given material. Ohnesorge number (Oh) is the ratio of viscous forces to inertial and capillary forces. In inkjet printing, the Ohnesorge number is useful when setting the range for the acceptable process between satellite droplet – excluding primary drop (small Ohnesorge number) - and non-ejection of fluid due to viscous dissipation (high Ohnesorge number).

The conclusions of the research [14] show that the selective deposits can be made with stabilized dot volume and reduced numbers of satellite droplets. The results look promising for HDI interconnect boards [14]. However, potential improvements appear to be required from the material point of view regarding Ohnesorge number. Solventless chemistry with UV curing offers shorter lead and cycle times and immediate protection. The masking process is also eliminated, which further reduced the time. Other than the study utilizing DROP-ON-DEMAND dispensing technologies such as piezzo inkjet dispense, aerosol jet printing, jetting by mechanical collision and screen printing for conformal coating as opposed to conventional methods, much insight can be gathered and scaled to implement a polyurethane automated spray coating process for SODIMM type conformal coating modules.

One of the earliest published applications of conformal coatings on SODIMMs is described in the form of a datasheet by GE Systems [12] for VMIVME -7851 (Intel® Pentium® 4 Processor – M Dual Slot VME Single Board Computer) by GE in the year 2000. The architecture for the same is described in Figure 2.4. The datasheet provides the product description as well as an option to conformally coat the motherboard at the customer's request. There is specific literature available on the conformal coating of SODIMM type memory modules. Hence the significance of this research.

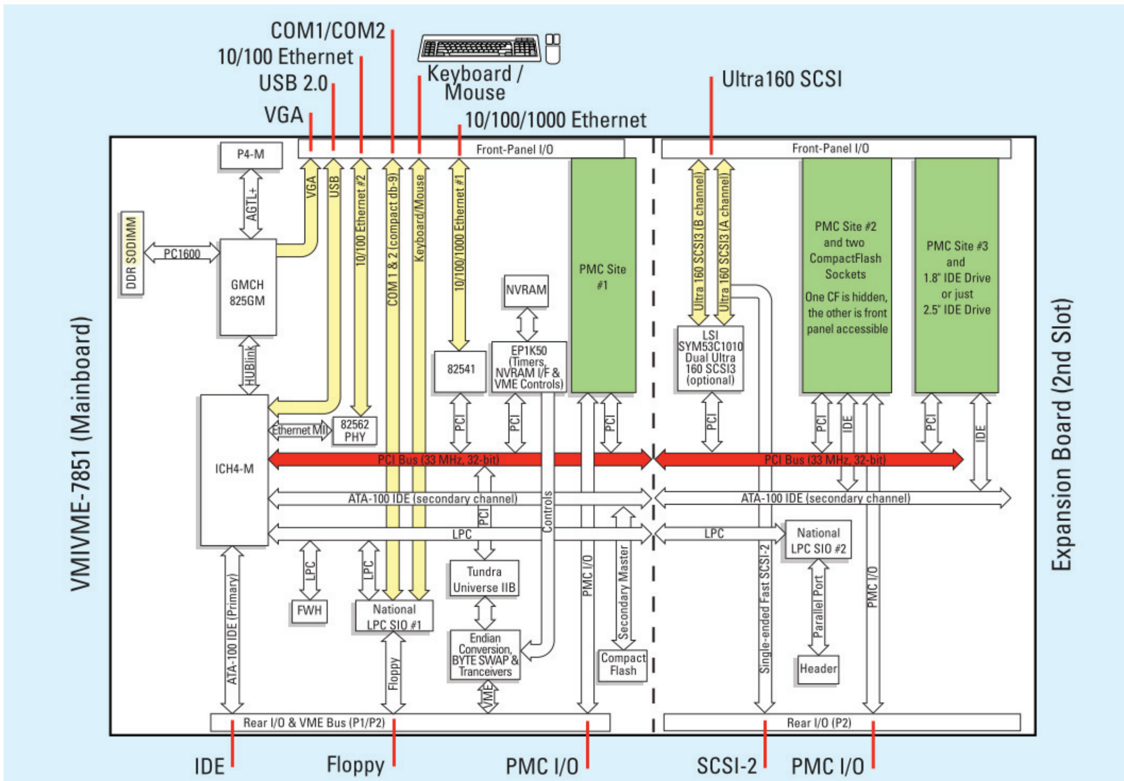


Figure 2.3: Architecture for VMIVME – 7851 [12]

2.5 Summary

Based on the literature discussed above, gaps can be observed in the existing research. Two of the many prominent gaps include the following:

1. The rework requirements for SODIMM conformal coating modules. SODIMM modules are smaller than most electronic memory systems. Therefore, it is essential to conduct a conformal coating process evaluation and qualification study specific to SODIMM modules.

2. Studies were not found specific to polyurethane conformal coating spray process development, analysis, and improvement.

These research gaps set the foundation for the research methodology adopted in this research endeavor, which will be discussed in the next chapter.

CHAPTER 3

Research Methodology

3.1 Introduction

This research focuses on developing a robust and repeatable process for conformally coating SODIMM electronic memory modules using an automated spray application. The material utilized for this purpose was a two-component polyurethane system. The sequence of this research was categorized into three parts namely process setup, process qualification, and process improvement. Figure 3.1 describes the flow of the research methodology.

3.2 Phase 1: Sub-process setup

The first phase involves initial purchase and installation for the equipment. The equipment used for the research includes the automatic board wash system, ionograph, plasma cleaning system, optical tensiometer, automated spray coating system and curing oven for conformal coating.

The sub-process setup was examined for visual and non-visual attributes of the equipment in comparison to operational, maintenance and configuration guidelines for the equipment

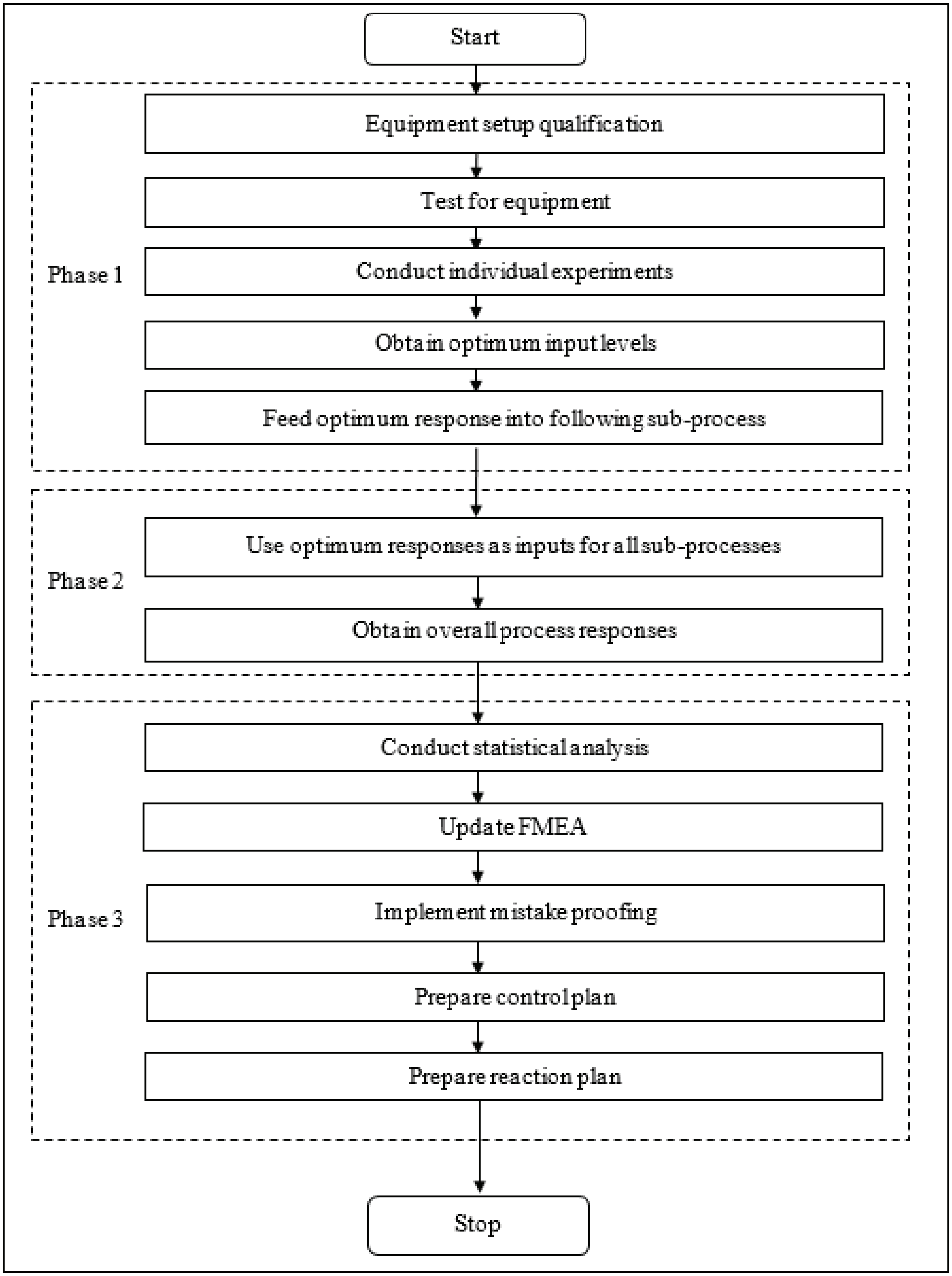


Figure 3.1: Research flowchart

and material, as provided by the vendor. The overall integrity of the system and package was inspected before receiving. Equipment installation support was provided through field service engineers. Once the internal and external physical inspection for the same was complete, equipment was inspected for power and operation related failures. Any issues encountered were immediately reported to the supplier. Checks for setup and functionality include visual examination, power-up, power-down, valves, piping, wiring, electromagnetic components, fuse and electrical ratings. Alarm setup was also verified for functionality due to its importance vis-à-vis quality and safety. Records for machine hardware initial calibration and certification per industrial standards and customer requirements were obtained for all equipment including but not limited to, health, safety, federal and industrial quality specifications. After procurement of all associated standards and confidence on the integrity of the equipment, equipment training and certification was obtained from the manufacturer and a record for the same was maintained.

Experiments for the individual sub-processes were conducted using input configurations based on existing processes and literature. The SODIMMs are exposed to treatments defined by the experimentation, and their respective outputs decide the optimum configurations. These configurations would minimize overall process cost while maximizing sub-process quality regarding yields and defects. Response from the optimal

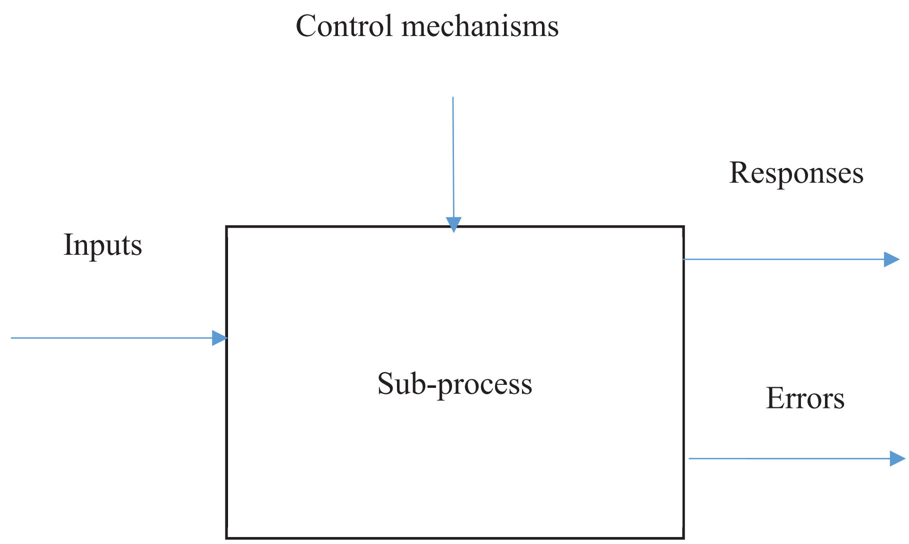


Figure 3.3: Representation of a sub-process visualized as a system

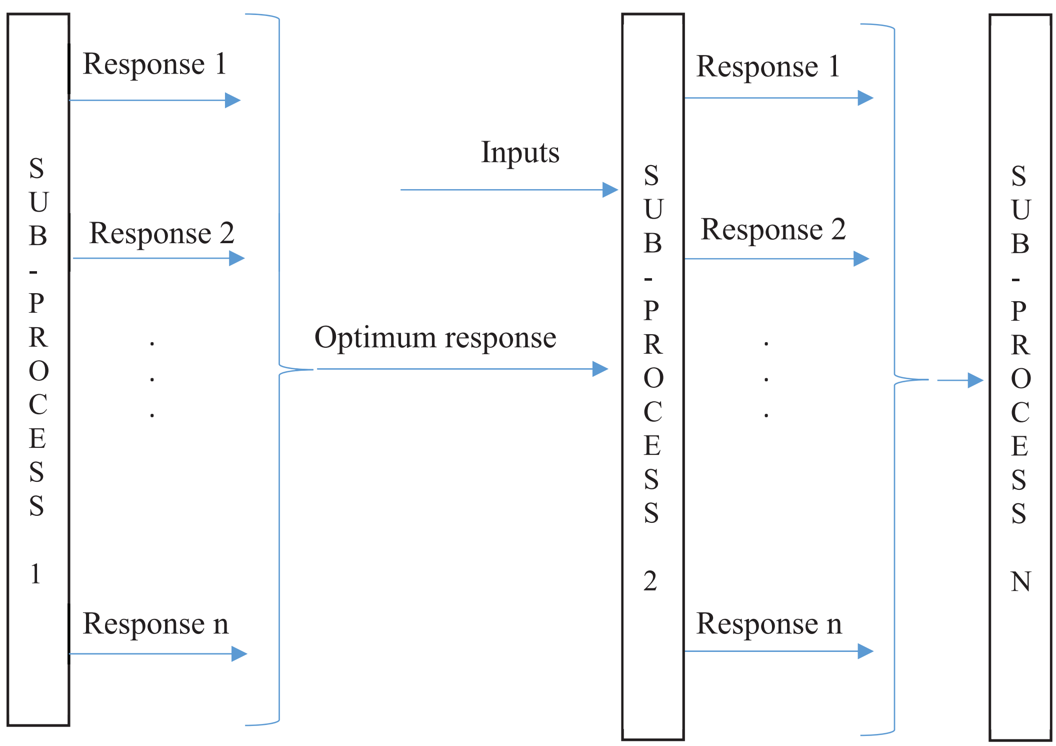


Figure 3.2: Optimum response conversion to input for the following system

response was directed as input to the next sub-process element, and this cycle was repeated for every sub-process. Figure 3.2 and 3.3 provide a visual representation of the system.

3.2.1 Board wash system experiments

The input factors for board washing system include wash temperature, dry temperatures, the concentration of wash solution, wash time, dry time, number of rinse and dry cycles. The objective for this sub-process was to obtain modules with minimum ionic contamination and no flux residue.

The initial run for an automated board wash system was tested for wash cycles with no assemblies loaded for the cycles. This introductory testing and priming involve monitoring of the sump and chamber temperatures. This was to investigate the abnormal increase in temperatures of the setup compared to the operational and safety limits specified by the supplier.

A 2^3 factorial experiment was conducted to evaluate the effectiveness against ionic contamination and flux residue levels of the SODIMMs, where all variables other than the wash time and wash temperature were kept as constant. Levels for wash temperature are 100, 125, 150 F and the levels for wash time are 25, 35, and 45 minutes. The treatments contain all unique combinations of levels from both factors. These nine treatments were applied to nine batches containing five SODIMMs each. The hypothesis to test the treatments was the absence of flux residue and ionic contaminants.

Next, a customized fixture was constructed using Semitron ESD 225 material with the capacity of 50 SODIMMs. Five devices were selectively loaded in the middle rows of the fixture. Wash cycles exhibited BGA shadowing effects on the board, and specific tests were conducted to identify root-causes. It was found that lower temperatures exhibit greater shadowing.

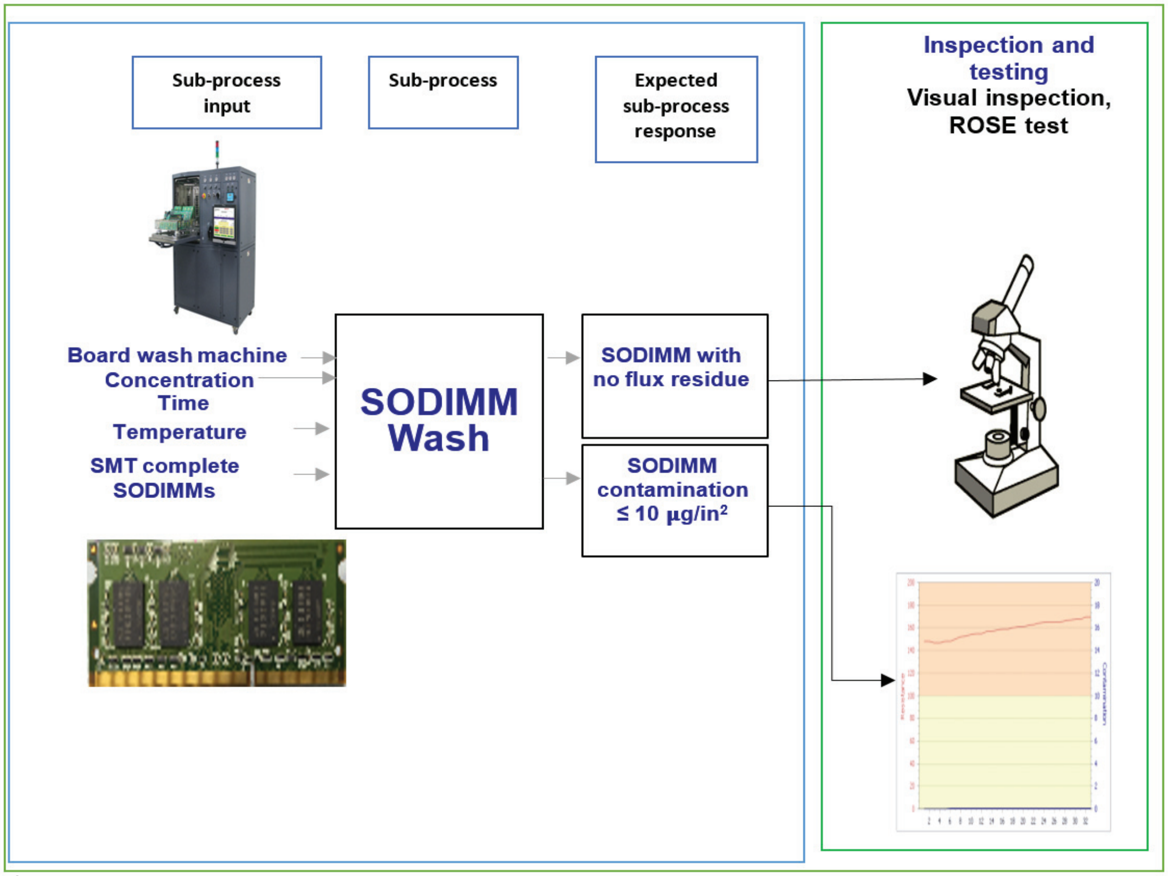


Figure 3.4: Board wash sub-process

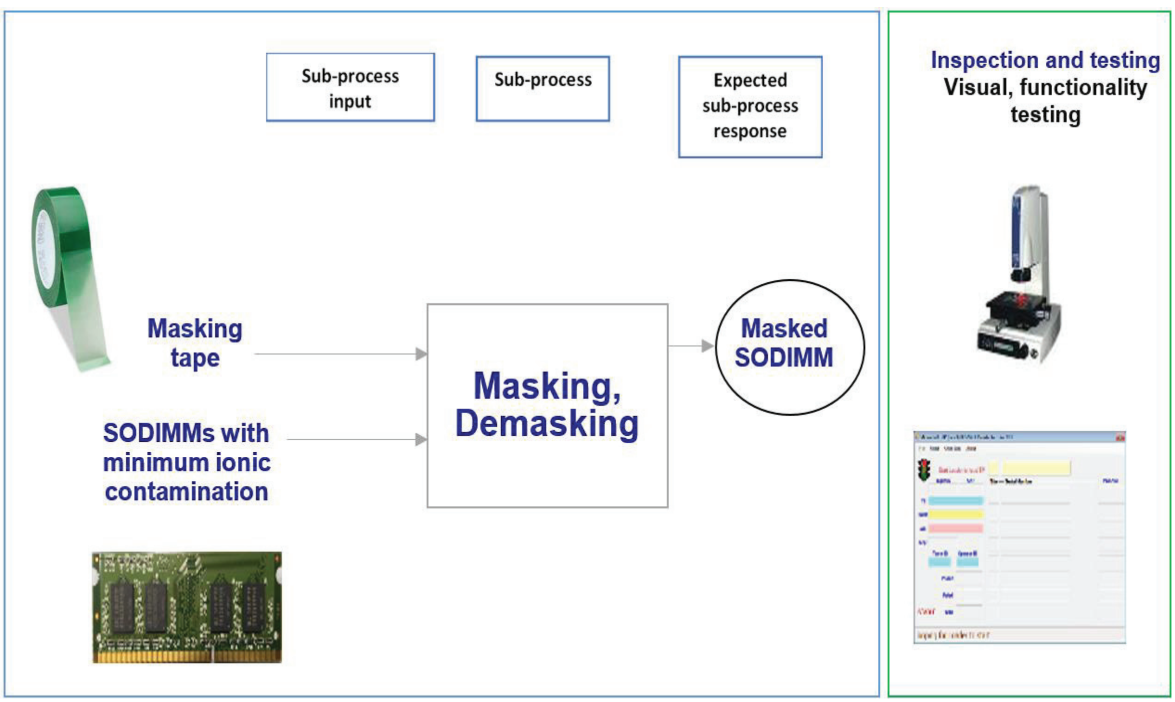


Figure 3.5: Masking-Demasking sub-process

3.2.2 Plasma cleaning experiment

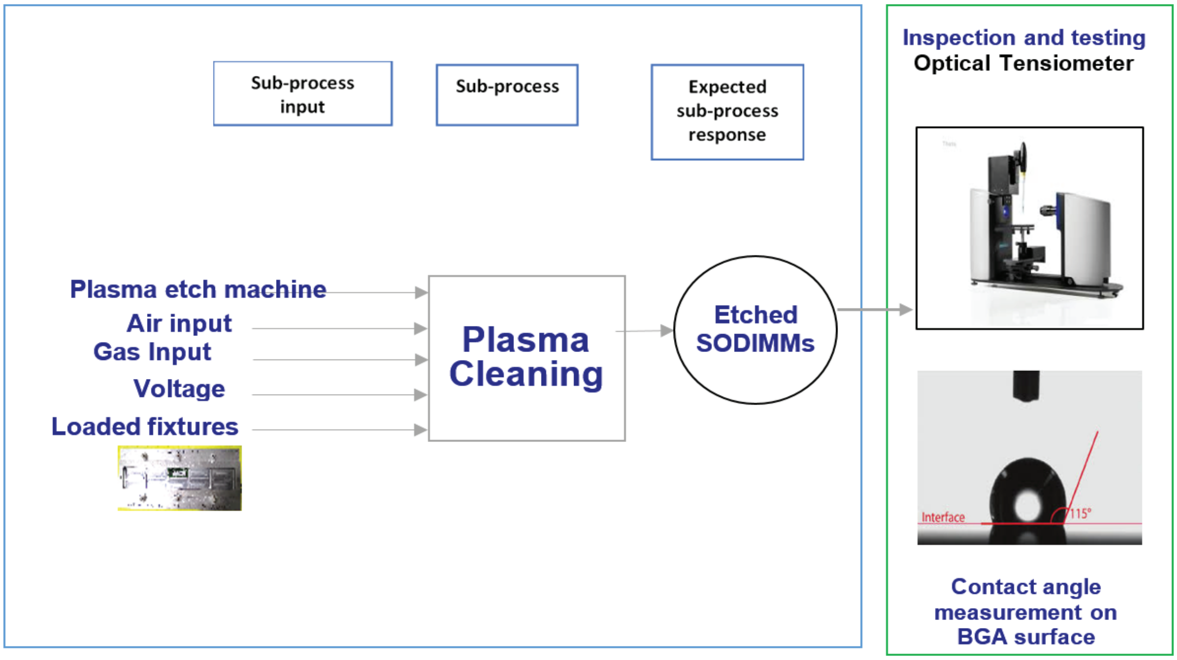


Figure 3.5: Plasma cleaning sub-process

The plasma cleaning experiment involves essential experimentation that helped to provide an understanding of the dynamics of a plasma clean process on PCBA and component surfaces in order to enhance wettability. Fifteen samples were divided into three lots, each containing five samples. Each lot was exposed to three different gas chemistries (oxygen, argon, oxygen, and argon in 1:4 ratio respectively) while all other variables were kept constant. From every lot, a sample was inspected using an optical tensiometer for wettability. The minimum contact angle was selected as the configuration of choice for the experiments to follow.

The next experiment with regards to plasma cleaning was conducted with a single aluminum mountable fixture with ten SODIMMs installed on the board, to verify the improvement of cleaning quality observed as a result of a customized fixture on the quality of clean. It was found that the contact angle measured on the BGA device was approximately four degrees with signs of immediate wetting on both sides of the SODIMM module. All input configurations for the plasma cleaning process remained the same as the previous implementations of the process. The Radio Frequency (RF) power in between the ground and power plates was set to 200W. The CDA (Clean Dry Air) pressure was set to 160 sccm (standard cubic centimeter per minute) while the oxygen input was set to 200 sccm. It was observed that a full load (fifty SODIMMs, five fixtures) requires additional power to achieve the same clean angle as an approximate contact angle of 10 degrees was observed for the same things. This issue, however, was resolved by increasing the RF power by 100 Watts which provided us with a sample contact angle of four degrees.

3.2.3 Conformal coating spray experiments

The conformal coating spray machine involves the input of material, an aluminum fixture with a capacity of 10 modules, atomizing air and the SODIMMs. The material volume, material concentration ratios, tank pressure, dispense height are controlled factors set at constant levels, 450 microns and 1:4 (1-part solvent and 4-parts polyurethane material). There were three different programs that tracked the trajectory and dispense rate. The idea was to increase or decrease the deposition by lowering or speeding-up the dispense speed, respectively. The first program used constant speeds for all three passes for the spray. The first step was to work on the edges adjacent to the gold fingers of the SODIMM modules by depositing a layer to cover the areas with potential fixture related shadowing. The next part of the program was to coat along the shorter edge of the fixtures across the area that requires coating with dwell times in between. This was done thrice. The atomizing pressure was kept greater than 3.5 psi. Taking a value higher than 3.5 resulted in rapid evaporation of volatiles from the coating material. Atomizing pressure less than 3.5 increases droplet size which results in an irregular pattern. The material storage tank pressure was locked in at about 40 psi.

The objective was to obtain a configuration that exhibits minimum defects before as well as after cure and damask. The defects include visual and functional issues directly related to conformal coating.

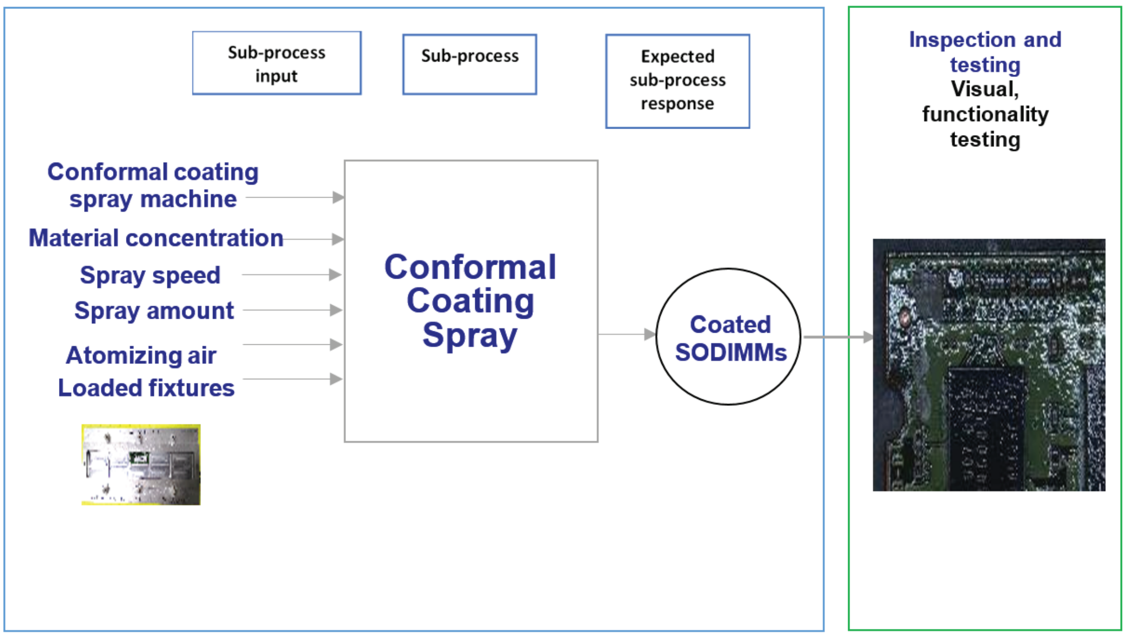


Figure 3.6: Conformal coating spray sub-process

3.2.4 Post-cure experiments

The lots obtained are set to cure at 190.4 F for 20 hours and are inspected post cure for any visual defects. The ten thickness measurements are taken on BGA surfaces to find the average for every sample from the lot. The SODIMMs are then demasked and inspected for symptoms of physical damage, peelability, edge cleanliness, conformal coating tape residue using visual inspection. All samples that pass visual inspection are sent for functionality testing and are reworked if required.

The configuration that performs consistently in all situations both before and after curing was selected as the optimal configuration specification throughout the process. Phase 2 qualification involves analysis and testing using the optimal settings for all subprocesses throughout the process cycle.

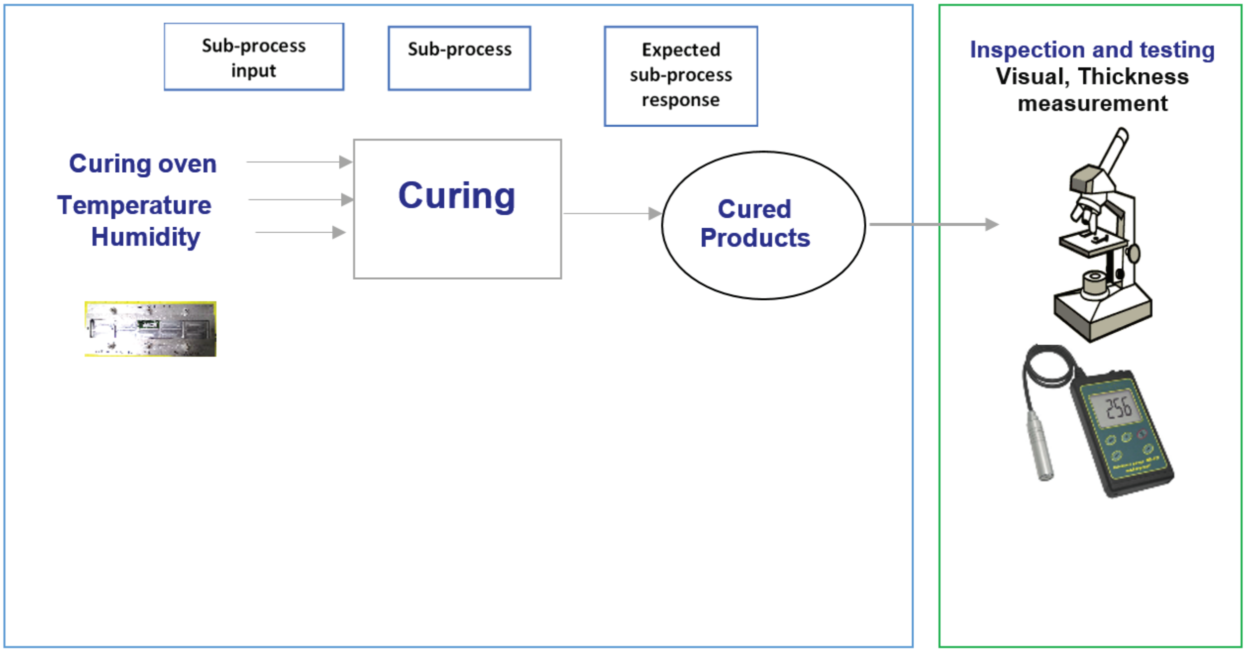


Figure 3.7: Curing sub-system

3.3 Phase 2: Process analysis

The process was regarded to be a single unit for the process analysis phase. The unique and common cause variation of outputs from one sub-process to another was assumed to be zero, and the sub-processes are considered to be configured optimally to achieve high overall process yield. The SODIMM samples are tested for all assembly and functionality level defects before starting with the process runs for the same. The sample size for this step involves five lots of 30 SODIMMs per lot. All lots are exposed to the same configurations and control mechanisms and are subjected to 100% inspection. At the end of the process, the overall process run data was collected for defects, yields by defect type and frequency.

3.4 Phase 3: Process improvement and control

Based on the data obtained in the previous phase, descriptive statistics and control charts and gage results are generated. The analysis includes hypothesis, capability and normality tests for the overall quality and control of the process. The inferences drawn are evaluated from different tools such as Process Failure Modes and Effects Analysis (PFMEA), Risk Assessment, Cause and Effect Analysis and Brainstorming to come up with updated targets acceptable limits, process indicators, risks, operating procedures and guidelines, control plans, maintenance plans and reaction plans. Phase three concludes with a process audit to assure, qualify and quantify process improvement against the former implementations of the process

3.5 Summary

This chapter aims at developing a robust process exhibiting increased process yields as compared to its former implementations. The focus was on individual process sub-systems as it was on the overall process behavior. This was hypothesized to provide optimal conditions and configurations of the expected process response through step-by-step quality improvement measures and the reduction of process variability along with an increase in yields. The next objective would be to implement procedures, control plans, reaction plans and maintenance plans based on assessed and observed risks and failure modes.

CHAPTER 4

Sub-process qualification experiment results

4.1 Introduction

Based on the experiments designed in the previous section, the observations for the process setup are discussed in this chapter. This chapter also encompasses the rationale behind deciding optimal input factors for every subsequent sub-process. Control lots are processed after the overall process qualification and results and inferences are discussed. Observed process indicators and issues are recorded and investigated for possible causes using supplementary analysis if required. Maintenance, containment, operation, quality control, safety and reaction plans are discussed based on the inferences drawn from the research.

4.2 Sub-process setup

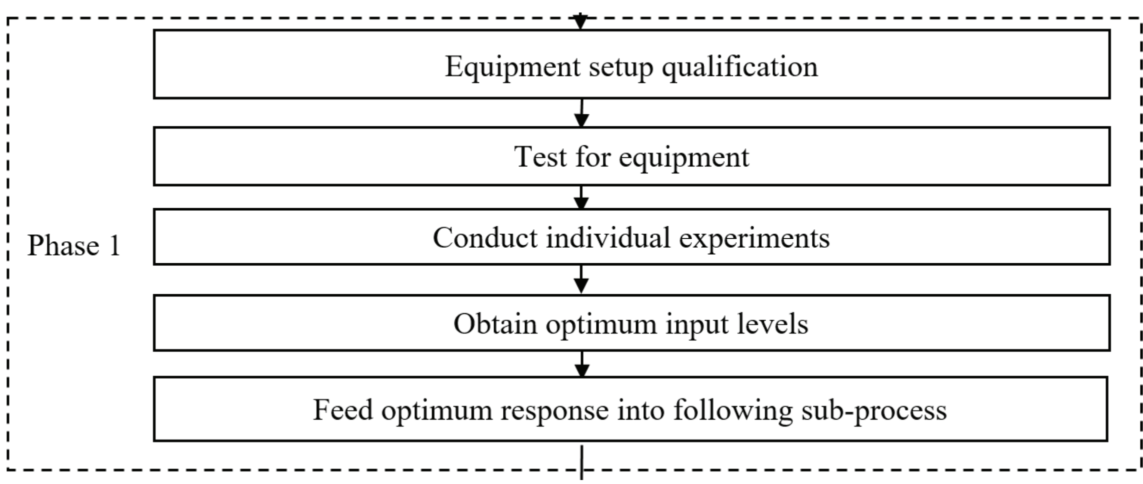


Figure 4.1: Phase 1: Sub-process setup

4.2.1 Equipment setup qualification

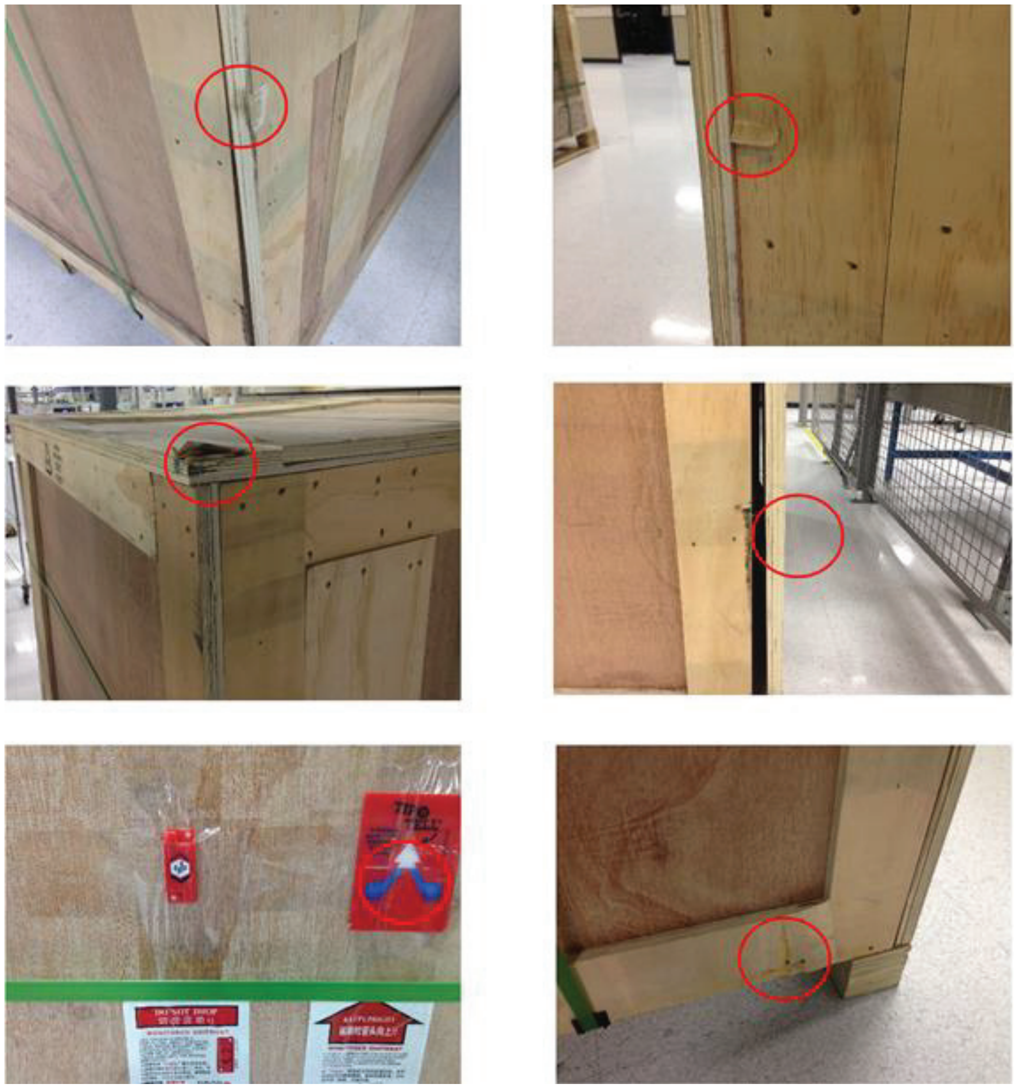


Figure 4.2: Damage on package flagged by Incoming quality assurance

As a novel process setup for on-site conformal coating, the process required the purchase of new or transferred equipment. All equipment except the despatch curing oven arrived before the setup of the project. The first step was to verify the integrity of the equipment before installation, testing, and operation. Incoming quality control verified the package dimensions, weight, pick-list, packing material, safety indicators, and markers. Any signs of damage or incongruity were required to be reported. This process highlighted damage on the package for the Nordson-March AP-1000 Plasma Cleaning System and issues were reported to the vendor immediately. The package contents, however, were found to be intact. All other equipment was received in proper conditions per new and transferred equipment checklists.

All equipment packages contained a complete set of calibration and maintenance tools, operating manuals and supporting documents. The power-up and down tests for all electronic equipment were successfully performed.

4.2.2 Board wash system experiment results

Table 4.1: Board wash experiment results

Batch	Wash Time (min)	Conc. (%)	Dry Time (min)	Wash Temp (°C)	Visual inspection samples					Ionograph results
					#1	#2	#3	#4	#5	
1	25	20	15	38	Fail	Pass	Pass	Fail	Pass	Pass
2	35	20	15	38	Pass	Pass	Pass	Pass	Pass	Pass
3	45	20	15	38	Pass	Pass	Pass	Fail	Pass	Pass
4	25	20	15	52	Pass	Pass	Pass	Pass	Pass	Pass
5	35	20	15	52	Pass	Pass	Pass	Pass	Pass	Pass
6	45	20	15	52	Pass	Pass	Pass	Pass	Pass	Pass
7	25	20	15	66	Pass	Pass	Pass	Pass	Pass	Pass
8	35	20	15	66	Pass	Pass	Pass	Pass	Pass	Pass
9	45	20	15	66	Pass	Pass	Pass	Pass	Pass	Pass

The ionograph test results were conducted for the settings mentioned above. The input factors considered for the sake of this experiment are wash time, concentration, wash temperature and dry time. For the sake of this experiment, per supplier recommendation as well as factor sensitivity, the concentrations for all the washes were kept the same. All modules were mounted into a fixture of Semitron ESD 225 material and loaded for variable wash times and wash temperatures (See Table 4.1).

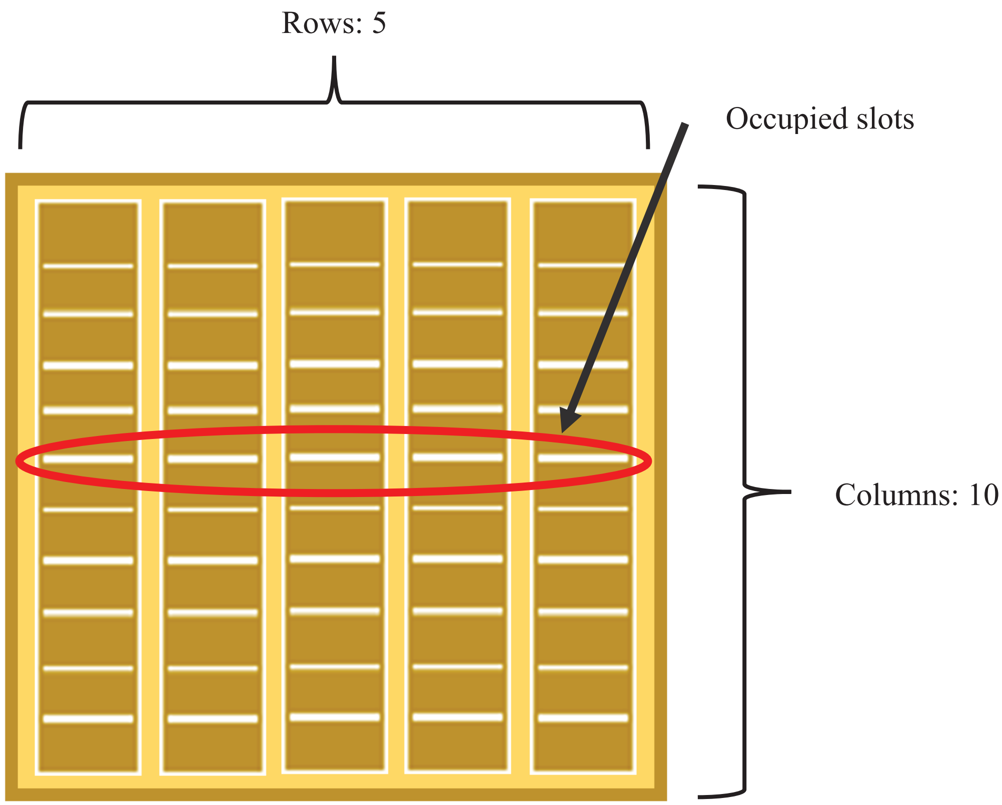


Figure 4.3: Semitron ESD board wash fixture for SODIMMs

It was observed on Batch 1, 3 location number 4, that samples failed for the visual test as the white residue was observed in minor amounts on the surface of the SODIMMs. It was also observed that the accumulation of flux residue occurred in specific locations at the lowest temperature. To understand the potential causes of this defect, a separate study for BGA device shadowing was conducted. It was hypothesized that due to the BGA devices, adjacent surfaces and components were shielded from exposure to the wash solution. The test was conducted on overall maximum, and minimum configurations of both input factors and it were found that the defects occurred in locations where wash temperature was low (i.e., 25 °C). Higher temperature caused complete flux shell removal. It was also concluded that the effect of BGA device shadowing is magnified depending on the operating temperature. This observation was made while conducting a visual inspection of the modules. It was found that sample 4 from batch 1 and sample 2 from batch 2 failed the test (See Table 4.2).

Table 4.2: BGA device shadowing experiment results

Batch	Wash Time (min)	Conc (%)	Dry Time (min)	Wash Temp (°C)	Visual inspection samples					Ionograph results
					#1	#2	#3	#4	#5	
1	25	20	15	38	Pass	Pass	Pass	Fail	Pass	Pass
2	45	20	15	38	Pass	Fail	Pass	Pass	Fail	Pass
3	25	20	15	66	Pass	Pass	Pass	Pass	Pass	Pass
4	45	20	15	66	Pass	Pass	Pass	Pass	Pass	Pass

After completion of the wash process and visual inspection, one module out of each batch was tested for ionic contamination using an Aqueous Zero-Ion ionograph. Before testing, the specific gravity of the IPA and distilled water solution was calibrated and set to 0.855g/L. The alcohol concentration in the mixture was 75. Solution regeneration caused the test flow to range from 1.340 GPM to 1.433 GPM (gallons per minute). The temperature variation was found to be 72F to 73F. The border area was fixed to 3.2 square inches for trials. The results for all sample modules were passed as in all cases, the level of contamination was found out to be less than ten µg/L. The optimum input for the next sub-process was decided to be a wash solution with 20% concentration, 35 minute wash time and a temperature of 52°C. At this configuration, all modules passed a visual inspection and ionograph tests. The maximum wash chamber temperature, as recommended by the vendor, was 66°C. It was observed that operating at this temperature setting caused high variability and overheating of equipment. The modules were blow-dried using an ionized air gun, baked and masked on gold fingers using 3M-851 masking adhesive tape.

4.2.3 Plasma cleaning experiment results

The first set of plasma cleaning experiments was conducted using SODIMM washed and tested SODIMM products placed in an aluminum basket as they are exposed to the respective gas chemistries. The bottom side of the module required elevation to allow the gas mixture to travel below the fixture and clean both surfaces.

The equipment RF cycle voltage was set to 300 W with the upper plate being the cathode while the lower is the ground. The gas input setting was set to 200 sccm (standard cubic centimeter per minute) and the RF exposure time was set to 5 minutes. The tests were conducted for three different batches each having their unique gas chemistries. The surface energy was measured for one module out of each batch using contact angles formed by dispensing distilled water over BGA surfaces on both sides of the module observed using an optical tensiometer. A higher value for contact angle was found to be an indicator of higher surface energy. To achieve maximum surface energy, a minimum contact angle was required. Regarding minimum contact angles, both argon and oxygen achieved minimum contact angles. However, a mixture of the two gases provided a higher contact angle indicating higher surface energy (See Table 4.3).

Table 4.3: Plasma cleaning experiments for BGA contact angle based on gas chemistries

Recipe	Top-side contact angle	Bottom-side contact angle
Pure O_2	**8°**	**8°**
O_2 − Ar (80%-20%)	**8°**	**12°**
Pure Ar	**8°**	**8°**

Another experiment conducted was to observe the cleaning efficiency of oxygen plasma on metalized interfaces that include surfaces such as copper, aluminum, and solder. In the case of experiments with aluminum, the observed contact angles before and after plasma

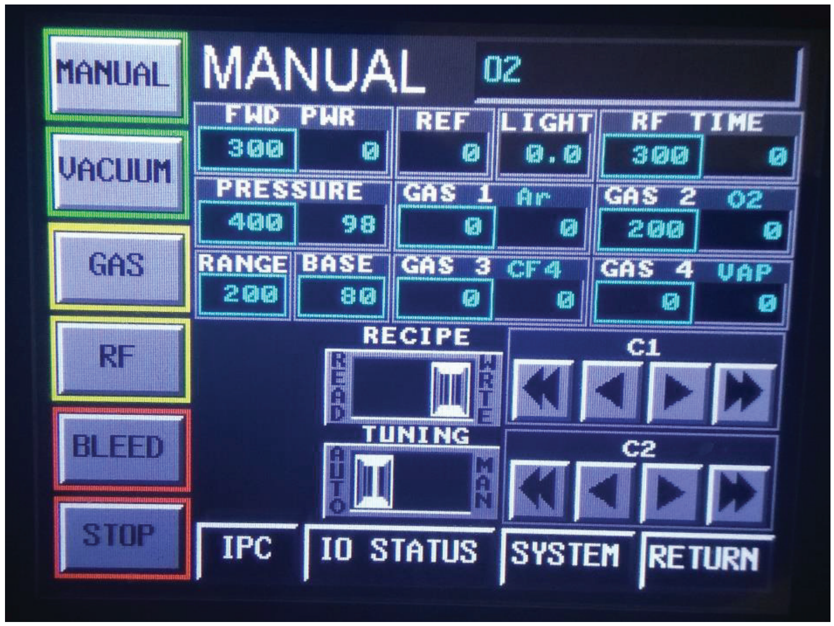


Figure 4.4: Plasma cleaning configuration for initial controlled lots

cleaning were found to be 63° and 60° respectively. This experiment indicated that interaction with oxygen plasma has a more significant impact on the surface energy levels for organics in comparison to inorganic interfaces.

Based on the relative immunity against the plasma cleaning process, a new fixture was developed for uniform exposure to plasma during the cleaning process. The fixture has the capability of holding ten modules at a time by the ends of masked gold fingers. The fixture revision was able to reduce the contact angle to 6° on both sides of the SODIMM for the same recipe for oxygen-based plasma cleaning which indicated improvement on the existing process.

4.2.4 Conformal coating spray experiment results

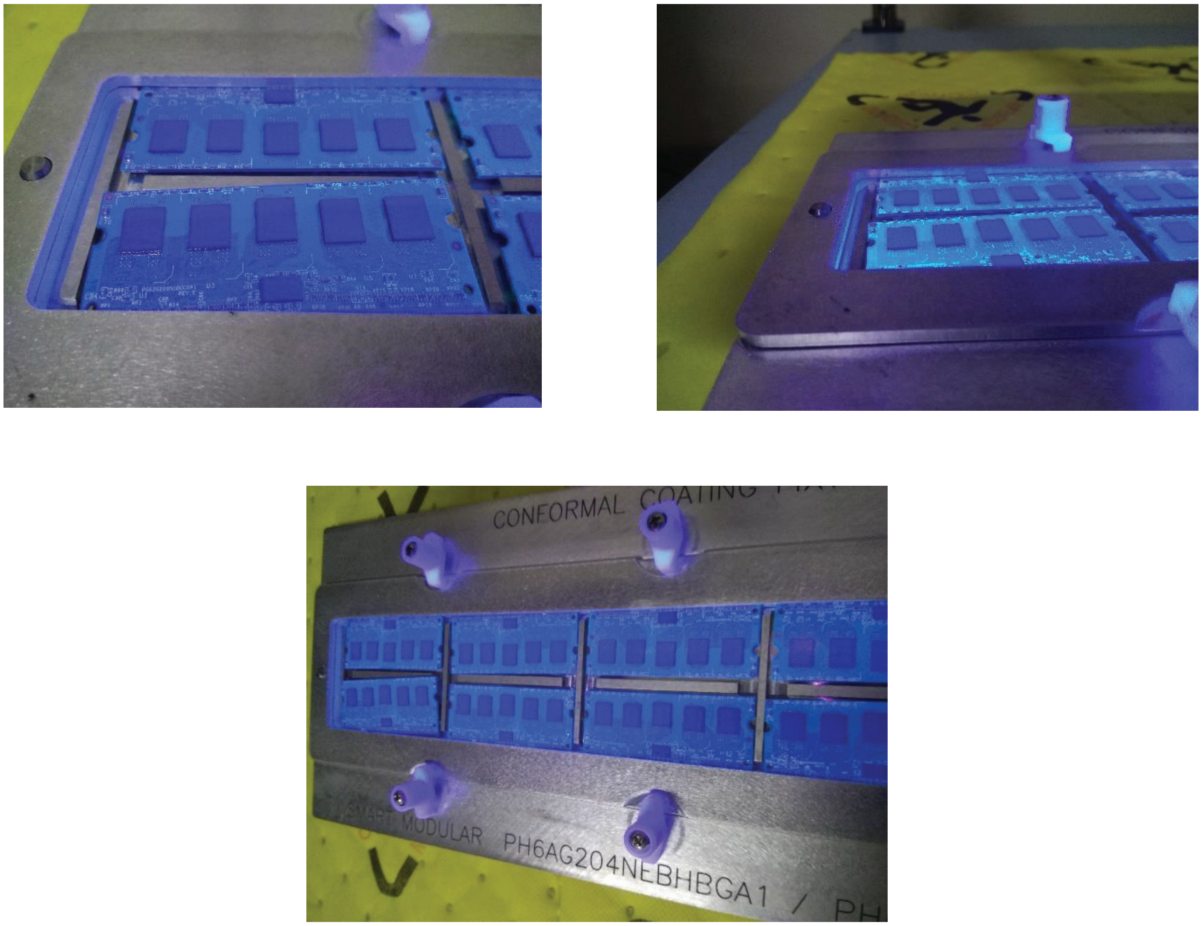


Figure 4.5: Wet spray results for Program 1, 2, and 3 respectively

The same aluminum fixtures with oxygen plasma cleaned and masked modules were then subjected to a spray application of a two-component polyurethane system. The mixing ratio of the two components was decided to be 20% thinner and 80% of Humiseal 1A33 polyurethane material which was kept constant throughout experimentation. The micrometer setting for the amount of volume dispensed per second was kept at 450 microns. The atomizing air pressure was kept at a constant of 3.5 PSI while the tank pressure was kept at a constant of 40 psi.

Once these fixed factors were locked, it was observed using preliminary experiments that multiple primer coats are required before a spray of thicker coats to improve spray deposition. This process is also known as a dry coat. However, higher speeds caused the material to dry up much faster than usual and hence it was understood that variable speeds were required for multiple coats.

It was also seen that due to the design of the existing fixture, there were observable shadowing effects adjacent to components and solder mask near gold fingers that prevented uniform deposition and wetting in the respective areas. Introducing cycles in the program that specifically focus on spraying the edges before filling in the area of the SODIMMs resolved the issue and no irregular wetting patterns were observed since their introduction. It was also observed that metallic-polyurethane interfaces wet out significantly less as compared to organic-polyurethane interfaces. Such areas include edges of passive components, exposed BGA pads and solder joints for resistor packages.

To improve on the existing issues observed as stated above, two configurations were tested:

1. Multiple thinner coats with an increased tack time in between spray passes
2. Suggested prolonged air tack instead of accelerated thermal tack

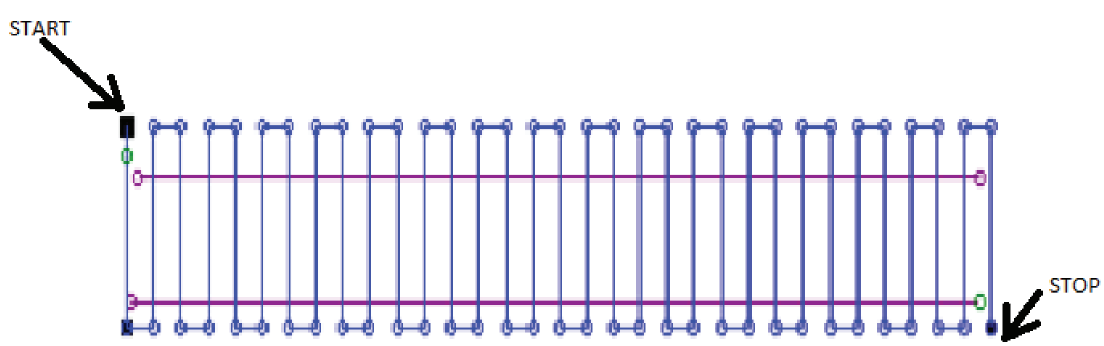


Figure 4.6: Spray valve trajectory for program 1

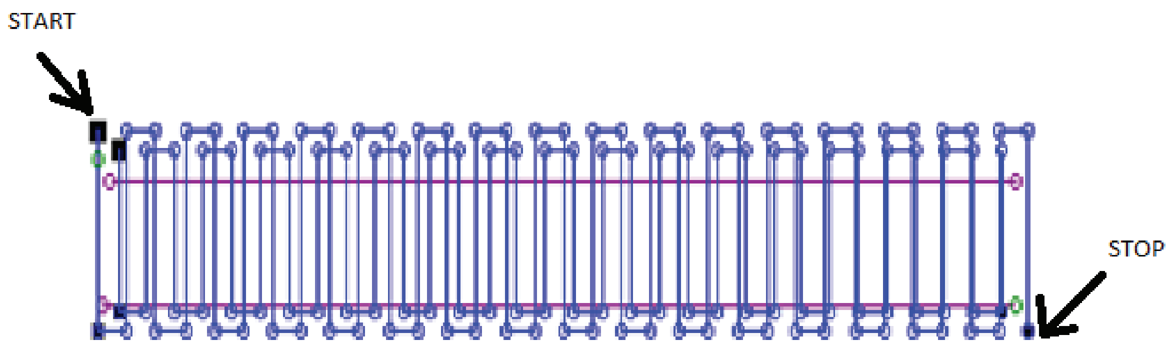


Figure 4.7: Spray valve trajectory for program 2

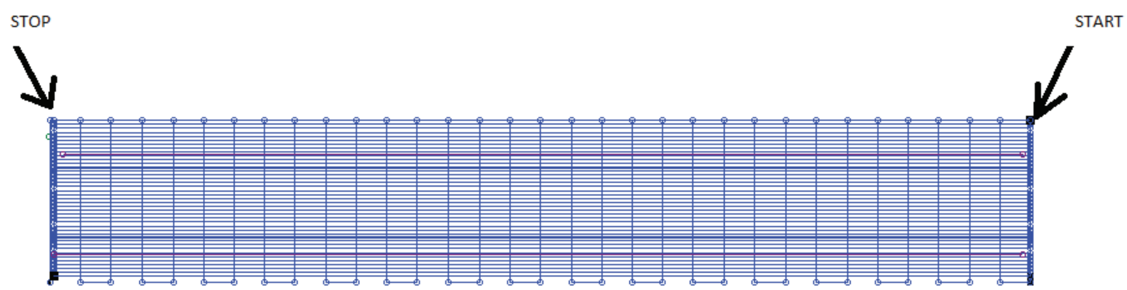


Figure 4.8: Spray valve trajectory for program 3

4.2.5 Post-cure experiment results

The post-cure experiments involved measurement of a 3 mm thick aluminum coupon induced inside the fixture and cured to measure for thickness and solved using this issue. Once the cure at 87° was complete, the coupon and the modules were inspected for the obtained thickness and visual quality of coating respectively. The results for program 1, 2 and 3 is as follows. Program 1 overshot the specifications for the coating while Program 2, 3 had lower average thicknesses.

Table 4.4: Average SODIMM coating thickness for Program 1

Program 1					
Reading	**Sample 1 (µm)**	**Sample 2 (µm)**	**Sample 3 (µm)**	**Sample 4 (µm)**	**Sample 5 (µm)**
1	124	120	128	108	158
2	168	150	128	112	116
3	222	114	122	118	126
4	154	144	134	92	116
5	152	128	138	108	150
6	200	200	198	142	192
7	238	198	216	132	212
8	226	214	178	290	226
9	244	212	188	176	178
10	194	176	202	180	222
Average (µm)	**192.2**	**165.6**	**163.2**	**145.8**	**169.6**
Average of Averages (µm)	**167.28**				

Table 4.5: Average SODIMM coating thickness for Program 2

Program 2					
Reading	**Sample 1 (µm)**	**Sample 2 (µm)**	**Sample 3 (µm)**	**Sample 4 (µm)**	**Sample 5 (µm)**
1	64	58	47	60	74
2	72	36	68	39	39
3	90	78	64	60	52
4	50	82	96	78	78
5	64	74	58	88	34
6	124	78	48	98	60
7	72	68	54	96	62
8	52	90	82	74	62
9	64	74	32	76	52
10	80	90	130	72	70
Average (µm)	**73.2**	**72.8**	**67.9**	**74.1**	**58.3**
Average of Averages (µm)	**69.26**				

Table 4.6: Average SODIMM coating thickness for Program 3

Program 3					
Reading	Sample 1 (µm)	Sample 2 (µm)	Sample 3 (µm)	Sample 4 (µm)	Sample 5 (µm)
1	98	100	52	45	43
2	48	36	86	54	49
3	66	76	70	54	118
4	52	84	88	114	82
5	120	116	62	45	49
6	58	112	82	108	92
7	88	72	52	90	62
8	86	98	126	54	44
9	104	64	52	68	104
10	114	68	82	56	70
Average (µm)	**83.4**	**82.6**	**75.2**	**68.8**	**71.3**
Average of Averages (µm)	**76.26**				

4.2.6 Sub-process analysis results

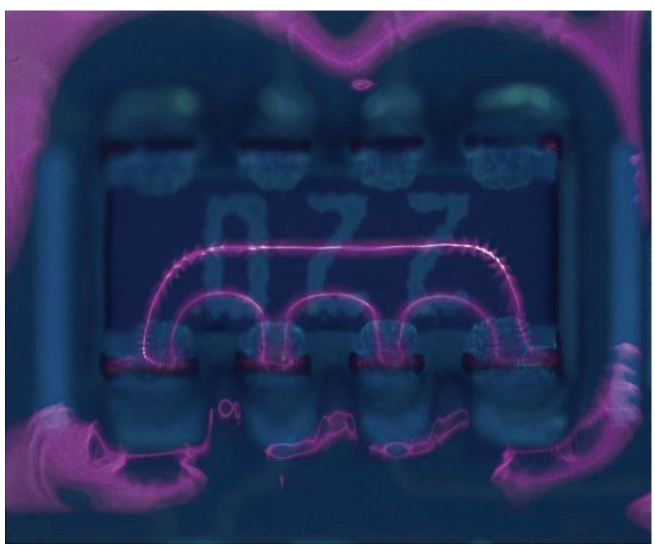


Figure 4.7: Exposed BGA pads (high, low magnification)

The observations of the spray and cure process show that the amount of material fluorescing at metalized areas such as the exposed BGA pads and metallization or edges of

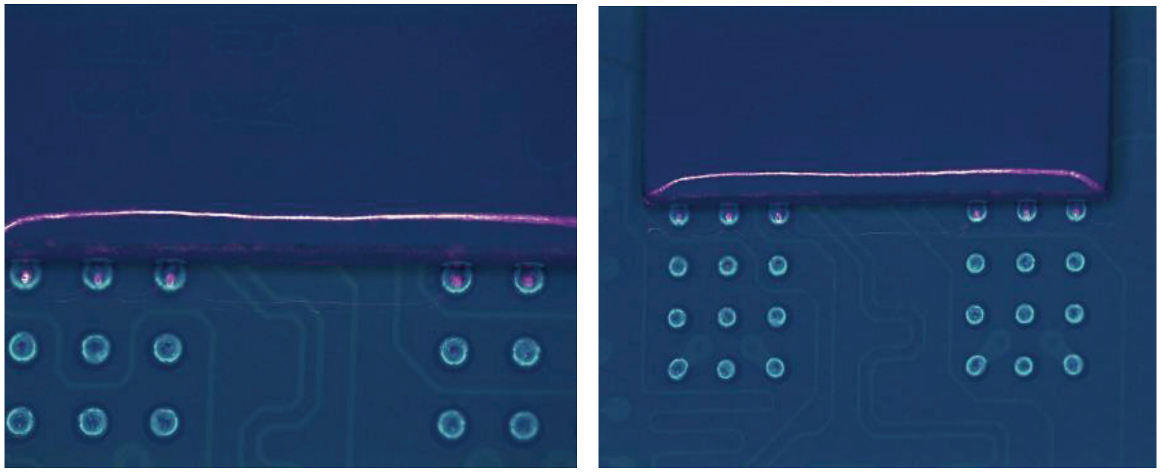


Figure 4.8: Resistor pack edges with thin coating

passives of resistor packs appeared to be inadequate. Upon further inspection, it was found that the issue appeared only as a result of reflection of light as shown in Figure 4.11, yet the coating at metalized edges was thin, and this issue required resolution before the control lot run. No other defects were observed in the process. The effect was confirmed by conducting open-short contact testing using an electronic multimeter. The result showed no electrical contact until the coating was scraped using a sharp object. Visual inspection of cured samples was conducted under UV light, and the results are shown below.

The module plasma clean duration was reduced to 2 minutes. By maximizing atomizing pressure to 5 psi and reducing the tank pressure to 30 psi, this issue was significantly minimized. A new program was created with a cross-linking pattern with each area fill containing seven independent passes. Every cross-directional trajectory pair of the area pattern was followed by a 15 second dwell time. At the end of all coats, an edge coat was applied for the peripheral shadowing of the components as a result of the fixture. Additionally, the fixtures were allowed to have a 60-minute air tack before cure. This configuration resolved the cosmetic quality issues observe.

4.3 Summary

This chapter describes the variety of inputs used to execute each step in the process. The optimal sub-process output converts to the input of the following sub-process. The wash experiments provide us with a suitable configuration to completely remove flux residue, the results for which can be monitored using the ionograph and microscope. The process reflects ionic contamination levels to be within specification limits for all configurations. The optimal configuration (20% concentration, 52°C, 35 minutes) was used as the optimum input for the plasma cleaning experiments. The plasma cleaning experiments involved experimentation with three gas chemistries at same RF power wattages and gas pressures. It was found that oxygen and argon performed equally well individually and obtained the same contact angles. However, when mixed, the mixture yields a contact angle of about 12°. As a result, the optimum gas chemistry input for the spray and post cure experiments is selected to be oxygen only.

The conformal coating spray experiments were inspected for three different valve trajectories at variable speeds. The tank pressure was fixed at 40 psi, the atomizing pressure was fixed at 3.5 psi, and the thinner to coating ratio was fixed at 4:1 respectively.

Upon inspection after cure, it was observed that Program 1 showed greater average thickness to be above specification limits while Programs 2, 3 were within the required range of 30-130 microns. A cosmetic issue was observed post cure that involved seemingly exposed edges for metalized regions of the coated SODIMM. Upon closer inspection, it was found that the issue was visual and that coating can be scraped off. Regardless, to resolve the issue, cross-linked pairs of trajectory passes were executed with 15-second dwell in-between passes that resolved the issue.

It was observed that to obtain a uniform and consistent coat; the passes need to be multidirectional, at variable speeds. Intermediate dwell is required, and an air tack before curing the modules is also crucial to allow the coating to set properly in harder to reach areas.

CHAPTER 5

Overall process qualification experiment results

5.1 Introduction

Based on the identified optimal parameters in the previous phase of the experimentation, controlled lots are processed using the optimal sub-process parameters identified in the previous chapter. A total of 75 SODIMM modules were sprayed, and the final yields were inspected for the visual defects. Ten samples were investigated for thickness, and the results are described in figure 5.2.

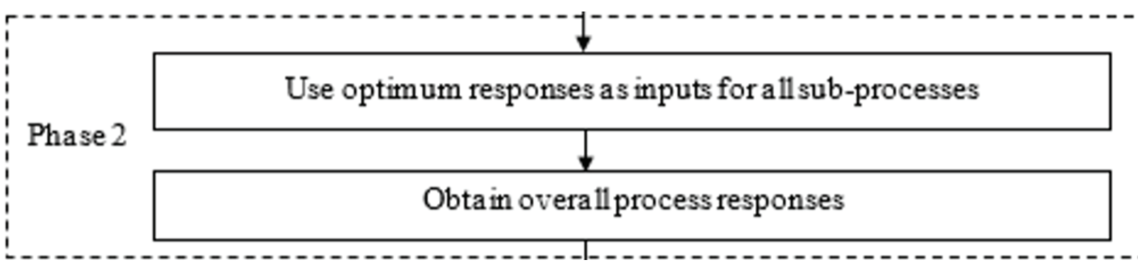


Figure 5.1: Phase 2: Overall process qualification

5.2 Coating thickness measurement

The experimental results show that the measured thickness for the samples is within the specification of 30-130 microns. The control limits were set to 50-110 microns. The results for the inspection of five samples from the lot is described further.

5.3 Defects and yields

The observations made in regards to the process efficiency in term of inspected yields:

1. There were no visual defects observed other than the presence of few instances of foreign particulates deposited on the surface of the coating
2. An increased one hour tack after the complete spray program allowed the coating to stabilize before curing. This additional step improved coverage on the edges for the conformal coating.
3. No instances of dewetting, chipping, fish-eyes and other common conformal coating defects were observed.
4. For complicated assemblies, fixture design may result in an issue, and hence it is important to consider design improvements in fixtures that would allow for improved clamping mechanisms.

Table 5.1: Thickness measurements of samples from a final controlled lot

Controlled lot thickness observations					
Reading	**Sample 1 (µm)**	**Sample 2 (µm)**	**Sample 3 (µm)**	**Sample 4 (µm)**	**Sample 5 (µm)**
1	47	88	78	72	50
2	86	124	118	114	96
3	66	45	98	82	130
4	72	86	94	128	128
5	82	43	58	84	86
6	100	45	60	104	100
7	64	78	86	88	96
8	78	52	62	116	106
9	40	56	104	124	74
10	98	72	52	124	108
Average (µm)	**73.3**	**68.9**	**81**	**103.6**	**97.4**
Average of Averages (µm)	**84.84**				

5. The aluminum coupon induced in the fixtures during the spray process provided us with a similar trend concerning the controlled lot. Hence, it proves to be a good option for first article inspection in production environments.

5.4 Conclusions

The results described throughout this chapter show that the new process setup for automated spray application provides higher yields and smaller defects. Is is also important, however, to understand the opportunities for improvement and the requirements of shorter lead times to provide increased throughput and reliability.

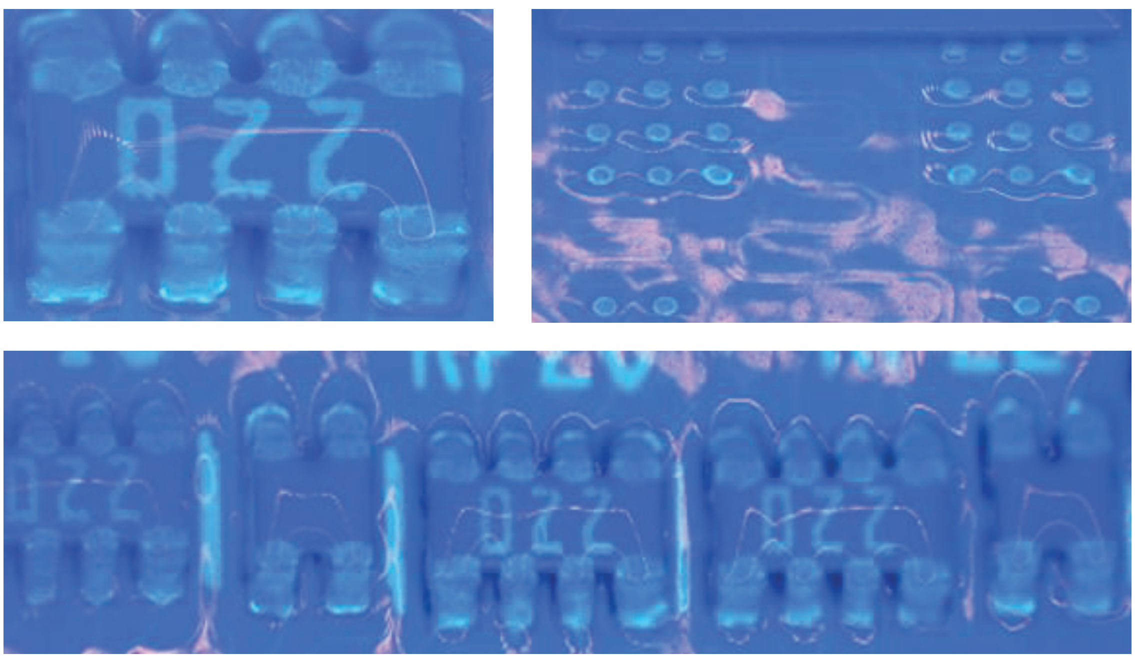


Figure 5.2: Images of samples from the controlled lot exhibiting improved coverage on BGA pads and resistor packs

5.5 Summary

This chapter described the results of overall process qualification. The optimal parameters obtained from analysis in the previous chapter were used as inputs to the sub-processes. The addition of multiple cross-linking passes and an extended air tack of 1 hour resolved the coverage issues be observed in the last phase of the sub-process experiments as seen in figure 5.2. As we can see, the coverage on unused BGA pads and resistor packs was significantly improved the process can meet required quality specifications per internal documents and IPC-CC-610. The time required for spraying ten modules is 1 hour and 20 minutes before they can be transferred to the oven and cured. This turns the final process in the cycle into a bottleneck that needs to be resolved to achieve high throughput. This leaves some opportunities for improvement which will be discussed in the next chapter.

CHAPTER 6

Scope for future work

6.1 Introduction

This chapter talks about the opportunities for improvement in the process based on findings observed in chapters 4 and 5. This chapter will aim to identify and discuss gaps in existing process based on issues observed. These opportunities for improvement have been identified using tools FMEA.

6.2 Opportunities for process improvement

1. The spray process can produce high degrees of thickness variations from one face to the fixture to the other. An adaptive program, or a set of programs, are required to reduce the variation.
2. Multiple programs may be required for spray coats depending on the complexity and density of the product. Greater diversity in movements, pressure, and speeds may increase programming time but will result in the reduction of spray time and air tack time which in turn may lead to increase throughput
3. Premixed two-phase systems supplied from the vendor may be considered for future studies in order to avoid variability in concentration ratios and downtime required to mix a fresh batch of conformal coating and measure viscosities before spray.

4. Preventive maintenance and periodic purge durations need to be studied to avoid deposition of conformal coating material on the insides of the atomizing spray valve and the input hose attached to the same. This is to avoid any effects of conformal coating deposition on the insides of the spray valve which can lead to an increase in thickness of conformal coating during multiple spray cycles in a production build.
5. Atomizing pressure exhibits variability and tolerances need to be decided on an allowed variation on the optimal value or mechanisms to lock in the required value
6. Wet film thickness gauges may be considered for a correlation of wet thickness with a thickness measured after curing the modules can be studied to use post cure inspection time
7. Binding effects of coupling agents on solder interfaces with conformal coating can be experimented with to improve wetting of polyurethane based conformal coatings on metalized surfaces

6.3 Safety and environmental concerns

A two-phase conformal coating system may contain toxic substances such as toluene which need to be disposed of cautiously. It was necessary to install extraction units and HEPA air filters to mitigate this issue. It is essential to make the process completely self-sufficient to establish minimum contact with such substances. In the case of emergencies, a control or reaction plan would be required to help with this issue based on the findings of the FMEA.

In the interim, operators will be trained to use proper safety gear to protect them from exposure to such chemicals. It is suggested that programs should be created offline to aid this issue further. The mixing and Zahn cup tests are to be conducted.

6.4 Documentation of procedures, control plans, and reaction plans

The operators in-charge of the process will be trained on the final documented process. Control plans would include raising an alert when the dry film thickness is below 30 microns or above 130 microns. Upon the study of the correlation between the wet film and dry film thickness, the wet film thickness observation on the first article inspection can be utilized to provide a quicker response if a process malfunction is observed.

The control plan for the process output, for now, includes SPC capability on the contactless dry film thickness device (Deflesko Positector 2000). Other conditions for establishing process control are as follows:

1. Periodic concentration check for wash solution on the defluxing unit to 20%
2. Periodic specific gravity calibration on the ionograph to 0.855 SG
3. The periodic purge of the spray system
4. Periodic concentration ratio and viscosity check
5. Periodic preventive maintenance for the following:
    a. Ionic calibration and cleaning for Ionograph
    b. Plasma chamber cleaning
    c. Board wash machine inspection and cleaning
    d. Conformal coating spray valve oiling and cleaning and inspection

6. FMEA meetings will be held on a quarterly basis unless significant issues/process revisions occur

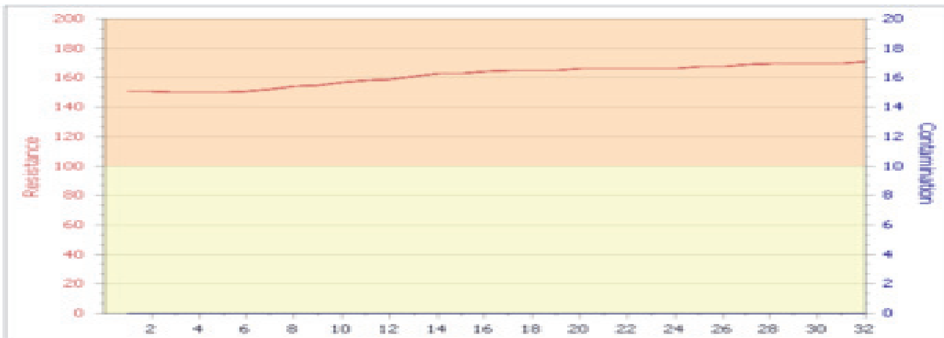
6.5 Summary

Based on the observations in the chapter and the document it can be established that the process is successfully set-up and can be used for a conformal coating process. There are however specific considerations that require to be addressed when it comes to safety and repeatability that were identified during the analysis and setup. The process can be safely released to production after verification and implementation of suggested process improvements, release documents and resolved safety concerns.

Appendix

Ionograph test reports

Test 1: 25 min 100F - Passed

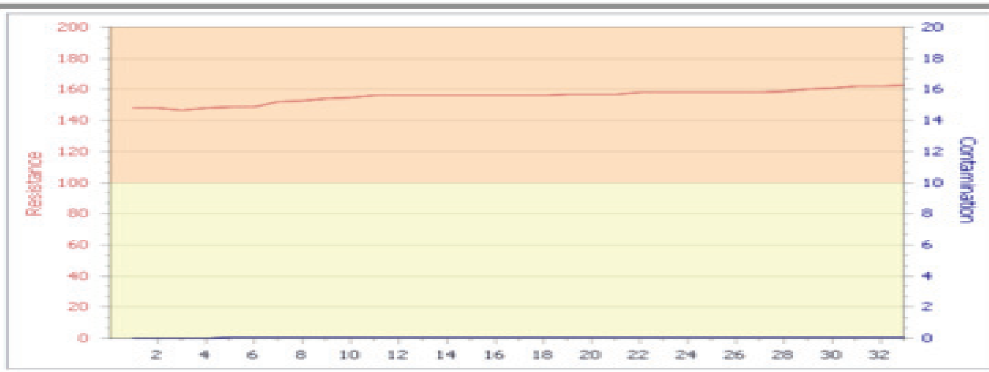


Alcohol concentration: 75%
Flow: 1.340 GPM
Temperature: 73 F
Board area: 3.2 in^2
PF limit: 10 µg/L

Test 2: 35 min 100F- Passed

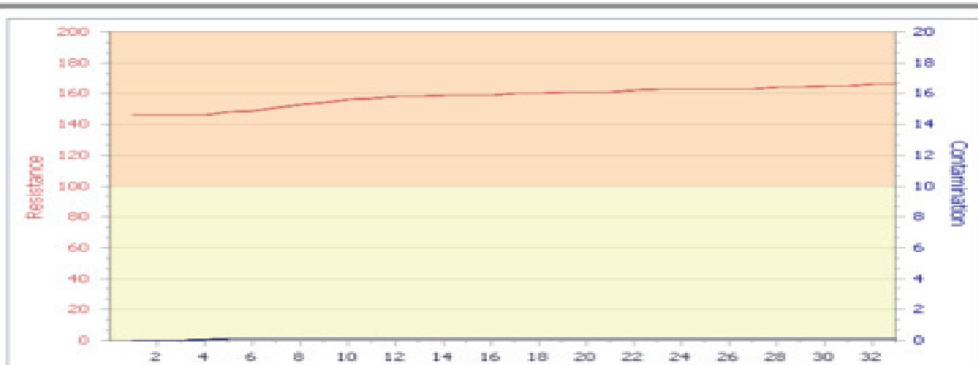
Alcohol concentration: 75%
Flow: 1.353 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 µg/L

Test 3: 45 min 100F- Passed



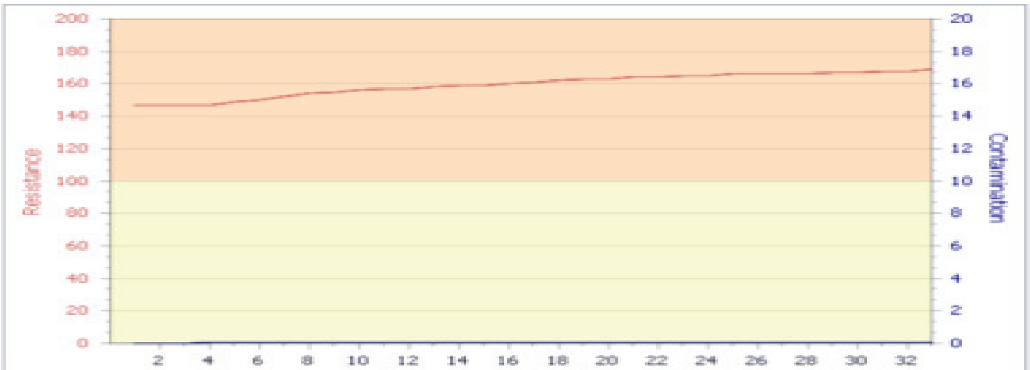
Alcohol concentration: 75%
Flow: 1.371 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 µg/L

Test 1: 25 min 125F- Passed



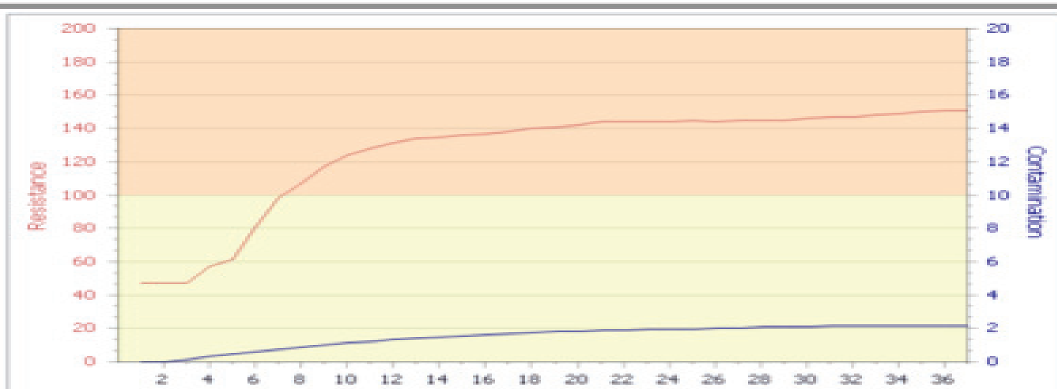
Alcohol concentration: 75%
Flow: 1.384 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 µg/L

Test 2: 35 min 125F - Passed



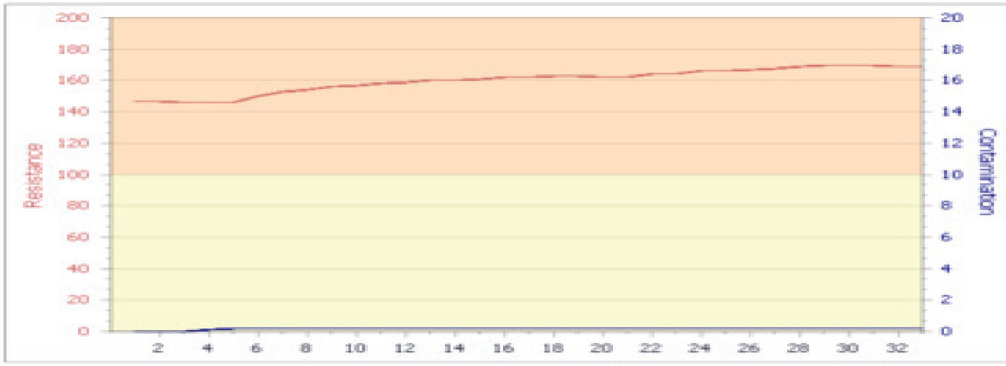
Alcohol concentration: 75%
Flow: 1.433 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 μg/L

Test 3: 45 min 125F - Passed



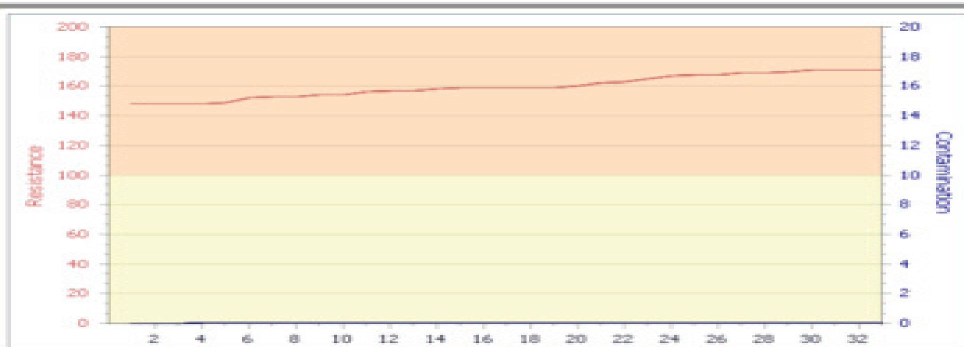
Alcohol concentration: 75%
Flow: 1.309 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 μg/L

Test 1: 25 min 150F - Passed

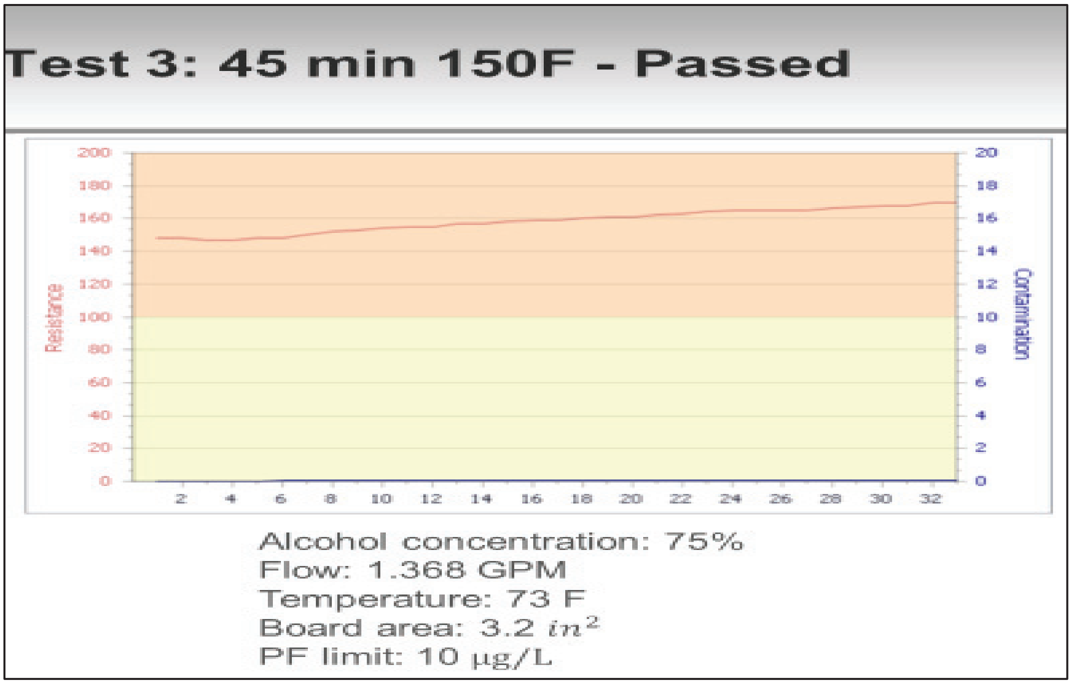


Alcohol concentration: 75%
Flow: 1.384 GPM
Temperature: 72 F
Board area: 3.2 in^2
PF limit: 10 μg/L

Test 2: 35 min 150F - Passed



Alcohol concentration: 75%
Flow: 1.384 GPM
Temperature: 73 F
Board area: 3.2 in^2
PF limit: 10 μg/L


Test 3: 45 min 150F - Passed
Resistance
Contamination
200
180
160
140
120
100
80
60
40
20
0
20
18
16
14
12
10
8
6
4
2
0
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
Alcohol concentration: 75%
Flow: 1.368 GPM
Temperature: 73 F
Board area: 3.2 in^2
PF limit: 10 μg/L

Spray program 1

CommandPositionOnOffSpeedOther
mm
DOE case 1
atm = 3.5 psi, tnk = 40 psi, 450 micron
MOVE138.33,12.18,-1.8XY then Z
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.00075.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.00075.000
131.63,17.28,-1.78
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.00075.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.00075.000
131.63,17.28,-1.78
MOVE138.33,12.18,-1.8XY then Z
AREA147.145,12.180,-1.800(1) W .03D 3.00075.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 15
AREA147.145,12.180,-1.800(1) W .03D 3.00050.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 60
AREA147.145,12.180,-1.800(1) W .03D 3.00050.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 60
AREA147.145,12.180,-1.800(1) W .03D 3.00050.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
MOVE138.33,12.18,-1.8XY then Z

Spray program 2

CommandPositionOnOffSpeedOther
mm
DOE case 2

Tnk 40 psi, atm 3.5 psi, mmeter 45
MOVE138.33,12.18,-1.8XY then Z
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000100.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000100.000
131.63,17.28,-1.78
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000100.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000100.000
131.63,17.28,-1.78
MOVE138.33,12.18,-1.8XY then Z
AREA147.145,12.180,-1.800(1) W .03D 3.000100.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 15
AREA147.145,12.180,-1.800(1) W .03D 3.00080.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 60
AREA147.145,12.180,-1.800(1) W .03D 3.00070.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
MOVE138.33,12.18,1.2XY then Z

Spray program 3

CommandPositionOnOffSpeedOther
mm
DOE case 3
All external settings are the same, seco
MOVE138.33,12.18,-1.8XY then Z
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000100.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000100.000

131.63,17.28,-1.78
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000100.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000100.000
131.63,17.28,-1.78
MOVE138.33,12.18,-1.8XY then Z
AREA147.145,12.180,-1.800(1) W .03D 3.000100.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
DWELLW 15
AREA140.640,20.405,1.250(1) W 0.3W 0.380.00012.000,0
91.760,20.585,1.250
91.760,380.835,1.250
DWELLW 60
AREA147.145,12.180,-1.800(1) W .03D 3.00070.00012.000,0
84.995,12.180,-1.800
84.995,391.995,-1.800
MOVE138.33,12.18,1.2XY then Z

Spray program 4

CommandPositionOnOffSpeedOther
mm
PROGRAM9
PROGRAM DESCRIPTION9
COMMENT
MOVE138.33,12.18,-1.8XY then Z
AREA144.355,389.425,-2.100(1) W .03D 3.000250.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.00250.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.000250.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.00250.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795

```
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.000250.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.00250.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.000180.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.00180.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.000180.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.00180.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.00040.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
AREA84.920,13.780,-1.795(1) W .03D 3.0040.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
DWELLW 15
AREA144.355,389.425,-2.100(1) W .03D 3.00040.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000150.000
93.33,386.565,-1.78
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000150.000
131.63,17.28,-1.78
DWELLW 120
MOVE93.33,13.78,-1.795XY then Z
LINE(2D)93.33,13.77,-1.78(1) W .08D 5.000150.000
93.33,386.565,-1.78
MOVE93.33,386.565,-1.78XY then Z
MOVE131.63,386.565,-1.78XY then Z
LINE(2D)131.63,386.565,-1.78(1) W .08D 5.000150.000
131.63,17.28,-1.78
```

```
DWELLW 120
AREA144.355,389.425,-2.100(1) W .03D 3.00040.00012.000,0
82.540,389.425,-2.100
82.540,12.065,-2.100
DWELLW 15
AREA84.920,13.780,-1.795(1) W .03D 3.0020.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
AREA84.920,13.780,-1.795(1) W .03D 3.0020.0003.0,0
84.920,389.300,-1.795
144.325,389.300,-1.795
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