Final Project Report

Reduction in Field Failures Due To Optics Fall-Off - A Design of Experiments Approach

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Abstract

A Bay Area company that specializes in customized solutions for a wide range of applications is faced with a significant challenge in response to an urgent problem with optical glue bonding. Customers have reported numerous failures in models X and Y over the past year, with specific cases involving optics mounted on the base plate that either detached or showed instability. This puts the company's reputation at risk in addition to interfering with their clients' shipment and production schedules. By starting a thorough root cause analysis and creating a corrective and preventive action plan, the company is proactively addressing these issues. The objective is to minimize the impact on customer operations and, by extension, their end customers, by reducing field failures by a predetermined percentage. Failure Mode and Effects Analysis (FMEA) is used in a risk assessment to accomplish this, with an emphasis on the adhesive's weak bond with the metal plate. Technicians have noticed that although the glue bonding on the optics is still strong, it is not as strong when it comes to the metal plate. We are methodically looking into potential causes, such as contamination on the metal plate, problems with the glue, or environmental factors influencing the performance of the product.

In the context of a design of experiments, the company is using fractional factorial designs to improve comprehension of these bonding difficulties. Temperature, humidity, and exposure duration are among the variables that are applied to the experimental setup. Due to resource limitations, the company chooses to collect data on four combinations that are highly recommended by professional engineers, even though a full factorial design would require eight combinations. With six lenses per setup, a total of 24 data points is obtained for analysis later on. A force test is performed after the adhesive has been exposed to various

environmental conditions in order to determine its bonding strength. Next, using specialized software like Minitab, the collected data is statistically analyzed using Design of Experiments and Analysis of Variance (ANOVA). In order to provide a solid solution to the problems associated with optical glue bonding and to promote greater customer satisfaction and trust, the objective is to determine the ideal ambient conditions that yield the strongest bonding strength.

Introduction

In response to a critical challenge faced by a Bay Area company specializing in tailored solutions, this project is dedicated to addressing pressing issues pertaining to optical glue bonding, specifically within models X and Y. Over the past year, a substantial number of failures have been reported by clients, specifically concerning the detachment or instability of optics mounted on the base plate. These incidents not only pose a threat to the company's reputation but also disrupt client shipments and production schedules. To proactively confront these challenges, the company has undertaken a comprehensive root cause analysis and implemented a corrective and preventive action plan. The primary objective is to minimize the impact on customer operations and, consequently, their end customers, by reducing field failures by a predetermined percentage.

In systematically investigating the challenges associated with optical glue bonding, the company has employed a root cause analysis approach with a distinct emphasis on the adhesive's weakened bond with the metal plate. Technicians have noted that, while the glue bonding on the optics remains robust, it demonstrates reduced strength when adhering to the metal plate. Potential causes, including contamination on the metal plate, glue-related issues, or environmental factors influencing product performance, are being methodically explored.

Leveraging the Design of Experiments (DoE) approach, the company is executing fractional factorial designs to gain a profound understanding of bonding difficulties. Critical variables, such as temperature, humidity, and exposure duration, are systematically applied in the experimental setup to pinpoint ideal ambient conditions for optimal bonding strength. Through the analysis of data collected from force tests conducted after exposing the adhesive to various environmental conditions, the project aims to utilize specialized software like Minitab, employing Design of Experiments and Analysis of Variance (ANOVA), to derive statistically sound solutions that enhance optical glue bonding, ensuring heightened customer satisfaction and trust.

Literature Review and Significance of the problem

Literature Review on Cleaner production of iron-coated quartz sand composites for efficient phosphorus adsorption in sanitary wastewater: A design of experiments (DoE) approach

In recent years, the synthesis of nanomaterials, particularly composites, has faced growing scrutiny due to environmental concerns and the need for sustainable practices. This literature review explores the significance of a project dedicated to the development and optimization of a synthesis process for Ion-Imprinted Chitosan-Quercetin-Supported Iron Oxide (ICQS) composites. The project places a strong emphasis on integrating green chemistry principles and sustainability metrics into the materials synthesis landscape.

The synthesis of nanomaterials, especially composites, presents unique challenges in sustainability assessment. Despite the heightened interest in green chemistry, there remains a scarcity of studies incorporating sustainability metrics into composite and nanomaterial syntheses. This literature review identifies a critical gap in the application of green metrics to nanomaterials, particularly the lack of systematic evaluations using biologically based methods.

Addressing this gap, the project introduces the Green Star (GS) methodology as an evaluative tool rooted in green chemistry principles. The GS methodology, encompassing 10 out of 12 green chemistry principles, provides a comprehensive framework for assessing the environmental friendliness of the ICQS composite synthesis. The Green Star Area Index (GSAI), a quantitative metric derived from GS, becomes a focal point, highlighting the environmentally friendly nature of the optimized synthesis method. The emphasis on waste reduction and increased atomic economy positions the project at the forefront of sustainable materials synthesis.

Energy efficiency (EE) emerges as a pivotal factor in the project, with the final optimized synthesis method, conducted at room temperature in a suspension format, showcasing substantial advantages. The emphasis on room temperature synthesis not only reduces energy consumption but also contributes to the economic viability of the resulting ICQS composite, reinforcing the project's alignment with green chemistry principles.

The literature review underscores the broader significance of the project's focus on developing a sustainable synthesis process for ICQS composites. The identified problem revolves around the limited application of sustainability metrics in the synthesis of composites and nanomaterials. Despite the growing interest in green chemistry, few studies systematically apply sustainability metrics to evaluate the environmental impact of composite synthesis.

The review articulates the urgent need for a systematic and holistic approach to assess the environmental friendliness of synthesis processes, especially for emerging materials like ICQS composites. The scarcity of comprehensive studies on sustainability metrics for nanomaterials, coupled with the challenges of characterizing and evaluating toxicity and environmental impacts, underscores the project's importance in addressing this critical gap.

By introducing the GS methodology and GSAI, the project makes a substantial contribution to the field. The robust framework provided for evaluating the sustainability of ICQS composite synthesis aligns with the broader goal of promoting cleaner and more sustainable practices in materials synthesis. In doing so, the project responds to the pressing need for environmentally friendly alternatives in the synthesis of nanomaterials.

In terms of process improvement, the project adopts a systematic approach through the application of Design of Experiments (DoE) techniques. Plackett-Burman and Central Composite experimental designs allow for the optimization of nine process parameters with a minimal number of experiments. The resulting ICQS composites exhibit enhanced phosphorus adsorption capacity and total iron amount, showcasing the efficiency and sustainability of the synthesized adsorbent material.

The project's applied methodology, driven by green chemistry principles and sustainability metrics, underscores its commitment to environmental responsibility. The systematic use of DoE techniques for process improvement and the development of a zero-waste synthesis process further enhances its significance. The synthesis of ICQS composites, supported by a robust framework and adherence to green principles, emerges as a promising avenue for sustainable materials synthesis practices. (Nunes, et al., 2023).

Table 1 Classification of Studied Research Papers Focused on Efficient Phosphorus Adsorption: Iron-Coated Quartz

Aspect	Details
Applied Methodology for Process Improvement	Design of Experiments (DoE) techniques, including Plackett-Burman and Central Composite experimental designs.
Techniques	Integration of green chemistry principles, Green Star (GS) methodology, and Green Star Area Index (GSAI) for evaluation.
Statistical Data Analytics	DoE techniques for optimization of nine process parameters.
Mathematical Optimization	Optimization of process parameters using DoE techniques.
Lean Techniques and Methodologies	Emphasis on waste reduction and increased atomic economy.
Mechanical Experiments	Synthesis of Ion-Imprinted Chitosan-Quercetin-Supported Iron Oxide (ICQS) composites.
Major Contribution Material	Development and optimization of a sustainable synthesis process for ICQS composites.
Software	Minitab
Major Contribution	Introduction of Green Star (GS) methodology and Green Star Area Index (GSAI) for comprehensive sustainability assessment.
Major Findings	Enhanced phosphorus adsorption capacity and total iron amount in the resulting ICQS composites.

Table 1-1 Classification of Studied Research Papers Focused on Efficient Phosphorus Adsorption: Iron-Coated Quartz

Authors	**Applied Methodology for Process Improvement**	**Material and Major Findings**
Abilio et al. (2021)	Adsorption properties of in natura and magnetic nanomodified sugarcane bagasse	Hexavalent chromium removal from water
Ahn et al. (2012)	Coprecipitation method for formation pathways of magnetite nanoparticles	Synthesis and formation pathways of magnetite nanoparticles
Baskar et al. (2022)	Review on recovery, regeneration, and sustainable management of spent adsorbents	Overview of strategies for managing spent adsorbents
Constable (2018)	Green chemistry metrics	Overview of green chemistry metrics
Cordell et al. (2021)	Commentary on phosphorus and circular food systems	Discussion on responsibility for phosphorus in circular systems
Diakonov et al. (1999)	Experimental study and modelling of iron (III) solubility and speciation	Study on iron (III) solubility and speciation in aqueous solutions
Dotro et al. (2017)	Biological Wastewater Treatment Series	Overview of biological wastewater treatment
García-Quintero and Palencia	Critical analysis of environmental sustainability metrics applied to green synthesis	Evaluation of environmental sustainability metrics in nanotechnology

(2021)		
Gorbounov et al. (2022)	Technical review on optimization of carbonaceous adsorbents and adsorption processes	Review on optimization strategies for adsorbents and processes
Hei et al. (2022)	Redox environment inducing strategy for enhancing biological phosphorus removal	Strategy for improving biological phosphorus removal
José et al. (2019)	Synthesis and application of yeast-based magnetic bio nanocomposite for Cu (II) removal	Removal of Cu (II) from water using magnetic bio nanocomposite
Kasemiire et al. (2021)	Design of experiments and design space approaches in pharmaceutical bioprocess optimization	Application of DoE and design space in bioprocess optimization
Klencsár et al. (2019)	Effect of preparation conditions on magnetite nanoparticles obtained via chemical co-precipitation	Study on the preparation conditions of magnetite nanoparticles
Lee et al. (2022)	Review of Design of Experiment (DOE) for water and wastewater treatment	Overview of key concepts and methodologies in DOE
Liao et al. (2021)	Adsorption of phosphorus oxyanions at the FeOOH (goethite)/Water interface	Study on the adsorption of phosphorus oxyanions at the interface
Liu et al. (2022)	Review of metal-based adsorbents for water eutrophication remediation	Evaluation of metal-based adsorbents for eutrophication remediation

Liu et al. (2018)	Review of metal (hydr)oxide and other adsorptive materials for phosphate removal	Evaluation of adsorptive materials for phosphate removal
Ma et al. (2014)	Coprecipitation for preparing Fe3O4 nanoparticles	Role of precipitant species in the coprecipitation process
Mao et al. (2022a)	Coprecipitation formation study of iron oxide nanoparticles with the assist of a gas/liquid mixed phase fluidic reactor	Study on the formation of iron oxide nanoparticles
Mao et al. (2022b)	Crystal phases of primary particles formed during the coprecipitation of iron oxides	Investigation of crystal phases in iron oxide nanoparticle formation
Mokhtar et al. (2022)	Nanocomposite of silica-coated magnetite nanoparticles and aniline-anthranilic acid co-polymeric nanorods	Synthesis of a nanocomposite for dispersive micro solid phase extraction
Ribeiro et al. (2010)	"Green Star": A holistic Green Chemistry metric for evaluation of teaching laboratory experiments	Evaluation of a metric for green chemistry in teaching laboratory experiments
Samrot et al. (2021a)	Adsorption efficiency of chemically synthesized superparamagnetic iron oxide nanoparticles (SPIONs)	Evaluation of SPIONs for crystal violet dye adsorption
Samrot et al. (2021b)	Review on synthesis, characterization, and potential biological applications of superparamagnetic iron oxide nanoparticles	Overview of synthesis and applications of superparamagnetic iron oxide nanoparticles
Santana et al.	Sustainable synthesis of natural deep	Synthesis methods for NADES

(2019)	eutectic solvents (NADES)	
Selvaraj et al. (2022)	Recent update on green-synthesized iron and iron oxide nanoparticles for environmental applications	Overview of environmentally friendly synthesis of iron nanoparticles
Sena et al. (2021)	Environmental impacts of phosphorus recovery through struvite precipitation	Assessment of environmental impacts of struvite precipitation
Shahid and Choi (2020)	Characterization and application of magnetite particles synthesized by reverse coprecipitation method	Study on magnetite particle characterization and application
You et al. (2022)	Sustainable approach for removing nitrate	Study on nitrate transformation and metabolic potential
Zang et al. (2022)	Eutrophication risk assessment considering joint effects of water quality and water quantity	Assessment of eutrophication risk considering water quality and quantity
Zhang et al. (2022)	Iron oxide coated sand (IOS): Scale-up analysis and full-scale application for phosphorus removal	Scale-up analysis and application of iron oxide coated sand for phosphorus removal
Zhang et al. (2021a)	Goethite dispersed corn straw-derived biochar for phosphate recovery	Study on phosphate recovery using biochar
Zhang et al. (2021b)	Comparative study for phosphate adsorption on amorphous FeOOH and goethite (α-FeOOH)	Investigation of phosphate adsorption on iron oxide minerals

Literature Review on Study of the nickel removal from water applying Design of Experiments and using natural clay honeycomb monoliths

The rising concern surrounding heavy metal contamination has prompted extensive research into effective and sustainable removal methods from aqueous solutions. Among these contaminants, nickel stands out due to its widespread presence and known environmental toxicity. A recurring theme in recent literature is the exploration of clay minerals as potential adsorbents for heavy metals, with a particular emphasis on nickel.

Recent studies have delved into the efficacy of clay minerals in adsorbing heavy metals, notably nickel. The current research project focuses on the application of clay honeycomb monoliths for this purpose, building upon prior successes in lead and cadmium removal. These monoliths present a cost-effective alternative, eliminating the need for complex modification procedures and showcasing practicality in heavy metal removal.

A distinctive aspect of the project lies in the incorporation of the Design of Experiments (DoE) methodology. This systematic approach, encompassing factorial design and response surface optimization, aligns with established experimental design methodologies, ensuring the reliability and robustness of the study.

The urgency to address heavy metal contamination, particularly nickel, stems from its pervasive environmental presence and associated health risks. The research project assumes significance in offering a potential solution through the application of natural clay honeycomb monoliths. These monoliths, known for their effectiveness in lead and cadmium removal, represent a practical and cost-effective means of tackling heavy metal pollution.

The project strategically adopts two key approaches for process improvement. Firstly, the systematic exploration of initial nickel concentration, salts concentration, and their interactions through DoE provides a comprehensive understanding of the sorption capacity optimization process. Secondly, the project avoids complex clay modification procedures, opting for a practical and cost-effective approach.

Methodologically, the project focuses on the systematic exploration and optimization of key parameters using DoE, resulting in a maximum sorption capacity of 0.830 mg Ni2+ per gram of clay under optimized conditions. These findings contribute significantly to the understanding of optimal conditions for nickel removal using natural clay honeycomb monoliths.

The research project emerges as a noteworthy endeavour in the quest for sustainable solutions to heavy metal contamination. Through the innovative application of clay honeycomb monoliths and the judicious use of DoE, the study not only contributes to academic discourse but also holds practical implications for environmental and public health. (Dolores Bellido-Milla a, 2023).

Table 2 Classification of Studied Research Papers Focused on : Nickel Removal: DOE with Clay Monoliths

Authors	Applied Methodology for Process Improvement	Material and Major Findings	Techniques and Statistical Data Analytics	Lean Techniques and Methodologies	Mechanical Experiments	Major Contribution	Simulation, Simulation Software, and Major Contribution
Dolores Bellido-Milla, Hilario Vidal, María Nún˜ez, et al.	Design of Experiments (DoE) using Atomic Absorption Spectroscopy	Moroccan illite-smectite clay extruded as honeycomb monoliths. Physicochemical characterization and adsorptive properties of Moroccan clay minerals extruded as lab-scale monoliths	Initial Nickel concentration, salts concentration, and interaction significantly affect nickel retention; flow, pH, temperature, and time have minimal influence. X-Ray Fluorescence (XRF) analysis, SEM-EDS of monolith surfaces, Scanning Electron Microscopy (SEM)	The clay honeycombs were extruded using only water without additives. Honeycomb monoliths showed potential to remove lead and cadmium from water	Investigated nickel entrance and the negative effect of salts presence through XRF and SEM-EDS analysis. Scanning Electron Microscope (SEM) observation of monoliths after use in adsorption tests	Clay honeycomb monoliths with potential to remove nickel from aqueous streams. Detection of nickel peaks in SEM-EDS analysis, homogeneous distribution of captured nickel in monoliths	High sorption capacity achieved under optimal conditions. Nickel capture and immobilization process appears almost completely reversible; potential for regeneration

Literature review on Design optimization of bladeless ceiling fan using design of experiments:

The contemporary investigation centres on the exploration of bladeless ceiling fans as a pragmatic alternative to conventional fan systems, placing particular emphasis on their potential to facilitate efficient evaporative cooling. A meticulous literature review navigates through antecedent research endeavours, delving into the domains of fan design, aerodynamics, and indoor climate control. The study draws extensively from foundational works, especially contributions elucidating ceiling fan performance by various scholars. Theoretical underpinnings are rooted in the established principles set forth by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), with a specific focus on ANSI/ASHRAE Standard 55-2017. This deliberate integration ensures a comprehensive alignment of the study with industry benchmarks, thereby fortifying the robustness of the research framework.

The literature review not only scrutinizes relevant works in fan design, aerodynamics, and ventilation but also underscores the significance of the problem at hand. At its core, the study aims to unravel the potential of bladeless ceiling fans as effective solutions for evaporative cooling, particularly in comparison to conventional fan systems. The overarching objective is to contribute to a nuanced understanding of the efficacy of bladeless fans across diverse applications, spanning tunnel cross ventilation to indoor/outdoor structure aeration.

Bladeless Fan Design Optimization: Building upon the seminal work of (Ehsan Adeeb1, 2015), the research zeroes in on optimizing the design of bladeless fans, with a keen eye on enhancing aerodynamic performance.

Integration with Air Conditioners: Future trajectories involve evaluating the synergy of bladeless ceiling fans with air conditioning systems, aspiring to furnish superior cooling solutions.

Application in Tunnel Ventilation: The technology is probed as a viable alternative for tunnel cross ventilation, especially in exigent scenarios like fires (Tiannian Zhou, 2019).

To ensure a comprehensive analysis and improvement, the project employs diverse **Methodologies:** Techniques from response surface methodology (H. Adeli, 2011) are leveraged to optimize the mechanical strength properties of fan components.

Simulation techniques are applied to model and analyze the performance of bladeless fans in various scenarios, particularly in tunnel cross ventilation (Ye Tao, 2014). The applied methodology is characterized by a holistic analysis of bladeless ceiling fan performance through numerical simulations. Algorithms derived from prior works (M. Jafari, 2016) are deployed for aerodynamic evaluation, forming the bedrock for performance analytics. The substantial contribution lies in establishing the efficacy of bladeless fans for specific applications, including tunnel cross ventilation and indoor/outdoor structure aeration.

The methodological arsenal encompasses experimental studies, potentially featuring computational fluid dynamics (CFD) simulations (C.J. Meyer, 2001) to dissect the flow field structure and aerodynamic performance of bladeless ceiling fans. Material considerations factor in the composition of fan components for optimal performance. Major findings coalesce around insights into the aerodynamic and aeroacoustics performance of bladeless fans. The simulation technique unfolds through the utilization of computational fluid dynamics (CFD) simulations to model the airflow and performance of bladeless fans. Employing sophisticated simulation software, such as ANSYS or COMSOL Multiphysics, ensures precision in the analysis. The overarching contribution lies in the nuanced understanding of the flow field structure and performance characteristics of bladeless fans across diverse conditions. (Kashif Mehmood a, 2023).

Table 3 Classification of Studied Research Papers Focused on Bladeless Ceiling Fan: DoE Optimization

Aspect	Information

Authors	Kashif Mehmood, Aamer Shahzad, Farooq Akram, Taimur Ali Shams, M.N. Mumtaz, Jehanzeb Masud
Applied Methodology	Optimization process involving Design of Experiments (DOE) using Box-Behnken Design (BBD), Computational Fluid Dynamics (CFD) analysis
Major Finding	Bladeless fans demonstrated a 60% enhancement in air delivery compared to conventional fans. Bladeless fans effectively increased the comfort zone by 76%.
Techniques	Optimization, Design of Experiments, Computational Fluid Dynamics (CFD), Statistical Analysis
Statistical Data Analytics	Regression models, analysis, and statistical validation.
Mathematical Optimization	Optimized parameters for the bladeless fan include a 1.4 m fan diameter, 0.00255 m jet width, 91.21° orientation angle, and 3.0 m/s jet velocity.
Mechanical Experiments	Experimental testing involved seven different conventional ceiling fans (1400 mm sweep size) and optimization through mechanical experiments.
Used Algorithms for Performance Analytics	The optimization process may have involved algorithms related to Design of Experiments and Computational Fluid Dynamics.
Major Contribution Material	Optimized bladeless ceiling fan parameters, comparison with conventional fans, insights into increased comfort zones.
Simulation	Computational Fluid Dynamics (CFD) analysis, which involved simulations of the optimized fan geometry.

Literature review on Optimisation of a grass cutting blade using design of experiments with qualitative and quantitative performance metrics

The comprehensive exploration of methodologies within this project aims to refine grass-cutting blade design through a meticulous blend of qualitative and quantitative evaluations. By embedding the study within the broader landscape of grass-cutting blade design, the literature review brings to the forefront critical parameters and performance metrics. Noteworthy studies are referenced, illuminating the profound influence of factors such as upturn angles, blade span, and rake angle on key performance indicators like clipping spread, clumping, and energy efficiency.

The literature consistently emphasizes crucial themes, ranging from safety considerations to adherence to impact testing standards. Notably, innovative features like the upturn web are spotlighted as contributors to advancements in blade technology. The synthesis of statistical methods and qualitative assessments underscores the project's commitment to a holistic evaluation of blade design, drawing from the wealth of knowledge present in existing literature.

This study confronts a pertinent challenge within grass-cutting technology, envisioning an enhancement of blade efficiency and effectiveness through a meticulous optimization process. The problem's significance is underscored by the far-reaching economic and operational implications tied to blade performance. For instance, the observed reductions in energy consumption and noise emissions carry substantial weight, promising operational cost-effectiveness and aligning with environmental considerations.

Recognizing the inherent complexities of optimizing grass-cutting blade design, the study grapples with the delicate task of balancing conflicting objectives, such as clipping spread and clumping. The problem gains heightened significance due to the intricate trade-offs required among various performance metrics, each intricately shaping the overall functionality of cutting blades. The unwavering commitment to safety standards and the subsequent validation of the optimized blade design further accentuate the project's dedication to real-world applicability and industry relevance.

In essence, the literature review serves as a compass, providing a thorough grasp of factors influencing grass-cutting blade design. This sets the stage for the project's innovative approach to optimization, with the overarching significance lying in the tangible benefits for operational efficiency, cost reduction, and the steadfast adherence to safety standards in the intricate realm of designing and manufacturing grass-cutting blades. (Thomas Archbold, 2023).

Table 4 Classification of Studied Research Papers Focused on Optimizing Grass Cutting Blade Through Experiments

Aspect	Information
Authors	B. IOSY, Systems Engineering, et al.
Applied Methodology	Fractional factorial experiments, Response Surface Method (RSM), Pareto Optimality, User Importance (UI) and Practical Significance (PS) ratings
Techniques	Response Surface Methodology (RSM), Experimental Design, Factorial Experiments, Pareto Optimality
Statistical Data Analytics	Analysis of fractional factorial experiments, Response Surface Method (RSM), Statistical significance testing
Mathematical Optimization	Used for Pareto Optimality in optimizing grass cutting blade design

Mechanical Experiments	Field testing with a tractor-pulled mower, measuring various metrics including clipping spread, clumping, brooming, uncut stalks, wheel marks, energy efficiency, and noise emissions
Major Contribution Material	Identification of factors influencing grass cutting blade performance, tractor, PTO (Power Take-Off), sound level meter, development of predictive models, optimization for Pareto efficiency
Major Contribution and Findings	Improved understanding of blade design factors, quantification of performance metrics. (upturn angle, radial angle, height, web, rake angle, blade span), significant effects on energy efficiency, noise emissions, and other factors.

Problem Statement

Consistent customer complaints about optical glue bonding defects in Models X and Y present a serious operational challenge for the company. The principal concern pertains to the inadequate adhesion of the adhesive to the metal plate, which presents a considerable risk to the smooth operation of the products. The increased danger of optics detachment impairs operations and causes customer dissatisfaction, highlighting how urgently the bonding problem needs to be resolved in order to maintain customer satisfaction and protect the company's reputation.

A comprehensive approach is necessary because of this significant problem. A thorough root cause analysis must be conducted in order to systematically identify and address the underlying factors causing the weak bonding issue. The company hopes to obtain a more sophisticated understanding of the problems by exploring the unique characteristics of the adhesive-metal plate interface. This will allow for the development of focused solutions to address the bonding defects in Models X and Y. In response to recurring customer concerns, the company's proactive approach is in line with its dedication to providing high-quality products and ensuring the dependability of its products and services.

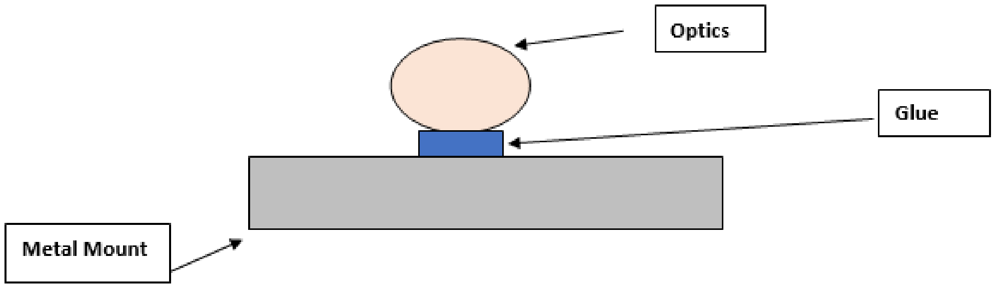

Figure 1-1 Optics mounted on metal

Methodology

In the project, various rigorous methodologies are employed to ensure systematic problem-solving and process optimization. The utilization of Minitab, a potent statistical software, assumes a pivotal role in the analysis and interpretation of data, enabling the derivation of meaningful insights and informed decisions based on statistical evidence. The Design of Experiments (DOE) serves as a structured approach, systematically varying factors to comprehend their impact on outcomes, thereby enhancing the ability to optimize and fine-tune critical processes. The Ishikawa diagram, commonly referred to as a fishbone diagram, proves invaluable in root cause analysis by visually mapping potential causes of a problem, facilitating a comprehensive understanding of contributing factors. Furthermore, the 5 Whys technique provides a structured inquiry process, enabling a profound exploration of the root causes of issues and the implementation of effective corrective measures. Through the integration of these methodologies, a robust framework is established for problem-solving, continuous improvement, and data-driven decision-making throughout the project lifecycle (Barsalou, 2023).

Objective

The primary objective of this study is to minimize instances of optics fall-off, which can lead to field failures and disrupt operations, adversely impacting end customers. The overarching aim is to boost the reliability and durability of optical systems by addressing the issue of weak adhesive bonding between optics and metal mounts. Accomplishing this goal is crucial for maintaining the seamless functionality of these systems, ultimately contributing to an enhanced customer experience.

In addition to the primary focus, the research includes a secondary objective that centres on utilizing Lean tools for a thorough analysis of factors influencing weak adhesive bonding. Through a methodical root cause analysis, the study aims to pinpoint and resolve the underlying issues contributing to less-than-optimal bonding strength between optics and metal plates. Additionally, the research incorporates a Design of Experiment to meticulously examine the impact of environmental variables such as temperature, humidity, and time of exposure at varying levels. This comprehensive approach seeks to reveal crucial insights that will guide strategies to improve the overall reliability and performance of optical systems in real-world conditions.

Data Collection

During the process of collecting data experienced technicians diligently examined each returned Model X unit thoroughly checking for any issues, with the bonding of the optics. These issues could be noticed as either movement or complete detachment of the components. To address and resolve these concerns we implemented a force testing protocol. This involved subjecting the optics components to a defined level of force using gauges. The N Grams force testing methodology was systematically applied to evaluate all optics within the product including those returned by customers and those being prepared for shipment. This process illustrated in the accompanying figure.

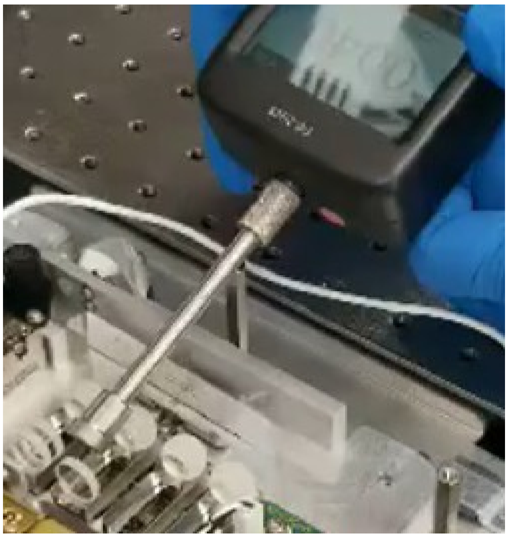

Figure 2-1 Force Test

Keysight received returns of Optics 7 and 8 because they became dislodged as shown in Figure 2-3. Interestingly upon inspection it was noticed that both optics were still attached with glue. When examining these optics, it was observed that the glue surface, which bonded to the metal mount had an appearance (as depicted in Figure 2-4). This smoothness suggests that the glue did not effectively bond with the metal side.

While investigating the problem on the other side, the engineer tried to remove the glue from the optics side, but it was firmly stuck, indicating a strong bond. Interestingly, this happened with both optics 7 and 8. This suggests that the issue doesn't lie with the glue itself but rather with the metal surface, which seems to be contaminated. In another case involving a unit with the serial number X 385, a similar situation occurred. One optic and two translation balls behaved the same way, with the optic side sticking strongly and the metal side of the glue easily coming off. This recurring pattern highlights the importance of thoroughly assessing the condition of the metal surface as a potential cause of the problem.

Figure 2-2 Keysight's Investigation of Optics 7 and 8

Figure 2-3 Real Item

Figure 2- 4 Seamless Adhesion: Glue to Metal Surface on Mount

Throughout the data collection phase, we made it a priority to address customer inquiries during our meetings. This proactive approach ensured that any concerns or questions raised by customers were promptly acknowledged and resolved. Our commitment, to responsive communication demonstrated our dedication to maintaining quality and customer satisfaction reinforcing our promise to deliver products that meet rigorous standards.

Sample Customer Questions

Q1 When did Keysight start reusing acetone?

A1. We did not plan to reuse the acetone.

Q2. How long has the acetone been reused?

A2. Occasionally it has been used

Q3. Why was a cleaning process added that does not exist in models other than X?

A3. Other models have a distinctive design. So, the cleaning process for other models is different

Q4. How do you control the amount of glue applied?

A4. The amount of adhesive applied is controlled by the software program. It is an automated process

Q5. Is the bonding performed by the operator?

A5. The bonding is controlled by the software program

Q6. How do you manage the light intensity and time?

A6. The Intensity and the time are controlled by the software program

Q7. How to confirm curing of the adhesive?

A7. Adhesive is qualified before it is used

ssQ8. Why is an additional time of storage required even though it is a programmed curable adhesive? Is it the specification of the adhesive?

A8. There is no exact time from the data sheet, but we are being careful. No, 18hours of curing is not the specification of the adhesive?

Q9. Is the curing tool located at one spot and all the units are cured there?

A9. Yes, it is located at one place and all the units are cured there

Measure

The Model X units were assessed for the magnitude of the optics fall-off issue, which showed a high yield loss of 93.3% due to failed units (baseline metric). This calculation demonstrates the big impact (600-40/600) *100. Another important thing is that we got process sigma level 3.00 to show how quickly and how much better we need to do. In order to systematically address and resolve the optics fall-off issue, Lean Methodology was used by our team, with this baseline metric playing a key role in terms of using the calculated sigma level and defect percentage as benchmarks for gauging progress and guiding improvement initiatives.

To begin with, this team collected field data from around the world where customers have installed their Model X for rise on the subject of optics fall off; laying a basis for Define-Measure-Analyze-Improve-Control (DMAIC) process. Among all customer sites globally there are only about 600 model x vehicles installed hence calculating process sigma by taking into account such number provides us with Baseline metric about Optics fall off. The 40 incidents reported between August 2022–January 2023 gave us a significant yield loss of 93.3% and the defect rate, for the pieces that were shipped is 6.67% overall. The comprehensive collection of data was a basis for the subsequent stages of DMAIC that allowed for an informed and targeted approach to address and fix the issue of drop off in optics.

Cause and Effect Diagram

Upon conducting a thorough root cause analysis using the 5 Whys technique, a sequence of events leading to contamination on the rail of metal mounts was unveiled. The initial investigation revealed that the contamination stemmed from operators using an acetone bath previously employed for other metal parts and not changing gloves with adequate frequency, resulting in cross-contamination. Delving deeper into the inquiry, it became evident that this improper practice was attributed to human error, shedding light on a gap in procedural adherence.

Further exploration into why these errors occurred brought to light a critical flaw in the existing process documentation: it did not explicitly prohibit the reuse of acetone baths or mandate frequent glove changes. Consequently, the core issue was traced back to insufficiently detailed process documentation. To address this root cause effectively, a proposed solution involves revising and enhancing the process instructions to incorporate specific and detailed protocols. This strategic approach aims to prevent the recurrence of the issue, thereby ensuring elevated standards of cleanliness and upholding the integrity of the product.

Measurement: Inadequate inspection for contamination on metal mounts and insufficient time for glue curing are factors related to measurement that can lead to optic detachment.

Method: The problem can arise from poor adhesion caused by applying too little glue, using runny glues, or neglecting an additional force test to confirm bond strength.

Material: Material issues for optics detachment involve adhesive contamination, poor metal mount compatibility, surface inaccuracies, and adhesive deterioration over time

Machine Issues: Misalignment during optics gluing or issues with placement tools, along with potential deterioration in the UV light source, could contribute to the problem.

Man: Inexperienced workers lacking essential skills may perform the procedure, or deviations from specified procedures, like not wearing fresh gloves, using proper cleaners, or ignoring equipment contamination, could be factors.

Environment: Contamination on plate or edge surfaces and operating equipment under excessive shock, vibrations, or varying temperature and humidity may lead to optic detachment.

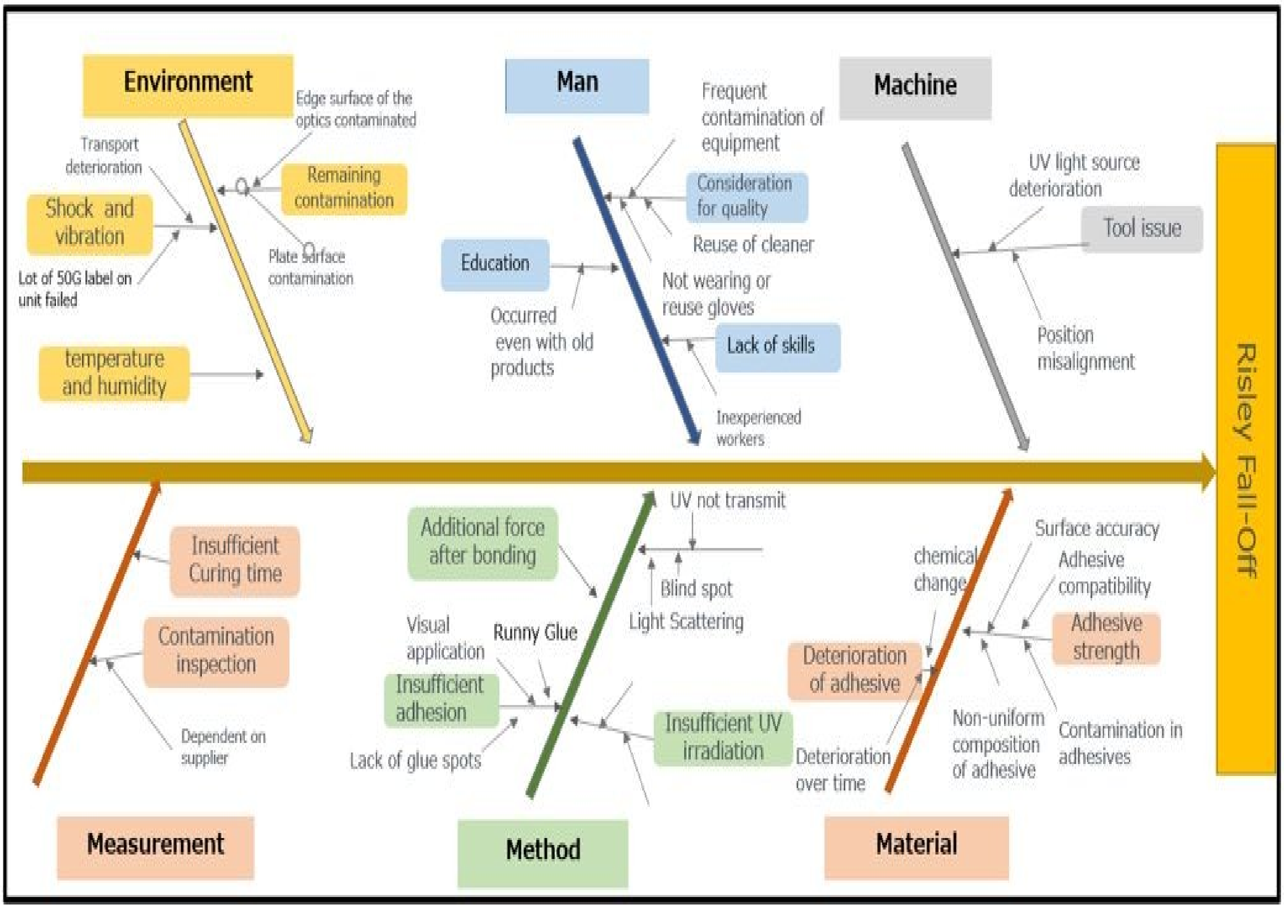

Figure 3-1 Root cause Analysis

5 Whys

A root cause analysis (using a 5-whys technique) identified that metal mount rail contamination originated from operators previously using an acetone bath used for rinsing other metals. This problem was aggravated by poor sanitation procedures and health care providers' failure to use gloves on a regular basis. Human error resulted from a deviation from the standard practice, which arose because there were no clear stipulations in the existing process. The failure to provide specific directions on the disposal of acetone exposed it to accidental pollution. It should point out weaknesses in the existing process and document in order to prevent a recurrence of better practices that support compliance.

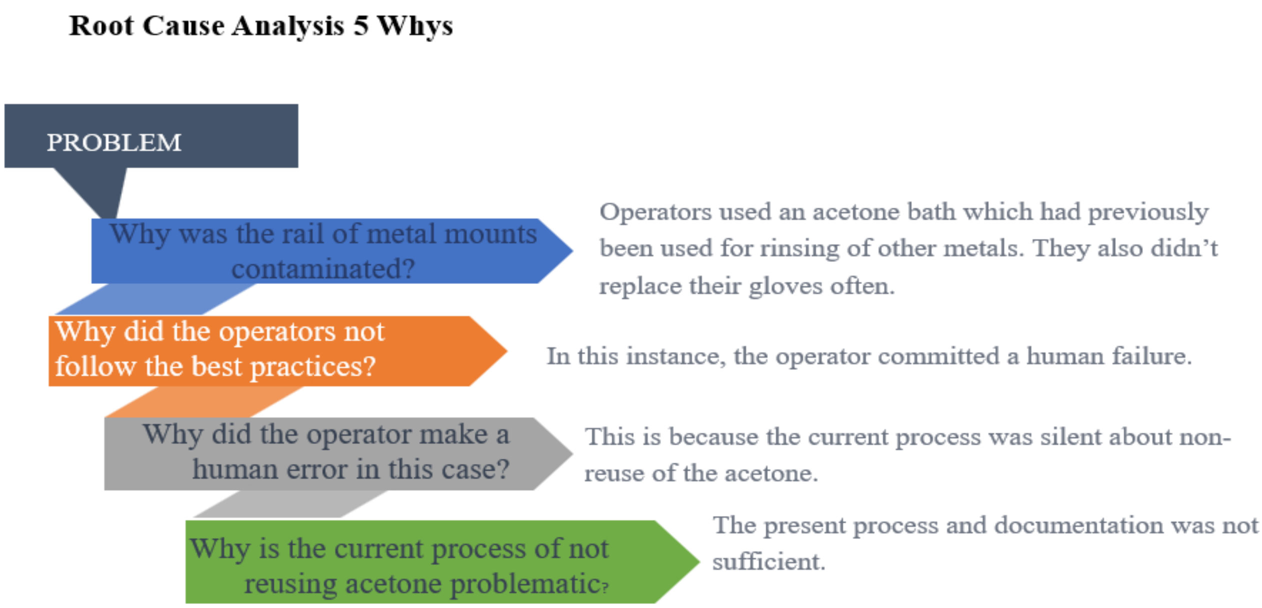

Figure 4-1 Five Why's

Design of Experiment

To conduct the DOE specifically to pinpoint which are the best environmental conditions with regard to reducing risks to the optics being displaced on international voyages. Bond strength between optics and base plates is a response variable critical to our study—attribute data comprising either strong or weak bonds. The factors under scrutiny for their potential impact on bonding strength include temperature, humidity, and time of exposure, each having two levels: low and high. We use a fractional factorial design as a practical substitute for the tedious full factorial one to facilitate a fair distribution of resources. As an economical way of examining the effects of each variable on others, this approach makes it possible to test for eight combinations comprising the factors.

It is anticipated that the deliberate deployment of DOE will provide useful information regarding the complex connections between temperature, humidity, exposure hour, and bond strength. Through understanding what the most critical environmental factors are, we intend to zero in on the best environment conducive to strong optic adhesion worldwide. Using such a systematic and statistically based strategy has allowed us to make further progress towards increasing reliability in our items, lowering the frequency of optic separation, and enhancing overall delivery standards across the globe.

Temperature	Humidity	Time of exposure
28degC	60% RH	48hrs
60degC	60% RH	24hrs
28degC	90% RH	24hrs
60degC	90% RH	48hrs

Table 5 - Environmental Exposure Conditions

The base plate was subjected to thorough tests, including exposure to diverse sets of climatic conditions during commercial oven operations. Thorough force testing was done on the optics to evaluate the extent to which these conditions had an effect on glue bonding. The use of this approach enabled a thorough assessment of the adhesion quality and overall effectiveness of the adhesion processes in various situations. These tests give information on the toughness and long-lasting nature of the adhesive bonds. This contributes to an all-round understanding of what happens to the base plate under these commercial oven conditions.

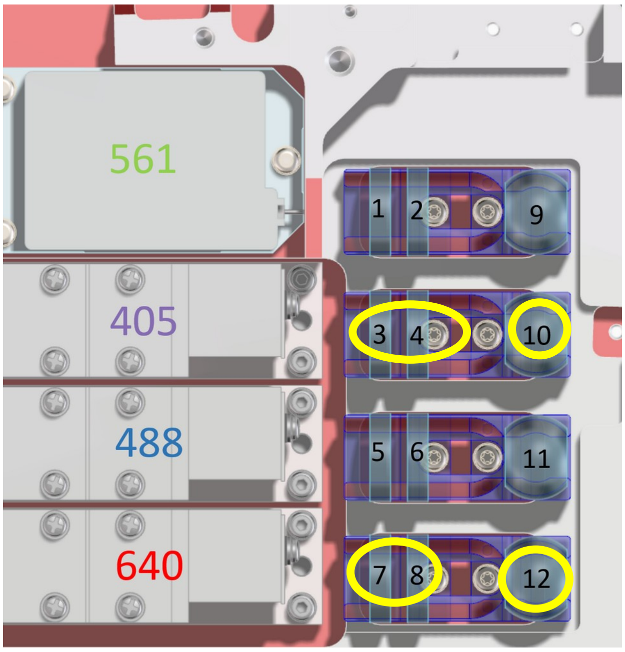

Figure Optics 5-1 - 7 and 8 Investigation

Environmental Test Data

The environmental test data reveals crucial insights into the robustness of our products under various conditions. Extensive testing involving temperature, humidity, and exposure time has been conducted to assess the performance and durability of our components. The data illustrates the impact of these environmental variables on glue adherence, indicating an inverse relationship with bonding strength. As temperature and humidity increase, the bonding strength decreases, emphasizing the vulnerability of certain bond configurations. These findings underscore the necessity of considering environmental factors in our manufacturing processes. The comprehensive analysis provided by the environmental test data serves as a valuable resource for optimizing our products, ensuring they meet the highest standards of reliability and performance across diverse operational environments.

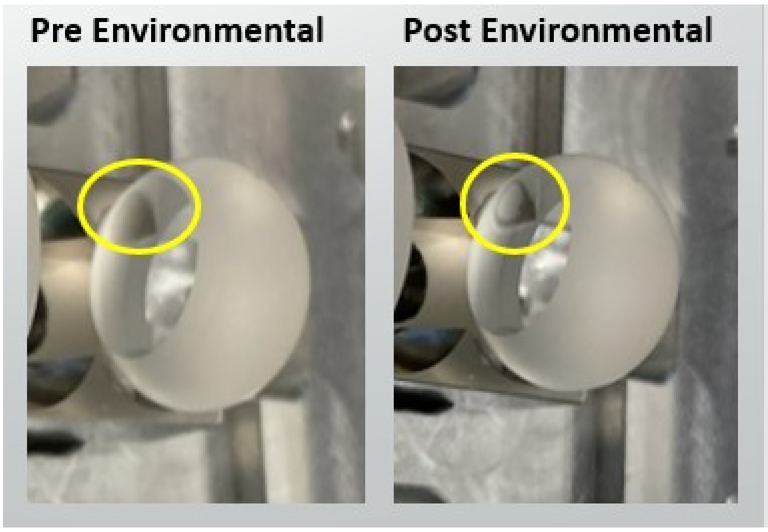

Figure 6 – 1 Pre and post Environmental

Case 1: 60degC, 90% RH, 48 hours

Lesco UV S/N:	1008221038	
Station:	4	
Glue:	Optocast 3408	
Batch #:	43-DL18-1	
Expire:	11/22/2023	
Environmental Test:	60degC @ 90% RH for 48 hrs. Ramp rate is 3degC/hr	
# of Squishes:	9	
Glue Viscosity:	47000 Cps	Spec: 35000 - 50000 Cps
Force Gauge:	2.5kgF	
Location	Force test (kg)	
	Pre-	Post-Environmental

	Environmental	
1	Not Glue	Not Glue
2	Not Glue	Not Glue
3	> 2	> 2.5
4	> 2	> 2.5
5	Not Glue	Not Glue
6	Not Glue	Not Glue
7	> 2	> 2.5
8	> 2	> 2.5
9	Not Glue	Not Glue
10	> 2	> 2.5
11	Not Glue	Not Glue
12	> 2	> 2.5

Table 6 - Environmental Test and Force Gauge Results

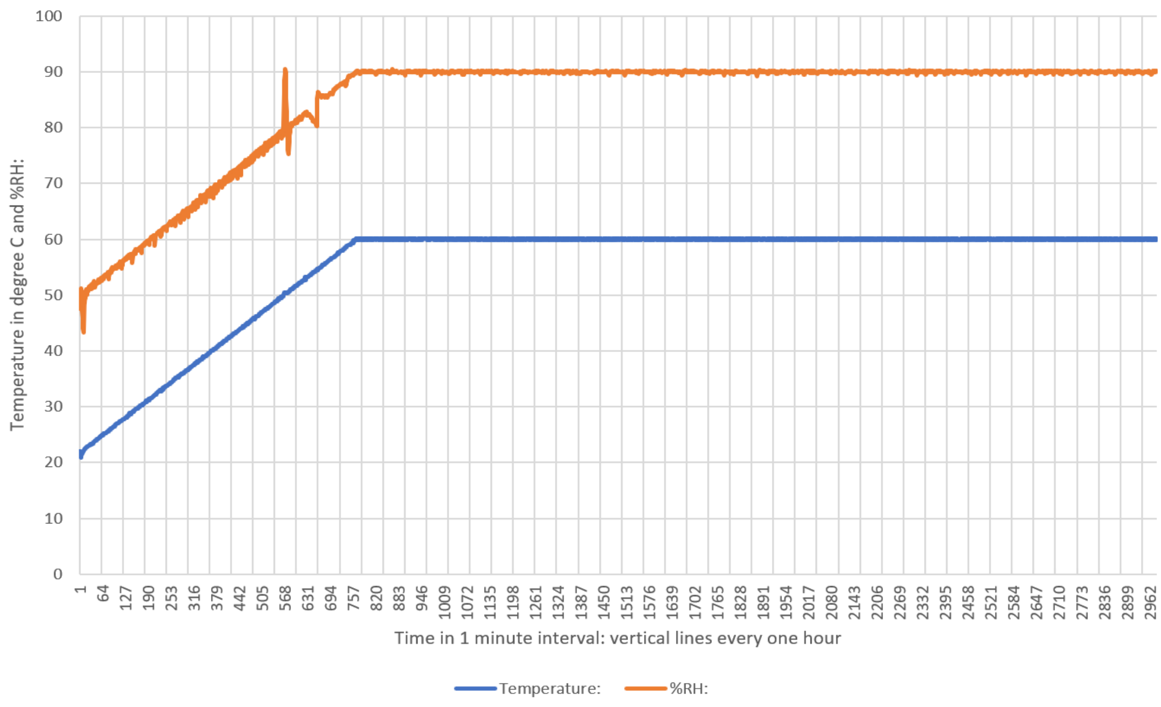

Figure 6 – 2: Temperature, Humidity VS Time

Case 2: 28°C, 60% RH, 48 hours

The bond strength on the glue joint for Lesco UV S/N 1008221038 at Station 4, using Optocast 3408 glue from Batch 43-DL18-1 with an expiration date of 22-11-2023, underwent an environmental test at 28°C and 60% RH for 48 hours with a ramp rate of 3°C/hr. The number of squishes was 9, and the glue viscosity measured 47000 Cps, within the specified range of 35000 - 50000 Cps. The force gauge used was 2.5kgF. The force test results before and after the environmental test are recorded for each of the 12 locations, indicating variations in bond strength, with some locations showing a significant increase post-environmental condition.

Bond Strength on Glue Joint	
Lesco UV S/N:	1008221038
Station:	4
Glue:	Optocast 3408
Batch #:	43-DL18-1
Expire:	22-11-2023
Environmental Test:	28degC @ 60% RH for 48 hrs. Ramp rate is 3degC/hr
# of Squishes:	9
Glue Viscosity:	47000 Cps Spec: 35000 - 50000 Cps
Force Gauge:	2.5kgF

Location	Force test (kg)	
	Pre-Environmental	Post-Environmental
1	Not Glue	Not Glue
2	Not Glue	Not Glue
3	> 2	> 2.5
4	> 2	> 2.5
5	Not Glue	Not Glue
6	Not Glue	Not Glue
7	> 2	> 2.5
8	> 2	> 2.5
9	Not Glue	Not Glue
10	> 2	> 2.5
11	Not Glue	Not Glue
12	> 2	> 2.5

Table 6-1: 28°C, 60% RH, 48 hours

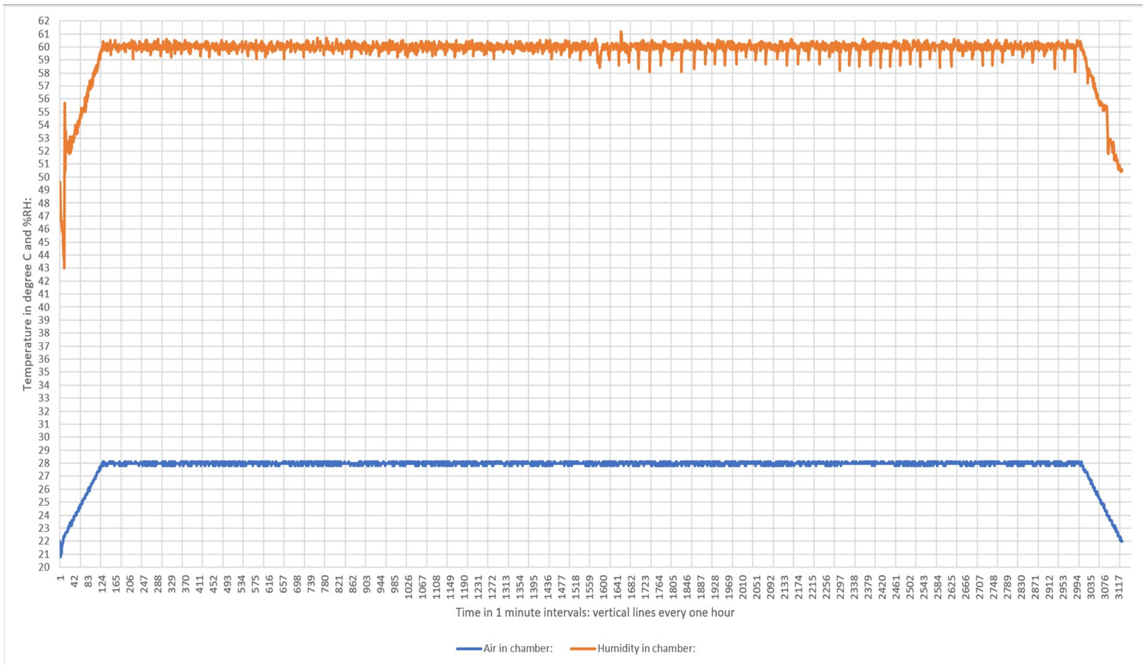

Figure 6 – 3: Temperature, Humidity VS Time

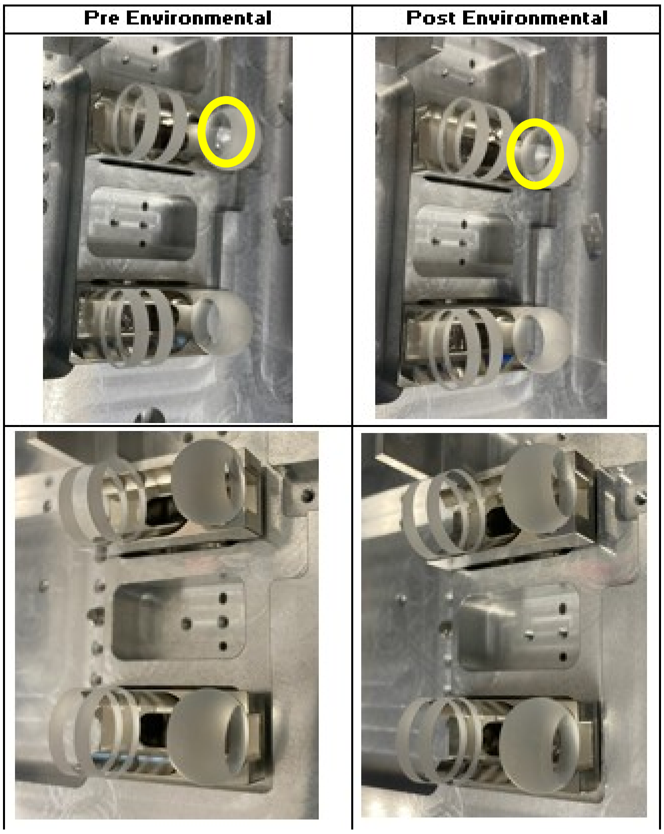

Figure 6 – 4: Pre and Post Environmental

Case 3: 60°C, 60% RH and 24 hours

The bond strength on the glue joint for Lesco UV S/N 1008221038 at Station 4, utilizing Optocast 3408 glue from Batch 43-DL18-1, with an expiration date of 22-11-2023, underwent an environmental test at 60°C and 60% RH for 24 hours, with a ramp rate of 3°C/hr. The number of squishes was 9, and the glue viscosity measured 47000 Cps, falling within the specified range of 35000 - 50000 Cps. The force gauge used was 2.5kgF. Recorded force test results before and after the environmental test for each of the 12 locations show variations in bond strength, with certain locations exhibiting a notable increase post-environmental condition. Additionally, pertinent notes have been included for reference.

Bond Strength on Glue Joint	
Lesco UV S/N:	1008221038
Station:	4
Glue:	Optocast 3408
Batch #:	43-DL18-1
Expire:	22-11-2023
Environmental Test:	60degC @ 60% RH for 24 hrs. Ramp rate is 3degC/hr
# of Squishes:	9
Glue Viscosity:	47000 Cps Spec: 35000 - 50000 Cps
Force Gauge:	2.5kgF

Location	Force test (kg)	
	Pre-Environmental	Post-Environmental
1	Not Glue	Not Glue
2	Not Glue	Not Glue
3	> 2	> 2.5
4	> 2	> 2.5
5	Not Glue	Not Glue
6	Not Glue	Not Glue
7	> 2	> 2.5
8	> 2	> 2.5
9	Not Glue	Not Glue
10	> 2	> 2.5
11	Not Glue	Not Glue
12	> 2	> 2.5

Table 6-2: 60°C, 60% RH, 24 hours

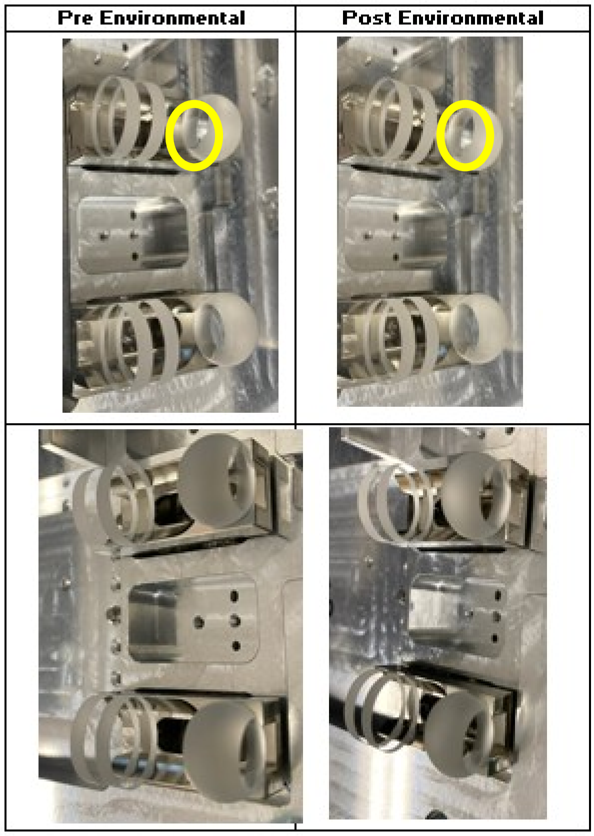

Figure 6 – 5: Pre and Post Environmental

Case 4: 28°C, 90% RH and 24 hours

The bond strength assessment on the glue joint for Lesco UV S/N 1008221038 at Station 4, utilizing Optocast 3408 glue from Batch 43-DL18-1 and with an expiration date of 22-11-2023, involved an environmental test at 28°C and 90% RH for 24 hours, with a ramp rate of 3°C/hr. There were 9 squishes performed, and the glue viscosity measured 47000 Cps, falling within the specified range of 35000 - 50000 Cps. The force gauge used was 2.5kgF. The force test results before and after the environmental test for each of the 12 locations are recorded, illustrating variations in bond strength. Notably, certain locations exhibited an increase post-environmental condition. Detailed notes accompanying the test provide additional context for analysis and interpretation.

Figure 6 – 6: Temperature, Humidity VS Time

Bond Strength on Glue Joint	
Lesco UV S/N:	1008221038
Station:	4
Glue:	Optocast 3408
Batch #:	43-DL18-1
Expire:	22-11-2023
Environmental Test:	28degC @ 90% RH for 24 hrs. Ramp rate is 3degC/hr
# of Squishes:	9
Glue Viscosity:	47000 Cps Spec: 35000 - 50000 Cps
Force Gauge:	2.5kgF

Location	Force test (kg)	
	Pre-Environmental	Post-Environmental
1	Not Glue	Not Glue
2	Not Glue	Not Glue
3	> 2	> 2.5
4	> 2	> 2.5
5	Not Glue	Not Glue
6	Not Glue	Not Glue
7	> 2	> 2.5

8	> 2	> 2.5
9	Not Glue	Not Glue
10	> 2	> 2.5
11	Not Glue	Not Glue
12	> 2	> 2.5

Table 6-3: 28°C, 90% RH, 24 hours

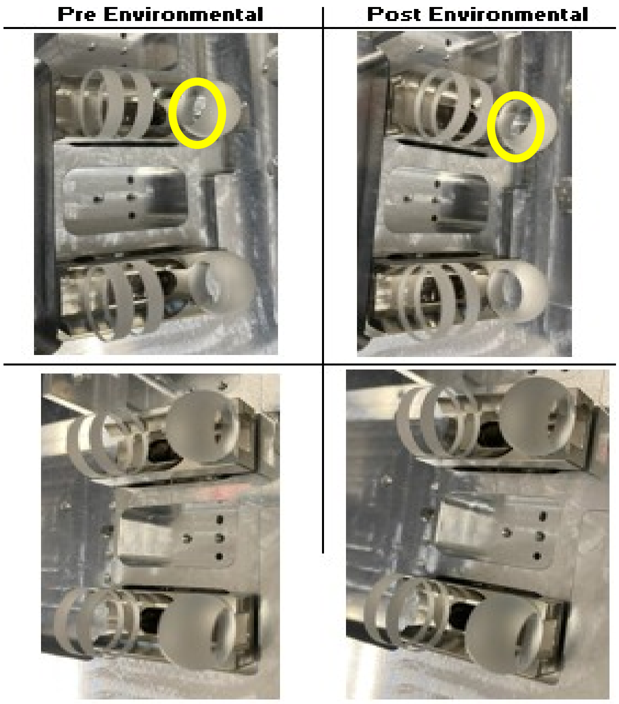

Figure 6 – 7: Pre and Post Environmental

Data Analysis and Result

The below dataset involves a series of experiments with different combinations of temperature, humidity, exposure time, and the resulting glue adherence (coded as 1 for adherence and 0 for non-adherence). This data was analysed using a regression model with coded coefficients. The coefficients for factors A, B, and C represent the effects of temperature, humidity, and exposure time on glue adherence, respectively. The coded coefficients indicate that each factor has a negative impact on glue adherence. The model summary suggests a perfect fit, with 100% R-squared, adjusted R-squared, and predicted R-squared values, indicating that the model effectively explains the variability in glue adherence based on the chosen factors.

The regression equation in uncoded units reveals that glue adherence is influenced by the factors A, B, and C, representing temperature, humidity, and exposure time, respectively. The negative coefficients for these factors suggest that higher values for temperature, humidity, and exposure time are associated with reduced glue adherence. The constant term in the regression equation is 3.438, and the analysis indicates that the model has a strong predictive capability. Overall, the results highlight the significance of temperature, humidity, and exposure time in determining glue adherence, offering valuable insights for optimizing the manufacturing process to achieve improved glue bonding.

Temperature	**Humidity**	**Exposure Time**	**Glue**
28	60	48	1
60	60	24	1
28	90	24	1
60	90	48	0
28	60	48	1
60	60	24	1
28	90	24	1
60	90	48	0
28	60	48	1
60	60	24	1
28	90	24	1

60	90	48	0
28	60	48	1
60	60	24	1
28	90	24	1
60	90	48	0
28	60	48	1
60	60	24	1
28	90	24	1
60	90	48	0
28	60	48	1
60	60	24	1
28	90	24	1
60	90	48	0

Table 7 - Environmental Exposure and Glue Application

WORKSHEET 1

Factorial Regression: Glue versus A, B, C

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		0.7500	0.0000	*	*	
A	-0.5000	-0.2500	0.0000	*	*	1.00
B	-0.5000	-0.2500	0.0000	*	*	1.00
C	-0.5000	-0.2500	0.0000	*	*	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0	100.00%	100.00%	100.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	4.50000	1.50000	*	*
Linear	3	4.50000	1.50000	*	*
A	1	1.50000	1.50000	*	*
B	1	1.50000	1.50000	*	*
C	1	1.50000	1.50000	*	*
Error	20	0.00000	0.00000		
Total	23	4.50000			

Regression Equation in Uncoded Units

Glue = 3.438 - 0.01563 A - 0.01667 B - 0.02083 C

Alias Structure

Factor	Name
A	A
B	B
C	C

Aliases
I + ABC
A + BC
B + AC
C + AB

*** NOTE * The normal plot of effects is not displayed because the standard error for effects is 0.**

Figure 8 - Analysis of Factorial Regression

Analysis of Contour Plot

The below graphs clearly show a pattern; when the temperature, humidity and exposure time increase the bonding strength decreases. This indicates that environmental factors have an impact, on how adhesive materials behave. The data points to an inverse relationship suggesting that prolonged exposure to temperatures and increased humidity levels have a negative effect, on the strength of the bonds. These findings highlight the need to take conditions into account when optimizing bonding processes as they reveal that certain combinations of temperature and humidity can make bonds more vulnerable.

Where A = temperature

B = Humidity

C = Exposure of Time

Glue = Response Variable

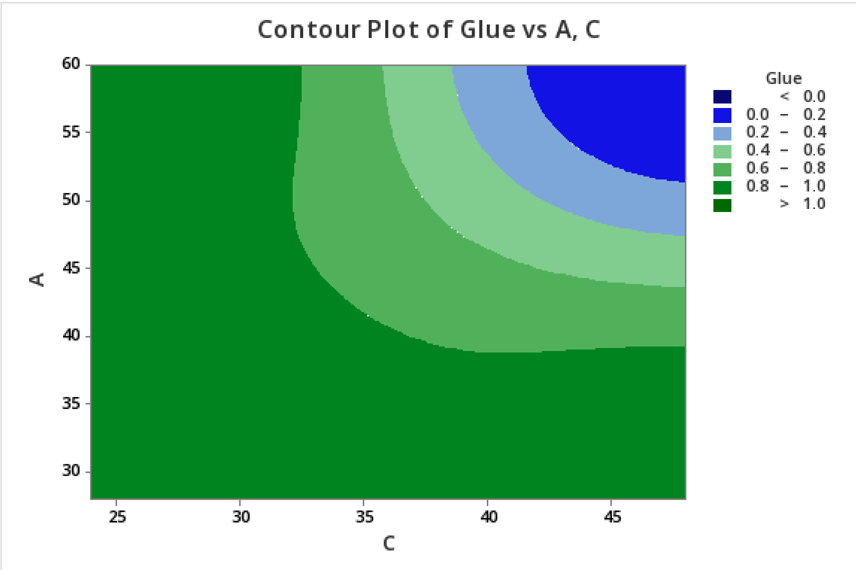

Figure 8-1 Contour Plot of temperature vs Exposure of Time

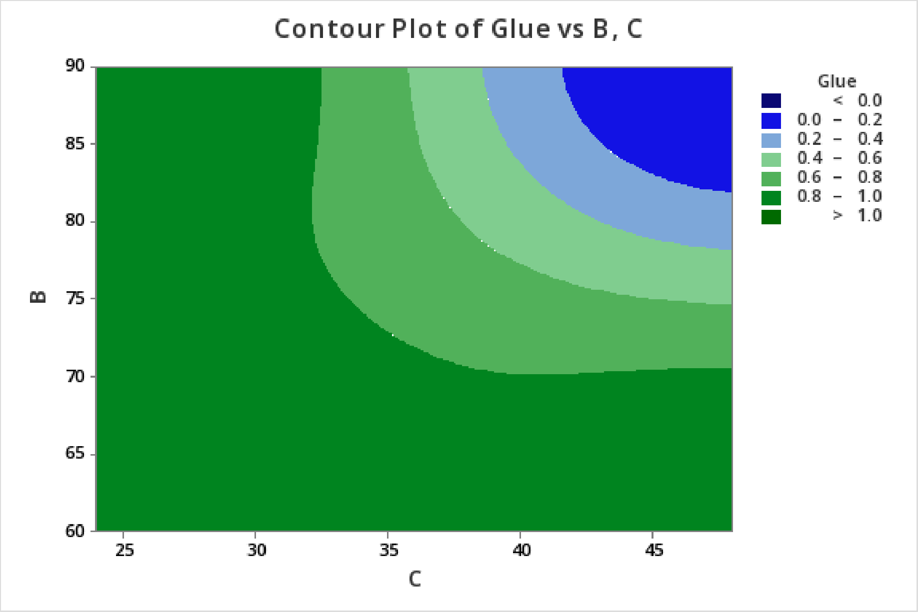

Figure 8-2 Contour Plot of Humidity VS Exposure of Time

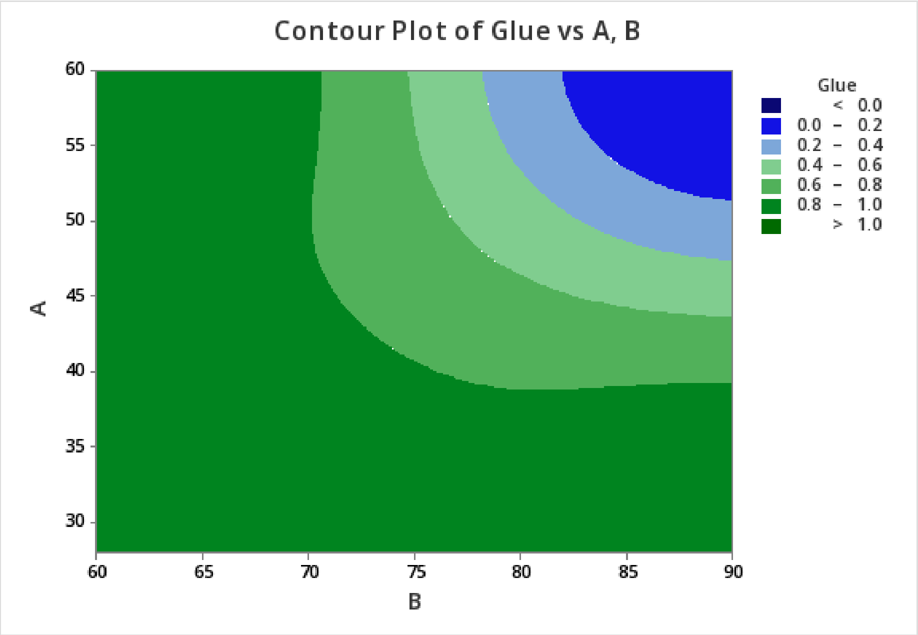

Figure 8-3 Contour Plot of temperature vs humidity

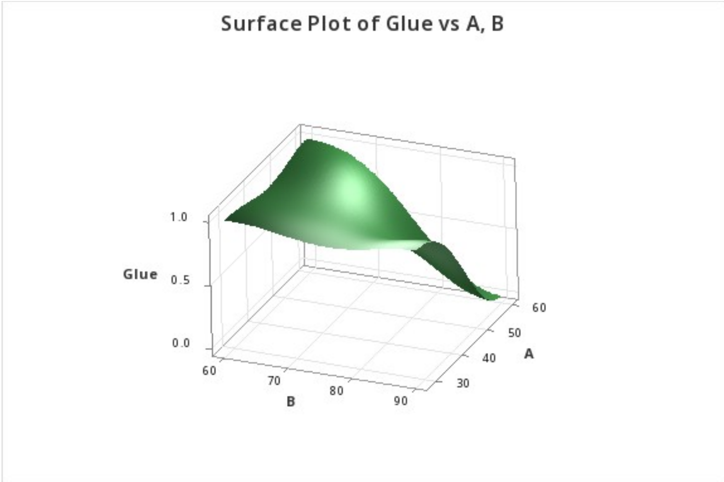

Figure 9-1 surface Plot of temperature vs humidity

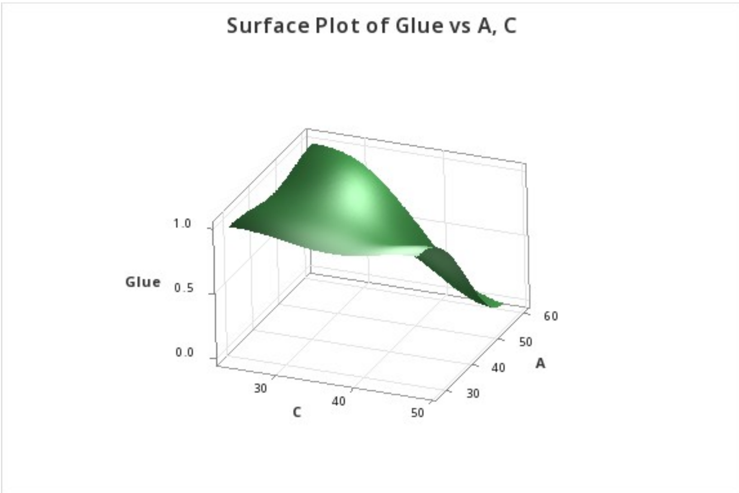

Figure 8-1 surface Plot of temperature vs Exposure of Time

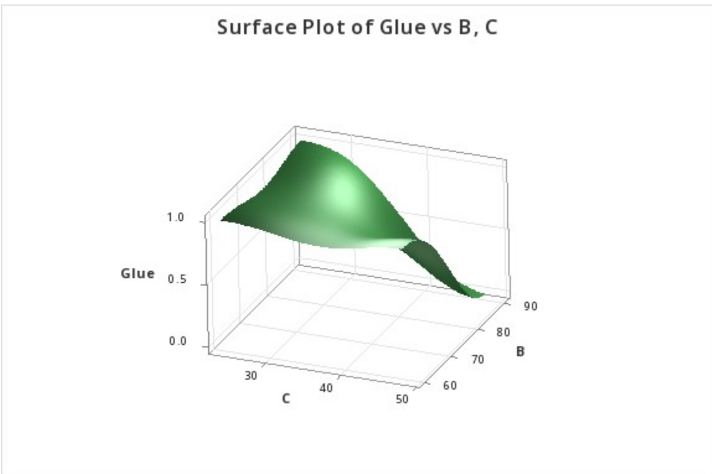

Figure 8-1 surface Plot of Humidity VS Exposure of Time

Corrective Actions

To resolve the problems that were identified we have taken Corrective actions. We have made improvements, to the cleaning procedure, for surfaces, including both optics and the metal base. The process document has been thoroughly. Updated to include the cleaning steps. In order to ensure implementation all operators have received training that aligns with the revised procedure. Our goal is to improve the cleanliness and maintenance of components, which will help minimize potential issues and increase the systems reliability.

Preventive Actions

To proactively address potential issues and bolster overall product quality, several preventive measures have been enacted. Firstly, the final testing procedure now includes an additional "Force Test," which applies external force to verify the secure bonding between the optics and the metal rail. For product shipments, a new practice involves utilizing vacuum wrapping to minimize the impact of environmental factors on glue bonding during transportation. Lastly, there is an increased emphasis on the importance of adhering to specified environmental conditions, particularly in terms of temperature and humidity, as outlined in the product manual. This emphasis aims to ensure customer compliance and, ultimately, enhance the reliability and durability of the product under diverse environmental circumstances.

Results

The analysis of measurements before and after the enhancements clearly shows an improvement in the quality of the product. The sigma, which measures process variation, experienced an increase from 3.0 prior to the improvements to 4.3 after the changes were implemented. This suggests a manufacturing process that's tightly controlled and dependable.

Additionally, there was a reduction in defect percentage, dropping from 6.67% before the improvements to a lower 2% after the changes were made.

Metric	Before Improvement	After Improvement
Sigma	3	4.3
Defect Percentage	6.67%	2%

Table 8 - Performance Metrics: Before and After Improvement

Future Research

Establishing on the outcomes of this study, our future research endeavours will centre on refining and optimizing the optical glue bonding process. Collaboration with industry experts and stakeholders will continue to be pivotal for gathering evolving insights and implementing refinements aligned with emerging technologies and best practices. Our investigations will include exploring the incorporation of advanced analytical techniques and real-time monitoring systems to enhance process control and predictive maintenance. Additionally, we will delve into the exploration of novel materials and adhesive formulations, coupled with an in-depth analysis of the long-term durability of bonded components under varying environmental conditions, which will be integral to ensuring sustained product reliability. A central focus will be on investigating the scalability of the optimized process for broader industry applications, fostering continuous improvement and innovation in optical system manufacturing.

Conclusion

The study successfully pinpoints and rectifies the underlying cause of optics detachment in Model X, highlighting the crucial role of contamination on metal surfaces. The adoption of containment, corrective, and preventive measures serves as a testament to the effectiveness of leveraging Six Sigma methodologies in tackling complex manufacturing issues. The ongoing collaboration and consistent monitoring implemented will play a pivotal role in ensuring enduring enhancements in the optics glue bonding process, with the possibility of further refinements based on evolving insights. Additionally, the incorporation of Design of Experiment (DOE) will provide a systematic framework for evaluating and optimizing various parameters, adding a robust layer to the research methodology and contributing to a more comprehensive understanding of the bonding process intricacies.

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