CHALLENGING THE PROCESS AND MATERIAL CHARACTERISTIC TO ADDRESS THE HIGH EPOXY USAGE/CONSUMPTION OF VI POWER PACKAGES

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New Product Development and Introduction
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ABSTRACT

In a fast-paced technology where competition is tough among companies, COST plays a vital role in survival.

This paper will discuss how the product was managed to be competitive in terms of manufacturing cost. Its cost components were analyzed to determine the focus of attention and eventually achieve the project goal. The processes, equipment, and materials involved were likewise verified using Statistical tools and various Engineering methodology to determine potential effects of change as part of the action that will be implemented.

The project provides short term action and challenges the current material characteristics to address the issue. The Project improves the manufacturing KPI on efficiency, yield, cycle time and productivity on top of the cost savings gained from the project which greatly impact the WWS (Worldwide Standard) of ST Calamba BEM&T.

The device involved in this paper is a wettable flank QFN 6x6 32L package driven by VI Power technology used for automotive applications.

1. 0 INTRODUCTION

Package cost determines how robust and optimized parameters and material you have. Be it direct or indirect, one must have a very competitive price to compete in the market. This is one of the biggest challenges for any semiconductor company in order to maintain its competitive market position and value.

Profit/gain is one of the measures of success in every company in the semiconductor industry. Building products with the minimal cost involved is a key to remaining competitive and gaining more customers. Various cost components need to be analyzed to obtain cost efficient product that will drive customers to enter business with us and at the same time achieve profit.

Our package is a wettable flank QFN 6x6 32L driven by VI Power technology used for automotive applications. This device is used as a body control module (BCM) for automotive front and rear control systems. BCM is a comprehensive system that communicates and integrates the work of all electronic modules through the vehicle bus whose main function is to control load drivers and coordinates activation of auto electronics units. In 2021, during its ramp to production, the main challenge faced by the team is the high unit cost and among its components, the direct material focusing on the epoxy is identified as the main contributor. This is one of the key indicators where the management is looking to remain competitive in the market and secure business.

1.1 VI POWER WETTABLE FLANK QFN 6X6 32L

The device is a lead frame-based package mounted with an M0A10 wafer/die using the silver epoxy as medium, wire bonded with Cu wires to form the interconnection and then molded and sawn into a single unit.

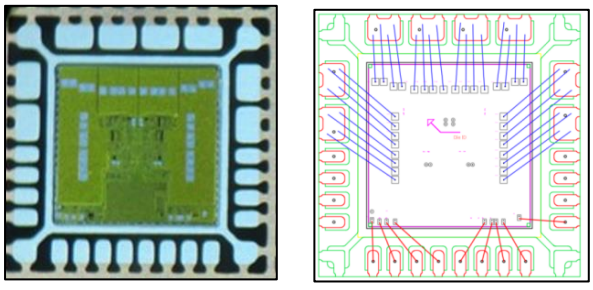

Figure 1. Sample photo of VI Power QFN 6x6 32L

2.0 METHODOLOGY

2.1 Define Phase

2.1.1 VI Power Unit Cost Components

Product unit Cost is comprised of various components, namely Direct materials, Indirect personnel, Depreciation,

Indirect Material, Energy, Utilities and Maintenance and Repair. After analyzing all these components, Direct material contributes 26% of the over-all unit cost as shown below.

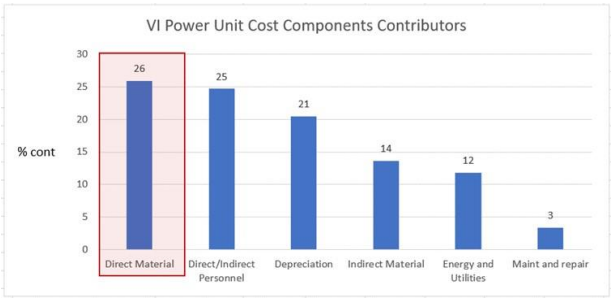

Illustration 1: Unit Cost Components

Further itemizing the direct materials used by this package, it shows that epoxy is the top contributor with 60.12% contribution on the over-all unit cost as shown in Illustration 2

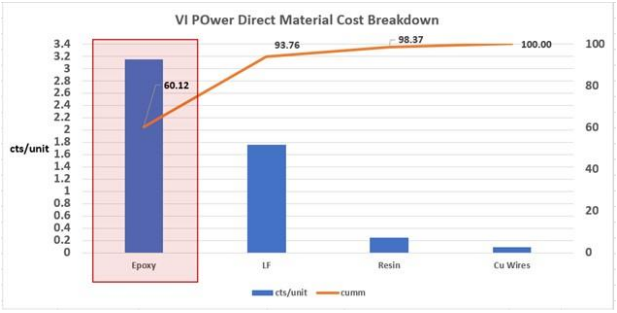

Illustration 2: Direct Material Cost Breakdown

Further checking of the monthly usage/consumption of epoxy for the last 5 months based on the given volume, an average of 4482grams against the average standard of 2481 grams was recorded from September '21 to January '22 as shown in Illustration 3

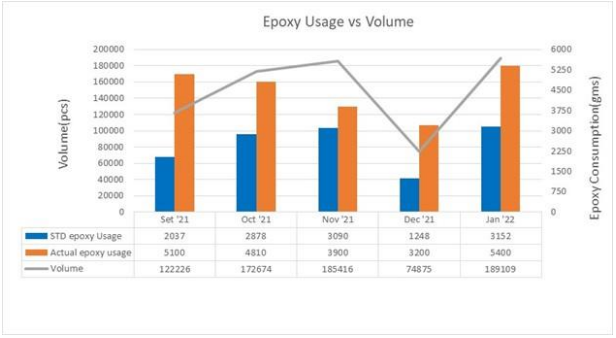

Illustration 3: Monthly consumption/usage of Epoxy

Converting this glue consumption in terms of usage per 100 units, it is averaging to **3.238 grams** and an average gap of **1.571grams** from the reference / standard.

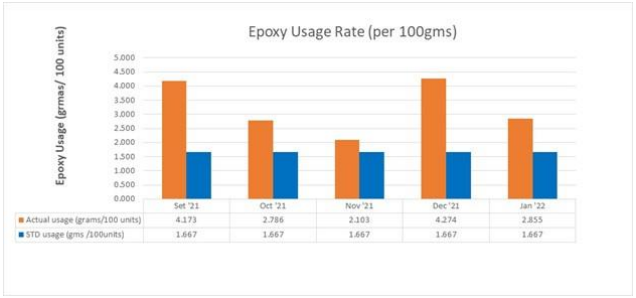

Illustration 4: Epoxy Usage rate

2.1.2 Direct Material and Its Application

The project focuses on the direct material which is the epoxy. It is the main component /material used to provide a good electrical connection and thermal conductivity between the die and the lead frame. This material upon thawing, has a floor life of 24 hours at room temperature.

Illustration 5: Epoxy material and the label (Perishable Material control)

Illustration 6 shows how this epoxy material is applied in the lead frame through board printing process. For the first step, a 300grams minimum amount of epoxy is placed on the stencil mask and then using the squeegee with applied printing parameters, it is printed on the lead frame. Printed lead frames are then processed at Die Mounting for die attachment and then undergo Glue curing process.

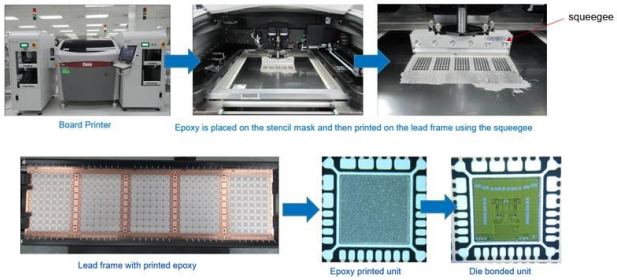

Illustration 6: Process Application/Flow

Epoxy usage/consumption is measured in terms of the amount of epoxy used per volume quantity produced. It is computed based on the **total grams** used over the **total**

volume produced and the **lower the usage rate**, the better in terms of **glue consumption.**

2.1.3 VOC (Voice of the Customer)

The project is driven by Calamba Top Management to improve product unit cost focusing on the direct material components for VI Power Automotive QFN Wettable Flank package. The voice of the customer focused on delivering products with competitive price and high level of quality which in turn aims to get more business from them.

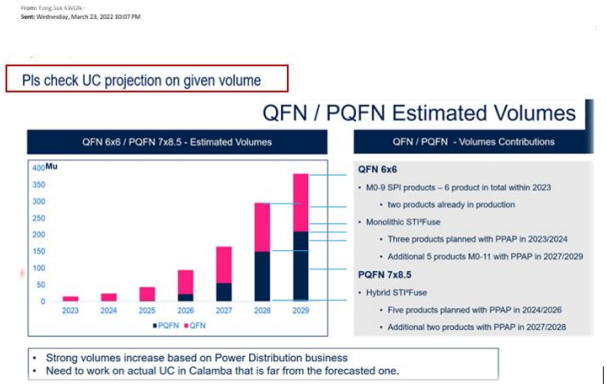

Illustration 7: Voice of the customer

2.1.4 Problem Statement

Based on the collected data and information, high epoxy consumption for VI POWER packages is averaging 4482 grams from September '21 to January '22 against the average standard of 2481gms. A significant improvement must be made to contribute to the unit cost.

2.2 Measure Phase

2.2.1 Process Flow

To have the full overview of the project and focus, Illustration 8 shows the macro map of VI Power process flow.

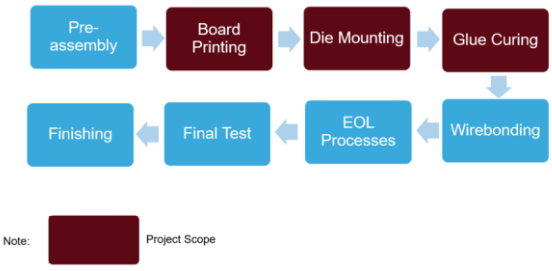

Illustration 8. VI Power Process Flow

2.2.2 SIPOC

After identifying the focused process, we use the SIPOC to identify all relevant factors/elements in the project before we start. Below diagram represents the Supplier, Input, Process, Output and Customer details about the project.

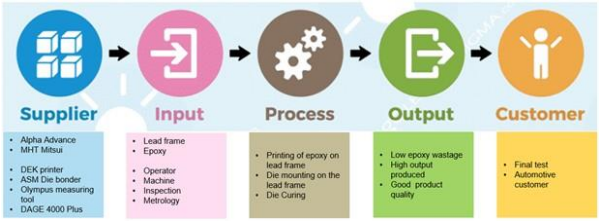

Illustration 9: SIPOC DIAGRAM

2.2.3 I/O Worksheet

After the SIPOC definition, identification of the potential X's root causes was performed using the Input-Output (IO) Worksheet (see Appendix 10.1) where 27 KPIV's identified as potential X.

2.2.3 Fishbone Diagram

Aside from the significant KPIV's identified in the I/O matrix, other potential root causes were also identified using the Fishbone diagram as additional inputs in the CE Matrix. Below is the outcome of the brainstorming performed by the team.

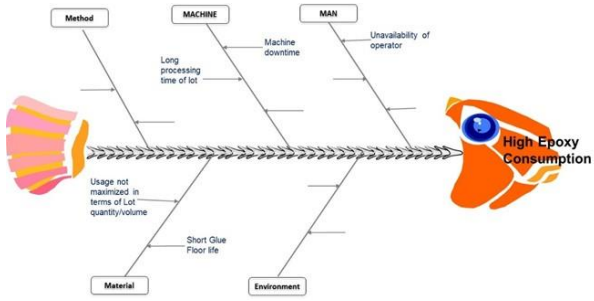

Illustration 10: Fishbone Diagram

2.2.4 Cause and Effect Prioritization

From the 27KPIVs identified in the I/O matrix, 5X's are identified as significant to Y (refer to Appendix 10.2). See below list:

2.2.4.1 Usage not maximized in terms of Lot quantity/volume.

2.2.4.2 Long processing time of Lots (High vs Low – output month)
2.2.4.3 Machine Downtime
2.2.4.4 Unavailability of operator
2.2.4.5 Short Glue floor life

2.2.5 Measurement System Analysis (MSA)

The amount of glue volume printed on the lead frame is determined by the **glue thickness** measured using the Olympus STM7 measuring microscope. Impact of the glue thickness was then verified after Die mount through the **bond line thickness** measurements using the STM Olympus measuring equipment. Furthermore, after Die Curing, the integrity of the die adhesion to the lead frame is assessed through the **hot die shear strength** measurements using the DAGE 4000 Plus Shear tester. To ensure that the measuring equipment is capable and stable, MSA was performed using 3 Appraisers

2.2.5.1 Equipment Olympus STM7 (Glue thickness)

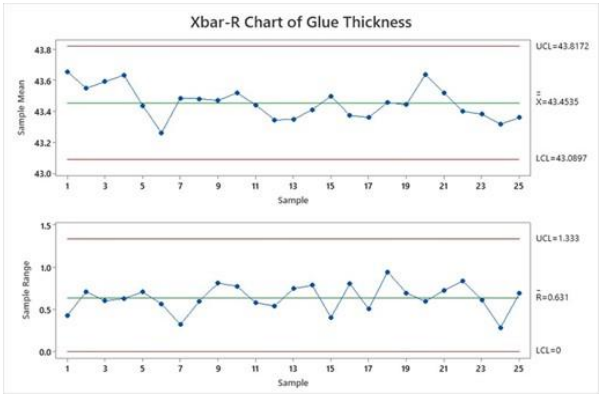

Illustration 11: Xbar -R Chart

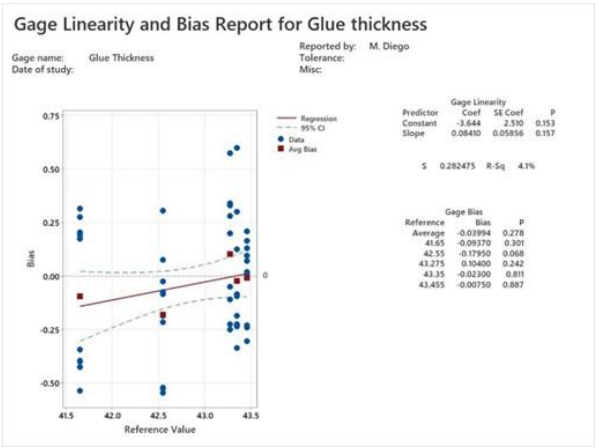

Illustration 12: Linearity and Bias Study (Glue Thickness)

Analysis:

- No OOC (out of control) on X bar-R charts for both Mean and Range, meaning data is stable.
- The slope p value of 0.157 which is more than the set alpha of 0.05 suggests that linearity of the system is statistically not significant, meaning bias is constant over the operating range of the gage.
- Average bias p value of 0.278 indicates the average bias in measurement system is not significant at alpha value of 0.05.

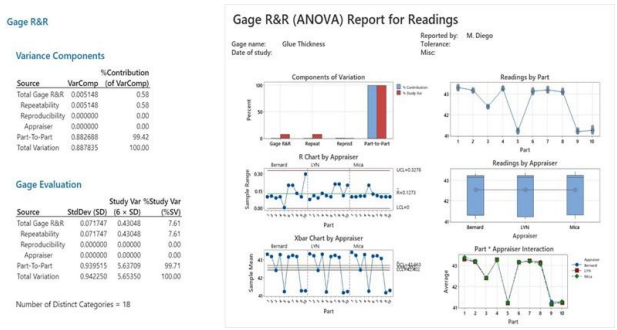

Illustration 13. Gage Repeatability and Reproducibility

Analysis:

- Total Gage R&R is 7.61% of the process variation and within the acceptable criteria of <10%, therefore measurement system is acceptable.
- Number of distinct categories (NDC) is 18 (>5) indicates the measurement system can distinguish results between parts.

The same approach of MSA study was conducted on the remaining measuring equipment, Olympus STM7 (Bond Line Thickness) and DAGE 4000 Plus Shear Tester (Hot Die Shear Test). Based on the results, all identified measuring equipment passes the MSA requirements.

2.2.6 Attribute MSA

To assess the accuracy of the inspectors performing the visual inspection after glue printing on the lead frame, an attribute MSA was conducted. 3 inspectors were assigned to do 100% inspection on 50 samples in 3 trials and compare results with the standards. Refer to appendix 10.3 for the MSA results.

2.2.7 Process Performance

Epoxy wastage was monitored on specific production days from Nov ’21 to April ’22. Illustration 28 shows the epoxy distribution in terms of usage and wastage.

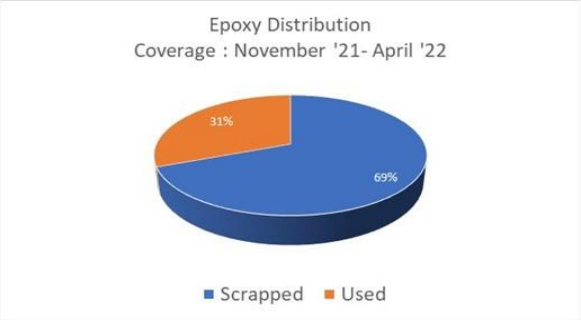

Illustration 14: Epoxy Distribution

Remarks:

- 69% of the total epoxy withdrawn was scrapped /expired while only 31% was used by the lot.

2.3 Analyze Phase

The identified critical X’s in the CE matrix will be validated to determine its contribution to the high epoxy usage/consumption. Refer to Appendix 10.5 for the Statistical Validation plan.

2.3.2 Usage not maximized in terms of Lot quantity/volume.

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Usage not maximized in terms of lot quantity/Volume	Ho: μ = 160	Ha:μ ≠ 160	1 Sample t Test	Glue Consumption

Step 1: Lot Scoping

To validate, the team extracted the daily loading quantity in FW from Aug ’21 to Dec ‘21 processed at Board printing and then converted to equivalent number of strips. In parallel, process validation/simulation on the maximum number good strips that can be produced using the 300gms epoxy volume was performed to be used for comparison. The maximum number of good strips obtained is **150 strips.**

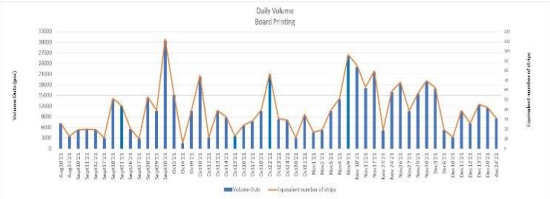

Illustration 15: Daily Volume Loading

Remarks:

Daily volume trend is erratic/inconsistent. Average daily loading is 40 strips (10.7kpcs). It is far below the maximum processable number of strips for every 300gms epoxy.

Step 1: Normality test

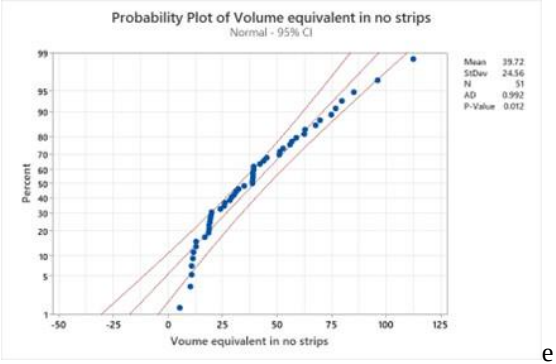

Illustration 16: Normality test

Remarks: Since the p value is **0.012** which is less than the set alpha of 0.05, we conclude that the daily volume data is not normally distributed.

Step 2: Sample t test

Based on Minitab, T value for Volume (no of strips) is -32.07 with a p-value of **0.000**

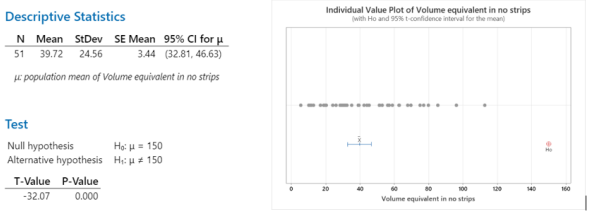

Illustration 17: Sample t test

Step 3: Conclusion

Since p value of **0.00** is less than the set alpha of **0.05,** we can dismiss the null hypothesis and conclude that there is statistically significant difference on the volume /number of strips produced in reference to the target volume (150 strips) needed for every 300grams of epoxy. Therefore, **lot quantity/volume** is significant.

The same approach of validation methodology was applied on other identified factors. Refer to Appendix 10.8 for the validation results.

2.3.8 Validation Summary

Based on validation results of all the identified factors in the CE matrix ,2/5 factors are considered significant hence actions are needed.

VALIDATION PLAN AND RESULTS									
Y (Response)	Unit of measure	Y treated as	X (Factors)	True Nature of X	Level of X	Statistical test	Alpha(α)	p value	Decision
Glue Consumption	grms/unit	nominal	Usage not maximized in terms of lot quantity/volume	Discreet	Low/ Reference	One Sample t test	0.05	0.000	X is significant
		nominal	Lot processing time	Discreet	Low/High	One way ANOVA	0.05	0.756	X is not significant
		nominal	Machine Downtime	Discreet	Low/High	Chi Square Test for Association	0.05	0.303	X is not significant
		nominal	Unavailability of operator	Discreet	Low/High	Chi Square Test for Association	0.05	0.928	X is not significant
Glue Print thickness	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05	0.000	48 hours is the optimum life
Bond line Thickness	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05	0.000	48 hours is the optimum life
Die tilt	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05	0.000	48 hours is the optimum life
Hot die shear strength	kgf	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05	0.000	36 hours is the optimum life
Glue Voids (single)	%	categorical	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	Chi-Square Test for Association	0.05	1.000	60 hours is the optimum life
Glue Voids (cummulative)	%	categorical	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	Chi-Square Test for Association	0.05	1.000	60 hours is the optimum life

Table 1: Validation Plan results

Validation of the consequential impact of the glue floor life on critical quality characteristics shows that the **48 hours** is the optimum life that meets all the requirements and achieves a comparable result with the POR/24 hours floor life.

Y (response)	Analysis	VALIDATION RESULTS			
		24 hours/POR	36 hours	48 hours	60 hours)
Glue Thickness	ANOVA				
Bond Line Thickness (wet)	ANOVA				
	PPK/CPK				
Die Tilt (wet)	ANOVA				
	Ppk				
Hot Die shear Strength	ANOVA				
	PPK/CPK				
Glue Voids (Single <5%))	Chi- Square Test for Association				
Glue Voids (cumulative <10%)	Chi- Square Test for Association				
Visual Quality	-				

Table 2: Validation Plan Results

4.0 RESULTS AND DISCUSSION

Results of the comprehensive analysis and investigations lead to the identification of the root causes/factors affecting the high epoxy usage/consumption. Actions were defined for each factor/root causes.

4.1 Action Plan Summary

Problem	Validated Cause	Actions	Control	Resp. Person	Target Date	Status
High Epoxy Usage/Consumption	Usage not maximized in terms of lot quantity/volume	Implement 40k volume batch loading	Planning starts Plan	J. Alomia	ww2229	Done
	Short Glue Floor life	Implement the 48 hours floor life	▪ Process Work Instruction ▪ Perishable Material Control Label	M. Amalin	ww2235	Done

4.2 Process Performance Validation

Large scale validation was performed on the 48hours glue floor life and validate impact on the identified risk quality characteristics. Refer to below results.

4.2.1 Glue Print Thickness

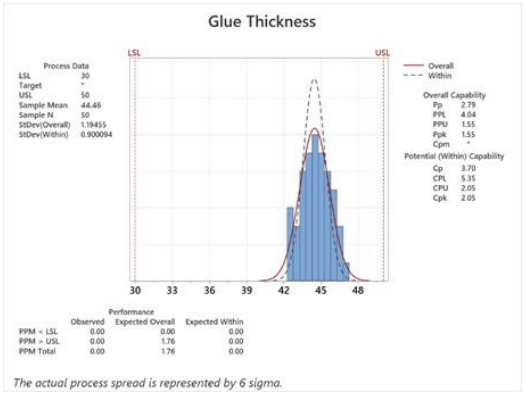

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Illustration 18: Process Capability

Using the normal data distribution, over-all process capability performance for Glue thickness has a Ppk value of **1.55** which improves from **1.19** but is still below the target of 1.67, therefore need to push for the improvement.

4.2.2 Bond Line Thickness

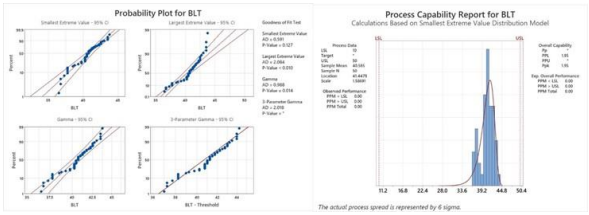


Illustration 19: Process Capability

Using the Individual Distribution Identification results as shown in **Illustration 19**, the most appropriate distribution is the **Smallest Extreme Value with** a p value of **0.127**. This suggests that the distribution is already normal. Using this model, the resulting over-all process capability (Ppk) is **1.95** and this is meeting the target of **1.67.**

4.2.3 Die Tilt

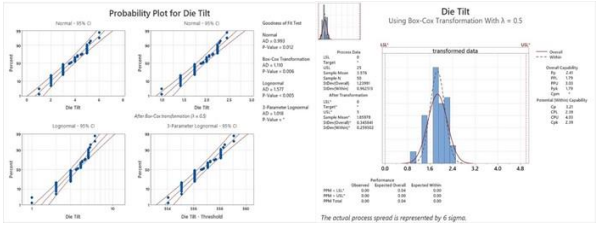


Illustration 20: Process Capability

Using the Individual Distribution Identification results as shown in **Illustration 20**, the most appropriate distribution is the **Box Cox Transformation with** a p value of **0.006**.

Using the Box Cox transformation and lambda of 0.50, distribution model for non-normal data, the resulting over-all process capability (Ppk) is **1.79** and this is meeting ST process capability requirement of 1.67.

4.2.4 Hot Die Shear Strength

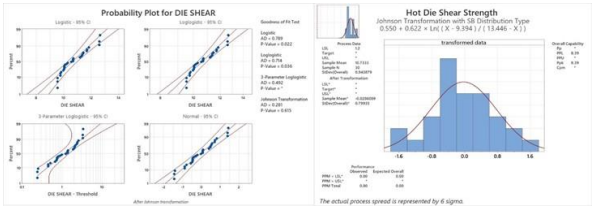


Illustration 23: Process Capability

Using the Individual Distribution Identification results as shown in **Illustration 23,** the most fitted distribution is the **Johnson Transformation** with a p value of **0.615.** Using this model, the resulting over-all process capability (Ppk) is **8.39** and this is meeting ST process capability requirement of **1.67.**

4.2.5 Glue voids (single)- all units passed the single voids criteria (<5%)

4.2.6 Glue Voids (cumulative)- all units passed the cumulative voids criteria (<10%)

4.2.8 Epoxy Usage Performance

Validating the results after action implementation, Illustration 90 shows the epoxy usage/performance trend before and after action was implemented. From an average of **3.238 grams/100** units, it went down **0.672grams/100units** and meeting the standard of 1.6grams/100units.

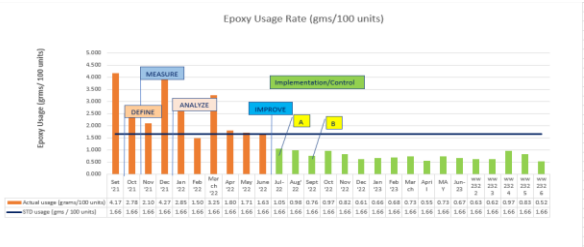


Illustration 24: Epoxy Usage Trend

Action Legend (Control):

A- Implement batch loading.

B- Implement the 48 hours epoxy floor life.

Furthermore, epoxy wastage/scrappage was also reduced from **69%** to **48.85%,** with equivalent **20%** improvement on the wastage.

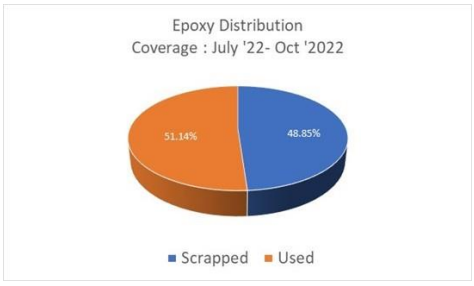


Illustration 25: Epoxy Distribution

4.3 Fan out and Standardization.

To sustain the improvement actions and proliferate the changes across all applicable packages, the following documentations were generated and updated.

Item	Details	Target Date	Responsible	Document Number	Status
1	Enroll the new epoxy floor life in Process Change Management System (PCMS) tool	ww2243	Marichu Amalin	PTM_CAL-088110	Done
2	Deploy the changes to shopfloor personnel for awareness of the changes on epoxy floorlife	ww2243	Marichu Amalin/ Marites Diego	n/a	Done
3	Update PMC system to reflect the new epoxy floor life (48hours)	ww2243	Alyssa Gablan	n/a	Done
4	Update Board Printing Work Instruction	ww2244	Marilyn Manguiat	DM00809230	Done
5	Review Control plan for applicable changes	ww2244	Nerie Gomez	DM00806833	Done
6	Review FMEA for applicable changes	ww2247	Marichu Amalin	F00014575	Done

Table 3: Documents Records

4.4 Tangible Benefits

Our project realized annualized cost savings amounting to **$209.78k** as validated and certified by our IE.

MATERIAL CONSUMPTION REDUCTION PROJECT
IE OWNER: EDUARD MUECO

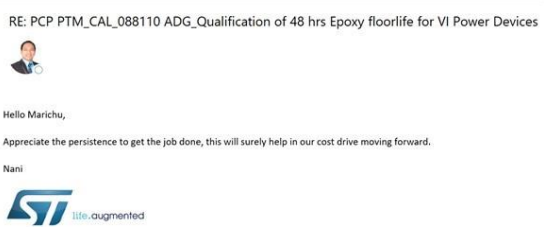
	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Total
Input Volume (K)	147.69	72.64	264.68	454.39	256.15	484.42	361.55	394.38	327.49	490.75	707.04	1,071.6	5,032.75
Material Glue usage per Unit (G)													
Baseline	0.01429	0.01429	0.01429	0.01429	0.01429	0.01429	0.01200	0.01200	0.01200	0.01200	0.01200	0.01200	
Actual	0.01021	0.00885	0.00763	0.00978	0.00820	0.00750	0.00750	0.00685	0.00733	0.00550	0.00735	0.00672	
Saved	0.00408	0.00544	0.00665	0.00451	0.00609	0.00679	0.00450	0.00515	0.00467	0.00650	0.00465	0.00528	
Savings (KS)													
Monthly	4.69	3.07	13.69	15.92	12.13	25.57	12.65	15.80	11.90	24.80	25.55	44.01	209.78
Cumulative	4.69	7.76	21.45	37.37	49.50	75.06	87.72	103.52	115.41	140.22	165.77	209.78	209.78

RESPONSIBILITY MATRIX	IE	Project Owner
CCRP Release #		M. Amalin
Actual Annualized Cost Savings (KS)	209.78	

Table 4: Cost Savings

4.5 Customer Feedback/Recognition

Our Internal and External Customer has given appreciation and feedback about the implementation of the actions. See below response from them.



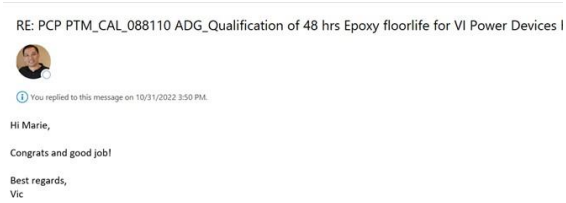
RE: PCP PTM_CAL_088110 ADG_Qualification of 48 hrs Epoxy floorlife for VI Power Devices

Hello Marichu,

Appreciate the persistence to get the job done, this will surely help in our cost drive moving forward.

Nani

life.augmented


RE: PCP PTM_CAL_088110 ADG_Qualification of 48 hrs Epoxy floorlife for VI Power Devices I

You replied to this message on 10/31/2022 3:50 PM.

Hi Marie,

Congrats and good job!

Best regards,
Vic

5.0 CONCLUSION

To stay competitive and achieve business growth, device units' cost must be challenged and finding ways to reduce it must be done. Using the Six Sigma methodology and principles, we were able to achieve the goal of the project. Factors affecting the high unit cost were identified and addressed. Focusing on the direct material consumption and challenging its characteristics and its impact on the form, fit and function of the product becomes a success and has contributed significantly to reduce the unit cost by improving the usage rate.

6.0 RECOMMENDATIONS

It is recommended that the corrective actions identified on this project be fanned out to other ongoing package development and share all the learning to other ST site with similar device structure.

7.0 ACKNOWLEDGMENT

The author would like to extend her sincerest appreciation to the following: Bong Arcebal, LJ Manuel, Sherwin Celestino, Victor Jordan and members from Assembly, Test Engineering and Reliability group for their full support to complete this important project milestone.

To my beloved family, colleagues, friends, and co-employees who gave their full support and serve as my inspiration to pursue this project.

Above all, to our Almighty God for the continuous blessings and guidance on our day-to-day undertakings.

8.0 REFERENCES

1. Build Sheet Assembly (BSA)
2. Minitab software for Statistical tests and analysis
3. Material technical data sheet
4. FW2 -Factory Works System

9.0 ABOUT THE AUTHORS

Marichu S. Amalin received his B.S degree in Electrical Engineering at Batangas State University in Batangas City. She has 23 years of solid experience in semiconductor company focusing on Process Engineering, Project Management, and New Product Introduction. She is currently a Project NPI Manager leading the AMS Analog Division of STMicroelectronics, Inc. She is a certified Black Belt practitioner and Subject matter Expert trainer for AIAG-VDA FMEA and 8D problem Solving Methodology in her company.

10.0 APPENDICES

10.1 Input-Output (I/O) Worksheet

Process Step	VA / NVA	Process Inputs (KPIVs)			
		Type of Input	Input	Characteristic of Input (KPIV / X)	C/N
BOARD PRINTING					
Tool and material preparation	VA	Raw Material / Information	Epoxy	floorlife	Controllable
	VA	Raw Material / Information	Leadframes	correct and in good condition	Controllable
	VA	Raw Material / Information	Leadframes	quantity\volume	Controllable
	VA	Equipment / Infrastructure	squeegee	correctness for the device requirement	Controllable
	VA	Equipment / Infrastructure	stencil mask	correctness for the device requirement	Controllable
Lot preparation	VA	SOP / WI / Checklist	runcard	readable with correct information	Controllable
	VA	Human Resources	Operator	qualified and available	Controllable
	VA	Raw Material / Information	engraved Leadframe	correctness	Controllable
Perform machine set up	VA	Equipment / Infrastructure	squeegee	correct set-up/installation	Controllable
	VA	Equipment / Infrastructure	stencil mask	correct set-up/installation	Controllable
	VA	Process Control / Method / Policy	process parameter	correctness	Controllable
	VA	Raw Material / Information	understencil cleaning paper	correctness	Controllable
	VA	Human Resources	Line Technician	certified and trained	Controllable
Run sample for PC buy off	VA	Raw Material / Information	leadframe	good visual quality	Controllable
	VA	Measurement	printed leadframe	glue print thickness	Controllable
	VA	Measurement	printed leadframe	glue placement	Controllable
	VA	Raw Material / Information	epoxy	floorlife expiration	Controllable
Perform FW transaction (TRACKIN)	VA	SOP / WI / Checklist	runcard	readable with correct information	Controllable
Fill out production logsheet	VA	SOP / WI / Checklist	logsheet	correctness of information	Controllable
Start Lot processing	VA	Raw Material / Information	engraved Leadframe	correctness	Controllable
	VA	Raw Material / Information	engraved Leadframe	good visual quality	Controllable
	VA	Human Resources	Operator	qualified and available	Controllable
Glue Printing process	VA	Raw Material / Information	engraved Leadframe	visual quality	Controllable
Lot Completion	VA	Others	printed Leadframe	glue print quality	Controllable
	VA	Others	printed Leadframe	staging prior diebond	Controllable
Update production logsheet	VA	SOP / WI / Checklist	logsheet	correctness of information	Controllable
Perform FW transaction (TRACKOUT)	VA	SOP / WI / Checklist	runcard	readable with correct information	Controllable

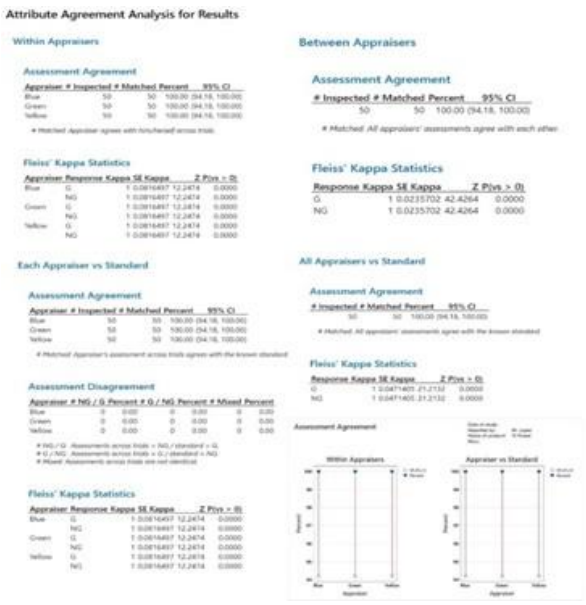
10.2 C-E Matrix

CAUSE & EFFECT MATRIX

			Is Y Continuous / Discrete?		High Epoxy Consumption	1
			Specification Limits (for Y)			
			Customer Priority			10
S.No	Process Step	Input	Characteristic of Input (KPIV / X)		Total	Is X Continuous / Discrete?
1	(In case of an X from the Fishbone Diagram, please mention Fishbone Diagram in this column)	(In case of an X from the Fishbone Diagram, leave this column blank)	(Please copy the Input Characteristic column from the Input-Output worksheet [column no 10] and paste in this column. Also add any extra X's identified from the Fishbone diagram)			
2	Tool and material preparation	Epoxy	Floorlife	3	30	Discrete
		Leadframes	quantity\volume	9	90	Discrete
	Lot preparation	Operator	qualified and available	9	90	Discrete
22	Run sample for PC buy off	epoxy	floorlife expiration	3	30	Discrete
35	Fishbone : MAN		unavailability of operator	9	90	Discrete
36	Fishbone : MATERIAL		Usage not maximized in terms of lot quantity\volume	9	90	Discrete
37	Fishbone : MATERIAL		short Glue Floorlife	3	30	Discrete
38	Fishbone : MACHINE		Machine downtime	9	90	Discrete
39	Fishbone : MACHINE		long processing of lot	3	30	Discrete

Operating Range (for X)	Count 3's	Count 5's	X Selected / Discarded?
	0	0	
supplier specs, 24 hours	1	0	Select the X
minimum, maximum	0	1	Select the X
available, not available	0	1	Select the X
after 24 hours from thawing	1	0	Select the X
Low, High	0	1	Select the X
Low, High	0	1	Select the X
24, >24H	1	0	Select the X
Low, High	0	1	Select the X
Low, High	1	0	Select the X

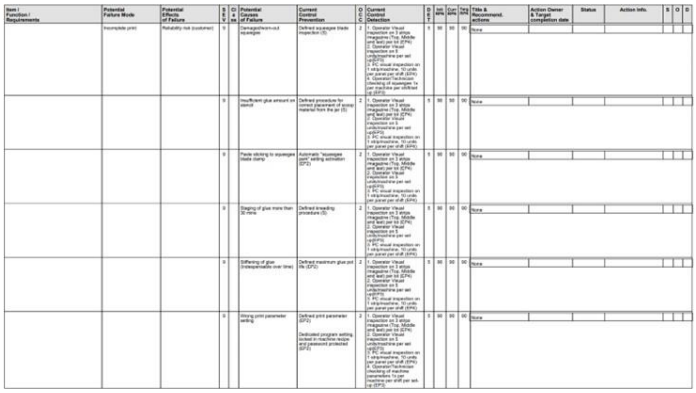
10.3 Attribute MSA



Analysis/Conclusion:

Over-all Kappa value of 1 denotes a strong agreement between Appraisers with respect to standards/reference. In terms of overall assessment agreement at lower CI between all appraisers and standard, value is at **94.18%** which is more than 90% therefore effectiveness was met.

10.4 FMEA for Board Printing

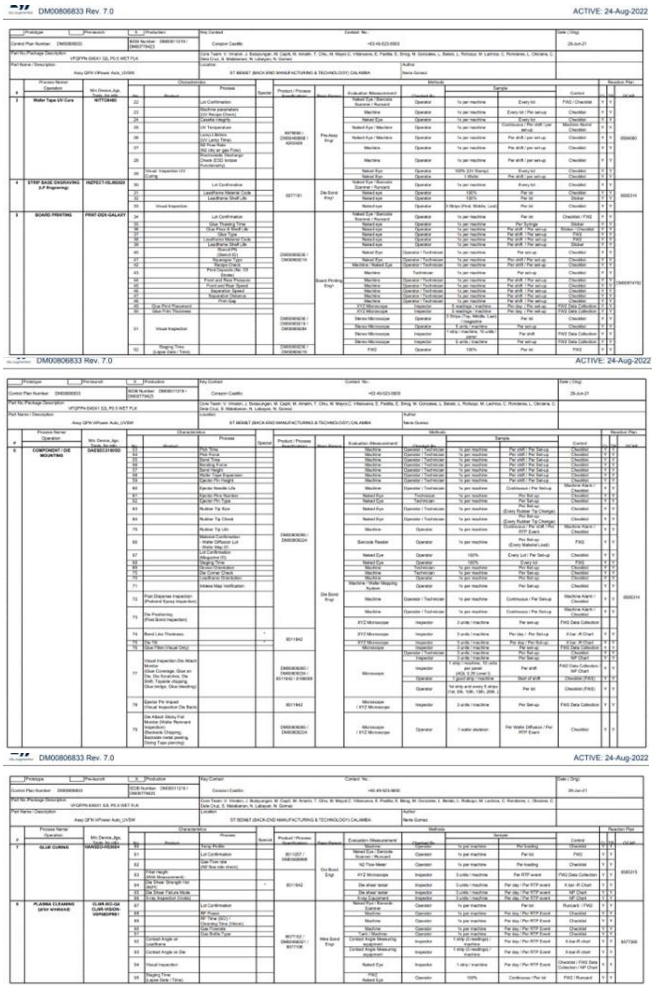


Remarks: No change on the FMEA. Identified risk related to glue floor life is already included.

10.5 Statistical Validation Plan

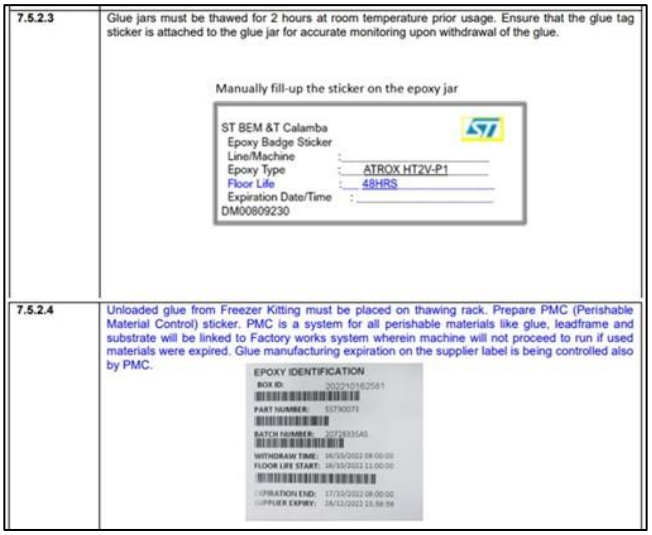
VALIDATION PLAN									
Y (Response)	**Unit of measure**	**Y treated as**	**X (Factors)**	**True Nature of X**	**Level of X**	**Statistical test**	**Alpha (α)**	**p value**	**Decision**
Glue Consumption	gms/unit	nominal	Usage not maximized in terms of lot quantity/volume	Discreet	Low/ Reference	One Sample t test	0.05		
		nominal	Lot processing time	Discreet	Low/High	One way ANOVA	0.05		
		nominal	Machine Downtime	Discreet	Low/High	Chi Square Test for Association	0.05		
		nominal	Unavailability of operator	Discreet	Low/High	Chi Square Test for Association	0.05		
Glue Print thickness	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05		
Bond line Thickness	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05		
Die tilt	um	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05		
Hot die shear strength	kgf	continuous	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	One way ANOVA	0.05		
Glue Voids (single)	%	categorical	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	Chi-Square Test for Association	0.05		
Glue Voids (cummulative)	%	categorical	Glue floorlife	Discreet	24hours 36 hours 48 hours 60hours	Chi-Square Test for Association	0.05		

10.6 Control Plan



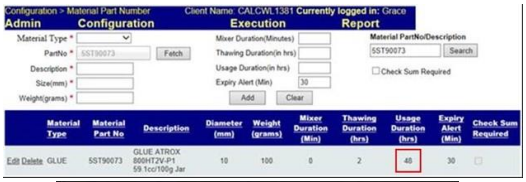
Remarks: No changes on the Control plan after review of the following processes: Board Printing, Die Mounting and Oven Curing

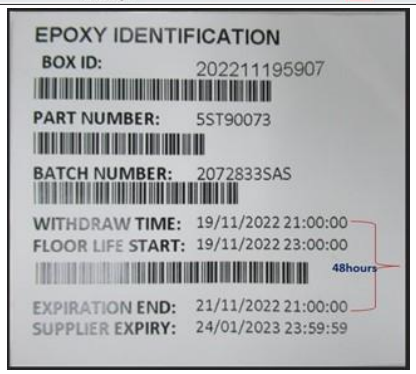
10.7 Process Work Instruction for Board printing (DM00809230)



Remarks: Glue floor life was updated in the Work Instruction including the use of Perishable Material Control label to monitor glue expiration/floor life.

10.8 Perishable Material Control (PMC)





Remarks: Perishable Material Control (PMC system) was updated to reflect the new floor life. The new floor life also reflects on the printed label.

10.8 Validation Results of the identified X in the CE matrix

10.8.1 Long processing time of Lots (High vs Low- output month)

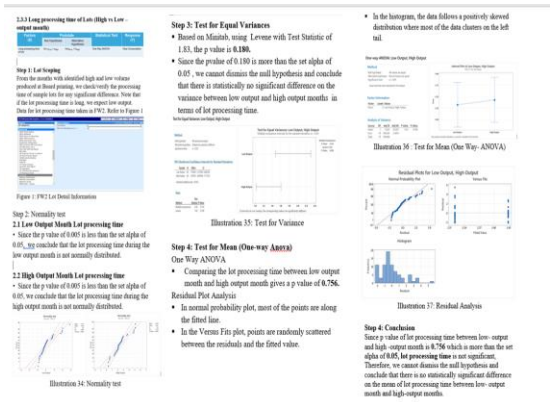


Illustration 34: Normality test

Illustration 35: Test for Variance

Illustration 36 : Test for Mean (One Way- ANOVA)

Illustration 37: Residual Analysis

10.8.2. Machine Downtime

2.3.4 Machine Downtime

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Machine downtime	Ho: $X'_{Low} = X'_{High}$	Ha: $X'_{Low} \neq X'_{High}$	Chi-Square Test for Association	Glue Consumption

Step 1: Lot Scoping

From the identified months with high and low volume Outs, the team extracted the machine performance in terms of unplanned downtime (TUD) that could affect the output quantity/volume.

	Low-Output Month	High-Output Month
TUD	86	73

Figure 3: Machine OEE Summary Tool

Remarks: Machine downtime summary extracted in the OEE Summary tool

Step 2: Chi-Square Test

Using Minitab, Chi-square statistic of 1.06289 and Degrees of Freedom of 1, p value is **0.303.**

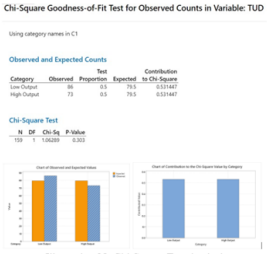


Illustration 38: Chi-Square Test Analysis

Step 3: Conclusion

- Since p-value of **0.303** which is more than the set alpha 0.05, we cannot dismiss the null hypothesis and conclude that there is statistically no significant difference on the number of hours of machine downtime that occurred during the low output month and high output month. Therefore, machine downtime is not considered significant affecting the output of the machine.

10.8.3 Unavailability of Operator

2.3.5 Unavailability of Operator

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Unavailability of operator	Ho: $X'_{Low} = X'_{High}$	Ha: $X'_{Low} \neq X'_{High}$	Chi-Square test for Association	Glue Consumption

Step 1: Mapping

Operator support matrix per team was identified including their attendance rate on the months with high and low volume outs to check for any difference. Note that operator support is critical for manning the machine/process.

BLUE		Green		Yellow	
ID #	Name	ID #	Name	ID #	Name
144173	ARAGON, Maria	144382	CAGUIMA, Myla Rose	257199	FABACIN, Alma
266749	DEL ROSARIO, Julieta	253044	ENRIQUEZ, Janina	243800	CANANDANG, Jona

Table 5: Operator Support Matrix

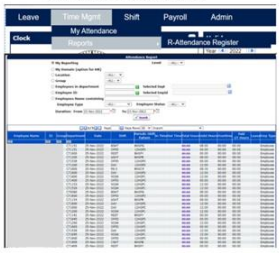


Illustration 39: Operator Attendance Tracker

Remarks: operator attendance extracted from the system

Step 2: Chi-Square Test for Association Analysis

Using Minitab, Pearson Chi-square statistic of 0.008 and Degrees of Freedom (DF) of 1, p value is **0.928**

Rows: C1 Columns: Operator Availability

	High Ouput Month	Low Output Month	All
Available	108	112	220
	108.23	111.77	
Not Available	14	14	28
	13.77	14.23	
All	122	126	248

Chi-Square Test

	Chi-Square	DF	P-Value
Pearson	0.008	1	0.928
Likelihood Ratio	0.008	1	0.928

Illustration 40: Chi-Square Test for Association Analysis

Step 3: Conclusion

Since p value **0.928** is more than the set alpha of **0.050**, we cannot dismiss the null hypothesis and conclude that there is statistically no significant difference between low output and high output months in terms of operator availability/attendance supporting the machine and lot processing. Therefore, operator availability is not significant.

10.8.4 Short Glue Floor life

2.3.6 Short Glue floor life

Based on the given running volume per day which is not enough for the maximum usage of glue, current floor life of epoxy at 24 hours is considered short, thus need to assess possible life extension to maximized usage. Fig 1 below shows the Perishable Material control label which is the reference detection for epoxy floor life and expiration.

Illustration 41: Perishable Material Control label for Epoxy

2.3.6.1 Floor Life Definition

To address the shorted glue floor life, three different floor life were assessed and validated to define the optimum life that will meet the quality requirements and at the same time maximized the usage in terms of high volume/quantity of lots produced.

2.3.6.1.1 Floor life Visual Quality Mapping

Visual Quality check was performed at different glue floor life using the current 24 hours as baseline/reference.

X'

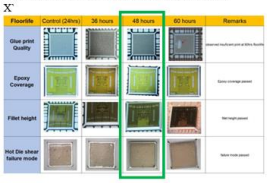


Table 5: Visual Quality Mapping per Floor life

Results:

Visual quality requirements are passing up to 48 hours floor life. Intermittent insufficient solder print was observed at 60 hours floor life.

2.3.7 Consequential Matrix Validation (Quality Characteristics Response)

2.3.7.1 Glue Print Thickness

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All means are equal	Ha: At least 1 mean is different	One Way ANOVA	Glue Print Thickness

Step 1: **Data and Sample Preparation**
Samples using 3 different glue floor life were prepared for comparison to the reference (24 hours floorlife).

Step 2: Normality Test

- Since p-value for 24 hours is 0.034 which is less than the set alpha (0.05), data is non normal.

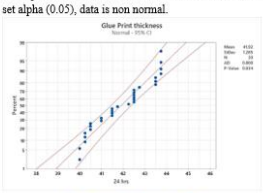


Illustration 42: Normality Test

- Since p value for 36 hours floor life is 0.289 which is less than the set alpha (0.05), data is normal.

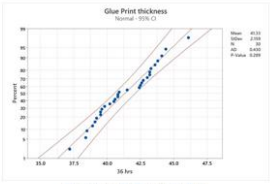


Illustration 43: Normality Test

- Since p value for 48 hours floor life is 0.382 which is more than the set alpha (0.05), data is normal.

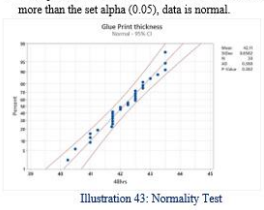


Illustration 43: Normality Test

- Since p value for 60 hours floor life is 0.204 which is more than the set alpha (0.05), data is normal.

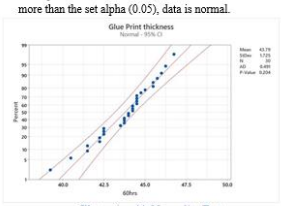


Illustration 44: Normality Test

Step 3: Correlation
Using Pairwise Pearson Correlations, p values between different floor life are >0.05, meaning epoxy floor life is not correlated with Glue Print Thickness

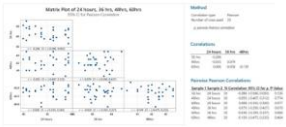


Illustration 45: Normality Test

Step 4: Test for Variance Analysis

- Based on Minitab, Levene test static is 7.66 having a p value of **0.00**
- Since p value of 0.00 is less than set alpha (0.05), we dismiss the null hypothesis and conclude that there is statistically significant difference on the variance of glue thickness at different glue floor life.
- Among the three-floor life, 48 hours has the least standard deviations and comparable with the 24 hours floor life (control reference) based on the graphical presentation of the multiple comparison intervals for standard deviation.

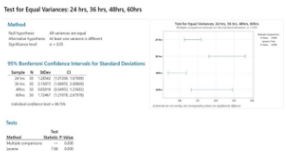


Illustration 46: Test for Variance Results

Step 5: Test for Mean (One Way ANOVA) Analysis
One Way ANOVA

- Using Welch test, p value for glue thickness at different floor life is **0.000.** Since this is less than the set alpha of 0.05, we can dismiss the null hypothesis and conclude that there is statistically significant difference between the mean glue thickness at different floor life.
- Based on the interval plot at 95% CI for the Mean, 48 hours is the optimum floor life comparable to 24 hours floor life of the glue.
- Using Fisher Pairwise Comparison, comparing the individual means with each other, 36 and 48 hours is comparable to 24 hours based on the same letter sharing, therefore we can use the **48 hours floor life** as the optimum floor life for the glue.

Residual Plot Analysis:

- In the Normal probability plot, most of the points are along the fitted line.
- In the Versus Fits plot, points are randomly scattered between the Residual versus fitted value.
- In the histogram, the data follows a normal distribution (bell curve).

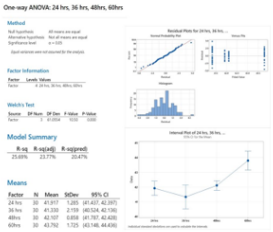


Illustration 47: ANOVA Analysis

Step 6: Conclusion:
Among the three different floor life validated, 48 hours is the optimum floor life limit that is comparable to 24 hours floor

2.3.7.2 Bond Line Thickness (Wet)

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All means are equal	Ha: At least 1 mean is different	One Way ANOVA	Bond Line Thickness

Step 1: Data and Sample Preparation
Samples using 3 different glue floor life were prepared for comparison with the reference (24 hours) to check for any change on the bond line thickness.

Step 2: Normality Test

- Since the p value for Bond line thickness at 24 hours floor life is 0.350 which is more than the set alpha (0.05), data is normal.

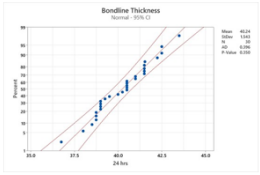
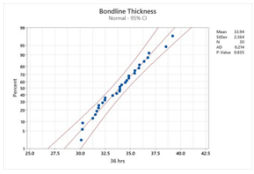


Illustration 48: Normality Test

- Since the p value for Bond line thickness at 36 hours floor life is **0.8350** which is more than the set alpha (0.05), data is normal.



Step 3: Correlation
Using Pairwise Pearson Correlations, p values between different floor life are >0.05, meaning epoxy floor life is not correlated with Bond line Thickness.

Illustration 52: Correlation Analysis

Step 4: Test for Equal Variances

- Based on Minitab, Levene test statistic is **5.44** with a p value of **0.002**.
- Since the p value of **0.002** is less than the set alpha (0.05), we can dismiss the null hypothesis and conclude that there is statistically significant difference on the variance of bond line thickness at different glue floor life.
- Among the 3 different floor life, 48 hours has the least standard deviations based on the interval plot for standard deviation.

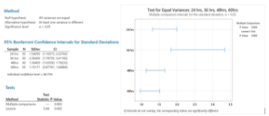


Illustration 53: Test for Variance

Step 5: Test for Mean (One-way Anova)

One Way Anova

- Using the Welch test, the p value for bond line thickness at different floor life is **0.000**. Since p value is less than the set alpha of 0.05, we can dismiss the null hypothesis and conclude that there is statistically significant difference between the mean bond line thickness at different floor life.

- Since the p value for Bond line thickness at 48 hours floor life is **0.056** which is more than the set alpha (0.05), data is normal.

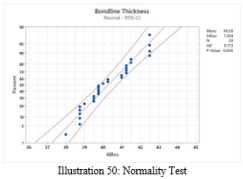


Illustration 50: Normality Test

- Since p value for Bond line thickness at 60 hours floor life is **0.199** which is more than the set alpha (0.05), data is normal.

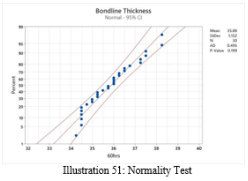
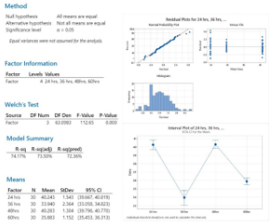


Illustration 51: Normality Test

- Based on the interval plot at 95% CI for the Mean, 48 hours is the optimum floor life comparable to 24 hours floor life of the glue.
- Using the Tukey Pairwise Comparison, comparing the individual means against each other, 24 hours and 48 hours are comparable /no significant difference, while 36 hours and 60 hours are significantly different. With this, we use the **48 hours** as the optimum glue floor life that is comparable with the POR. (24 hours).

Residual Plot Analysis:

- In the Normal probability plot, most of the points are along the fitted line.
- In the Versus Fits plot, points are randomly scattered between the Residual versus fitted value.
- In the histogram, the data follows a normal distribution (bell curve).



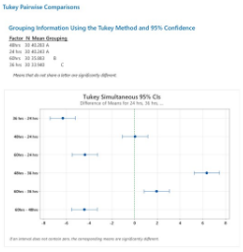


Illustration 54: Test for Mean

Comparing the process capability performance of the different floor life, all of them are meeting the target of 1.67.

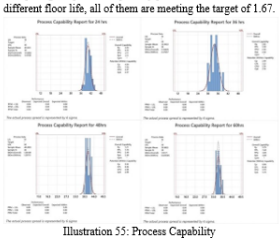


Illustration 55: Process Capability

Step 6: Conclusion

Among the three different floor life validated, **48 hours is the optimum floor life** that is comparable to 24 hours floor life of the glue based on their individual interval plot for standard deviation and mean and mean comparison using the Tukey pairwise Comparison. This was further confirmed through their individual process capability performance where all are meeting the target of 1.67.

2.3.7.3 Die Tilt (Wet)

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All means are equal	Ha: At least 1 mean is different	One Way ANOVA	Die Tilt

Step 1: Data and Sample Preparation

Samples using 3 different glue floor life was prepared for comparison with the reference.
(24 hours) to check for any change on die tilt.

Step 2: Normality test

- Since p value for die tilt at 24 hours floor life is 0.037 which is less than the set alpha (0.05), data is non normal.

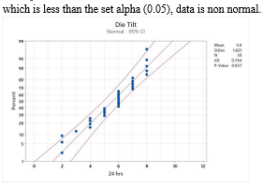


Illustration 56: Normality Test

- Since the p value for die tilt at 36 hours floor life is 0.311 which is more than the set alpha (0.05), data is normal.

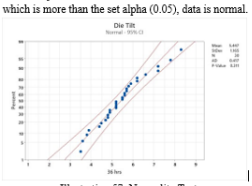


Illustration 57: Normality Test

- Since p value for die tilt at 48 hours floor life is <0.005 which is less than the set alpha (0.05), data is non normal.

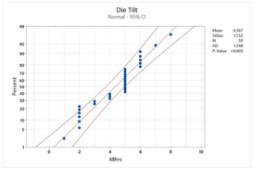


Illustration 58: Normality Test

- Since p value for die tilt at 60 hours floor life is <0.005 which is less than the set alpha (0.05), data is non normal.

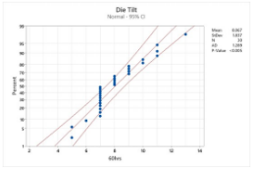


Illustration 59: Normality Test

Step 3: Correlation

- Using Pairwise Pearson Correlations, p values between different floor life are >0.05, meaning epoxy floor life is not correlated with Die tilt.

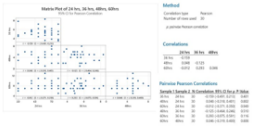


Illustration 60: Correlation Analysis

Step 4: Test for Equal Variances

- Based on Minitab, Levene test statistic is 1.40 having a p value of **0.247.**
- Since the p value of **0.247** is more than the set alpha (0.05), we cannot dismiss the null hypothesis and conclude that there is statistically no significant difference on the variance of die tilt at different glue floor life.
- The 3 different floor life is comparable /equal with the 24 hours floor life in terms of variance.

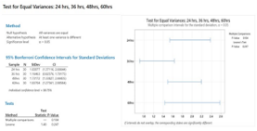


Illustration 61: Test for Variance

Step 5: Test for Mean (One-way Anova)

One Way Anova

- Using the ANOVA, p value for die tilt at different floor life is 0.000. Since p-value is less than the set alpha of 0.05, we can dismiss the null hypothesis and conclude that there is statistically significant difference between the mean die tilt at different floor life.
- Using the Tukey Pairwise Comparison, comparing the individual means against each other, 24 hours vs 36 hours, 36 hours vs 48 hours are comparable and no significant difference with each other while 60 hours are significantly different among others. For die tilt, the lower the value, the better as we are aiming for zero tilting of die, therefore we can use the 48 hours floor life as the optimum life since it has the lowest die tilt measured at **4.367um.**

Residual plot Analysis

- In the Normal probability plot, most of the points are along the fitted line.
- In the Versus Fits plot, points are randomly scattered between the Residual versus fitted value.
- In the histogram, the data follows a normal distribution (bell curve).

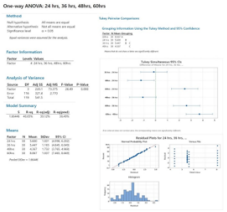


Illustration 62: Test for Mean

Process Capability Performance of die tilt on different floorlife were also compared. On illustration 59, using the Individual Distribution identification in Minitab, the most appropriate distribution is the **Box Cox Distribution** with a p value of **0.037** which suggest that the distribution is non normal. Using Box Cox distribution with lambda of 1.0, over-all Ppk is **3.53** and meeting the target of **1.67.**

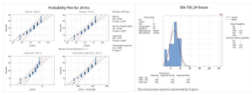


Illustration 63: Process Capability

For 36 hours floor life based on a normal distribution, overall process capability is **5.60** and meeting the target of **1.67.**

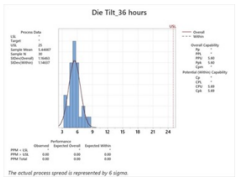


Illustration 64: Normality Test

For 48 hours, using the Individual Distribution identification in Minitab, the most appropriate distribution is the **Box Cox Distribution** with a p value of <0.005 which suggest that the distribution is non normal. Using Box Cox distribution with lambda of 0.50, over-all Ppk is **2.19** and meeting the target of 1.67.

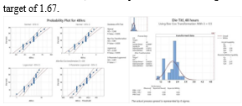


Illustration 65: Process Capability

For 60 hours, using the Individual Distribution identification in Minitab, the most appropriate distribution is the Box Cox Distribution with a p value of <0.005 which suggest that the distribution is non normal. Using Box Cox distribution with lambda of 0.50, over-all Ppk is **2.29** and meeting the target of 1.67.

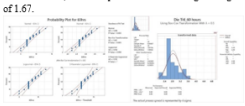


Illustration 66: Process Capability

Summary:

Over-all process capability of die tilt on different floor life are all above 1.67 and meeting ST target.

Step 6: Conclusion

Among the three different floor life validated, **48 hours** is **the optimum floor life** where it has the lowest mean (better). It was further confirmed by their individual process capability performance (Ppk) where all the 3x floor life meets the target of 1.67.

2.3.7.4 Hot Die Shear Strength

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All means are equal	Ha: At least 1 mean is different	One Way ANOVA	Hot Die shear Strength

Step 1: Data and Sample Preparation

Samples using 3 different glue floor life was prepared for comparison with the reference.
(24 hours) to check for any change on die shear strength.

Step 2: Normality Test

- Since p value for die shear strength at 24 hours floor life is **0.220** which is more than the set alpha (0.05), data is normal.

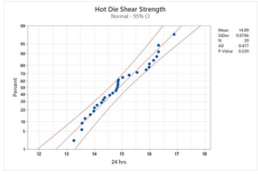


Illustration 67: Normality Test

- Since p value for die shear strength at 36 hours floor life is **0.192** which is more than the set alpha (0.05), data is normal.

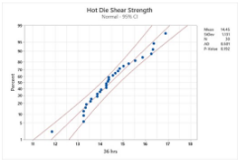


Illustration 68: Normality Test

- Since p value for die tilt at 48 hours floor life is **0.217** which is more than the set alpha (0.05), data is normal.

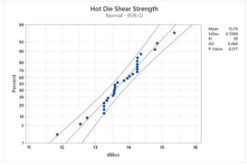


Illustration 69: Normality Test

- Since p value for die tilt at 60 hours floor life is **0.991** which is more than the set alpha (0.05), data is normal.

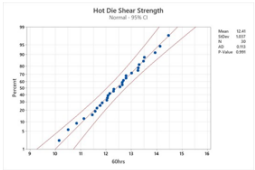


Illustration 69: Normality Test

Step 3: Correlation

- Using Pairwise Pearson Correlations, p values between different floor life are >0.05, meaning epoxy floor life is not correlated with Hot die shear strength.

Illustration 70: Correlation

Step 4: Test for Variance

- Based on Minitab, Levene test statistic is 1.58 having a p value of **0.197.**
- Since the p value of 0.197 is more than the set alpha (0.05), we cannot dismiss the null hypothesis and conclude that there is statistically no significant difference on the variance of die shear strength at different glue floor life.
- The 3 different floor life is comparable /equal with the 24 hours floor life in terms of variance.

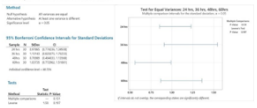


Illustration 71: Test for Variance

Step 5: Test for Mean (One-way Anova)

One Way Anova

- Using Anova, the p value for hot die shear strength at different floor life is **0.000.** Since p value is less than the set alpha of 0.05, we can dismiss the null hypothesis and conclude that there is statistically significant difference between the die shear strength at different floor life.
- Comparing the means at different floor life based on Tukey Pairwise Comparisons, 36 hours has statistically no significant difference to 24 hours while 48 hours and 60 hours has statistically significant difference with other floor life. This needs further verification on the resulting process capability performance to assess the optimum glue/epoxy floor life.

Residual Plot Analysis:

- In the Normal probability plot, most of the points are along the fitted line.
- In the Versus Fits plot, points are randomly scattered between the Residual versus fitted value.
- In the histogram, the data follows a normal distribution (bell curve).

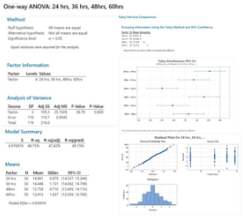


Illustration 72: Test for Mean

Comparing their process capability performance, all are meeting the target of 1.67 but 48 hours floor life has the highest Ppk value at **5.90** compared to the others, therefore we can choose the 48 hours as the optimum floor life of the glue.

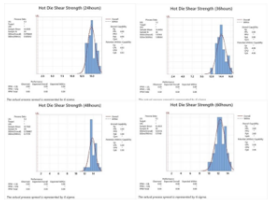


Illustration 73: Process Capability

2.3.7.5 Glue Voids (single)

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All proportions are equal	Ha: At least 1 proportion is different	Chi-Square Test for Association	Glue Voids (single)

Step 1: Data and Sample Preparation

Samples using 3 different glue floor life were prepared for comparison with the reference.

(24 hours) to check for single glue voids occurrence based on 5% criteria. Samples were inspected and quantified the acceptable and reject units based on criteria.

Step 2: Chi-Square for Test Association

Using Minitab, Pearson Chi-square statistic of 15.652 has a p value of **0.001.**

Rows: C1 Columns: Worksheet columns

	Good	Reject	All
24 hrs	30	0	30
	28.750	1.250	
36hrs	30	0	30
	28.750	1.250	
48hrs	30	0	30
	28.750	1.250	
60hrs	25	5	30
	28.750	1.250	
All	115	5	120

Cell Contents
Count
Expected count

Chi-Square Test

	Chi-Square	DF	P-Value
Pearson	15.652	3	0.001
Likelihood Ratio	14.536	3	0.002

4 cell(s) with expected counts less than 5.

Illustration 74: Chi-square Test

Step 3: Conclusion

- Since the p value of **0.001** is less than the set alpha of 0.05, occurrence of glue voids at different floor life has statistically significant difference, therefore we reject the null hypothesis.
- 48 hours floor life is the optimum life of the glue with passing the single glue voids criteria <5%.

2.3.7.6 Glue Voids (cumulative)

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All proportions are equal	Ha: At least 1 proportion is different	Chi-Square Test for Association	Glue Voids (cumm)

Step 1: **Data and Sample Preparation**

Samples using 3 different glue floor life was prepared for comparison with the reference (24 hours) to check for cumulative glue voids occurrence based on 10% criteria. Samples were inspected and quantified acceptable and rejected based on criteria.

Step 2: Chi-Square Test for Association

Using Minitab, Pearson Chi-square statistic of 22.301 has p value of **0.000.**

Rows: C1 Columns: Worksheet columns

	Good	Reject	All
24 hrs	30	0	30
	28.250	1.750	
36hrs	30	0	30
	28.250	1.750	
48hrs	30	0	30
	28.250	1.750	
60hrs	23	7	30
	28.250	1.750	
All	113	7	120

Cell Contents
Count
Expected count

Chi-Square Test

	Chi-Square	DF	P-Value
Pearson	22.301	3	0.000
Likelihood Ratio	20.769	3	0.000

4 cell(s) with expected counts less than 5.

Illustration 75: Chi-square Test

Step 3: Conclusion

- Since the p value of **0.000** is less than the set alpha of 0.05, occurrence of cumulative glue voids at different floor life has statistically significant difference, therefore we can reject the null hypothesis.
- 48 hours floor life is the optimum life of the glue that passes the cumulative voids criteria <10%

2.3.7.7 Fillet Height (dry)

Factors (X)	Postulate		Statistical Test	Response (Y)
	Null Hypothesis	Alternative Hypothesis		
Glue Floor life	Ho: All means are equal	Ha: At least 1 mean is different	One Way ANOVA	Fillet Height (dry)

Step 1: **Data and Sample Preparation**

Samples using 3 different glue floor life was prepared for comparison with the reference
(24 hours) to check for any change on fillet height.

Step 2: **Normality Test**

- Since p value for die tilt at 24 hours floor life is 0.211 which is more than the set alpha (0.05), data is normal.

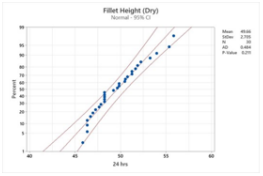


Illustration 76: Normality Test

- Since p value for die tilt at 36 hours floor life is **0.277** which is more than the set alpha (0.05), data is normal.

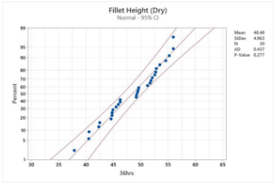


Illustration 77: Normality Test

- Since p value for die tilt at 48 hours floor life is 0.294 which is more than the set alpha (0.05), data is normal.

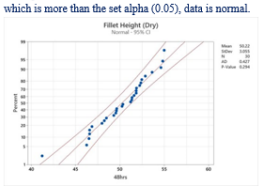


Illustration 78: Normality Test

- Since p value for die tilt at 60 hours floor life is **0.039** which is less than the set alpha (0.05), data is non normal.

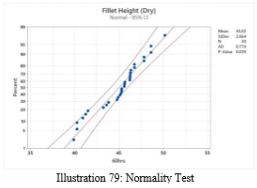


Illustration 79: Normality Test

Step 3: Test for Variance

- Based on Minitab, Levene test statistic is **6.76** having a p value of **0.00.**
- Since the p value of 0.00 is less than the set alpha (0.05), we can dismiss the null hypothesis and conclude that there is statistically significant difference on the variance of fillet height at different glue floor life.
- 48 hours and 60 hours floor life are comparable to 24 hours based on their overlapping intervals on the multiple comparison interval for standard deviation plot.

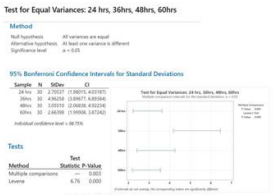


Illustration 80: Test for Variance

Step4 : Test for Mean (One Way ANOVA)

One Way Anova

- Using the Welch test, p value for fillet height at different floor life is 0.000. Since the p value is less than the set alpha of 0.05, we can dismiss the null hypothesis and conclude that there is statistically significant difference between the mean fillet height thickness at different floor life.
- Based on the individual plot (box plot) 48 hours floor life is comparable with 24 hours (POR)
- Using the Tukey Pairwise Comparison, comparing the individual means against each other, 24 hours, 36 hours and 48 hours are comparable and has no significant difference with each other, while 60 hours are significantly different. With this, we use the **48 hours** as the optimum glue floor life that is comparable with the POR (24 hours).

Residual Plot Analysis:

- In the Normal probability plot, most of the points are along the fitted line.
- In the Versus Fits plot, points are randomly scattered between the Residual versus fitted value.
- In the histogram, the data follows a slight negatively skewed distribution where most of the data clusters on the right tail.

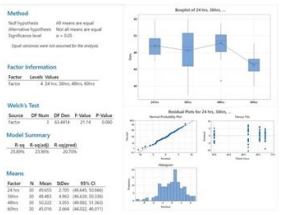


Illustration 81: Test for Mean

Step 5: **Conclusion**

Based on the above results, optimum floor life of epoxy is **48 hours** where both variance and the mean are comparable /equal to 24 hours floor life.